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Groundwater Chemistry of Springs and Water Supply Wells in Lusaka:
Results of the sampling campaigns conducted in 2008

by
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Groundwater Chemistry of Springs and Water Supply Wells in Lusaka

Results of the sampling campaigns conducted in 2008

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Executive Summary

A groundwater reconnaissance sampling campaign in the Lusaka aquifer systems was designed and conducted between January and October 2008 under the "Groundwater Resources for Southern Province" (GReSP) Project. Sampling points included perennial and seasonal springs as well as water supply wells operated by Commercial Utility, the Lusaka Water and Sewerage Company (LWSC). The main aquifers around Lusaka include the crystalline dolomite and dolomitic limestone of the Lusaka Dolomite and Cheta formations, and the schists of the Chunga Formation (Fm).

The objectives of the reconnaissance sampling were to

(1) locate and map major springs in the study area,

(2) analyse the groundwater composition and identify the major groundwater types,

(3) preliminarily assess the extent of groundwater pollution in urban areas,

(4) obtain reliable groundwater quality information for the planning and design of more detailed field studies under the Project.

Major findings of the study can be summarised as follows:

In this reconnaissance survey, 28 springs were found and mapped within the Lusaka aquifers comprising the dolomite and limestone aquifers of the Lusaka and Cheta formations and minor aquifers in the schists. At current knowledge, 15 out of the 28 springs are perennial. Four additional springs located outside the Lusaka aquifer systems were visited during the campaign. Results from previous studies suggest that a few additional springs exist that were not discovered during the field visits.

The water quality sampling included analyses of major and minor constituents of groundwater, heavy metals and trace elements as well as micro-organisms. In total, 76 samples were analysed by the BGR laboratories. Apart from springs, water from 31 of the about 80 production wells located within and near the outskirts of the City was sampled and analysed.

The water from springs and water supply wells in the limestones and dolomites corresponds to the Ca-Mg-HCO_3 type as was expected. In terms of water hardness, the water is generally hard (>250 mg/L $CaCO_3$) to very hard (>375 mg/L $CaCO_3$). Calcium and magnesium values are typically in the range of 70 -130 mg/L and 15 - 50 mg/L, respectively, and bicarbonate concentrations usually vary between 300 and 450 mg/L. Calculated ratios of $Mg^{2+}/(Mg^{2+} + Ca^{2+})$ varies between 1:2 indicative of pure dolomite to 1:6 indicating the

dominance of calcite. Groundwater hosted by schist can be distinguished from the carbonate springs by overall lower TDS, slightly lower pH, lower HCO_3:SiO_2 ratios as well as much lower hardness and alkalinity (i.e. buffering capacity).

The groundwater found in the Lusaka Forest Reserves, Chalimbana springs and Mwembeshi areas was found to be largely unaltered by urban pollution sources. From the chemical analyses it can be concluded that natural (unpolluted) groundwater from the karst aquifers should, with only local exceptions, have an EC of less than 800 μS/cm and concentrations in sodium, chloride, nitrate and sulphate below 10 mg/L. Higher levels in these parameters hence suggest the presence of urban pollution sources.

Groundwater pollution from human activities was apparent in higher levels of EC reaching 1450 μS/cm, sodium contents up to 138 mg/L, chloride levels up to 123 mg/L, and sulphate concentrations up to 172 mg/L. Whilst these values still comply with the Zambian Drinking Water Standard (ZDWS), nitrate levels frequently exceeded the recommended standard of 10 mg/L NO_3-N equalling 44.3 mg/L NO_3. Nitrate concentrations above 100 mg/L were found at Zingalume and Makeni Burkley springs as well as at Bauleni and Chawama 1 wells. The highest value was measured at Chainda well with 336 mg/L. Chawama, Zingalume and Bauleni are largely unplanned residential areas that are exclusively served by pit latrines and septic tanks. The high nitrate loads can be therefore be linked to the overall poor sanitary situation in these areas.

It was found that microbiological contamination is widespread confirming descriptions of numerous previous publications.

Concentrations of heavy metals and iron were low throughout the campaign. This could be due to the low solubility of iron and the heavy metals such as cadmium, lead and zinc at the prevailing high pH and the abundance of bicarbonate ions.

Comparison of water chemistry data with available data from the 1970s shows no significant differences although a slightly higher number of samples with increased levels of alkali ions, chloride, nitrate and sulphate were found during the 2008 sampling. Hence, no clear indication was found that the quality of groundwater has worsened or improved over time.

Even though pollution by human activities in the City area proved evident, the overall contamination within the main well field (areas around Shaft 5, Waterworks and Roadside wells) by inorganic pollutants was comparatively small. This may astonish considering the shallow water tables and the general absence of an effective protective cover. An explanation for this could be the comparatively large amounts of direct recharge and the high permeability of the karst aquifers producing a large “turnover” of pollutants. Groundwater of

the main well field is possibly further diluted by clean water drawn (through the natural or induced hydraulic gradient) from areas with little human activities such as the Local Forest Reserves.

In summary, the following **major conclusions and recommendations** were derived from the groundwater reconnaissance sampling campaign in the Lusaka aquifer systems:

1. **Despite high vulnerability and the presence of pollution sources groundwater in the main abstraction areas in Lusaka still complies with national and international drinking water standards with respect to inorganic constituents. Protective measures should be taken to ensure that groundwater quality will not deteriorate in the future.**
2. **Measured nitrate concentrations at Zingalume and Makeni Burkley springs and at Bauleni, Chawama 1 and Chainda public wells exceed the drinking water standards and are potentially dangerous to infants.**
3. **Since most springs are used for domestic purposes and water supply, they need to be better protected against pollution from human activities.**
4. **Water from Chinyunyu Hot Springs is not suitable for human consumption due to high levels of fluoride (exceeds Zambian Drinking Water Standard by a factor of 8).**
5. **A continuous monitoring of groundwater quality at selected sites, in particular for nitrate and micro-organisms, should be established. Trends in increase in total inorganic load (salt content) could perhaps be detected by monitoring electrical conductivity.**
6. **The impact of groundwater contamination by toxic organic substances is not known and therefore needs to be further looked into.**

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List of Abbreviations

BGR	Bundesanstalt für Geowissenschaften und Rohstoffe (Federal Institute for Geosciences and Natural Resources)
DWA	Department of Water Affairs
EC	Electrical conductivity
Fm	Formation
LWSC	Lusaka Water and Sewerage Company
TDS	Total dissolved solids
ZDWS	Zambian Drinking Water Standards
m asl	Meters above sea level
m bgs	Meters below ground surface

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1. Introduction

A groundwater reconnaissance sampling campaign was designed and conducted between January and October 2008 under the "Groundwater Resources for Southern Province" (GReSP) Project that is jointly carried out by the Department of Water Affairs (DWA) and the German Federal Institute for Geosciences and Natural Resources (BGR). The sampling points included perennial and seasonal springs as well as water supply wells operated by the local service provider, the Lusaka Water and Sewerage Company (LWSC). The area covered includes the main aquifers around Lusaka found within the crystalline dolomite and dolomitic limestone of the Lusaka Dolomite and Cheta formations, and the schists of the Chunga Formation (Fm).

The GReSP Project has recently established a comprehensive groundwater information system for Southern Province and is currently working on extending the information system to the Lower Kafue and Chongwe catchments which include the Lusaka aquifers. The overall objective of the upcoming project phase is to establish a groundwater management and protection strategy for the Capital.

The objectives of the reconnaissance sampling were to

(5) locate and map major springs in the study area,

(6) analyse the groundwater composition and identify the major groundwater types,

(7) preliminarily assess the extent of groundwater pollution in urban areas,

(8) use the results to make recommendations on a more detailed sampling campaign during 2009 and consecutive years in the desk study and work programme report (Bäumle & Kang'omba 2009).

Springs can be considered discharge points of groundwater systems and provide "integrated" information on groundwater chemistry and pollution over their catchment. The water supply wells of the LWSC are favourable sampling points since they produce groundwater continuously and often over a considerable radius of influence. Furthermore, no additional infrastructure (pumps, power supply, etc.) was needed for sampling. For these reasons, both springs and supply wells were considered an obvious choice for the reconnaissance sampling.

2. Sampling procedure

This report covers the activity of sampling springs during the rainy season from January 18th 2008 to mid-march 2008 and at the end of the dry season during October 2008. In total, 30 springs in five different river catchments were detected near Lusaka, namely the Chalimbana and Ngwerere (Chongwe), Chilongolo and Chunga-Mwembeshi (Kafue), and Funswe (Kafue Gorge) catchments. Only a preliminary attempt was made to characterise the hydrology of the springs at this stage. A more thorough investigation of the spring's discharge characteristics and dynamics will be part of future investigations and is therefore beyond the scope of this report. Due to the pronounced difference between the rainy and dry season, spring discharge varies strongly between the seasons. Many springs are seasonal or intermittent. The variation in discharge likely affects the groundwater composition as, compared to peak flow, dry season runoff represents flow with higher mean residence time.

Sampling of production wells was carried out between 29 July and 25 August on selected boreholes operated by the LWSC. 32 boreholes in total were sampled. Samples were collected off the tap of the water point. Where online chlorinators had been fixed, the water was tapped before chlorination.

In addition, two recently drilled boreholes in the Lusaka South Forest Reserve No. 26 were sampled.

Measured in-situ parameters included pH, electrical conductivity (EC), reduction-oxidation potential (Eh), temperature and dissolved oxygen. All samples were tested by the BGR laboratory in Germany. The chemical parameters analysed comprised inorganic major, minor and trace constituents of water. The analysis methods applied are summarised in Table 1.

Table 1 Analysis methods applied by BGR laboratory

Parameter	**Analysis Method**
Br, Cl, F, NO_2, NO_3, SO_4	Ion chromatography
HCO_3	Titrimetric
NH_4	Photometric
Al, Ba, B, Ca, Fe, K, Mg, Mn, Na, PO_4, SiO_2, Sr, Zn	ICP-OES [1)]
Other metals and rare elements	HR-ICP-MS [2)]

1) Inductively Coupled Plasma with Optical Emission Spectroscopy
2) High Resolution Inductively Coupled Plasma Mass Spectrometry

The production wells were also tested for microbiological contamination. Prior to collecting a microbiological sample for laboratory analysis, the outlet was disinfected. A portable microbiological testing laboratory, the Potalab® equipment by Wagtech Int., was used for the detection of total and faecal coliforms. The equipment provides bacteriological testing using the method of membrane filtration and incubation of faecal and total coliforms as an indicator of the presence of other harmful bacteria and viruses. The membrane filtration unit was sterilised under a flame and by applying methylated spirit prior to filtration of a water sample. Samples were incubated for 24 hours in the DWA laboratory on the day of sampling.

3. Previous studies and documentation

3.1. Springs

Previous studies on springs in the Lusaka area include the groundwater management studies carried out by the BGR in cooperation with the Lusaka City Council during the mid- and late 1970s (von Hoyer et al. 1978) as well as borehole inspections carried out in the framework of the North-West Lusaka Water Project (GIBB Ltd. 1999b). Chinyunyu Hot Spring has previously been described by Legg (1974). The report includes five chemical analyses of the spring water samples that were taken between 1959 and 1972.

The BGR study report describes 25 spring locations and includes estimated discharge during the 1976/1977 season. The highest flows observed this rainy season did not exceed 10 l/s according to this source.

The borehole database by GIBB Ltd. mainly covers the area to the west of Lusaka along the Mumbwa road. It contains 27 springs including a brief description of their usage and estimated discharge.

The location of the springs described by von Hoyer et al. and GIBB Ltd.are plotted together with the springs visited during this study in the location map shown in Figure 5. Although the spring locations detected by the individual studies are usually located in close vicinity, their locations seldom match completely. This may be due to the fact that some springs are minor or run only occasionally and hence, could not be detected by all investigators, or that some springs represent a group rather than individual spring outlets. The spring inventory by GIBB Ltd. includes several water filled karst clefts. These karst features may overflow during the rainy season. During the dry season they contain a water body that intersects the phreatic zone. The karst clefts are often widened and used as natural wells by residents. It should also be noted that coordinates taken during the 1970s do not reach the precision of today's GPS readings. Finally, it is believed that some springs (e.g. the springs near the University of Zambia) have ceased to flow due to a presumed lowering of the groundwater table over the last 30 years.

3.2. Water Supply Wells

Information on the water supply wells in Lusaka is largely drawn from records at the LWSC. The service provider operates almost 80 wells in various parts of the City largely from aquifers within the crystalline limestone and dolomite. The oldest wells are Lusaka Waterworks Well No. 1 and 2 drilled during 1953/1954. The major well fields in the southern

parts of the City and along Mumbwa Road were completed during the 1960s. More recently drilled production wells produce water for isolated supply systems within townships, the so-called Satellite Water Supply system. Most recently, six wells located in George Compound were put in operation. Unfortunately, borehole completion reports could only be retrieved for exploration or production boreholes drilled after 1999. These include Chelston (GIBB 1999, 2000, 2002l), NRDC Ranch (GIBB 1999, 2000, 2002 a-e, 2002 l), Mass Media and Kafue Road Quarries areas (GIBB 1999c, 2002 f, 2002 g), Avondale (GIBB 2002 h-k, Lusaka Water & Sewerage Company 2007), Marian Shrine (GIBB 2002 l) and Buckley (GIBB 2002 m).

Appendix 3 includes the borehole logs from completion reports of the two boreholes sampled in the Lusaka Local Forest area. The reports were obtained from the DWA borehole records and Oriental Consultants & Yachiyo Engineering (2008).

3.3. Urban groundwater pollution

Various studies have reported on microbiological and chemical pollution of the Lusaka aquifers and have outlined the high vulnerability of the karstified rocks to pollution from poor sanitary facilities, leaking sewage pipes and underground petroleum tanks, industrial effluents, unlined waste disposal sites and other pollution sources. Von Hoyer et al. (1978) found increased chloride, sulphate and phosphate contents in the light industrial areas, and high nitrates exceeding 44 mg/L that were sometimes accompanied by high sulphate and chloride values, during the rainy season 1977/78 in the informal settlements. More recent investigations confirmed the pollution of groundwater with nutrients (nitrate, phosphate and traces of ammonia) and an increase in salinity in the urban areas (EC > 1000 μS) together with widespread contamination with total and faecal coliforms (NKhuwa 1996, 2006, Nyambe & Maseka 2000, Kampeshi 2003, de Waele et al. 2004, Mpamba 2008). The probably most comprehensive compilation of potential pollution sources within Lusaka Urban was presented by Kampeshi (2003).

While the previous studies added valuable information on the groundwater chemistry and were very indicative towards the status of pollution of the Lusaka aquifers, the area covered by the individual studies was usually restricted to the limestone and dolomite of the City area, or of parts of the City area. None of the previous studies covered the chemistry of Lusaka's springs. Furthermore, the chemical analyses were generally incomplete by covering only selected parameters. The various analyses programs, with a few exceptions, did not comprise heavy metals, pesticides and hydrocarbons. In addition, the results of the analyses commonly lacked accuracy and reliability due to the deficiency in the capabilities of the local laboratories.

4. Geological setting

The investigation area includes parts of the geological maps (1:100,000) degree sheets 1527NE, 1528NW, 1528 NE and 1528SW mapped and described respectively by Simpson (1962), Simpson et al. (1963), Garrard (1968) and Smith (1963). Further descriptions of the geological setting of the Lusaka area include Drysdall (1960), Matheson & Newman (1966) Turner & Turner (1986) and Nkhuwa (1996). Recent reviews of the geological sequence on a more regional scale were presented by Porada & Berhorst (2000) and Johnson et al. (2007).

Regionally, the Lusaka rocks are part of the Zambezi Belt that, by definition, is separated by the Mwembeshi Shear Zone, from the Lufilian Belt to the north. The Lusaka area is covered by strongly folded overthrusted metasedimentary rocks of Katanga (Neoproterozoic) age which have been intruded by granitic and basic bodies. The rocks are part of the "Zambezi supracrustal sequence" (Hanson et al. 1994, Johnston et al. 2008) within the Zambezi Belt. The sequence is composed of a succession of metasedimentary clastic and carbonate rocks, with a thick sequence of basal volcanics and lavas, and underlain by a variety of Early to Late Precambrian metamorphosed gneisses, quartzites, metasediments and granitoids. The area is believed to have undergone three phases of folding and subsequent fracture tectonics. Owing to the intense tectonical deformation of the Katanga sequence, the stratigraphic succession and its regional correlation are still not fully clarified. Based on the stratigraphical succession proposed by Simpson et al. (1963) the metasedimentary cover can be divided into three formations: the Chunga Fm comprising schist and quartzites, the Cheta Fm including schist and carbonates and the Lusaka Dolomite Fm. All carbonate rocks within the sequence were commonly referred to as limestone and dolomite. However, they are crystalline metamorphic rocks, and should therefore be named marbles.

The Chunga Formation is considered the oldest formation in this sequence; its most common rock type is quartz-muscovite-biotite schist interbedded with psammites, quartzites and minor calcareous horizons. Massive quartz veins occur often standing as small topographic highs.

The Cheta Formation is made up of two calcareous and two schist members. The schists include various rock types dominated by quartzites, quartz-muscovite-chlorite schists and quartz-muscovite schists. Compared to the Chunga Fm the rocks are believed to be of lower-grade metamorphism (Porada & Berhorst 2000).

The calcareous rocks of the Cheta Fm have been described as grey and white, banded dolomitic limestones and dolomite and grey scapolite argillaceous limestone that is thought to have undergone regional metamorphism (Simpson 1962). The lower and thicker of the two calcareous members is referred to as Mampompo Limestone on map sheets 1528NE and

1528SW. The calcareous rock contains streaks, continuous laminae or lenses of schistose material presumably representing highly modified argillaceous beds.

The Lusaka Dolomite occurs as crystalline banded, grey and white dolomitic limestone. Compared to other calcareous rocks of the Katanga sequence, it appears to be purer and includes a much higher proportion of dolomitic rocks, particular the massive, pink, white and grey varieties. Quartz-muscovite schist is found instead of scapolite-biotite schist within the thin shaly (argillaceous) limestones.

According to Lambert (1962), von Hoyer et al. (1978) and Nkhuwa (1996) the metasedimentary carbonate rocks have suffered extreme differential dissolution, resulting in the development of a system of subterranean conduits and solution channels. Some parts of the dolomite are brecciated. The Lusaka Dolomite Fm is known to host abundant groundwater resources with wells producing at rates exceeding 50 l/s.

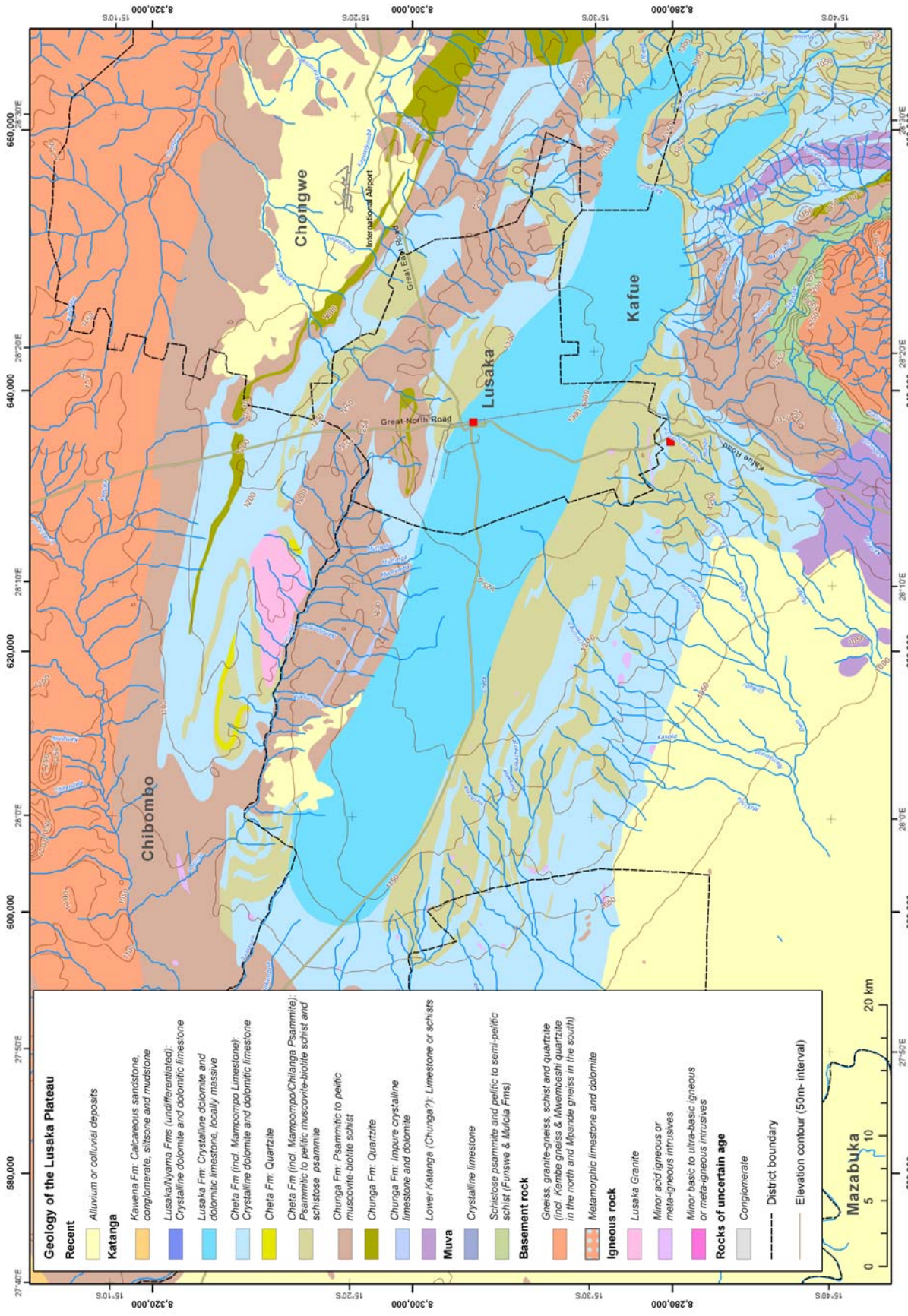

Figure 1 Geological map of Lusaka and outlying areas (digitised from Geological Maps Series, scale 1:100,000).

5. Surface and groundwater drainage

5.1. Surface drainage

The Lusaka plateau forms a 70 km long and 10 km wide ESE-WNW stretching low ridge with an elevation ranging from 1200 to above 1300 m above sea level (asl) (Figure 2). Due to the karstified nature of the Lusaka Dolomite Fm, virtually no surface drainage pattern has developed on the plateau. At the edge of the plateau, on the lesser permeable rocks of the Cheta and Chunga formations, smaller streams emerge and feed west- and southwards into the catchments of the Chunga, Mwembeshi, Chilongolo and Funswe Rivers that are part of the Kafue Catchment and north- and eastwards into the Ngwerere and Chalimbana which are tributaries of the Chongwe River (Figure 3). A large number of springs can be found along the edges of the karstified plateau indicating that underground drainage is directed from the centre towards the edges of the ridge.

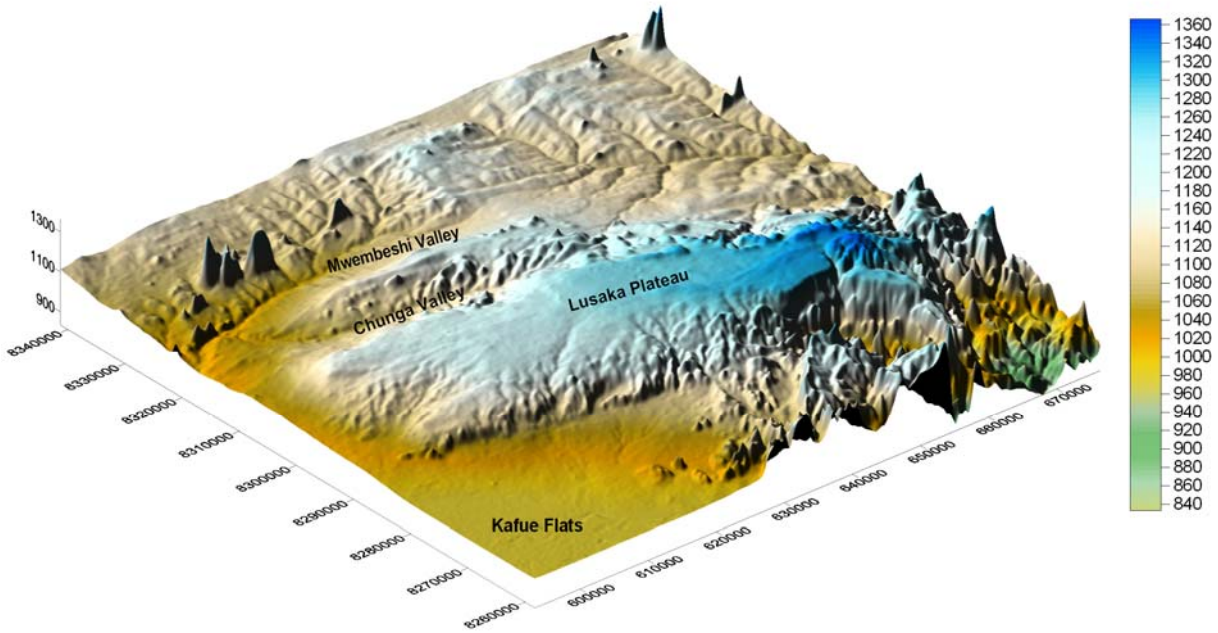

Figure 2 Block diagram showing the topography of the Lusaka plateau.

A lack of surface drainage is also characteristic for the ESE-WNW stretching outcrop of Cheta limestone located between the Mwembeshi and Chunga Rivers, a smaller outcrop of Lusaka Dolomite southeast of the Lusaka Local Forest No. 55, and the carbonate rocks allocated to the Chunga Fm located SE of the Chalimbana Training College in the far east of the area shown in Figure 3.

A dendritic river system has developed on areas covered by schist and less permeable carbonate rocks. In the southeast an extraordinarily dense river network can be observed

owing to the small permeability of the rock and the steepness of the terrain that favours surface runoff. Please also note that in the southwest some streams (such as the Cheta) disappear after entering the Kafue Flats within a distance of a few kilometres indicating infiltration of runoff.

5.2. Aquifers and groundwater flow

The aquifers of the Lusaka comprise (Lambert 1962, Chenov 1978, von Hoyer 1978):

1. Highly productive aquifer within the Lusaka Dolomite Fm which is sometimes combined with adjacent and more permeable parts of the Cheta limestones.
2. Locally productive aquifers within the scapolite limestone and dolomite of the Cheta Fm
3. Aquifers of limited or very localized potential within the weathered or fractured zones of the schists and quartzites

It is generally accepted that the main aquifer is hosted by the karstified limestone and dolomite rocks and that the karst water is under free (phreatic) water table conditions.

Apart from this regional classification perched aquifers developed within the epikarst or weathered zones within the schists are sometimes distinguished from the underlying regional aquifers (Lambert 1962, GIBB 1999b, in Kapeshi 2003).

Groundwater flow directions can be established from existing groundwater contour maps by von Hoyer et al. (1978), GIBB (1999b, in Bäumle & Kang'omba 2009), Mpamba (2008) and Mpamba et al. (2008). The maps by von Hoyer et al. which were generated for three distinct seasonal scenarios during the years 1976 to 1978, and by Mpamba (prepared for the rainy season 2004/2005) show groundwater level contours for the City and the Lusaka Forest areas in the southeast whereas the map by GIBB Ltd. (prepared for the period June/July 1998) cover only the western portion of the Lusaka Dolomite aquifer. The contour map shown in Figure 4 extends over the whole area underlain by the Lusaka aquifer systems except for the area covered by Cheta limestones in the northwest and was prepared in the framework of this project (Bäumle & Kang'omba 2009, in prep.). The map is based on groundwater level measurements taken at 126 points throughout the area during November 2008 including dynamic water level data from October 2008 provided by the LWSC.

Similar to the surface water pattern, a water divide crosscutting the Lusaka Forest area can be determined. South of this divide groundwater flow is directed south- and south-eastwards towards Shantumbu area and the Funswe River Catchment whereas groundwater to the

north follows a north-westerly direction. In the eastern parts of town (Leopard Hill and Bauleni areas) groundwater flow is directed to the northeast. The Chalimbana River and tributaries to the Ngwerere River clearly act as drainage channels for groundwater through areas of less permeable schists. Within the City area, groundwater flow is considerably influenced by the cone of depressions created by public wells. Observed drawdowns, however, are usually less than 10 meters owing to the high permeability of the karst aquifer around the major production wells. In the western portion groundwater moves generally in north-westerly direction towards Mwembeshi in the far west following the axis of the elongated Lusaka Dolomite body. Along this flow path, groundwater apparently branches out towards a major groundwater discharge zone located along dolomite/schist boundaries to the north (Chunga tributaries) and towards the southeast (Cheta stream and tributaries). Within the metasediments of the Cheta Fm sediments in the southeast no springs were found, and depths to water table are fairly high. This indicates that underground water is well drained owing to the comparatively high permeability of these rocks.

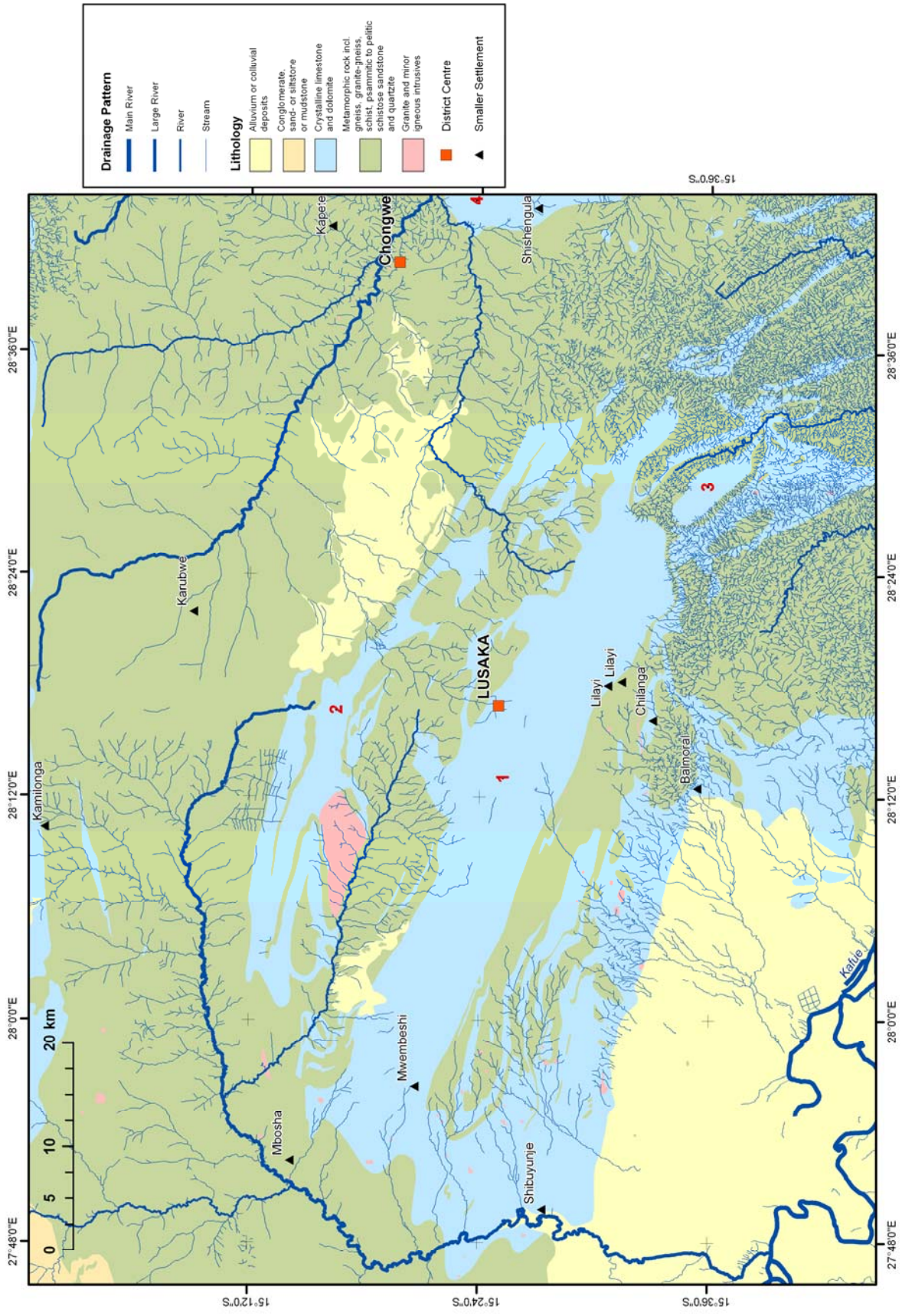

Figure 3 Drainage pattern developed in the Lusaka area (Rivers digitised from topographic map series 1:50,000). 1 = Lusaka Plateau, 2 = Cheta Fm (Lusaka North), 3 =Smaller outcrop of Lusaka Dolomite, 4 = Chunga Fm SE of Chalimbana Training College)

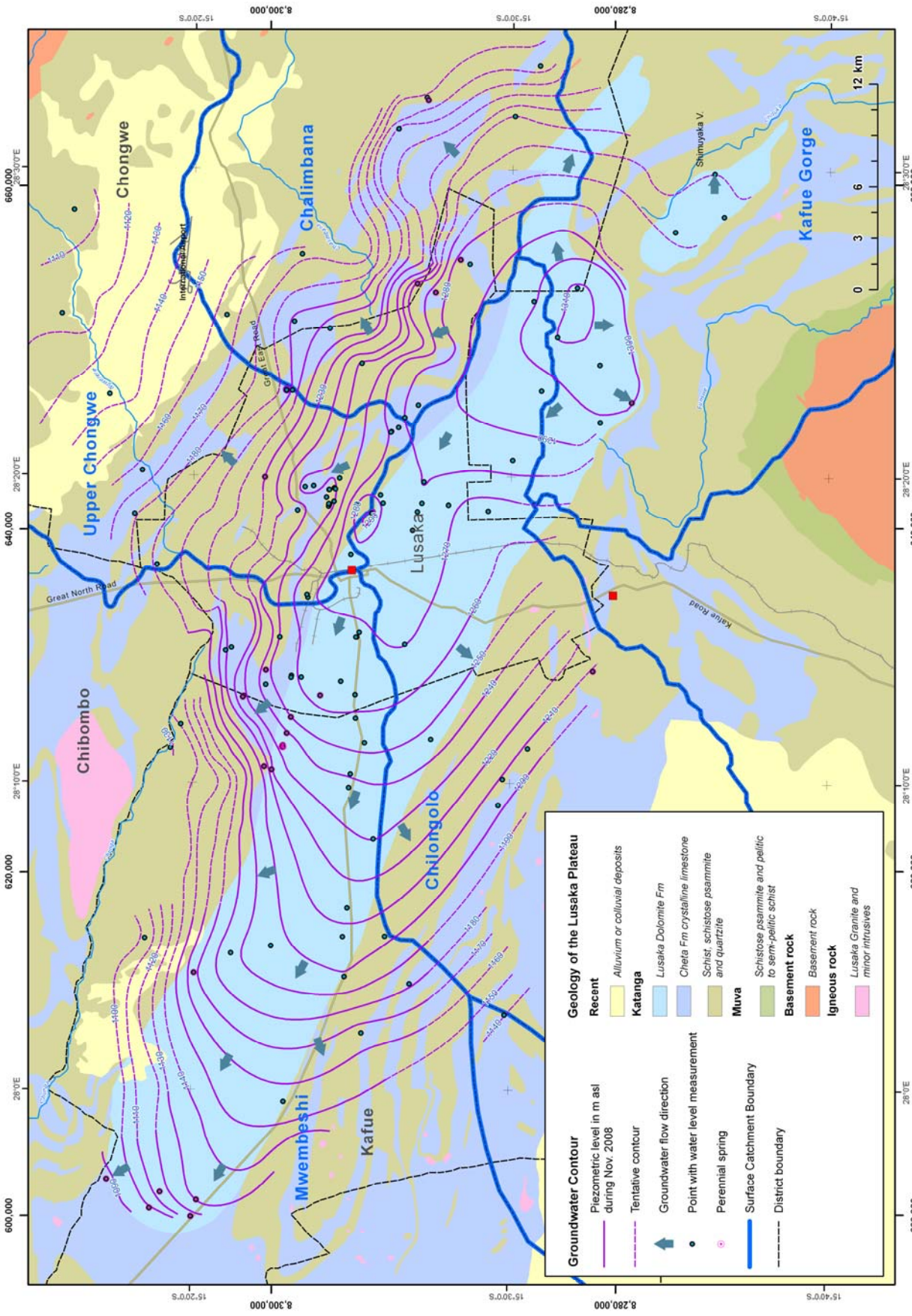

Figure 4 Groundwater contour map for November 2008

6. Occurrences of springs in the Lusaka area

Depending on their hydraulic (discharge) behaviour springs can be divided into **perennial** (springs that flow throughout the year), **seasonal** (springs that cease to flow during the dry season) and **intermittent** (springs that fall dry several times a year).

Owing to the karstic nature of the calcareous rocks in Lusaka, springs within the Lusaka Dolomite and locally the limestones of the Cheta Fm can be regarded as **karst springs**. This type of spring emerges at the outlet of a subterranean network of conduits formed, to various degrees depending on the maturity of the karst, by fractures, smaller dissolution cavities and large, pipe-like caverns. **Sinkhole springs** occur where groundwater is under artesian pressure and a subterranean cavern is connected to a shaft that rises to the surface. Karst springs are generally characterised by a pronounced and rapid fluctuation in discharge.

Apart from this, three types of springs are prominent in the Lusaka area, namely depression springs, contact springs and fault springs.

Depression springs are formed along a slope or in a topographical depression when the water table reaches the land surface. These springs may fall dry depending on the annual water table fluctuations.

Contact springs occur where less permeable rock is underlying an aquifer and precludes the flow of all water that flows within the top layer. Such a lithological contact is often marked by a line of springs which may either be in the main water table or in a perched water table (Bryan 1919, in Fetter 2001). Less permeable layers within the Katanga sequence could be formed by schist, argillaceous bands within the calcareous rocks or areas of massive, intact carbonate rock.

Joint and fault springs can form in low-permeability hard rock (such as the Chunga schists) where permeable joints or faults facilitate water movement through the rock and intersect the land surface.

6.1. Location and characteristics of springs in Lusaka

The springs visited during the sampling campaign are summarised in Table 2. The locations of the springs are shown in Figure 5. Most of the springs in the Lusaka area are associated with karstified carbonate rocks. In the discussion following below, these springs were divided into four groups based on their location with respect to river catchments, namely the:

- Mwembeshi Group in the *Mwembeshi* Catchment
- Lusaka West Group in the *Chunga* Catchment, a sub-catchment within the Mwembeshi

- Chalimbana Group in the *Chalimbana* Catchment
- Makeni/Lusaka South Group in the *Chilongolo* and *Funswe* Catchments

Five springs detected within the city limits lie within schist rock. Except for Independence Park spring, they belong to the *Ngwerere* Catchment. The remaining springs visited are located in a considerable distance from the City boundaries within Lusaka Province.

Usage and protection of springs

Most springs sampled in Lusaka are used for either drinking, domestic purposes, livestock or small-scale agricultural purposes.

Spring protection measures have only been constructed at Ng'ombe and to a lesser extent, Palabana Dairy Institute. Ng'ombe spring has been well protected with concrete blocks extending into the ground along with monthly chlorination. The only protective measures at Palabana Dairy spring include canalised flow of water. The rest of the springs are not protected against pollution by human activities or livestock. Large earth dams were constructed downstream of Shantumbu and Palabana Dairy springs.

Table 2 Location and characteristics of springs

No.	Name of Spring	Sub-Catchment – Catchment	Formation	Longitude (WGS84)	Latitude	Elevation m asl	Discharge	Sampled: RS[1)]	Sampled: DS[2)]
1	Good Hope Farm	Chalimbana - Chongwe	Cheta crystalline limest.	28.45100	15.47300	1285	Seasonal	yes	no
2	Palabana A	Chalimbana - Chongwe	Cheta crystalline limest.	28.52200	15.44010	1226	Seasonal	yes	no
3	Palabana Dairy	Chalimbana - Chongwe	Cheta crystalline limest.	28.53760	15.45560	1218	Perennial	yes	yes
4	State Lodge	Chalimbana - Chongwe	Cheta crystalline limest.	28.43790	15.45040	1266	Perennial	yes	yes
5	State Lodge Zimb/we Farm	Chalimbana - Chongwe	Cheta crystalline limest.	28.43310	15.46000	1276	Perennial	yes	yes
6	Ng'ombe	Ngwerere - Chongwe	Chunga Schist	28.33213	15.35794	1223	Seasonal	yes	yes
7	Palmwood Lodge	Ngwerere - Chongwe	Chunga Schist	28.33260	15.37100	1220	Seasonal	yes	no
8	Saint Mary's School	Ngwerere - Chongwe	Chunga Schist	28.26590	15.37730	1264	Seasonal	yes	no
9	Saint Monica's B School	Ngwerere - Chongwe	Chunga Schist	28.26780	15.37900	1267	Seasonal	yes	no
10	Linda Mwandila	Chilongolo – Kafue Flats	Lusaka Dolomite	28.22780	15.54360	1209	Perennial	yes	yes
11	Makeni Burkley	Chilongolo – Kafue Flats	Lusaka Dolomite	28.22790	15.51360	1241	Seasonal	yes	no
12	Makeni Valley Spring	Chilongolo – Kafue Flats	Lusaka Dolomite	28.24660	15.44140	1275	Seasonal	yes	no
13	Chimbwete	Chunga-Mwembeshi	Lusaka Dolomite	28.19356	15.38311	1240	Perennial	no	yes
14	Handamana Section A	Chunga-Mwembeshi	Lusaka Dolomite	28.18627	15.38063	1234	Perennial	yes	yes
15	Handamana Section B	Chunga-Mwembeshi	Lusaka Dolomite	28.18595	15.38120	1234	Perennial	no	no
16	Independence park	Chunga-Mwembeshi	Chunga Schist	28.26720	15.37040	1261	Seasonal	yes	no
17	Kasanova Kanyimbu A	Chunga-Mwembeshi	Lusaka Dolomite	28.19240	15.41160	1253	Seasonal	yes	no
18	Kasanova Kanyimbu B	Chunga-Mwembeshi	Lusaka Dolomite	28.19230	15.41160	1253	Seasonal	yes	no
19	Laughing Waters	Chunga-Mwembeshi	Lusaka Dolomite	28.17540	15.37130	1204	Perennial	yes	yes
20	Nsanje Muleke	Chunga-Mwembeshi	Lusaka Dolomite	28.18697	15.38100	1237	Perennial	yes	yes
21	St. Charles Catholic	Chunga-Mwembeshi	Lusaka Dolomite	28.20230	15.38520	1250	Seasonal	yes	no
22	Zingalume	Chunga-Mwembeshi	Cheta crystalline limest.	28.22770	15.37200	1251	Perennial	yes	yes
23	Kashembe Farm A	Mwembeshi	Lusaka Dolomite	27.93567	15.31198	1099	Perennial	no	yes
24	Kashembe Farm B	Mwembeshi	Lusaka Dolomite	27.94432	15.31754	1116	Perennial	no	yes
25	Michelo	Mwembeshi	Lusaka Dolomite	27.95114	15.28940	1086	Perennial	no	yes

No.	Name of Spring	Sub-Catchment – Catchment	Formation	Longitude (WGS84)	Latitude	Elevation m asl	Discharge	Sampled: RS[1)]	Sampled: DS[2)]
26	Mwembeshi Prison	Mwembeshi	Lusaka Dolomite	27.94010	15.33660	1140	Perennial	yes	yes
27	Mwembeshi Satellite	Mwembeshi	Lusaka Dolomite	27.93130	15.33370	1120	Perennial	yes	yes
28	Namayani Stream	Mwembeshi	Lusaka Dolomite	27.95333	15.28569	1079	(Sealed)	no	no
29	Shantumbu A B. School	Funswe – Kafue Gorge	Lusaka Dolomite	28.37400	15.56330	1302	Perennial	yes	yes
30	Shimuyaka Village	Chisuko – Kafue Gorge	Lusaka Dolomite	28.49847	15.60619	1263	Seasonal	no	no
31	Shalenga A Village	Kafue Flats	Metamorphic rock (Katanga)	28.11630	15.69270	1002	?	yes	no
32	Shalenga B Village	Kafue Flats	Metamorphic rock (Katanga)	28.11530	15.69170	1006	?	yes	no
33	Kanakantapa	Kanakantapa	Basement	28.65640	15.18650	1162	?	yes	no
34	Chinyunyu Hot Spring	Lunsemfwa	Basement	29.02390	15.26130	986	Perennial	yes	no

1) RS = during rainy season, Jan. - March 2008 2) DS = during dry season, Oct. 2008

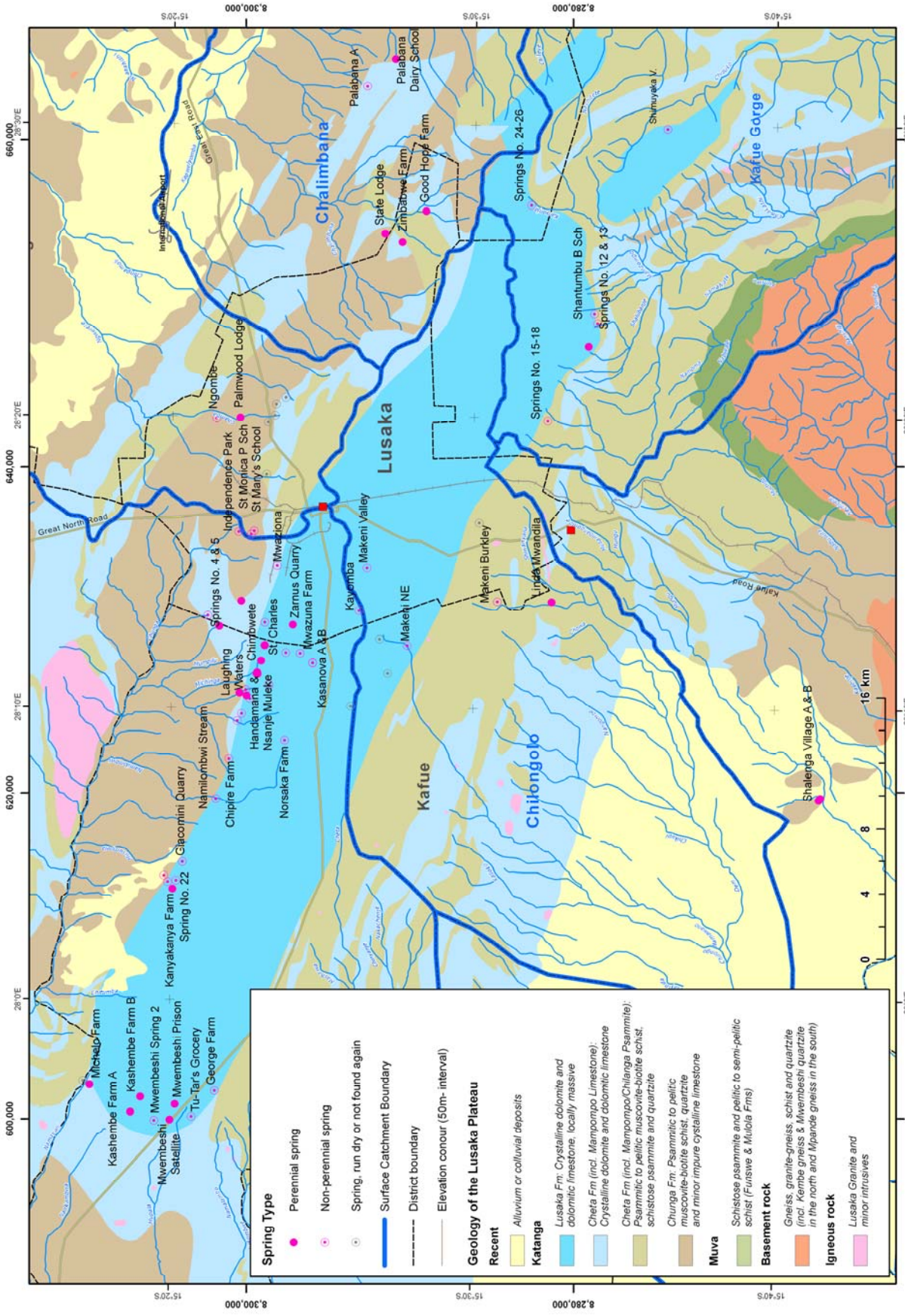

Figure 5 Map showing the location of the springs in Lusaka Province. Please note that Kankantapa and Chinyunyu Hot springs are not displayed on this map.Karst springs

Mwembeshi Group

This group of springs lie some 40 km west of Lusaka along the western edge of the Lusaka plateau near the junction of Mumbwa Road and District Road D170 (Mungwi Road, in old reports referred to as Botha Rust Road) and includes Mwembeshi Prison and Mwembeshi Satellite springs, Michelo spring as well as Kashembe Farm A and B springs. All five springs are perennial.

The terrain in this area is markedly dipping from 1150 to 1050 m asl within a distance of 5 to 7 km towards the valleys of small tributaries of the Mwembeshi River (e.g. Namayabi, Namkambwa and Mupala streams). The springs emerge at an elevation of between 1080 – 1140 m asl near the geological boundary between the Lusaka Dolomite and the carbonaceous rocks of the Cheta Fm. The topographic situation and the location of the springs near the contact between the Lusaka Dolomite and the potentially less permeable Cheta calcareous rocks favour the occurrence of springs in this area. The Mwembeshi, Michelo and Kashembe Farm springs, however, all occur within major, over 1 meter wide grikes (see Figure 6 to Figure 9) and should therefore be classified as joint or fault springs despite the fact that no faults are present on the geological maps. Michelo Spring is identical to Spring No. 23 on Farm no. 190A that was mentioned by both von Hoyer et al. (1978) and GIBB Ltd. (1999b). It is located in the extension of a prominent NNW-SSE trending fault.

Figure 6 Kashembe Farm B spring., Oct. 2008

Figure 7 Michelo spring, Oct. 2008

Mwembeshi Prison spring is used for gardening (banana, vegetables). Kashembe A is used for domestic purposes, fish farming, livestock and small-scale irrigation (orchards) whereas Kashembe B is only used for livestock.

Figure 8 Mwembeshi Prison spring, Oct. 2008

Figure 9 Mwembeshi Satellite spring, Oct. 2008

It was reported by residents that a spring existed at the source of the Namayani stream. Today, the Namayani spring is covered by earth that was moved there, but water seeps out further downstream to feed the small stream.

Three additional springs were reported by GIBB Ltd. (1999b) in the area. They include “Tu Tar’s Grocery spring” in Mwembeshi Village, “Mwembeshi Spring 2” located approx. 1 km north of Mwembeshi Satellite spring, and one spring on George Farm south of Mwembeshi. These springs, however, could not be found during this study.

Lusaka West Group

A series of springs that all form part of the perennial Chunga River Catchment extends over about 25 km along and south of District Road D170 that runs parallel to the northern margin of the dolomite. Among the springs visited were Handamana section (Figure 10) Laughing waters (Figure 11), Nsanje Muleke (Figure 12), Chimbwete (Figure 13), Zingalume Overspill (Figure 14) and Kasanova Kanyimbu A and B. At Handamana section two springs were observed within a distance of approx. 100 m that were not sampled individually. Additional springs were reported in previous studies, in particular in the farming area further to the west such as the perennial (?) Kanyakanya Farm spring. According to von Hoyer (1978) the perennial Namilombwe stream collects seepage water (observed dry water flow about 5 l/s).

Figure 10 Handamana Section spring, Mar 2008

Figure 11 Laughing waters spring Mar 2008

The topography is gently dipping towards the Chunga valley in north-westerly directions. The spring elevation near Zingalume, Laughing Waters and Kasanova springs is about 1200 – 1260 m asl. The springs seem to feed into smaller tributaries of the Chunga River such as the Mulyukuyuku, Muchumba, Michinga and Mumpilu streams. The elevation of springs located west of Namulombwi stream is 1120 – 1150 m asl.

Handamana, Laughing Waters, Nsanja Muleke, Chimbwete and Zingalume are considered perennial springs.

The springs discharge the aquifer hosted by the Lusaka Dolomite Fm with exception of the springs near Barlaston (e.g. Zingalume) which are located within calcareous rock of the Cheta Fm. Many of the springs can be classified as contact springs occurring at the boundary of the dolomites to the schists of the Chunga Fm. Zingalume is probably a joint or fault spring. Water from Kasanova and Zingalume springs flow a short distance over the carbonate rocks to disappear underground further downstream. Lambert (1962) explains the existence of Kasanova springs by the occurrence of the synclinal core of a north-easterly cross-fold composed of massive dolomite with few fractures. Groundwater flowing northwards against this low-permeable internal barrier is forced to move upward and rise to the surface.

Figure 12 Nsanje Muleke spring, Oct 2008

Figure 13 Chimbwete spring, Oct 2008

The Nsanje Muleke, Handamana, Chimbwete and Zingalume springs are mainly used for domestic purposes. The Laughing Waters spring itself remains largely unused, but water is drawn from the stream further downwards and used for small-scale irrigation.

Figure 14 Zingalume Overspill Spring, Mar 2008

Makeni/Lusaka South Group

Several springs occur along the southern limits of the City including the Linda Mwandila (Figure 15), Makeni Valley and Makeni Burkley springs (Figure 16) as well as Shantumbu School spring which is located at the southern margin of the Lusaka South Forest Reserve and Shimuyaka Village spring in the far south-east. These springs can be allocated to either the depression or contact spring type. The lower permeable rock below the dolomite is formed by Cheta crystalline dolomitic limestone of the Mampompo member or by muscovite and biotite bearing metasiltstones locally known as “Chilanga psammite” (Smith 1963).

The Makeni springs are part of the Chilongolo Catchment and occur at 1250 – 1280 m asl within the Lusaka Dolomites that include an extensive outcrop of massive pink dolomite in this area. Makeni Burkley and Linda Mwandila springs are located further south presumably within the Mampompo member at an elevation of 1241 m and 1209 m asl, respectively. Only Linda Mwandila is considered a perennial spring. Its water is used for domestic purposes and for the construction of bricks.

The perennial Chilongolo River collects seepage water with an estimated minimum flow of 5 l/s according to von Hoyer et al. (1978). A seasonal spring near the source of this river was found by GIBB Ltd. (1999b). Springs No. 2 and 19 - 22 given by von Hoyer et al. could not be discovered during later surveys.

Figure 15 Linda Mwandila spring, Oct 2008

Figure 16 Makeni Burkley spring, Mar 2008

Several springs were reported by von Hoyer (Springs No. 12, 13, 15-18 and 24-26) to surface along the southern margin of the Lusaka Forest Reserve at the contact of the dolomites to the Chilanga (schistose) psammites. During this sampling campaign, however, only the spring near Shantumbu School could be found. The occurrence of seasonal springs to the southeast of Shantumbu which could correspond to Springs No. 12 and 13 was reported by local residents during the October survey. The elevation of the springs ranges from 1290 to 1310 m asl. The springs feed into the Funswe River and smaller contributing streams such as the Shelubenje, Mampompo and Kanyaja.

The main spring at Shantumbu is of the sinkhole type (Figure 17). The spring, however, is surrounded by a group of karstic collapse structures which are covered with soil and from which groundwater seeps out. The discharge from Shantumbu springs is collected in a large earth dam constructed a few hundred meters further downstream, which is used for livestock and small-scale gardening. The discharge from Shantumbu was high during the rainy

season, but during October 2008, the flow just fed a small rivulet emerging from the main sinkhole spring. Despite these observations, the spring is assumed to be perennial.

Figure 17 Shantumbu Basic School spring, Oct 2008

Figure 18 Shimuyaka Village spring, Nov 2008

Shimuyaka Village spring (Figure 18) was found during a field visit in November 2008. The spring feeds into the Chisuko River and is thought to occur at the contact between Lusaka Dolomite and Chilanga psammite since it is located on the steep slope towards the river valley. At the time of visit, the water was not freely flowing, but local residents have dug about 1 meter into the spring to collect water.

Chilambana Group

None of the springs of this Group were described in previous studies. Springs in the Chalimbana Catchment include State Lodge, State Lodge Zimbabwe farm, Good Hope farm, Palabana A and Palabana Dairy farm. The former emerge at 1265 – 1285 m asl whereas the elevation of the Palabana springs is between 1215 m and 1230 m asl. Some of these springs occur along or in the vicinity of fault zones separating the carbonaceous and karstified rocks of the Cheta Fm (Mampompo member) from quartz-muscovite biotite schist of the Chunga Fm.

State Lodge, State Lodge Zimbabwe Farm and Palabana Dairy springs are perennial.

State Lodge spring (Figure 19) is used for small-scale irrigation and constitutes a major tributary to the Chalimbana River. State Lodge Zimbabwe Farm (Figure 20) is mainly used for domestic purposes. Small-scale irrigation schemes can be found further downstream. Good Hope Farm remains largely unused.

Figure 19 State Lodge Springs, Mar 2008

Figure 20 State Lodge Zimbabwe Farm, Mar 2008

Figure 21 Good Hope farm, Mar 2008

The Palabana Dairy spring (Figure 22) forms a small stream along that collects groundwater over a distance of some 100 meters. The spring likely occurs at the contact of the limestone and schists, but rocks were covered by thick soil and could not be mapped. During the first visit in the rainy season the starting point of the Palabana stream could not be accessed due to the strong flow and the thickets surrounding it. The spring water is collected by an earth dam and used for cattle drinking and small-scale irrigation by the State farm.

Palabana A spring (Figure 23) is a sinkhole spring situated within the crystalline limestones of the Cheta Fm. The spring is seasonal, and the water level in the sinkhole has dropped by about 3 to 4 m below ground surface until October 2008. Its water is used for domestic purposes by the local residents.

The State Lodge Zimbabwe farm is located in area with intense faulting near the contact of limestone and schist according to the geological maps.

Figure 22 Palabana Dairy Spring stream during the rainy season (left) and dry season (right) 2008

Figure 23 Palabana Spring A during the rainy season (left) and dry season (right) 2008

6.1.1. Schist springs

Springs within the Chunga Fm are found in Matero (Independence Park, St Mary, St Monica) and in Roma (University of Zambia, Palmwood Lodge, Ng'ombe). The latter are located along the Chamba stream that flows in northward direction towards the Ngwerere River. All five springs visited are seasonal and probably fall under the category depression springs.

The Matero springs are situated very close to the catchment boundary between the Chunga River to the west and the Ngwerere River to the east at an elevation of approximately 1265 m asl. In fact, the Independence Park spring lies within the Chunga Catchment whereas the other two springs that are separated from the Independence Park by the Matero quartzite ridge fall into the Ngwerere Catchment. Owing to their position at the margins of two river catchments on either side of a ridge, it is likely that their drainage area is of very local nature. St Mary and St Monica springs have been identified as seepage areas. Nevertheless, their total discharge can cause serious flooding of the residential area.

Ng'ombe and Palmwood Lodge springs rise to the surface at 1220 -1225 m asl. Ng'ombe spring is tapped through a shaft (Figure 24) and used for domestic purposes throughout the year.

Figure 24 The shaft at Ng'ombe spring during Mar 2008 (left) and Oct. 2008 (right)

6.1.2. Other springs

Shalenga Springs

Two springs are located near Shalenga village approximately 11 km NW of Kafue. The water issues at 1000 - 1010 m asl near undifferentiated metamorphic rock of Precambrian age that is exposed within alluvium at the north-western margins of the Kafue Flats. The springs owe their existence most likely the occurrence of faults within the Precambrian rock.

Kanakantapa Spring

The Kanakantapa Scheme spring is located 16 km north of Chongwe within basement rock comprising gneiss and granite-gneiss. The springs belong to the Kankantapa River (Upper Chongwe) Catchment. Water issues at an elevation of approximately 1160 m asl.

Chinyunyu Hot springs

Chinyunyu is a famous hot spring and situated within 90 km from the Capital along the Great East Road. The springs are part of the Mwapula Catchment and rise at an elevation of approximately 990 m asl. According to Legg (1974) the spring occurs in an area underlain by basement rocks on an extension of young faults. The combined discharge of the springs was estimated at 6 l/s by Legg.

Figure 25 Chinyunyu Hot spring, Mar 2008

7. Location and characteristics of water supply wells

The LWSC currently operates 79 production wells in the City of Lusaka. Production from the aquifers from these wells totals 125,000 m^3/d according to recent data obtained from the LWSC (Bäumle & Kang'omba 2009, in prep.). Information on the location and geology of the sampled production wells are given in Table 3. The sampled wells can be allocated to the surface water catchments of the Ngwerere, Chalimbana, Chunga/Mwembeshi and Chilongolo rivers as indicated in the table. Please note that the location of the groundwater divides may differ substantially from the surface water boundaries due to the complex geological setting and the influence of intensive pumping from the aquifers.

The production rates of the wells range widely from <10 m^3/h to over 500 m^3/h. Some of the strongest and oldest wells are found within the Lusaka Dolomite Fm in the southern parts of the City (Figure 26). The most productive boreholes (numbers in brackets refer to current production rates provided by LWSC, in Bäumle & Kang'omba 2009, in prep.) in the Lusaka Dolomite include the wells at Shaft No. 5 (507 and 547 m^3/h), Waterworks (167 and 330 m^3/h), the Roadside wells along Mumbwa Road (75 - 150 m^3/h), Lumumba Road (138 m^3/h) and Lilayi Road (116 and118 m^3/h). Productive aquifers are also found within the crystalline limestones of the Cheta Fm except where they are compact and massive and show little fracturing and karstification. High yields within this formation were found at Leopards Hill (80 and 188 m^3/h), and on Malo Farm located along Great East Road (94 and 120 m^3/h). Lower yields in this formation were encountered in the vicinity of Malo Farm at Avondale, Chelston, Chainda and NRDC. In the boreholes at Mass Media (30 - 130 m^3/h), the Cheta limestones are overlain by schist. A similar geological setup is likely for the boreholes at International School.

The wells at Buckley and Freedom Water Trust are located in the far South of Lusaka District. They fall within schistose metamorphic rock and are characterised by relative low yields (4 - 13 m^3/h).

Table 3 Location of supply wells and boreholes sampled during the Jul/Aug 2008 campaign

No.	Name of Well/Borehole	P.R.[1)] [m3/h]	Catchment	Surface Geology[3)]	Longitude	Latitude (WGS84)
Water Supply Wells:						
1	Avondale 1	82.4	Chalimbana - Chongwe	Cheta crystalline limestone	28.40912	15.37743
2	Bauleni	40.4 [2)]	Chalimbana - Chongwe	Cheta crystalline limestone	28.38013	15.44198
3	Chainda	25.9	Chalimbana - Chongwe	Cheta crystalline limestone	28.40456	15.38948
4	Chelston 2	22.7 [2)]	Ngwerere - Chongwe	Cheta crystalline limestone	28.37990	15.38190
5	International 6A	81.6	Ngwerere - Chongwe	Cheta schist & minor quartzite	28.31719	15.40446
6	International 6E	82.9	Ngwerere - Chongwe	Cheta schist & minor quartzite	28.32184	15.40328
7	International 6F	45	Ngwerere - Chongwe	Cheta schist & minor quartzite	28.31964	15.40731
8	Kabanana	44.7	Ngwerere - Chongwe	Cheta crystalline limestone	28.30468	15.36039
9	Lumumba Rd 4A	137.9	Ngwerere - Chongwe	Lusaka Dolomite	28.26719	15.40460
10	Mass Media 2	52.7	Ngwerere - Chongwe	Cheta schist & minor quartzite	28.32679	15.40738
11	Mass Media 3	54.9	Ngwerere - Chongwe	Cheta schist & minor quartzite	28.32631	15.40794
12	Mulungushi 6A	n/a	Ngwerere - Chongwe	Cheta crystalline limestone	28.30943	15.38800
13	Mulungushi 6H	42.5	Ngwerere - Chongwe	Cheta crystalline limestone or schist	28.30880	15.38713
14	Northmead 2	70.1	Ngwerere - Chongwe	Cheta crystalline limestone	28.30546	15.39679
15	NRDC 1	17.2	Ngwerere - Chongwe	Cheta crystalline limestone	28.37660	15.34027
16	NRDC 2	40.1	Ngwerere - Chongwe	Cheta crystalline limestone	28.37993	15.34126
17	Chunga 2 [2)]	8.9	Chunga - Mwembeshi	Cheta crystalline limestone	28.25127	15.35620

No.	Name of Well/Borehole	P.R.[1)] [m3/h]	Catchment	Surface Geology[3)]	Longitude	Latitude (WGS84)
18	Chunga 6E [2)]	99.2	Chunga - Mwembeshi	Cheta crystalline limestone	28.25260	15.35382
19	George 2	n/a	Chunga - Mwembeshi	Cheta crystalline limestone	28.23478	15.38700
20	George 3	n/a	Chunga - Mwembeshi	Cheta crystalline limestone	28.22764	15.38489
21	George 5	n/a	Chunga - Mwembeshi	Lusaka Dolomite	28.23292	15.38964
22	George 6	n/a	Chunga - Mwembeshi	Lusaka Dolomite	28.23836	15.39139
23	George 7	n/a	Chunga - Mwembeshi	Cheta crystalline limestone	28.23575	15.38958
24	Roadside 1	124.6	Chunga - Mwembeshi	Lusaka Dolomite	28.24588	15.41960
25	Buckley 1	12.8 [2)]	Chilongolo - Kafue Flats	Cheta schist & minor quartzite	28.23663	15.52958
26	Buckley 2	10.8 [2)]	Chilongolo - Kafue Flats	Cheta schist & minor quartzite	28.23287	15.52960
27	Chawama 1	80	Chilongolo - Kafue Flats	Lusaka Dolomite	28.28520	15.46339
28	Freedom Water Trust [2)]	4.4	Chilongolo - Kafue Flats	Cheta schist & minor quartzite	28.26772	15.53998
29	Lilayi Rd 2	133.3	Chilongolo - Kafue Flats	Lusaka Dolomite	28.35442	15.43623
30	Shaft 5	444.5	Chilongolo - Kafue Flats	Lusaka Dolomite	28.30870	15.48703
31	Waterworks 2	167	Chilongolo - Kafue Flats	Lusaka Dolomite	28.31787	15.45303
Boreholes:						
1	Forest 26 BH-7	0	Chilongolo - Kafue Flats	Lusaka Dolomite	28.34230	15.50096
2	MFEZ BH J4	0	Chilongolo - Kafue Flats	Lusaka Dolomite	28.37932	15.51232

1) P.R. = Production rate in cubic meters per hour after data by KRI et al. (2008)

2) Intermittent supply

3) As observed on geological map series scale 1:100,000

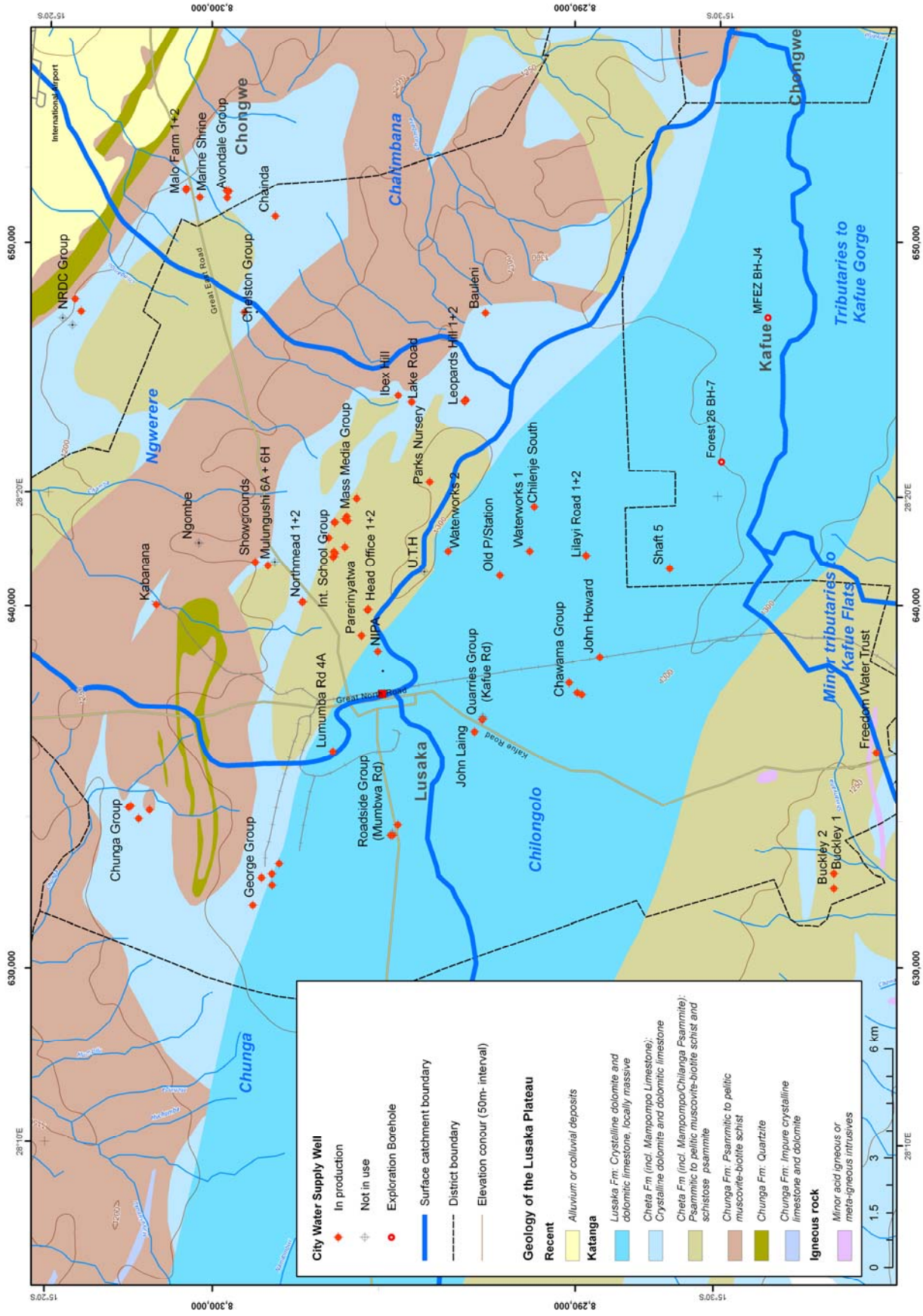

Figure 26 Map showing the location of the City's water supply wells and the sampled boreholes in Forest 26

8. Results and Interpretation

Groundwater pollution in Lusaka urban and peri-urban areas can originate from industrial effluents, traffic, on-site sanitation and disposal of domestic waste water by latrines or septic tanks, domestic refuse dumps and junk yards, municipal solid waste disposal sites, domestic gardening or peri-urban agriculture. Pollution may often be attributed to lack of infrastructure such as poor on-site sanitation facilities or leaking sewer or stormwater pipes.

On-site sanitation may release heavy loads of nitrate to the subsurface and are the most common source of microbiological contamination to groundwater. Leachate from waste disposal sites may contain inorganic components in largely varying quantities such as chlorides, sulfates, nitrogen compounds and metals, and a wide range of organic compounds (e.g. Nonner 2002). Animal waste or inorganic fertilizers used in agriculture and domestic gardening contain highly soluble nitrogen and phosphorous compounds to stimulate crop growth and enrich the soil with potassium, calcium, chloride, nitrate and phosphate. Other supplements used as growth enhancers contain magnesium, sulfate, and metals such as cobalt, molybdenum and copper. Furthermore, application of pesticides adds to the risk of groundwater contamination. Leaking fuel tanks and oil spillage expose the subsurface and hence groundwater to hydrocarbons.

In this study, samples were only analyzed for inorganic contaminants and microbiology (total and faecal coliforms) but not for organic pollutants.

8.1. Chemistry of springs

A summary on the characteristic nature of the chemistry of spring water during the rainy season 2007/2008 is given below. The table of in situ measurements and laboratory results is attached as **Appendix 1**. A Piper diagram showing the water composition of all springs sampled is presented in Figure 27.

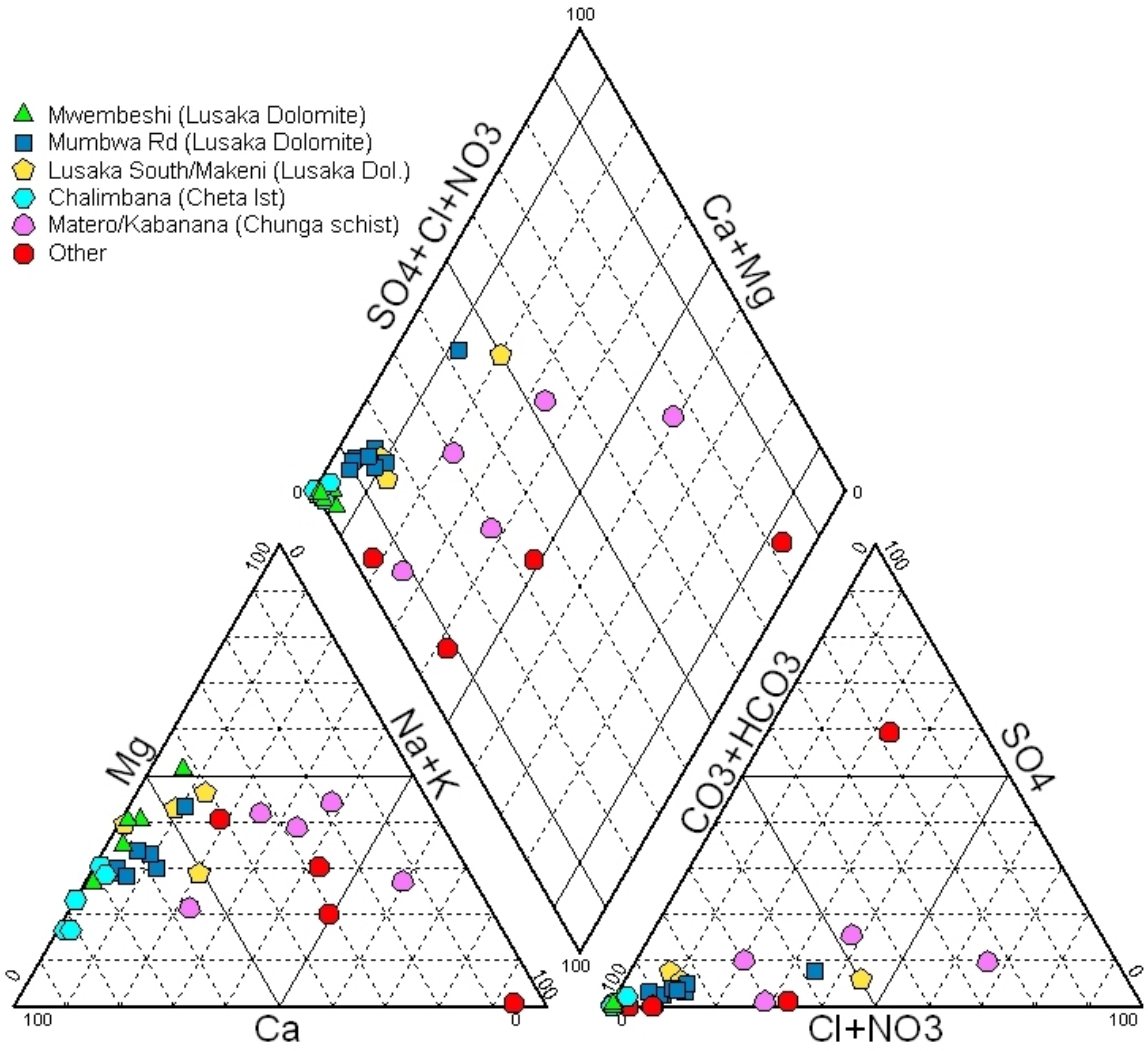

Figure 27 Piper diagram showing the composition of water at springs

8.1.1. Carbonate springs

The chemistry of spring waters emanating from the carbonate rocks are dominated by the congruent dissolution of the carbonate minerals calcite ($CaCO_3$) and dolomite $CaMg(CO_3)_2$:

$$^{CALCITE}\ CaCO3 + H_2O + CO_2 \rightarrow Ca^{2+} + 2HCO_3^-$$

$$^{DOLOMITE}\ CaMg(CO3)_2 + 2H_2O + 2CO_2 \rightarrow Ca^{2+} + Mg^{2+} + 4HCO_3^-$$

The major ions chemistry data for two characteristic karst springs is visualized in Figure 28 using a radar diagram. With the dissolution of dolomitic limestone as the principal geochemical process, the groundwater chemistry of most karst springs corresponds to the calcium-magnesium bicarbonate **(Ca-Mg-HCO_3)** type. Good Hope Farm and Palabana Dairy

Spring of the Chalimbana Group are of the calcium- bicarbonate **(Ca-HCO_3)** type. The dissolution of pure dolomite results in a $Mg^{2+}/(Mg^{2+} + Ca^{2+})$ ratio of 1:2 (or 50%) if all concentrations are expressed as meq/L. Observed Mg:Ca ratios as defined above vary between 1:7 and just above 1:2 indicating various percentages of dolomite content. Relatively low Mg:Ca ratios (1:7 to 1:3) are encountered at springs of the Chalimbana Group and at Handanama Section, Nsanje Muleke and St. Charles Catholic Church springs. The latter are part of the Lusaka West Group and located within a distance of less than 2 km from each other. The Chalimbana springs are located within the calcareous rocks of the Cheta Fm which is known to contain a smaller proportion of dolomite.

The water from the carbonate springs generally shows a considerable carbonate (temporary) hardness. The water of the karst springs can be classified as “hard” (>250 mg/L $CaCO_3$) or “very hard” (>375 mg/L $CaCO_3$). Very hard water was found at Mwembeshi Satelite, Linda Mwandila, Zingalume and Palabana Dairy springs. The pH of most springs is neutral to alkaline with values ranging from 7.0 to 7.8. Total dissolved solids (TDS) content characteristically varies between 400 and 600 mg/L with EC usually ranging from 500 to 750 µS/cm.

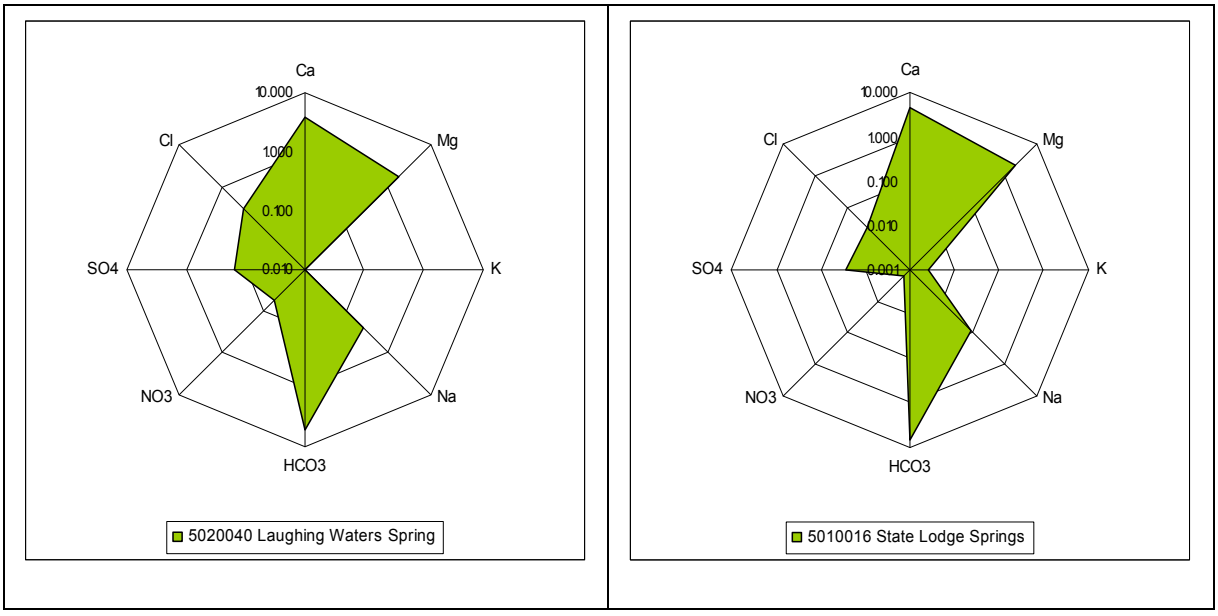

Figure 28 Radar diagram showing characteristic main water composition of karst springs. (left: Laughing Waters, Chunga Catchment. Right: State Lodge Spring, Chalimbana Catchment. Units are meq/L. Please note the logarithmic scale along the axis.

With 25 to 40 mg/L SiO_2, Makeni Burkley and Linda Mandila Springs show a comparatively high silicate content. The HCO_3:SiO_2 ratio is approximately 15:1 indicating that silicate weathering or possibly mixing with water from clastic sediments is likely to affect the chemistry of these spring waters. An explanation could be the higher degree of impurities within the carbonaceous rocks of the Mampompo Member and weathering products of non-

carbonaceous rocks such as the Chilanga psammites. As a comparison, at other carbonate springs in Lusaka silicate concentrations are typically between 5 and 20 mg/L and the HCO_3:SiO_2 ratio usually ranges from 30:1 to 60:1.

Urban pollution

No indications of urban or agricultural pollution could be found at the springs of the Chalibamba and Mwembeshi Groups as well as at Laughing Waters of the Lusaka West Group and at Shantumbu Spring of the Lusaka South Group. Kasanova and Nsanje Muleke springs seem to be only slightly affected by urban contaminant sources. The Kasanova springs show only slightly elevated chloride contents (23 mg/L), and Nsanje Muleke Spring and Handamana Section had slightly higher nitrate concentrations (11 - 14 mg/L).

Table 4 Inorganic components of carbonate spring water indicating pollution from urban sources

	NO_3^- [mg/L]	SO_4^{2-} [mg/L]	Na^+ [mg/L]	Cl^- [mg/L]	EC [µS/cm]
ZDWS [1)]	44	400	400	600	≈1000 [2)]
Non-polluted springs	<10	<10	<10	<10	500-750
Springs with possible contamination from urban sources					
St. Charles Catholic	34.3	11.9	11.4	16.9	735
Makeni Burkley	13.5	27.2	20.5	13.1	780
Linda Mwandila					
15.02.08	40.2	26.1	19.9	16.2	828
18.10.08	25.8	26.1	21.8	19.2	924
Springs at which contamination from urban sources is obvious					
Makeni Valley	84.2	23.9	38.1	83.3	851
Zingalume					
10.03.08	118	41.8	32.4	78.2	1154
24.10.08	192	44.7	35.9	111	1061

1) Zambian Drinking Water Standard

2) TDS 1500 mg/L

Some carbonate springs of the Lusaka West and Lusaka South Groups, however, show above-normal concentrations of nitrate (NO_3), sulfate (SO_4) and sodium-chloride (NaCl) as well as overall increased TDS and EC (Table 4), which can likely be attributed to urban pollution sources. The overall water composition for the two springs most affected is displayed in Figure 27 as a radar diagram. The composition is clearly altered compared to non-polluted springs. Due to the higher chloride content (>20% meq%) the Makeni Valley spring corresponds to the type Ca-Mg-HCO_3-Cl. The nitrate concentrations at Makeni Valley and Zingalume springs exceed the Zambian Water Drinking Standard (ZWDS) by a factor of 2 to 3. High nitrate concentrations were also found at St. Charles Catholics (36 mg/L) and

Linda Mwandila springs (26 – 40 mg/L). The poor sanitary conditions in these areas are the most likely cause of the high nitrate contents. The elevated sulfate content (20 – 45 mg/L) at those springs is about, or below 10% of the ZDWS but are significantly higher compared to springs that are assumed to be unpolluted. A similar pattern can be observed for the and overall salt load.

Kashembe B was the only spring within the carbonate aquifers with high iron content (0.9 mg/L). Nitrite that was present (> 1 mg/L) in three samples, namely at Makeni Valley, Kashembe Farm A and Mwembeshi Satellite spring (during the November sampling). Phosphate concentrations were generally below the detection limit or well below 0.1 mg/L.

Heavy metal concentrations were generally well below the ZWDS and did not show any exceptional features. Concentrations of lead, for instance, were typically below 1 μg/L compared to the ZDWS of 50 μg/L, copper contents below 10 μg/L compared to the ZDWS of 1500 μg/L, and zinc contents below 0.1 mg/L compared to the ZDWS of 5 mg/L.

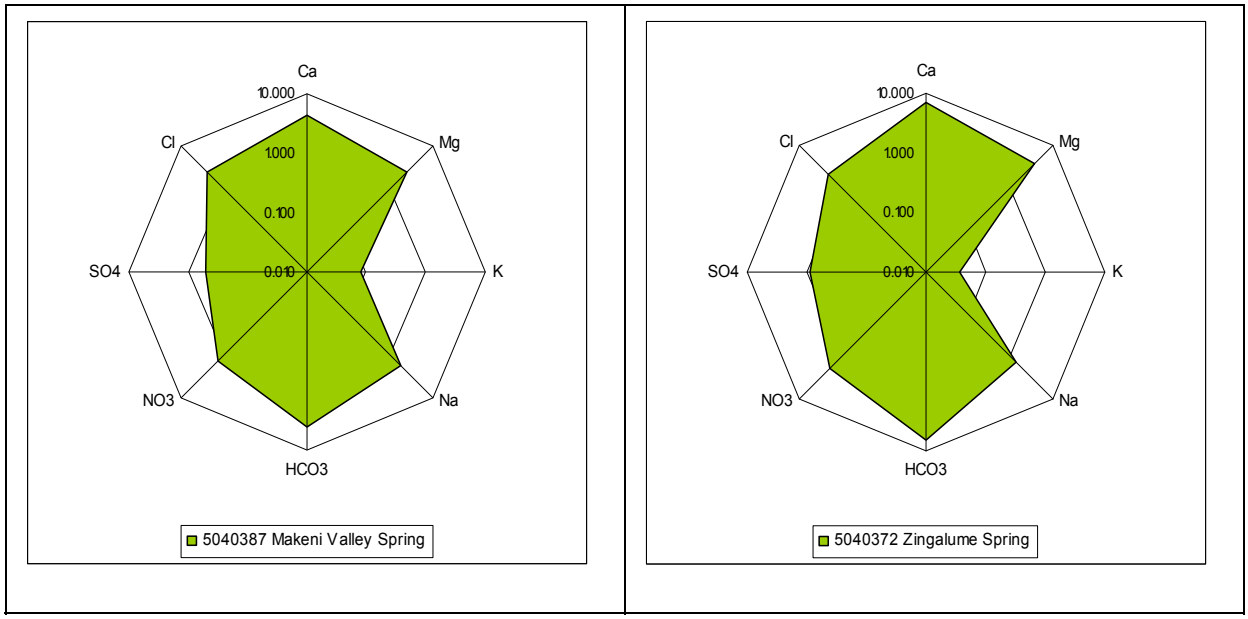

Figure 29 Radar diagram showing the possible influence on urban groundwater pollution on springs at Makeni Valley (left) and Zingalume (right)

Microbiological contamination

Microbiological tests were carried out during the October 2008 sampling campaign. The results tabulated in **Appendix 2** show that contamination with total and faecal coliform bacteria is common. The main reason for this seems to be the poor protection of the springs. Cattle are regularly drinking from and defecating in the vicinity of the springs. Additionally, decomposing organic matter was often found in the water pooling around the springs.

8.1.2. Springs occurring in schist

Geochemical processes within the Chunga Fm include the incongruent weathering of the intermixed silicates such as quartz, feldspar (plagioclase, albite) and mica (muscovite, biotite) and locally, the dissolution of interbedded impure dolomitic limestone. Since silicate weathering is a slow process the total dissolved load of minerals in groundwater is usually lower (<500 mg/L) compared to carbonate rocks. Examples of weathering reactions for silicate minerals are given below (Appelo & Postma 2007):

$$^{ALBITE}\ 2Na(AlSi_3)O_8 + 2H^+ + 9H_2O \rightarrow {}^{KAOLINITE}\ Al_2Si_2O_5(OH)_4 + 2Na^+ 4H_4SiO_4$$

$$^{BIOTITE}\ 2K(Mg_2Fe)(AlSi_3)O_{10}(OH)_2 + 10\ H^+ + 0.5O_2 + 7H_2O \rightarrow {}^{KAOLINITE}\ Al_2Si_2O_5(OH)_4 + 2K^+ 4Mg^{2+} + 2Fe(OH)_3 + 4H_4SiO_4$$

The effect of silicate weathering on the water chemistry is the additions of dissolved silica as well as cations such as sodium from the weathering of albite (Na-feldspar) or magnesium and iron from the weathering of mica. The increase in cation concentration is accompanied by the dissociation of bicarbonate acid (CO_2 + $H_2O \leftrightarrow H_2CO_3$) resulting in an increase in bicarbonate (HCO_3^-).

The water type at the springs visited varies between magnesium-sodium-bicarbonate **(Mg-Na-HCO_3)** found at Ng'ombe springs, magnesium-calcium-sodium-bicarbonate **(Mg-Ca-Na-HCO_3)** at Palmwood and St. Monica springs, sodium-magnesium-chloride-bicarbonate (**Na-Mg-Cl-HCO_3)** (St. Mary) and calcium-magnesium-bicarbonate (**Ca-Mg-HCO_3)** at Independence Park spring. The major ion composition of Ng'ombe and Palmwood springs are displayed in Figure 30.

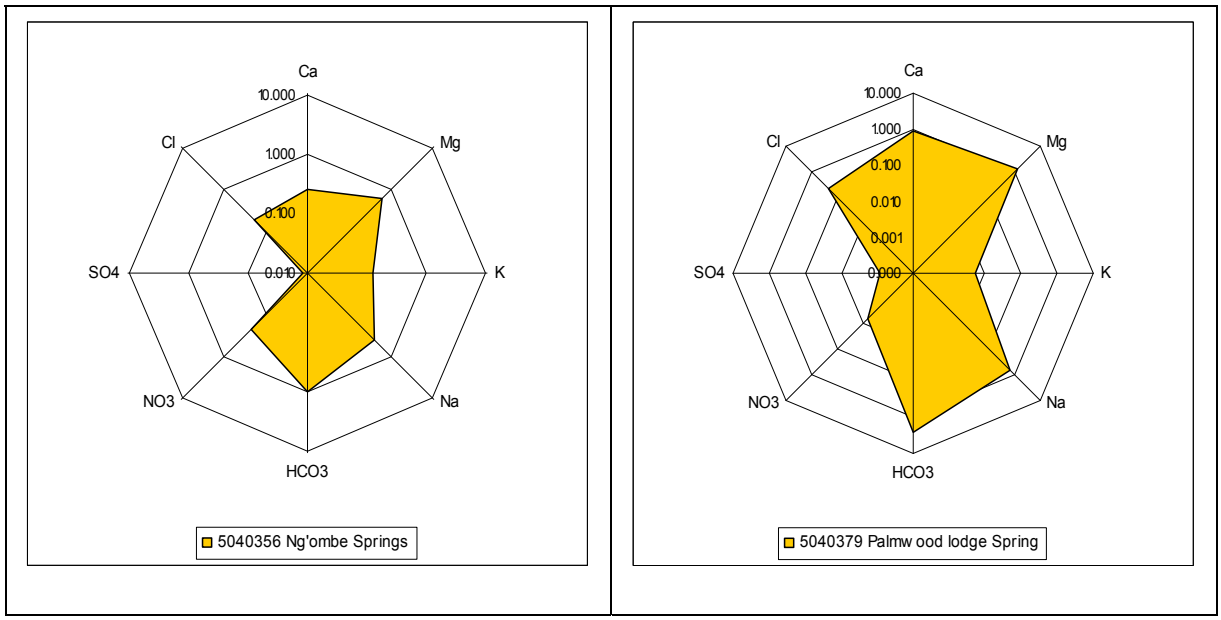

Figure 30 Main water composition of two springs within the Chunga Fm, Ngwerere Catchment (left: Ng'ombe Spring. Right: Palmwood Spring)

Apart from their overall water type and difference in their major ion composition, the springs in the Chunga Fm can be distinguished from the carbonate springs by overall lower TDS, slightly lower pH as well as much lower hardness and alkalinity (i.e. buffering capacity). The hardness of the water from the springs in the Chunga Fm is typically "soft" (<125 mg/L $CaCO_3$), to "intermediate" (125 – 250 mg/L $CaCO_3$). The softest water was found at Ng'ombe spring with just 41 mg/L $CaCO_3$. The pH was acidic at Ng'ombe (pH 6.1) and neutral (pH7) at the other springs. The content in total dissolved solids (TDS) showed a strong variation between Ng'ombe (100 mg/L) Palmwood Lodge, Independence Park and St. Mary springs (200 – 300 mg/L) and St. Monica spring (600 mg/L).

Dissolved silica contents vary strongly among the springs under investigation. With 34 mg/L and 24 mg/L SiO_2, respectively, Ng'ombe and Independence Park springs are relatively rich in silica. At Palmwood springs on the contrary, silica content is unusually low (4 mg/L SiO_2). Similarly, HCO3:SiO_2 ratios vary strongly between 2:1 at Ng'ombe indicating the dominance of silicate weathering, and 38:1 at Palmwood spring, a value that is considered more typical for carbonaceous rocks. Overall, Ng'ombe spring discharges water that is considered most characteristic for schist.

Saint Mary's Basic School exhibits rare elements such as Barium (Ba), Lanthanum (La), Neodymium (Nd), and Rubidium (Rb) in noticeable quantities.

Urban pollution

Like some of the carbonate springs, the springs in the Matero area show signs of urban pollution. This can be concluded from increased concentrations in nitrate, sulphate and NaCl as well as increased EC (Table 5). Nitrate levels at St. Mary and St. Monica springs exceed the ZDWS by 30% to 100%. The water at Ng'ombe contained phosphate in concentrations between 0.4 and 0.7 mg/L.

Table 5 Inorganic components of schist spring water indicating pollution from urban sources

	NO_3^- [mg/L]	SO_4^{2-} [mg/L]	Na^+ [mg/L]	Cl^- [mg/L]	EC [µS/cm]
ZDWS [1)]	44	400	400	600	≈1000 [2)]
Non-polluted springs	<10	<10	<20	<10	<600
Springs with possible contamination from urban sources					
Independence Park	27.1	19.9	16.4	14.4	516
Springs at which contamination from urban sources is obvious					
St. Mary	57.8	23.6	63.7	87.7	623
St. Monica	82.3	61.6	48.7	64.9	842

1) Zambian Drinking Water Standard
2) TDS 1500 mg/L

8.1.3. Other springs

Other springs examined are located at considerable distance from the Lusaka groundwater systems. They include Shalenga A and B springs in Kafue District as well as Kanakantapa springs and Chinyunyu hot springs in Chongwe District.

Shalenga A and B springs in Kafue District are of the sodium-magnesium-chloride-bicarbonate **(Na-Mg-Cl-HCO_3)** type (Figure 31). The springs are characterised by very soft water (20-30 mg/L $CaCO_3$) and a low content in TDS of about 70 mg/L. Considering the relatively high content in dissolved silica is (9 – 10 mg/L SiO_2) and the rather low HCO_3:SiO_2 ratio (4:1 to 5:1) silicate weathering is to be considered the dominant geochemical process despite the fact that the outcrops surrounding the springs were described as limestones of Lower Katanga age in the geological map (Smith 1963).

The Kanakantapa spring discharges iron-calcium-magnesium-bicarbonate **(Fe-Ca-Mg-HCO_3)** water (Figure 31). As to be expected from a spring emanating from basement rock, the water is very soft (30 mg/L $CaCO_3$) and carries an overall small total dissolved load (84 mg/L). Possible sources of iron (9 mg/L) are iron-rich minerals within the granite-gneiss & granite

such as biotite. The water contains also noteworthy yet non-critical contents in dissolved heavy metals such as copper (62 µg/L), nickel (12 µg/L), cobalt (8 µg./l) and lead (5 µg/L).

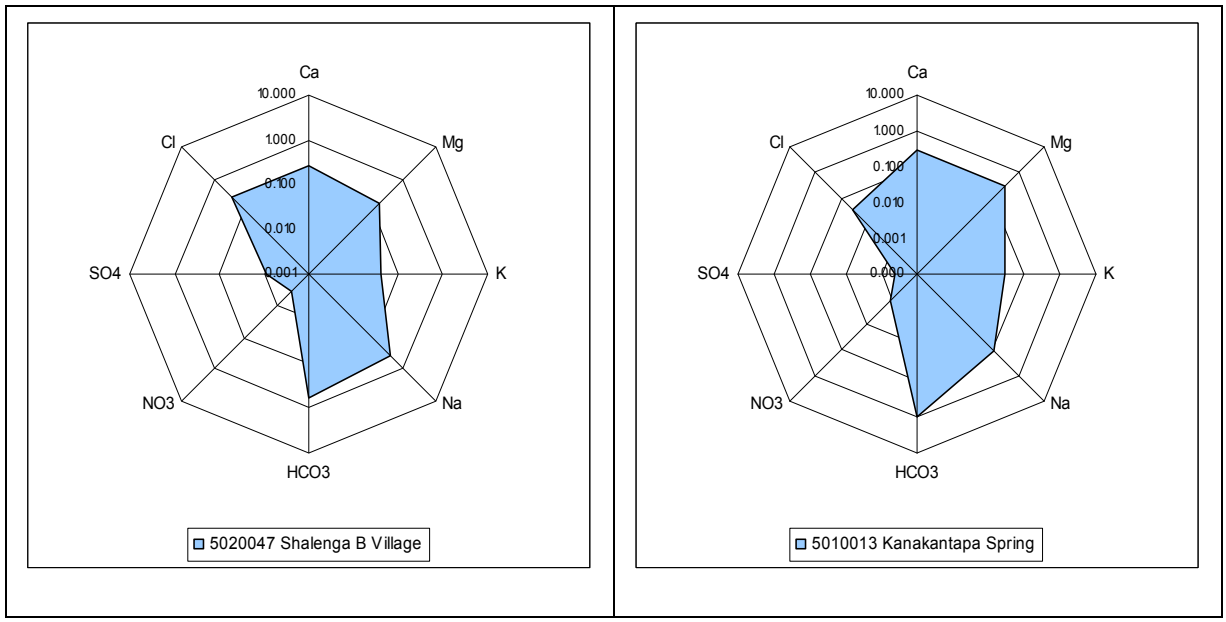

Figure 31 Main water composition of two springs metamorphic rock (left: Shalenga B Village, Kafue Catchment. Right: Kanakantapa, Chongwe Catchment)

The thermal water at Chinyunyu is of the sodium-sulphate-chloride **(Na-SO_4-Cl)** type. The spring is rich in sulphates (170 mg/L) and dissolved silica (78 mg/L). The water is very soft (21 mg/L $CaCO_3$) with temperatures exceeding 60°C, and has a pH of around 8 and TDS of around 450 mg/L. **The water at Chinyunyu springs is unsuitable for human consumption due to high levels in fluoride.** The measured fluoride content was 11.5 mg/L (equalling 9.1 meq%) which exceeds the ZDWS by a factor of almost 8. Lithium, occasionally an important trace element in thermal waters, was found at relatively low concentrations of 0.17 mg/L. Radar diagrams of the recent and previous chemical analyses by Legg (1974) are shown in Figure 32. The variation may be due in part by variations of the water composition at different points that may be enhanced by human activities (bathing, washing, etc).

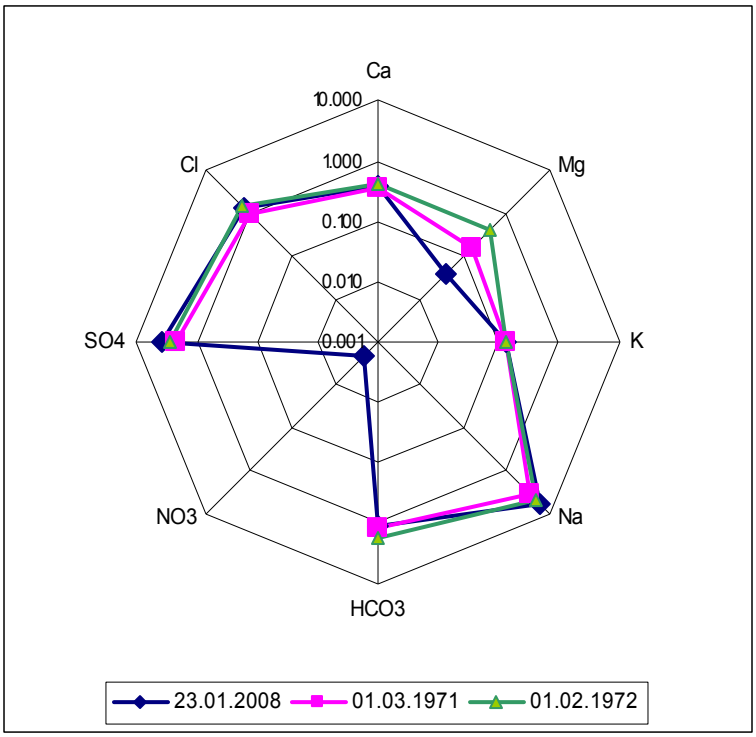

Figure 32 Water of the Na-SO4-Cl type at Chinyunyu Hot springs as identified by this and the recent study by Legg (1974)

8.2. Seasonal variations in spring water chemistry

Twelve of the springs sampled during the rainy season were re-sampled in November 2008. The main composition of the waters did not change during this period although variations in the minor constituents such as potassium and nitrate could be observed. The perennial springs of the Chalimbana Group (State Lodge, Zimbabwe Farm, Palabana Dairy) as well as Shantumbu Village and Laughing Water springs had potassium concentrations that were by about 50% lower compared to the rainy season. Lower nitrate concentrations during the dry season were found at Handamana section, Shantumbu and Mwembeshi Prison (Figure 33).

No consistent pattern in seasonal variation in EC and pH could be determined.

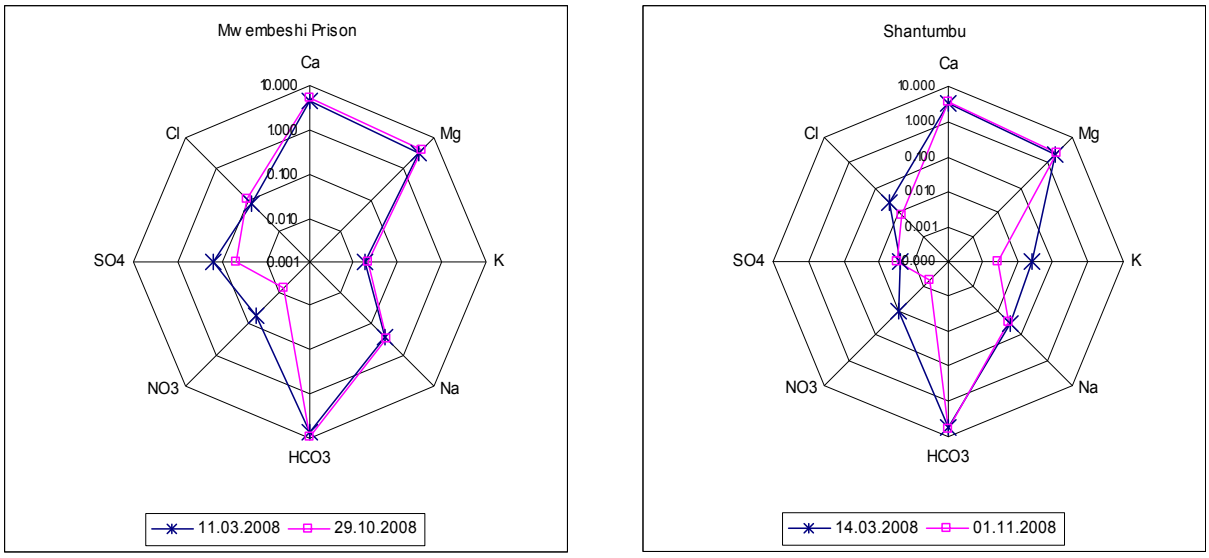

Figure 33 Comparison of chemical composition of spring water during the rainy dry season 2008 at Mwembeshi Prison (left)and Shantumbu Village (right)

8.3. Chemistry of water supply wells and boreholes in Forest 26

The chemistry of all water wells tested is consistent with groundwater that occurs in carbonate rocks. This includes the wells that are located within the schist formations according to the geological maps indicating the occurrence of carbonate layers at greater depth. The groundwater chemistry is characterised by relatively high concentrations of bicarbonate, typically between 300 and 450 mg/L, and calcium, typically between 70 and 130 mg/L and varying contents of magnesium ranging from 15 to 50 mg/L. All waters hence are of the calcium-magnesium bicarbonate **(Ca-Mg-HCO_3)** or calcium bicarbonate **(Ca-HCO_3)** type. With values ranging from 280 to 500 mg/L $CaCO_3$, the pumped water can be classified as “hard” (>250 mg/L $CaCO_3$) or “very hard” (>375 mg/L $CaCO_3$). The wells at George Compound, notably well no. 7 and to a minor extent wells no. 2 and 6 produce water of lower hardness and with comparably low contents in bicarbonate and calcium.

The overall water chemistry within the Lusaka Dolomite and the Cheta limestones is very similar although regional differences in, for instance, the Mg:Ca ratios can be observed across the formation boundaries as can be seen from the Piper diagram (Figure 34). The major differences in the groundwater composition are related to various contents in sodium, chloride, sulfate, nitrate and overall salt content (as measured by EC), which can be attributed to various sources of urban pollution. The wells Shaft No. 5, Water Works 2, Lumumba Road 4A, and Lilayi Road 2 as well as the boreholes located in the Local Forest area, which are all located within the main body of the Lusaka Dolomite, are characterized by rather low contents in the parameters mentioned above (see the radial diagram in Figure 35

for Shaft No. 5 as an example). Only the nitrate concentrations in the production wells which range from 14 to 30 mg/L seem to be elevated compared to the values below 10 mg/L found at the boreholes of the Forest Area and unpolluted springs.

A second group of boreholes including the wells at International School, Mulungushi House, Northmead, Avondale, Chelston, George Compound, Buckley 1 and, to a minor extent, NRDC show somewhat higher concentrations in sodium, chloride, sulfate or nitrate. All values, including nitrate, however are within the limits for potable water according to the ZDWS. Except for Buckley 1, the wells are located in the Cheta Fm either close to the City Centre or to the northeast along Great East Road. The boreholes of George Compound are located near the boundary of Lusaka Dolomite and Cheta limestones according to the geological map 1:100,000.

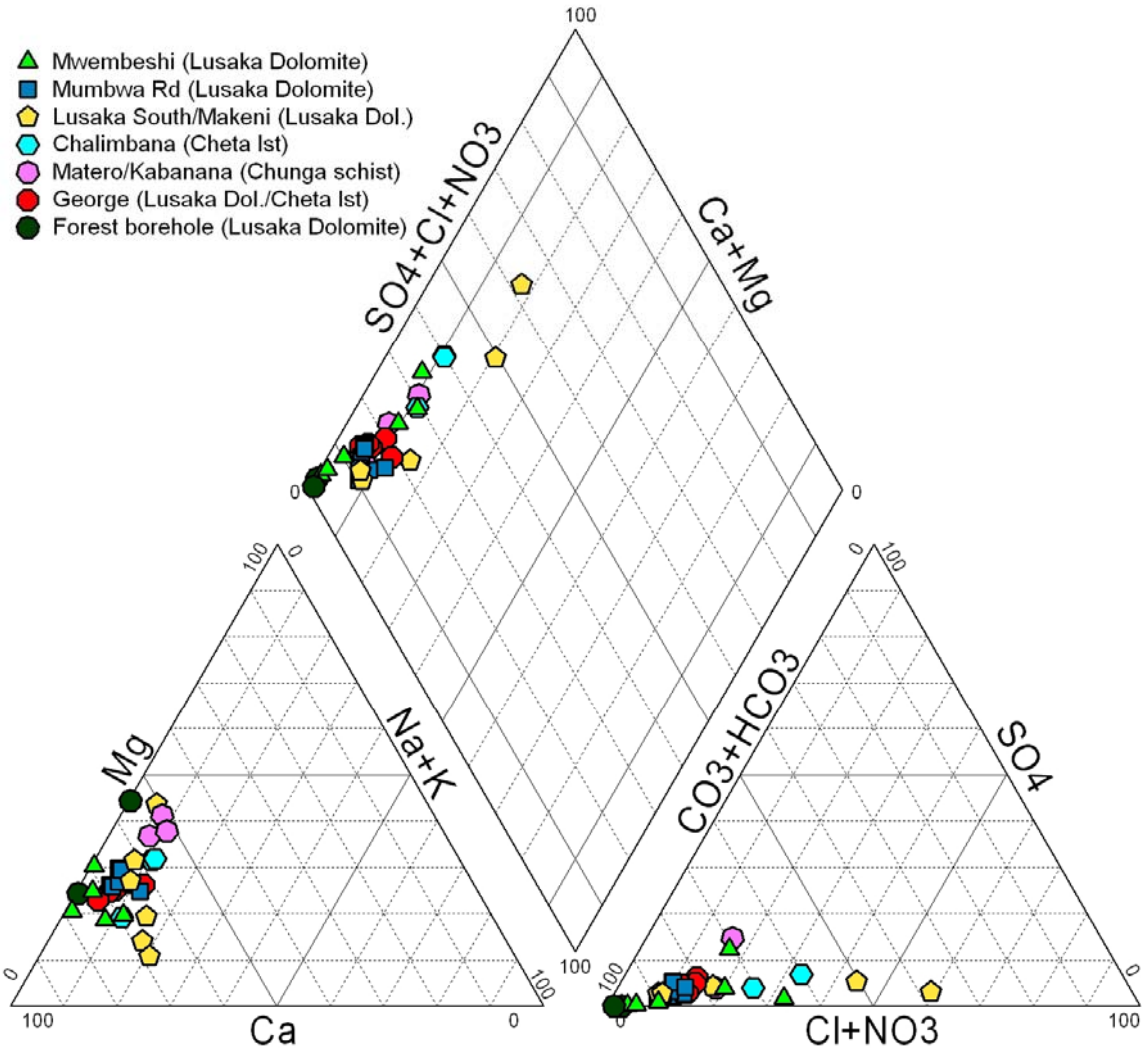

Figure 34 Piper diagram showing the composition of water at production wells and boreholes

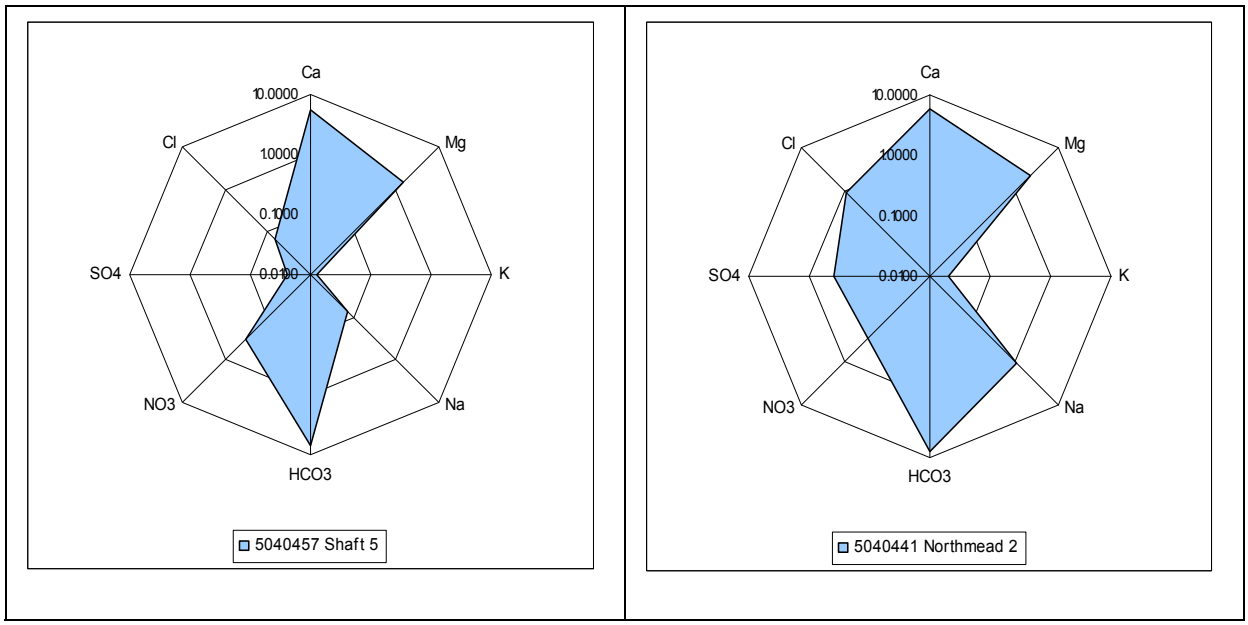

Figure 35 Main water composition of pumped water at Shaft No. 5 (left) compared to Northmead 2 (right)

Two wells at the southern margins of Lusaka (Buckley 2, Freedom Watertrust) as well as Chunga, Kabanana and the Mumbwa Roadside wells show a similar pattern to the wells described in the paragraph above except that the concentrations in sulfate and sodium chloride take higher values and that nitrate concentrations in these wells range between 50 and 80 mg/L, thus exceeding the recommended value of 44 mg/L NO_3 (or 10 mg/L NO_3-N). The water chemistry at the two wells sampled at Chunga is displayed in a radial diagram as an example (Figure 35). A clear sign of pollution is also the overall high salt content at the Buckley 2, Freedom Water Trust and the Chunga wells as indicated by the EC of their water reaching approx 1000 µS/cm (Table 6).

Table 6 Inorganic components of wells with strongest evidence of pollution from urban sources during the Oct 2008 sampling campaign

	NO_3^- [mg/L]	SO_4^{2-} [mg/L]	Na^+ [mg/L]	Cl^- [mg/L]	EC [µS/cm]
ZDWS [1)]	44	400	400	600	≈1000 [2)]
Chunga 2	64	37	27	95	1000
Chunga 6E	63	37	28	95	1013
Freedom Water Trust	66	79	25	95	993
Buckley 2	81	22	18	27	954
Bauleni	141	23	23	55	1101
Chawama 1	172	28	47	71	1069
Chainda	336	22	54	123	1459

1) Zambian Drinking Water Standard

2) TDS 1500 mg/L

The water at the wells Chawama, Bauleni and Chainda contained very high levels of nitrate exceeding the Zambian standard (and international standards) by a factor of 3 to 8. The high EC (>1000 µS/cm) is associated with increased levels of sodium and chloride. Due to the high nitrate concentrations the pumped water at Chawama 1 and Chainda changes from a Ca-HCO_3 type into a **Ca-HCO_3-NO_3** and a **Ca-HCO_3-NO_3-Cl** type, respectively. With an EC of 1440 µS/cm, the water at Chainda was found to be brackish. The extreme content of 336 mg/L nitrate may cause a serious health threat in particular for babies and subsequent monitoring of nitrate levels should be undertaken. Nitrite was also present (1 mg/L) in this well.

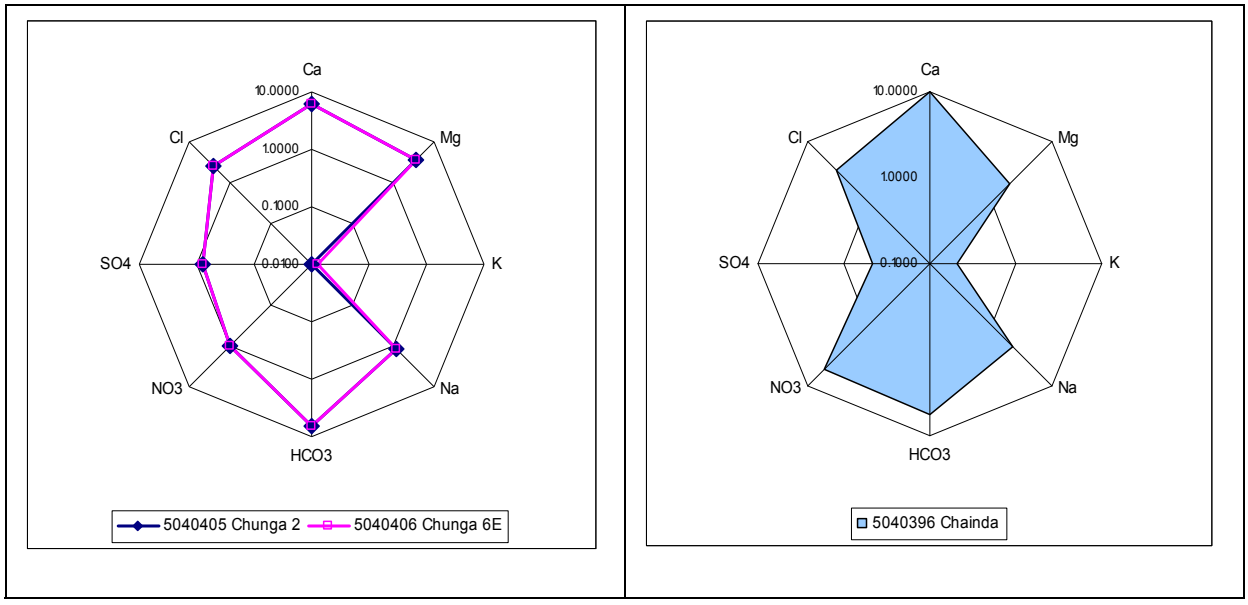

Figure 36 Main water composition of pumped water at Chunga (left) compared to Chainda (right)

Phosphate levels were below the detection limit of 0.03 mg/L throughout.

It is noteworthy to mention that measured metal and heavy metal concentrations at all wells sampled are generally very low. Except for the wells at George 5 and Northmead, iron concentrations were close to or below the detection limit of approx. 3 µg/l. George 5 is the only well with noticeable contents of iron (235 µg/l) and heavy metals (e.g. zinc 782 µg/l, copper 106 µg/l, lead 22 µg/l).

Microbiological Contamination

Contamination with total coliforms is widespread among the water supply wells **(Appendix 2**). The only boreholes in which no coliform bacteria were detected during the October 2008 sampling campaign included Avondale 1, International School 6E, Kalabana, Mass Media wells no. 2 and 3 and, despite the high nitrate levels observed in those wells,

Bauleni, Buckley 2 and Chainda. Total coliforms too numerous to count were found at Buckley 1, Freedom Watertrust, George Compound wells no. 2, 3 and 7, Shaft 5 and Waterworks 2.(

Faecal coliforms could be detected in just one case, namely George 3.

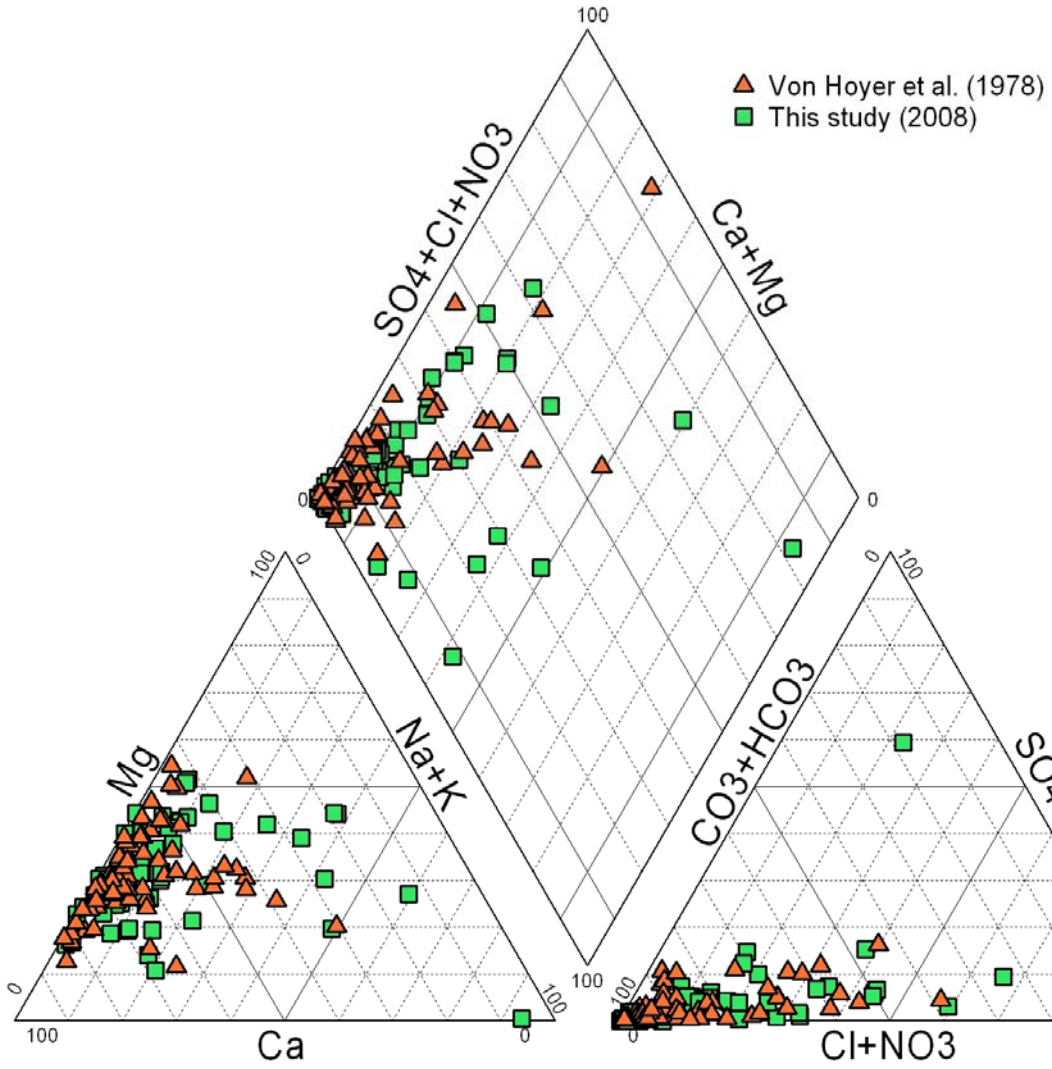

Figure 37 Comparison of groundwater composition from the mid-1970s (von Hoyer et al. 1978) and from 2008 (this study)

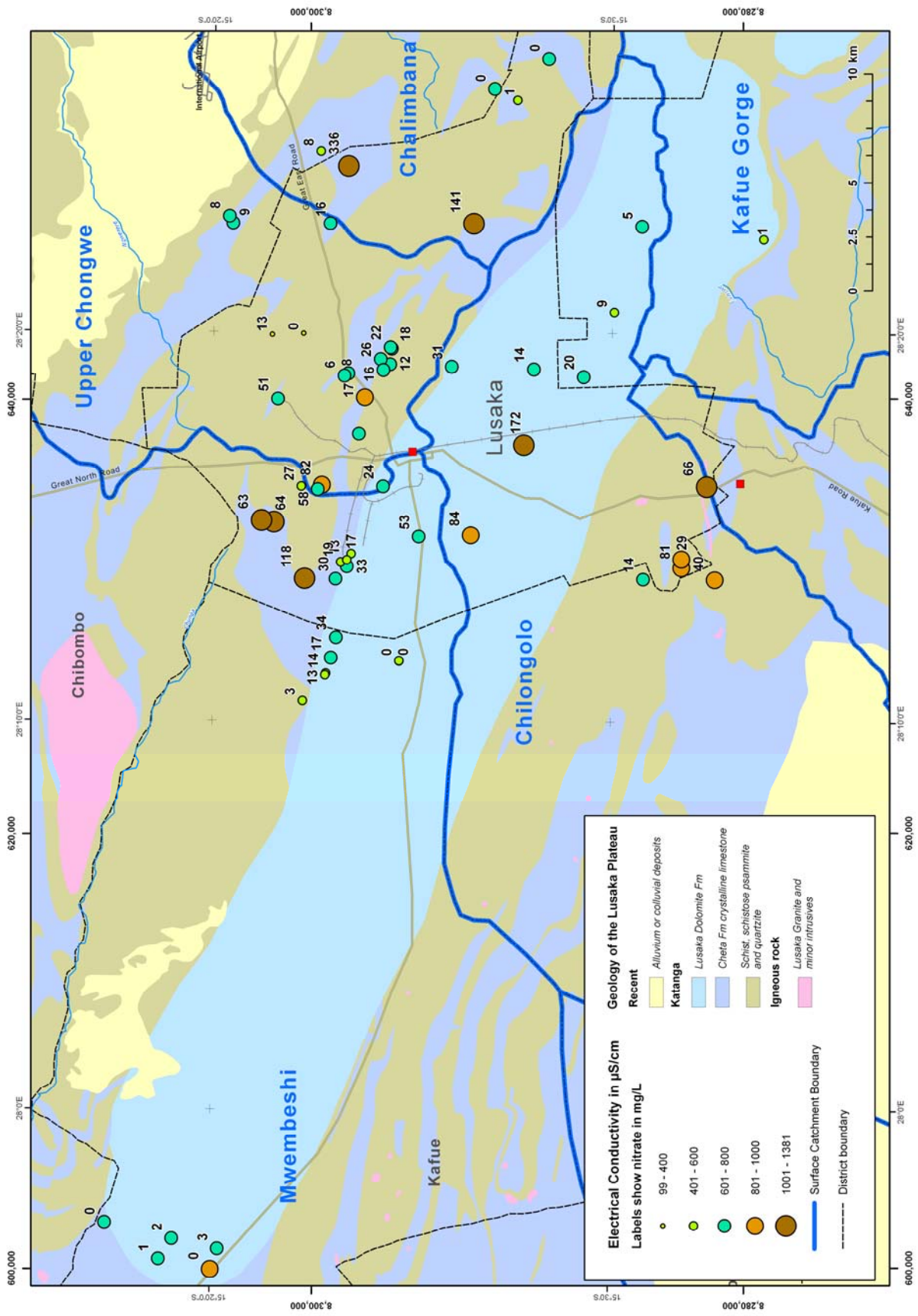

Figure 38 Electrical conductivity and nitrate contents at water points (springs, wells and boreholes) sampled during this study.

9. Discussion

The findings of the groundwater sampling campaigns carried out during 2008 can be summarised as follows:

1. As expected, the water from springs and water supply wells in the limestones and dolomites corresponds to the Ca-Mg-HCO_3 type. The water is generally hard (>250 mg/L $CaCO_3$) to very hard (>375 mg/L $CaCO_3$). Calcium and magnesium values are typically in the range of 70 -130 mg/L and 15 - 50 mg/L, respectively, and bicarbonate concentrations usually vary between 300 and 450 mg/L. Calculated ratios of $Mg^{2+}/(Mg^{2+} + Ca^{2+})$ varies between 1:2 indicative of pure dolomite to 1:6 indicating the dominance of calcite. Groundwater hosted by schist can be distinguished from the carbonate springs by overall lower TDS, slightly lower pH, lower HCO_3:SiO_2 ratios as well as much lower hardness and alkalinity (i.e. buffering capacity).

2. Groundwater largely unaltered by urban pollution sources was found in the Local Forest, Chalimbana springs and Mwembeshi areas. From the chemical analyses it can be concluded that natural (unpolluted) groundwater from the karst aquifers should, with only local exceptions, have an EC of less than 800 μS/cm and concentrations in sodium, chloride, nitrate and sulphate below 10 mg/L. Higher levels in these parameters hence suggest the presence of urban pollution sources.

3. Groundwater pollution from human activities was apparent in higher levels of EC reaching 1450 μS/cm, sodium contents up to 138 mg/L, chloride levels up to 123 mg/L, and sulphate concentrations up to 172 mg/L. Whilst these values still comply with the ZDWS, nitrate levels frequently exceeded the recommended standard of 10 mg/L NO_3-N equalling 44.3 mg/L NO3. Nitrate concentrations above 100 mg/L were found at Zingalume and Makeni Burkley springs as well as at Bauleni and Chawama 1 wells. The highest value was measured at Chainda well with 336 mg/L. Chawama, Zingalume and Bauleni are largely unplanned residential areas that are exclusively served by pit latrines and septic tanks. The high nitrate loads can be therefore be linked to the overall poor sanitary situation in these areas.

4. The study confirmed the results of previous studies that microbiological contamination is also prevalent. High nitrate concentrations, however, do not show an obvious relationship with the degree of microbiological contamination. Despite the fact that most springs are used for domestic purposes and water supply, they are not or poorly protected.

5. Pollution by human activities in the city area is widespread. Considering the shallow water tables and the absence of an effective protective cover, the overall contamination within the main aquifer (areas around Shaft 5, Waterworks and Roadside wells) by inorganic pollutants may, however, be considered less severe than one could have imagined or feared (see Figure 38). The reason for this could be the comparatively large amounts of direct recharge that, according to previous studies, may vary between below 10% to over 60% of mean annual rainfall (Mpamba 2008, Bäumle & Kang'omba 2009). Groundwater might be further diluted by clean water drawn (through the natural or induced hydraulic gradient) from areas with little human activities such as the Local Forest reserves in the southeast.

6. Concentrations of heavy metals and iron were low throughout the campaign. This could be due to the low solubility of the metal compounds such as siderite ($FeCO_3$) or otavite ($CdCO_3$) at the prevailing high pH and the abundance of bicarbonate ions. It is recommended to confirm this preliminary finding by additional sampling and geochemical modelling (e.g. speciation calculations using PHREEQC).

7. The water at Chinyunyu Hot Springs was found to be unsuitable for human consumption due to high levels of fluoride (about 8 times the ZDWS).

8. No systematic changes in water chemistry and quality of springs between the dry season and the wet season could be recognized in this study. This confirms the earlier finding by von Hoyer et al. (1978).

9. Comparison of water chemistry data by von Hoyer et al. (1978) and this study show no significant differences. In the 2008 sampling, there is a slightly higher number of samples with increased levels of alkali ions, chloride, nitrate and sulphate as can be seen in the Piper diagram shown in Figure 37. It must be considered, however, that the sampling points were not identical, and that no time series of water quality data are available. Hence, based on available data, no clear indication was found that the quality of groundwater has worsened or improved over time.

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Appendix 1

Chemical Analyses Results

A. In Situ Physical Parameters

B. Laboratory Physical Parameters

C. Main & Minor Constituents

D. Trace Elements (Selection)

A. In Situ Physical Parameters

No.	Sample name	Sample Date	T_{H20} °C	T_{AIR} °C	EC µS/cm	pH	Eh mV	O_2 mg/l	O_2sat %	T_Alkal. mg/l $CaCO_3$	Odour	Taste
1	Avondale 1	06.08.2008	25.4	22.9	546	7.4	-36	7.0	105		none	none
2	Bauleni	24.08.2008	24.9	22.5	1136	6.8	12	1.2	22	381	none	none
3	Buckley 1	24.08.2008	24.8		878	7.1	-4	2.2		455	none	none
4	Buckley 2	12.08.2008	26.9	22.9	1000	7.0	2	5.1	75	522	none	none
5	Chainda	06.08.2008	25.9	22.5	1381	7.0	-10	2.3	34		none	none
6	Chawama 1	25.08.2008	25.9	22.6	1103	7.0	2	7.8		285	none	none
7	Chelston	08.08.2008	25.4	22.4	689	7.1	-17	2.1	28		none	none
8	Chimbwete Spring	26.10.2008	26.6	25.9	603	7.9	-52	2.1	15	259		
9	Chinyunyu Hot Spring	23.01.2008	26.4	27.7	728	8.0	61				none	none
10	Chunga 2	10.08.2008	24.9	22.2	1314	7.0	5	3.4	47	353	none	none
11	Chunga 6E	10.08.2008	23.3	21.4	1089	7.2	-18	4.7	65	378	none	none
12	Forest 26 BH-7	17.03.2008			543	7.3					none	none
13	Freedom Water Trust	24.08.2008	25.2		1080	7.0	-1	2.3		359	none	none
14	George 2	19.08.2008	20.4		599	7.9	-50	7.2	94	276	none	none
15	George 3	19.08.2008	26.4	22.5	781	7.3	-14	5.0	73	329	none	none
16	George 5	12.08.2008	23.5	21.4	699	7.2	-11	6.9	96	342	none	none
17	George 6	11.08.2008	25.8	22.6	549	7.5	-28	5.8	84	274	none	none
18	George 7	19.08.2008	29.5		410	7.7	-34	4.7	72	307	none	none
19	Good Hope	10.03.2008	23.2	25.0	619	7.3	-17	4.4			none	none
20	Handamana Section	10.03.2008	25.0	26.4	536	6.9	4	3.3			none	none
21	Handamana Section	25.10.2008	25.0	22.0	560	7.2	10	1.4	20	250		
22	Independence Park	11.03.2008	23.1	25.1	516	7.2	-15	5.8	80		none	none
23	International 6A	21.08.2008	23.9	21.4	725	7.1	1	3.5	48	342	none	none
24	International 6E	21.08.2008	24.8	21.6	742	7.1	-1	3.8	54	329	none	none
25	International 6F	21.08.2008	28.6		749	7.1	0	4.3	64	414	none	none
26	Kabanana	25.08.2008	24.5	22.0	756	7.2	9	7.8		288	none	none
27	Kanakantapa	02.02.2008	23.1	24.1	132	6.9	76	1.1			none	none
28	Kasanova Kanyimbu A	06.03.2008	22.5	23.4	572	7.4	-24	0.3	3		none	none
29	Kasanova Kanyimbu B	11.02.2008	22.8	25.0	586	7.4	-23	2.4	33		none	none
30	Kashembe Farm Spring A	01.11.2008	24.3	23.1	710	7.0	-3	0.8	10	427		
31	Kashembe Farm Spring B	18.10.2008	23.1	22.0	751	7.2	-13	0.2	2	347		
32	Laughing Waters	10.03.2008	24.5	26.0	468	7.8	-46	8.9			none	none
33	Laughing Waters	24.10.2008	23.1	22.6	599	7.1	-7	1.0	14	300		
34	Lilayi Rd 2	22.08.2008	25.2	22.5	605	7.1	-1	3.9	56	302	none	none
35	Linda Mwandila	15.02.2008	23.2	24.9	828	7.8	-50	6.5			none	none
36	Linda Mwandila	26.10.2008	21.7	20.2	924	7.2	-15	1.7	24	456		
37	Lumumba Rd 4A	25.08.2008	25.7	22.9	714	7.2	-12	1.7	28	291	none	none

A. In Situ Physical Parameters

No.	Sample name	Sample Date	T_{H20} °C	T_{AIR} °C	EC µS/cm	pH	Eh mV	O_2 mg/l	O_2sat %	T_Alkal. mg/l $CaCO_3$	Odour	Taste
38	Makeni Burkley Spring	15.02.2008	24.1	25.0	780	6.9	-40	6.0			none	none
39	Makeni Valley Spring	05.03.2008	24.2	25.0	851	8.3	-61	13.9			none	none
40	Massmedia 2	09.08.2008	25.6	22.3	640	7.1	-17	4.1			none	none
41	Massmedia 3	09.08.2008	26.3	22.6	677	7.4	-33	6.8	98		none	none
42	MFEZ B/h J4	29.07.2008	24.7		653	6.9	3	4.0	55	425	none	none
43	Michelo Farm Spring	18.10.2008	25.7	23.4	645	6.8	9	1.0	13	310		
44	Mulungushi 6A	20.08.2008	26.0	23.1	742	7.2	-3	2.8	39	320	none	none
45	Mulungushi 6H	20.08.2008	25.6	23.0	721	7.5	2	2.2	32	444	none	none
46	Mumbwa Roadside 1	11.08.2008	26.4	22.7	770	7.1	-3	2.6	38	329	none	none
47	Mwembeshi Prison	11.03.2008	25.4	26.0	722	7.7	40	8.2			none	none
48	Mwembeshi Prison	18.10.2008	26.9	24.0	807	6.7	13	1.3	20	464		
49	Mwembeshi Satellite	11.03.2008	24.2	25.5	821	7.7	-40	8.6			none	none
50	Mwembeshi Satellite	26.10.2008	21.7	20.0	883	7.1	-13	1.1	13	551		
51	Ng'ombe Spring	18.01.2008	24.6	25.7	210	6.1	57	3.1			none	none
52	Ng'ombe Spring	27.10.2008	25.8	22.6	510	6.7	-28	1.4	20	59		
53	Northmead 2	20.08.2008	28.5		842	7.2	-11	5.8	86	396	none	none
54	NRDC 1	05.08.2008	26.1	22.5	662	7.2	-20	4.9	71		none	none
55	NRDC 2	05.08.2008	25.7	22.8	676	7.2	-23	5.2	74		none	none
56	Nsanje Muleke	10.03.2008	25.7	27.1	567	6.9	4	3.0			none	none
57	Nsanje Muleke	24.10.2008	25.8	22.3	551	7.0	-2	1.1	16	246		
58	Palabana A	13.03.2008	26.9	27.5	622	7.2	-14	5.7			none	none
59	Palabana Dairy	13.03.2008	24.4	25.6	777	7.0	-3	4.3			none	none
60	Palabana Dairy	28.10.2008	24.1	23.4	741	7.2	-8	1.9	13	381		
61	Palmwood Lodge Spring	13.03.2008	24.9	26.1	281	7.3	-20	5.2			none	none
62	Shaft 5	22.08.2008	21.4		633	6.9	5	3.0	40	430	none	none
63	Shalenga V Spring A	11.03.2008	24.9	26.0	99	7.2	-16	4.0			none	none
64	Shalenga V Spring B	11.03.2008	28.1	29.0	106	6.0	27	4.8			none	none
65	Shantumbu B Sch Spring A	14.03.2008	24.1	25.0	492	7.0	0	6.9			none	none
66	Shantumbu B Sch Spring A	27.10.2008	23.4	24.0	515	7.5	-30	1.6	17	260		
67	St Mary School Spring	11.03.2008	26.9	28.0	623	6.9	-7	7.2			none	none
68	St Monica School Spring	11.02.2008	24.5	25.0	842	6.7	17	0.8	17		none	none
69	St Charles Spring	10.03.2008	26.4	27.7	735	6.9	1	4.5			none	none
70	State Lodge	18.01.2008	21.7	24.7	659	7.5	-37	6.9			none	none
71	State Lodge	29.10.2008	23.4	22.1	562	7.9	-74	0.1	2	409		
72	Waterworks 2	23.08.2008	25.1	23.4	748	7.1	-5	2.9		361	none	none
73	Zimbabwe Farm	10.03.2008	24.4	25.6	459	7.7	-41	5.5			none	none
74	Zimbabwe Farm	29.10.2008	22.4	21.0	464	7.2	40	0.6	7	142		
75	Zinaglume Overspill	10.03.2008	24.0	25.0	1154	7.0	1	1.3			none	none
76	Zinaglume Overspill	28.10.2008	24.5	23.1	1061	7.1	-37	2.5	36	313		

B. Laboratory Physical Parameters

No.	Sample name	Sample Date	Sampling Person	Sampling Method	Lab	EC µS/cm	EC_cal µS/cm	pH	T_Hard cal mg/l $CaCO_3$	SAR
1	Avondale 1	06.08.2008	Museteka	Tapping	BGR	576	579	8.0	300	0.6
2	Bauleni	24.08.2008	Museteka	Tapping	BGR	1101	1082	7.4	539	1.1
3	Buckley 1	24.08.2008	Museteka	Tapping	BGR	643	682	7.7	350	0.8
4	Buckley 2	12.08.2008	Museteka	Tapping	BGR	954	983	7.6	509	1.0
5	Chainda	06.08.2008	Museteka	Tapping	BGR	1459	1443	7.6	594	2.5
6	Chawama 1	25.08.2008	Museteka	Tapping	BGR	1069	1011	7.6	411	2.6
7	Chelston	08.08.2008	Museteka	Tapping	BGR	682	726	7.7	330	1.7
8	Chimbwete Spring	26.10.2008			BGR				288	0.6
9	Chinyunyu Hot Spring	23.01.2008	Museteka	Collecting	BGR		685		21	34.1
10	Chunga 2	10.08.2008	Museteka	Tapping	BGR	1000	1032	7.7	490	1.5
11	Chunga 6E	10.08.2008	Museteka	Tapping	BGR	1013	1028	7.6	486	1.5
12	Forest 26 BH-7	17.03.2008	Museteka	Pumping	BGR		533		308	0.0
13	Freedom Water Trust	24.08.2008	Museteka	Tapping	BGR	993	1003	7.6	487	1.4
14	George 2	19.08.2008	Museteka	Tapping	BGR	483	511	7.9	249	0.8
15	George 3	19.08.2008	Museteka	Tapping	BGR	685	753	7.7	367	1.4
16	George 5	12.08.2008	Museteka	Tapping	BGR	663	667	8.2	338	0.7
17	George 6	11.08.2008	Museteka	Tapping	BGR	492	547	7.7	279	0.6
18	George 7	19.08.2008	Museteka	Tapping	BGR	392	398	7.9	201	0.4
19	Good Hope	10.03.2008	Museteka	Collecting	BGR		618		350	0.1
20	Handamana Section	10.03.2008	Museteka	Collecting	BGR		569		308	0.4
21	Handamana Section	25.10.2008			BGR	536	569	6.9	295	0.4
22	Independence Park	11.03.2008	Museteka	Collecting	BGR		405		163	1.5
23	International 6A	21.08.2008	Museteka	Tapping	BGR	698	703	7.7	356	1.0
24	International 6E	21.08.2008	Museteka	Tapping	BGR	725	730	7.8	384	0.6
25	International 6F	21.08.2008	Museteka	Tapping	BGR	718	712	7.8	368	0.9
26	Kabanana	25.08.2008	Museteka	Tapping	BGR	719	716	7.8	338	1.2
27	Kanakantapa	02.02.2008	Museteka	Collecting	BGR		94		29	0.6
28	Kasanova Kanyimbu A	06.03.2008	Museteka	Collecting	BGR		492		236	1.0
29	Kasanova Kanyimbu B	11.02.2008	Museteka	Collecting	BGR		592		303	0.9
30	Kashembe Farm Spring A	01.11.2008			BGR				398	0.1
31	Kashembe Farm Spring B	18.10.2008			BGR				432	0.1
32	Laughing Waters	10.03.2008	Museteka	Collecting	BGR		510		274	0.4
33	Laughing Waters	24.10.2008			BGR				327	0.4
34	Lilayi Rd 2	22.08.2008	Museteka	Tapping	BGR	582	588	7.7	329	0.1
35	Linda Mwandila	15.02.2008	Museteka	Collecting	BGR		895		470	1.1
36	Linda Mwandila	26.10.2008			BGR				487	1.2
37	Lumumba Rd 4A	25.08.2008	Museteka	Tapping	BGR	701	704	7.7	328	1.2

B. Laboratory Physical Parameters

No.	Sample name	Sample Date	Sampling Person	Sampling Method	Lab	EC µS/cm	EC_cal µS/cm	pH	T_Hard cal mg/l $CaCO_3$	SAR
38	Makeni Burkley Spring	15.02.2008	Museteka	Collecting	BGR		675		328	1.4
39	Makeni Valley Spring	05.03.2008	Museteka	Collecting	BGR		811		338	2.5
40	Massmedia 2	09.08.2008	Museteka	Tapping	BGR	629	696	7.6	365	0.7
41	Massmedia 3	09.08.2008	Museteka	Tapping	BGR	672	714	7.6	372	0.8
42	MFEZ B/h J4	29.07.2008	Museteka	Pumping	BGR	585	698	7.5	400	0.1
43	Michelo Farm Spring	18.10.2008			BGR				366	0.1
44	Mulungushi 6A	20.08.2008	Museteka	Tapping	BGR	627	718	7.7	374	0.6
45	Mulungushi 6H	20.08.2008	Museteka	Tapping	BGR	719	732	7.8	386	0.6
46	Mumbwa Roadside 1	11.08.2008	Museteka	Tapping	BGR	735	754	7.7	374	1.1
47	Mwembeshi Prison	11.03.2008	Museteka	Collecting	BGR		687		392	0.4
48	Mwembeshi Prison	18.10.2008			BGR				457	0.4
49	Mwembeshi Satellite	11.03.2008	Museteka	Collecting	BGR		770		429	0.8
50	Mwembeshi Satellite	26.10.2008			BGR				496	0.8
51	Ng'ombe Spring	18.01.2008	Museteka	Collecting	BGR		134		42	1.8
52	Ng'ombe Spring	27.10.2008			BGR				45	1.8
53	Northmead 2	20.08.2008	Museteka	Tapping	BGR	739	822	7.7	410	1.4
54	NRDC 1	05.08.2008	Museteka	Tapping	BGR	625	699	7.6	353	1.0
55	NRDC 2	05.08.2008	Museteka	Tapping	BGR	666	728	7.6	378	0.8
56	Nsanje Muleke	10.03.2008	Museteka	Collecting	BGR		563		304	0.4
57	Nsanje Muleke	24.10.2008			BGR				290	0.4
58	Palabana A	13.03.2008	Museteka	Collecting	BGR		580		327	0.0
59	Palabana Dairy	13.03.2008	Museteka	Collecting	BGR		772		443	0.3
60	Palabana Dairy	28.10.2008			BGR				412	0.2
61	Palmwood Lodge Spring	13.03.2008	Museteka	Collecting	BGR		247		101	2.0
62	Shaft 5	22.08.2008	Museteka	Tapping	BGR	639	641	7.6	356	0.1
63	Shalenga V Spring A	11.03.2008	Museteka	Collecting	BGR		90		28	2.2
64	Shalenga V Spring B	11.03.2008	Museteka	Collecting	BGR		89		22	2.3
65	Shantumbu B Sch Spring A	14.03.2008	Museteka	Collecting	BGR		484		277	0.1
66	Shantumbu B Sch Spring A	27.10.2008			BGR				294	0.0
67	St Mary School Spring	11.03.2008	Museteka	Collecting	BGR		546		106	8.0
68	St Monica School Spring	11.02.2008	Museteka	Collecting	BGR		800		268	3.8
69	St Charles Spring	10.03.2008	Museteka	Collecting	BGR		703		359	0.7
70	State Lodge	18.01.2008	Museteka	Collecting	BGR		592		333	0.1
71	State Lodge	29.10.2008			BGR				311	0.1
72	Waterworks 2	23.08.2008	Museteka	Tapping	BGR	629	657	7.6	355	0.3
73	Zimbabwe Farm	10.03.2008	Museteka	Collecting	BGR		488		263	0.3
74	Zimbabwe Farm	29.10.2008			BGR				323	0.2
75	Zinaglume Overspill	10.03.2008	Museteka	Collecting	BGR		1112		532	1.7
76	Zinaglume Overspill	28.10.2008			BGR				599	1.8

C. Main & Minor Constituents

No.	Sample name	Sample Date	Na mg/l	K mg/l	Ca mg/l	Mg mg/l	NH4 mg/l	Fe_tot mg/l	Mn mg/l	F mg/l	Cl mg/l	NO_3 mg/l	NO_2 mg/l
1	Avondale 1	06.08.2008	8.1	0.3	64.9	33.7	-0.01	0.01	0.001	0.09	20.3	7.9	-0.01
2	Bauleni	24.08.2008	22.6	0.6	172.0	26.6	-0.01	-0.01	-0.001	0.10	55.1	141.0	-0.01
3	Buckley 1	24.08.2008	12.7	1.4	84.3	33.9	-0.01	0.02	0.002	0.37	11.6	28.7	0.05
4	Buckley 2	12.08.2008	18.4	2.6	113.0	55.2	-0.01	-0.01	0.001	0.39	27.3	81.1	-0.01
5	Chainda	06.08.2008	53.7	8.0	197.0	24.7	-0.01	0.02	0.004	0.06	123.0	336.0	1.06
6	Chawama 1	25.08.2008	46.7	4.9	142.0	13.7	-0.01	-0.01	-0.001	0.37	71.2	172.0	-0.01
7	Chelston	08.08.2008	27.1	2.3	102.0	18.4	-0.01	-0.01	-0.001	0.18	42.1	16.1	-0.01
8	Chimbwete Spring	26.10.2008	9.1	0.6	74.2	25.1	0.03	-0.01	0.003	0.18	15.0	16.6	-0.01
9	Chinyunyu Hot Spring	23.01.2008	138.0	5.1	7.7	0.5	0.02	0.02	0.003	11.50	48.8	0.1	-0.01
10	Chunga 2	10.08.2008	27.2	0.4	127.0	42.1	-0.01	-0.01	0.027	0.15	95.3	63.5	-0.01
11	Chunga 6E	10.08.2008	27.5	0.5	125.0	42.3	0.12	-0.01	0.001	0.17	95.0	63.3	-0.01
12	Forest 26 BH-7	17.03.2008	0.1	0.5	68.6	33.2	0.04	0.01	0.020	0.05	0.8	8.8	-0.01
13	Freedom Water Trust	24.08.2008	24.6	2.0	113.0	50.0	-0.01	-0.01	-0.001	0.42	26.7	66.4	-0.01
14	George 2	19.08.2008	10.4	1.3	70.6	17.7	-0.01	-0.01	0.001	0.12	16.1	18.8	-0.01
15	George 3	19.08.2008	22.0	1.6	103.0	26.6	-0.01	-0.01	-0.001	0.17	25.4	29.7	0.05
16	George 5	12.08.2008	11.2	1.2	98.7	22.2	0.02	0.24	0.018	0.10	17.3	33.0	-0.01
17	George 6	11.08.2008	8.1	0.5	82.3	17.8	-0.01	-0.01	-0.001	0.16	14.6	17.4	-0.01
18	George 7	19.08.2008	4.4	0.6	61.0	11.8	-0.01	-0.01	-0.001	0.15	8.5	13.0	0.02
19	Good Hope	10.03.2008	2.0	0.3	117.0	14.1	-0.01	0.12	0.046	0.24	1.5	0.4	-0.01
20	Handamana Section	10.03.2008	6.0	0.2	86.3	22.4	0.01	0.01	0.001	0.11	11.3	12.5	0.02
21	Handamana Section	25.10.2008	5.9	0.1	82.5	21.7	-0.01	-0.01	0.003	0.12	11.0	11.5	-0.01
22	Independence Park	11.03.2008	16.4	8.4	47.4	10.9	-0.01	0.01	0.011	0.28	14.4	27.1	-0.01
23	International 6A	21.08.2008	16.2	0.6	101.0	25.2	-0.01	-0.01	0.001	0.09	22.9	15.6	0.09
24	International 6E	21.08.2008	10.4	0.3	111.0	25.9	-0.01	-0.01	-0.001	0.08	22.6	25.7	0.04
25	International 6F	21.08.2008	15.3	0.4	104.0	26.3	-0.01	-0.01	0.002	0.07	17.6	11.9	0.09
26	Kabanana	25.08.2008	19.1	1.6	106.0	17.7	-0.01	-0.01	0.002	0.22	41.0	51.2	-0.01
27	Kanakantapa	02.02.2008	2.4	1.1	5.9	3.5	0.01	8.81	0.295	0.10	1.3	0.1	-0.01
28	Kasanova Kanyimbu A	06.03.2008	12.3	0.3	48.8	27.7	-0.01	0.01	0.110	0.17	23.4	0.3	0.27
29	Kasanova Kanyimbu B	11.02.2008	13.2	0.4	77.6	26.6	-0.01	0.01	0.001	0.20	23.2	0.0	-0.01
30	Kashembe Farm Spring A	01.11.2008	2.4	5.5	102.0	35.0	0.01	0.19	0.240	0.10	1.2	0.7	1.45
31	Kashembe Farm Spring B	18.10.2008	2.5	0.1	103.0	42.6	0.03	0.9	0.154	0.13	1.4	1.5	-0.01
32	Laughing Waters	10.03.2008	5.6	0.4	75.7	20.7	-0.01	0.01	0.001	0.17	9.9	3.4	-0.01
33	Laughing Waters	24.10.2008	6.5	0.2	89.1	25.4	0.01	-0.01	0.002	0.08	10.6	3.4	-0.01
34	Lilayi Rd 2	22.08.2008	0.8	0.3	91.6	24.3	-0.01	0.01	0.001	0.19	1.0	14.4	-0.01
35	Linda Mwandila	15.02.2008	19.9	1.8	99.9	53.7	0.01	-0.01	0.005	0.52	16.2	40.2	0.03
36	Linda Mwandila	26.10.2008	21.8	2.5	104.0	55.3	0.02	0.05	0.123	0.57	19.2	25.8	-0.01
37	Lumumba Rd 4A	25.08.2008	18.3	1.9	102.0	17.7	0.40	-0.01	-0.001	0.05	32.2	23.5	0.06

C. Main & Minor Constituents

No.	Sample name	Sample Date	Na mg/l	K mg/l	Ca mg/l	Mg mg/l	NH4 mg/l	Fe_tot mg/l	Mn mg/l	F mg/l	Cl mg/l	NO_3 mg/l	NO_2 mg/l
38	Makeni Burkley Spring	15.02.2008	20.5	3.1	61.6	42.5	0.04	0.01	0.001	0.42	13.1	13.5	-0.01
39	Makeni Valley Spring	05.03.2008	38.1	3.2	86.2	29.8	0.01	0.03	0.029	0.11	83.3	84.2	2.69
40	Massmedia 2	09.08.2008	10.9	0.5	106.0	24.4	-0.01	0.01	0.002	0.09	16.0	21.8	0.04
41	Massmedia 3	09.08.2008	12.5	0.5	106.0	26.0	-0.01	0.01	0.001	0.07	16.4	17.7	0.10
42	MFEZ B/h J4	29.07.2008	0.9	0.4	121.0	23.7	-0.01	0.01	0.002	0.36	0.7	5.2	0.02
43	Michelo Farm Spring	18.10.2008	2.4	0.3	107.0	24.0	-0.01	0.01	0.002	0.14	1.3	0.2	-0.01
44	Mulungushi 6A	20.08.2008	10.4	0.7	103.0	28.5	-0.01	0.01	0.266	0.11	23.4	8.4	0.02
45	Mulungushi 6H	20.08.2008	10.0	0.7	106.0	29.6	-0.01	0.01	0.111	0.11	24.6	6.1	0.04
46	Mumbwa Roadside 1	11.08.2008	17.4	1.5	106.0	26.5	-0.01	-0.01	-0.001	0.06	28.8	53.1	-0.01
47	Mwembeshi Prison	11.03.2008	6.0	0.7	91.6	39.7	0.01	0.01	0.003	0.28	2.7	3.1	-0.01
48	Mwembeshi Prison	18.10.2008	6.9	0.8	107.0	46.2	0.06	0.02	0.014	0.27	3.6	0.4	-0.01
49	Mwembeshi Satellite	11.03.2008	13.2	0.4	77.6	57.3	-0.01	0.02	0.009	0.31	2.7	0.0	-0.01
50	Mwembeshi Satellite	26.10.2008	14.3	1.7	91.2	65.5	-0.01	0.03	0.010	0.28	4.2	1.4	3.71
51	Ng'ombe Spring	18.01.2008	8.8	4.8	4.9	7.2	0.03	0.06	0.019	0.15	6.3	13.3	0.02
52	Ng'ombe Spring	27.10.2008	9.0	5.3	5.4	7.7	0.06	0.13	0.054	0.16	4.8	10.9	-0.01
53	Northmead 2	20.08.2008	24.7	0.8	118.0	28.0	-0.01	0.1	0.002	0.08	31.9	17.1	0.04
54	NRDC 1	05.08.2008	15.2	1.2	99.3	25.6	-0.01	0.01	0.003	0.18	19.2	8.4	-0.01
55	NRDC 2	05.08.2008	13.4	1.2	99.7	31.3	-0.01	-0.01	0.002	0.20	21.3	8.9	-0.01
56	Nsanje Muleke	10.03.2008	5.8	0.3	85.1	22.2	-0.01	0.01	0.001	0.11	11.3	13.6	0.01
57	Nsanje Muleke	24.10.2008	6.0	0.2	81.0	21.3	-0.01	-0.01	0.002	0.12	10.8	12.6	-0.01
58	Palabana A	13.03.2008	0.2	0.2	101.0	18.1	-0.01	0.01	0.006	0.05	0.5	0.1	-0.01
59	Palabana Dairy	13.03.2008	4.8	0.5	147.0	18.4	-0.01	0.01	0.003	0.27	2.1	7.9	-0.01
60	Palabana Dairy	28.10.2008	3.9	0.2	136.0	17.5	0.01	0.01	0.011	0.29	1.4	4.9	-0.01
61	Palmwood Lodge Spring	13.03.2008	15.8	0.2	17.6	13.8	-0.01	0.68	0.257	0.30	7.3	0.4	-0.01
62	Shaft 5	22.08.2008	1.7	0.5	113.0	18.0	-0.01	-0.01	-0.001	0.32	2.5	19.8	-0.01
63	Shalenga V Spring A	11.03.2008	9.2	0.5	5.4	3.6	-0.01	0.08	0.010	0.27	2.7	0.0	-0.01
64	Shalenga V Spring B	11.03.2008	8.9	1.6	5.5	2.1	0.26	0.06	0.010	0.19	10.3	0.2	-0.01
65	Shantumbu B Sch Spring A	14.03.2008	0.8	1.0	66.9	26.8	0.37	0.01	0.010	0.06	0.9	0.6	0.04
66	Shantumbu B Sch Spring A	27.10.2008	0.6	0.1	70.5	28.7	-0.01	0.02	0.012	0.04	0.3	0.0	-0.01
67	St Mary School Spring	11.03.2008	63.7	13.9	14.4	17.2	0.02	0.05	0.038	0.09	87.7	57.8	-0.01
68	St Monica School Spring	11.02.2008	48.7	22.9	44.4	38.2	-0.01	0.03	0.018	0.26	64.9	82.3	-0.01
69	St Charles Spring	10.03.2008	11.4	1.2	100.0	26.5	-0.01	0.01	0.001	0.16	16.9	34.3	-0.01
70	State Lodge	18.01.2008	1.9	0.1	92.5	24.9	-0.01	0.05	0.023	0.20	0.8	0.1	-0.01
71	State Lodge	29.10.2008	1.8	-0.1	85.7	23.7	-0.01	0	0.001	0.18	1.3	0.4	-0.01
72	Waterworks 2	23.08.2008	4.5	0.7	106.0	21.9	-0.01	-0.01	-0.001	0.15	6.7	31.2	0.02
73	Zimbabwe Farm	10.03.2008	3.5	0.5	74.2	18.8	-0.01	0.13	0.049	0.21	1.0	0.7	-0.01
74	Zimbabwe Farm	29.10.2008	3.8	0.0	94.1	21.4	-0.01	0.05	0.028	0.20	0.6	0.0	-0.01
75	Zinaglume Overspill	10.03.2008	32.4	1.4	141.0	43.9	-0.01	0.01	0.004	0.13	78.2	118.0	0.04
76	Zinaglume Overspill	28.10.2008	35.9	1.0	157.0	50.5	0.04	0.01	0.006	0.13	111.0	192.0	-0.01

Note: Minus sign in front of value reads as “below the given detection limit”.

C. Main & Minor Constituents

No.	Sample name	Sample Date	SO_4 mg/l	HCO_3 mg/l	SiO_2 mg/l	PO_4 tot mg/l	Σ CAT meq/l	Σ ANI meq/l	Electr. Bal. %
1	Avondale 1	06.08.2008	8.8	344	7.9	-0.03	6.37	6.52	-1.2
2	Bauleni	24.08.2008	9.9	477	12.9	-0.03	11.77	11.85	-0.4
3	Buckley 1	24.08.2008	12.0	412	35.1	-0.03	7.58	7.79	-1.4
4	Buckley 2	12.08.2008	21.6	535	39.2	-0.03	11.05	11.30	-1.1
5	Chainda	06.08.2008	22.4	345	12.7	-0.03	14.40	15.01	-2.1
6	Chawama 1	25.08.2008	27.7	335	11.7	-0.03	10.37	10.85	-2.3
7	Chelston	08.08.2008	17.0	386	16.1	-0.03	7.84	8.13	-1.8
8	Chimbwete Spring	26.10.2008	10.2	328	7.9	-0.03	6.18	6.28	-0.8
9	Chinyunyu Hot Spring	23.01.2008	172.0	64.9	78.7	-0.02	6.56	6.02	4.3
10	Chunga 2	10.08.2008	36.8	411	28.0	-0.03	10.99	11.21	-1.0
11	Chunga 6E	10.08.2008	36.8	411	16.9	-0.03	10.92	11.20	-1.3
12	Forest 26 BH-7	17.03.2008	0.2	353	5.5	-0.02	6.17	5.96	1.8
13	Freedom Water Trust	24.08.2008	79.4	474	57.2	-0.03	10.87	11.25	-1.7
14	George 2	19.08.2008	16.5	269	8.1	-0.03	5.46	5.51	-0.4
15	George 3	19.08.2008	20.5	418	9.4	-0.03	8.32	8.47	-0.9
16	George 5	12.08.2008	10.5	383	10.0	-0.03	7.27	7.52	-1.7
17	George 6	11.08.2008	13.2	304	8.4	-0.03	5.94	5.95	-0.1
18	George 7	19.08.2008	8.0	225	6.6	-0.03	4.22	4.30	-1.0
19	Good Hope	10.03.2008	1.8	419	11.0	-0.02	7.09	6.95	1.0
20	Handamana Section	10.03.2008	7.0	337	8.2	-0.02	6.41	6.19	1.8
21	Handamana Section	25.10.2008	6.8	330	7.9	-0.03	6.16	6.05	0.9
22	Independence Park	11.03.2008	19.4	174	26.3	0.07	4.19	4.10	1.1
23	International 6A	21.08.2008	8.6	422	21.8	-0.03	7.83	7.99	-1.0
24	International 6E	21.08.2008	11.3	422	17.1	-0.03	8.13	8.20	-0.5
25	International 6F	21.08.2008	8.1	446	18.9	-0.03	8.03	8.17	-0.9
26	Kabanana	25.08.2008	14.2	336	21.1	-0.03	7.62	7.78	-1.1
27	Kanakantapa	02.02.2008	-0.1	60	15.6	0.25	0.72	1.02	-17.6
28	Kasanova Kanyimbu A	06.03.2008	12.3	279	5.2	-0.02	5.26	5.49	-2.2
29	Kasanova Kanyimbu B	11.02.2008	12.3	338	5.4	0.02	6.64	6.45	1.5
30	Kashembe Farm Spring A	01.11.2008	0.2	491	11.4	0.22	8.21	8.10	0.7
31	Kashembe Farm Spring B	18.10.2008	0.1	528	12.4	-0.03	8.76	8.72	0.2
32	Laughing Waters	10.03.2008	7.6	308	9.1	-0.02	5.73	5.54	1.7
33	Laughing Waters	24.10.2008	7.7	395	11.1	-0.03	6.82	6.99	-1.2
34	Lilayi Rd 2	22.08.2008	0.5	395	10.2	-0.03	6.61	6.75	-1.0
35	Linda Mwandila	15.02.2008	26.1	533	39.1	-0.02	10.31	10.39	-0.3
36	Linda Mwandila	26.10.2008	26.1	570	38.2	0.03	10.75	10.84	-0.4
37	Lumumba Rd 4A	25.08.2008	45.4	331	8.4	-0.03	7.39	7.66	-1.8

C. Main & Minor Constituents

No.	Sample name	Sample Date	SO_4 mg/l	HCO_3 mg/l	SiO_2 mg/l	PO_4 tot mg/l	Σ CAT meq/l	Σ ANI meq/l	Electr. Bal. %
38	Makeni Burkley Spring	15.02.2008	27.2	396	26.4	0.02	7.54	7.65	-0.7
39	Makeni Valley Spring	05.03.2008	23.9	256	2.1	0.03	8.49	8.40	0.5
40	Massmedia 2	09.08.2008	12.0	413	15.8	-0.03	7.78	7.82	-0.3
41	Massmedia 3	09.08.2008	10.6	440	17.1	-0.03	7.98	8.18	-1.2
42	MFEZ B/h J4	29.07.2008	0.2	489	12.7	0.03	8.04	8.12	-0.6
43	Michelo Farm Spring	18.10.2008	0.8	445	9.2	0.03	7.42	7.35	0.5
44	Mulungushi 6A	20.08.2008	20.4	421	17.0	-0.03	7.95	8.12	-1.0
45	Mulungushi 6H	20.08.2008	20.9	428	16.7	-0.03	8.18	8.24	-0.4
46	Mumbwa Roadside 1	11.08.2008	16.0	386	9.0	-0.03	8.26	8.33	-0.4
47	Mwembeshi Prison	11.03.2008	7.6	456	17.6	-0.02	8.12	7.76	2.2
48	Mwembeshi Prison	18.10.2008	2.2	563	18.9	0.05	9.46	9.38	0.4
49	Mwembeshi Satellite	11.03.2008	8.3	539	18.4	-0.02	9.17	9.09	0.5
50	Mwembeshi Satellite	26.10.2008	7.6	629	18.6	0.03	10.61	10.61	0.0
51	Ng'ombe Spring	18.01.2008	0.6	59.2	34.2	0.42	1.34	1.38	-1.2
52	Ng'ombe Spring	27.10.2008	0.2	67.4	41.1	0.70	1.43	1.42	0.4
53	Northmead 2	20.08.2008	18.6	474	20.5	-0.03	9.28	9.33	-0.3
54	NRDC 1	05.08.2008	10.1	440	14.4	-0.03	7.75	8.10	-2.2
55	NRDC 2	05.08.2008	11.6	451	14.0	-0.03	8.16	8.38	-1.3
56	Nsanje Muleke	10.03.2008	7.1	332	8.3	-0.02	6.33	6.13	1.6
57	Nsanje Muleke	24.10.2008	6.7	328	8.0	-0.03	6.06	6.02	0.3
58	Palabana A	13.03.2008	0.2	409	7.1	-0.02	6.54	6.73	-1.4
59	Palabana Dairy	13.03.2008	8.9	509	17.5	-0.02	9.07	8.72	2.0
60	Palabana Dairy	28.10.2008	7.6	505	16.9	0.05	8.40	8.56	-0.9
61	Palmwood Lodge Spring	13.03.2008	-0.1	151	3.9	-0.02	2.71	2.69	0.4
62	Shaft 5	22.08.2008	1.2	420	13.7	-0.03	7.20	7.30	-0.7
63	Shalenga V Spring A	11.03.2008	-0.1	53.6	10.2	-0.02	0.98	0.95	1.2
64	Shalenga V Spring B	11.03.2008	0.4	36.2	8.9	-0.02	0.88	0.90	-1.1
65	Shantumbu B Sch Spring A	14.03.2008	0.1	325	6.2	-0.02	5.60	5.37	2.2
66	Shantumbu B Sch Spring A	27.10.2008	0.1	359	5.9	0.04	5.91	5.90	0.1
67	St Mary School Spring	11.03.2008	23.6	76	10.3	-0.02	5.26	5.14	1.1
68	St Monica School Spring	11.02.2008	61.6	240	12.7	0.02	8.06	8.37	-1.9
69	St Charles Spring	10.03.2008	11.9	411	10.2	-0.02	7.70	8.02	-2.0
70	State Lodge	18.01.2008	1.4	414	8.7	-0.02	6.75	6.84	-0.7
71	State Lodge	29.10.2008	0.9	376	8.3	0.10	6.30	6.23	0.6
72	Waterworks 2	23.08.2008	3.4	410	11.2	-0.03	7.30	7.48	-1.2
73	Zimbabwe Farm	10.03.2008	0.3	341	12.2	-0.02	5.41	5.64	-2.0
74	Zimbabwe Farm	29.10.2008	0.3	405	12.5	0.05	6.62	6.66	-0.3
75	Zinaglume Overspill	10.03.2008	41.8	412	13.7	-0.02	12.09	11.73	1.5
76	Zinaglume Overspill	28.10.2008	44.7	420	13.8	0.04	13.57	14.04	-1.7

Note: Minus sign in front of value reads as “below the given detection limit”.

D. Trace Elements (Selection)

No.	Sample name	Sample Date	Br mg/l	Li mg/l	Be µg/l	B µg/l [B]	Al µg/l	Sc µg/l	Ti µg/l	V µg/l
1	Avondale 1	06.08.2008	0.02	-0.0004	-0.030	10.0	-3.0	0.01	0.05	0.45
2	Bauleni	24.08.2008	0.05	-0.0008	-0.060	-10.0	-3.0	-0.02	0.03	0.29
3	Buckley 1	24.08.2008	0.02	0.0019	-0.030	0.0	-3.0	0.02	0.10	1.40
4	Buckley 2	12.08.2008	0.02	0.0032	-0.060	20.0	3.0	-0.02	-0.02	2.28
5	Chainda	06.08.2008	0.70	-0.0016	-0.120	10.0	-3.0	-0.04	-0.04	0.34
6	Chawama 1	25.08.2008	0.06	0.0037	-0.060	10.0	-3.0	-0.02	-0.02	0.36
7	Chelston	08.08.2008	0.06	0.0006	-0.030	20.0	-3.0	0.01	-0.01	0.36
8	Chimbwete Spring	26.10.2008	0.03	0.0070	0.003	7.9	4.2	0.05	0.00	1.86
9	Chinyunyu Hot Spring	23.01.2008	0.34	0.1690	0.127	1260.0	47.0	0.18	0.45	0.11
10	Chunga 2	10.08.2008	0.09	0.0021	-0.060	10.0	-3.0	-0.02	-0.02	1.39
11	Chunga 6E	10.08.2008	0.08	-0.0008	-0.060	10.0	-3.0	-0.02	0.03	0.79
12	Forest 26 BH-7	17.03.2008	-0.01	-0.0004	-0.030	-10.0	6.0	0.05	0.11	0.08
13	Freedom Water Trust	24.08.2008	0.05	0.0031	-0.060	20.0	-3.0	0.02	-0.02	6.27
14	George 2	19.08.2008	0.03	-0.0004	-0.030	20.0	-3.0	-0.01	-0.01	0.92
15	George 3	19.08.2008	0.04	0.0009	-0.030	20.0	-3.0	0.02	-0.01	20.55
16	George 5	12.08.2008	0.04	0.0014	-0.030	10.0	32.0	-0.01	0.65	0.44
17	George 6	11.08.2008	0.03	0.0006	-0.030	10.0	-3.0	0.01	-0.01	0.40
18	George 7	19.08.2008	0.02	-0.0004	-0.030	10.0	-3.0	-0.01	0.17	0.64
19	Good Hope	10.03.2008	-0.01	-0.0004	-0.030	-10.0	8.0	0.07	0.11	0.35
20	Handamana Section	10.03.2008	0.01	0.0005	-0.030	-10.0	5.0	0.05	0.07	0.76
21	Handamana Section	25.10.2008	0.03	0.0060	0.002	6.4	4.3	0.03	0.00	0.57
22	Independence Park	11.03.2008	0.02	-0.0004	-0.030	10.0	5.0	0.12	0.08	1.56
23	International 6A	21.08.2008	0.03	-0.0004	-0.030	0.0	-3.0	0.02	-0.01	0.21
24	International 6E	21.08.2008	0.02	-0.0004	-0.030	0.0	-3.0	0.01	-0.01	0.12
25	International 6F	21.08.2008	0.03	0.0006	-0.030	10.0	-3.0	0.02	0.06	0.22
26	Kabanana	25.08.2008	0.04	0.0008	-0.030	-10.0	-3.0	0.03	-0.01	0.38
27	Kanakantapa	02.02.2008	-0.01	0.0023	1.202	20.0	112.0	0.16	0.91	1.77
28	Kasanova Kanyimbu A	06.03.2008	0.01	-0.0004	-0.030	-10.0	9.0	0.03	0.15	0.07
29	Kasanova Kanyimbu B	11.02.2008	-0.01	-0.0004	-0.030	-10.0	8.0	0.04	0.13	0.11
30	Kashembe Farm Spring A	01.11.2008	0.03	0.0070	0.005	7.3	9.6	0.04	0.40	0.04
31	Kashembe Farm Spring B	18.10.2008	0.03	0.0060	0.007	6.1	2.8	0.06	0.05	0.01
32	Laughing Waters	10.03.2008	0.02	-0.0004	-0.030	-10.0	6.0	0.04	0.09	0.46
33	Laughing Waters	24.10.2008	0.03	0.0050	0.003	5.3	2.9	0.05	0.15	0.47
34	Lilayi Rd 2	22.08.2008	0.01	0.0026	-0.030	0.0	-3.0	-0.01	0.07	0.33
35	Linda Mwandila	15.02.2008	0.01	0.0026	-0.030	-10.0	7.0	0.19	0.07	1.78
36	Linda Mwandila	26.10.2008	0.03	0.0060	0.003	5.9	22.8	0.09	0.81	1.75
37	Lumumba Rd 4A	25.08.2008	0.05	0.0006	-0.030	30.0	-3.0	0.01	-0.01	0.57

D. Trace Elements (Selection)

No.	Sample name	Sample Date	Br mg/l	Li mg/l	Be µg/l	B µg/l [B]	Al µg/l	Sc µg/l	Ti µg/l	V µg/l
38	Makeni Burkley Spring	15.02.2008	0.02	0.0005	-0.030	10.0	8.0	0.13	0.19	3.48
39	Makeni Valley Spring	05.03.2008	0.07	-0.0004	-0.030	10.0	23.0	0.03	0.63	1.13
40	Massmedia 2	09.08.2008	0.02	-0.0004	-0.030	10.0	-3.0	-0.01	0.09	0.14
41	Massmedia 3	09.08.2008	0.02	-0.0004	-0.030	20.0	-3.0	0.02	0.02	0.13
42	MFEZ B/h J4	29.07.2008	0.01	0.0092	-0.030	0.0	-3.0	0.02	0.12	0.28
43	Michelo Farm Spring	18.10.2008	0.03	0.0080	0.003	3.4	2.5	0.05	0.00	0.38
44	Mulungushi 6A	20.08.2008	0.02	0.0004	-0.030	10.0	-3.0	0.01	0.13	0.25
45	Mulungushi 6H	20.08.2008	0.00	-0.0004	-0.030	10.0	-3.0	0.01	0.13	0.31
46	Mumbwa Roadside 1	11.08.2008	0.05	-0.0004	-0.030	10.0	-3.0	-0.01	-0.01	0.76
47	Mwembeshi Prison	11.03.2008	0.01	0.0009	-0.030	-10.0	6.0	0.09	0.07	1.49
48	Mwembeshi Prison	18.10.2008	0.02	0.0110	0.010	4.2	2.8	0.06	0.09	1.71
49	Mwembeshi Satellite	11.03.2008	-0.01	0.0017	-0.030	-10.0	6.0	0.10	0.04	0.49
50	Mwembeshi Satellite	26.10.2008	0.02	0.0070	0.006	4.3	5.4	0.07	0.09	0.20
51	Ng'ombe Spring	18.01.2008	0.01	0.0037	0.069	20.0	45.0	0.09	0.92	1.29
52	Ng'ombe Spring	27.10.2008	0.05	0.0150	0.054	9.0	87.7	0.12	3.07	1.06
53	Northmead 2	20.08.2008	0.05	0.0006	-0.030	10.0	-3.0	0.02	0.14	0.24
54	NRDC 1	05.08.2008	0.03	0.0013	0.031	20.0	3.0	0.02	0.12	2.32
55	NRDC 2	05.08.2008	0.03	0.0010	-0.030	20.0	-3.0	-0.01	-0.01	3.96
56	Nsanje Muleke	10.03.2008	0.01	0.0004	-0.030	-10.0	5.0	0.04	0.10	0.63
57	Nsanje Muleke	24.10.2008	0.02	0.0050	0.001	2.6	2.2	0.03	0.05	0.39
58	Palabana A	13.03.2008	-0.01	-0.0004	-0.030	-10.0	5.0	0.05	0.13	0.18
59	Palabana Dairy	13.03.2008	-0.01	0.0009	-0.030	-10.0	6.0	0.09	0.16	0.38
60	Palabana Dairy	28.10.2008	0.01	0.0070	0.010	2.0	11.2	0.08	0.13	0.16
61	Palmwood Lodge Spring	13.03.2008	-0.01	-0.0004	-0.030	10.0	12.0	0.02	0.44	0.17
62	Shaft 5	22.08.2008	0.01	0.0049	-0.030	0.0	-3.0	-0.01	-0.01	0.34
63	Shalenga V Spring A	11.03.2008	-0.01	-0.0004	-0.030	-10.0	7.0	0.04	0.09	0.11
64	Shalenga V Spring B	11.03.2008	0.02	-0.0004	-0.030	-10.0	10.0	0.05	0.16	0.06
65	Shantumbu B Sch Spring A	14.03.2008	-0.01	-0.0004	-0.030	10.0	10.0	0.04	0.30	3.29
66	Shantumbu B Sch Spring A	27.10.2008	0.01	0.0080	0.003	1.9	10.5	0.03	0.13	1.40
67	St Mary School Spring	11.03.2008	0.06	-0.0004	0.063	-10.0	3.0	0.05	0.04	0.21
68	St Monica School Spring	11.02.2008	0.01	-0.0004	-0.030	20.0	12.0	0.08	0.39	0.51
69	St Charles Spring	10.03.2008	0.03	0.0018	-0.030	-10.0	6.0	0.04	0.21	0.48
70	State Lodge	18.01.2008	-0.01	0.0010	-0.030	-10.0	7.0	0.06	0.07	0.04
71	State Lodge	29.10.2008	0.01	0.0080	0.000	0.7	0.2	0.05	0.00	0.16
72	Waterworks 2	23.08.2008	0.01	0.0014	-0.030	0.0	-3.0	-0.01	-0.01	0.33
73	Zimbabwe Farm	10.03.2008	-0.01	-0.0004	-0.030	-10.0	7.0	0.06	0.14	0.43
74	Zimbabwe Farm	29.10.2008	0.01	0.0120	0.009	2.0	16.6	0.06	0.55	1.02
75	Zinaglume Overspill	10.03.2008	0.04	-0.0004	-0.030	10.0	6.0	0.08	0.12	0.40
76	Zinaglume Overspill	28.10.2008	0.10	0.0060	0.008	7.6	5.0	0.06	0.00	0.37

Note: Minus sign in front of value reads as “below the given detection limit”.

D. Trace Elements (Selection)

No.	Sample name	Sample Date	Cr-VI µg/l	Co µg/l	Ni µg/l	Cu µg/l	Zn mg/l	Ga µg/l	As µg/l	Se µg/l	Rb µg/l
1	Avondale 1	06.08.2008	0.06	0.02	0.7	3.26	0.016	-0.008	-0.10	-5.0	0.5
2	Bauleni	24.08.2008	-0.06	0.03	0.4	0.21	0.001	-0.016	-0.20	-10.0	1.0
3	Buckley 1	24.08.2008	0.23	0.10	0.5	0.71	0.052	0.017	-0.10	-5.0	3.1
4	Buckley 2	12.08.2008	0.18	0.09	0.3	1.03	0.018	0.049	-0.20	-10.0	0.9
5	Chainda	06.08.2008	-0.12	0.10	1.1	2.46	0.025	-0.032	-0.40	-20.0	2.2
6	Chawama 1	25.08.2008	-0.06	0.12	0.4	0.29	0.002	-0.016	-0.20	-10.0	1.7
7	Chelston	08.08.2008	0.14	0.03	0.2	0.21	-0.001	-0.008	-0.10	-5.0	3.8
8	Chimbwete Spring	26.10.2008	0.03	0.05	0.1	0.38	0.008	0.030	0.10	0.7	0.7
9	Chinyunyu Hot Spring	23.01.2008	0.40	0.05	0.7	2.00	0.004	2.488	-0.10	-5.0	58.8
10	Chunga 2	10.08.2008	-0.06	0.23	0.4	0.17	0.001	-0.016	0.60	-10.0	0.2
11	Chunga 6E	10.08.2008	0.06	0.09	0.4	3.25	0.012	-0.016	-0.20	-10.0	1.1
12	Forest 26 BH-7	17.03.2008	0.27	0.18	2.0	0.46	0.013	0.143	-0.10	-5.0	2.7
13	Freedom Water Trust	24.08.2008	7.41	0.10	0.3	0.23	0.002	-0.016	-0.20	-10.0	3.4
14	George 2	19.08.2008	0.04	0.04	0.3	1.55	0.008	0.056	-0.10	-5.0	1.1
15	George 3	19.08.2008	0.07	0.03	0.2	0.17	-0.001	0.032	0.20	-5.0	0.9
16	George 5	12.08.2008	0.40	0.20	2.7	106.10	0.782	0.024	-0.10	-5.0	2.1
17	George 6	11.08.2008	0.08	0.02	0.2	0.16	-0.001	-0.008	-0.10	-5.0	0.6
18	George 7	19.08.2008	0.07	0.01	0.1	0.29	-0.001	0.012	-0.10	-5.0	0.6
19	Good Hope	10.03.2008	0.11	0.26	0.6	0.23	0.150	0.069	0.10	-5.0	0.4
20	Handamana Section	10.03.2008	0.06	0.03	0.3	0.22	0.003	0.027	-0.10	-5.0	0.3
21	Handamana Section	25.10.2008	0.12	0.03	0.2	0.66	0.009	0.003	0.05	0.1	0.5
22	Independence Park	11.03.2008	0.08	0.14	0.6	0.49	0.072	0.591	-0.10	-5.0	1.2
23	International 6A	21.08.2008	0.06	0.03	0.6	0.78	0.001	-0.008	-0.10	-5.0	1.8
24	International 6E	21.08.2008	0.04	0.02	0.1	0.08	-0.001	-0.008	-0.10	-5.0	0.5
25	International 6F	21.08.2008	0.11	0.03	0.3	11.40	0.038	-0.008	-0.10	-5.0	0.7
26	Kabanana	25.08.2008	-0.03	0.05	0.8	1.32	0.001	0.010	-0.10	-5.0	0.8
27	Kanakantapa	02.02.2008	2.11	7.69	12.4	62.06	0.224	0.350	1.00	-5.0	8.2
28	Kasanova Kanyimbu A	06.03.2008	0.20	0.16	0.5	0.44	0.008	0.090	0.10	-5.0	0.5
29	Kasanova Kanyimbu B	11.02.2008	0.26	0.08	1.9	1.43	0.143	0.087	0.10	-5.0	0.6
30	Kashembe Farm Spring A	01.11.2008	0.05	0.52	1.0	1.20	0.006	0.013	0.24	0.0	2.7
31	Kashembe Farm Spring B	18.10.2008	0.02	0.77	0.3	0.33	0.012	0.023	0.37	0.0	0.3
32	Laughing Waters	10.03.2008	0.10	0.05	0.4	0.35	0.004	0.038	-0.10	-5.0	0.5
33	Laughing Waters	24.10.2008	0.04	0.03	0.2	0.49	0.008	0.007	0.03	0.2	0.5
34	Lilayi Rd 2	22.08.2008	0.07	0.01	0.1	1.23	0.047	-0.008	-0.10	-5.0	0.4
35	Linda Mwandila	15.02.2008	0.28	0.13	0.6	0.29	0.133	0.064	-0.10	-5.0	2.2
36	Linda Mwandila	26.10.2008	0.44	0.68	0.9	0.85	0.006	0.016	0.18	0.3	3.6
37	Lumumba Rd 4A	25.08.2008	0.07	0.05	0.4	0.36	-0.001	0.024	-0.10	-5.0	1.0

D. Trace Elements (Selection)

No.	Sample name	Sample Date	Cr-VI µg/l	Co µg/l	Ni µg/l	Cu µg/l	Zn mg/l	Ga µg/l	As µg/l	Se µg/l	Rb µg/l
38	Makeni Burkley Spring	15.02.2008	0.22	0.24	1.4	2.95	0.015	0.166	0.30	-5.0	3.8
39	Makeni Valley Spring	05.03.2008	0.32	0.30	1.2	2.48	0.027	0.074	0.30	-5.0	3.6
40	Massmedia 2	09.08.2008	0.09	0.03	5.7	5.09	0.021	-0.008	-0.10	-5.0	1.1
41	Massmedia 3	09.08.2008	0.08	0.03	2.4	9.65	0.038	-0.008	-0.10	-5.0	0.7
42	MFEZ B/h J4	29.07.2008	0.10	0.05	0.4	0.37	0.019	0.023	-0.10	-5.0	0.9
43	Michelo Farm Spring	18.10.2008	0.09	0.01	0.1	0.33	0.007	0.003	0.02	0.0	0.7
44	Mulungushi 6A	20.08.2008	-0.03	0.13	2.0	1.56	0.019	-0.008	-0.10	-5.0	1.3
45	Mulungushi 6H	20.08.2008	0.05	0.28	0.6	3.51	0.018	0.008	-0.10	-5.0	1.4
46	Mumbwa Roadside 1	11.08.2008	0.03	0.04	0.3	0.19	-0.001	0.017	-0.10	-5.0	1.1
47	Mwembeshi Prison	11.03.2008	0.07	0.10	0.2	0.33	0.079	0.136	-0.10	-5.0	1.0
48	Mwembeshi Prison	18.10.2008	0.05	0.06	0.2	0.49	0.008	0.003	0.04	0.1	1.1
49	Mwembeshi Satellite	11.03.2008	0.05	0.27	0.7	0.52	0.058	0.089	1.40	-5.0	0.7
50	Mwembeshi Satellite	26.10.2008	0.39	0.18	0.3	0.28	0.010	0.000	0.60	0.1	0.8
51	Ng'ombe Spring	18.01.2008	0.38	0.29	2.8	32.59	0.118	0.184	-0.10	-5.0	2.3
52	Ng'ombe Spring	27.10.2008	2.52	2.71	21.4	11.96	0.087	0.041	0.18	0.0	6.1
53	Northmead 2	20.08.2008	0.03	0.04	0.2	4.08	0.067	-0.008	-0.10	-5.0	1.0
54	NRDC 1	05.08.2008	0.20	0.05	1.2	5.59	0.012	0.028	0.10	-5.0	2.3
55	NRDC 2	05.08.2008	0.07	0.06	0.5	0.21	0.001	-0.008	0.10	-5.0	1.4
56	Nsanje Muleke	10.03.2008	0.05	0.05	0.3	0.25	0.006	0.033	-0.10	-5.0	0.4
57	Nsanje Muleke	24.10.2008	0.04	0.02	0.1	0.28	0.007	0.000	0.04	0.1	0.4
58	Palabana A	13.03.2008	0.12	0.12	0.6	0.66	0.023	0.019	0.10	-5.0	0.3
59	Palabana Dairy	13.03.2008	0.14	0.06	0.9	0.18	0.007	0.054	-0.10	-5.0	0.9
60	Palabana Dairy	28.10.2008	0.10	0.05	0.3	0.61	0.010	0.000	0.02	0.0	1.1
61	Palmwood Lodge Spring	13.03.2008	0.11	1.00	0.7	0.49	0.007	0.126	0.30	-5.0	0.3
62	Shaft 5	22.08.2008	0.06	0.01	0.1	0.05	-0.001	0.017	-0.10	-5.0	0.7
63	Shalenga V Spring A	11.03.2008	0.08	0.37	0.5	0.76	0.003	0.132	0.20	-5.0	1.1
64	Shalenga V Spring B	11.03.2008	0.07	0.43	0.9	1.41	0.006	0.151	0.10	-5.0	3.5
65	Shantumbu B Sch Spring A	14.03.2008	0.09	0.13	4.2	2.71	0.016	0.021	-0.10	-5.0	1.5
66	Shantumbu B Sch Spring A	27.10.2008	0.70	0.07	0.6	1.14	0.014	0.006	0.03	0.0	0.5
67	St Mary School Spring	11.03.2008	0.05	1.18	1.3	0.20	0.061	1.292	-0.10	-5.0	16.8
68	St Monica School Spring	11.02.2008	1.40	0.30	1.8	20.33	0.015	0.750	-0.10	-5.0	10.8
69	St Charles Spring	10.03.2008	0.06	0.05	0.7	0.22	0.004	0.040	-0.10	-5.0	1.4
70	State Lodge	18.01.2008	0.06	0.34	0.2	0.23	0.088	0.184	0.10	-5.0	0.2
71	State Lodge	29.10.2008	0.02	0.04	0.2	0.61	-0.001	0.000	0.15	0.0	0.7
72	Waterworks 2	23.08.2008	0.06	0.02	0.1	0.10	-0.001	-0.008	-0.10	-5.0	0.7
73	Zimbabwe Farm	10.03.2008	0.06	0.22	0.3	0.13	0.076	0.441	0.10	-5.0	0.4
74	Zimbabwe Farm	29.10.2008	1.61	0.29	1.7	14.39	0.077	0.009	0.04	0.0	1.1
75	Zinaglume Overspill	10.03.2008	0.03	0.16	0.7	0.16	0.013	0.094	-0.10	-5.0	0.6
76	Zinaglume Overspill	28.10.2008	0.15	0.10	0.4	0.64	0.041	0.012	0.04	0.1	0.8

Note: Minus sign in front of value reads as “below the given detection limit”.

D. Trace Elements (Selection)

No.	Sample name	Sample Date	Sr µg/l	Y µg/l	Zr µg/l	Nb µg/l	Mo µg/l	Ag µg/l	Cd µg/l
1	Avondale 1	06.08.2008	60.0	0.072	0.006	-0.010	0.076	0.006	0.010
2	Bauleni	24.08.2008	223.0	0.004	-0.010	-0.010	0.017	-0.004	-0.004
3	Buckley 1	24.08.2008	266.0	0.200	0.006	-0.010	0.142	0.004	0.004
4	Buckley 2	12.08.2008	336.0	0.097	-0.010	-0.010	0.155	0.007	0.005
5	Chainda	06.08.2008	323.0	0.224	-0.020	-0.030	0.020	0.043	-0.008
6	Chawama 1	25.08.2008	312.0	0.005	-0.010	-0.010	0.030	-0.004	-0.004
7	Chelston	08.08.2008	415.0	0.004	-0.005	0.010	0.019	-0.002	-0.002
8	Chimbwete Spring	26.10.2008	127.5	0.008	0.005	0.002	0.022	0.004	0.003
9	Chinyunyu Hot Spring	23.01.2008	171.0	0.032	0.026	0.030	4.320	0.002	0.027
10	Chunga 2	10.08.2008	194.0	0.003	-0.010	-0.010	0.127	-0.004	-0.004
11	Chunga 6E	10.08.2008	178.0	0.150	-0.010	-0.010	0.052	0.006	0.004
12	Forest 26 BH-7	17.03.2008	25.0	0.011	-0.005	-0.010	0.147	0.003	0.013
13	Freedom Water Trust	24.08.2008	282.0	0.008	-0.010	-0.010	0.115	-0.004	-0.004
14	George 2	19.08.2008	105.0	0.044	-0.005	-0.010	0.020	-0.002	0.003
15	George 3	19.08.2008	138.0	0.002	-0.005	-0.010	0.118	-0.002	-0.002
16	George 5	12.08.2008	115.0	0.168	0.010	-0.010	0.018	0.004	0.042
17	George 6	11.08.2008	90.0	-0.001	-0.005	-0.010	0.031	-0.002	-0.002
18	George 7	19.08.2008	76.0	0.001	-0.005	-0.010	0.032	-0.002	-0.002
19	Good Hope	10.03.2008	180.0	0.092	0.018	-0.010	0.043	-0.002	0.074
20	Handamana Section	10.03.2008	98.0	0.026	-0.005	-0.010	0.025	-0.002	0.011
21	Handamana Section	25.10.2008	90.9	0.020	0.003	0.001	0.027	0.002	0.013
22	Independence Park	11.03.2008	148.0	0.096	-0.005	-0.010	0.097	-0.002	0.020
23	International 6A	21.08.2008	107.0	0.001	-0.005	0.010	0.051	-0.002	-0.002
24	International 6E	21.08.2008	113.0	0.002	-0.005	0.020	0.020	-0.002	-0.002
25	International 6F	21.08.2008	115.0	0.048	-0.005	-0.010	0.030	0.003	0.005
26	Kabanana	25.08.2008	139.0	0.003	-0.005	0.010	0.032	0.016	-0.002
27	Kanakantapa	02.02.2008	43.0	0.648	0.100	0.010	0.416	0.013	0.174
28	Kasanova Kanyimbu A	06.03.2008	120.0	0.014	-0.005	-0.010	0.031	0.002	0.084
29	Kasanova Kanyimbu B	11.02.2008	120.0	0.017	-0.005	-0.010	0.027	0.002	0.026
30	Kashembe Farm Spring A	01.11.2008	83.2	0.062	0.023	0.002	0.036	0.002	0.008
31	Kashembe Farm Spring B	18.10.2008	79.2	0.196	0.014	0.001	0.009	0.000	0.011
32	Laughing Waters	10.03.2008	121.0	0.013	-0.005	-0.010	0.064	-0.002	0.018
33	Laughing Waters	24.10.2008	133.0	0.010	0.006	-0.001	0.034	0.003	0.002
34	Lilayi Rd 2	22.08.2008	78.0	0.127	-0.005	-0.010	0.012	-0.002	0.002
35	Linda Mwandila	15.02.2008	295.0	0.131	-0.005	-0.010	0.191	-0.002	0.008
36	Linda Mwandila	26.10.2008	262.6	0.168	0.021	0.002	0.214	0.005	0.008
37	Lumumba Rd 4A	25.08.2008	108.0	0.001	-0.005	0.010	0.023	-0.002	-0.002

D. Trace Elements (Selection)

No.	Sample name	Sample Date	Sr µg/l	Y µg/l	Zr µg/l	Nb µg/l	Mo µg/l	Ag µg/l	Cd µg/l
38	Makeni Burkley Spring	15.02.2008	244.0	0.016	0.011	-0.010	0.508	-0.002	0.025
39	Makeni Valley Spring	05.03.2008	126.0	0.080	0.013	-0.010	0.255	0.005	0.029
40	Massmedia 2	09.08.2008	114.0	0.034	-0.005	-0.010	0.017	0.003	0.005
41	Massmedia 3	09.08.2008	119.0	0.039	0.006	-0.010	0.013	0.004	0.009
42	MFEZ B/h J4	29.07.2008	122.0	0.238	0.011	-0.010	0.027	0.249	0.006
43	Michelo Farm Spring	18.10.2008	241.5	0.097	0.004	0.001	0.011	0.001	0.002
44	Mulungushi 6A	20.08.2008	135.0	0.038	-0.005	-0.010	0.070	-0.002	0.011
45	Mulungushi 6H	20.08.2008	138.0	0.030	-0.005	-0.010	0.074	-0.002	0.009
46	Mumbwa Roadside 1	11.08.2008	103.0	-0.001	-0.005	-0.010	0.024	-0.002	-0.002
47	Mwembeshi Prison	11.03.2008	144.0	0.116	0.005	-0.010	0.048	-0.002	0.013
48	Mwembeshi Prison	18.10.2008	154.0	0.086	0.006	0.001	0.049	0.001	0.006
49	Mwembeshi Satellite	11.03.2008	184.0	0.034	0.027	-0.010	0.126	-0.002	0.009
50	Mwembeshi Satellite	26.10.2008	194.2	0.034	0.019	-0.010	0.107	0.001	0.006
51	Ng'ombe Spring	18.01.2008	65.0	0.078	0.035	0.010	0.214	0.003	0.074
52	Ng'ombe Spring	27.10.2008	40.6	0.189	0.079	0.008	0.095	7.169	0.125
53	Northmead 2	20.08.2008	137.0	0.129	-0.005	-0.010	0.036	-0.002	0.003
54	NRDC 1	05.08.2008	343.0	0.147	0.015	-0.010	0.049	0.013	0.008
55	NRDC 2	05.08.2008	343.0	0.004	0.006	0.010	0.071	-0.002	-0.002
56	Nsanje Muleke	10.03.2008	95.0	0.026	-0.005	-0.010	0.027	-0.002	0.013
57	Nsanje Muleke	24.10.2008	83.0	0.026	0.001	0.001	0.015	0.004	0.003
58	Palabana A	13.03.2008	48.0	0.016	-0.005	-0.010	0.040	-0.002	0.009
59	Palabana Dairy	13.03.2008	363.0	0.128	-0.005	-0.010	0.048	-0.002	0.008
60	Palabana Dairy	28.10.2008	302.0	0.119	0.003	0.001	0.019	0.007	0.005
61	Palmwood Lodge Spring	13.03.2008	110.0	0.039	0.007	-0.010	0.097	-0.002	0.008
62	Shaft 5	22.08.2008	126.0	0.001	-0.005	0.010	0.016	-0.002	-0.002
63	Shalenga V Spring A	11.03.2008	35.0	0.040	0.010	-0.010	0.039	-0.002	0.005
64	Shalenga V Spring B	11.03.2008	23.0	0.039	0.006	-0.010	0.113	-0.002	0.007
65	Shantumbu B Sch Spring A	14.03.2008	28.0	0.078	0.006	-0.010	0.068	-0.002	0.038
66	Shantumbu B Sch Spring A	27.10.2008	27.9	0.076	0.005	0.001	0.014	0.006	0.004
67	St Mary School Spring	11.03.2008	92.0	1.990	-0.005	-0.010	0.017	-0.002	0.009
68	St Monica School Spring	11.02.2008	256.0	0.043	0.014	-0.010	0.789	0.004	0.041
69	St Charles Spring	10.03.2008	122.0	0.087	-0.005	-0.010	0.044	-0.002	0.007
70	State Lodge	18.01.2008	157.0	0.012	-0.005	-0.010	0.010	-0.002	0.011
71	State Lodge	29.10.2008	117.9	0.001	0.001	0.001	0.013	0.001	0.001
72	Waterworks 2	23.08.2008	131.0	0.001	-0.005	-0.010	0.018	-0.002	-0.002
73	Zimbabwe Farm	10.03.2008	133.0	0.018	0.012	-0.010	0.065	-0.002	0.016
74	Zimbabwe Farm	29.10.2008	157.8	0.128	0.008	0.002	0.228	0.156	0.049
75	Zinaglume Overspill	10.03.2008	202.0	0.084	0.010	-0.010	0.046	-0.002	0.007
76	Zinaglume Overspill	28.10.2008	205.2	0.076	0.014	0.002	0.053	0.004	0.005

Note: Minus sign in front of value reads as “below the given detection limit”.

D. Trace Elements (Selection)

No.	Sample name	Sample Date	Sn µg/l	Sb µg/l	Te µg/l	Cs µg/l	Ba µg/l	W µg/l	Pb µg/l	U µg/l
1	Avondale 1	06.08.2008	0.050	0.033	-0.020	0.005	14.0	0.010	0.512	0.21
2	Bauleni	24.08.2008	0.020	0.017	-0.040	0.010	20.0	-0.004	0.042	0.26
3	Buckley 1	24.08.2008	0.030	0.023	-0.020	0.022	22.0	0.008	0.459	1.67
4	Buckley 2	12.08.2008	0.020	0.018	-0.040	-0.006	36.0	-0.004	0.142	2.79
5	Chainda	06.08.2008	0.050	0.064	-0.080	0.021	68.0	0.052	0.521	0.48
6	Chawama 1	25.08.2008	0.010	0.020	-0.040	0.028	38.0	-0.004	0.087	0.29
7	Chelston	08.08.2008	0.010	0.019	-0.020	0.020	11.0	0.026	-0.015	0.95
8	Chimbwete Spring	26.10.2008	0.014	0.054	0.004	0.002	9.5	0.108	0.075	0.56
9	Chinyunyu Hot Spring	23.01.2008	0.100	0.042	-0.020	44.660	16.0	52.789	0.794	0.02
10	Chunga 2	10.08.2008	-0.010	0.008	-0.040	-0.006	22.0	0.008	0.052	5.09
11	Chunga 6E	10.08.2008	0.050	0.017	-0.040	0.035	7.0	0.206	0.334	1.47
12	Forest 26 BH-7	17.03.2008	0.020	0.021	-0.020	0.022	41.0	0.014	0.309	0.15
13	Freedom Water Trust	24.08.2008	0.010	0.006	-0.040	0.030	9.0	0.013	-0.030	1.80
14	George 2	19.08.2008	0.020	0.020	-0.020	0.015	24.0	3.134	0.216	0.33
15	George 3	19.08.2008	-0.010	0.105	-0.020	0.009	35.0	0.076	-0.015	4.50
16	George 5	12.08.2008	0.320	0.062	-0.020	0.022	18.0	-0.002	21.796	0.17
17	George 6	11.08.2008	-0.010	0.015	-0.020	0.009	9.0	0.062	-0.015	0.11
18	George 7	19.08.2008	0.010	0.020	-0.020	0.006	11.0	0.033	-0.015	0.14
19	Good Hope	10.03.2008	0.010	0.029	-0.020	0.003	25.0	0.012	0.322	3.77
20	Handamana Section	10.03.2008	0.020	0.013	-0.020	0.004	13.0	0.005	0.187	0.20
21	Handamana Section	25.10.2008	0.013	0.025	0.006	0.006	14.8	0.086	0.174	0.21
22	Independence Park	11.03.2008	0.010	0.027	-0.020	0.006	154.0	0.014	0.150	0.16
23	International 6A	21.08.2008	0.010	0.033	-0.020	0.009	2.0	0.170	-0.015	1.88
24	International 6E	21.08.2008	0.010	0.007	-0.020	0.006	-1.0	0.012	-0.015	0.71
25	International 6F	21.08.2008	0.110	0.058	-0.020	0.007	-1.0	0.014	1.233	1.06
26	Kabanana	25.08.2008	0.010	0.039	-0.020	0.005	17.0	0.013	-0.015	1.54
27	Kanakantapa	02.02.2008	0.280	0.304	-0.020	0.481	90.0	0.160	5.342	0.15
28	Kasanova Kanyimbu A	06.03.2008	0.030	0.031	-0.020	0.004	28.0	0.047	0.972	0.13
29	Kasanova Kanyimbu B	11.02.2008	0.050	0.040	-0.020	0.005	29.0	0.016	0.263	0.10
30	Kashembe Farm Spring A	01.11.2008	0.012	0.017	0.006	0.007	28.2	0.082	0.136	0.27
31	Kashembe Farm Spring B	18.10.2008	0.015	0.017	0.008	0.004	16.5	0.102	0.214	0.26
32	Laughing Waters	10.03.2008	0.030	0.020	-0.020	-0.003	14.0	0.005	0.188	0.35
33	Laughing Waters	24.10.2008	0.017	0.014	0.002	0.002	18.4	0.082	0.060	0.43
34	Lilayi Rd 2	22.08.2008	0.010	0.008	-0.020	0.004	12.0	-0.002	0.257	0.09
35	Linda Mwandila	15.02.2008	0.010	0.008	-0.020	0.018	20.0	0.007	0.132	2.59
36	Linda Mwandila	26.10.2008	0.012	0.022	0.006	0.009	27.9	0.036	0.303	2.88
37	Lumumba Rd 4A	25.08.2008	0.010	0.043	-0.020	0.018	11.0	0.016	-0.015	0.13

D. Trace Elements (Selection)

No.	Sample name	Sample Date	Sn µg/l	Sb µg/l	Te µg/l	Cs µg/l	Ba µg/l	W µg/l	Pb µg/l	U µg/l
38	Makeni Burkley Spring	15.02.2008	0.020	0.056	-0.020	0.006	47.0	0.016	2.379	3.46
39	Makeni Valley Spring	05.03.2008	0.080	0.188	-0.020	0.015	20.0	0.024	0.852	0.33
40	Massmedia 2	09.08.2008	0.040	0.022	-0.020	0.006	1.0	0.977	0.436	0.98
41	Massmedia 3	09.08.2008	0.030	0.025	-0.020	0.003	-1.0	0.101	1.138	0.98
42	MFEZ B/h J4	29.07.2008	0.020	0.018	-0.020	0.012	55.0	0.020	0.175	0.17
43	Michelo Farm Spring	18.10.2008	0.004	0.010	0.002	0.015	11.4	0.054	0.094	0.36
44	Mulungushi 6A	20.08.2008	0.010	0.055	-0.020	0.041	7.0	0.008	0.114	1.07
45	Mulungushi 6H	20.08.2008	0.010	0.015	-0.020	0.064	6.0	0.005	0.089	1.05
46	Mumbwa Roadside 1	11.08.2008	0.010	0.014	-0.020	0.008	16.0	0.009	-0.015	0.11
47	Mwembeshi Prison	11.03.2008	0.010	0.091	-0.020	0.007	47.0	0.008	0.127	0.87
48	Mwembeshi Prison	18.10.2008	0.022	0.111	0.006	0.005	56.2	0.406	0.052	1.27
49	Mwembeshi Satellite	11.03.2008	0.010	0.023	-0.020	0.004	30.0	0.007	0.132	3.01
50	Mwembeshi Satellite	26.10.2008	0.015	0.017	0.002	0.004	37.0	0.031	0.471	1.90
51	Ng'ombe Spring	18.01.2008	0.130	0.261	-0.020	0.017	65.0	0.057	2.451	0.06
52	Ng'ombe Spring	27.10.2008	0.090	0.999	0.002	0.031	417.7	0.091	11.082	0.04
53	Northmead 2	20.08.2008	0.010	0.011	-0.020	0.008	1.0	0.002	0.317	3.10
54	NRDC 1	05.08.2008	0.090	0.039	-0.020	0.017	51.0	0.008	0.652	1.74
55	NRDC 2	05.08.2008	0.010	0.031	-0.020	0.014	25.0	0.044	-0.015	2.09
56	Nsanje Muleke	10.03.2008	0.020	0.012	-0.020	0.005	13.0	0.006	0.129	0.18
57	Nsanje Muleke	24.10.2008	0.009	0.013	0.008	0.004	13.1	0.041	0.047	0.18
58	Palabana A	13.03.2008	0.020	0.011	-0.020	-0.003	6.0	0.006	0.219	0.06
59	Palabana Dairy	13.03.2008	0.020	0.012	-0.020	0.026	18.0	0.006	0.195	1.32
60	Palabana Dairy	28.10.2008	0.007	0.047	0.000	0.023	22.8	0.043	0.250	1.18
61	Palmwood Lodge Spring	13.03.2008	0.030	0.035	-0.020	0.014	39.0	0.068	0.212	0.14
62	Shaft 5	22.08.2008	-0.010	0.012	-0.020	0.007	12.0	0.012	-0.015	0.15
63	Shalenga V Spring A	11.03.2008	0.020	0.013	-0.020	-0.003	41.0	0.005	0.180	0.01
64	Shalenga V Spring B	11.03.2008	0.030	0.018	-0.020	0.006	33.0	0.006	0.310	0.01
65	Shantumbu B Sch Spring A	14.03.2008	0.290	0.030	-0.020	0.029	4.3	0.223	0.447	0.04
66	Shantumbu B Sch Spring A	27.10.2008	0.008	0.012	0.004	0.003	6.6	0.048	0.165	0.04
67	St Mary School Spring	11.03.2008	0.010	0.019	-0.020	0.054	393.0	0.017	0.081	0.01
68	St Monica School Spring	11.02.2008	0.220	0.153	-0.020	0.097	227.0	0.179	4.107	0.31
69	St Charles Spring	10.03.2008	0.020	0.010	-0.020	0.024	16.0	0.004	0.157	0.18
70	State Lodge	18.01.2008	0.020	0.006	-0.020	-0.003	67.0	0.007	0.121	1.19
71	State Lodge	29.10.2008	0.001	0.025	0.002	0.002	59.2	0.073	0.002	0.36
72	Waterworks 2	23.08.2008	0.010	0.014	-0.020	0.006	15.0	0.019	-0.015	0.14
73	Zimbabwe Farm	10.03.2008	0.010	0.015	-0.020	0.003	146.0	0.012	0.140	2.10
74	Zimbabwe Farm	29.10.2008	0.112	0.303	0.004	0.010	112.3	0.225	0.781	1.67
75	Zinaglume Overspill	10.03.2008	0.020	0.018	-0.020	-0.003	36.0	0.008	0.180	0.88
76	Zinaglume Overspill	28.10.2008	0.006	0.048	0.004	0.002	42.9	2.762	0.210	1.02

Note: Minus sign in front of value reads as “below the given detection limit”.

Appendix 2

Bacteriological Results

Bacteriological results July/August 2008

NAME	Faecal Coliforms (cfu/100ml)	Total Coliforms (cfu/100ml)
Avondale 1	ND	0
Bauleni	ND	0
Buckley 1	ND	TNTC
Buckley 2	ND	0
Chainda	ND	0
Chawama	ND	22
Chelston	ND	5
Chunga 2	ND	44
Chunga 6E	ND	4
Freedom Water Trust	ND	TNTC
George 2	ND	TNTC
George 3	D (2)	TNTC
George 5	ND	94
George 6	ND	16
George 7	ND	TNTC
International 6A	ND	35
International 6E	ND	0
International 6F	ND	11
Kabanana	ND	0
Lilayi Road	ND	21
Lumumba Rd 4A	ND	11
Massmedia 2	ND	0
Massmedia 3	ND	0
Mulungushi 6A	ND	96
Mulungushi 6H	ND	16
Northmead 2	ND	76
NRDC 1	ND	14
NRDC 2	ND	8
Roadside 1	ND	34
Shaft 5	ND	TNTC
Waterworks 2	ND	TNTC

TNTC = Too numerous to count
ND = not detectable
D = Detectable

Bacteriological results October 2008

NAME	Faecal Coliforms (cfu/100ml)	Total Coliforms (cfu/100ml)
Chimbwete	Present (1)	TNTC
Handamana Section	TNTC	TNTC
Kashembe Farm A	Present (256)	TNTC
Kashembe Farm B	Present(128)	TNTC
Laughing waters	Present (3)	TNTC
Linda Mwandila	TNTC	TNTC
Michelo Farm	Present	TNTC
Mwembeshi Prison	Absent	TNTC
Mwembeshi Satelite	Absent	TNTC
Ng'ombe	Present (4)	TNTC
Nsanje Muleke	TNTC	TNTC
Palabana dairy	Absent	TNTC
Shantumbu	Present (4)	TNTC
State lodge	TNTC	TNTC
Zimbabwe farm (State Lodge)	TNTC	TNTC
Zingalume Over spill	TNTC	TNTC

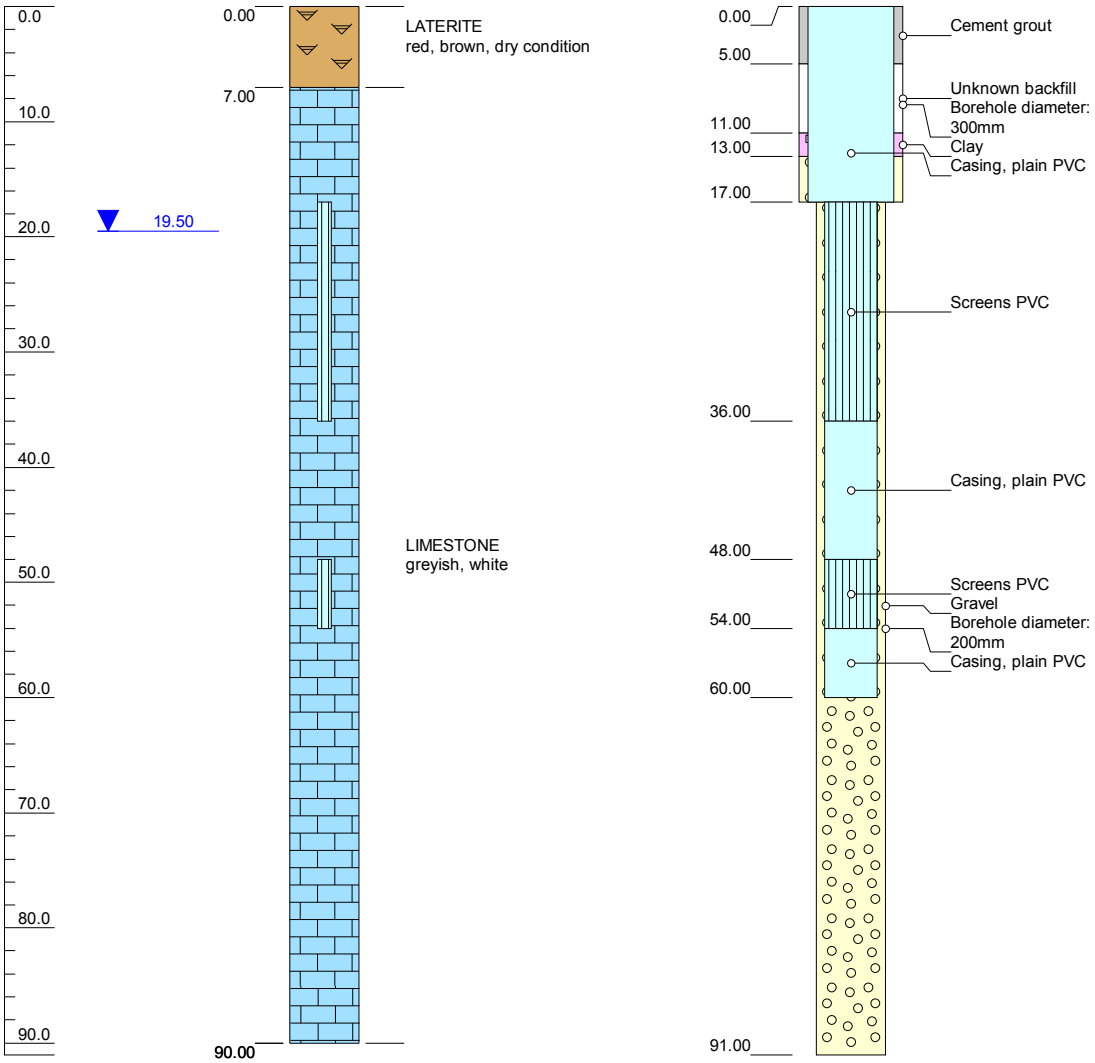
TNTC = Too numerous to count
ND = not detectable
D = Detectable

Appendix 3

Borehole Logs

m below ground surface (1311.74 m)

MFEZ BH-J4



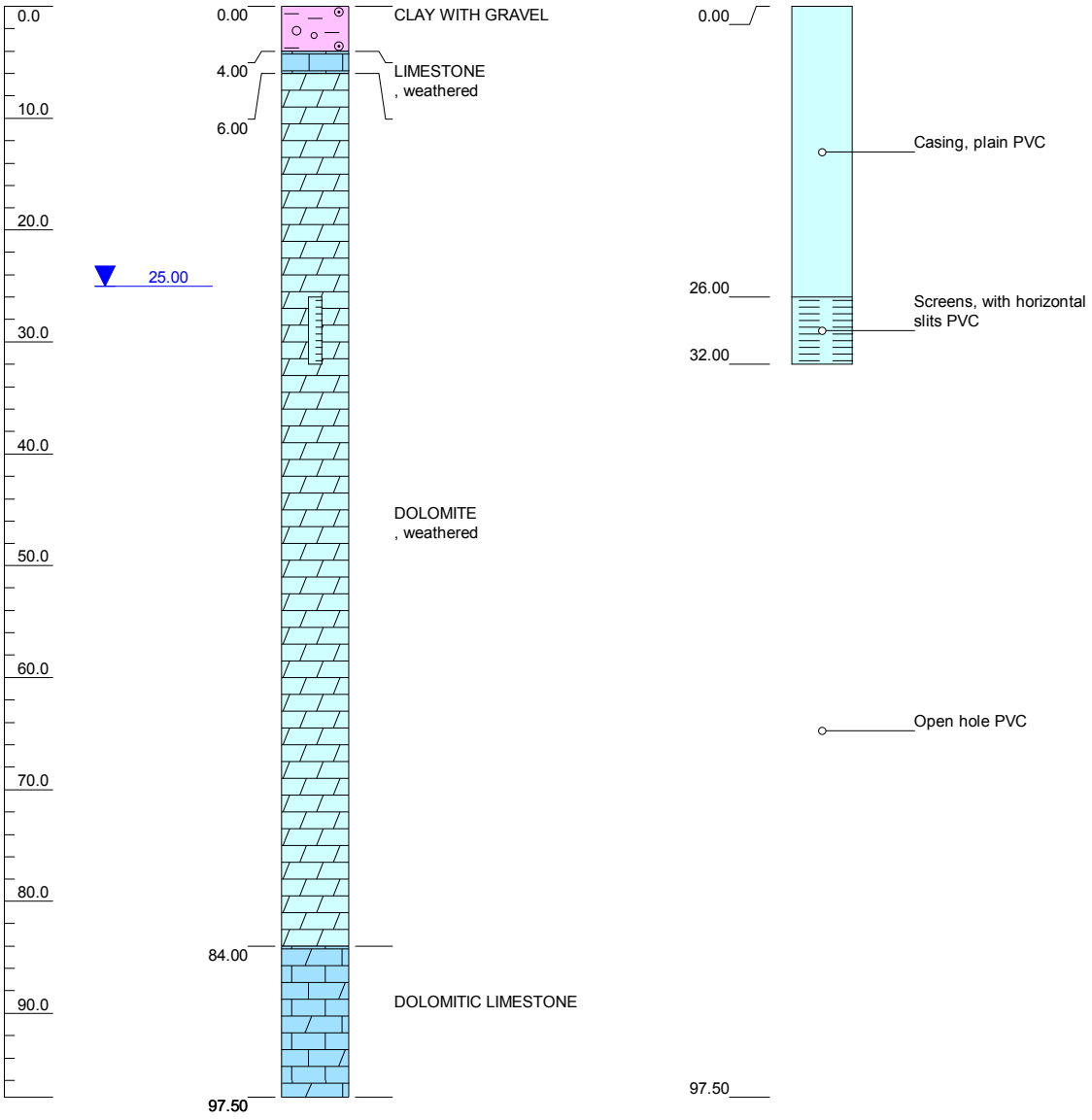
Vertical scale: 1:600 Horizontal scale: 1:20

Page 1 of 1

Water point number:	**5020213**		
Water point funded by	**JICA**	**Data Source:**	**GReSP**
Locality:		East:	28.37932
Ward:	Malundu	South:	15.51232
District:	Kafue	Altitude:	1311.74 m
Province:	Lusaka	Total depth of borehole:	91.0 m

m below ground surface (1300.17 m)

Forest 26 BH-7



Vertical scale: 1:600 Horizontal scale: 1:20

Water point number:	**5020198**		
Water point funded by:		**Data Source:DWA**	
Locality:		East:	28.34230
Ward:	Malundu	South:	15.50096
District:	Kafue	Altitude:	1300.17 m
Province:	Lusaka	Total depth of borehole:	97.5 m

Addendum

(Compiled on May 7, 2009)

During the April campaign of 2009, ten additional springs were discovered in the process of conducting groundwater level measurements.

The majority of these springs belong to the Lusaka West Group in the Chunga catchment and included Dora SDA, J. Mataka, Mr. Nyoni, and Government Farm B springs. Three springs can be allocated to the Mwembeshi Group, namely Prison Orchard, Mr. Chilomo and Mr. Zulu Farm springs. Mr Phiri farm spring is located along Great North Road in the Ngwerere catchment. The remaining springs are part of the Makeni/ Lusaka South group which falls in the Funswe catchment and composes the Chimoka A and B springs.

Since the campaign was conducted towards the end of the rainy season and long-term observations are not available, it was difficult to determine whether the springs are perennial or seasonal. Future campaigns during the dry season could reveal more details on their hydrological characteristics.

The newly discovered springs are summarised as follows:

No.	Name of Spring	Sub-Catchment – Catchment	Formation	Longitude (WGS84)	Latitude	Elevation m asl
1	Dora SDA	Chunga – Mwembeshi	Chunga Schist	28.06825	15.32438	1,156
2	J. Mataka	Chunga – Mwembeshi	Lusaka Dolomite	28.18172	15.38508	1,229
3	Mr. Nyoni	Chunga – Mwembeshi	Lusaka Dolomite	28.18487	15.37537	1,233
4	Govt. farm B	Chunga – Mwembeshi	Lusaka Dolomite	28.07265	15.35288	1,192
5	Prison Orchard	Mwembeshi	Lusaka Dolomite	27.93585	15.33477	1,123
6	Mr. Chilomo Farm	Mwembeshi	Lusaka Dolomite	27.97135	15.33467	1,168
7	Mr. Zulu	Mwembeshi	Lusaka Dolomite	27.93743	15.33677	1,148
8	Mr. Phiri	Ngwerere – Chongwe	Chunga Schist	28.29237	15.32143	1,222
9	Chimoka A	Funswe – Kafue Gorge	Lusaka Dolomite	28.45418	15.58978	1,283
10	Chimoka B	Funswe – Kafue Gorge	Lusaka Dolomite	28.45305	15.59142	1,242

Dora SDA

J. Mataka

Mr. Nyoni

Govt. farm B

Prison Orchard

Mr. Chilomo Farm

Mr. Zulu

Mr. Phiri

Chimoka A spring

Chimoka B Spring

Groundwater Chemistry of Springs and Water Supply Wells in Lusaka, April 2009.

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