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BGR

Development of a Groundwater Information & Management Program for the Lusaka Groundwater Systems

TECHNICAL NOTE NO. 3

HYDROCHEMICAL SAMPLING OF GROUNDWATER IN THE LUSAKA URBAN AREA (APRIL/MAY 2010) AND PRELIMINARY FINDINGS

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Lusaka, November 2010

Development of a Groundwater Information & Management Program for the Lusaka Groundwater Systems

Hydrochemical Sampling of Groundwater in the Lusaka Urban Area (April/May 2010) and Preliminary Findings

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Abbreviations

BGR	Bundesanstalt für Geowissenschaften und Rohstoffe (Federal Institute for Geosciences and Natural Resources)
BTEX	Benzene, toluene, ethylbenzene, and xylene
CVOC	Chlorinated Volatile Organic Carbon
CU	Commercial Utility
DNAPL	Dense Non-aqueous Phase Liquids
DO	Dissolved Oxygen
DOC	Dissolved Organic Carbon
DWA	Department of Water Affairs
EC	Electrical conductivity
E. coli	Escherichia coli
ET	(Actual) Evapotranspiration
Fm	Formation
GIS	Geographic Information System
GC-MS	Gas Chromatography Mass Spectrometry
GReSP	Groundwater Resources for Southern Province (project title)
HR-ICP-MS	High Resolution Inductively Coupled Plasma Mass Spectrometry
ICP-OES	Inductively Coupled Plasma with Optical Emission Spectroscopy
LCC	Lusaka City Council
LWSC	Lusaka Water and Sewerage Company
m asl	Meters above sea level
m bgs	Meters below ground surface
MAR	Mean annual rainfall
MB	Monitoring Borehole
MEWD	Ministry of Energy and Water Development
MPN	Most Probable Number
NISIR	National Institute for Scientific and Industrial Research
NPOC	Non Purgeable Organic Carbon
NWASCO	National Water and Sanitation Council
ORP	Oxidation Reduction Potential
T	Temperature (water)
T_{air}	Air Temperature
TC	Total Coliforms
TDS	Total dissolved solids
TIC/TOC	Total Inorganic Carbon / Total Organic Carbon
UNZA	University of Zambia
WHO	World Health Organisation
WT	Water Trust
YEC	Yachiyo Engineering Co. Ltd.
ZDWS	Zambian Drinking Water Standard

List of reports compiled by the project in Phase II

Date	Authors	*Title*	Type	Target group
Apr 2009	Museteka L. & R. Bäumle	*Groundwater Chemistry of Springs and Water Supply Wells in Lusaka - Results of the sampling campaigns conducted in 2008*	Technical Report No. 1	DWA, Counterparts, Stakeholder
Oct 2009	R. Bäumle. & S. Kang'omba	*Development of a Groundwater Information & Management Program for the Lusaka Groundwater System: Desk Study and Proposed Work Program Report*	Technical Report No. 2	DWA, Counterparts, Stakeholder
March 2010	Hahne K.	*Karstification, Tectonics and Land Use in the Lusaka region*	Technical Report No. 3	DWA, Counterparts, Stakeholder
Oct 2010	Mayerhofer C., Shamboko-Mbale B. & R.C. Mweene	*Survey on Commercial Farming and Major Industries: Land Use, Groundwater Abstraction & Potential Pollution Sources-*	Technical Report No. 4	DWA, Counterparts, Stakeholder
Oct 2010	Tena T., Mweene R.C., & R. Bäumle	*GeODin Manual*	Manual	DWA, Counterparts to be trained (in pilot provinces and districts)
Nov 2010	Tena, T., Nick. A.	*Capacity Building and Awareness Raising Strategy for Phase II (2010-2012)*	Technical Note No. 2	DWA, Counterparts
Nov 2010	Nick, A., Museteka, L., Kringel, R.	*Hydrochemical Sampling of Groundwater in the Lusaka Urban Area (April/May 2010) and Preliminary Findings*	Technical Note No. 3	DWA, Counterparts, Stakeholder

Summary

In order to evaluate the pollution status of Lusaka's groundwater, a sampling campaign was conducted in April and May 2010, targeting most of the public water supply boreholes (managed by Lusaka Water and Sewerage Company) as well as monitoring boreholes of the Department of Water Affairs (DWA) and private boreholes. The parameters analysed comprise in-situ measurements of physical parameters, inorganic compounds and microbiological indicators. The sampling and analysis of chlorinated volatile organic carbon (CVOC) and mono-aromatic compounds (BTEX) was included in the campaign as an experiment. Both groups of organic chemical compounds are well known groundwater contaminants of anthropogenic origin. Due to the lack of a suitable organic laboratory the samples were analyzed at BGR. This resulted in storage and transport influencing the original concentrations. Results will be provided in a separate report. This campaign amends and extends the findings of the reconnaissance water quality study carried out by the project in 2008 (with sampling taking place in February/March and August/September/October).

The results from the microbiological analyses show that elevated concentrations of E. coli occur much less frequent than of Total Coliforms. Only one third of samples stay below the Total Coliform limit given in the Zambian Drinking Water Standard (MPN=20).

Regarding inorganic compounds, no significant difference in chemical composition is found when comparing the 2010 results to the samples that were taken during 2008 (Museteka & Bäumle 2009). Under the prevailing pH (median = 7.0, min = 5.8, max = 8.0) in the calcareous geological environment, potentially toxic heavy metals like Pb, Cd or As as well as iron or manganese tend to form hydroxy- and carbonate complexes which are insoluble and can therefore not be found in the water. Concentrations of Pb, Cd and As are far below a toxic level in all samples analyzed. Nitrate levels were found to be very high in many boreholes and often exceeded the ZDWS limit of 44 mg/L. The median for nitrate in the study area is 16.9 mg/L, with two samples showing values below detection limit and a maximum value of 260 mg/L. While the large production boreholes of the commercial utility exhibit nitrate concentrations below the Zambian Drinking Water Standard, boreholes for the local supply of peri-urban (high-density settlement) areas show considerably higher values of more than 44 mg/L (some even of more than 100 mg/L).

Based on the results from the 2010 sampling campaign nine (9) production boreholes and one spring were chosen for regular water quality monitoring. Monitoring will be conducted monthly, starting from November 2010.

1. INTRODUCTION

Lusaka, with an estimated population of about 1.3 million in 2005, is experiencing a rapid population growth of about 3.7 percent per annum and an increase in population density of over 400 % over the last 40 years (LCC 2008). According to the National Water and Sanitation Council (NWASCO), the water supply coverage by the Commercial Utility, the Lusaka Water and Sewerage Company (LWSC) is 68 %, while the sanitation coverage is only 17 % (NWASCO 2009).

Lacking sanitation facilities constitutes a major pollution source to groundwater, both in terms of microbiological and inorganic contamination, i.e. mainly nitrates. If water supply boreholes are located in direct neighbourhood to malfunctioning pit latrines or septic tanks, microbiological pollution of the borehole will trigger a vicious faecal-oral infection cycle threatening public health. In Lusaka this threat becomes real especially during the rainy season when cholera outbreaks occur in the informal settlements almost annually (since 2003). Full sanitation coverage in combination with sustainable sanitation solutions reduces microbiological pollution, as well as unwanted dissolved organic and inorganic substances in the groundwater body.

Unaffected groundwater is an inexpensive and safe drinking water source, which makes long-distance water supply or expensive surface water treatment unnecessary. Thus, every precaution in form of sustainable sanitation and appropriate groundwater protection is much more cost-effective than any subsequent and costly treatment of unsafe water resources or distance water supply.

Lusaka’s underground is mainly composed of carbonate rocks being subject to intensive karstification. The main groundwater body is hosted by the marbles of the Lusaka Dolomite Formation. Karstification is an ongoing process in carbonate rocks that dissolves the rock and enlarges the fissures and fractures through which groundwater flows. This feature makes groundwater in Lusaka even more vulnerable to pollution for two reasons: the protective cover can be bypassed and water moving through large fractures is not subjected to a filtering process.

In order to evaluate the pollution status of Lusaka’s groundwater in terms of microbiological indicators, inorganic and organic substances, a sampling campaign was conducted in April and May 2010, targeting most of the public water supply boreholes (managed by Lusaka Water and Sewerage Company) as well as monitoring boreholes of the Department of Water Affairs (DWA) and private boreholes. As an experiment, the sampling and analysis of chlorinated volatile organic carbon (CVOC) and mono-aromatic compounds (BTEX) was included in the campaign. Both groups of organic chemical compounds are well known groundwater contaminants of anthropogenic origin. Due to the lack of a suitable organic laboratory the samples were analyzed at BGR. This resulted in storage and transport influencing the original concentrations. Results will be provided in a separate report. This campaign amends and extends the findings of the reconnaissance water quality study carried out by the project in 2008 (with sampling taking place in February/March and August/September/October).

This report intends to present the data and preliminary results of the sampling campaign. It will not provide a thorough data analysis and interpretation which will be part of the final project report. The results presented here will be used to give a recommendation for a long term water quality monitoring programme.

2. HYDROGEOLOGICAL SITUATION

2.1. GEOLOGY AND AQUIFER CHARACTERISTICS

The Lusaka area contains strongly folded overthrusted metasedimentary rocks of Katanga (Neoproterozoic) age which have been intruded by granitic and basic bodies. The metasedimentary cover can be divided into three formations: the Chunga Formation (Fm) comprising schist and quartzite, the Cheta Fm including schist and carbonate and the Lusaka Dolomite Fm (see **Map 1**). The main aquifer is hosted by the marbles of the Lusaka Dolomite Formation. The metasedimentary carbonate rocks have suffered extreme differential dissolution (Nkhuwa 1996), resulting in the development of a system of subterranean conduits and solution channels. Lambert (1962) describes cavities in boreholes of 15 cm to 1 m in height, with rare occasions of 2 m to 3 m, but most of the cavities are smaller. The majority of cavities were encountered at depths from 5 to 30 m (see Figure 1, von Hoyer et al. 1978). The total thickness of the formation is unknown due to the lack of deep exploration drillings. Nkhuwa (1996) suggests a maximum thickness of the marble of more than 250 m.

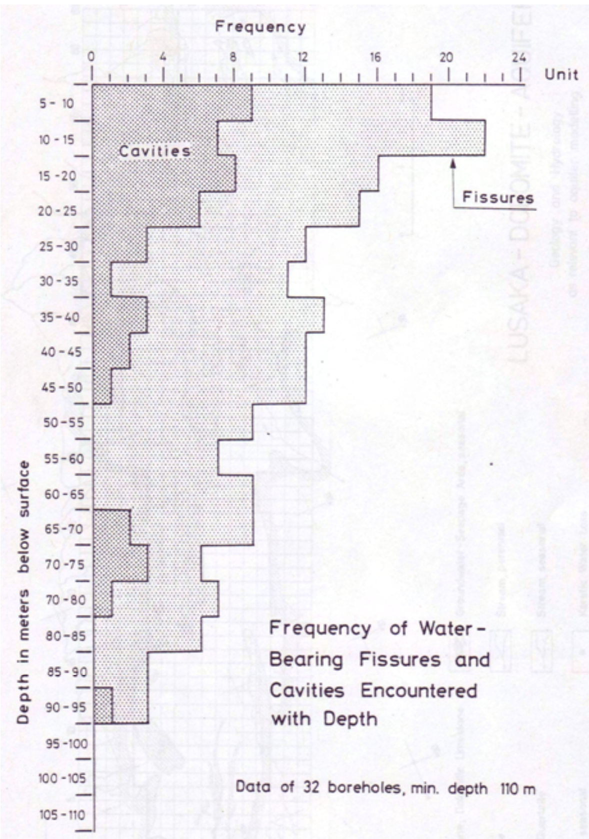

Figure 1 Frequency of water-bearing fissures and cavities encountered with depth (after von Hoyer et al. 1978).

On the surface, an epikarstic zone has developed with an average depth of 5 m extending to a maximum depth of 25 m below the surface. Epikarst, also referred to as subcutaneous zone, is a horizon at the top of the vadose zone of a karst aquifer characterised by enhanced storage capacity and high porosity and permeability as a result of enhanced weathering (dissolution) near the ground surface. The nature of the epikarst hence strongly influences the distribution and amount of groundwater recharge. Karstic features are superimposed over the whole outcropping surface of the Lusaka marbles. Solution weathering has produced a pinnacle karst. The hollows between the residual pillars are commonly filled with pisolitic laterite.

No surface drainage is developed on the dolomite and limestone indicating that rainfall that is not evapotranspirated drains into fissures and swallow holes or infiltrates through the lateritic soil. This suggests that a considerable portion of rainfall directly recharges the groundwater during the rainy season.

According to drilling results the aquifer permeability is highest in the top-most layer (0-25 m) and decreases rapidly below depths of 50 m due to a general decrease in enlarged solution cavities. Fissures and smaller solution cavities were observed down to depths of 85 m (the approximate range of maximum drilling depth). The topography and elevation of springs dewatering the karst aquifer do not provide evidence that a deep groundwater circulation is active under the current conditions (as suggested by Nkhuwa 1996).

Nkhuwa (1996) found that 40 % of the Lusaka meta-carbonate rocks are pure marbles (>90 % calcite/aragonite) and 20 % are pure dolomite (>90 % $CaMg(CO_3)_2$) and the remainder are mixtures between the two. Pure dolomite is usually coarser grained. He found that sinkholes are most abundant in areas of calcitic dolomite with calcite content between 70 % and 90 %, or, locally in the southeast of the mapped area, between 50 – 70 %. Areas with fewer sinkholes are associated with pure dolomite which he explained by their coarse-grained texture. Varieties with less than 30 % calcite/aragonite form little surface karst. Pure dolomites therefore form bodies of low permeability within the aquifer (von Hoyer et al. 1980). In some areas the pure dolomites may act as partial boundaries to groundwater flow (Bäumle & Nkhoma 2008). Figure 2 shows the karst morphology of the Lusaka area, including swallow holes. Within the remote sensing analysis for land-use classification which was conducted by the project, karst features were mapped and will be represented in the land-use map (to be completed in 2011).

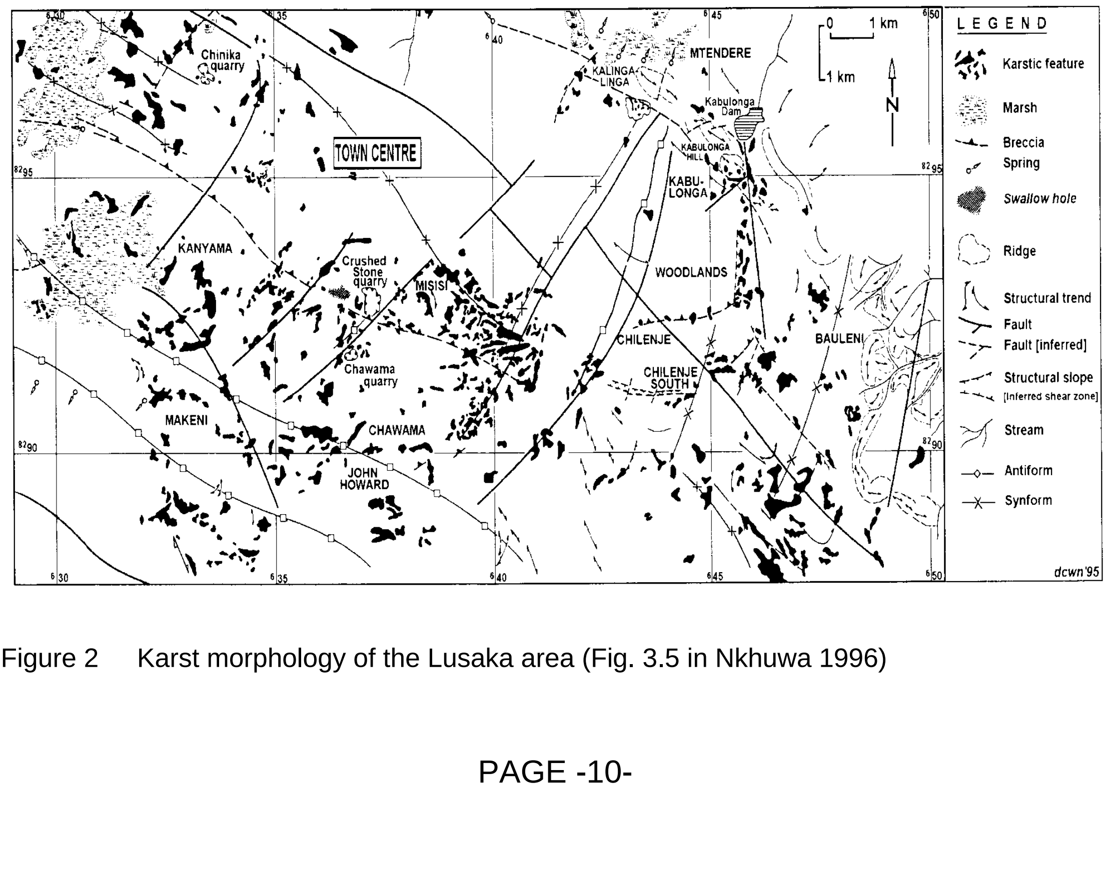

Figure 2 Karst morphology of the Lusaka area (Fig. 3.5 in Nkhuwa 1996)

Springs and seepage zones typically occur along the margins of the elongated body of the Lusaka Dolomite Formation at the contact between the carbonate rocks and the surrounding schists or other less permeable rocks. Many of the springs are seasonal with an average discharge rarely exceeding 5 L/s (Schmidt 2001).

2.2. CLIMATIC CONDITIONS

Lusaka has a tropical continental highland climate. Tyrrell (1986) distinguishes four seasonal weather types, each with very distinct prevailing circulation and pressure systems and characteristic distributions of rainfall, wind speed and directions and sunshine. These are the summer rainy season, the winter dry season, the pre-rain hot season and the post-rain warm season.

Annual rainfall for the thirty-year period from 1963 to 1993 averages at 857 mm (mean annual rainfall, MAR). Rainfall amounts usually peak during January with monthly totals ranging from 206 to 237 mm. 82 % of the total annual rainfall occurs during the four-month period from December to January. The average number of rainfall days is approximately 77. Compared with other tropical cities on the continent, however, an unusually small proportion of total rainfall comes from storms of short duration over Lusaka.

Estimations of actual evapotranspiration (ET) range from 412 mm to 739 mm per year (Von Hoyer et al. 1978, YEC 1995, Maseka 1994, Nkhuwa 1996), while potential ET is mainly assumed to be between 1500 and 1600 mm/year (YEC 1995).

2.3. GROUNDWATER RECHARGE PATTERN

Principal sources of recharge of the Lusaka aquifers are direct recharge through rainfall, unaccounted-for water from the water supply network, septic tanks and latrines and return flow from irrigation of commercial farm land and gardens (Mpamba 2008).

Existing estimates of recharge rates vary between below 10 % to over 60 % of annual rainfall owing to the complexity of recharge processes, the heterogeneity of the rock formations and surface cover and the high temporal and spatial variability of rainfall. Results from previous studies suggest that average recharge rates may be in the order of 20% to 25% of annual rainfall (i.e. 170 to 215 mm of MAR respectively) except for years with particularly low rainfall. Nevertheless, it is unlikely that recharge can simply be correlated with annual rainfall amounts.

Comparatively little is known on the dynamics of groundwater recharge, i.e. the seasonal variation of recharge and the relationship between rainfall duration and intensity and recharge. Similarly, there is very little information on how water moves and how it is stored in the aquifer. A point widely neglected so far is that a considerable amount of recharged groundwater may be drained very quickly, say within days or weeks, through large underground channels and karst springs. Recharge rates could therefore be misleading if not put into relation with mean residence times of groundwater for individual groundwater flow compartments.

Furthermore, little information is available on recharge by means of processes other than direct recharge, e.g. by return flow from agriculture and gardening or housing. The loss in the water supply transmission line (bulk water supply system) due to leakages was estimated at 3,000 m^3/d or 8 % of total capacity during 2002 (KRI et. al 2008). In terms of water quality, an estimation of losses from sewer lines and overflowing septic tanks would be interesting as well.

2.4. GROUNDWATER FLOW

Groundwater contour maps distinguishing seasonal patterns were previously drawn by von Hoyer et al. (1978) and Gibb Ltd. (1999, in Schmidt 2001). Recent groundwater contours representing the dry and wet season conditions in 2008 and 2009 respectively were produced by the GReSP project. The map of dry season conditions of 2008 is shown in **Map 2**.

The contours indicate a groundwater divide near the boundary of the Forest No. 26 and No. 55 Reserves separating groundwater flowing in north-westerly direction towards Lusaka from a southern flow direction towards the Funswe Catchment. Towards the City of Lusaka, a general north-westerly flow direction corresponding to the main axis of the synform dominats. Towards the margins of the dolomite body the flow lines branch out in northerly and southerly directions to feed the numerous springs or seepage zones along the contact between the carbonate rocks and schists.

The groundwater contours for the end of the rainy season 2009 indicate that a high portion of the natural recharge is equally distributed throughout the area in which the Lusaka Dolomite Formation forms the land surface.

According to von Hoyer et al. (1978) the karstic aquifer is unconfined. In most areas the water table is near the surface, mainly between 4 and 10 m below ground level in the dry season, except where it is affected by pumping.

Figure 3 Abandoned quarry with open groundwater near Chilenje Compound.

3. REVIEW OF WATER QUALITY STUDIES

The following three chapters shall give a brief overview on the results of former water quality studies in Lusaka. The list is not exhaustive but comprises studies which investigated similar parameters to the study at hand within the City of Lusaka.

3.1. GReSP, Study on Springs and LWSC boreholes, 2008

The groundwater sampling carried out in 2008 as a reconnaissance study under the GReSP project (Museteka & Bäumle 2009) covered about 25 springs and the untreated water of 32 public supply wells. The analysed parameters comprised major ions, trace elements as well as microbiological indicators. Two main water types were identified in correspondence with the geology.

As to be expected, groundwater in 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 $CaCO_3$). The non-carbonate (permanent) hardness is very low. 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 a dominance of calcite.

(Na, K, Ca, Mg)-HCO_3 water prevails in groundwater hosted by or originating from schists. It can be distinguished from water in carbonate rocks by overall lower TDS, slightly lower pH, and lower $HCO_3 : SiO_2$ ratios as well as much lower hardness and alkalinity (i.e. buffering capacity). After interpreting chemical analyses results from sites that are considered largely unaffected by human activities and urban pollution sources such as the Local Forest Reserve, Chalimbana springs and Mwembeshi areas, Museteka and Bäumle (2008) concluded that natural (unpolluted) groundwater from the karst aquifers should, with only local exceptions, have an electrical conductivity (EC) of less than 800 µS/cm and concentrations in sodium, chloride, nitrate and sulphate below 10 mg/L. Higher levels in these parameters could consequently indicate the presence of urban pollution sources.

Museteka and Bäumle (2009) found no significant or systematic differences in water chemistry between the data sets from the 1970's (von Hoyer et al. 1978) and the 2008 sampling. Hence, no indication was found that the quality of groundwater has worsened or improved over time.

3.2. ECZ, Lusaka Groundwater Contamination Assessment Project 2003

The Environmental Council of Zambia (ECZ) with financial and technical assistance from the Canadian International Development Agency commissioned a study to identify potential groundwater pollution sources in Lusaka (Kampeshi 2003). Three suspected hotspots of pollution were identified for the investigation, namely Leopards Hill Cemetery, Libala Waste Tipping Site and the industrial area. Drilling of monitoring boreholes, water level measurement and sampling took place during November 1999 up to March 2001. The samples were analysed for physical parameters, oxygen demand, nutrients, microbiology, cations, anions and heavy metals. The following is summarized from Kampeshi 2003:

1) Leopards Hill Cemetery is situated on the limestones of the Cheta Formation, over the Chunga schists. Cavities were found during drilling which ranged from 1 – 4 m with the largest extending over 10 meters. Two

drillings came across 11 and 16 m of clay as superficial deposit, respectively. Apart from bacterial contamination the groundwater sampled met the drinking water guidelines of Zambia and WHO.

2) Libala Waste Tipping Site operated from 1993 to 2001. The main deposit were solid household wastes as well as medical waste, used batteries and liquid waste found on the site. Due to the proximity of two major public drinking water supply boreholes the site was finally closed. The site is situated on the Lusaka Dolomite with a lateritic cover, which has been partly removed by quarrying activities. The analytical results did not meet the drinking water standards for bacterial content, nutrients as well as for manganese, iron, mercury, lead, cadmium and cyanide. Despite these findings, it must be emphasized that the reliability of analytical results from local laboratories was not found satisfactory.

3) The Lusaka industrial area is underlain by the Lusaka Dolomite and Cheta Formation. Contamination was indicated by elevated electrical conductivity as well as nutrients and coliforms. Unfortunately due to analytical irregularities, the results from the detailed analysis were not found to be reliable. The borehole at ZamLeather showed a chromium concentration of 2 mg/L (p. 123).

The ECZ study also claims that local laboratories are not able to provide reliable analytical results. It states that no internal quality control is pursued. A blank sample appeared to have high concentrations in nutrients, chloride and lead, although it was supposedly prepared from distilled water.

3.3. UNEP, Assessment of pollution Status and Vulnerability of Water Supply Aquifers of African cities, 2005

The study commissioned by UNEP, UNESCO, UN-Habitat and the Zambian Ministry for Energy and Water Development (UNEP 2005) investigated the pollution status and vulnerability of three areas within Lusaka, namely Misisi, John Laing and Mass Media. Nkhuwa (2000) as the main author also published the results. The investigated parameters were in-situ-measurements, nutrients and microbiological indicators.

1. The most important water quality problem in the project areas of John Laing and Misisi is faecal pollution together with the associated disease-causing organisms. This is particularly serious during the rainy season, when faecal contamination is flushed into the groundwater system. Minor spikes during the dry season are interpreted as a result of local through-flow since the locations are in an abandoned quarry, i.e. at a lower elevation than the surrounding area, thus receiving recharge from most of the surrounding area.

2. Water from boreholes is less affected by bacteriological problems than that from shallow wells.

3. Chemical pollution in the aquifer correlates inversely with the bacteriological load. Conductivity and nitrate generally show elevated levels during the dry season and lower concentrations during the wet season, probably resulting from dilution due to increased saturation in the aquifer. This is found to be the trend for almost all chemical elements, higher concentrations during dry season being caused by the lowering of the recharge rates (due to reduced flows) and the rise in mineralisation.

4. WATER QUALITY SAMPLING 2010

In April and May 2010 a sampling campaign for water quality was conducted by the GReSP project covering 34 public water supply wells (run by LWSC), 13 local water supply boreholes (run by Water Trusts), 8 monitoring boreholes from DWA and GReSP, as well as 34 private boreholes at both domestic properties and private sector entities. A complete list of sampling locations is given in Annex 1.

4.1. PARAMETERS

The parameters analysed comprise in-situ measurements of physico-chemical parameters, inorganic compounds, microbiological indicators as well as organic pollutants. It was not possible to sample for the organic parameters at every location, due to the requirement that the water must not have had contact with air (i.e. for example no sampling of water storage tanks).

- In-situ parameters

  Electrical conductivity (EC)
  Water temperature (T)
  Air temperature (T_{air})
  pH
  Dissolved oxygen (DO)
  Operational redox potential (ORP, [E_H])

- Inorganic parameters

  Major species: Cl, SO_4, HCO_3, NO_3, K, Na, Mg, Ca, SiO_2

  Minor species: PO_4, NO_2, F, Br, Fe, Mn, NH_4

  Trace elements: Al, B, Co, Cu, Ni, Pb, Sr, Zn, Ag, As, Ba, Be, Bi, Cd, Ce, Cr, Cs, Dy, Er, Eu, Ga, Gd, Ge, Hf, Hg, Ho, La, Lu, Mo, Nb, Nd, Pr, Rb, Sb, Sc, Se, Sm, Sn, Ta, Tb, Te, Th, Ti, Tl, Tm, U, V, W, Y, Yb, Zr

- Microbiology

  Total Coliformes (TC)
  Escherichia coli (E. coli)

- Total Inorganic/Organic Carbon (TIC/TOC)

- Organic parameters

  Chlorinated volatile organic carbon (CVOC)'s: Trichlorofluoromethane, cis-1.2-dichloroethene, trichloromethane, trichloroethene, Bromodichloromethane, Tetrachloroethene, Dibromochloromethane, Tribromomethane, Chlorobenzene)

  Monoaromatics (Benzene, Toluene, Ethylbenzene, Xylene (BTEX); Cumol, n-Propylbenzol, 1,3,5-Trimethylbenzol, 1,2,3-Trimethylbenzol, 1,2,4-Trimethylbenzol, m+p-Ethyltoluol, o-Ethyltoluol, Naphtalin)

  Aliphatic hydrocarbons

Figure 4 shows the set of different sampling bottles used for the campaign. For analysis of anions, two 250 ml bottles were filled of which one would be sent to the laboratory in BGR while the second would be used for analysis of alkalinity in the DWA laboratory. For cations, a 100 ml pre-acidified bottle was filled with filtered sample water (using a 0.45 µm filter). The sealed microbiology sampling bottles were opened just before sampling and filled with 100 ml sample. About 28 ml were taken in glass bottles for TIC/TOC analysis. In-situ measurements were taken using a flow cell (Figure 5) which reduces flow velocities and prevents contact with the atmosphere. The sampling procedure for organic pollutants will be described in more depth in a separate report.

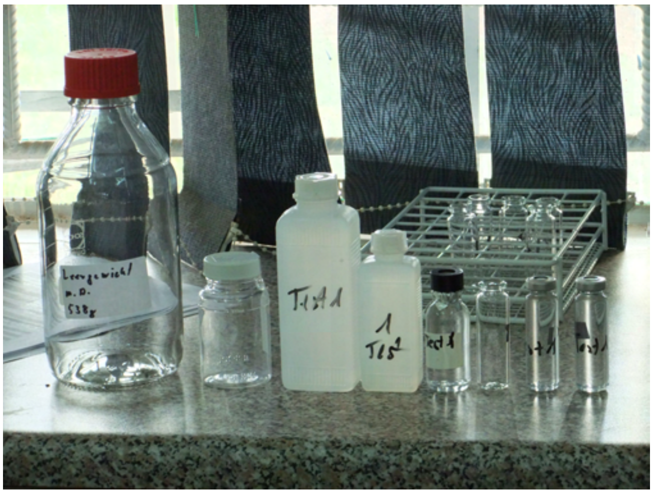

Figure 4 Set of different sampling bottles.

Figure 5 Flow cell with in-situ probes.

4.2. LOCATIONS

A total of 91 samples were taken during the campaign, most of them in the urban and peri-urban area of Lusaka. The boreholes from which sampling was conducted comprised 34 public water supply wells (run by LWSC), 13 local water supply boreholes (run by Water Trusts), 8 monitoring boreholes from DWA and GReSP, as well as 34 private boreholes at domestic properties as well as private sector entities. Two small-scale wastewater treatment sites were sampled, one settling pond at ZamLeather (the local leather production company), the other at a private school comprising a biogas plant, anaerobic baffled reactor and a gravel filter. **Map 3** gives an overview on the sampling locations.

4.3. Laboratory Analysis

Microbiology tests were carried out using the quantitative method IDEXX QuantiTray®. IDEXX Quanti-Trays are designed to give bacterial counts of a 100 ml sample using a substrate reagent defined by IDEXX. The reagent/sample mixture is poured into a Quanti-Tray, sealed and incubated for 24 hours at 37 °C. The number of positive cells, indicated by the yellow colour, is counted and a MPN table used for determination of the Most Probable Number (MPN) of Total Coliforms. The same procedure applies to determination of E. Coli MPN, for which the QuantiTray is irradiated with a UV-lamp and affected cells show fluorescence (see Figure 6).

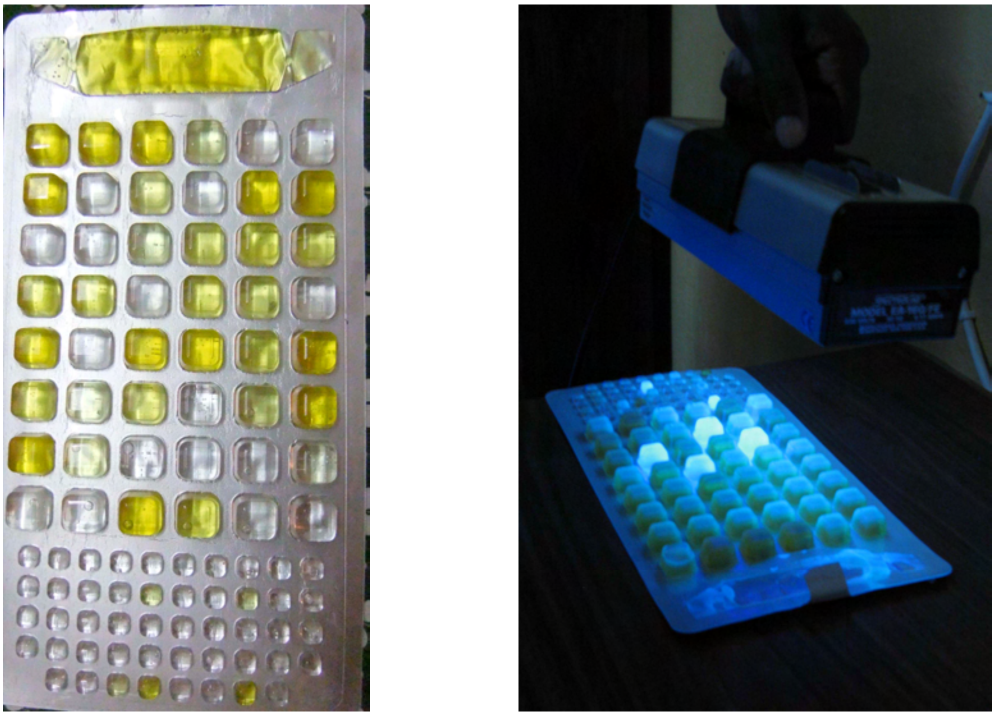

Figure 6 IDEXX QuantiTray for Total Coliforms (yellow) and E. Coli (fluorescent).

Inorganic components were analysed by the BGR water laboratory in Germany. The applied analysis methods are summarised in Table 1 and more detailed analysis procedures are described below.

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 trace elements	HR-ICP-MS [2)]
DOC	IR-spectometrically

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

Concentrations of main components Na, K, Ca, Mg, B, Al, Si, Mn and Fe are analyzed from acidified solution with ICP-OES (inductively coupled plasma optical emission spectroscopy) based on standard DIN EN ISO 11885 (1998).

Concentrations of trace elements As, Cd, Co, Cr, Cu, Hg, Mo, Ni, Pb, Pt, Sb, Sn, Tl and Zn are analyzed from acidified solution with magnetic sector field ICP-MS (inductively coupled plasma mass spectrometry). With low mass resolution ($m/\Delta m$ = 350) the elements Mo, Cd, Sn, Sb, Pt, Hg, Tl and Pb, with medium mass resolution ($m/\Delta m$ = 3800) the elements Cr, Co, Ni, Cu und Zn and with high mass resolution ($m/\Delta m$ = 7500) the element As is analyzed. The element Rh is used as an internal standard.

For the determination of alkalinity (acid neutralizing capacity) of a water sample a 10 mL aliquot of the unfiltrated sample is titrated with 0.02 N HCl down to pH=4.3. (DIN 38409 1979; Schuster 2002). The endpoint is determined potentiometrically using a 2-cell pH-glass electrode.

For the determination of the anions F^-, Cl^-, Br^-, NO_3^-, SO_4^{2-}, an IC method (ionic chromatography) based on DIN EN ISO 10304-1 (1995) is used. The anions-peaks are detected by electrical conductivity, following neutralization of the alkaline KOH-eluent with a membrane suppressor technique, H2SO4 is used for regenerating the system.

The concentration of DOC (dissolved organic carbon) is determined according to DIN EN 1484 (1997). Prior to analysis, TIC (total inorganic carbon) is removed by acidification and sparging with CO_2-free air. TIC is detected IR-spectometrically as CO_2. The remaining non-volatile organic substances are oxidized under CO_2-free O_2 in the oven and detected IR-spectometrically as CO_2. The result is given as NPOC (non purgeable organic carbon). NPOC is equivalent to TOC and DOC for most practical applications in the range of groundwaters.

Nitrite is determined by a photometric method as a complex based on standard DIN EN 26777 (1993).

Phosphate is determined by a photometric method as a complex based on standard DIN EN 1189 (1996).

Ammonium is determined by a photometric method as a complex based on standard DIN 38406 (1983).

Organic components were analysed by gas chromatography with mass spectrometry (GC-MS). A defined volume of the unfiltered, homogenized sample is heated to $80^{o}C$ in a gas tight container. Thereby equilibrium of the volatile substances in solution between gas and liquid phase develops. From the gas-filled headspace a part of the volume is abstracted and introduced into a gas chromatograph (GC). After gas chromatographic partition, the analysis of the volatile organic substances is conducted through a mass-selective detector (MS).

5. RESULTS

5.1. MICROBIOLOGICAL INDICATORS

The microbiological indicators used in this study, namely Total Coliforms (TC) and Escherichia coli (E. coli), can be seen in their spatial variation in Figure 7 (complete dataset in larger scale, see **Map 4**). The data on sewer lines were provided by the commercial utility, Lusaka Water and Sewerage Company.

The sources of the total coliform group of bacteria include the faeces of warm-blooded animals, the intestinal contents of cold-blooded animals, soils, and plants (Allan & Geldreich 1974). Modern total coliform tests cover more bacteria species than the ones of faecal origin. According to Manafi (2005) positive total coliform results do not necessarily prove that water is contaminated with pathogens. Allan & Geldreich (1974) suggest that as total coliforms originate from a variety of sources they may be of limited significance in moderate densities (i.e. 1 to 10 organisms per 100 ml) in the groundwater microflora. Nevertheless, MPN values (most probable number, as a measure of concentration for bacteria) as high as 500 and above should be regarded as an alarming sign for faecal contamination. This is underlined by the fact that samples were taken directly from the borehole and not at the end of a complex and potentially "inhabited" distribution network.

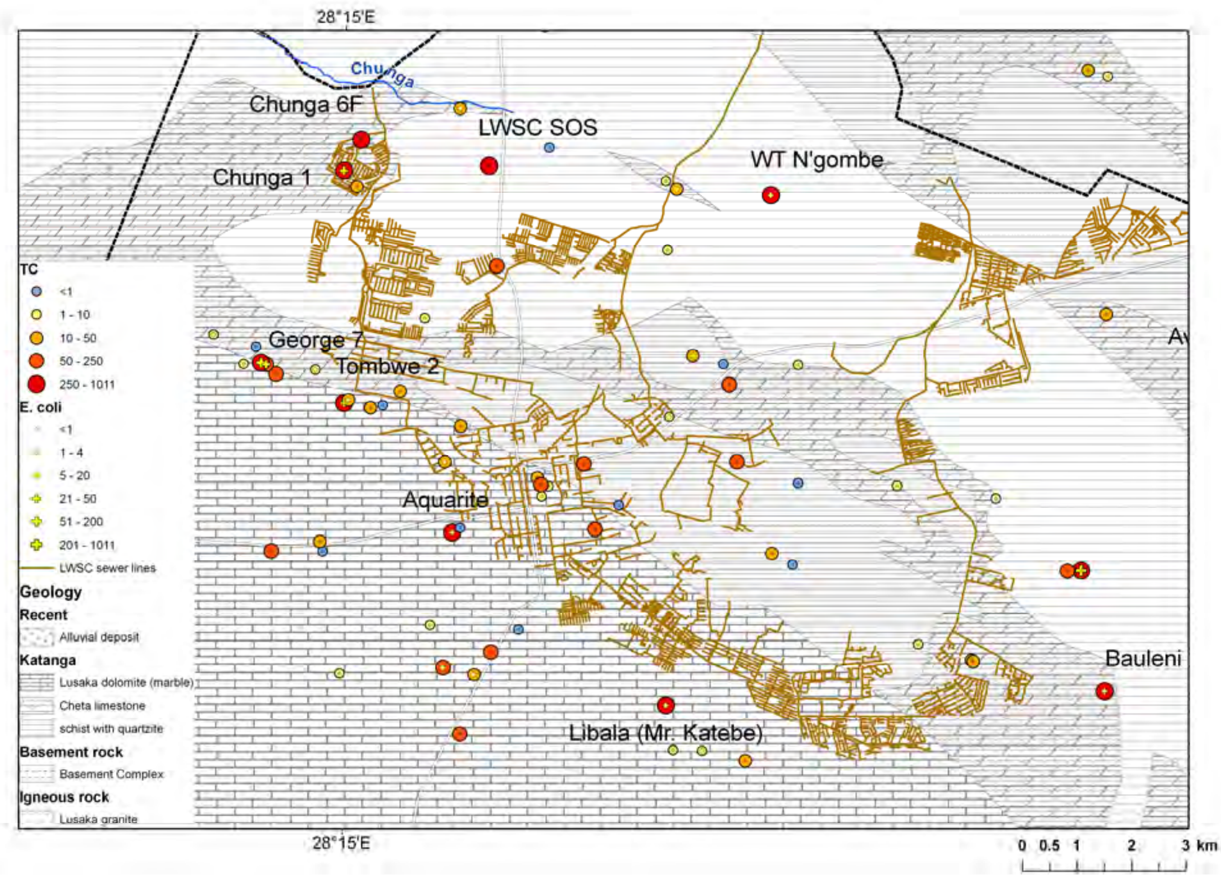

Figure 7 Spatial distribution of Total Coliforms and E. coli in April/May 2010.

The limit for Total Coliforms in the Zambian Drinking Water Standard (ZDWS) is an MPN of 10 in any two consecutive samples (100 ml) for untreated water entering and inside the piped distribution system. Treated water in piped water supplies is required to contain zero Total Coliforms in 100 ml sample. For unpiped water supplies the limit increases to a MPN of 20 in any two consecutive samples (100 ml). The ZDWS gives a limit of zero Faecal Coliforms in a 100 ml sample for any kind of water supply system. For further information on limits given in the ZDWS see Annex 2.

Elevated MPN of E. coli occur much less frequent than TC, as shown in the histograms (Figure 8 and 9). Nevertheless one should notice that only 13 out of 88 locations sampled for microbiology show no Total Coliforms, and only one third of the samples stay below the ZDWS.

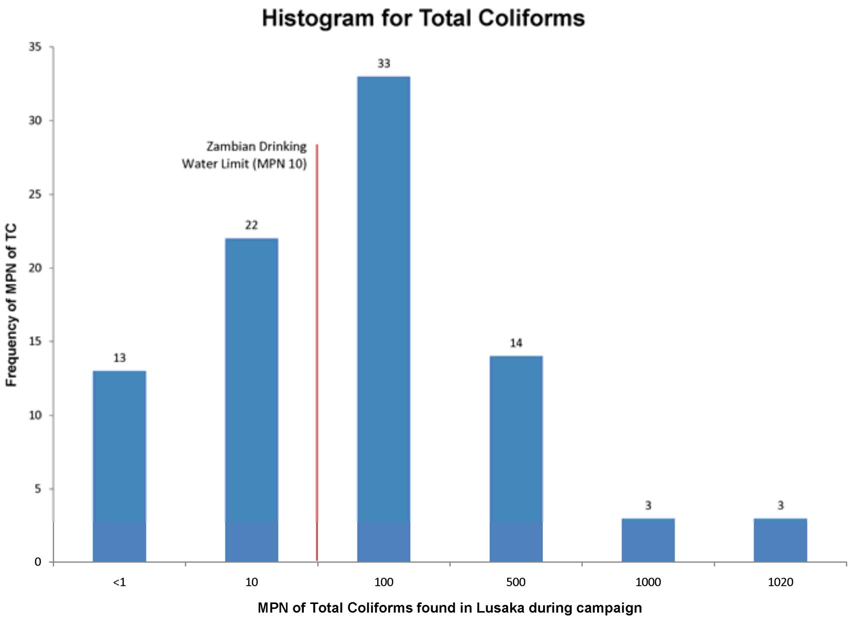

Figure 8 Histogram of Total Coliforms in groundwater samples in April/May 2010.

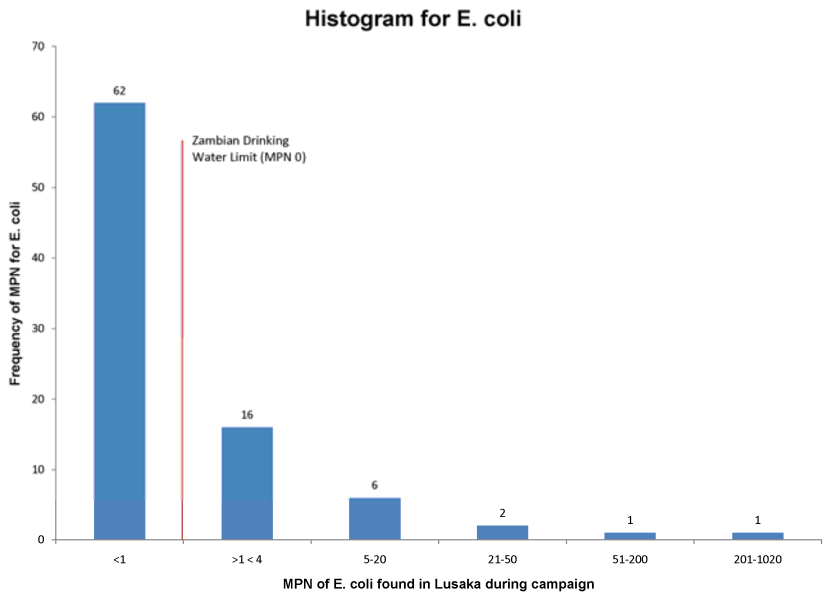

Figure 9 Histogram of E. coli in groundwater samples in April/May 2010.

5.2. INORGANIC SPECIES

The inorganic species comprise the major ions as well as the trace elements.

The correlation of electrical conductivity and nitrate concentrations (Figure 10) shows no difference in mineralisation and anthropogenic pollution between the two sampling campaigns in 2010 and 2008 (Bäumle & Museteka 2009). The cross plot exhibits a correlation between electrical conductivity and nitrate as an indicator for anthropogenic contamination. Samples with an EC ≤800 µS/cm largely meet the Zambian Drinking Water Standard with respect to nitrate whereas an EC >1000 µS/cm is a clear indication of anthropogenic contamination with corresponding elevated nitrate levels. In their study, Bäumle and Museteka (2009) find that natural groundwater from the karst aquifers should have EC values of <800 µS/cm and concentrations of sodium, chloride, nitrate and sulphate of <10 mg/L.

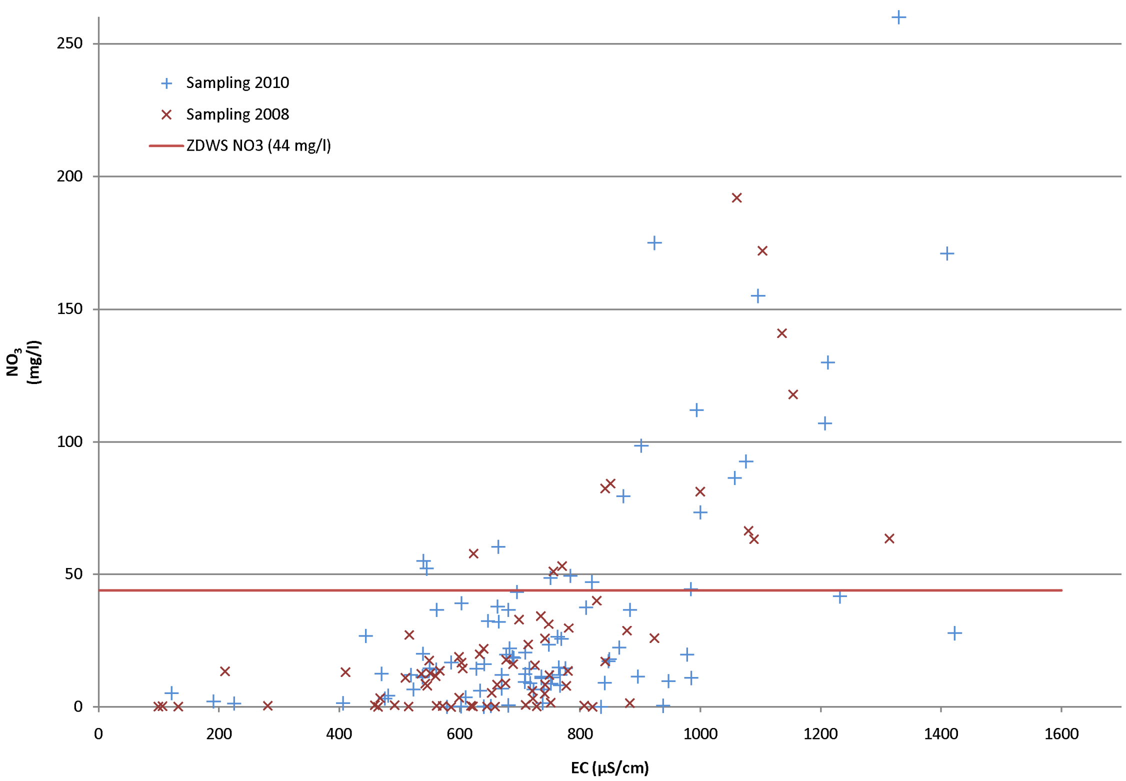

Figure 10 Correlation of electrical conductivity and nitrate concentrations of groundwater samples from 2008 and 2010 (red line shows the Zambian limit for NO_3^-).

The three samples of the 2010 sampling ranging between 150 and 250 µS/cm have been taken from boreholes in the Chunga schists. Their very low mineralisation level is an indication for a low residence time of the groundwater and/or the substantially lower solubility of silicate minerals compared to carbonate minerals.

In the piper diagram (Figure 11) the samples were grouped according to their geological origin as well as their nitrate concentration level (high: above 50 mg/L, low: below 50 mg/L). Most of the samples plot as calcium-magnesium bicarbonate (Ca-Mg-HCO_3) type, while samples from the schist and quartzite areas have slightly higher Na+K-equivalent percentages.

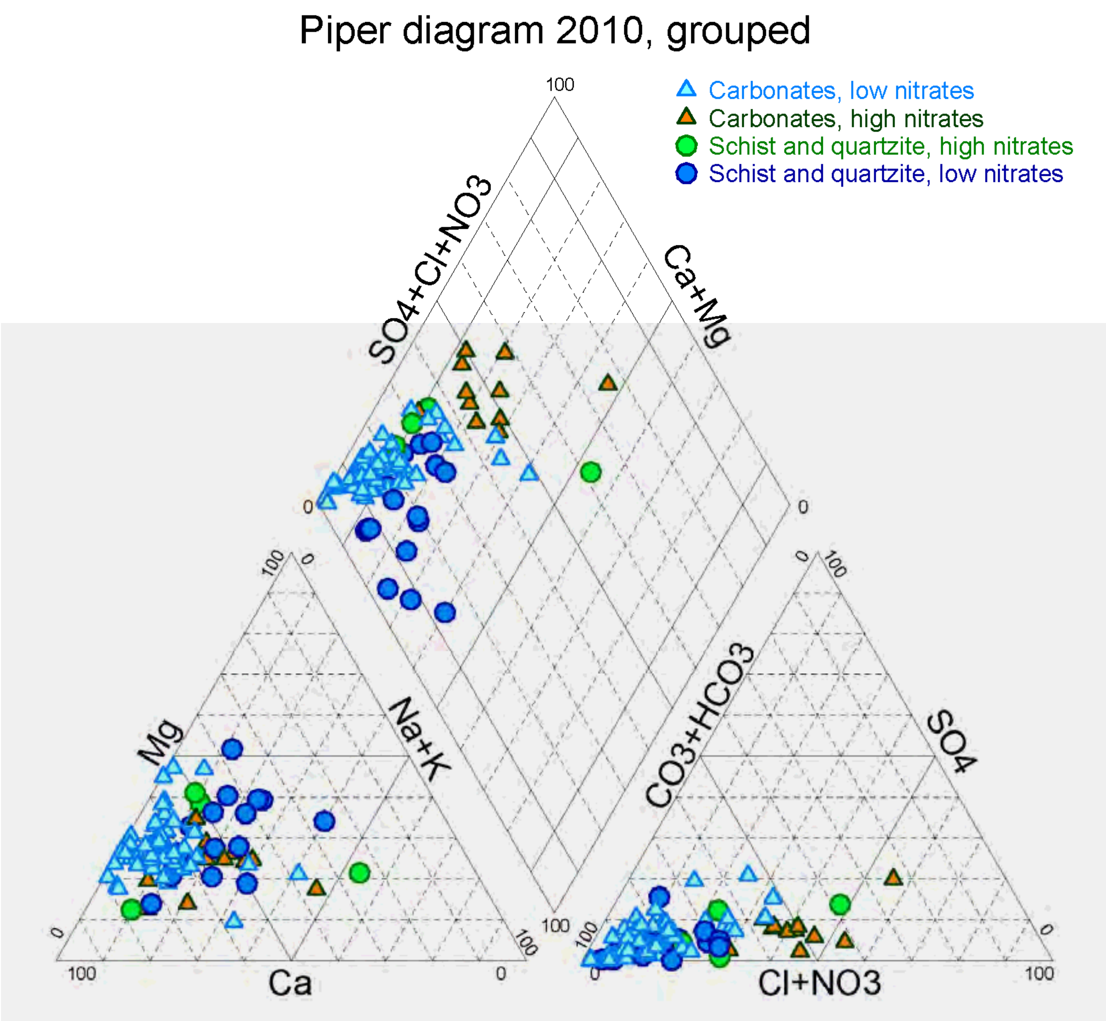

Figure 11 Piper diagram of groundwater samples (April/May 2010).

Comparing the 2010 results to the samples taken during 2008 (Museteka & Bäumle 2009), no significant difference in chemical composition is found (see Figure 13).

In terms of inorganic pollutants the northern part of the industrial area shows a very heterogeneous picture (see **Maps 4** and **5**, marked boreholes: George 7, Tombwe 2, Zamleather). One reason for this could be that it is situated on the contact zone between the Lusaka Dolomite and Cheta limestones. Figure 12 shows a cross section running slightly west of the area where samples were taken. Only few samples from this potentially highly polluted area actually show signs of anthropogenic pollution. As most of the borehole depths are unknown, especially from the privately owned wells, some of them may tap the contact zone while others receive water from the Lusaka Dolomite. Another possible explanation is that the same aquifer is tapped but in different depths, supposing that mean residential time increases with depth due to different fracturing conditions (see Figure 1, page 4).

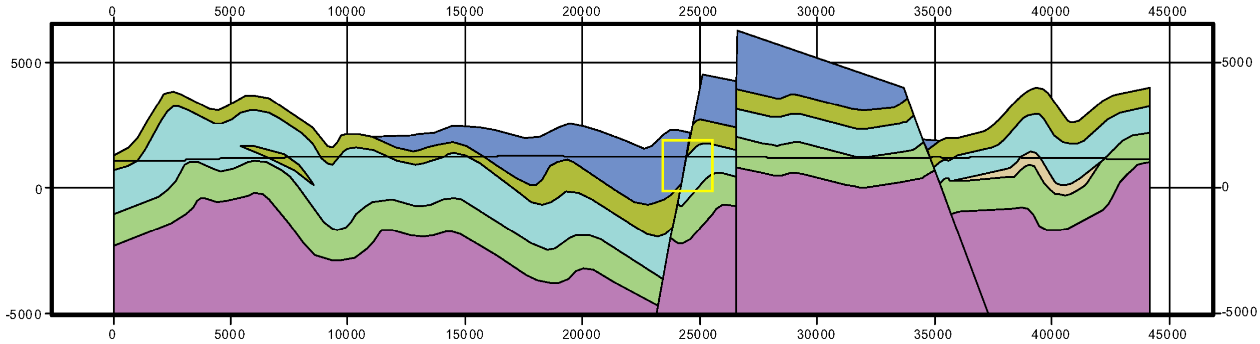

Figure 12 Geological profile intersecting SSW to NNE west of the industrial area (yellow square indicates position of area), unpublished results from structural geological study (Andreas Günther 2010, dark blue=Lusaka Dolomite, olive green=Cheta Schist, turquoise=Cheta limestone, green=Chunga Schist, purple=basement).

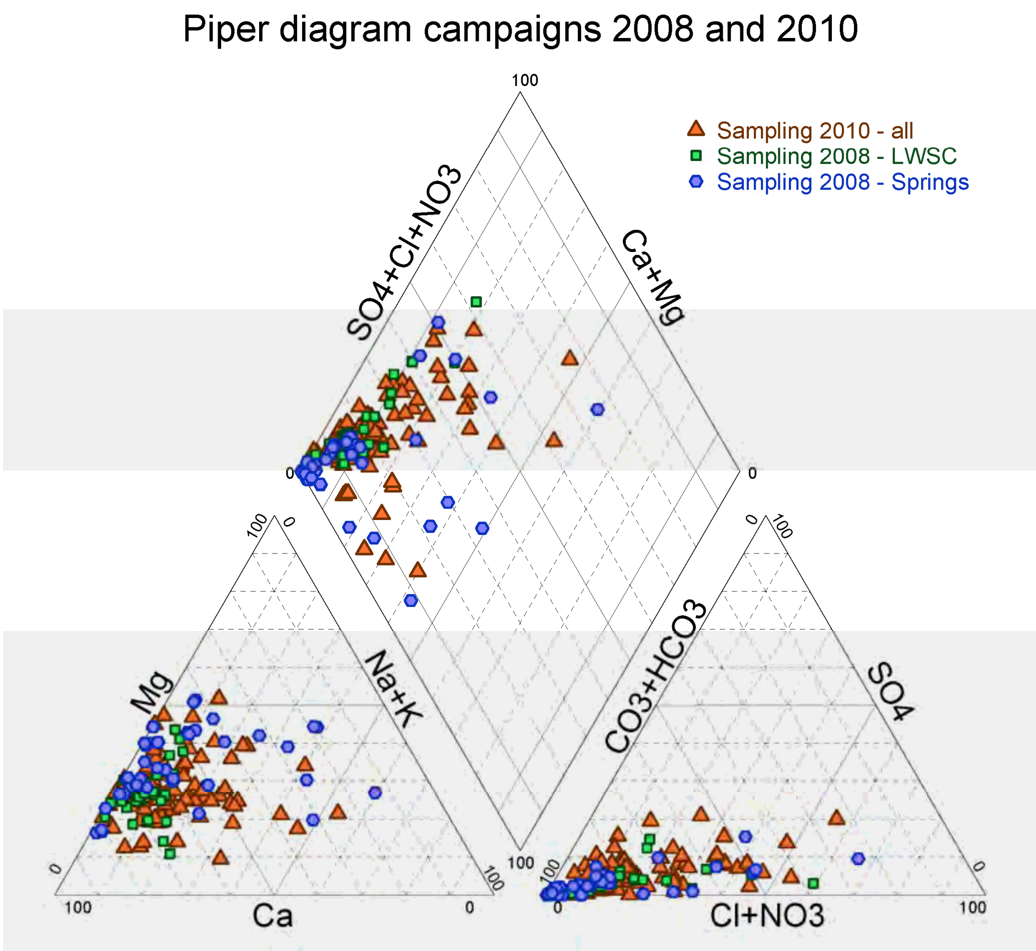

Figure 13 Piper diagram of groundwater samples from 2008 and 2010.

Under the prevailing pH (median = 7.0, min = 5.8, max = 8.0) in the calcareous geological environment, potentially toxic heavy metals like Pb, Cd or As as well as iron or manganese tend to form hydroxy- and carbonate complexes which are insoluble and can therefore not be found in the water. Concentrations of Pb, Cd and As are far below a toxic level in all samples analyzed. The only samples that showed trace element values higher than the limit according to the Zambian Drinking Water Standard were

- for manganese (ZDWS 0.1 mg/L): Maziopa E1, Water Trust Ng'ombe (not yet in use) and Mulungushi 6A which is highly polluted by BTEX and other hydrocarbons (see next chapter). Maziopa and Ng'ombe show concentrations that are just above the WHO recommended limit (0.4 mg/L).
- for iron (ZDWS 1 mg/L): Water Trust Ng'ombe (7.36 mg/L). This borehole was not in use when sampled. After drilling it had not been equipped due to administrative problems. Due to the large diameter of the borehole, after an hour of well purging procedure (550 l, borehole volume approx. 800 l) the water had not cleared from the red-brown colour of the iron-oxide. Iron concentrations would probably drop below the ZDWS limit once the borehole is pumped clear and in use. The iron concentration found in the nearby Ng'ombe spring during 2008 (Museteka & Bäumle 2009) were much lower (0.06 mg/L in January and 0.13 mg/L in October) while slightly elevated compared to samples taken in the carbonate aquifers. This may be explained by the weathering of mica present in the Chunga schists which contains iron in its crystal structure. The very high concentrations found in the unused borehole of the Water Trust Ng'ombe though might rather originate from corrosion of the steel tubing.

As expected from the microbiological results, nitrate levels were found to be very high in many boreholes and often exceeded the ZDWS limit of 44 mg/L (see **Map 5**). High levels of nitrate in drinking water can cause Methaemoglobinaemia (also known as "blue baby" syndrome). It occurs mostly with bottle-fed children under 3 months of age; therefore a limit of 50 mg/L NO_3^- is recommended by WHO. The median for nitrate in the study area is 16.9 mg/L, with two samples showing values below detection limit and a maximum value of 260 mg/L. The two samples which have a nitrate concentration of close to the analytical determination limit are the outlet of a decentralised wastewater treatment plant and a borehole at a fuel station. The treatment plant includes a biogas unit, an anaerobic baffled filter as well as a constructed wetland. All nutrients (as well as microbiology) are removed for wastewater in this unit if in good working order. The low nitrate concentration at the fuel station might point to the existence of a leakage causing fuel to enter the groundwater where nitrate reacts with the hydrocarbons in an aerobic environment.

Figure 14 shows the nitrate concentrations of the LWSC bulk water supply boreholes and smaller sources of local supply in the main aquifer (Lusaka Dolomite Fm). The main water supply boreholes of the utility (defined here as daily production of > 3,000 m^3/d) produce more than half of the total daily abstraction volume. Depending on the availability of the boreholes due to seasonal flooding or maintenance works, the number of these bulk supply boreholes is around 10, out of 73 supply boreholes run by the utility. Among these 10 large production boreholes are (Fig. 12) Shaft No. 5, Lumumba Road 4A, Lilayi Road 1, Leopards Hill 1 (in the Cheta marbles), and some adjacent boreholes, namely Waterworks 2 (next to Waterworks 1) and International School 6B (next to Int. Sch. 6D, in the schists).

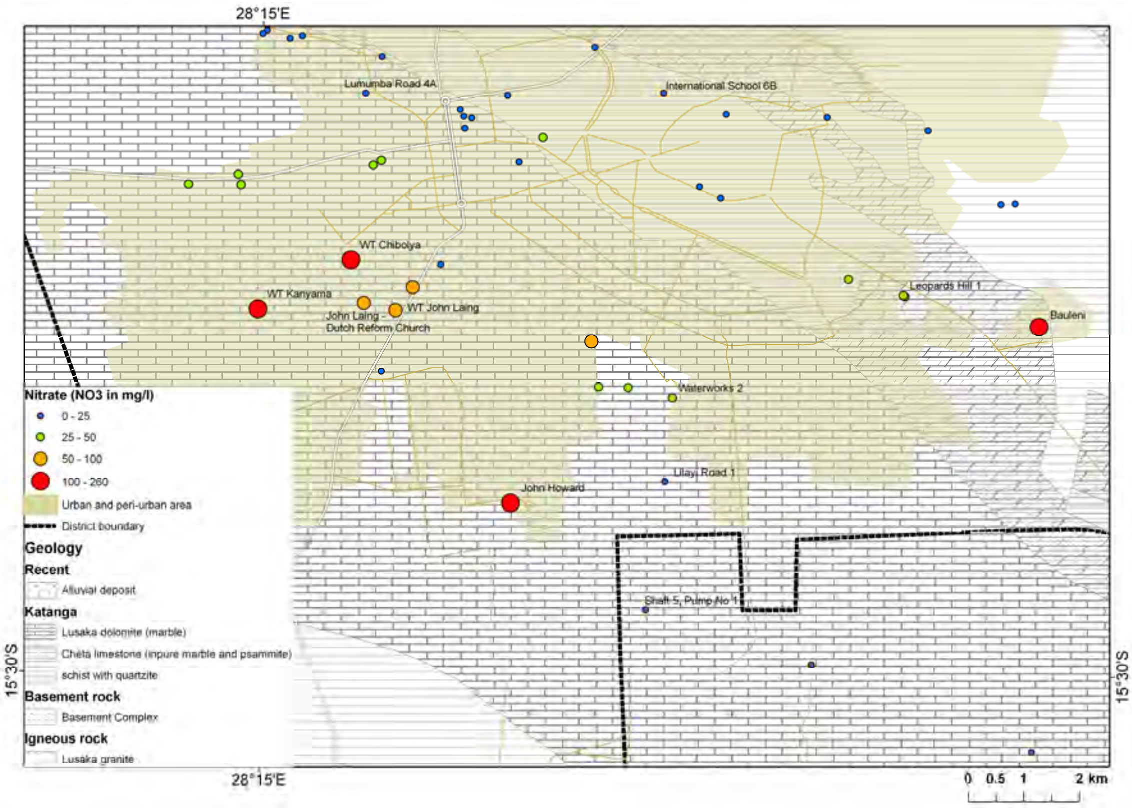

Figure 14 Nitrate concentrations in local supply boreholes and production boreholes of the LWSC bulk water supply.

While the large production boreholes exhibit nitrate concentrations below the Zambian drinking water standard, boreholes for the local supply of peri-urban areas such as Water Trust or LWSC boreholes in Kanyama, Chibolya, John Laing as well as John Howard and Bauleni show considerably higher values of more than 44 mg/L (some even of more than 100 mg/L). Nitrate pollution as an indicator of faecal contamination of the local water supply in peri-urban areas is a critical issue. Therefore strategies to reduce high nitrate levels have to be developed. Furthermore, a network will be established to monitor the seasonal fluctuations of nitrate levels (see chapter 6).

5.3. ORGANIC COMPOUNDS

This chapter only gives a preliminary summary of findings regarding organic pollutants in the groundwater of the Lusaka area. A separate report will be compiled which will give in-depth information on the results of this sampling activity.

The following results are still subject to interpretation regarding firstly: the actual quantity of compounds in the affected samples and secondly: the cause of their occurrence at the particular locations. Measured concentrations are lower than the actual concentrations in the original and fresh sample taken in the field, because samples needed to be stored for an extended period of time and transported as cooled courier airfreight to the laboratory in Hannover. As this is an ongoing experimental approach, the quantification of original concentrations reduction is not yet available. What is available at present are minimum concentrations. This means that concentrations at the time of sampling may have been higher by a considerable factor yet unclear. In order to find out where the source of the organic contamination is, further investigations would be needed.

So far, there is only one massively contaminated borehole, Mulungushi 6A, which has been taken off the production scheme by LWSC when the smell of hydrocarbons became obvious beginning of 2010. It still needs clarification where the pollution source is and whether the contamination plume will also affect the neighbouring production borehole (Mulungushi 6H).

Apart from Mulungushi 6A, six boreholes were analysed positively for at least two contaminant substances, namely Mumbwa Roadside 4, Decotex, WT Chazanga, NIPA, George 5 and Total Independence Stadium. Furthermore, a number of boreholes exhibit only one component, mainly Trichloromethane, in concentrations between 0.3 and 6.5 µg/L. These were namely the LWSC boreholes Parerinyatwa, International School 6B, Mass Media 1, Waterworks 2, Chainda, Mumbwa Roadside 6, Chunga 2, Lumumba Road 4, WT Kabanana, WT Chibolya, commercially owned boreholes at Tombwe 1 and 2, Zambian Breweries, BP Depot, BP Castle, Engen Mumbwa Road, Petroda Kalingalinga, the DWA monitoring borehole F55 ZAWA Park 4 (only in the upper filter stretch), and a domestic borehole in Woodlands.

Apart from the lightly volatile halogenated hydrocarbons (CVOCs) and mono-aromatic hydrocarbons (BTEX), the samples which showed a perceivable smell of hydrocarbons (mostly perceived as “oil smell”) were additionally sampled for aliphatic hydrocarbons. The locations where samples were taken comprise Mulungushi 6H, Zesco 2, 3 and 4, Total Headquarters/Depot, BP Depot, Total Great East Road, Total Matero, and Total Independence Stadium. The analysis of the nine samples was performed in a contracted laboratory in Hildesheim, Germany. None of the samples was tested positively; all concentrations were below the detection limit.

6. RECOMMENDATIONS

6.1. REGULAR WATER QUALITY MONITORING

After the broad reconnaissance study in 2008 (Museteka & Bäumle 2009) and this large sampling campaign, it is suggested that the focus now should be on regular monitoring.

Based on the results from the 2010 sampling campaign the production boreholes given in Table 2 should be taken into consideration for regular monitoring. They were chosen according to

- their geographical distribution throughout the city area,
- the aquifer which they are considered to tap and
- due to elevated concentrations in the given parameters (bold values are above the ZDWS limit).

Table 2 Proposed boreholes for quality monitoring with results from April 2010.

BhID	BhName	EC	TC	Ecoli	NO3	NO2	Cl	SO4	Mn	Fe	Pb	Cd
		µS/cm	MPN	MPN	mg/l	mg/l	mg/l	mg/l	µg/l	mg/l	µg/l	µg/l
5010124	Avondale 3	519	791.5	2	11.9	0	3.2	1.42	1	0.041	0.18	0.023
5040393	Bauleni	994	298.7	2	112	0.02	52	13.8	1	0.018	2.78	0.02
5040396	Chainda	1330	4.1	1	260	0.07	100	28.7	1	0.003	0.18	0.003
5040404	Chunga 1	1207	416	33.2	107	0	109	53.2	9	0.005	0.17	0.009
5040924	George 7	406	344.1	152.9	1.3	0.01	10	11.9	1	0.003	0.08	0.001
5040418	John Howard	924	3.1	<1	175	0	48.6	10.2	0	0	0.11	0.005
5040460	Waterworks 1	**663*	*12.6*	*<1*	*37.9*	*0.01*	*7.9*	*3.93*	*0*	*0*	*0.27*	*0.007*
5041093	WT Chibolya	1096	1	0	155	0.22	91.7	30.7	1	0.005	0.5	0.008
5041102	WT Chipata	664	<1	<1	60.4	0	37.1	3.16	0.001	0.003	0.21	0.007
Zambian Drinking Water Standard			10	0	44	1	250	400	100	1	50	5

* *values taken from Waterworks 2* (WW 1 was not sampled in 2010 nor 2008)

The wells at Bauleni and Chainda also showed high levels of nitrate in the 2008 sampling campaign, with 141 mg/L and 336 mg/L respectively (Museteka & Bäumle 2009). Sampling took place during August 2008 when nitrate levels in other boreholes were considerably lower than the values found in April 2010. A continuous quality monitoring will provide a clearer picture of seasonal fluctuations of nitrate concentrations and microbiological parameters. Waterworks 1 represents one of the largest production boreholes (second highest daily volume) and does not show alarming signs of pollution. It is proposed for monitoring as a comparison.

Additionally it is proposed to conduct regular sampling at the **spring Laughing Waters** which was sampled in 2008 (Museteka & Bäumle 2009). This spring is situated in the west of Lusaka and is part of the groundwater discharge from the Lusaka Dolomites. Therefore time series of electrical conductivity and temperature values resulting from the sampling are expected to give an idea of the mean residence time in the aquifer. They will also serve as a baseline compared to the boreholes in the city area, because the spring is considered to be unaffected by human activities.

Monitoring will be conducted monthly, starting from November 2010, as far as possible in conjunction with water level monitoring and gauge reading.

6.2. VULNERABILITY MAPPING AND GROUNDWATER PROTECTION ZONING

The two GReSP sampling campaigns give a clear indication that the Lusaka groundwater is under enormous threat from anthropogenic pollution. The “hot spots” in terms of most vulnerable areas prone to groundwater pollution due to a lack of protective cover or shallow groundwater tables however have not yet been identified. A vulnerability map for Lusaka's groundwater resources which covers these issues will be produced in the course of the ongoing project phase. As a following step, areas of protection need to be defined on the basis on the water quality findings and this vulnerability map. For the future preservation of groundwater quality, and thus drinking water quality for the Lusaka population, it is of highest importance to identify the areas where pollution has a large impact on the resource (e.g. where recharge takes place and where drinking water is produced) and to protect them from contamination. This includes the restriction of activities inside the protection areas. Guidelines regarding these restrictions need to be developed.

Regarding the organic pollution it is highly recommended that risks related to oil are handled adequately in Zambia. It must be presumed that quite a number of pollution sources of solvents and oil exist throughout Lusaka (and presumably other cities in Zambia). The contamination plumes originating from these sources need intensive mapping and measurements over a longer period. Such investigations can then lead to a model which predicts the direction and velocity of contaminant flow. One of the main preconditions for such operations is a laboratory which can effectively analyse water samples for organic contamination (i.e. ideally on the same day a sample is taken). Another requirement would be the scientific expertise to carry out the interpretation.

6.3. SANITATION

One of the main sources of pollution in Lusaka is lacking or inappropriate sanitation. This is obvious through microbiological results as well as from nitrate levels that reach values as high as 260 mg/L. The highest pollution levels (in terms of inorganic and microbiological contamination) occur in the peri-urban areas which are mainly unserviced in terms of sanitation infrastructure. Sanitation consists of pit latrines and septic tanks that are probably overflowing, introducing wastewater straight into the subsurface bypassing the natural soil filter. This way of disposal is unsafe, a risk for public health and a threat to long-term water quality, especially in areas with shallow water tables as in most areas of the city during and after the rainy season. It is recommended to identify suitable options of safe and adequate sanitation for the peri-urban areas and to implement them as soon as possible.

6.4. IMPROVEMENT OF WATER LABORATORY FACILITIES AND CAPACITIES

The effectiveness of groundwater resource protection depends among others on the reliability of analytical results for water quality monitoring. It is therefore crucial for the resource management that the laboratory staff analyzing the samples from water quality monitoring is trained in laboratory management and analytical procedures. It is generally accepted that the capacity for water analysis and water quality monitoring in the present situation is insufficient in Zambia. Currently there are a number of laboratories, e.g. at UNZA, NISIR, Food and Drugs, DWA and five Commercial Utilities. A capacity study of the water sector (Stoltz et al. 2007) recommends to continue the support of local water laboratories to increase the number and qualification of staff.

The improvement of the water quality analysis capacity of the DWA Water Laboratory remains a challenge which is crucial for the reliability of monitoring results. It is recommended to further strengthen the laboratory capacity through capacity building and provision of equipment.

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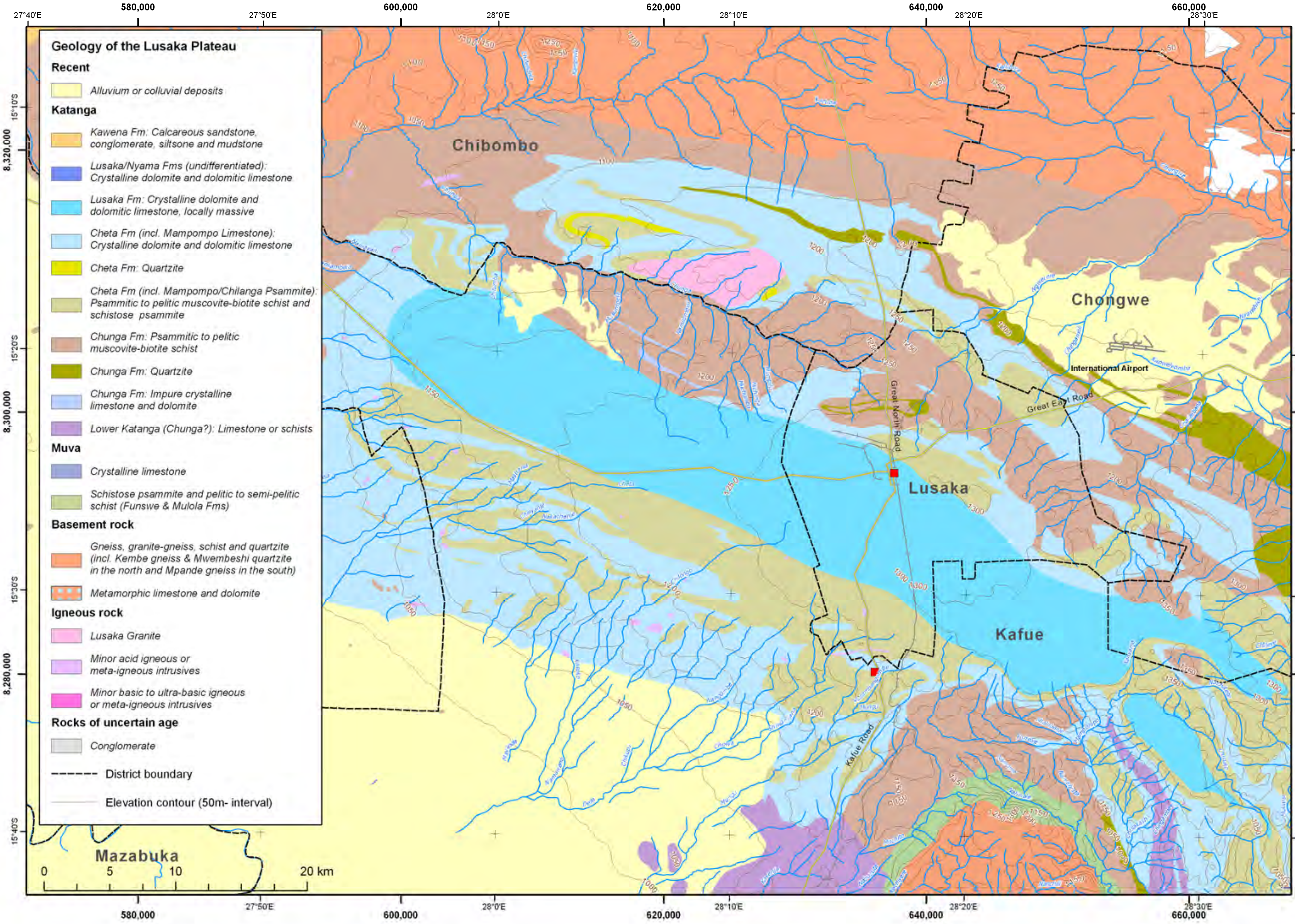
Map 1

Geology of the Lusaka Plateau

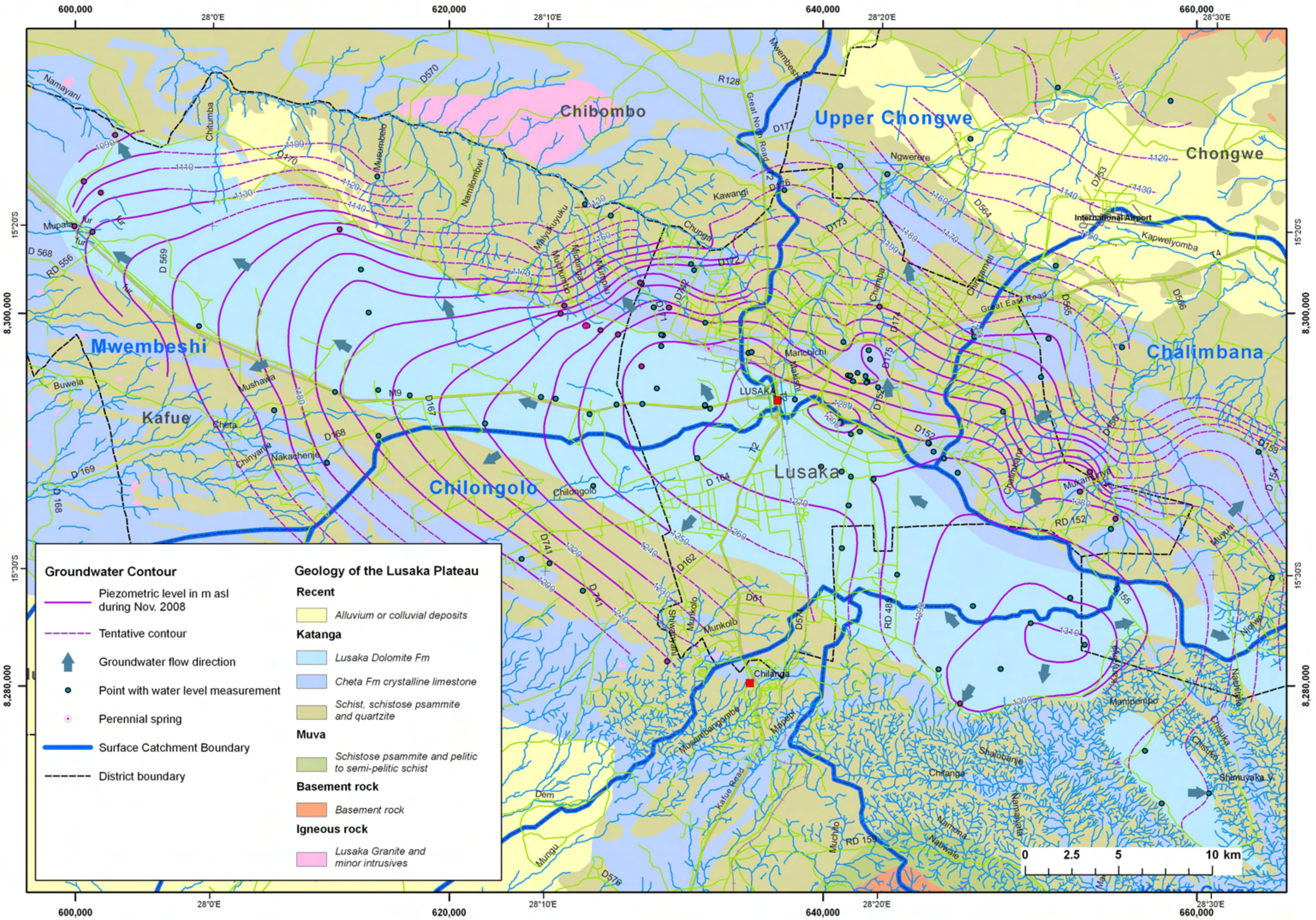
Approximate scale 1:250,000


Geology of the Lusaka Plateau
Recent
Alluvium or colluvial deposits
Katanga
Kawena Fm: Calcareous sandstone, conglomerate, siltsone and mudstone
Lusaka/Nyama Fms (undifferentiated): Crystalline dolomite and dolomitic limestone
Lusaka Fm: Crystalline dolomite and dolomitic limestone, locally massive
Cheta Fm (incl. Mampompo Limestone): Crystalline dolomite and dolomitic limestone
Cheta Fm: Quartzite
Cheta Fm (incl. Mampompo/Chilanga Psammite): Psammitic to pelitic muscovite-biotite schist and schistose psammite
Chunga Fm: Psammitic to pelitic muscovite-biotite schist
Chunga Fm: Quartzite
Chunga Fm: Impure crystalline limestone and dolomite
Lower Katanga (Chunga?): Limestone or schists
Muva
Crystalline limestone
Schistose psammite and pelitic to semi-pelitic schist (Funswe & Mulola Fms)
Basement rock
Gneiss, granite-gneiss, schist and quartzite (incl. Kembe gneiss & Mwembeshi quartzite in the north and Mpande gneiss in the south)
Metamorphic limestone and dolomite
Igneous rock
Lusaka Granite
Minor acid igneous or meta-igneous intrusives
Minor basic to ultra-basic igneous or meta-igneous intrusives
Rocks of uncertain age
Conglomerate
District boundary
Elevation contour (50m- interval)
Chibombo
Chongwe
Lusaka
Kafue
Mazabuka
International Airport
Great North Road
Great East Road
Kafue Road
0
5
10
20 km
580,000
600,000
620,000
640,000
660,000
27°40'E
27°50'E
28°0'E
28°10'E
28°20'E
28°30'E
8,320,000
8,300,000
8,280,000
15°10'S
15°20'S
15°30'S
15°40'S

Map 2

Groundwater Contours of dry season 2008

Approximate scale 1:215,000

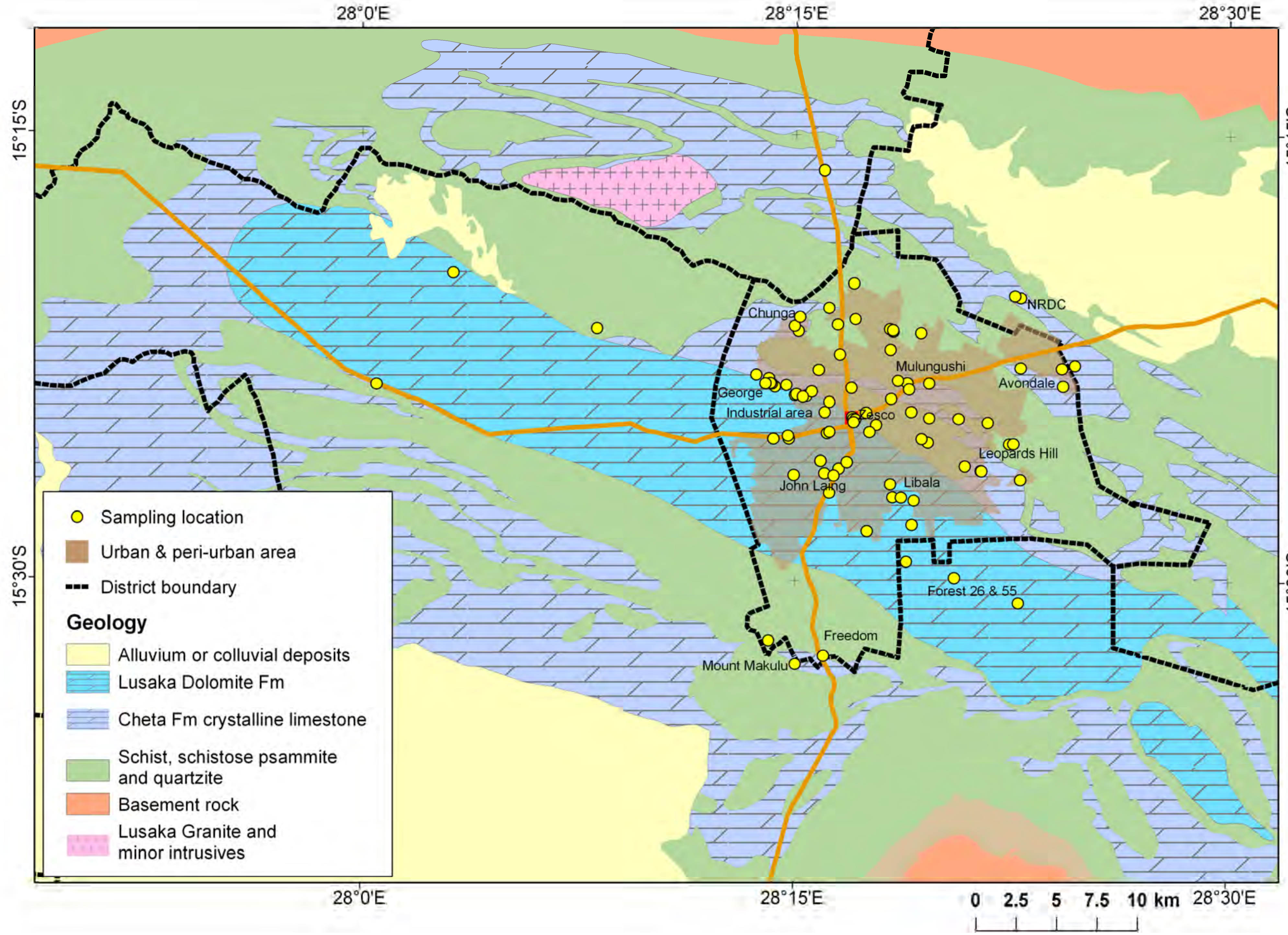


Groundwater Contour
Piezometric level in m asl during Nov. 2008
Tentative contour
Groundwater flow direction
Point with water level measurement
Perennial spring
Surface Catchment Boundary
District boundary
Geology of the Lusaka Plateau
Recent
Alluvium or colluvial deposits
Katanga
Lusaka Dolomite Fm
Cheta Fm crystalline limestone
Schist, schistose psammite and quartzite
Muva
Schistose psammite and pelitic to semi-pelitic schist
Basement rock
Basement rock
Igneous rock
Lusaka Granite and minor intrusives
Chibombo
Upper Chongwe
Chongwe
Mwembeshi
Chalimbana
Kafue
Chilongolo
Lusaka
LUSAKA
Chilanda
International Airport
Great East Road
Great North Road
Kafue Road
600,000
620,000
640,000
660,000
28°0'E
28°10'E
28°20'E
28°30'E
15°20'S
15°30'S
8,300,000
8,280,000
0
2.5
5
10 km

Map 3

Sampling locations during 2010 GReSP water quality campaign

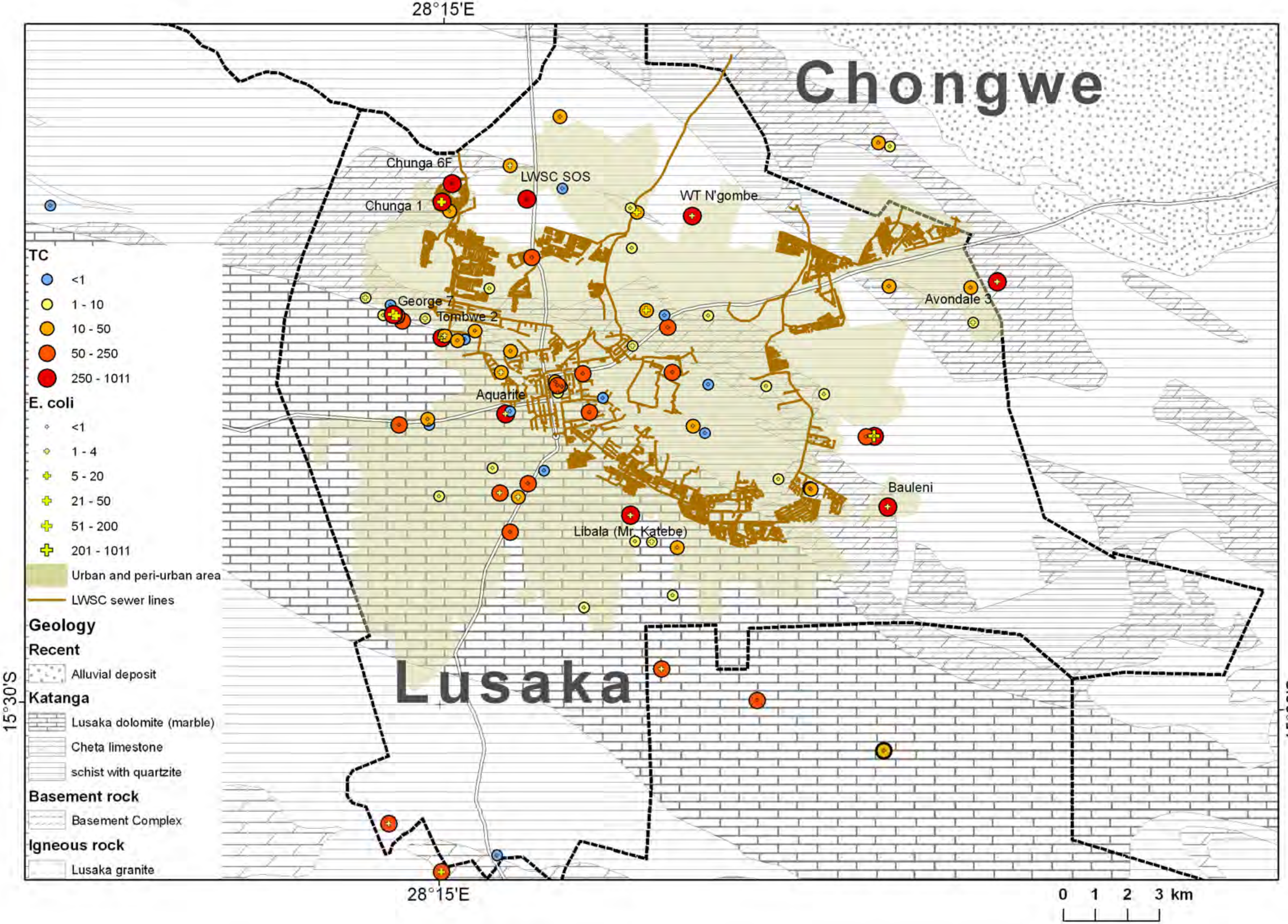
Approximate scale 1:200,000


28°0'E
28°15'E
28°30'E
15°15'S
15°30'S
Chunga
NRDC
Mulungushi
Avondale
George
Industrial area
Zesco
Leopards Hill
John Laing
Libala
Forest 26 & 55
Freedom
Mount Makulu
0 2.5 5 7.5 10 km
Sampling location
Urban & peri-urban area
District boundary
Geology
Alluvium or colluvial deposits
Lusaka Dolomite Fm
Cheta Fm crystalline limestone
Schist, schistose psammite and quartzite
Basement rock
Lusaka Granite and minor intrusives

Map 4

Spatial distribution of Total Coliforms and E. coli in April/May 2010

Scale 1:100,000

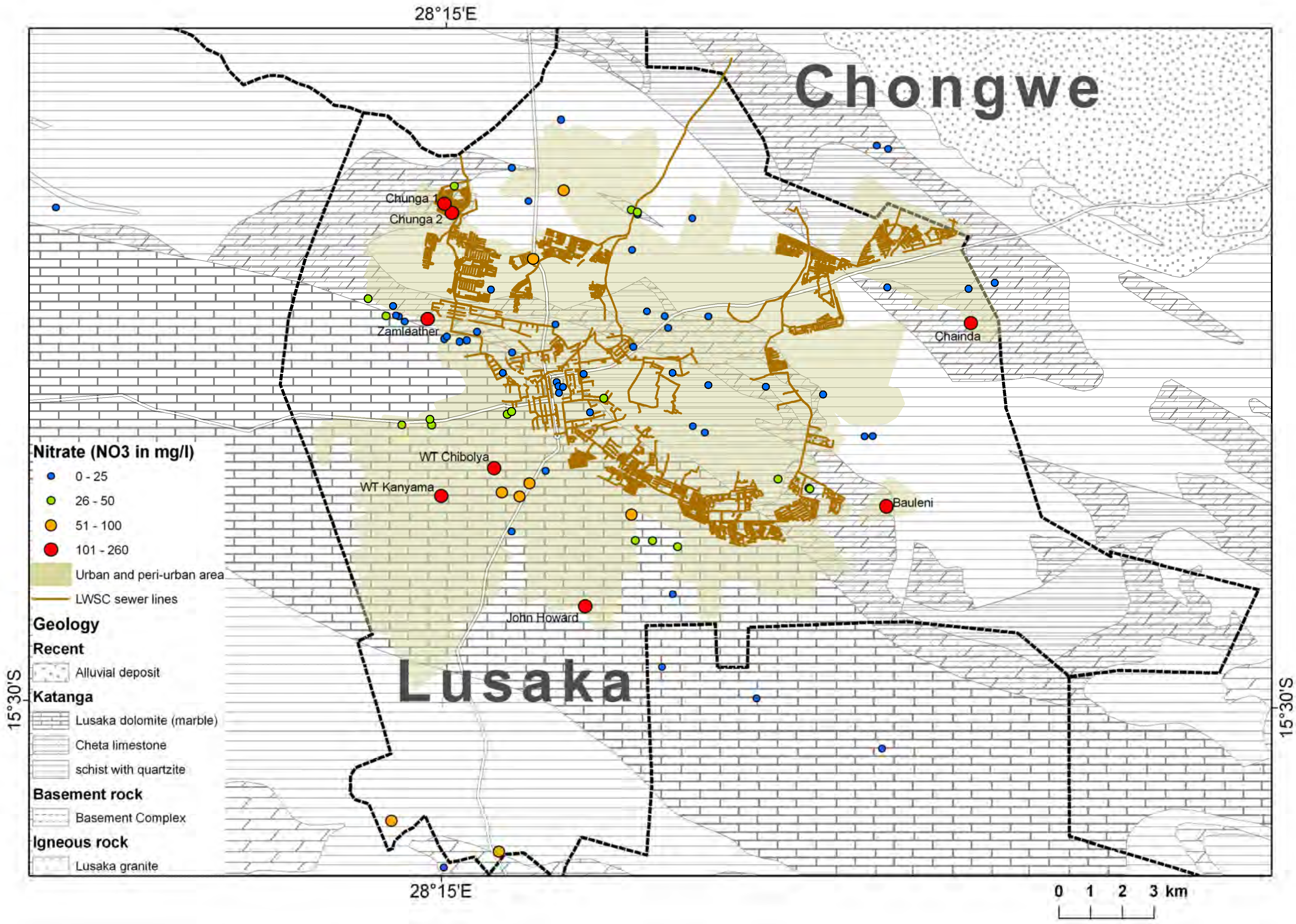


28°15'E
Chongwe
Chunga 6F
LWSC SOS
Chunga 1
WT N'gombe
TC
<1
1 - 10
10 - 50
50 - 250
250 - 1011
George 7
Tombwe 2
Avondale 3
Aquarite
E. coli
<1
1 - 4
5 - 20
21 - 50
51 - 200
201 - 1011
Bauleni
Libala (Mr. Katebe)
Urban and peri-urban area
LWSC sewer lines
Geology
Recent
Alluvial deposit
Katanga
Lusaka dolomite (marble)
Cheta limestone
schist with quartzite
Basement rock
Basement Complex
Igneous rock
Lusaka granite
Lusaka
15°30'S
15°30'S
28°15'E
0 1 2 3 km

Map 5

Spatial distribution of nitrate concentrations in April/May 2010

Scale 1:100,000


28°15'E
Chongwe
Chunga 1
Chunga 2
Zamleather
Chainda
WT Chibolya
WT Kanyama
Bauleni
John Howard
Lusaka
15°30'S
Nitrate (NO3 in mg/l)
0 - 25
26 - 50
51 - 100
101 - 260
Urban and peri-urban area
LWSC sewer lines
Geology
Recent
Alluvial deposit
Katanga
Lusaka dolomite (marble)
Cheta limestone
schist with quartzite
Basement rock
Basement Complex
Igneous rock
Lusaka granite
0 1 2 3 km

Annex 1

A. Sampling locations

ID	Sample name	Borehole ID	Latitude	Longitude	Borehole Type [(1)]	Borehole Depth	Pump Depth	Sample Date	Samples taken [(2)]	Analytic Date (LNAPL)
			WGS 84							
1	WT Garden	5040927	-15.39198	28.28260	WT			14-04-2010	TT, MB, I	
2	Mazyopa E1	5041088	-15.36037	28.30647	WT	45		14-04-2010	all	04.05.2010
3	Mazyopa E3	5041089	-15.35969	28.30640	WT	60		14-04-2010	all	04.05.2010
4	PARERINYATWA	5040447	-15.41284	28.29690	LWSC	80	51	15-04-2010	all	04.05.2010
5	Northmead 2	5040441	-15.39817	28.30547	LWSC		27	15-04-2010	all	04.05.2010
6	INT. SCH 6B	5040413	-15.40558	28.31705	LWSC	81	39	15-04-2010	all	04.05.2010
7	MASS MEDIA 1 (MM1)	5040430	-15.40900	28.32753	LWSC	70	36	15-04-2010	all	04.05.2010
8	WATERWORKS 2	5040461	-15.45512	28.31880	LWSC	70	46	16-04-2010	all	04.05.2010
9	SHOWGROUNDS	5040458	-15.39275	28.31565	LWSC	83	48	16-04-2010	all	06.05.2010
10	JOHN HOWARD	5040418	-15.47228	28.29181	LWSC	81		16-04-2010	all	06.05.2010
11	Libala South	5041090	-15.45350	28.31140	private			16-04-2010		
12	SHAFT 5, Pump No 1	5020631	-15.48950	28.31451	LWSC	66	44	16-04-2010	all	06.05.2010
13	LILAYI ROAD 1	5040424	-15.46866	28.31758	LWSC			16-04-2010	all	11.05.2010
14	NIPA	5040439	-15.41691	28.29291	LWSC	75		19-04-2010	all	11.05.2010
15	CHELSTON 1	5040400	-15.38073	28.37994	LWSC	55		19-04-2010	all	11.05.2010
16	CHAINDA	5040396	-15.39083	28.40456	LWSC		30	19-04-2010	all	11.05.2010
17	AVONDALE new	5041142	-15.38100	28.40380	LWSC	81		19-04-2010	all	11.05.2010
18	AVONDALE 3	5010124	-15.37926	28.41145	LWSC	70	32	19-04-2010	all	11.05.2010
19	Mumbwa Roadside 4	5040454	-15.42082	28.24640	LWSC	81	48	20-04-2010	all	11.05.2010
20	Mumbwa Roadside 6	5040456	-15.41915	28.24590	LWSC	65	36	20-04-2010	all	14.05.2010
21	WT Kanyama	5041091	-15.44104	28.24937	WT	60		20-04-2010	all	14.05.2010
22	John Laing - Dutch Reform	5041092	-15.43998	28.26708	private			20-04-2010	all	14.05.2010
23	WT Chibolya	5041093	-15.43297	28.26484	WT			20-04-2010	all	14.05.2010
24	WT JOHN LAING	5040419	-15.44112	28.27238	WT	55	36	21-04-2010	all	31.05.2010
25	WT Freedom BH2	5041056	-15.54239	28.26683	WT	65	36	21-04-2010	all	31.05.2010
26	Mt. Makulu	5020200	-15.54707	28.25068	MB	48		21-04-2010	all	31.05.2010
27	Mt. Makulu Lutheran Church	5041129	-15.53380	28.23522	private			21-04-2010	all	31.05.2010
28	Zamleather	5041094	-15.39065	28.24502	private	48		22-04-2010	all	31.05.2010
29	outlet of Zamleather treatment		-15.39065	28.24502	no BH			22-04-2010	TT, I	
30	LEOPARDS HILL 2	5040423	-15.43823	28.35733	LWSC			20-04-2010	all	31.05.2010
31	LEOPARDS HILL 1	5040422	-15.43844	28.35762	LWSC	88	45	20-04-2010	MB, I	
32	Pestalozzi School Leopards	5041095	-15.42325	28.37596	private			20-04-2010	MB, I	
33	outlet of gravel filter Pestalozzi		-15.42325	28.37596	no BH			20-04-2010	MB, I	
34	BAULENI	5040393	-15.44323	28.38010	LWSC	46	27	20-04-2010	all	04.06.2010
35	WT Kalikiliki	5041140	-15.41139	28.36129	WT	53		20-04-2010	all	04.06.2010
36	Chunga 2	5040405	-15.36025	28.25195	LWSC	50	36	21-04-2010	all	04.06.2010
37	CHUNGA 1	5040404	-15.35761	28.24971	LWSC	70	39	21-04-2010	all	04.06.2010
38	CHUNGA 6F	5040407	-15.35249	28.25264	LWSC			21-04-2010	all	04.06.2010
39	LWSC SOS	5040983	-15.35667	28.27442	LWSC			21-04-2010	all	04.06.2010
40	WT Chazanga new	5041096	-15.33343	28.28383	WT			21-04-2010	all	04.06.2010
41	WT Chazanga old	5041097	-15.34726	28.26949	WT			21-04-2010	all	04.06.2010
42	WT Kabanana	5040420	-15.35906	28.30463	WT	37.5		21-04-2010	all	04.06.2010
43	Tombwe 1	5041098	-15.39620	28.24993	private			22-04-2010	all	07.06.2010
44	Tombwe 2	5041099	-15.39620	28.24993	private			22-04-2010	all	07.06.2010
45	Decotex	5041100	-15.39992	28.26987	private			22-04-2010	all	07.06.2010
46	MACHINERY HOUSE 3 (George)	5040923	-15.38492	28.22756	LWSC			22-04-2010	all	07.06.2010
47	MACHINERY HOUSE 6 (George)	5040920	-15.39140	28.23830	LWSC			22-04-2010	all	07.06.2010
48	MACHINERY HOUSE 2 (George)	5040922	-15.38692	28.23481	LWSC			22-04-2010	all	07.06.2010
49	Zambian Breweries	5041101	-15.39564	28.25068	private			23-04-2010	all	07.06.2010
50	WT Chipata	5041102	-15.35359	28.28469	WT	60		23-04-2010	all	07.06.2010
51	NRDC 2	5010199	-15.34126	28.37993	LWSC	50	38	26-04-2010	all	07.06.2010

A. Sampling locations

ID	Sample name	Borehole ID	Latitude WGS 84	Longitude	Borehole Type (1)	Borehole Depth	Pump Depth	Sample Date	Samples taken (2)	Analytic Date (LNAPL)
52	NRDC 1	5010139	-15.34027	28.37660	LWSC	31	25	26-04-2010	all	09.06.2010
53	MULUNGUSHI 6H	5040437	-15.38939	28.31466	LWSC	88	40	27-04-2010	all	09.06.2010
54	MULUNGUSHI 6A	5040436	-15.38800	28.30943	LWSC	41	30	27-04-2010	all	09.06.2010
55	LUMUMBA RD 4A	5040426	-15.40586	28.26719	LWSC	70	36	27-04-2010	all	09.06.2010
56	Aquarite	5041104	-15.41755	28.26853	private			27-04-2010	all	09.06.2010
57	Chikumbi Social Development	1010776	-15.27008	28.26644	MB		25	29-04-2010	all	
58	WT N'gombe	5041105	-15.36131	28.32260	WT	61	40	29-04-2010	all	09.06.2010
59	UNZA 1 Education	5040362	-15.38942	28.32742	MB		20	30-04-2010	all	18.06.2010
60	Chinyanja B Sch Monitoring	5020746	-15.39106	28.00845	MB	50	30	07-05-2010	all	18.06.2010
62	Roma (Doetsch)	5041106	-15.37051	28.30500	private	45		27-04-2010	all	09.06.2010
63	Lusaka Golf Club 1	5041107	-15.42257	28.32664	private	50		27-04-2010	MB, I	
64	Lusaka Golf Club 2	5041116	-15.42072	28.32315	private	100		27-04-2010	all	09.06.2010
65	Leopards Hill Secondary	5041108	-15.42346	28.37356	private			28-04-2010	all	09.06.2010
66	F55 ZAWA Park 4	5020205	-15.51232	28.37930	MB	91	17	28-04-2010	all	11.06.2010
67	F55 ZAWA Park 4	5020205	-15.51232	28.37930	MB	91	36	28-04-2010	TT, MB, I	
68	Forest 26 BH7	5020198	-15.49830	28.34234	MB	97.5	22	28-04-2010	all	11.06.2010
69	Libala (Mr. Katebe)	5041109	-15.44601	28.30517	private			29-04-2010	all	11.06.2010
70	Libala (Pastor Phiri)	5041111	-15.45343	28.30647	private			29-04-2010	all	11.06.2010
71	Woodlands (Stoll)	5041110	-15.43565	28.34818	private	76	60	29-04-2010	all	18.06.2010
73	Air Force Barracks/ Sekelela-Z	5020792	-15.35931	28.13568	private			11-05-2010	all	18.06.2010
74	SDA Campsite Monitoring	5020748	-15.32845	28.05244	MB	42		11-05-2010	all	18.06.2010
75	Zesco 1 (Fly over)	5041112	-15.40844	28.28300	private	56		19-05-2010	all	18.06.2010
76	Zesco 2 (Front area)	5041113	-15.40953	28.28360	private			19-05-2010	all	18.06.2010
77	Zesco 3 (NCC)	5041114	-15.40981	28.28490	private			19-05-2010	all	18.06.2010
78	Zesco 4 (Clinic)	5041115	-15.41144	28.28377	private	80	20	20-05-2010	all	18.06.2010
79	Maschinery House 8 (George)	5041134	-15.38988	28.23661	LWSC			20-05-2010	all	18.06.2010
80	Maschinery House 7 (George)	5040924	-15.38958	28.23573	LWSC			20-05-2010	all	18.06.2010
81	Maschinery House 5 (George)	5040921	-15.38980	28.23278	LWSC			20-05-2010	all	18.06.2010
82	Total HQ - Depot	5041117	-15.39655	28.25653	private			24-05-2010	all	18.06.2010
83	Engen HQ - Depot	5041118	-15.39414	28.25951	private	50	45	27-05-2010	all	18.06.2010
84	BP Depot	5041119	-15.39697	28.25447	private	50	25	27-05-2010	all	18.06.2010
85	BP Kafue Rd	5041120	-15.43734	28.27524	private			28-05-2010	MB, I	
86	Petroda Kafue Rd	5041121	-15.43363	28.27991	private	50		28-05-2010	all	18.06.2010
87	BP Castle	5041122	-15.45102	28.27004	private			28-05-2010	all	18.06.2010
88	Engen Mumbwa Rd	5041123	-15.42081	28.23762	private			28-05-2010	all	18.06.2010
89	Petroda Kalingalinga	5041124	-15.40937	28.34442	private			01-06-2010	all	18.06.2010
90	Engen Chinika	5041125	-15.41678	28.26985	private	50		02-06-2010	all	18.06.2010
91	Total Great East Road	5041126	-15.40606	28.29094	private			03-06-2010	all	18.06.2010
92	Total Matero	5041127	-15.38206	28.26362	private			03-06-2010	all	18.06.2010
93	Total Independence Statium	5041128	-15.37333	28.27588	private			03-06-2010	all	18.06.2010

(1) WT = Water Trust, LWSC = Lusaka Water and Sewerage Company production borehole, MB = monitoring borehole

(2) all = LNAPL, TT, MB, I; LNAPL=light non-aqueous phase liquids, TT=total inorganic/organic carbon, MB=microbiology, I=major ions and trace elements

B. In Situ Physical Parameters

ID	Sample name	T_{H20} °C	T_{AIR} °C	EC µS/cm	pH	ORP EH/SHE	O_2 mg/l	O_2sat %	Odour 0=none	Colour 0=none	Turbidity 0=none
1	WT Garden	23.3		709	7.4	517	5.12	71.82	0	0	0
2	Mazyopa E1	23.5		896	7.1	387	0.85	11.50	0	0	0
3	Mazyopa E3	23.5	23.70	810	7.1	368	0.95	10.72	0	0	0
4	PARERINYATWA	24.8	24.40	769	6.6	405	0.50	6.50	0	0	0
5	Northmead 2	26.3	30.90	847	6.3	207	0.41	5.50	0	0	0
6	INT. SCH 6B	24.0		765	6.9	313	4.10	57.00	0	0	0
7	MASS MEDIA 1 (MM1)	24.0	27.30	709	6.9	411	4.55	62.70	0	0	0
8	WATERWORKS 2	24.6		663	6.9	307	1.84	25.60	0	0	0
9	SHOWGROUNDS	24.0	31.00	776	6.7	340	1.44	10.20	0	0	0
10	JOHN HOWARD	24.0	33.10	924	6.6	367	0.30	4.10	0	0	0
11	Libala South	24.5	25.00	562	7.0	372	3.40	48.40	0	0	0
12	SHAFT 5, Pump No 1	24.0	26.00	641	6.8	436	4.14	58.20	0	0	0
13	LILAYI ROAD 1	24.1		586	6.8	447	4.20	60.40	0	0	0
14	NIPA	25.5	34.30	717	6.8	366			0	0	0
15	CHELSTON 1	22.3	30.00	736	7.1	365	10.22	133.00	0	0	0
16	CHAINDA	24.3		1330	7.0	405	2.10	29.30	0	0	0
17	AVONDALE new	23.7		716	7.2	413	2.36	33.50	0	0	0
18	AVONDALE 3	25.0		519	7.3	419	5.24	74.50	0	0	0
19	Mumbwa Roadside 4	26.9		784	6.8	912	5.62	83.20	chlorine	0	0
20	Mumbwa Roadside 6	24.9		820	7.5	479	0.90	12.80			
21	WT Kanyama	24.3		1212	7.4	436	0.82	11.30			
22	John Laing - Dutch Reform	24.1	24.00	902	7.7	302	1.77	24.60			
23	WT Chibolya	24.5	24.00	1096	7.6	401	0.87	12.18	0	0	0
24	WT JOHN LAING	25.0	30.00	872	7.1	622	0.73	10.30	0	0	0
25	WT Freedom BH2	24.2	30.00	1076	6.9	465	2.03	27.10			
26	Mt. Makulu	25.9		978	7.0	387	1.02	29.50			
27	Mt. Makulu Lutheran Church	25.2		1000	6.9	331	2.47	36.30	0	0	0
28	Zamleather	29.1		2910	7.0	446	7.00	100.00	rotten		0
29	outlet of Zamleather treatment	22.5		31000	8.0	207					
30	LEOPARDS HILL 2	24.6		681	6.8	404	2.42	34.10	chlorine	0	0
31	LEOPARDS HILL 1	24.2		695	7.0	403	3.35	46.50	0	0	0
32	Pestalozzi School Leopards Hill	24.1		225	6.4	207			0	0	0
33	outlet of gravel filter Pestalozzi			579		207			stale	milky	0
34	BAULENI	24.3		994	6.8	378	0.17	2.40	0	0	0
35	WT Kalikiliki	24.0		523	6.6	437	5.59	77.00	0	0	0
36	Chunga 2	24.6	31.00	1410	7.0	411	1.12	15.60	0	0	0
37	CHUNGA 1	24.8	31.00	1207	6.9	346	0.61	9.00	0	0	0
38	CHUNGA 6F	24.8	31.00	984	6.9	349	5.65	77.90	0	0	0
39	LWSC SOS	25.0	31.00	470	6.8	517	0.52	7.40	0	0	0
40	WT Chazanga new	24.6	30.00	481	7.1	384	0.93	13.00	0	0	0
41	WT Chazanga old	24.8	30.00	610	6.9	437	1.15	16.00	0	0	0
42	WT Kabanana	23.8	30.00	751	7.0	441	0.13	1.80	0	0	0
43	Tombwe 1	24.0		670	7.1	417	0.86	12.70	0	0	0
44	Tombwe 2	25.2		690	7.3	433	5.04	76.80	0	0	0
45	Decotex	24.7		849	6.9	414	0.62	9.00	0	0	0
46	MACHINERY HOUSE 3 (George)	24.4		763	6.9	369	0.00	0.00	0	0	0
47	MACHINERY HOUSE 6 (George)	24.6		538	7.3	377	1.25	18.60	0	0	0

B. In Situ Physical Parameters

ID	Sample name	T_{H20} °C	T_{AIR} °C	EC µS/cm	pH	ORP EH/SHE	O_2 mg/l	O_2sat %	Odour 0=none	Colour 0=none	Turbidity 0=none
48	MACHINERY HOUSE 2 (George)	25.1		561	7.1	304	0.88	13.90	0	0	0
49	Zambian Breweries	26.0		688	7.1	371	6.48	92.50	0	0	0
50	WT Chipata	25.1		664	7.0	445	0.91	12.70	0	0	0
51	NRDC 2	24.4	25.00	740	7.1	405	7.58	109.80	0	0	0
52	NRDC 1	24.4		754	7.0	430	8.09	112.90	0	0	0
53	MULUNGUSHI 6H	23.8		841	6.9	294	3.56	51.00	0	0	0
54	MULUNGUSHI 6A	25.0		736	7.0	280	2.42	31.80	oil	brown	turbid
55	LUMUMBA RD 4A	25.2		748	7.0	336	2.20	31.70	0	0	0
56	Aquarite	24.4		1232	6.7	408	0.60	8.00	0	0	0
57	Chikumbi Social Development	26.5	28.00	550	7.0	362	0.88	12.60	0	0	0
58	WT N'gombe	24.6	27.00	191	6.5	116	0.11	1.60	iron	reddish	0
59	UNZA 1 Education	24.6	24.00	640	7.0	197	1.09	15.30	iron	reddish	turbid
60	Chinyanja B Sch Monitoring	26.3		883	6.7	410	2.17	30.90	iron	reddish	turbid
62	Roma (Doetsch)	24.5		938	6.6	352	1.23	17.10	iron	reddish	0
63	Lusaka Golf Club 1	23.3		767	7.1	419	2.92	39.40	0	0	0
64	Lusaka Golf Club 2	23.8		947	6.9	361	0.13	1.70	0	0	0
65	Leopards Hill Secondary	23.4		121	5.8	372	8.72	121.00	0	0	0
66	F55 ZAWA Park 4	24.3		670	6.8	372	3.27	47.20	0	0	0
67	F55 ZAWA Park 4	24.3		708	6.7	336	2.58	41.80	0	0	0
68	Forest 26 BH7	24.1		539	7.1	219	1.87	26.20	iron	reddish	0
69	Libala (Mr. Katebe)	25.2		545	7.2	391	1.18	16.50	0	0	0
70	Libala (Pastor Phiri)	25.1		603	7.1	360	2.15	30.10	0	0	0
71	Woodlands (Stoll)	24.0		444	6.2	395	0.35	4.80	0	0	0
73	Air Force Barracks/ Sekelela-Z	23.0		865	7.0	196	0.64	8.50	0	0	0
74	SDA Campsite Monitoring	24.8		602	7.0	366	0.13	1.90	0	0	0
75	Zesco 1 (Fly over)	24.8		723	6.9	379	0.02	0.30	0	0	0
76	Zesco 2 (Front area)	24.5		738	6.8	369	0.08	1.10	oil	0	0
77	Zesco 3 (NCC)	24.3		752	6.9	381	0.06	0.70	oil	0	0
78	Zesco 4 (Clinic)	24.5		634	7.0	314	0.03	0.50	oil	0	0
79	Maschinery House 8 (George)	24.7		476	7.3	394	0.06	8.30	0	0	0
80	Maschinery House 7 (George)	24.7		406	7.4	383	0.73	10.10	0	0	0
81	Maschinery House 5 (George)	25.6		665	7.1	392	3.15	44.80	0	0	turbid
82	Total HQ - Depot	24.6		985	7.1	293	0.06	1.00	oil	0	0
83	Engen HQ - Depot	23.5		767	6.9	367	0.53	7.10	0	0	0
84	BP Depot	26.6		681	7.1	74	0.12	1.80	oil	0	0
85	BP Kafue Rd	25.7	25.00	1057	7.2	338	2.29	32.60	0	0	0
86	Petroda Kafue Rd	24.9		683	7.1	299	0.04	0.60	0	0	0
87	BP Castle	25.7		652	7.5	340	3.77	52.60	0	0	0
88	Engen Mumbwa Rd	24.4		647	7.2	220	0.55	7.60	0	0	0
89	Petroda Kalingalinga	24.0		677	7.0	363	0.91	12.30	0	0	0
90	Engen Chinika	25.9		1423	7.0	280	0.38	5.20	0	0	0
91	Total Great East Road	25.2		835	6.8	23	0.26	3.70	oil	0	0
92	Total Matero	24.1		628	6.6	320	2.53	31.40	oil	0	0
93	Total Independence Statium	24.4		540	5.9	261	0.13	1.80	oil	0	0

C. Laboratory Physical Parameters

ID	Sample name	Lab	EC µS/cm	EC_cal µS/cm	T_Hard cal mg/l $CaCO_3$	Hardness class	Water Type
1	WT Garden	BGR	709	707	19	5	Ca-Mg-HCO3
2	Mazyopa E1	BGR	896	881	24.7	5	Ca-Mg-HCO3
3	Mazyopa E3	BGR	810	803	22.3	5	Ca-Mg-HCO3
4	PARERINYATWA	BGR	769	761	21.1	5	Ca-Mg-HCO3
5	Northmead 2	BGR	847	831	23	5	Ca-Mg-HCO3
6	INT. SCH 6B	BGR	765	745	21.2	5	Ca-Mg-HCO3
7	MASS MEDIA 1 (MM1)	BGR	709	687	19.7	5	Ca-Mg-HCO3
8	WATERWORKS 2	BGR	663	663	20.2	5	Ca-Mg-HCO3
9	SHOWGROUNDS	BGR	776	762	22.7	5	Ca-Mg-HCO3
10	JOHN HOWARD	BGR	924	876	22.2	5	Ca-HCO3
11	Libala South	BGR	562	486	14	4	Ca-Mg-HCO3
12	SHAFT 5, Pump No 1	BGR	641	623	19.5	5	Ca-Mg-HCO3
13	LILAYI ROAD 1	BGR	586	572	18	4	Ca-Mg-HCO3
14	NIPA	BGR	717	720	20.7	5	Ca-Mg-HCO3
15	CHELSTON 1	BGR	736	704	18.5	5	Ca-HCO3
16	CHAINDA	BGR	1330	1264	28.7	5	Ca-HCO3
17	AVONDALE new	BGR	716	703	20.3	5	Mg-Ca-HCO3
18	AVONDALE 3	BGR	519	508	15.8	4	Ca-Mg-HCO3
19	Mumbwa Roadside 4	BGR	784	764	18.8	5	Ca-Mg-HCO3
20	Mumbwa Roadside 6	BGR	820	795	18.7	5	Ca-Mg-HCO3
21	WT Kanyama	BGR	1212	1161	24.5	5	Ca-Mg-HCO3
22	John Laing - Dutch Reform	BGR	902	891	18.5	5	Ca-Mg-HCO3
23	WT Chibolya	BGR	1096	1035	22.8	5	Ca-Mg-Na-
24	WT JOHN LAING	BGR	872	837	19.8	5	Ca-Mg-HCO3
25	WT Freedom BH2	BGR	1076	1061	28.4	5	Ca-Mg-HCO3
26	Mt. Makulu	BGR	978	979	26.8	5	Mg-Ca-HCO3
27	Mt. Makulu Lutheran Church	BGR	1000	959	27.2	5	Ca-Mg-HCO3
28	Zamleather	BGR	2910	2967	43.1	6	Na-Ca-Cl-HCO3
29	outlet of Zamleather treatment	BGR	31000				
30	LEOPARDS HILL 2	BGR	681	688	20.5	5	Ca-HCO3
31	LEOPARDS HILL 1	BGR	695	691	20.2	5	Ca-HCO3
32	Pestalozzi School Leopards Hill	BGR	225	173	3.9	1	Ca-Mg-Na-
33	outlet of gravel filter Pestalozzi	BGR	579	457	8.5	3	Ca-NH4-HCO3
34	BAULENI	BGR	994	985	26.9	5	Ca-HCO3
35	WT Kalikiliki	BGR	523	512	12	4	Mg-Ca-Na-
36	Chunga 2	BGR	1410	1456	37	6	Ca-Mg-HCO3
37	CHUNGA 1	BGR	1207	1214	29.4	5	Ca-Mg-HCO3
38	CHUNGA 6F	BGR	984	980	25.4	5	Ca-Mg-HCO3
39	LWSC SOS	BGR	470	437	11.8	3	Ca-Mg-HCO3
40	WT Chazanga new	BGR	481	475	12.7	4	Ca-HCO3
41	WT Chazanga old	BGR	610	617	16.8	4	Ca-Mg-HCO3
42	WT Kabanana	BGR	751	755	19.7	5	Ca-Mg-HCO3
43	Tombwe 1	BGR	670	640	16.2	4	Ca-Mg-HCO3
44	Tombwe 2	BGR	690	674	17.5	4	Ca-Mg-HCO3
45	Decotex	BGR	849	827	22.6	5	Ca-Mg-HCO3
46	MACHINERY HOUSE 3 (George)	BGR	763	751	19.7	5	Ca-Mg-HCO3
47	MACHINERY HOUSE 6 (George)	BGR	538	526	14.8	4	Ca-Mg-HCO3

C. Laboratory Physical Parameters

ID	Sample name	Lab	EC µS/cm	EC_cal µS/cm	T_Hard cal mg/l $CaCO_3$	Hardness class	Water Type
48	MACHINERY HOUSE 2 (George)	BGR	561	541	14.8	4	Ca-Mg-HCO3
49	Zambian Breweries	BGR	688	698	18.6	5	Ca-Mg-HCO3
50	WT Chipata	BGR	664	654	17.3	4	Ca-HCO3
51	NRDC 2	BGR	740	719	20.5	5	Ca-Mg-HCO3
52	NRDC 1	BGR	754	717	21	5	Ca-Mg-HCO3
53	MULUNGUSHI 6H	BGR	841	807	23.5	5	Ca-Mg-HCO3
54	MULUNGUSHI 6A	BGR	736	699	20.2	5	Ca-Mg-HCO3
55	LUMUMBA RD 4A	BGR	748	747	19.1	5	Ca-Mg-HCO3
56	Aquarite	BGR	1232	1181	24.2	5	Ca-Mg-HCO3
57	Chikumbi Social Development	BGR	550	554	16.9	4	Ca-Mg-HCO3
58	WT N'gombe	BGR	191	152	2.8	1	Mg-Ca-HCO3
59	UNZA 1 Education	BGR	640	685	20.4	5	Ca-Mg-HCO3
60	Chinyanja B Sch Monitoring	BGR	883	885	28.1	5	Ca-Mg-HCO3
62	Roma (Doetsch)	BGR	938	934	23.2	5	Ca-Mg-HCO3
63	Lusaka Golf Club 1	BGR	767	767	20.6	5	Ca-Mg-HCO3
64	Lusaka Golf Club 2	BGR	947	929	22.9	5	Ca-Mg-Na-
65	Leopards Hill Secondary	BGR	121	115	2	1	Na-Mg-Ca-
66	F55 ZAWA Park 4	BGR	670	668	21.3	5	Ca-Mg-HCO3
67	F55 ZAWA Park 4	BGR	708	725	23.3	5	Ca-Mg-HCO3
68	Forest 26 BH7	BGR	539	541	17	4	Ca-Mg-HCO3
69	Libala (Mr. Katebe)	BGR	545	559	15.4	4	Ca-Mg-HCO3
70	Libala (Pastor Phiri)	BGR	603	601	17.7	4	Ca-Mg-HCO3
71	Woodlands (Stoll)	BGR	444	440	10.7	3	Ca-Mg-HCO3
73	Air Force Barracks/ Sekelela-Z	BGR	865	864	26.8	5	Ca-Mg-HCO3
74	SDA Campsite Monitoring	BGR	602	613	19.6	5	Ca-Mg-HCO3
75	Zesco 1 (Fly over)	BGR	723	743	21.4	5	Ca-Mg-HCO3
76	Zesco 2 (Front area)	BGR	738	746	21.3	5	Ca-Mg-HCO3
77	Zesco 3 (NCC)	BGR	752	773	21.5	5	Ca-Mg-HCO3
78	Zesco 4 (Clinic)	BGR	634	648	18.3	5	Ca-Mg-HCO3
79	Maschinery House 8 (George)	BGR	476	489	13.6	4	Ca-Mg-HCO3
80	Maschinery House 7 (George)	BGR	406	416	11.9	3	Ca-Mg-HCO3
81	Maschinery House 5 (George)	BGR	665	675	19.5	5	Ca-Mg-HCO3
82	Total HQ - Depot	BGR	985	989	24.9	5	Ca-Mg-HCO3
83	Engen HQ - Depot	BGR	767	769	22.8	5	Ca-Mg-HCO3
84	BP Depot	BGR	681	671	17	4	Ca-Mg-HCO3
85	BP Kafue Rd	BGR	1057	1057	24.5	5	Ca-Mg-Na-
86	Petroda Kafue Rd	BGR	683	689	18.7	5	Ca-Mg-HCO3
87	BP Castle	BGR	652	649	12.7	4	Ca-Na-HCO3
88	Engen Mumbwa Rd	BGR	47	658	19.2	5	Ca-Mg-HCO3
89	Petroda Kalingalinga	BGR	677	686	20.2	5	Ca-Mg-HCO3
90	Engen Chinika	BGR	1423	1409	24.8	5	Na-Ca-Mg-
91	Total Great East Road	BGR	835	854	25.6	5	Ca-Mg-HCO3
92	Total Matero	BGR	628	597	13.5	4	Ca-Mg-HCO3
93	Total Independence Statium	BGR	540	427	4.4	2	Na-HCO3

D. Sum Parameters and Microbiological Indicators

ID	Sample name	NPOC mg/l	TIC mg/l	Total Coliforms Most Probable No.	E. coli MPN
1	WT Garden	1.2	78		
2	Mazyopa E1	0.8	113	50.4	17.3
3	Mazyopa E3	0.3	92		
4	PARERINYATWA	0.3	99.5	<1	<1
5	Northmead 2	0.1	121	1	1
6	INT. SCH 6B	0.1	106	223	<1
7	MASS MEDIA 1 (MM1)	0.1	98.3	<1	<1
8	WATERWORKS 2	0	89.2	12.6	<1
9	SHOWGROUNDS	0.1	102	185	<1
10	JOHN HOWARD	0.1	65.9	3.1	<1
11	Libala South	0	56	3.1	1
12	SHAFT 5, Pump No 1	0	104	57.3	4.1
13	LILAYI ROAD 1	0	77.9	6.3	<1
14	NIPA	0.2	95	51.2	<1
15	CHELSTON 1	0.3	83	33.6	<1
16	CHAINDA	0.2	82.2	4.1	1
17	AVONDALE new	0.2	87.4	12.2	<1
18	AVONDALE 3	0	74.2	791.5	2
19	Mumbwa Roadside 4	0.3	71	<1	<1
20	Mumbwa Roadside 6	0.4	78.1	30.1	<1
21	WT Kanyama	0.7	85.2	2	<1
22	John Laing - Dutch Reform	0.5	64.9	71.7	1
23	WT Chibolya	0.4	70.3	1	<1
24	WT JOHN LAING	0.2	69	14.6	3
25	WT Freedom BH2	0.3	109	<1	<1
26	Mt. Makulu	0.4	120	143.9	7.3
27	Mt. Makulu Lutheran Church	0.4	121	98.7	2
28	Zamleather	0.9	98.1	2	1
29	outlet of Zamleather treatment	1340	510		
30	LEOPARDS HILL 2	0.3	101	32.7	<1
31	LEOPARDS HILL 1			15.8	<1
32	Pestalozzi School Leopards Hill			116.2	<1
33	outlet of gravel filter Pestalozzi			1011.2	1011.2
34	BAULENI	0.1	120	298.7	2
35	WT Kalikiliki	0.3	106	1	<1
36	Chunga 2	0.2	118	20.3	<1
37	CHUNGA 1	0.4	110	416	33.2
38	CHUNGA 6F	0.4	99.2	1011.2	<1
39	LWSC SOS	0.2	70.4	313	<1
40	WT Chazanga new	0.1	64.7	37.4	<1
41	WT Chazanga old	0.2	96	14.4	1
42	WT Kabanana	0.3	80.1	8.5	<1
43	Tombwe 1	0.3	72.9	<1	<1
44	Tombwe 2	0.2	70.9	629.4	11
45	Decotex	0.6	96.2	12	<1
46	MACHINERY HOUSE 3 (George)	0.5	89.4	4.1	3.1
47	MACHINERY HOUSE 6 (George)	0.1	66.5	88.6	<1

D. Sum Parameters and Microbiological Indicators

ID	Sample name	NPOC mg/l	TIC mg/l	Total Coliforms Most Probable No.	E. coli MPN
48	MACHINERY HOUSE 2 (George)	0.1	66.4	<1	<1
49	Zambian Breweries	0.2	82.3	42	1
50	WT Chipata	0	72	<1	<1
51	NRDC 2	0.2	107	3.1	<1
52	NRDC 1	0.2	103	11	<1
53	MULUNGUSHI 6H	0.3	119	<1	<1
54	MULUNGUSHI 6A	0.4	86.5	18.7	6.3
55	LUMUMBA RD 4A	0.4	78.2	32.7	1
56	Aquarite	1.9	102	1011.2	3
57	Chikumbi Social Development	0.2	82.9	1	2
58	WT N'gombe	0.2	31.3	272.3	1
59	UNZA 1 Education	0.5	98	6.3	<1
60	Chinyanja B Sch Monitoring	1.1	108	146.7	<1
62	Roma (Doetsch)	1	116	3.1	<1
63	Lusaka Golf Club 1			<1	<1
64	Lusaka Golf Club 2	0.4	125	18.5	<1
65	Leopards Hill Secondary	0.2	38	146.5	<1
66	F55 ZAWA Park 4	0.1	116	78.5	<1
67	F55 ZAWA Park 4	0.1	136	21.3	<1
68	Forest 26 BH7	0.1	75.3	86.2	<1
69	Libala (Mr. Katebe)	0.1	61.9	960.6	4.1
70	Libala (Pastor Phiri)	0	80.1	2	<1
71	Woodlands (Stoll)	0.3	80.9	1.1	<1
73	Air Force Barracks/ Sekelela-Z	1.6	116	<1	<1
74	SDA Campsite Monitoring	1.2	80.4	25.9	<1
75	Zesco 1 (Fly over)	4.8	99.7	18.5	<1
76	Zesco 2 (Front area)	3.2	114	185	<1
77	Zesco 3 (NCC)	2.3	101	2	<1
78	Zesco 4 (Clinic)	2	72.9	2	<1
79	Maschinery House 8 (George)	1.1	48.7	129.1	38.4
80	Maschinery House 7 (George)	1	41.1	344.1	152.9
81	Maschinery House 5 (George)	1.1	76.7	1	<1
82	Total HQ - Depot	1.4	78.9	<1	<1
83	Engen HQ - Depot	2.6	111	10.8	<1
84	BP Depot	1.8	76.8	17.1	<1
85	BP Kafue Rd			52.8	<1
86	Petroda Kafue Rd	1.4	79	<1	<1
87	BP Castle	2.1	44.4	64.4	<1
88	Engen Mumbwa Rd	1	78.4	75.9	<1
89	Petroda Kalingalinga	1.1	98.6	1	<1
90	Engen Chinika	1.8	49.7	<1	<1
91	Total Great East Road	3.4	138	248.9	<1
92	Total Matero	2	82.8	4.1	<1
93	Total Independence Statium	2.9	75.4	82	<1

E. Main & Minor Constituents

ID	Sample name	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	SO_4 mg/l	HCO_3 mg/l
1	WT Garden	21.1	1.1	94.5	25	0	0.005	0.002	0.23	27.5	12.3	0	33.2	375
2	Mazyopa E1	27.2	1.4	111	39.8	0	0.061	0.414	0.229	39.2	11.4	1.75	19.1	519
3	Mazyopa E3	20.2	0.9	113	28.3	0	0.003	0.097	0.236	35.1	37.5	0.01	22.7	420
4	PARERINYATWA	22.6	1.5	93	35	0	0.004	0.002	0.201	32.9	25.6	0.03	18.6	410
5	Northmead 2	26.9	0.6	117	28.9	0	0.007	0.002	0.099	30.7	17.1	0.01	20.3	484
6	INT. SCH 6B	18.4	0.6	106	27.8	0	0	0	0.089	27	14.7	0.01	11.7	437
7	MASS MEDIA 1 (MM1)	12.3	0.4	99.3	25.3	0	0.005	0	0.087	16.9	20.4	0	14.3	409
8	WATERWORKS 2	5.5	0.5	107	22.6	0	0	0	0.146	7.9	37.9	0.01	3.93	395
9	SHOWGROUNDS	11.3	0.3	114	29.4	0	0	0	0.067	24.2	14.5	0	15.9	448
10	JOHN HOWARD	27	1.1	136	14.1	0	0	0	0.445	48.6	175	0	10.2	298
11	Libala South	5.2	0.5	65.9	20.9	0	0.057	0.001	0.138	8.6	36.6	0	3.4	267
12	SHAFT 5, Pump No 1	1.1	0.3	111	17.4	0	0	0	0.33	1.6	16.1	0.02	0.99	412
13	LILAYI ROAD 1	0.8	0.2	89.1	23.9	0	0	0	0.182	1.7	16.7	0	0.61	374
14	NIPA	13.9	0.3	104	26.9	0	0.006	0.001	0.089	24.1	8.9	0	22.7	413
15	CHELSTON 1	23.6	2.8	103	17.8	0	0	0	0.155	38.1	10.7	0.01	12.9	385
16	CHAINDA	57.8	7.5	169	22	0.36	0.003	0.001	0.058	100	260	0.07	28.7	336
17	AVONDALE new	14.3	0.4	71.3	44.8	0	0	0	0.371	30.9	14.3	0	13.8	397
18	AVONDALE 3	1.2	0.7	59.2	32.9	0	0.041	0.001	0.168	3.2	11.9	0	1.42	331
19	Mumbwa Roadside 4	30.4	4	92.7	25.6	0	0.006	0	0.056	47.6	49.4	0.01	31.7	332
20	Mumbwa Roadside 6	38.2	6.4	90	26.6	0.16	0.003	0	0.042	56.5	47.1	0.04	34.9	334
21	WT Kanyama	71.6	11.4	117	35.6	3.4	0	0	0.061	108	130	0.02	43.9	387
22	John Laing - Dutch Reform	59	6.8	86.2	28	2.68	0.134	0.002	0.031	80.1	98.6	0.08	32.7	311
23	WT Chibolya	56.9	6.6	107	34.2	0.41	0.005	0.001	0.081	91.7	155	0.22	30.7	320
24	WT JOHN LAING	38.2	2.3	98.1	26.4	0.02	0.006	0	0.096	70	79.4	0	33.5	303
25	WT Freedom BH2	28.8	2	115	53.5	0	0	0	0.497	41.6	92.7	0	69.5	466
26	Mt. Makulu	26.9	3.1	79.9	68.1	0	0.01	0.007	1.026	23	19.6	0.01	84	521
27	Mt. Makulu Lutheran Church	20.2	3.2	107	53.2	0	0.373	0.004	0.414	32.8	73.3	0.02	22.6	517
28	Zamleather	308	1	208	61	0	0.005	0.021	0.041	534	109	0	287	438
29	outlet of Zamleather treatment													
30	LEOPARDS HILL 2	6	1	119	16.9	0	0.006	0	0.103	10.9	36.6	0	6.59	409
31	LEOPARDS HILL 1	5.1	4.4	118	16.2	0	0.006	0	0.103	9.1	43.4	0	9.78	403
32	Pestalozzi School Leopards Hill	9.5	1.9	17.6	6.3	0	0.041	0.009	0.125	2	1.24	0	0.21	112
33	outlet of gravel filter Pestalozzi	24.3	12.2	44.2	10.1	27.9	1.27	0.139	0.164	13.6	0	0	3.12	325
34	BAULENI	23.5	0.5	151	25.2	0.01	0.018	0.001	0.105	52	112	0.02	13.8	452
35	WT Kalikiliki	29.3	3.8	41.6	27	0	0.018	0.007	0.205	13.2	6.57	0.01	12.4	306
36	Chunga 2	42.3	1.2	160	63.5	0	0.017	0.077	0.179	132	171	0	62.4	476
37	CHUNGA 1	50.7	0.7	137	44.6	0	0.005	0.009	0.133	109	107	0	53.2	442
38	CHUNGA 6F	33.1	0.2	116	40.1	0	0.019	0	0.165	84.9	44.4	0.01	37.7	421
39	LWSC SOS	13.8	1.3	59.1	15.3	0	0.006	0.003	0.092	4	12.4	0.01	0.56	278
40	WT Chazanga new	15.3	1.1	76.3	8.8	0	0.022	0.005	0.138	9.7	4.21	0	2.21	298
41	WT Chazanga old	21.7	0.7	89.8	18.6	0	0.006	0.001	0.311	12.8	3.49	0	6.37	392
42	WT Kabanana	25.6	1.6	107	20.5	0	0.004	0.002	0.208	42.9	48.7	0	17.9	356
43	Tombwe 1	11.1	22.9	85.1	18.6	0.06	0.003	0	0.096	24.8	11.9	0	25.7	332
44	Tombwe 2	11.1	18.6	91.1	20.8	0	0	0	0.103	23.7	18.4	0.01	32	345
45	Decotex	15.7	0.3	118	26.4	0	0.008	0.008	0.097	59	17.9	0.01	42.6	385
46	MACHINERY HOUSE 3 (George)	24	2	96.2	27.1	0	0	0.001	0.19	32.1	26.4	0	28.2	399
47	MACHINERY HOUSE 6 (George)	8.4	0.4	76.7	17.6	0	0	0	0.145	14.4	11.1	0	12.9	303

E. Main & Minor Constituents

ID	Sample name	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	SO_4 mg/l	HCO_3 mg/l
48	MACHINERY HOUSE 2 (George)	10.6	1.3	77	17.6	0	0	0	0.119	16.6	14	0.02	19.1	293
49	Zambian Breweries	18.1	4.5	95.6	22.9	0	0.003	0.031	0.123	28.8	18.6	0	25.7	371
50	WT Chipata	14.4	1.7	107	10.4	0	0.003	0.001	0.17	37.1	60.4	0	3.16	302
51	NRDC 2	15.9	1.2	101	27.7	0	0.004	0.001	0.162	17.8	6.57	0	12.9	454
52	NRDC 1	13.6	1	98.9	31.4	0	0	0.022	0.178	15.2	11	0	10.2	451
53	MULUNGUSHI 6H	16.4	0.4	115	32.2	0	0.003	0.001	0.082	25.1	8.97	0.01	16.9	497
54	MULUNGUSHI 6A	11.1	0.7	97.1	28.8	0	0.353	1.27	0.132	18.8	11.3	0.08	19.8	417
55	LUMUMBA RD 4A	21.6	2.1	105	19.1	0.23	0.005	0.003	0.04	26.6	23.4	0.14	75	325
56	Aquarite	71.4	17.9	116	34.7	8.5	0.005	0.019	0.019	88	41.7	0.2	127	421
57	Chikumbi Social Development	1.8	0.5	86.2	21.2	0.22	0	0.02	0.216	2.6	14.4	0.03	4.04	360
58	WT N'gombe	5.6	2.4	9.9	6.3	0.65	7.36	0.431	0.11	9.5	2	0.06	0.11	78.4
59	UNZA 1 Education	8.3	1.2	91	33.5	0.01	0.25	0.195	0.311	9.9	0.07	0.03	21.5	434
60	Chinyanja B Sch Monitoring	7.4	1.2	120	49.4	0	0.01	0.016	0.169	12.6	36.7	0	1.91	571
62	Roma (Doetsch)	45.6	3.2	109	34.5	0	0.064	0.124	0.185	81.8	0.35	0	35.6	444
63	Lusaka Golf Club 1	29.4	1.5	84.4	38.2	0	0.005	0.023	0.154	31.5	8.03	0	19.6	446
64	Lusaka Golf Club 2	52.7	2.3	88.3	46	0	0.008	0.002	0.183	52.3	9.65	0	22.9	534
65	Leopards Hill Secondary	9.8	2.2	6.3	5	0	0.038	0.001	0.111	2.4	5.1	0	0.72	64.7
66	F55 ZAWA Park 4	0.9	0.3	116	21.9	0	0.004	0	0.408	0.9	6.82	0	0.4	462
67	F55 ZAWA Park 4	0.8	0.2	122	27.2	0	0.003	0.001	0.293	0.7	9.36	0	0.14	506
68	Forest 26 BH7	0.4	0.1	66.8	33.2	0.09	0.098	0.036	0.035	1	20	0.01	0.2	356
69	Libala (Mr. Katebe)	10.7	0.4	69.7	24.8	0	0.065	0.003	0.117	12.7	52.2	0.02	8.93	287
70	Libala (Pastor Phiri)	6.7	0.5	93.5	20.1	0	0.035	0.001	0.214	7.5	39.1	0	4.86	349
71	Woodlands (Stoll)	15.8	2	39.6	22.3	0	0	0.005	0.073	28.3	26.7	0	10.9	193
73	Air Force Barracks/ Sekelela-Z	7.2	1.1	116	46.1	0	0.292	0.059	0.099	32.2	22.3	0.03	9.86	515
74	SDA Campsite Monitoring	2	0.9	103	22.7	0	0.162	0.234	0.144	4	0.09	0	0.6	410
75	Zesco 1 (Fly over)	14.7	0.5	113	24.5	0	0.01	0.6	0.092	14.4	6.43	0.53	41.4	418
76	Zesco 2 (Front area)	17.3	2.1	110	25.6	0.01	0.015	0.589	0.092	14.3	1.33	0.06	31.2	450
77	Zesco 3 (NCC)	19.8	0.4	111	26	0	0.004	0.283	0.094	23.1	8.76	0.05	51	406
78	Zesco 4 (Clinic)	13.8	2.5	98.3	19.7	0.18	0.007	0.395	0.147	15.8	6.09	0.05	25	368
79	Maschinery House 8 (George)	8.6	1.1	71.3	15.7	0	0.004	0.003	0.146	18	3.05	0	20.9	255
80	Maschinery House 7 (George)	5.4	0.6	64.4	12.8	0	0.003	0.001	0.137	10	1.3	0.01	11.9	237
81	Maschinery House 5 (George)	12.2	1.3	101	23.4	0	0.004	0.001	0.176	18.2	32.1	0	12.3	372
82	Total HQ - Depot	42.1	1	124	33	0.08	0.014	0.077	0.159	91.6	10.8	0.05	52.7	417
83	Engen HQ - Depot	8.1	0.4	106	34.8	0	0.025	0.065	0.114	18.8	12	0.02	36.3	442
84	BP Depot	27.9	1.2	87.6	20.5	0.41	1.04	2.26	0.199	56.2	0.51	0.01	7.74	335
85	BP Kafue Rd	55.7	9.4	119	34.4	0	0.013	0.002	0.092	83	86.3	0.8	53.6	385
86	Petroda Kafue Rd	18.9	3	93.8	24.1	0.78	0.006	0.001	0.188	31.3	21.9	0	20.6	355
87	BP Castle	50.8	1	78.1	7.8	0	0.014	0.165	0.271	77.8	0.33	0.02	33.2	223
88	Engen Mumbwa Rd	8.1	0.1	97	24.7	0	0.003	0.002	0.184	18.2	32.4	0.01	24.7	337
89	Petroda Kalingalinga	12.3	0.9	97.2	28.6	0	0.004	0.001	0.245	15.1	19.6	0	17	395
90	Engen Chinika	134	11.4	114	38.5	0.15	0.018	0.074	0.033	158	27.7	0.02	110	472
91	Total Great East Road	16	1.2	126	34.9	0.24	1.53	1.4	0.168	29.8	0	0	11.1	533
92	Total Matero	30.5	3.9	71.1	15.6	0	0.034	0.239	0.106	53.5	14.3	0.03	10.4	269
93	Total Independence Statium	35	11.4	16.8	8.8	14.7	0.091	12.2	0.06	49.1	55.1	0.01	31.2	111

E. Main & Minor Constituents

ID	Sample name	SiO_2 mg/l	PO_4 tot mg/l	Σ CAT meq/l	Σ ANI meq/l	Electr. Bal. %
1	WT Garden	15.4	0.03	7.723	7.824	1.3
2	Mazyopa E1	20.3	0.06	10.053	10.244	1.9
3	Mazyopa E3	18.1	0	8.875	8.964	1.0
4	PARERINYATWA	31.8	0.17	8.545	8.461	1.0
5	Northmead 2	18.3	0	9.404	9.502	1.0
6	INT. SCH 6B	20.3	0	8.395	8.409	0.2
7	MASS MEDIA 1 (MM1)	15.1	0	7.584	7.811	3.0
8	WATERWORKS 2	9.6	0	7.453	7.397	0.7
9	SHOWGROUNDS	17.5	0	8.608	8.593	0.2
10	JOHN HOWARD	10.7	0	9.155	9.313	1.7
11	Libala South	7.6	0	5.258	5.287	0.6
12	SHAFT 5, Pump No 1	11.9	0	7.029	7.094	0.9
13	LILAYI ROAD 1	8.8	0	6.454	6.468	0.2
14	NIPA	14.5	0	8.018	8.069	0.6
15	CHELSTON 1	13.2	0	7.711	7.834	1.6
16	CHAINDA	11.3	0	12.974	13.123	1.1
17	AVONDALE new	16.7	0	7.877	7.916	0.5
18	AVONDALE 3	6.5	0	5.734	5.744	0.2
19	Mumbwa Roadside 4	7.1	0	8.159	8.244	1.0
20	Mumbwa Roadside 6	7.1	0	8.515	8.558	0.5
21	WT Kanyama	7.6	0	12.360	12.404	0.4
22	John Laing - Dutch Reform	5.6	0	9.497	9.631	1.4
23	WT Chibolya	7.3	0	10.821	10.980	1.5
24	WT JOHN LAING	6.6	0	8.791	8.924	1.5
25	WT Freedom BH2	51.1	0	11.450	11.779	2.8
26	Mt. Makulu	37.4	0	10.844	11.307	4.2
27	Mt. Makulu Lutheran Church	33.1	0	10.698	11.073	3.4
28	Zamleather	17.1	0	28.827	29.979	3.9
29	outlet of Zamleather treatment					
30	LEOPARDS HILL 2	9.8	0	7.619	7.744	1.6
31	LEOPARDS HILL 1	9	0	7.558	7.772	2.8
32	Pestalozzi School Leopards Hill	41	0.35	1.879	1.926	2.4
33	outlet of gravel filter Pestalozzi	42.2	17.7	5.977	5.967	0.2
34	BAULENI	11.3	0.16	10.649	10.976	3.0
35	WT Kalikiliki	39.4	0.36	5.676	5.767	1.6
36	Chunga 2	24.9	0.07	15.088	15.593	3.3
37	CHUNGA 1	17.3	0	12.732	13.160	3.3
38	CHUNGA 6F	15.4	0	10.536	10.805	2.5
39	LWSC SOS	28.8	0	4.845	4.886	0.8
40	WT Chazanga new	22.8	0.08	5.234	5.280	0.9
41	WT Chazanga old	25.8	0	6.978	6.991	0.2
42	WT Kabanana	20.6	0	8.184	8.214	0.4
43	Tombwe 1	8.3	0	6.851	6.876	0.4
44	Tombwe 2	8.3	0	7.218	7.293	1.0
45	Decotex	15.4	0	8.754	9.156	4.5
46	MACHINERY HOUSE 3 (George)	8.7	0	8.127	8.468	4.1
47	MACHINERY HOUSE 6 (George)	7.6	0	5.652	5.828	3.1

E. Main & Minor Constituents

ID	Sample name	SiO_2 mg/l	PO_4 tot mg/l	Σ CAT meq/l	Σ ANI meq/l	Electr. Bal. %
48	MACHINERY HOUSE 2 (George)	7.5	0	5.786	5.901	2.0
49	Zambian Breweries	9.3	0	7.561	7.736	2.3
50	WT Chipata	26.7	0.05	6.872	7.046	2.5
51	NRDC 2	13.4	0.03	8.048	8.326	3.4
52	NRDC 1	12.2	0	8.143	8.219	0.9
53	MULUNGUSHI 6H	18.5	0	9.114	9.354	2.6
54	MULUNGUSHI 6A	14.5	0	7.778	7.968	2.4
55	LUMUMBA RD 4A	7.3	0	7.819	8.022	2.6
56	Aquarite	7	0.03	12.672	12.707	0.3
57	Chikumbi Social Development	10.8	0	6.151	6.301	2.4
58	WT N'gombe	15.4	0	1.630	1.595	2.1
59	UNZA 1 Education	26.9	0.07	7.710	7.859	1.9
60	Chinyanja B Sch Monitoring	23.9	0	10.409	10.354	0.5
62	Roma (Doetsch)	27.6	0.05	10.354	10.343	0.1
63	Lusaka Golf Club 1	31.8	0.03	8.675	8.745	0.8
64	Lusaka Golf Club 2	31.6	0.08	10.545	10.870	3.0
65	Leopards Hill Secondary	43.2	0.55	1.222	1.237	1.2
66	F55 ZAWA Park 4	12.7	0	7.641	7.738	1.3
67	F55 ZAWA Park 4	11.5	0	8.369	8.482	1.3
68	Forest 26 BH7	5.9	0	6.094	6.191	1.6
69	Libala (Mr. Katebe)	8.1	0	6.003	6.096	1.5
70	Libala (Pastor Phiri)	8.8	0	6.638	6.674	0.6
71	Woodlands (Stoll)	50.2	0.35	4.553	4.627	1.6
73	Air Force Barracks/ Sekelela-Z	20.5	0.03	9.939	9.920	0.2
74	SDA Campsite Monitoring	9.9	0	7.137	6.854	4.0
75	Zesco 1 (Fly over)	9.3	0	8.333	8.240	1.1
76	Zesco 2 (Front area)	11.1	0	8.429	8.457	0.3
77	Zesco 3 (NCC)	11.4	0	8.564	8.515	0.6
78	Zesco 4 (Clinic)	10.4	0	7.218	7.106	1.6
79	Maschinery House 8 (George)	7.4	0.03	5.254	5.180	1.4
80	Maschinery House 7 (George)	6.2	0	4.518	4.442	1.7
81	Maschinery House 5 (George)	9.2	0	7.534	7.393	1.9
82	Total HQ - Depot	10.7	0.04	10.770	10.700	0.7
83	Engen HQ - Depot	18.1	0	8.527	8.731	2.4
84	BP Depot	10.1	0	7.447	7.256	2.6
85	BP Kafue Rd	8.2	0.04	11.434	11.182	2.2
86	Petroda Kafue Rd	8.3	0	7.607	7.493	1.5
87	BP Castle	6.6	0.03	6.785	6.562	3.4
88	Engen Mumbwa Rd	7.7	0	7.229	7.083	2.0
89	Petroda Kalingalinga	20.5	0.03	7.763	7.583	2.4
90	Engen Chinika	8.5	0.03	14.990	14.934	0.4
91	Total Great East Road	30.1	0.06	10.007	9.818	1.9
92	Total Matero	41.1	0.23	6.285	6.376	1.4
93	Total Independence Statium	8.5	0	4.628	4.747	2.5

F. Trace Elements (Selection)

ID	Sample name	Br	Li	Be	B [BO2]	Al	Ti	V	Cr-VI	Co	Ni	Cu	Pb	Zn	As
		mg/l	mg/l	µg/l	mg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	mg/l	µg/l
1	WT Garden	0.04	0	0.007	0	0	0.13	0.27	0.05	0.04	1.26	22.1	1.18	0.072	0.05
2	Mazyopa E1	0.03	0	0.006	0.02	0	0.1	1.31	0.01	0.41	0.7	1.19	0.17		0.1
3	Mazyopa E3	0.02	0	0.005	0.02	0	0.13	1.6	0.02	0.08	0.19	1.24	0.13		0.07
4	PARERINYATWA	0.05	0	0.042	0.01	0	0.17	1.23	0.03	0.14	1.76	0.95	0.11		0.05
5	Northmead 2	0.03	0	0.003	0.01	0	0.14	0.16	0.03	0.04	0.15	4.6	0.29		0.06
6	INT. SCH 6B	0.03	0	0.003	0	0	0.11	0.12	0.04	0.02	0.03	2.4	0.32		0.05
7	MASS MEDIA 1 (MM1)	0.02	0	0.005	0	0	0.1	0.1	0.08	0.02	0.66	0.85	0.13		0.05
8	WATERWORKS 2	0.01	0	0.004	0	0	0.13	0.3	0.31	0.03	0.09	1.48	0.27		0.06
9	SHOWGROUNDS	0.02	0	0.006	0	0	0.18	0.25	0.02	0.03	0.07	1.75	0.37		0.07
10	JOHN HOWARD	0.03	0.007	0.007	0	0	0.06	0.77	0.03	0.07	0.07	1.05	0.11		0.06
11	Libala South	0.01	0	0.003	0	0	0.06	0.33	0.02	0.04	0.07	1.97	0.36	0.266	0.05
12	SHAFT 5, Pump No 1	0	0.005	0.005	0	0	0.11	0.36	0.05	0.01	0.06	5.62	0.3		0.08
13	LILAYI ROAD 1	0.01	0.003	0.008	0	0	0.08	0.34	0.05	0.02	0.04	2.09	0.18		0.07
14	NIPA	0.02	0	0.006	0.01	0	0.12	0.32	0.02	0.04	0.21	3.95	2.47		0.08
15	CHELSTON 1	0.03	0	0.009	0.01	0	0.15	0.24	0.17	0.05	0.08	1.02	0.13		0.08
16	CHAINDA		0	0.007	0.01	0	0.17	0.25	0.02	0.1	0.13	1.28	0.18		0.09
17	AVONDALE new	0.02	0	0.006	0.01	0	0.14	0.88	0.02	0.04	0.12	2.83	0.23		0.07
18	AVONDALE 3	0	0	0.008	0.01	0.003	0.13	0.34	0.11	0.04	0.29	2.72	0.18		0.07
19	Mumbwa Roadside 4	0.03	0	0.003	0.02	0	0.1	0.64	0.06	0.1	0.1	3.53	1.25		0.08
20	Mumbwa Roadside 6	0.06	0	0.005	0.02	0	0.14	0.66	0.05	0.11	0.09	1.27	0.71		0.08
21	WT Kanyama	0.07	0	0.006	0	0	0.09	0.5	0.03	0.19	0.14	1.5	0.48		0.09
22	John Laing - Dutch Reform	0.06	0	0.003	0.01	0	0.08	0.32	0.04	0.21	0.12	0.37	0.05		0.08
23	WT Chibolya	0.07	0	0.005	0.01	0	0.05	0.46	0.02	0.15	0.09	1.52	0.5		0.1
24	WT JOHN LAING	0.06	0	0.003	0.01	0	0.13	0.41	0.02	0.09	0.1	1.69	0.64		0.07
25	WT Freedom BH2	0.03	0.005	0.007	0.02	0	0.17	6.63	7.2	0.15	0.22	1.24	0.45		0.12
26	Mt. Makulu	0.02	0.003	0.012	0.01	0.006	0.5	3.37	0.39	0.11	0.81	0.83	1.82		0.12
27	Mt. Makulu Lutheran Church	0.02	0.005	0.005	0.01	0	0.12	1.36	0.04	0.17	0.51	5.24	0.55	0.082	0.1
28	Zamleather	0.14	0	0.016	0.01	0	0.05	1.86	629	0.23	0.28	0.3	0.18		0.1
29	outlet of Zamleather treatment														
30	LEOPARDS HILL 2	0.02	0	0.005	0.02	0	0.07	0.27	0.04	0.03	0.05	2.46	2.22		0.05
31	LEOPARDS HILL 1	0.01	0	0.008	0.04	0	0.1	0.27	0.06	0.04	0.05	0.59	0.12		0.08
32	Pestalozzi School Leopards	0	0.007	0.026	0.01	0.077	2.89	3.05	0.09	0.09	0.36	0.67	0.06	0.227	0.1
33	outlet of gravel filter Pestalozzi	0.01	0.007	0.005	0.04	0.008	1.28	1.24	0.2	0.89	1.03	0.57	0.05		0.42
34	BAULENI	0.03	0	0.009	0	0	0.1	0.27	0.03	0.04	0.08	3.6	2.78		0.06
35	WT Kalikiliki	0.02	0.008	0.024	0.02	0	0.08	3.37	0.02	0.08	0.94	3.78	0.16		0.09
36	Chunga 2	0.12	0.003	0.005	0.02	0	0.13	1.08	0.03	0.26	0.21	3.52	1.94	0.086	0.09
37	CHUNGA 1	0.1	0	0.01	0.01	0	0.11	3.02	0.05	0.05	0.07	1.13	0.17		0.08
38	CHUNGA 6F	0.07	0	0.007	0.01	0	0.11	0.95	0.04	0.06	0.41	2.26	1.22		0.08
39	LWSC SOS	0.01	0	0.008	0.01	0.009	0.12	0.52	0.02	0.03	0.18	1.81	0.76		0.05
40	WT Chazanga new	0.03	0.006	0.025	0	0	0.1	0.12	0.03	0.16	0.41	15.1	1.13		0.07
41	WT Chazanga old	0.03	0	0.009	0	0	0.11	0.51	0.02	0.02	0.06	2.36	0.69		0.07
42	WT Kabanana	0.03	0	0.008	0	0.003	0.27	0.44	0.01	0.06	0.11	1.72	0.15		0.06
43	Tombwe 1	0.19	0	0.005	0.03	0	0.1	0.57	0.09	0.1	0.14	3.4	0.37		0.07
44	Tombwe 2	0.1	0	0.007	0.03	0	0.11	0.58	0.07	0.15	0.18	1.77	0.15		0.07
45	Decotex	0.09	0	0.009	0	0	0.08	1.49	0.04	0.1	0.16	3.31	0.42		0.07
46	MACHINERY HOUSE 3	0.03	0	0.007	0.01	0	0.08	19.5	0.05	0.08	0.26	0.97	0.08		0.15
47	MACHINERY HOUSE 6	0.03	0	0.005	0.02	0	0.12	0.46	0.08	0.03	0.02	0.36	0.05		0.07
48	MACHINERY HOUSE 2	0.03	0	0.007	0.01	0	0.14	0.94	0.04	0.04	0.05	1.67	0.11		0.07
49	Zambian Breweries	0.08	0	0.006	0.04	0	0.11	0.46	0.08	0.21	0.32	4.53	3.07		0.1
50	WT Chipata	0.06	0.003	0.004	0	0	0.17	0.16	0.04	0.02	0.08	2.21	0.21		0.04
51	NRDC 2	0.03	0	0.012	0	0	0.18	2.57	0.09	0.03	0.21	3.65	0.27		0.14
52	NRDC 1	0.02	0	0.007	0	0	0.12	4.04	0.03	0.12	0.27	3.4	0.21		0.07
53	MULUNGUSHI 6H	0.03	0	0.009	0	0	0.08	0.23	0.01	0.04	0.09	3.76	0.51		0.07
54	MULUNGUSHI 6A	0.04	0	0.005	0.01	0	0.11	0.16	0.01	0.92	0.82	0.9	0.11		0.17
55	LUMUMBA RD 4A	0.03	0	0.006	0.03	0	0.05	0.62	0.04	0.08	0.15	1.79	0.36		0.08

F. Trace Elements (Selection)

ID	Sample name	Br	Li	Be	B [BO2]	Al	Ti	V	Cr-VI	Co	Ni	Cu	Pb	Zn	As
		mg/l	mg/l	µg/l	mg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	mg/l	µg/l
56	Aquarite	0.17	0	0.006	0.04	0	0.06	0.3	0.03	0.18	0.28	2.02	0.1		0.08
57	Chikumbi Social Development	0.01	0	0.008	0	0	0.08	0.31	0.1	0.17	0.34	1.11	4.69		0.1
58	WT N'gombe	0.02	0.005	0.007	0	0.016	0.1	0.04	0.03	2.03	0.82	0.92	0.12		0.08
59	UNZA 1 Education	0.02	0	0.004	0	0.004	0.19	0.26	0.04	1.54	0.16	0.16	0.06		0.1
60	Chinyanja B Sch Monitoring	0.02	0	0.014	0	0	0.13	0.24	0.31	0.08	1.01	2.38	0.64		0.09
62	Roma (Doetsch)	0.04	0.006	0.011	0.05	0	0.13	1.16	0.04	0.43	0.72	1.37	0.12		0.09
63	Lusaka Golf Club 1	0.04	0.006	0.008	0.02	0	0.16	0.25	0.01	0.22	0.09	0.55	0.03		0.12
64	Lusaka Golf Club 2	0.07	0.004	0.004	0.01	0	0.11	0.22	0.06	0.05	0.11	1.6	0.23		0.17
65	Leopards Hill Secondary	0	0.007	0.087	0.01	0.056	1.49	1.35	0.17	0.09	0.69	1.56	0.16		0.07
66	F55 ZAWA Park 4	0.01	0.01	0.009	0	0	0.12	0.33	0.18	0.03	0.23	1.14	0.39		0.07
67	F55 ZAWA Park 4	0	0.011	0.01	0	0	0.1	0.33	0.33	0.03	0.38	1.43	1.23		0.06
68	Forest 26 BH7	0	0	0.006	0	0	0.09	0.12	0.08	0.22	0.55	0.2	0.04		0.06
69	Libala (Mr. Katebe)	0.02	0	0.006	0	0	0.1	0.26	0.02	0.1	0.17	4.1	0.53	0.197	0.06
70	Libala (Pastor Phiri)	0.01	0.003	0.007	0	0	0.13	0.25	0.04	0.05	0.1	3.74	1.17	0.351	0.06
71	Woodlands (Stoll)	0.03	0.004	0.034	0.01	0	0.16	1.52	0.04	0.16	1.91	1.65	0.1		0.06
73	Air Force Barracks/ Sekelela-	0.04	0	0.006	0	0	0.06	0.55	0.05	0.2	0.45	0.81	0.16	0.059	0.09
74	SDA Campsite Monitoring	0.01	0	0.013	0	0.003	0.15	0.12	0.12	1.04	1.2	0.45	8.88		0.12
75	Zesco 1 (Fly over)	0.03	0	0.004	0.04	0	0.11	0.68	0.01	0.38	0.27	1.07	0.57	0.06	0.09
76	Zesco 2 (Front area)	0.03	0	0.005	0.07	0	0.1	1.09	0.02	0.36	0.27	1.13	0.14		0.09
77	Zesco 3 (NCC)	0.07	0	0.007	0	0	0.14	1.29	0.01	0.36	0.23	0.96	0.13	0.055	0.08
78	Zesco 4 (Clinic)	0.03	0	0.01	0.07	0	0.08	0.89	0.02	0.43	0.56	1.05	0.16		0.08
79	Maschinery House 8 (George)	0.04	0	0.004	0.01	0	0.14	0.47	0.08	0.04	0.11	2.53	0.18		0.08
80	Maschinery House 7 (George)	0.02	0	0.004	0	0	0.07	0.5	0.05	0.02	0.08	0.6	0.08		0.08
81	Maschinery House 5 (George)	0.03	0	0.004	0	0	0.05	0.38	0.18	0.03	0.05	3.23	0.36	0.09	0.07
82	Total HQ - Depot	0.05	0	0.006	0	0	0.15	0.26	0.01	0.15	0.95	1.52	0.22		0.11
83	Engen HQ - Depot	0.1	0	0.009	0	0	0.1	2.09	0.01	0.13	0.27	3.61	0.23	0.215	0.07
84	BP Depot	0.03	0	0.008	0	0	0.09	0.08	0.03	2.45	0.75	0.48	0.16		0.95
85	BP Kafue Rd	0.08	0	0.007	0	0	0.15	0.54	0.02	0.16	0.12	0.49	0.07		0.08
86	Petroda Kafue Rd	0.04	0	0.005	0	0	0.12	0.49	0.03	0.06	0.06	0.71	0.16		0.08
87	BP Castle	0.06	0	0.005	0	0	0.04	0.14	0	0.69	0.36	1.22	0.03	0.18	0.22
88	Engen Mumbwa Rd	0.03	0	0.006	0	0	0.11	2.52	0.06	0.04	0.06	0.52	0.08		0.07
89	Petroda Kalingalinga	0.03	0	0.009	0	0	0.13	0.52	0.05	0.06	0.53	2.01	0.11		0.08
90	Engen Chinika	0.18	0	0.008	0.02	0	0.1	0.55	0.03	0.3	1.02	1.58	0.09		0.1
91	Total Great East Road	0.13	0	0.014	0	0.009	0.27	0.17	0.11	1.99	0.53	0.13	0.07		0.26
92	Total Matero	0.21	0.006	0.084	0	0	0.15	1.23	0.02	0.21	0.65	0.72	0.08	0.446	0.14
93	Total Independence Statium	0.14	0	0.317	0	0.005	0.15	0.04	0	39.7	8.33	1.01	0.07		0.1

F. Trace Elements (Selection)

ID	Sample name	Se	Rb	Sr	Y	Zr	Mo	Ag	Cd	Sn	Sb	Te	Cs	Ba	W	U
		µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l
1	WT Garden	0.03	1.91	0.113	0.108	0.003	0.018	0.029	0.056	0.08	0.048	0.015	0.014	0.006	0.013	1.74
2	Mazyopa E1	0.08	0.69	0.2	0.16	0.005	0.083	0.003	0.025	0.01	0.014	0.022	0.003	0.069	0.008	3.59
3	Mazyopa E3	0.16	0.89	0.168	0.139	0.003	0.064	0.002	0.032	0.02	0.011	0.022	0.017	0.032	0.01	2.61
4	PARERINYATWA	0.03	1.76	0.153	0.046	0.014	0.079	0.004	0.005	0.01	0.008	0.023	0.004	0.114	0.008	2.02
5	Northmead 2	0.05	1	0.123	0.135	0.004	0.046	0.004	0.008	0.08	0.014	0.019	0.008	0	0.007	3.86
6	INT. SCH 6B	0.13	1.08	0.106	0.031	0.002	0.028	0.003	0.005	0.03	0.006	0.007	0.006	0	0.007	2.23
7	MASS MEDIA 1 (MM1)	0.05	1.04	0.103	0.029	0.003	0.022	0.002	0.009	0.01	0.006	0.025	0.004	0	0.008	1.21
8	WATERWORKS 2	0.05	0.96	0.115	0.169	0.005	0.022	0.003	0.007	0.02	0.013	0.035	0.006	0.014	0.007	0.157
9	SHOWGROUNDS	0.09	0.63	0.099	0.171	0.004	0.094	0.002	0.006	0.03	0.012	0.014	0.006	0	0.006	1.52
10	JOHN HOWARD	0.09	2.49	0.201	0.219	0.002	0.034	0.002	0.005	0.02	0.018	0.014	0.023	0.039	0.011	0.32
11	Libala South	0.06	0.76	0.046	0.06	0.001	0.021	0.002	0.013	0.02	0.018	0.011	0.006	0.008	0.005	0.053
12	SHAFT 5, Pump No 1	0.08	0.68	0.113	0.172	0.006	0.017	0.02	0.005	0.03	0.012	0.009	0.009	0.011	0.008	0.173
13	LILAYI ROAD 1	0.05	0.46	0.064	0.132	0.004	0.014	0.008	0.007	0.03	0.008	0.034	0.006	0.008	0.005	0.098
14	NIPA	0.02	1.15	0.107	0.181	0.005	0.02	0.007	0.023	0.05	0.368	0.022	0.006	0.015	0.01	0.42
15	CHELSTON 1	0.03	4.18	0.406	0.22	0.003	0.018	0.003	0.005	0.01	0.025	0.016	0.021	0.036	0.008	0.951
16	CHAINDA	0.05	2.57	0.24	0.243	0.004	0.011	0.005	0.003	0.02	0.016	0.012	0.022	0.052	0.003	0.574
17	AVONDALE new	0.32	0.71	0.076	0.27	0.005	0.133	0.005	0.006	0.02	0.012	0.023	0.006	0.013	0.011	0.724
18	AVONDALE 3	0.1	1.82	0.047	0.064	0.009	0.082	0.037	0.023	0.1	0.37	0.016	0.123	0.008	0.006	0.168
19	Mumbwa Roadside 4	0.04	1.6	0.081	0.08	0.002	0.012	0.012	0.016	0.02	0.341	0.024	0.008	0.028	0.009	0.108
20	Mumbwa Roadside 6	0.04	1.86	0.084	0.077	0.002	0.012	0.003	0.01	0.03	0.394	0.013	0.006	0.034	0.006	0.104
21	WT Kanyama	0.03	8.43	0.121	0.07	0.003	0.006	0.005	0.014	0.02	0.459	0.019	0.09	0.037	0.007	0.166
22	John Laing - Dutch Reform	0.06	6.49	0.085	0.039	0.001	0.01	0.003	0.005	0.02	0.365	0.014	0.059	0.032	0.01	0.068
23	WT Chibolya	0.04	3.88	0.104	0.073	0.002	0.007	0.002	0.008	0.02	0.499	0.025	0.041	0.041	0.003	0.111
24	WT JOHN LAING	0.07	1.78	0.098	0.077	0.003	0.009	0.005	0.01	0.03	0.326	0.013	0.01	0.023	0.006	0.115
25	WT Freedom BH2	0.54	3.74	0.265	0.151	0.003	0.102	0.005	0.01	0.01	0.449	0.03	0.035	0.008	0.005	2.2
26	Mt. Makulu	0.57	6.36	0.201	0.122	0.02	0.515	0.001	0.02	0.01	1.76	0.015	0.075	0.029	0.02	4.32
27	Mt. Makulu Lutheran Church	0.46	1.08	0.268	0.07	0.002	0.284	0.003	0.015	0.02	0.352	0.02	0.01	0.037	0.028	3.46
28	Zamleather	0.1	1.01	0.29	0.031	0.021	0.492	0.003	0.006	0.02	0.468	0.008	0.014	0.063	0.009	8.26
29	outlet of Zamleather treatment															
30	LEOPARDS HILL 2	0.05	1.09	0.148	0.164	0.004	0.012	0.006	0.013	0.03	0.206	0.008	0.007	0.043	0.012	0.176
31	LEOPARDS HILL 1	0.06	1.61	0.139	0.173	0.003	0.014	0.018	0.008	0.02	0.414	0.018	0.008	0.091	0.009	0.192
32	Pestalozzi School Leopards	0.26	0.45	0.039	0.036	0.09	0.042	0.013	0.012	0.01	1.08	0.016	0.009	0.015	0.004	0.238
33	outlet of gravel filter Pestalozzi	0.08	20.3	0.109	0.02	0.049	0.138	0.002	0.002	0.02	2.09	0.018	0.049	0.03	0.026	0.025
34	BAULENI	0.03	1.23	0.184	0.22	0.005	0.018	0.003	0.02	0.04	0.294	0.018	0.012	0.018	0.014	0.299
35	WT Kalikiliki	0.16	0.47	0.193	0.011	0.003	0.421	0.002	0.01	0.03	0.739	0.014	0.003	0.012	0.008	2.52
36	Chunga 2	0.05	0.24	0.209	0.052	0.012	0.102	0.006	0.017	0.03	0.305	0.014	0.003	0.027	0.014	7.51
37	CHUNGA 1	0.05	0.92	0.167	0.15	0.006	0.037	0.002	0.009	0.02	0.653	0.014	0.004	0.021	0.012	1.44
38	CHUNGA 6F	0.08	0.87	0.148	0.203	0.007	0.049	0.003	0.014	0.04	0.936	0.028	0.032	0.006	0.029	1.66
39	LWSC SOS	0.01	0.94	0.089	0.218	0.002	0.016	0.002	0.006	0.02	0.667	0.031	0.003	0.035	0.007	0.665
40	WT Chazanga new	0.03	2.02	0.106	0.2	0.002	0.05	0.004	0.024	0.03	0.935	0.023	0.023	0.033	0.005	1.74
41	WT Chazanga old	0.14	2.03	0.183	0.137	0.003	0.027	0.003	0.008	0.03	0.608	0.021	0.012	0.002	0.009	1.91
42	WT Kabanana	0.04	0.8	0.126	0.087	0.005	0.02	0.002	0.024	0.02	0.832	0.021	0.003	0.003	0.009	1.93
43	Tombwe 1	0.04	2.73	0.102	0.086	0.003	0.023	0.002	0.009	0.03	0.363	0.023	0.012	0.033	0.012	0.159
44	Tombwe 2	0.06	5.34	0.102	0.065	0.004	0.023	0.001	0.007	0.02	0.556	0.026	0.02	0.027	0.005	0.194
45	Decotex	0.02	0.39	0.104	0.145	0.007	0.06	0.001	0.007	0.02	0.709	0.024	0.005	0.011	0.011	1.41
46	MACHINERY HOUSE 3	0.1	0.96	0.129	0.063	0.013	0.116	0.001	0.009	0.03	0.52	0.044	0.009	0.034	0.011	3.95
47	MACHINERY HOUSE 6	0.04	0.48	0.079	0.059	0.003	0.013	0.001	0.004	0.01	0.711	0.017	0.01	0.008	0.008	0.127
48	MACHINERY HOUSE 2	0.15	1.06	0.091	0.046	0.003	0.019	0.001	0.003	0.02	0.297	0.036	0.021	0.02	0.009	0.361
49	Zambian Breweries	0.07	1.93	0.111	0.095	0.003	0.059	0.002	0.011	0.04	0.815	0.019	0.024	0.152	0.008	0.215
50	WT Chipata	0.02	2.74	0.291	0.086	0.004	0.016	0.008	0.007	0.03	0.499	0.017	0.06	0.006	0.01	0.751
51	NRDC 2	0.2	1.39	0.31	0.158	0.007	0.046	0.003	0.011	0.04	0.692	0.027	0.015	0.046	0.01	2.12
52	NRDC 1	0.09	1.19	0.306	0.31	0.007	0.054	0.003	0.014	0.03	0.43	0.027	0.011	0.065	0.007	2.26
53	MULUNGUSHI 6H	0.05	0.61	0.117	0.216	0.004	0.056	0.003	0.011	0.04	0.487	0.029	0.006	0.008	0.009	2.93
54	MULUNGUSHI 6A	0.04	1.95	0.144	0.194	0.004	0.169	0.001	0.007	0.02	0.207	0.012	0.106	0.147	0.011	0.827
55	LUMUMBA RD 4A	0.04	1.35	0.098	0.145	0.003	0.022	0.002	0.004	0.03	0.333	0.029	0.018	0.017	0.008	0.154

F. Trace Elements (Selection)

ID	Sample name	Se	Rb	Sr	Y	Zr	Mo	Ag	Cd	Sn	Sb	Te	Cs	Ba	W	U
		µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l	µg/l
56	Aquarite	0.04	10.8	0.125	0.112	0.002	0.013	0.004	0.006	0.02	0.658	0.033	0.126	0.093	0.006	0.111
57	Chikumbi Social Development	0.11	2.39	0.092	0.061	0.012	0.165	0.001	0.047	0.01	0.271	0.014	0.024	0.013	0.014	1.57
58	WT N'gombe	0.02	3.66	0.032	0.08	0.004	0.153	0.001	0.014	0.02	0.904	0.012	0.025	0.005	0.007	0.019
59	UNZA 1 Education	0.02	0.91	0.22	0.054	0.014	3.55	0.001	0.003	0.02	1.31	0.03	0.002	0.039	0.035	3.68
60	Chinyanja B Sch Monitoring	0.22	4.24	0.195	0.308	0.037	0.34	0.001	0.009	0.03	0.009	0.018	0.043	0.056	0.021	1.03
62	Roma (Doetsch)	0.03	0.58	0.164	0.022	0.014	0.08	0.002	0.014	0.02	1.02	0.018	0.002	0.042	0.013	9.33
63	Lusaka Golf Club 1	0.04	0.62	0.109	0.071	0.005	0.861	0.006	0.012	0.01	0.444	0.024	0.007	0.04	0.009	4.99
64	Lusaka Golf Club 2	0.24	1.42	0.162	0.011	0.002	0.257	0.01	0.008	0.01	0.243	0.028	0.006	0.088	0.011	13.9
65	Leopards Hill Secondary	0.12	0.4	0.026	0.014	0.029	0.017	0.002	0.008	0.01	0.479	0.023	0.005	0.026	0.009	0.069
66	F55 ZAWA Park 4	0.06	0.62	0.115	0.197	0.005	0.049	0.002	0.017	0.02	0.224	0.028	0.013	0.017	0.099	0.173
67	F55 ZAWA Park 4	0.03	0.75	0.106	0.259	0.005	0.079	0.003	0.014	0.01	0.171	0.016	0.012	0.015	0.01	0.183
68	Forest 26 BH7	0.02	0.87	0.025	0.036	0.004	0.142	0.002	0.008	0.01	0.331	0.028	0.013	0.007	0.009	0.322
69	Libala (Mr. Katebe)	0.03	1.06	0.06	0.059	0.003	0.023	0.001	0.009	0.04	0.302	0.011	0.006	0.01	0.009	0.078
70	Libala (Pastor Phiri)	0.05	1.23	0.09	0.107	0.002	0.021	0.003	0.014	0.03	0.513	0.034	0.011	0.029	0.007	0.141
71	Woodlands (Stoll)	0.03	1.07	0.104	0.012	0.001	0.119	0.003	0.004	0.01	0.791	0.025	0.002	0.135	0.009	0.16
73	Air Force Barracks/ Sekelela-	0.02	1.74	0.145	0.037	0.018	0.116	0.003	0.007	0.02	0.019	0.019	0.005	0.028	0.057	1.36
74	SDA Campsite Monitoring	0.02	1.76	0.209	0.159	0.02	0.322	0.002	0.011	0.02	0.019	0.013	0.006	0.063	0.01	0.972
75	Zesco 1 (Fly over)	0.03	0.7	0.142	0.135	0.004	0.048	0.002	0.011	0.02	0.025	0.022	0.007	0.027	0.008	0.483
76	Zesco 2 (Front area)	0.03	0.47	0.221	0.226	0.004	0.065	0.002	0.012	0.01	0.027	0.021	0.005	0.074	0.006	0.37
77	Zesco 3 (NCC)	0.03	0.37	0.135	0.183	0.003	0.027	0.003	0.009	0.01	0.018	0.017	0.007	0.074	0.008	0.381
78	Zesco 4 (Clinic)	0.02	1.04	0.175	0.134	0.005	0.108	0.002	0.032	0.02	0.024	0.021	0.008	0.036	0.013	0.264
79	Maschinery House 8 (George)	0.03	0.73	0.079	0.031	0.002	0.02	0.002	0.007	0.01	0.877	0.017	0.009	0.013	0.009	0.151
80	Maschinery House 7 (George)	0.04	0.62	0.069	0.028	0.002	0.025	0.002	0.001	0.01	0.849	0.025	0.005	0.021	0.015	0.11
81	Maschinery House 5 (George)	0.07	1.26	0.106	0.086	0.005	0.013	0.003	0.006	0.03	0.01	0.014	0.022	0.015	0.008	0.179
82	Total HQ - Depot	0.02	1.31	0.16	0.116	0.003	0.233	0.001	0.007	0.02	0.012	0.012	0.035	0.08	0.005	0.511
83	Engen HQ - Depot	0.05	0.67	0.119	0.071	0.003	0.046	0.002	0.005	0.02	0.014	0.023	0.007	0.017	0.005	2.19
84	BP Depot	0.02	0.9	0.125	0.149	0.002	0.368	0.002	0.009	0.01	0.011	0.029	0.011	1.685	0.006	0.114
85	BP Kafue Rd	0.03	3.66	0.125	0.109	0.002	0.012	0.004	0.006	0.01	0.464	0.029	0.018	0.054	0.013	0.151
86	Petroda Kafue Rd	0.01	2.58	0.092	0.108	0.003	0.016	0.004	0.006	0.01	0.026	0.026	0.04	0.012	0.007	0.189
87	BP Castle	0.03	1.46	0.115	0.039	0.002	0.066	0.002	0.013	0.02	0.05	0.028	0.007	0.081	0.011	0.167
88	Engen Mumbwa Rd	0.05	0.29	0.086	0.087	0.003	0.032	0.001	0.008	0.01	0.021	0.024	0.004	0.011	0.008	0.206
89	Petroda Kalingalinga	0.06	1.35	0.097	0.22	0.012	0.029	0.003	0.007	0.01	0.006	0.022	0.009	0.008	0.007	3.36
90	Engen Chinika	0.03	3.72	0.153	0.162	0.004	0.048	0.005	0.014	0.01	0.043	0.039	0.016	0.062	0.007	0.204
91	Total Great East Road	0.02	1.71	0.132	0.191	0.043	0.14	0.001	0.005	0	0.022	0.036	0.008	0.114	0.009	1.4
92	Total Matero	0.05	1.16	0.115	0.013	0.004	0.172	0.001	0.025	0.02	0.487	0.026	0.003	0.074	0.015	2.14
93	Total Independence Statium	0.07	7.7	0.247	6.16	0.004	0.092	0.002	0.019	0	0.195	0.007	0.189	0.708	0.006	1.09

Annex 2

Zambian Drinking Water Standard

General Physical and Chemical Characteristics of Drinking Water

Characteristics	Maximum permissible limit (mg/litre)	Method of test ZS 312 Part
Cobalt (Co)	0.5	7
Colour (Hazen units or TCU)	15	5
Conductivity (umho/cm)	2300	4
Dissolved solids (total)	1500	2
Hardness (total) as Calcium carbonate $CaCO_3$	500	
pH	6.5-8.0	27
Turbidity (NTU Scale)	10	3
Taste	unobjectionable to most consumers	
	unobjectionable to most consumers	
Odour		1

Non -Toxic Chemical Substances in Drinking Water

Substance	Maximum Permissible Limit (mg/litre)	Method of test ZS 312 Part
Calcium (Ca)	200	6
Chloride(Cl)	250	17
Chlorine residue	0.2	17
Copper (Cu)	1.0	7
Iron(Fe)	1.0	28
Magnesium (Mg)	150	25
Sulphate (SO_4^{2-})	400	16
Zinc (Zn)	5	7
Phenolic compounds (as phenol)	0.002	20
Detergents (alkyl benzene sulphate)	1.0	29

Toxic Chemical Substances in Drinking Water

Substance	Maximum Permissible Limit (mg/litre)	Method of test ZS 312 Part
Arsenic (As)	0.05	10
Cadmium (Cd)	0.005	7
Chromium (Cr)	0.05	12
Cyanide (CN^-)	0.1	24
Fluoride (F^-)	1.5	11
Lead (Pb)	0.05	7
Mercury (Hg)	0.001	22
Manganese (Mn)	0.1	
Nitrates (NO^-_3	10	14
Nitrite	1	36
Selenium (Se)	0.01	15
Aluminium (Al)	0.2	30
Silver (Ag)	0.05	31

Pesticide Limits in Drinking Water

Pesticide	Maximum permissible limit (ug/litre)	Method of test ZS 312 Part
Aldrin/dieldrin	0.03	32
Chlordane	0.3	32
2,4-D	100	32
DDT	1	32
Endonsulfan	2	32
Endrin	0.2	32
Heptachlor and heptachlor epoxide	0.1	32
Hexachlorobenzene	0.01	32
Lindane (Gamma BHC)	3	32
Methoxychlor	30	32
Toxaphene	5	32