Groundwater Resources for Lusaka and selected Catchment Areas

TECHNICAL REPORT NO. 2

THE CHONGWE CATCHMENT:

A HYDROLOGICAL, HYDROGEOLOGICAL AND HYDROCHEMICAL CHARACTERIZATION FOR THE ESTABLISHMENT OF A CATCHMENT MANAGEMENT PLAN

Andrea Nick

Lusaka, November 2015

REPUBLIC OF ZAMBIA
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BGR Bundesanstalt für Geowissenschaften und Rohstoffe

Groundwater Resources for Lusaka and selected Catchment Areas

The Chongwe Catchment: A hydrological, hydrogeological and hydrochemical characterization for the establishment of a catchment management plan

Author: Andrea Nick (BGR)

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Project: Groundwater Resources for Lusaka and selected Catchment Areas

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SUMMARY

Authors: Andrea Nick

Title: The Chongwe Catchment: A hydrological, hydrogeological and hydrochemical characterization for the establishment of a catchment management plan

Keywords: Chongwe, Zambia, catchment assessment, hydrochemistry, stable isotopes

The relevance of groundwater use in the Chongwe catchment is marginal so far.

The only moderately yielding aquifer is the carbonate lense south-east of Chongwe town. This aquifer shows a very high level of direct recharge with extremely short lag times above a threshold of unsaturated zone storage capacity. This results in a high degree of vulnerability.

Overall, the water quality in the Chongwe catchment is good, but as described above can quite easily be put at risk. Findings from stable isotope analysis suggest a groundwater recharge process that includes direct recharge but is not ultimately clarified. Further sampling is suggested.

If population and economic growth continue in Chongwe, groundwater resources will play a more important role in future. To prevent pollution and overextraction, landuse planning has to consider results from future pumping tests in the carbonate aquifer and the limitation of risk factors like unsafe sanitation facilities or industrial water polluters.

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ABBREVIATIONS

BGR	Bundesanstalt für Geowissenschaften und Rohstoffe (Federal Institute for Geosciences and Natural Resources)
D	Deuterium
DE	Deuterium Excess
DO	Dissolved Oxygen
DWA	Department of Water Affairs
EC	Electrical conductivity
E_H	Redox potential referring to the standard hydrogen electrode
E-LMWL	Emmasdale Local Meteoric Water Line
EPSG	European Petroleum Survey Group
ET	(Actual) Evapotranspiration
Fm	Formation
GC-MS	Gas Chromatography Mass Spectrometry
GIS	Geographic Information System
GMWL	Global Meteoric Water Line
GReSP	Groundwater Resources Management Support Project
GRZ	Government of the Republic of Zambia
HR-ICP-MS	High Resolution Inductively Coupled Plasma Mass Spectrometry
ICP-OES	Inductively Coupled Plasma with Optical Emission Spectroscopy
LWSC	Lusaka Water and Sewerage Company
m asl	Meters above sea level
MAR	Mean annual rainfall
MEWD	Ministry of Energy and Water Development
ORP	Oxidation Reduction Potential
QGIS	Quantum Geographic Information System (Eigenname, mit rein?)
SLAP	Standard Light Atmospheric Precipitation
T	Temperature (water)
T_{air}	Air Temperature
TDS	Total dissolved solids
UNZA	University of Zambia
UTM	Universal Transversal Mercator
VSMOW	Vienna Standard Mean Ocean Water
WARMA	Water Resources Management Authority
WHO	World Health Organisation
ZDWS	Zambian Drinking Water Standard

LIST OF REPORTS COMPILED BY THE PROJECT IN PHASE III

Date	Authors	*Title*	Type
May 2015	Megan Jenkins; Andrea Nick; Dickson Mwelwa; Timothy Simwanza	*Impact of Small Scale Farming on the Chongwe River.* *Survey on Land Use and Water Abstraction from Chongwe River*	Report No. 1
September 2015	Andrea Nick	*The Chongwe Catchment: A hydrological, hydrogeological and hydrochemical characterization for the establishment of a catchment management plan*	Report No. 2
Nov. 2013	Tewodros Tena & Tobias El-Fahem	*Survey on the Technical Forum*	Advisory Report No. 01
March 2014	Andrea Nick; Tobias El-Fahem & Roland Bäumle	*Groundwater quality and vulnerability in the area of Lusaka West*	Advisory Report No. 02
May 2013	Martin Blümel	*IT-Infrastructure GReSP*	Technical Note 01

EXECUTIVE SUMMARY

The Groundwater Resources Management Support Programme (GReSP) is a bilateral cooperation project between the German Federal Institute for Geosciences and Natural Resources and the Zambian Water Resources Management Authority (WARMA) under the Ministry for Energy and Water Resources (MEWD). This report is the result of a geoscientific assessment of the Chongwe catchment between May 2014 and October 2015.

Data on groundwater in the Chongwe catchment is very scarce and various in quality. The relevance of groundwater use in the Chongwe catchment is marginal so far. In the Chongwe catchment the prevailing lithologies are schists, quartzites and basement complex rocks (gneiss and granite mainly).

The only moderately yielding aquifer is the carbonate lense south-east of Chongwe town. This aquifer shows a very high level of direct recharge with extremely short lag times above a threshold of unsaturated zone storage capacity. This results in a high degree of vulnerability.

The Chongwe catchment is part of the Middle Zambezi catchment. It covers a total area of 5,150 km^2. It consists of the following subcatchments: Upper Chongwe, Kanakantapa, Ngwerere, Chalimbana, Middle Chongwe, Luimba, and Lower Chongwe. The rivers which are mainly used for agricultural purposes are the Ngwerere, Chalimbana, as well as the Upper and Middle parts of Chongwe river. There are several dams along these rivers, Ray's Dam on the Upper Chongwe reach being the largest. In comparison to the agricultural dams, the LWSC water supply dam for Chongwe town is very small. It was not mapped on the remote sensing based landuse map (Hahne & Shamboko 2010) and is barely visible on the satellite images.

Annual average rainfall for a thirty-year period in Chongwe provided by World Meteorological Organization is 930 mm while the 2014/15 season delivered 772 mm of rainfall.

The main river gauging station 5-025 is on the western bank of Chongwe river at the Great East Road bridge. It has been equipped with an automatic pressure logger in March 2015 and three flood events were recorded.

Two water quality sampling campaigns were conducted, one during dry conditions and the other at the end of the rainy season. Overall, the water quality in the Chongwe catchment is good, but can easily be put at risk. Findings from stable isotope analysis suggest a groundwater recharge process that includes direct recharge but is not ultimately clarified. Further sampling is suggested.

If population and economic growth continue in Chongwe, groundwater resources will play a more important role in future. To prevent pollution and overextraction, landuse planning has to consider results from future pumping tests in the carbonate aquifer and the limitation of risk factors like unsafe sanitation facilities or industrial water polluters.

1. INTRODUCTION

The Chongwe catchment drew the attention of the public in the dry seasons of 2012, 2013 and 2014 due to the emergency water supply required in Chongwe town (GRZ 2012, 2013, 2014). The utility's dam on the Chongwe river which usually supplies most of Chongwe's residents had fallen dry in these years, letting thousands of people face drought conditions in years with average rainfall amounts. According to the records of the Department of Water Affairs reaching back to 1968 (with merely a few gaps), Chongwe river – at the gauging station 5-025 near Chongwe town – had previously recorded extremely low or no flow in very few years, namely in 1995, 1998 and 2005.

The Groundwater Resources Management Support Programme (GReSP), a bilateral cooperation project between the German Federal Institute for Geosciences and Natural Resources and the Zambian Water Resources Management Authority (WARMA) under the Ministry for Energy and Water Resources (MEWD), decided in May 2014 to direct its geoscientific focus onto the Chongwe catchment. The catchment had already been part of the work package in 2010-2012 (see Bäumle et al. 2012, Bäumle & Kang'omba 2012, Bäumle & Kang'omba 2013) but the persisting low water level situation caused WARMA to extend the evaluation period. For some topics, such as geology, this report refers to the publications of GReSP Phase 2, as they have not been reassessed.

Data on groundwater in the Chongwe catchment is very scarce and various in quality. This study therefore cannot offer answers to all hydrogeological questions and should rather be understood as a guideline for future reassessments when more data is available through a longer monitoring period.

All maps in this report were produced with the open source software QGIS. They are drawn in the Zambian reference datum and projection, Arc 1950 / UTM 35S, EPSG code 20935, which is based on the Clarke 1880 Spheroid. The scale of each main map is 1:650,000 while the overview inset maps are approximately 1:6,800,000.

The Chongwe catchment covers the districts of Lusaka (Ngwerere and Chalimbana subcatchments), Chongwe (all subcatchments, at least partially), Chibombo (Upper Chongwe and Kanakantapa) and Kafue (Lower Chongwe and Luimba). A very small fraction of the Luangwa district is inside the Lower Chongwe subcatchment. Under the late Zambian President Michael Chilufya Sata a number of new districts were created and some of the boundaries of old districts shifted, but the effects on the Chongwe catchment are marginal. The map published by the Surveyor General in early 2015 contains the new district boundaries as shown in Figure 1.

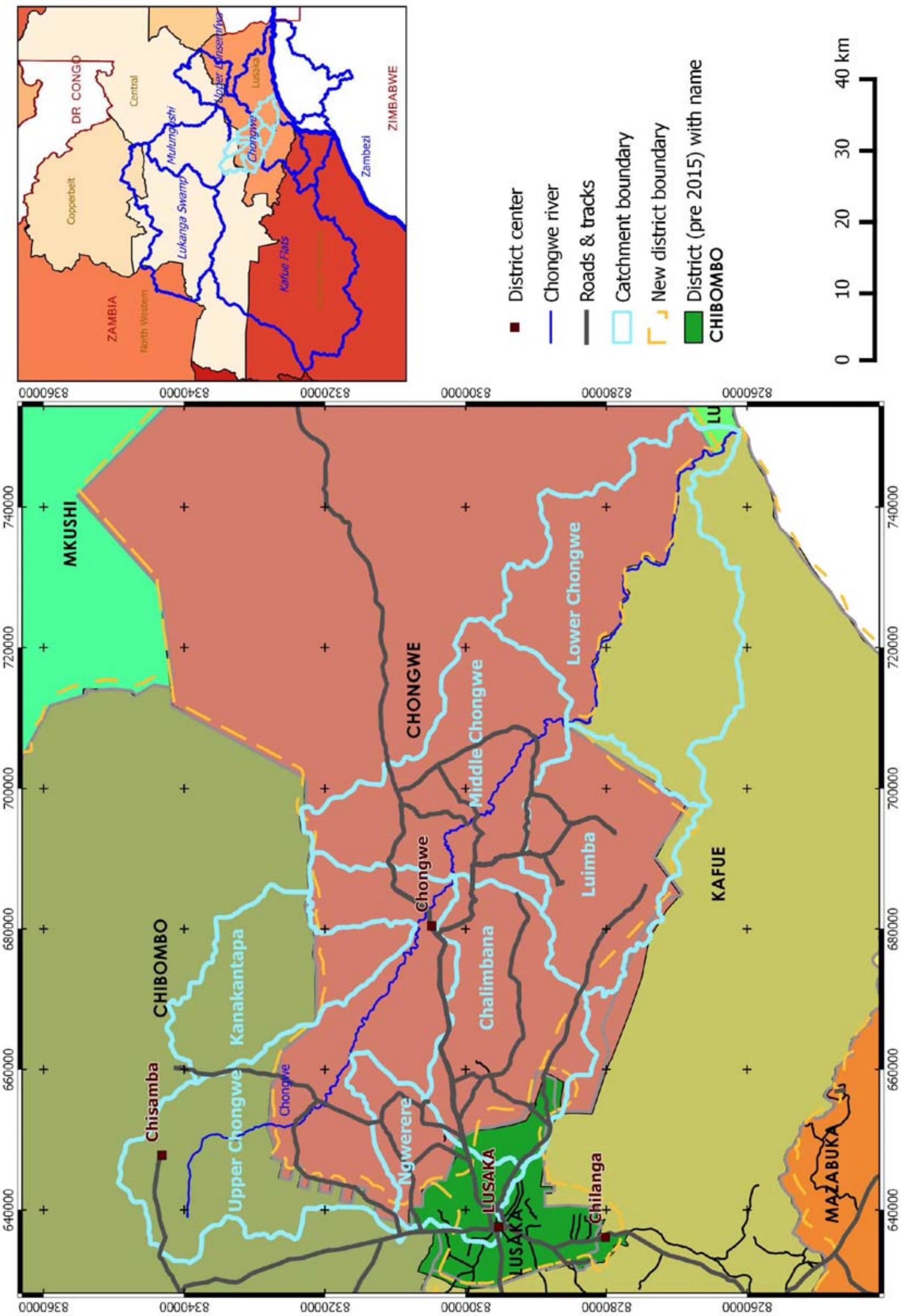

Figure 1: Administrative boundaries and district centres in the Chongwe catchment.

2. PHYSIOGRAPHY

2.1. TOPOGRAPHY

The Chongwe catchment can be divided into the mountainous lower part dominated by the Zambezi escarpment and the relatively flat upper part comprising all subcatchments but the Lower Chongwe (see Figure 2). The upper part ranges between an elevation of 1000 and 1300 meters above sea level while the Lower Chongwe reaches from approximately 1300 m (with peaks up to 1500 m) to the Zambezi River at 330 m asl.

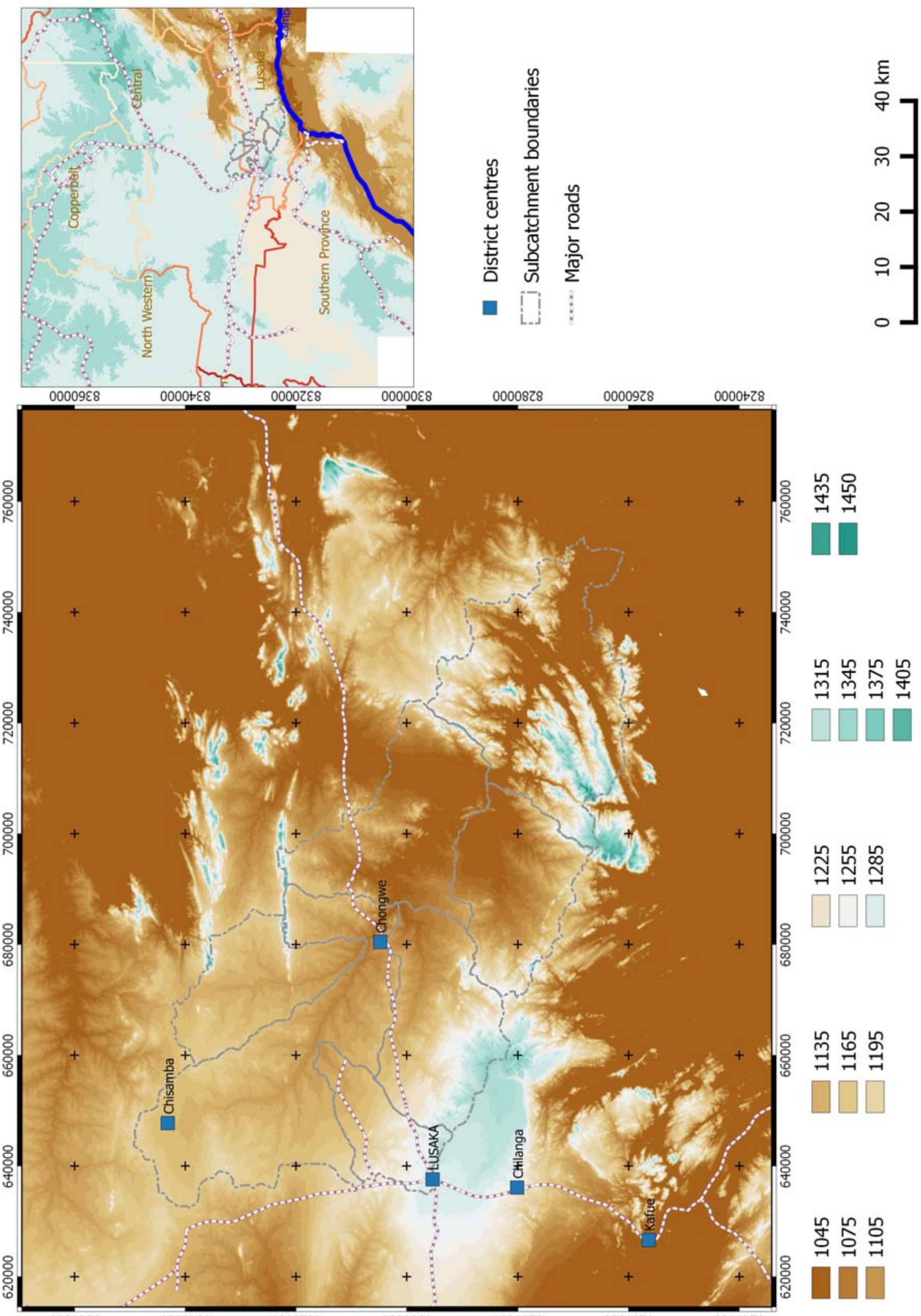

Figure 2: Digital elevation map of the Chongwe catchment (values in the legend are classes in meters above sea level).

2.2. CLIMATE

The Lusaka area including the Chongwe catchment has a tropical continental highland climate.

Annual average rainfall for a thirty-year period in Chongwe provided by World Meteorological Organization is 930 mm while the 2014/15 season delivered 772 mm of rainfall. Estimations of actual evapotranspiration (ET) range from 412 mm to 739 mm per year for Lusaka (Von Hoyer et al. 1978, YEC 1995, Maseka 1994, Nkhuwa 1996) with a potential ET of 1500 to 1600 mm/year (YEC 1995).

At the Chongwe Government Complex the District Agricultural Office runs a fully equipped climate station for the Meteorological Service. With the help of UNDP the data from this station is available online in real-time with daily values.

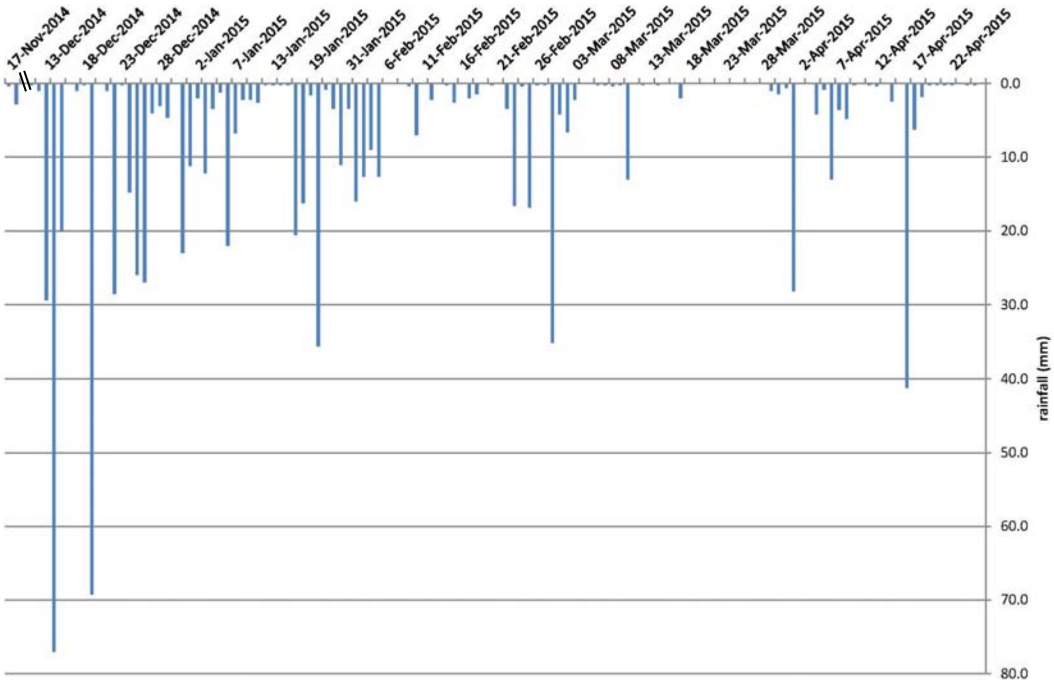

Figure 3: Rainfall for season 2014/15 in Chongwe, District Agricultural Office.

Figure 3 shows the rainfall data from this station for the rainy season 2014/2015. The first rains of the season occurred around November 17th. Between 17th / 18th of November and 11th of December no rainfall was recorded. Mid December, several days of strong rainfall occur including the heaviest event of the entire season with 77 mm on December 14th. After another strong event on the 19th of December yielding 69 mm the rains fall more evenly distributed until beginning of March when dry periods start occurring between single or multiple events. The rainfall events of April are of special interest in this report as runoff and groundwater levels were recorded since end of March. The strongest events of April occur on the 1st (28 mm), the 6th (13 mm) and the 16th (41 mm) and will be discussed in the relevant context in the following chapters.

3. GEOLOGY

In the Chongwe catchment the prevailing lithologies are schists, quartzites and basement complex rocks (gneiss and granite mainly). 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 dominating the south-western half of the Chongwe catchment comprises mainly of the Cheta formation's schists and carbonates. The north-eastern half as well as the Zambezi escarpment dominated eastern (downstream) part of the catchment dominated by the Zambezi Escarpment is underlain by the basement complex with Muva quartzites and schists. The geology of the catchment with the major faults is shown in Figure 4.

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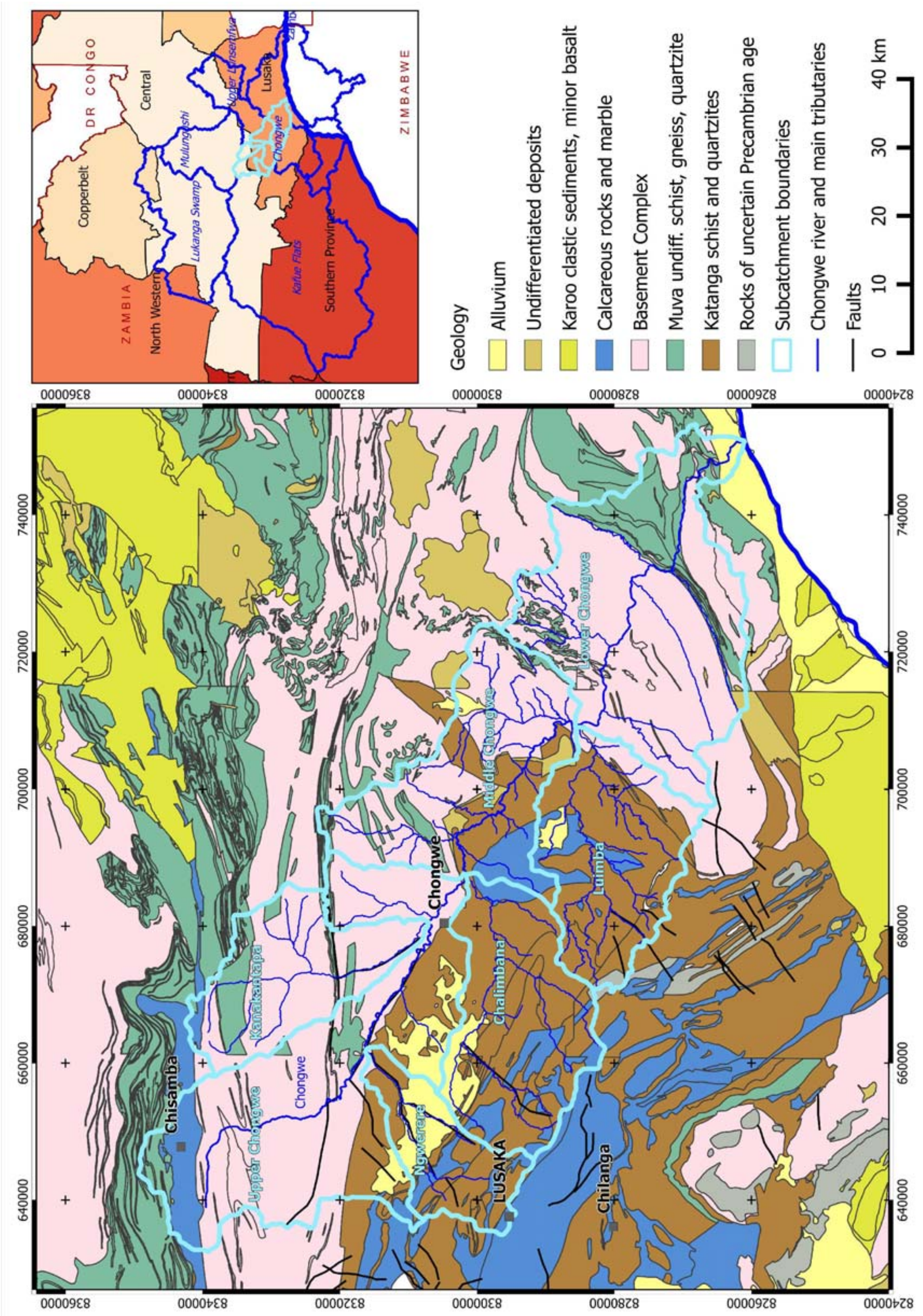

Figure 4: Geological map of the Chongwe catchment (adjusted and simplified after Simpson et al (1962, 1963), Cairney (1967) and Garrard (1968)).

4. HYDROLOGY

The Chongwe catchment is part of the Middle Zambezi catchment. It covers a total area of 5,150 km^2. It consists of the following subcatchments (

Figure 5):

Upper Chongwe	1,234 km^2
Kanakantapa	483 km^2
Ngwerere	299 km^2
Chalimbana	654 km^2
Middle Chongwe	762 km^2
Luimba	590 km^2
Lower Chongwe	1,131 km^2

The rivers which are mainly used for agricultural purposes are the Ngwerere, Chalimbana, as well as the Upper and Middle parts of Chongwe river. There are several dams along these rivers, Ray's Dam on the Upper Chongwe reach being the largest. In comparison to the agricultural dams, the LWSC water supply dam for Chongwe town is very small. It was not mapped on the remote sensing based landuse map (Hahne & Shamboko 2010) and is barely visible on the satellite images.

According to DWA, there are five (5) gauging stations in the Chongwe catchment (Figure 5), of which three stations are along the Chongwe river (5-013, 5-024 and 5-025) and one is situated on the Chalimbana river (5-029). The stations on the Upper Chongwe 5-013 and 5-024 are not serviced or read by gauge readers. If only one of the stations can be sustained in the long run, station 5-024 is better accessible and also records the Ngwerere river runoff as it is situated directly after the confluence.

The gauging station at the mouth of the Chongwe has not yet been established (labelled "New" in Figure 5). The site is located close to the gate of Lower Zambezi National Park. During the dry season it can be reached by car and during the rainy season by boat. Due to shallow water depth it is not possible to go further upstream by boat and there are very few roads or tracks and all of them are only accessible during the dry season (Krekeler 2015). During dry season the water levels of the Chongwe river are very low, and it is unclear if discharge measurements can be carried out from a boat at such low flow conditions. It might be necessary to use a wading instrument like the Acoustic Digital Current meter (ADC). However, so close to a National Park crocodiles and elephants are abundant and jeopardize the safety of measurements. Despite the scientific interest of measuring the total Chongwe runoff at such a station, it is not seen as a priority to build a gauging station at the mouth of the Chongwe.

If another gauging station can be built along the Chongwe, it should be situated just after the confluence of the Luimba River. The runoff monitored at such station would integrate all current anthropogenic activities on the Chongwe flow. As was found during field trips in March 2015, there is however no suitable site for a gauging station on the Chongwe on this reach of the river (Krekeler 2015). DWA continues to search for a suitable site.

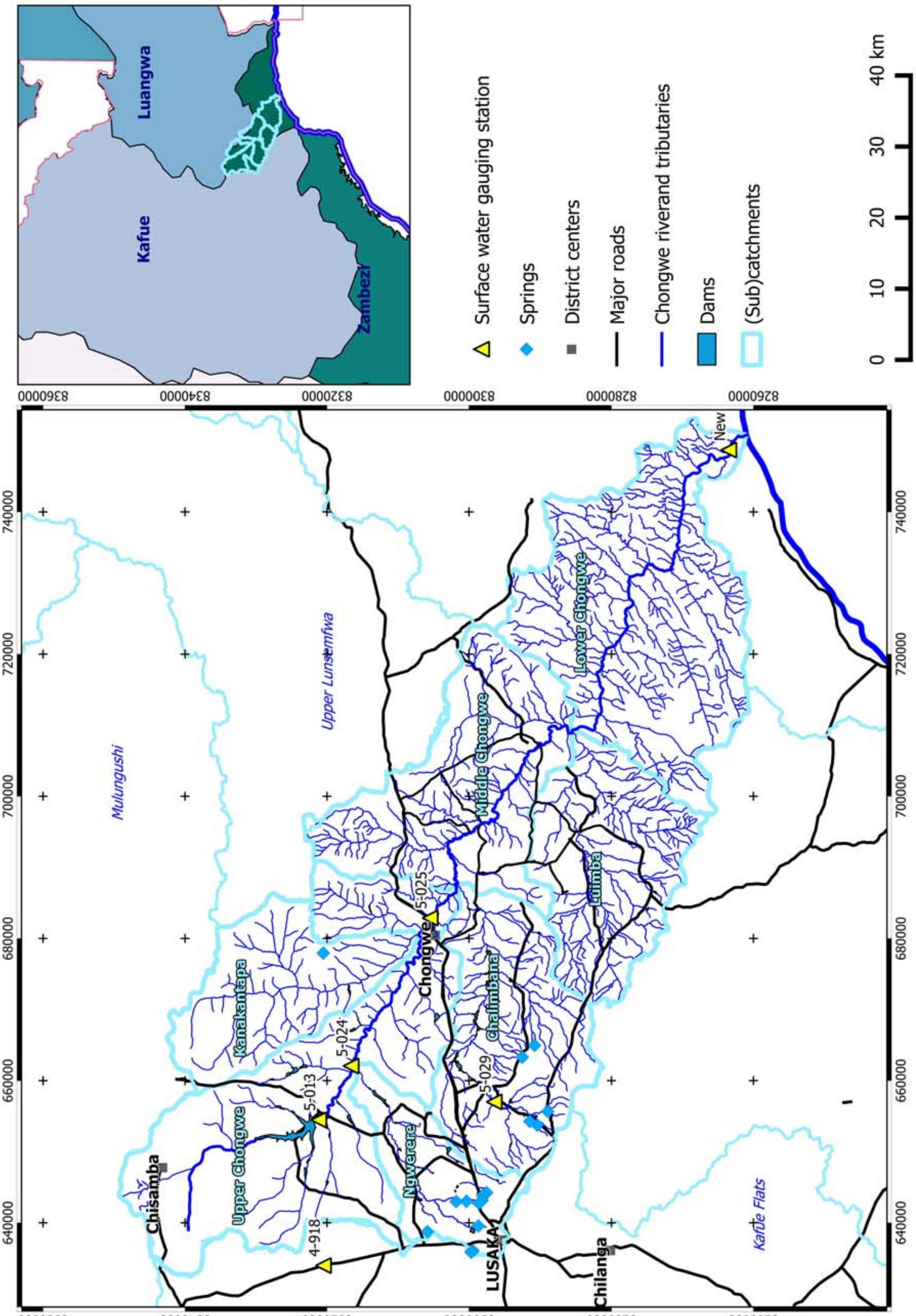

Figure 5: Subcatchments and main rivers within the Chongwe catchment.

Figure 6: Gauging station 5-024 on Chongwe river after Ngwerere confluence, March 2015.

Gauging station 5-025 is on the western bank of Chongwe river at the Great East Road bridge. It is being read by a gauge reader three times a day and has been equipped with an automatic pressure logger in March 2015. In the beginning of July 2015 the logger, which is attached to the lowest gauge plate at 1 m water level, fell dry and was subsequently removed to prevent theft.

As Figure 7 shows, the heavy rainfall events that took place late in the rainy season, which were recorded at Chongwe District Administration, could very well be linked to the runoff graph recorded by the water level logger at gauging station 5-025.

The rainfall event on the 1st of April 2015 yielded 28 mm but only sparked a response in the river on the 2nd of April at noon of 9.3 m^3/s. As the preceding major rainfall event had already been on the 10th of March, it is assumed that most rainfall infiltrated, causing direct groundwater recharge. Rainfall on the 4th of April of 4 mm and on the 6th of April of 13 mm were then enough to evoke a spike in the Chongwe runoff starting in the night from 5th to 6th of April reaching 17.8 m^3/s on the 9th of April. When the last major rainfall event of the season yielded a 41.2 mm on 15th of April, the system was well saturated and rainfall developed quickly into runoff, flooding the gauge station with 23.6 m^3/s on the 18th of April.

The lag time of 2-3 days suggests that the midsized catchment is relatively quick-responding to rainfall events. As the gauge station is downstream of the LWSC supply dam, a buffer effect from the dam also needs to be considered. The event of April 1st probably filled up the dam, and the events of April 6th and 16th caused a spill over which resulted in the flood waves recorded downstream at 5-025 station. To prove this assumption as correct, dam water level records from LWSC would be needed, but were unavailable at the time of this study.

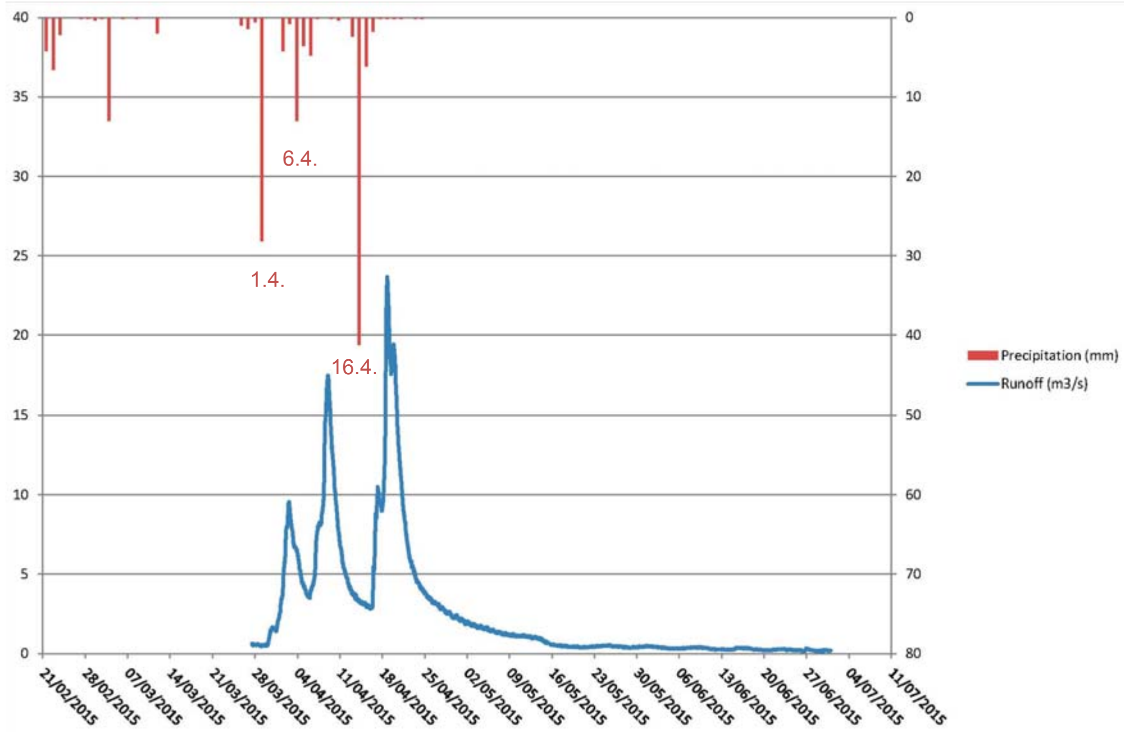

Figure 7: Rainfall-runoff graph of Chongwe river at gauging station 5-025 between March and June 2015.

After the end of the rains, the system drains quite quickly. Between 20th of April and 13th of May, base flow reaches a level of 1 m^3/s.

5. LANDUSE

The Chongwe catchment can be divided in an upper half in which agriculture as landuse prevails and a lower half which lies in the Zambezi escarpment. Here, slopes are too steep for the common agricultural practices and no major settlements exist. A part of the lower eastern catchment is taken up by the Lower Zambezi National Park. Figure 8 shows the landuse in the catchment.

Commercial agriculture is hosted mainly in the Ngwerere and Chalimbana subcatchments. A total area of 200 km^2 was found by Hahne & Shamboko (2010) in relation to the Chongwe catchment. Commercial agriculture uses approximately 30 Mm^3/a in Upper Chongwe, Chalimbana and Ngwerere catchments (Siwale et al. 2012).

The size of the cultivated area used by small scale farmers in the Chongwe catchment is approximately 300 km^2. This results from digitizing the farmed areas from satellite pictures (google satellite) of 2014. The digitized areas were checked against the mapped commercial agricultural areas, which had been published in the landuse map (Hahne & Shamboko 2010) to prevent overlaps.

Water permits for the catchment are currently under review. As of September 2015, there were no granted water permits for commercial agriculture as the transfer procedure from water right to water permit within WARMA was still ongoing. Pending were 26 permits with a total of 90 l/s in the application process (personal communication WARMA, December 17th, 2015).

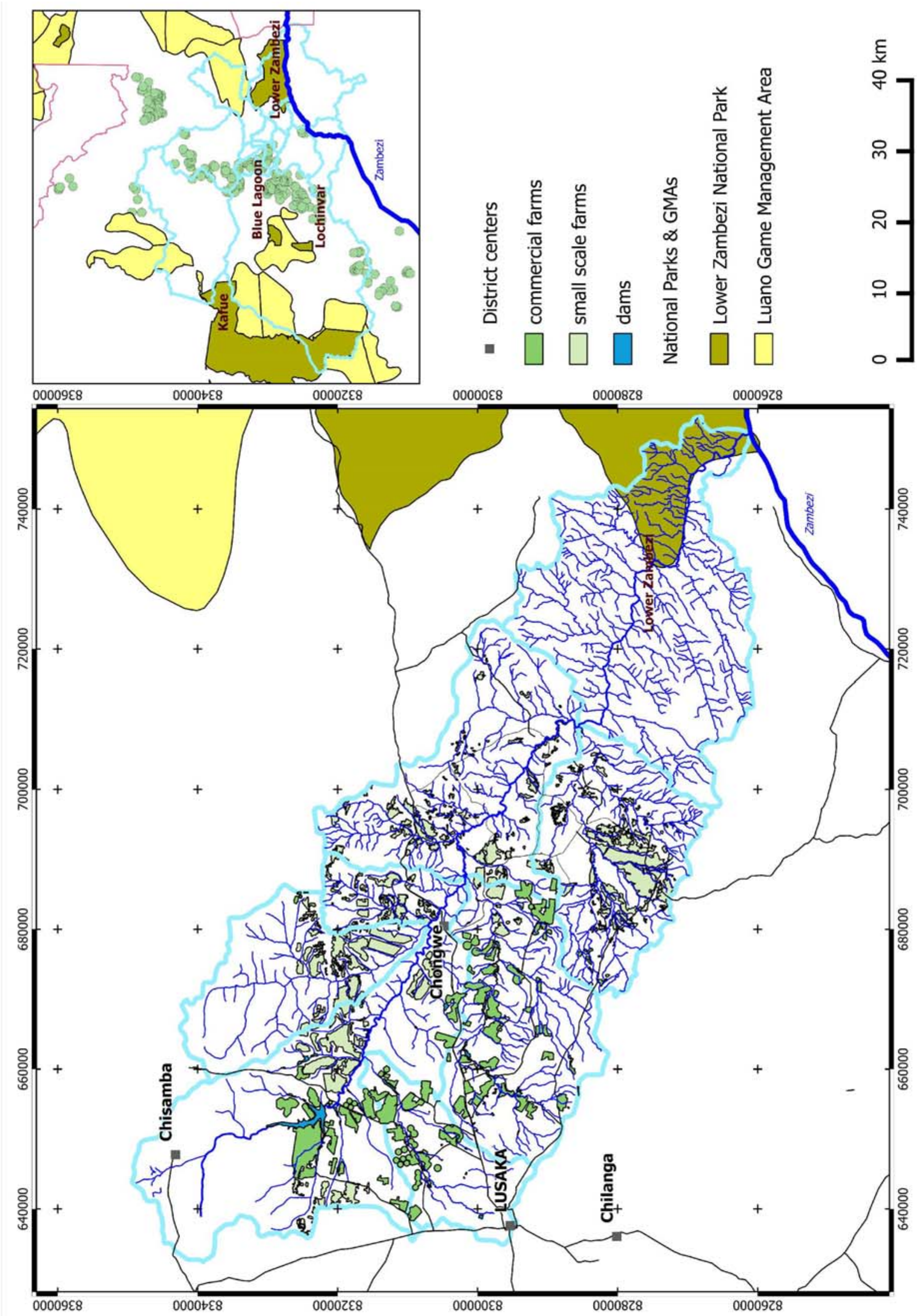

Figure 8: Landuse map of the Chongwe catchment.

6. GROUNDWATER RESOURCES

6.1. General Overview

There are only few aquifers in the Chongwe catchment as such, the most productive ones in the far western (Lusaka) area. These aquifers have been described in depth by Kang’omba and Bäumle (2013).

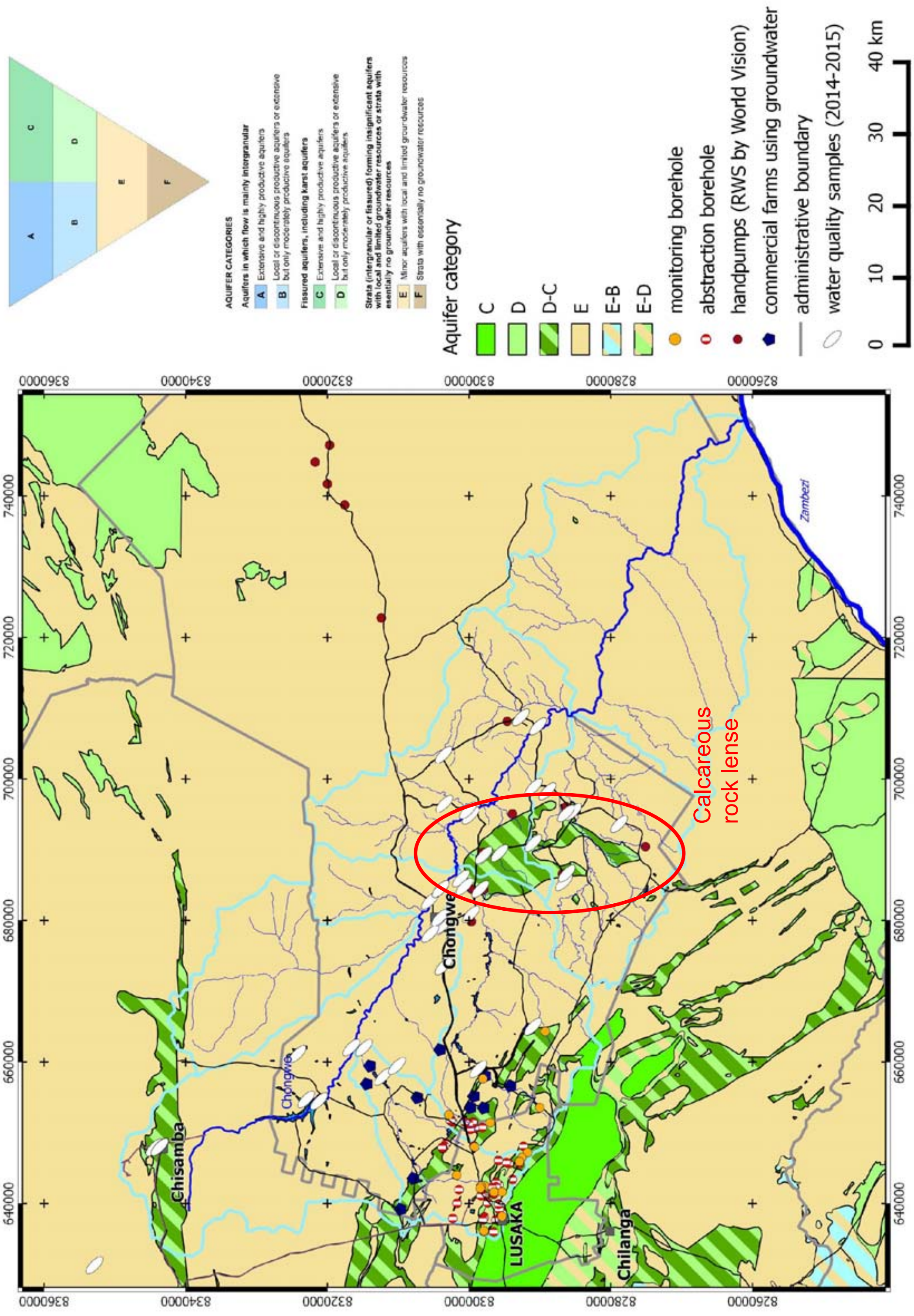

Figure 9: Hydrogeological map indicating aquifer categories after Struckmeyer and Margat (1995) and hydrochemical sampling locations.

The calcareous rock lens cropping out south-east of Chongwe town (Figure 9) has an area of 140 km^2 and an estimated thickness of more than 50 m, but no deep drillings have been done. It is known from the carbonate aquifers in the Lusaka area that the abundance of cavities is drastically reduced below 50 m depth. Hence the productive part of the aquifer is assumed to be between 5 and 50 m depth.

The aquifer is being tapped into only by rural water supply boreholes equipped with handpumps. Many of these boreholes have been drilled by the non-governmental organization World Vision which employs their own drilling team. Reports were made available, but pumping test data was not good enough for analysis (example is given in Figure 10).

The expected yield of the 15 tested boreholes averages at 0.4 l/s which is quite low yielding for a carbonate aquifer. It is sufficient for rural water supply, but it does not confirm the mapped aquifer category assumption of the carbonate lense. In this regard, it must be considered to reclassify the C-D category to E, limited groundwater potential, if professionally conducted pumping tests return similar results.

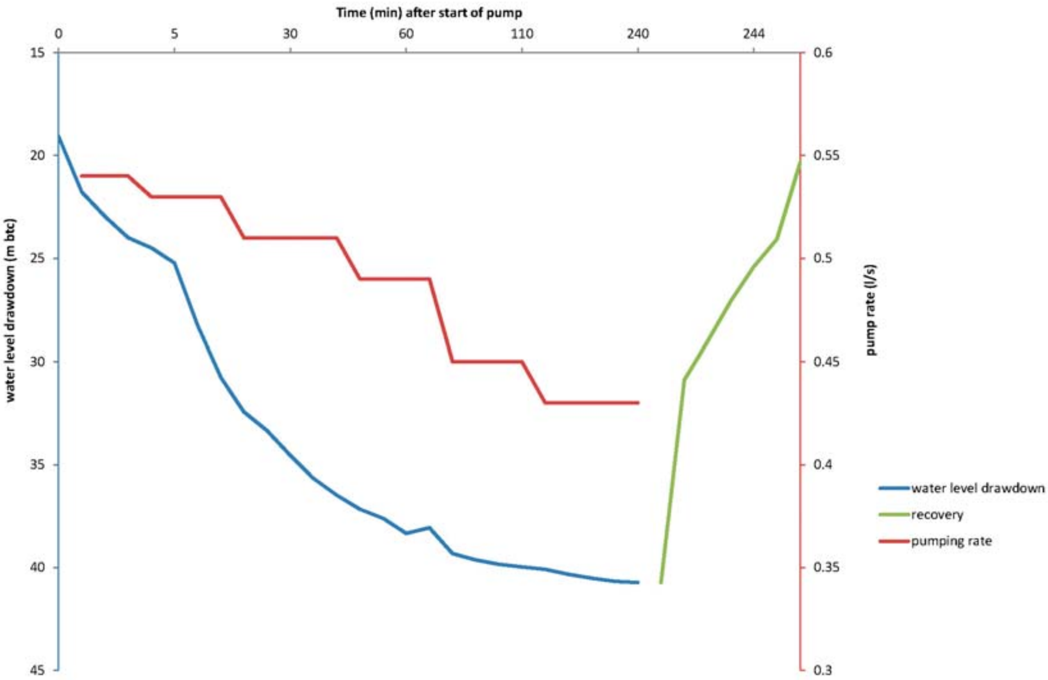

Figure 10: Drawdown levels at Shamboshi World Vision “pumping test” in June 2013.

No pumping tests for production boreholes have ever been carried out. Lusaka Water and Sewerage Company has planned to construct and pump test several production boreholes in the aquifer as a back-up water supply for Chongwe town. The planned site for the drilling was Chalimbana University, south-east of Chongwe town. The works however did not start within the project’s lifespan.

Groundwater recharge has been calculated by various authors in the past and figures for carbonate rock areas in the Lusaka area range from 5 % of MAR (von Hoyer 1978) to 80% (Mpamba 2008). Hennings (in Kang’omba & Bäumle 2013) calculated a recharge of 16% of MAR for non-carbonate parent material (schists, quartzites and basement rocks) using pedo-transfer functions.

In March 2015 automatic data loggers were installed in 3 monitoring boreholes in the catchment, namely Palabana University, Chilyabale and Kampekete (see Figure 11).

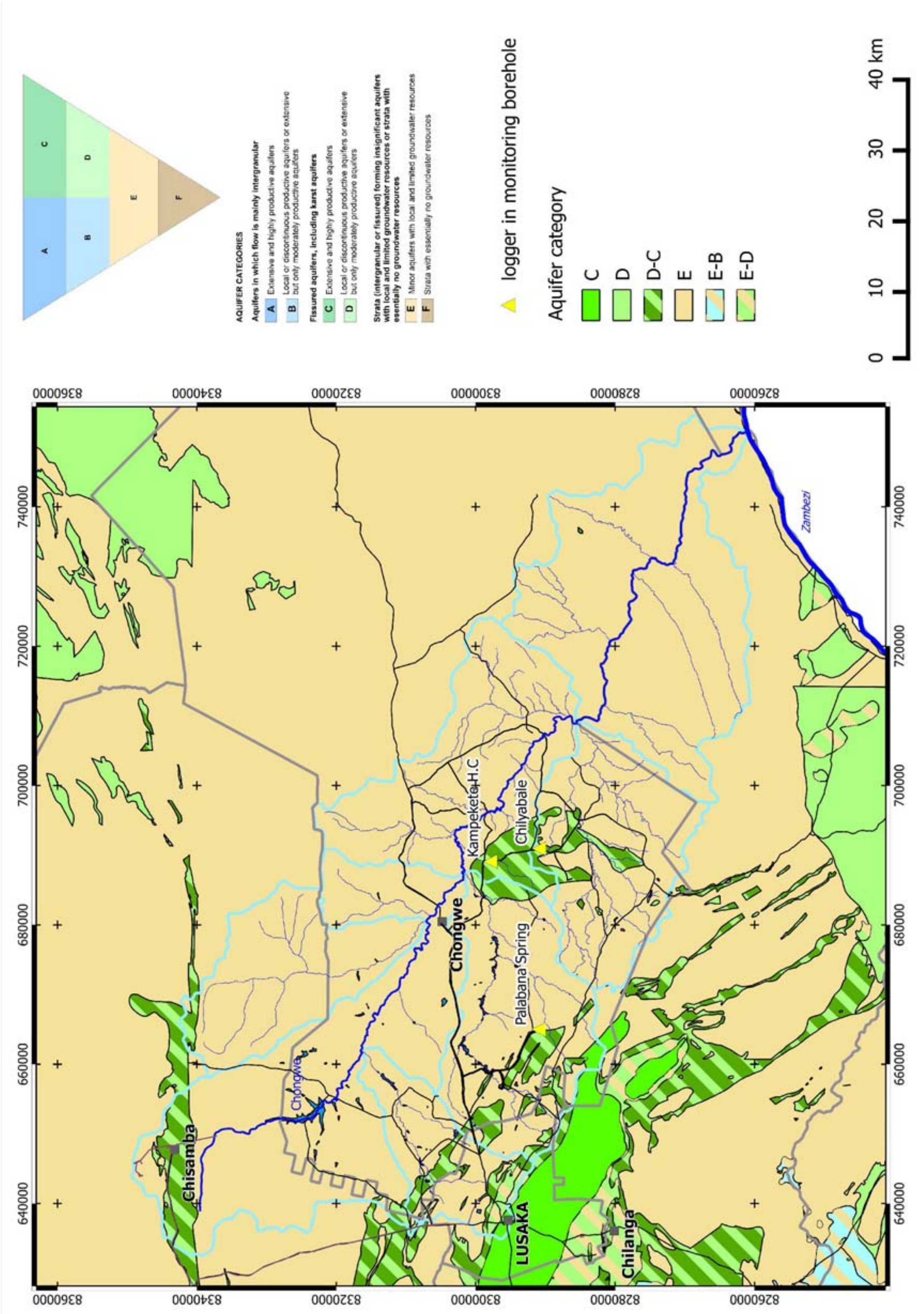

Figure 11: Locations of loggers installed in monitoring boreholes in 2015.

The groundwater level line at Kampekete (green line in Figure 12) shows two sudden increases in water level, both on or shortly after days with heavy rainfall (8th and 16th of April, 2015). On April 16th, the water level increases by 14.5 cm within 9 hours. In comparison: At Palabana University monitoring borehole during the time of recording the water level changed by 62 cm over the course of six weeks (Figure 13) and showed no sudden peaks.

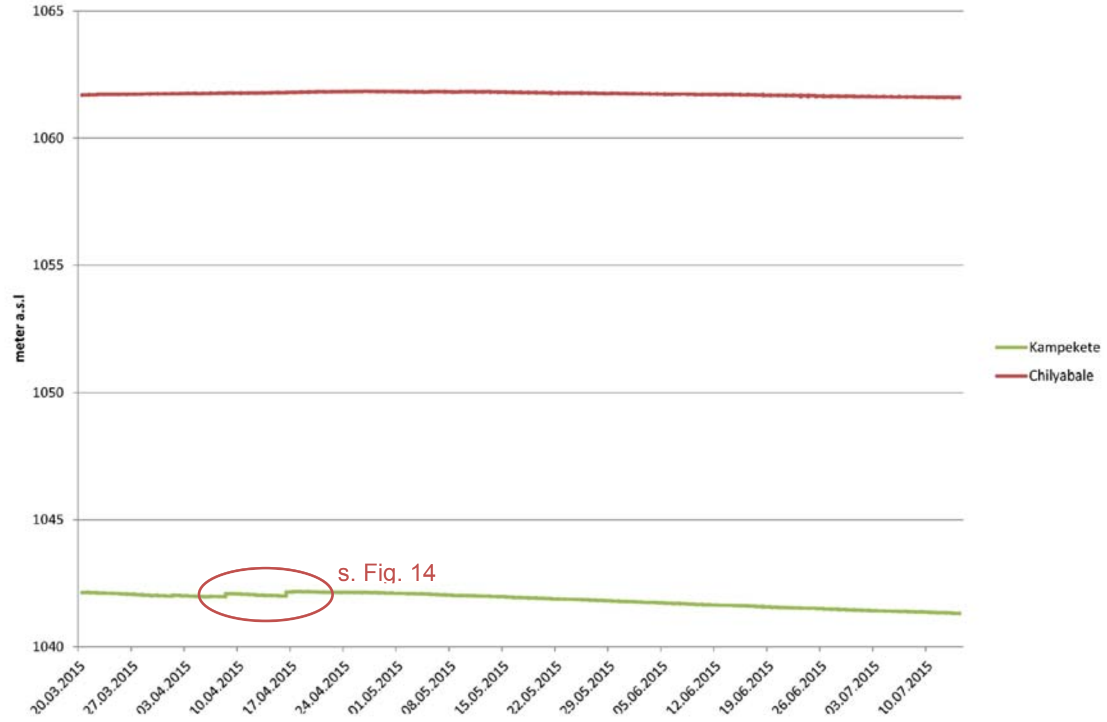

Figure 12: Recorded groundwater levels at Kampekete and Chilyabale.

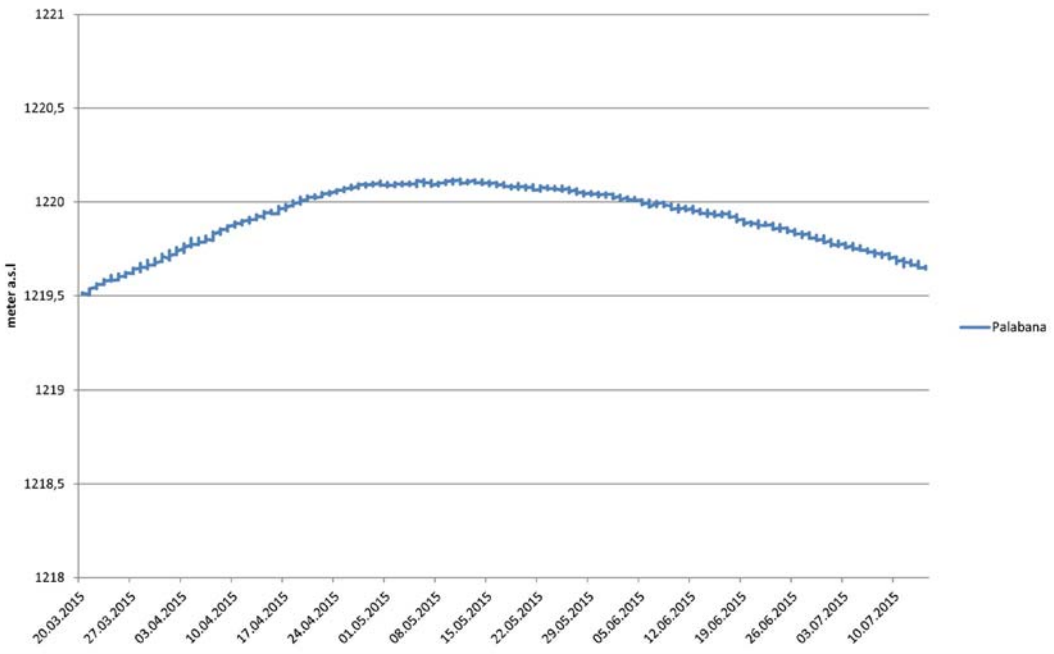

Figure 13: Recorded groundwater level at Palabana University.

The hydrochemical analysis of the handpump situated less than 50 m away from the Kampekete monitoring borehole does not show any difference between dry and rainy season in chemical water composition.

If there was a hydraulic shortcut in the set-up of the monitoring borehole causing local surface runoff/sheet flow to enter into the annulus, it would be expected that water level rises faster than within 9 hours.

The behaviour of the Kampekete borehole can be explained with the karstic flow concept. The first two heavy rainfall events (1^{st} and 6^{th} of April) are needed to fill up the unsaturated zone with water while the comparably small rainfall event on the 8^{th} of April gives the additional volume of recharged water to activate the void into which the borehole apparently is drilled. Hence the sudden increase in groundwater level on the 9^{th} of April (while the river runoff needs another day to reach its peak) with only one day lag time. After the 41 mm rainfall event on the 16^{th} of April the borehole water level increases very rapidly and almost instantly within 3 hours after it started raining.

To get an idea of the very short reaction times to rainfall of the Chongwe limestone area, rainfall, runoff and Kampekete groundwater level, were plotted in Figure 14.

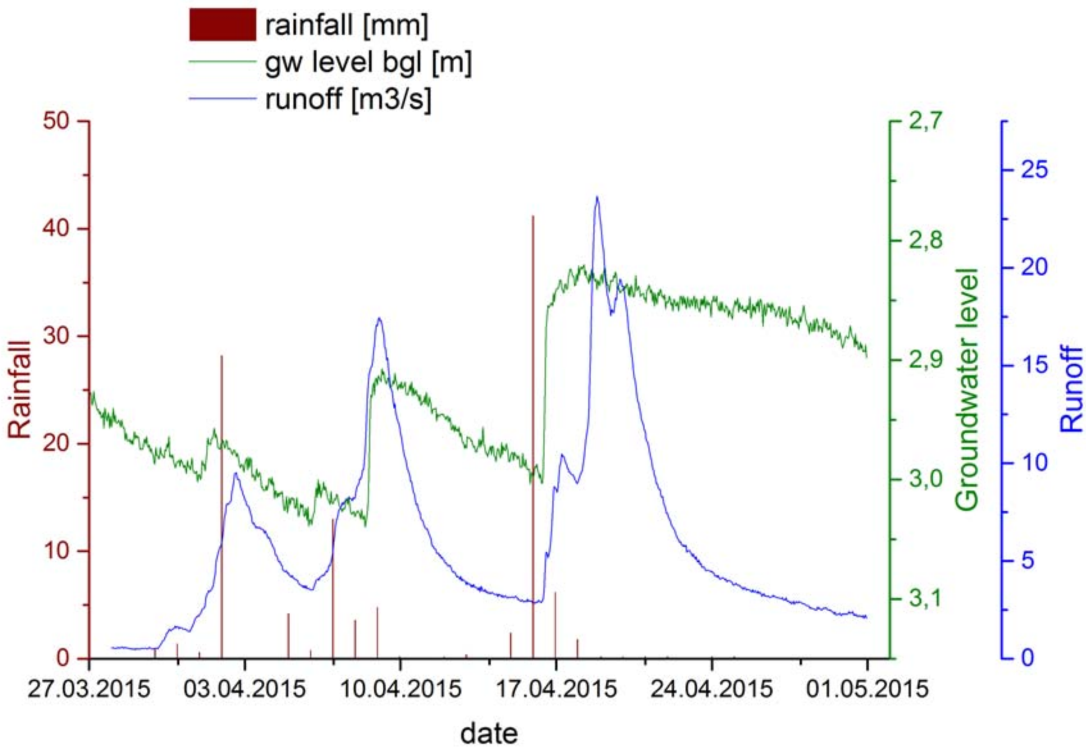

Figure 14: Rainfall-runoff-groundwater level timeline.

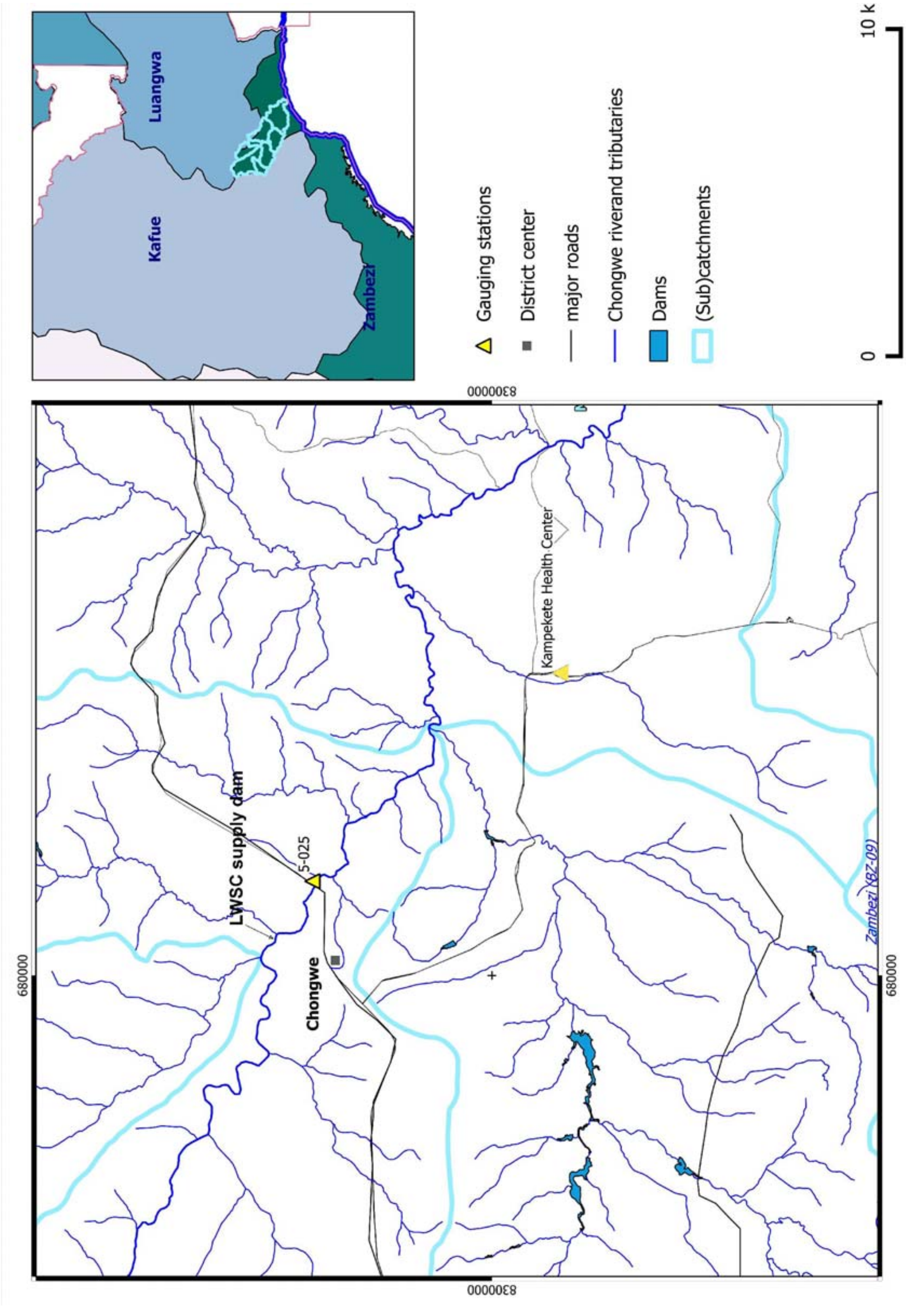

Figure 15: Overview of hydrological sites (scale 1:38,500).

7. GUIDELINE ON GROUNDWATER PERMITS FOR CHONGWE CATCHMENT

Up to the completion of this report, there was no commercial user of the groundwater resource in the carbonate aquifer, south-east of Chongwe town. If commercial use of groundwater in the Chongwe catchment is planned, an assessment of the water balance would be needed. Due to the lack of data and short monitoring time span, there are only assumptions that can be made on the conceptional model of the hydrological processes in with regard to groundwater.

So far it can be stated that presumably no significant flow from the surrounding Katanga schists and quartzites into the carbonate aquifer takes place, as drainage pattern is dense and dendritic. Hence groundwater recharge on the schists and quartzites is assumed to be minimal, while on the carbonate lense recharge is high, inferring from the lack of surface runoff.

Once Lusaka Water and Sewerage Company (LWSC) starts abstracting water for Chongwe town from the carbonate lense aquifer, there is need for them to get a permit for the amount they will be allowed to pump. In order to allocate a sensible amount to them, it is indispensable to receive proper pump test data from LWSC, including both a step test and a continuous 48 hours test. WARMA should request for an independent hydrogeologist to supervise the pump testing and to analyse the data.

In order to allocate a yearly water permit to LWSC or other groundwater users, the following aquifer parameters have to be established:

- Area and thickness of aquifer (see chapter 6.1)
- hydraulic conductivity and transmissivity (pumping tests)
- groundwater flow direction (water level measurements at several boreholes and on two defined dates)
- current assessment of aquifer productivity (low yielding)

In the absence of a reliable estimate of recharge rates, groundwater monitoring is essential. Thus, WARMA is recommended to keep groundwater monitoring in place in the monitoring boreholes at Kampekete and Chilyabale as well as requesting LWSC to build at least one monitoring borehole at their production site as well.

In Chalimbana and Ngwerere catchments the commercial farms that use groundwater for irrigation, abstract less than 2 million m^3/a (per catchment), as found in 2010 by Mayerhofer et al. In comparison, commercial farmers in Ngwerere catchment used 10 million m^3/a of surface water in 2010 (Mayerhofer et al 2010).

For the permitting of groundwater abstractions it is necessary to look at the aquifer from which the water is taken. This aquifer might – and in the case of the Lusaka area often does – stretch over more than one surface water catchment.

8. GROUNDWATER QUALITY

Two sampling campaigns for water quality were conducted in December 2014 and March/April 2015, respectively. The December campaign reflects the hydrochemical situation at the end of the dry season. This must be well noted as December is often considered a wet month already, while in 2014, the area experienced a very late onset of the rains. The March/April campaign then pictured wet conditions after approximately 660 mm of the season's rainfall. As shown in Figure 9, the campaigns covered 41 sampling points, comprising of 36 groundwater, one spring and four surface water sampling locations. The groundwater wells were mainly handpumps for rural water supply (either village use or private use), two out of which were situated close to two of the DWA monitoring boreholes in the Chongwe catchment. A complete list of sampling locations is given in Annex 1 and locations are shown in Figure 9.

8.1. PARAMETERS

The parameters analysed comprise in-situ measurements of physico-chemical parameters, inorganic compounds, and stable isotopes (18-O and 2-H).

- In-situ parameters
  Electrical conductivity (EC)
  Water temperature (T)
  Air temperature (T_{air})
  pH
  Dissolved oxygen (DO) *for most locations*
  Operational redox potential (ORP, [E_H]) *for most locations*
- 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, As, BO2, Ba, Be, Cd, Co, Cr, Cu, Li, Ni, Pb, Sc, Sr, Ti, V, Zn
- Stable water isotopes
  $\delta^{18}O$
  $\delta^{2}H$

For analysis of anions, 250 ml bottles were filled. For cations, a 100 ml pre-acidified bottle was filled with filtered sample water (using a 0.45 µm filter). 50 ml wide neck bottles were used for isotope sampling, which were filled to the top to prevent evaporation effects in the bottle. In-situ measurements were taken using a beaker and handheld WTW probes.

8.2. LABORATORY ANALYSIS

Inorganic components were analysed by the BGR water laboratory in Germany. The applied analysis methods are summarised in Table 1. Detailed analysis procedure descriptions are given in Nick et al. (2010).

Table 1 Analysis Methods applied by BGR laboratory.

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

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

8.3. RESULTS

Inorganic Species

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

Overall the water quality is very good in the whole catchment with no raised trace element concentrations and no values above the Zambian drinking water standard. The plot of nitrate and electrical conductivity (EC) shows that the parameters are not correlated and concentrations remained below the 44 mg/l maximum permissible value for nitrate in drinking water, although in some samples high EC values were found (Figure 16).

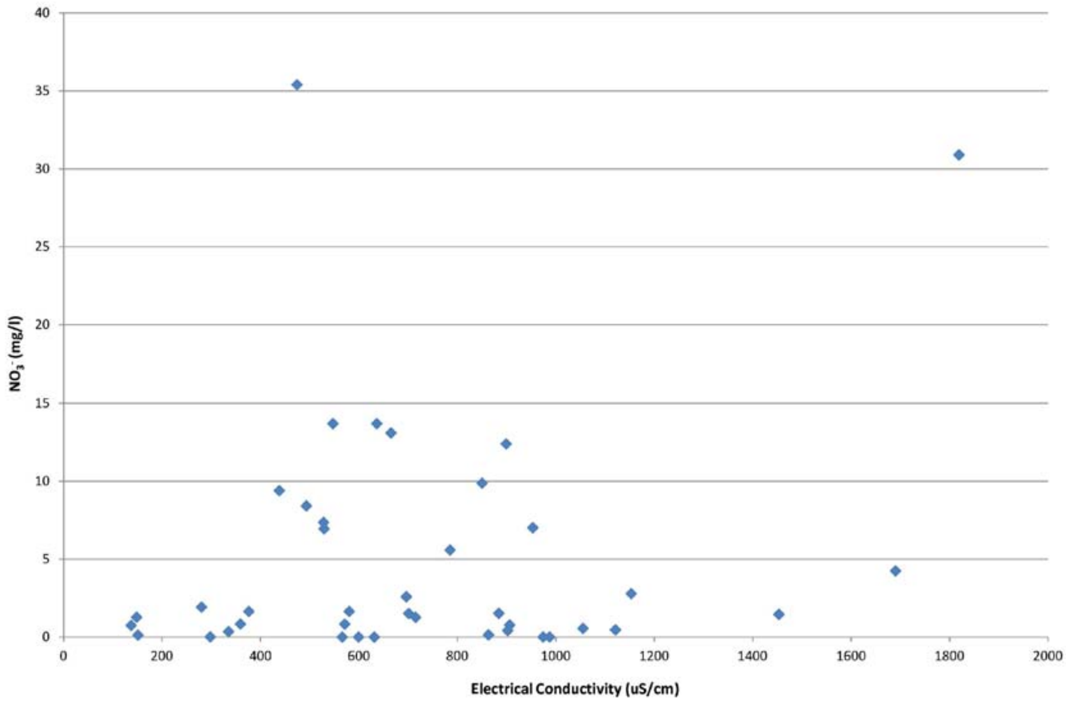

Figure 16: Correlation of nitrate (NO_3^-) and electrical conductivity for all samples taken.

In the Piper diagram (Figure 17) the samples were grouped according to their geological origin. Most of the samples plot as calcium-magnesium bicarbonate (Ca-Mg-HCO_3) type, with only three showing increased SO_4^{2-}, NO_3^-, Cl^- contents. These are two samples from Mukankaulwa village and one from Saili and the increased nutrient contents are assumed to stem from excreta disposal in pit latrines.

Palabana Spring and Sable Farm both plot in the HCO_3^- dominant corner of the Piper diagramme which is where most of the unpolluted samples from the Lusaka dolomite aquifer plot (Nick et al. 2010). For the spring this is not surprising, as it presents a contact spring that drains the local Cheta limestone lense. Sable Farm however is situated in the Muva quarzite rocks, less than 10 km north of the Chongwe catchment boundary (the only sample taken outside catchment boundaries). The quartzites show high numbers of faults and it is possible that groundwater from the higher lying carbonates on the northern boundary of Chongwe catchment drain into these faults.

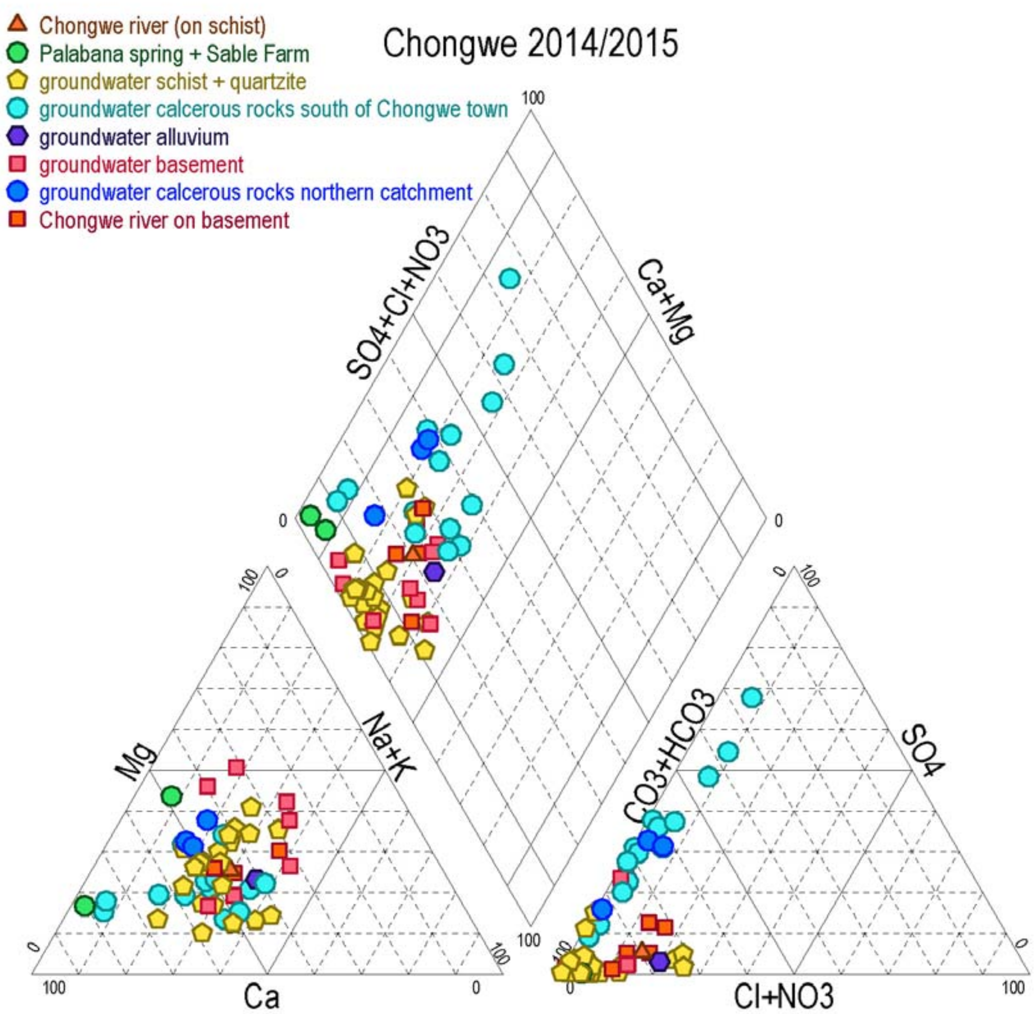

Figure 17: Piper diagram of Chongwe water samples (December 2014 and March/April 2015).

16 groundwater sites and one surface water site were chosen to be sampled in both campaigns, allowing for comparison of dry and wet conditions.

Figure 19 displays 12 groundwater and the one surface water samples in comparison. The four sites that were left out showed the least variation between the seasons and are considered to be reflected in the displayed analyses.

Figure 19 stiff diagram gives sampling IDs of the individual samples as well as site names (mainly the village names). The two columns compare each site at the two sampled seasons, in which December 2014 presents dry conditions and March 2015 presents wet conditions.

Hardly any variation occurs between dry and wet conditions (with the excemption of Saili). In the granitic and quarzitic geological environments the ion content of the groundwater is naturally low and does not get altered much by the rains as can be seen from the examples of Luimba, Kasolo, Mwalumina and Chamulimba. At the Secondary School, Mwachilele and the Chongwe river sample there is a slight increase of hydrocarbonate in the March/April sample, which in the case of the river is more pronounced than the general increase in ion load caused by surface water runoff and particle intake.

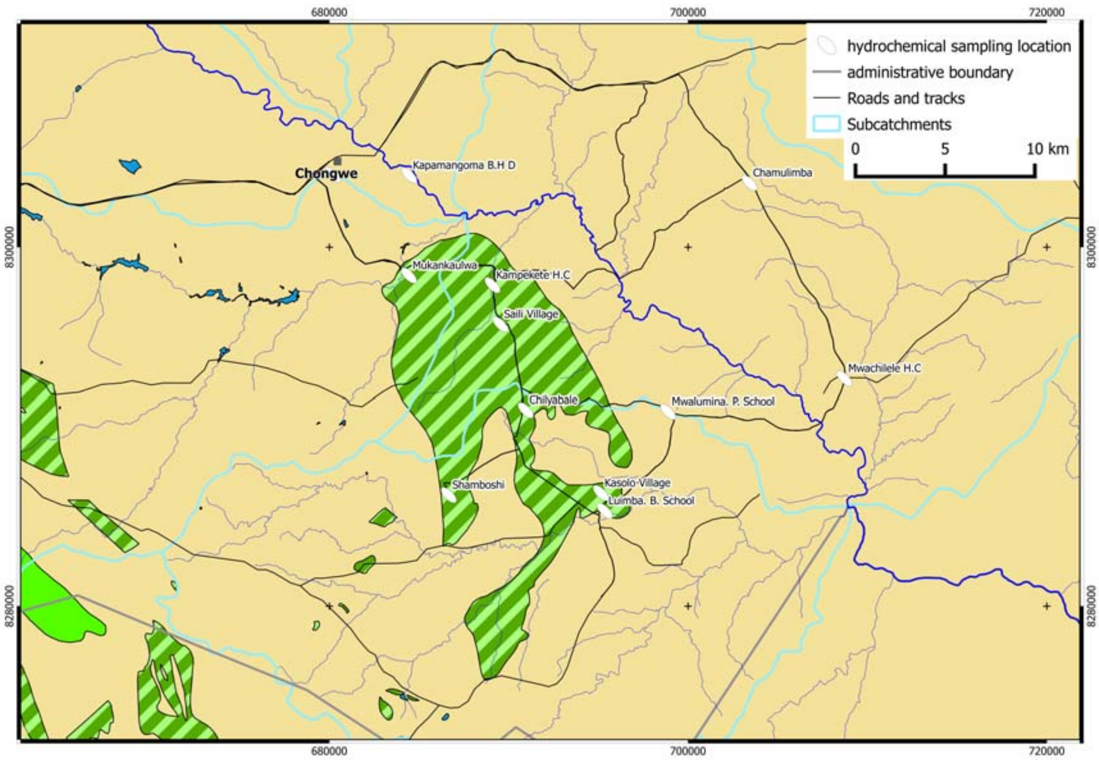

Figure 18: Map showing the sampling locations referred to in the Stiff diagram.

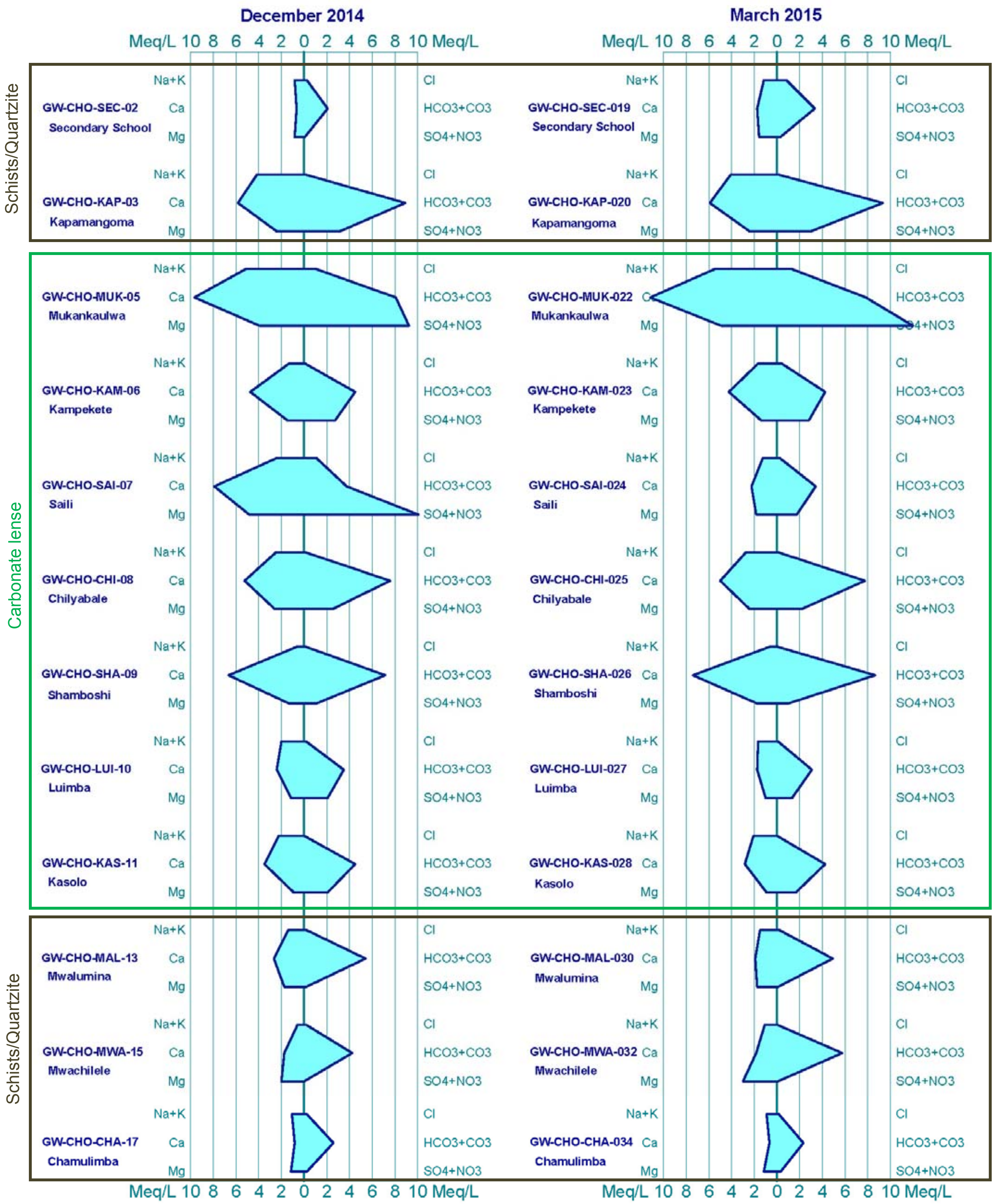

Figure 19: Stiff diagrams comparing 12 sites sampled in December and March.

Stable isotopes

Stable isotope samples for δ^2H (delta ^2H, deuterium, heavy isotope of hydrogen) and $\delta^{18}O$ (delta ^{18}O, heavy isotope of oxygen) were analysed at the Stable Isotope Laboratory of the BGR in Hannover. All values are given as δ-values in per mil (‰) against a standard as defined by equation (1),

$$\delta = \left[\left(\frac{R_{SA}}{R_{ST}} \right) - 1 \right] \times 1000 \qquad (1)$$

where R_{SA} (-) denotes the isotope ratio of $^2H/H$ or $^{18}O/^{16}O$ of a sample and R_{ST} (-) of the standard respectively. The analyses were done using a Picarro cavity ring down spectrometer (CRDS) connected to a vaporizer and equipped with a CTC-PAL auto sampler. The measurements were normalized to the VSMOW/SLAP (Vienna Standard Mean Ocean Water/Standard Light Antarctic Precipitation) scale, where values of 0 ‰ and -428 ‰ for δ^2H and 0‰ and -55.5 ‰ for $\delta^{18}O$ were assigned to VSMOW and SLAP, respectively. The external reproducibility (standard deviation of a control standard during all runs) is better than 1.0 ‰ and 0.20 ‰ for δ^2H and $\delta^{18}O$, respectively.

Samples were taken from rainfall in Chongwe next to the meteorological station at the District Agricultural Office between December 2014 and April 2015, i.e. for one complete rainy season. As shown in Figure 20 the weighted monthly means for the Chongwe rainfall relate very well to the weighted monthly means of the rainfall samples taken at the Department of Water Affairs offices in Lusaka, Emmasdale which were gathered since 2012. The trendline for the Emmasdale data has a slope of 7.4 and an intercept value of 9.5, which is quite close to the Global Meteoric Water Line (GMWL) with a slope of 8 and an intercept of 10. As the five weighted data points for the Chongwe rainfall sampling station were not seen fit for yielding a trendline, in the following graphs the GMWL and the Emmasdale trendline (E-LMWL) are shown for orientation together with the weighted monthly mean isotopic values for Chongwe rainfall.

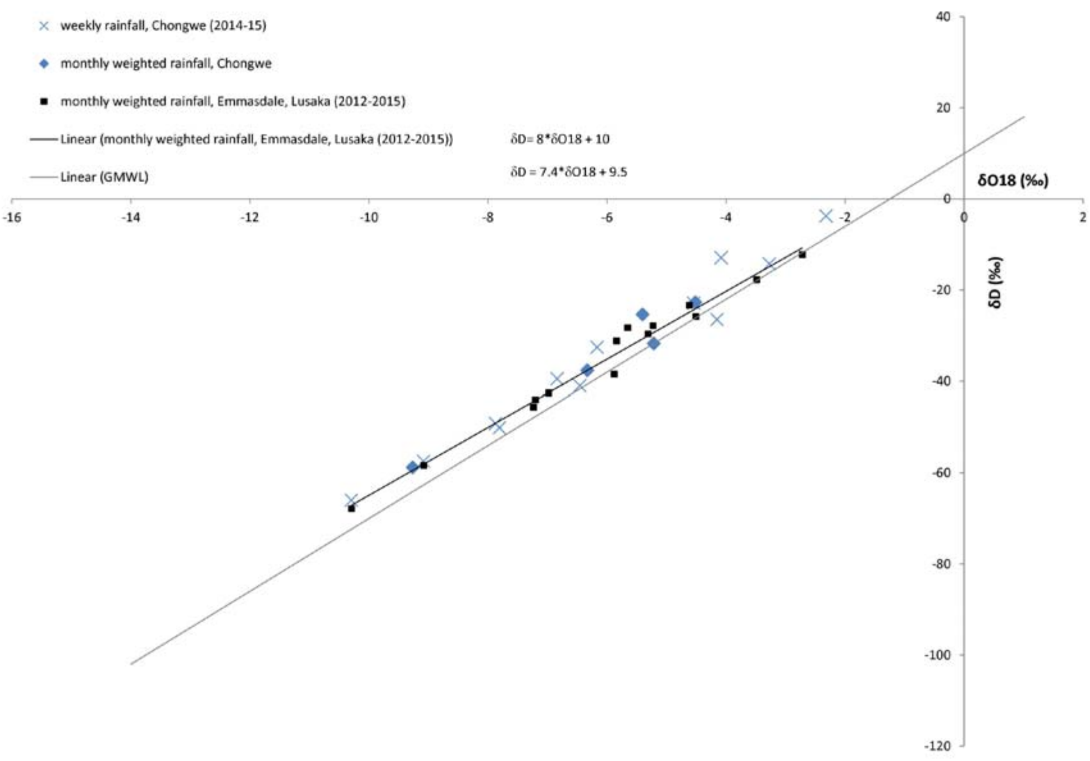

Figure 20: Weekly samples and weighted monthly rainfall for Chongwe, compared to Lusaka.

Between June 2014 and May 2015 a total of 78 samples for stable isotopes were collected from surface water, groundwater (mainly handpumps) and springs in the Chongwe catchment. During the two sampling campaigns isotope samples were always collected alongside the hydrochemical samples, and in some places isotope samples were collected outside these campaigns and with no accompanying hydrochemical sample (see Figure 21 and Figure 22).

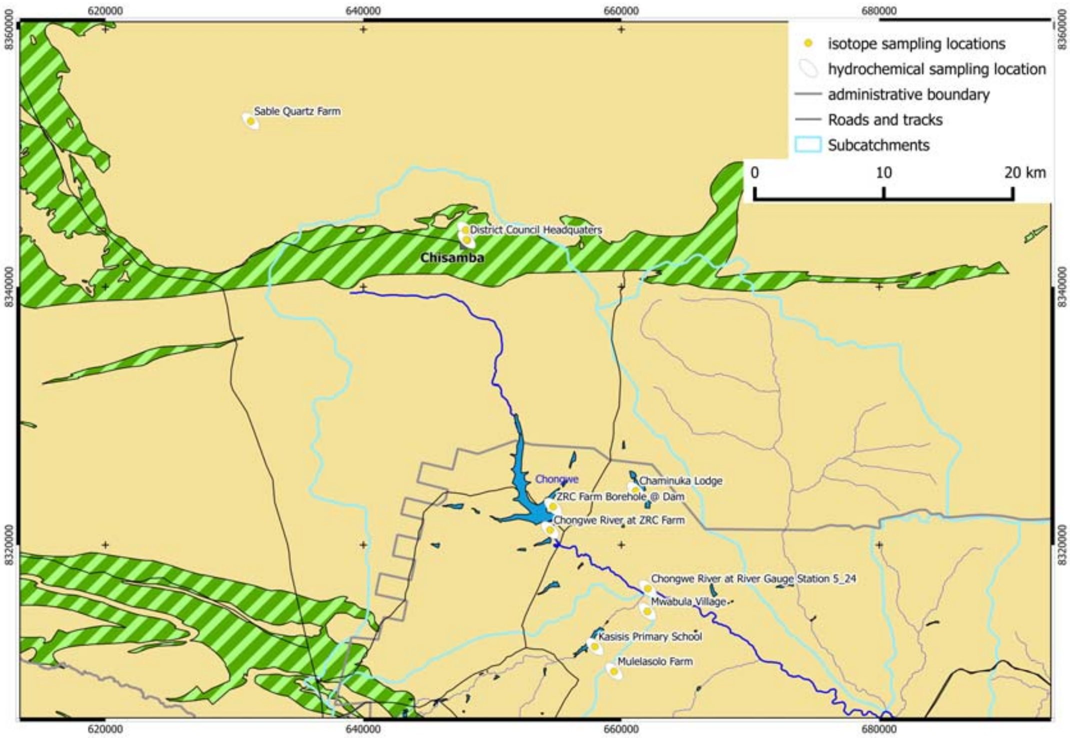

Figure 21: Sampling locations for stable isotopes, June 2014 and May 2015, northern part.

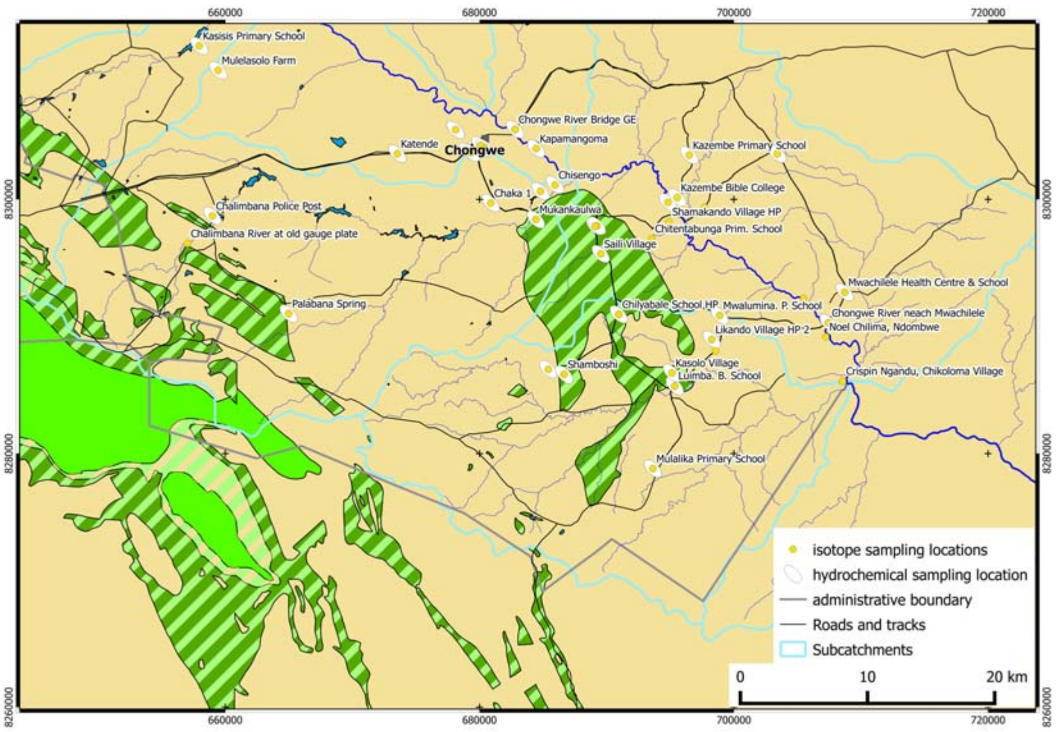

Figure 22: Sampling locations for stable isotopes, June 2014 and May 2015, southern part.

All groundwater samples are shown in relation to the isotopic composition of rainfall in Figure 23. Apart from three samples, all data points conglomerate very close to the E-LMWL and around the GMWL. Three samples showing more positive values indicating evaporation effects, which can be referred to influences of evaporated surface water (more detailed discussion below).

There is a strong indication for direct groundwater recharge happening all over the Chongwe catchment. The samples occur between -40 ‰ and -50 ‰ δ^{2}H and -6 ‰ and -8 ‰ δ^{18}O with an arithmetic mean of -7 ‰ δ^{2}H and -45 ‰ δ^{18}O. In relation to the weighted mean values per month of the sampled rainy season the groundwater samples are relatively depleted. In fact they are lighter than the arithmetic mean of all rainfall samples (Lusaka and Chongwe). This can only be explained by mixing with a lighter end member (around -8 ‰ δ^{2}H and -55 ‰ δ^{18}O) which hasn't been identified yet, or with an amount effect, which would imply that only rainfall events with relatively depleted values contribute to groundwater recharge.

Large rainfall events are often marked by more negative isotope signatures due to the amount effect. However, correlating the Lusaka and Chongwe rainfall δ^{2}H values with the rainfall amount per event along the timescale of two rainy seasons, does not show a clear amount effect (Figure 24). From the diagram in Figure 24 it can only be derived that events with more than 50 mm have δ^{2}H values of less than -20 ‰, but this does not explain the negative groundwater signatures. The <10mm sample with -102 ‰ for δ^{2}H was taken at the end of an event of which the first and larger part of precipitation had already been sampled beforehand. Hence the remaining part and sample rainwater was depleted as expected caused by condensation. The diagram also does not show a seasonal effect (e.g. signatures become more negative during the colder season). The isotope composition of rainfall events seem to be quite equally distributed throughout the months.

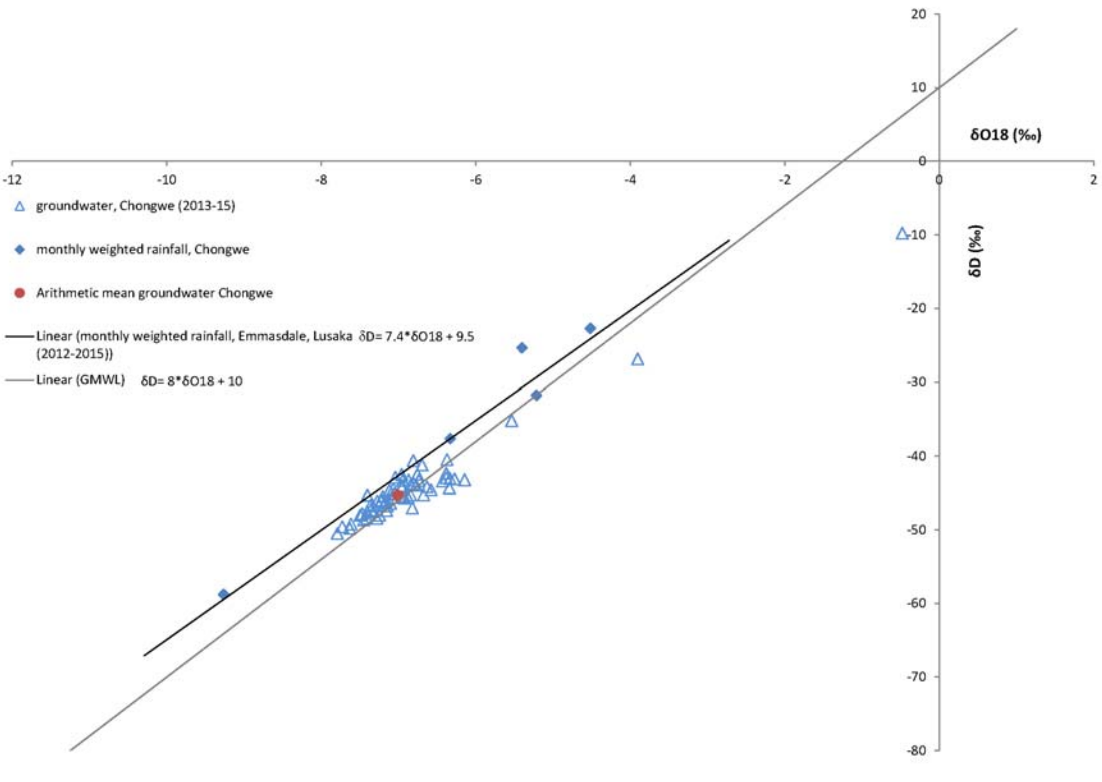

Figure 23: Groundwater samples from Chongwe catchment in relation to rainfall isotopic signature.

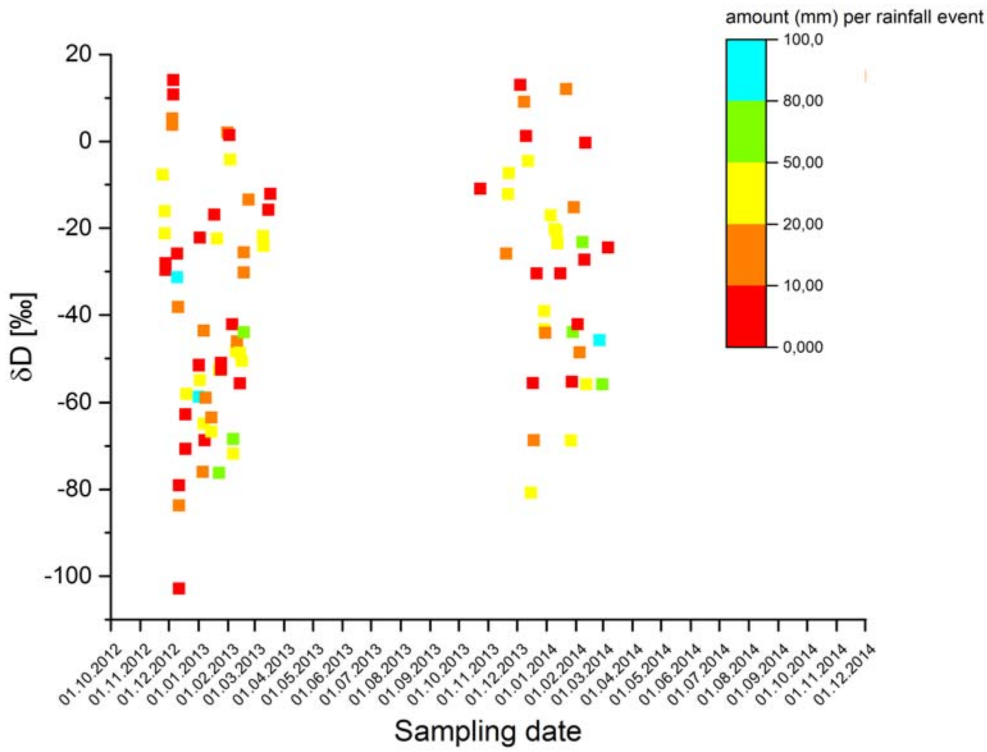

Figure 24: Correlation of deuterium values, rainfall amount and time.

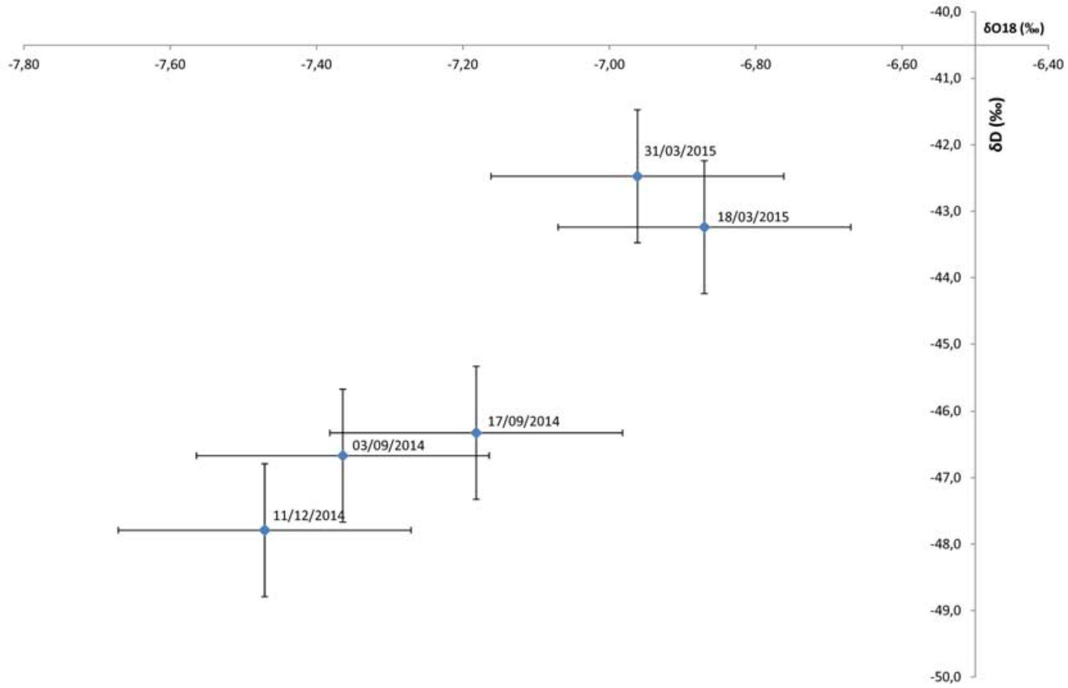

Figure 25: Stable isotope samples taken from Kampekete handpump (within 20 m from monitoring borehole).

Looking at the Kampekete area (samples were taken at the handpump about 20 m from the monitoring borehole) five samples were taken between September 2014 and March 2015 (see Figure 25).

Samples taken toward the end of the rainy season (March 2015) are enriched in heavy isotopes relatively to those samples taken during the dry season and at the onset of the rains (September and December 2014, respectively). Although five samples and a single year as observation period may not allow a final conclusion, it can be seen that there is variation in the groundwater isotopic composition so there are short-term processes that influence the groundwater. It is yet not clear if isotopic composition of the rainfall gets more enriched towards the end of the rainy season or if mixing of direct recharge with depleted values of recharged groundwater from elsewhere dominates at the end of the season; this needs to be further investigated. So far there is no indication to either of the two.

When comparing the two samples gained at Palabana spring to the groundwater samples (Figure 26), there is no deviation. The groundwater sample at -5.5 ‰ and -35 ‰ for $\delta^{18}O$ and $\delta^{2}H$, respectively, is slightly enriched in comparison to the bulk groundwater samples. Close to the borehole (at the Secondary School in Chongwe) a dambo probably contributes isotopically enriched water to the groundwater.

One surface water sample was taken from Chalimbana river and the isotope signature is quite close to the groundwater samples and in line with the meteoric water lines. Only a slight evaporation effect is visible for this surface water sample. Most surface water samples were taken from the Chongwe river. The results can be divided into several groups.

The sample which is labelled with its sampling date in Figure 26 was taken at the bridge over the Chongwe near Mwachilele village on the 23rd of December, 2014. The sample plots clearly above the E-LMWL and GMWL which could render it as an outlier. An alternative explanation could be that the runoff in Chongwe river consisted for a large part of rain water. In the night before the sampling, recorded by the rain gauge as 22nd of December, a 28 mm event took place. Potentially the system was highly saturated after the two large storm events of December 13 and 19 with about 70 mm each, and rainfall developed quickly into runoff.

The sample with the most positive (heaviest) isotope signature (A) originates from the large Ray's dam at the ZRC Farm. The groundwater sample next to it was taken from a borehole some 50-100 m from the dam. The infiltration of evaporated dam water into the local groundwater resource is obvious. The other sample in group A was taken in September at the Chongwe River Great East Bridge and also clearly show evaporation effects, either due to ponding conditions in the river or from evaporated baseflow with slow flow velocities.

The second group of surface water samples (B) also show the evaporation effect. The two samples were taken in June and September 2014 at different locations on the Chongwe River, i.e. in the dry season when the river water consists of baseflow which evaporates and gets enriched in heavier isotopes.

The third group consists of four surface water samples (C) between the evaporated samples and the GMWL and one groundwater sample. The SW samples were taken at different locations along the Chongwe on two consecutive days, namely the 30th of March and the 1st of April 2015, towards the end of the rainy season when the river water consisted mainly of direct runoff which consequently had evaporated slightly. The groundwater sample originates from a household borehole which is situated near the dambo that also feeds the borehole at Chongwe Secondary School. It is assumed that evaporated water from the dambo wetland contributes to the groundwater yielding in the borehole.

The last group of surface water samples (D) plots on the GMWL. These five samples were taken along the furthest downstream reach accessible, near Mwachilele village, four of the five on the 10th of March and the fifth sample on the 18th of March. In this area small scale farmers irrigate tomatoes and maize plants year round (Jenkins et al. 2015). This should however not influence the isotopic signature (as irrigation water is pumped directly from the river at the very site of the farm plot where it then reinfiltrates and possibly rejoins the river). Possibly surface runoff at that time of the season was dominated by rainfall, or a mix of more negative groundwater values or baseflow and more positive, evaporation influenced runoff.

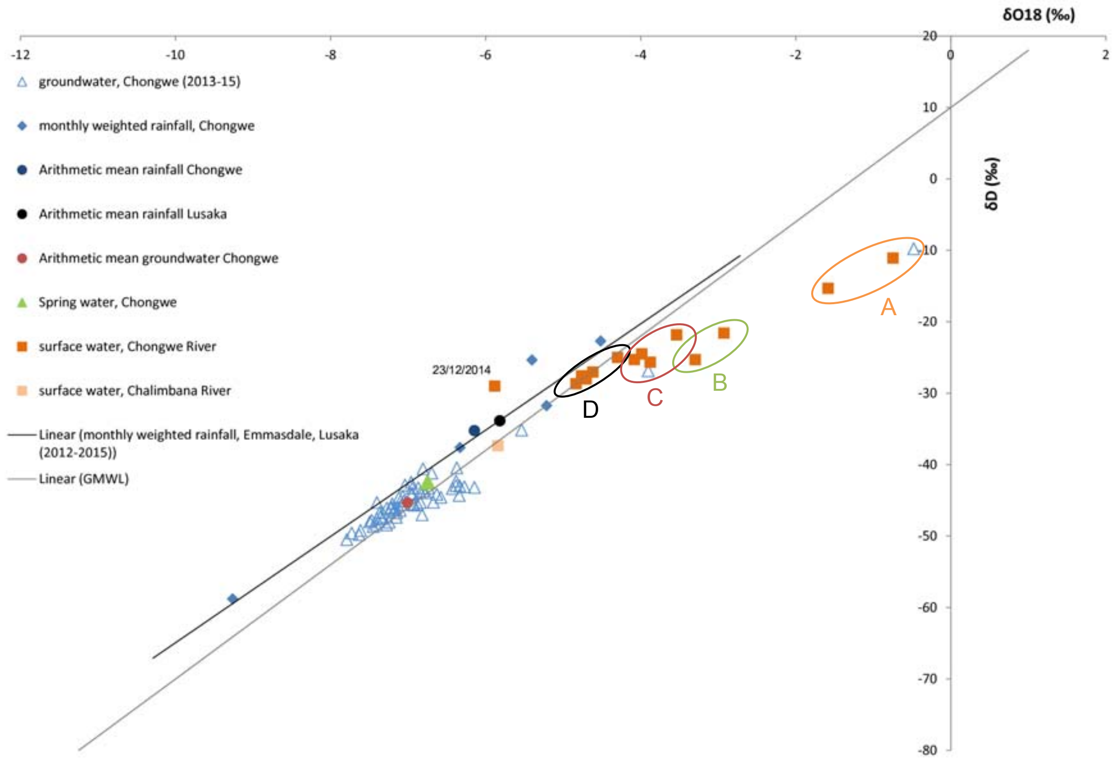

Figure 26: Surface water, groundwater and spring isotope samples from Chongwe catchment.

9. GROUNDWATER MONITORING

It is proposed that water resources in the Chongwe catchment are monitored continuously for a period of 3-5 years. After establishing a reliable water balance based on this monitoring data, a quarterly monitoring of groundwater levels and surface water gauging can be established.

The water level of the Chongwe river at its main gauge, the Great East bridge station 05-25, is recommended to be continuously measured by an automated pressure logger. The gauge readers at the other three gauging stations in the catchment should be reactivated and checks should be carried out regarding the correctness of readings every three months.

Groundwater loggers can remain in two of the three monitoring boreholes currently equipped, preferably Palabana University and Kampekete Health Post. In case Lusaka Water and Sewerage Company completes its planned water supply production boreholes near Chalimbana University (south-west of Chongwe town), they should be obliged to drill a separate monitoring borehole and equip it with an automated logger.

The abstractions by small-scale farmers using submersible pumps along the Chongwe river need to be measured ideally by water meters. It should be a requirement to the renewal of water permits that meter readings are submitted on a yearly base with a prescribed reading schedule. Farmers using groundwater should be obliged to either install meters or automatic groundwater level loggers in their borehole with the same requirement to hand in the data (Jenkins et al. 2015).

In addition to this quantitative monitoring approach, water quality should also be examined routinely in both surface and groundwater. A sampling campaign on pesticide is proposed in the areas where the effects of farming on the ecosystem is completely unknown so far. Such campaign will inform the authorities if pesticides need to be reviewed consecutively or if other, easier detectable, substances can serve as indicators. As for major ions there is no acute monitoring need as in all sampled locations the critical values are below Zambian drinking water standard’s limits. An annual check of major ions is nevertheless recommended for the following boreholes:

- Kasisi Primary School
- Mukankaulwa
- Saili
- Chongwe Secondary School
- Kampekete Health Post

As Kasisi Primary School and Mukankaulwa showed higher nitrate values than all other samples, it is suggested to check for microbiological indicators (Total and Fecal Coliforms) there.

10. CONCLUSIONS AND OUTLOOK

The relevance of groundwater use in the Chongwe catchment is marginal so far.

The only moderately yielding aquifer is the carbonate lense south-east of Chongwe town. This aquifer shows a very high level of direct recharge with extremely short lag times above a threshold of unsaturated zone and matrix storage capacity.

This implies a high degree of vulnerability of the groundwater in the carbonate aquifer. If onsite sanitation facilities connect hydraulically to karst cavities, microbial pollution will reach drinking water wells very quickly.

Overall, the water quality in the Chongwe catchment is good, but as described above can quite easily be put at risk.

If population and economic growth continue in Chongwe, groundwater resources will play a more important role in future. To prevent pollution and overextraction, landuse planning has to consider results from future pumping tests in the carbonate aquifer and the limitation of risk factors like unsafe sanitation facilities or industrial water polluters.

Findings from stable isotope analysis suggest a groundwater recharge process that includes direct recharge but is not ultimately clarified. Further sampling is suggested.

Monitoring activities are also proposed to be continued, both quantitatively and in five boreholes with regard to water quality.

Regarding water scarcity in the supply dam of LWSC, it is assumed that the dam capacity is lower than the water supply demand from the expanding number of customers. To further investigate this, volumetric figures on dam storage and supply rates are needed from LWSC.

11. REFERENCES

[1] Cairney T. (1967): The Geology of the Leopard Hill area. – Explanation of degree sheet 1528, SE quarter.- Republic of Zambia, Ministry of Lands and Mining, Report of the Geological Survey No. 21; 64 pages; Lusaka.

[2] Garrard P. (1968): The geology of the Chainama Hills area. – Report of the Geological Survey No. 24, Explanation of degree sheet 1528, NE quarter; Republic of Zambia, Ministry of Mines and Minerals Development, Geological Survey Department; 80 pages; Government Printer, Lusaka.

[3] GRZ (2012): Chongwe District Development Coordinating Committee, Annual Report 2012.

[4] GRZ (2013): Chongwe District Development Coordinating Committee, Annual Report 2013.

[5] GRZ (2014): Chongwe District Development Coordinating Committee, Annual Report 2014.

[6] Hahne, K. & Shamboko, B. (2010):): Development of a Groundwater Information & Management Program for the Lusaka Groundwater Systems, Technical Report No. 3, Karstification, Tectonics and Land Use in the Lusaka region.- Ministry of Energy and Water Development - Department of Water Affairs and Federal Institute for Geosciences and Natural Resources; 75 pages; Lusaka.

[7] Jenkins, M., Nick, A., Mwelwa, D., Simwanza, T. (2015): Impact of Small Scale Farming on the Chongwe River. Survey on Land Use and Water Abstraction from Chongwe River - Department of Water Affairs, Zambia & Federal Institute for Geosciences and Natural Resources, Germany; 37 pages; Lusaka (unpublished report).

[8] Kang'omba, S. & Bäumle, R. (Eds.) (2013): Development of a Groundwater Information & Management Program for the Lusaka Groundwater Systems - Key Recommendations and Findings. Ministry of Energy and Water Development - Department of Water Affairs and Federal Institute for Geosciences and Natural Resources; 1st ed.; Hannover – Lusaka.

[9] Krekeler, T. (2015): Report on a mission to Zambia: Counterpart Training: Measurement of discharge, site selection for river gauging stations and installation of data loggers for groundwater and surface water level monitoring; internal field report, 14 pages, Hannover (unpublished report).

[10] Mayerhofer, Ch.; Shamboko-Mbale, B.; Mweene, R. (2010): Survey on Commercial Farming and Major Industries: Land Use, Groundwater Abstraction & Potential Pollution Sources. Report No. 4 - Department of Water Affairs, Zambia & Federal Institute for Geosciences and Natural Resources, Germany; Unpublished Report; 54 pages, Lusaka.

[11] Maseka Ch. (1994): A ground-water resource evaluation of fractured rock aquifers at Lusaka. Unpublished MSc Thesis at the University of New South Wales; 131 pages; Sydney.

[12] Mpamba N. H. (2008): Data acquisition models for groundwater assessment and management in the urban and rural areas of Zambia.- Thesis, Feb. 2008; University of Zambia, School of Mines - Department of Geology; 239 pages; Lusaka.

[13] Nick, A., Museteka, L., Kringel, R. (2010): Hydrochemical Sampling of Groundwater in the Lusaka Urban Area (April/May 2010) and Preliminary Findings, Technical Note 3 - Department of Water Affairs, Zambia & Federal Institute for Geosciences and Natural Resources, Germany; 30 pages, Lusaka.

[14] Nkhuwa D.C.W. (2000): Management of groundwater resources in Lusaka, Zambia, and expectations for the future.- In Sililo, O. et al. (eds) (2000): Proc. XXXH IAH Congress on Groundwater: Past Achievements and Future Challenges , Cape Town, 26 Nov-1 Dec 2000, 993-998; Balkema, Rotterdam.

[15] Simpson J. G. (1962): The geology of the Mwembeshi River area.- Report of the Geological Survey No. 11, Explanation of degree sheet 1527, NE quarter, Northern Rhodesia Ministry of Labour and Mines; 29 pages; Government Printer, Lusaka.

[16] Simpson J. G., Drysdall A. R. & H. H. J. Lambert (1963): The geology and groundwater resources of the Lusaka area.– Report of the Geological Survey No. 16, Explanation of degree sheet 1528, NW. quarter; Northern Rhodesia Ministry of Labour and Mines; 59 pages; Government Printer, Lusaka.

[17] Siwale C. & Bäumle R. (2012): Hydrological/Hydrogeological Year Book of the Mwembeshi and Chongwe Sub-catchments, 2009/10 and 2010/11.- Ministry of Mines, Energy and Water Development, Department of Water Affairs; 65 pages; Lusaka.

[18] Struckmeyer, W.F. & J. Margat (1995): Hydrogeological maps – A guide and a standard legend. International Association of Hydrogeologists, 177 pp.; Hannover, Heise.

[19] Von Hoyer H., Köhler G. & G. Schmidt (1978): Groundwater and Management Studies for Lusaka Water supply, Part 1: Groundwater Studies, Vol. I: Text, 152 pages; Vol. III+IV: Annexes, Vol V: Maps.- Federal Institute for Geosciences and Natural Resources (BGR) & Lusaka City Council; Lusaka.

[20] YEC – Yachiyo Engineering Co. Ltd. (1995): The Study on the National Water Resources Master Plan in the Republic of Zambia.- Japan International Cooperation Agency & Republic of Zambia, Ministry of Energy and Water Development, Final Report – Supporting Volume 1, Oct. 1995; Lusaka.

Annex 1

A. Sampling locations and in-situ parameters

Sample ID	Borehole name	Longitude	Latitude	date	time	T air	T w	EC	pH	Eh	O	O
		WGS84				°C	°C	µS/cm		mV	(mg/l)	(%)
GW-CHO-DAL/1	Daliyo Borehole	28,65893	-15,32369	10.12.2014	10:45	31	24,3	549	7,1	-4		
GW-CHO-SEC-SCH-02	Chongwe Secondary School	28,68044	-15,33630	10.12.2014	12:05	33,9	25,5	241	6,5	253		
GW-CHO-Kapa-BH-D-03	Kapamangoma	28,71806	-15,33665	10.12.2014	13:15	26,7	25,9	1083	6,9	173		
GW-CHO-04	Katende	28,61641	-15,34111	10.12.2014	15:40	28	25,5	546	7,1	63		
GW-CHO-Mukan-05	Mukankaulwa	28,71828	-15,38712	11.12.2014	12:45	32,7	26,6	1548	6,9	14		
GW-CHO-Kampe-H.C-06	Kampekete Health Center	28,76304	-15,39129	11.12.2014	13:40	33,7	25,4	667	6,8	4		
GW-CHO-saili-07	Pa Saili Village	28,76598	-15,41136	11.12.2014	14:45	32,1	24,8	1313	6,6	-22		
GW-CHO-Chilya-sch-08	Chilyabale School HP	28,77955	-15,45433	11.12.2014	15:45	29,5	24,5	902	7,2	10		
GW-CHO-Sham-09	Shamboshi	28,73987	-15,49738	11.12.2014	16:40	27,6	25,2	812	7,1	57		
GW-CHO-Luim-10	Luimba.B.School	28,82103	-15,50470	12.12.2014	09:15	24,5	24,2	540	7,2	78		
GW-CHO-Kas-11A	Kasolo village	28,81893	-15,49574	12.12.2014	10:15	24	24,1	607	6,9	68		
GW-CHO-Mula-sch-12	Mulalika Primary School	28,80550	-15,56360	12.12.2014	12:00	26,1	25,4	323	7	184		
GW-CHO-Mwalu-Sch-13	Mwalumina Primary School	28,85352	-15,45451	12.12.2014	13:40	27,5	25,7	531	7	161		
GW-CHO-Likan-14	Likando Village HP 2	28,84791	-15,47172	12.12.2014	14:15	26,8	25,2	1007	7,1	120		
GW-CHO-Mwachi-H.C-15	Mwachilele Health Centre	28,94497	-15,43717	23.12.2014	13:30	29,5	26,2	392	7	46		
S-CHO-River-16	Chongwe River near Mwachilele	28,93325	-15,45908	23.12.2014	13:50	32,1	24,9	103	7	158		
GW-CHO-CHAM-17	Chamulimba	28,89469	-15,33900	23.12.2014	14:50	32,7	25,1	284	6,9	184		
S-CHO-PAL-02	Palabana Spring	28,5376	-15,4556	31.03.2015	14:51	25,6	23,8	785	7,1	295	3,63	49,6
SW-CHO-B-005	Chongwe River Bridge GE	28,70247	-15,32308	30.03.2015	14:12		25,9	298	7,7	227	6,11	85,1
GW-CHO-DAL-018	Daliyo (Borehole)	28,65893	-15,32369	30.03.2015	13:17		25,1	599	7,3	-100	2,9	39,9
GW-CHO-SEC-019	Chongwe Secondary School (Borehole)	28,678507	-15,3367	30.03.2015	11:37		24,7	438	6,9	278	4,03	55
GW-CHO-KAP-020	Kapamangoma B.H D	28,71806	-15,33665	02.04.2015	09:50	24,5	24,5	1153	6,8			
GW-CHO-KAT-021	Katende	28,61641	-15,34111	02.04.2015	14:30	24,3	24,2	1453	7			
GW-CHO-MUK-022	Mukankaulwa	28,718305	-15,38713	31.03.2015	11:11	27,2	24,9	1819	7,1	107	4,27	58,5
GW-CHO-KAM-023	Kampekete H.C	28,761771	-15,39168	31.03.2015	10:30	25,8	24,2	696	6,9	99	3,4	48,1
GW-CHO-SAI-024	Saili Village	28,76598	-15,41136	31.03.2015	10:15	25,9	24,6	529	6,6	166	3,14	42,9
GW-CHO-CHI-025	Chilyabale	28,77955	-15,45433	31.03.2015	09:40	23,4	24,1	899	7,2	168	65,5	36,2
GW-CHO-SHA-026	Shamboshi	28,73987	-15,49738	02.04.2015	12:52	26,8	25,1	1690	6,7			
GW-CHO-LUI-027	Luimba. B. School	28,82103	-15,50470	01.04.2015	14:25	23,1	23,9	906	6,4			
GW-CHO-KAS-028	Kasolo Village	28,81893	-15,49574	01.04.2015	13:58	27	24	1121	6,5			
GW-CHO-MUL-029	Mulalika. P. School	28,80550	-15,56360	01.04.2015	15:10	28,6	25,6	636	6,7			
GW-CHO-MAL-030	Mwalumina. P. School	28,85352	-15,45451	01.04.2015	11:56	23,6	25,6	953	6,6			
GW-CHO-LIK-031	Likando Village HP2	28,84791	-15,47172	01.04.2015	12:58	25,2	25,3	987	6,8			
GW-CHO-MWA-032	Mwachilele H.C	28,94497	-15,43717	01.04.2015	10:55	22,4	24,8	1055	7,1			
SW-CHO-RMW-033	Chongwe River at Mwachilele	28,93325	-15,45908	01.04.2015	11:26	21,4	23,8	715	7,1			
GW-CHO-CHA-034	Chamulimba	28,89469	-15,33900	01.04.2015	10:17	22,8	24,2	547	6,4			
GW-CHO-HOS-035	Chongwe District Hospital (Borehole)	28,668429	-15,33897	30.03.2015	10:20		24,4	566	7,2	226	3,94	53,8
GW-CHO-HOS-036	Chongwe District Hospital Doctor's Housing	28,670425	-15,34003	30.03.2015	09:30		23,4	359	6,8	222	5,65	75,3
GW-CHO-SCH-037	Klaus and Martina Weber	28,677238	-15,33456	30.03.2015	11:00		24,4	493	7,4	232	6,55	89,4
SW-CHO-KAZ-038	Kazembe Bible College	28,814961	-15,3742	30.03.2015	15:01		25,1	335	7,7	247	6,72	92,3
GW-CHO-KAZ-039	Kazembe Bible College (Borehole)	28,821681	-15,3707	30.03.2015	15:56		25,7	376	6,6	268	4,66	63
GW-CHO-KAZS-040	Kazembe Primary School (Borehole)	28,830232	-15,34045	30.03.2015	16:22		25,2	631	6,9	72	1,81	25,3
GW-CHO-CPP-041	Chalimbana Police Post	28,481247	-15,38636	31.03.2015	15:33	27,2	24,1	665	6,8	84	2,32	31,7
SW-CHO-RGS-042	Chongwe River @ River Gauge Station 05-024	28,508642	-15,22425	01.04.2015	09:30		23,4	571	7,7	207	3,82	50,8
GW-CHO-MBL-043	Mwabula Village	28,508436	-15,24033	01.04.2015	10:03		24,9	280	6,7	82	3,32	45,7
GW-CHO-KPS-044	Kasisis Primary School	28,470706	-15,26518	01.04.2015	11:00		23,5	474	6,9	194	6,35	83,1
GW-CHO-MUL-045	Mulelasolo Farm	28,484704	-15,28256	01.04.2015	11:50		24,2	148	7	217	5,37	73,2
SW-CHO-ZRC-046	Chongwe River @ ZRC Farm	28,437855	-15,18362	01.04.2015	12:52		24,1	151	7,1	198	2,2	29,6
GW-CHO-RDB-047	ZRC Farm Borehole @ Dam	28,439898	-15,16711	01.04.2015	13:30		25,7	137	7,1	225	3,27	45,6
GW-CHO-CHA-048	Chaminuka Lodge	28,499527	-15,15556	01.04.2015	14:22		23,4	386	7,4	223	4,2	56,6
GW-CHO-ZCF-049	Chisamba ZCF Compound	28,375723	-14,97381	02.04.2015	10:00		23,3	701	7,4	-42	3,13	41,9
GW-CHO-LWS-050	Chisamba - Lukanga Water and Sewerage Borehole	28,376699	-14,98084	02.04.2015	10:14		23,9	884	7,7	196	8,77	117
GW-CHO-DCH-051	District Council Headquaters	28,376218	-14,98056	02.04.2015	10:30		24,2	850	7,3	94	3,9	70
GW-CHO-SAB-052	Sable Quartz Farm	28,220228	-14,89819	02.04.2015	11:28		24	528	6,9	162	6,89	93,9
GW-CHO-CHS-053	Chisengo	28,732085	-15,36246	02.04.2015	10:53	24,8	24,3	902	6,7			
GW-CHO-KPU-054	Kapuka B	28,721472	-15,36704	02.04.2015	11:20	21,2	24,2	580	6,3			
GW-CHO-CHK-055	Chaka 1	28,68512	-15,37573	02.04.2015	11:55	22,1	23,5	974	6,9			
GW-CHO-YAL-056	Chiyalusha D	28,72827	-15,49393	02.04.2015	13:15	24	23,9	863	6,9			

B. Major and minor constituents

Sample ID	K	Na	Cl	Mg	Ca	SO4	HCO3	Fe(II)	Mn	NO3	Br	NH4	NO2	F	PO4
	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
GW-CHO-DAL/1	5,4	35,2	2,46	12,8	67,7	2,86	365	3,03	0,233	0,04	0,017	0,03	-0,003	0,076	-0,03
GW-CHO-SEC-SCH-02	6,1	15,1	9,45	10,1	14,1	2,94	127	0,016	0,032	2,36	0,014	-0,01	0,016	0,104	0,70
GW-CHO-Kapa-BH-D-03	7,5	90,5	4,81	29,2	117	150	543	0,016	0,002	3,11	0,007	-0,01	0,005	0,369	-0,03
GW-CHO-04															
GW-CHO-Mukan-05	13,6	111	38,5	47,6	194	427	494	0,772	0,055	19,5	0,060	-0,01	0,142	0,186	-0,03
GW-CHO-Kampe-H.C-06	3,3	27,8	2,64	17,8	95,5	133	274	1,98	0,061	0,27	0,004	-0,01	0,009	0,162	-0,03
GW-CHO-saili-07	4,5	53,5	37,3	58,5	158	483	228	6,81	0,069	0,05	0,041	0,03	-0,003	0,184	0,16
GW-CHO-Chilya-sch-08	5,1	54,9	5,20	31,0	105	112	465	0,573	0,044	12,7	0,018	0,01	0,143	0,456	-0,03
GW-CHO-Sham-09	4,3	12,5	4,46	16,0	133	49,0	438	0,179	0,007	5,52	0,005	-0,01	0,003	1,02	-0,03
GW-CHO-Luim-10	3,7	44,4	5,56	14,3	49,1	100	215	0,004	0,026	1,45	0,005	-0,01	0,008	0,316	0,08
GW-CHO-Kas-11A	1,6	51,4	0,946	10,9	70,1	98,4	276	0,180	0,007	0,64	0,003	-0,01	0,003	0,265	0,04
GW-CHO-Mula-sch-12	10,3	15,2	7,53	14,0	29,9	0,794	190	-0,003	-0,001	14,5	0,008	-0,01	-0,003	0,078	0,15
GW-CHO-Mwalu-Sch-13	6,3	29,0	8,12	21,1	52,7	1,90	333	0,007	0,028	8,48	0,008	0,03	-0,003	0,160	0,13
GW-CHO-Likan-14	6,6	101	0,336	17,8	103	83,1	591	0,066	0,041	0,02	0,004	-0,01	-0,003	0,230	-0,03
GW-CHO-Mwachi-H.C-15	8,2	9,5	5,70	24,3	34,6	0,616	258	0,103	0,006	0,4	0,003	-0,01	0,006	0,181	-0,03
S-CHO-River-16	4,5	2,7	2,78	2,92	8,45	5,22	39,3		0,087	2,02	0,003	0,01	0,006	0,161	0,25
GW-CHO-CHAM-17	7,9	20,9	8,65	14,2	16,4	3,67	159	0,013	0,015	10,8	0,019	-0,01	0,006	0,083	0,18
S-CHO-PAL-02	0,6	5,5	1,81	18,0	143	8,19	521	0,007	0,003	5,59	-0,003	-0,01	0,004	0,292	0,03
SW-CHO-B-005	7,8	18,0	18,5	9,69	28,8	7,80	149	0,183	0,065	0,02	0,024	0,04	0,061	0,170	0,06
GW-CHO-DAL-018	8,9	39,0	5,72	13,1	67,9	2,87	381	5,65	0,057	0,007	0,014	0,01	-0,003	0,048	-0,03
GW-CHO-SEC-019	10,2	20,1	30,8	19,6	35,3	7,46	204	0,004	0,015	9,40	0,024	-0,01	0,031	0,108	0,11
GW-CHO-KAP-020	7,5	89,9	4,65	28,9	118	140	571	0,017	0,001	2,79	0,006	-0,01	0,008	0,371	-0,03
GW-CHO-KAT-021	5,3	59,2	53,2	21,2	61,5	11,1	360	1,34	0,062	1,46	0,005	0,02	0,040	0,611	-0,03
GW-CHO-MUK-022	11,8	119	47,7	59,6	223	554	476	0,528	0,051	30,9	0,072	0,01	0,006	0,183	-0,03
GW-CHO-KAM-023	1,4	37,5	14,1	17,2	84,8	133	257	0,663	0,028	2,59	0,005	0,01	-0,003	0,288	-0,03
GW-CHO-SAI-024	0,5	28,9	8,86	22,4	45,7	81,5	209	0,387	0,009	6,95	-0,003	0,02	0,024	0,367	-0,03
GW-CHO-CHI-025	4,0	61,5	5,61	28,9	101	98,0	474	0,847	0,032	12,4	0,005	0,04	0,207	0,448	-0,03
GW-CHO-SHA-026	2,6	13,9	3,80	21,5	149	42,8	527	1,29	0,015	4,25	0,003	0,04	0,027	1,05	-0,03
GW-CHO-LUI-027	2,6	37,7	2,87	12,0	35,1	65,0	190	0,005	0,018	0,776	-0,003	-0,01	0,003	0,310	0,08
GW-CHO-KAS-028	1,3	47,7	1,34	10,7	56,0	78,5	259	0,027	0,012	0,470	-0,003	-0,01	0,003	0,282	-0,03
GW-CHO-MUL-029	5,0	16,0	2,09	13,8	27,5	0,307	180	0,003	-0,001	13,7	0,003	-0,01	0,012	0,069	0,14
GW-CHO-MAL-030	6,3	31,0	7,45	21,7	38,1	1,76	299	0,007	0,025	7,02	0,005	0,01	0,062	0,149	0,12
GW-CHO-LIK-031	7,4	112	0,361	20,2	97,9	63,0	635	6,79	0,073	0,008	-0,003	0,04	-0,003	0,221	-0,03
GW-CHO-MWA-032	10,0	18,5	0,811	36,1	36,8	4,27	349	0,510	0,030	0,562	-0,003	-0,01	0,090	0,165	-0,03
SW-CHO-RMW-033	3,9	18,5	14,0	11,5	33,2	8,87	178	0,052	0,233	1,27	0,020	-0,01	-0,003	0,177	0,03
GW-CHO-CHA-034	2,5	19,9	5,20	14,5	14,0	3,57	144	0,028	0,014	13,7	0,006	0,02	-0,003	0,101	0,13
GW-CHO-HOS-035	6,2	38,2	3,66	16,3	60,2	10,9	363	0,003	0,015	0,004	0,026	-0,01	-0,003	0,085	-0,03
GW-CHO-HOS-036	1,0	20,2	2,04	11,6	35,4	3,61	222	0,011	0,005	0,841	0,003	-0,01	-0,003	0,129	-0,03
GW-CHO-SCH-037	12,6	23,7	39,6	25,7	34,3	12,5	228	0,003	0,099	8,42	0,022	0,07	-0,003	0,107	0,07
SW-CHO-KAZ-038	7,9	19,2	18,5	10,9	31,8	9,15	171	0,082	0,061	0,355	0,022	0,02	0,009	0,180	-0,03
GW-CHO-KAZ-039	5,1	19,4	8,12	12,3	34,4	0,262	214	0,003	-0,001	1,65	0,022	-0,01	0,014	0,210	0,28
GW-CHO-KAZS-040	5,7	32,5	13,6	20,6	64,3	1,23	379	1,83	0,097	0,004	0,021	-0,01	-0,003	0,218	0,07
GW-CHO-CPP-041	4,1	24,9	8,51	26,2	73,9	7,01	408	0,418	0,041	13,1	0,014	0,04	0,008	0,209	0,04
SW-CHO-RGS-042	9,3	28,7	33,9	18,2	55,8	31,8	253	0,092	0,039	0,836	0,031	0,02	0,015	0,208	0,72
GW-CHO-MBL-043	2,7	12,1	2,14	9,79	28,6	0,519	163	1,36	0,027	1,93	0,011	-0,01	0,003	0,091	0,05
GW-CHO-KPS-044	4,0	18,4	21,1	7,36	60,2	3,79	202	0,003	-0,001	35,4	0,040	0,01	0,005	0,071	0,03
GW-CHO-MUL-045	2,8	10,8	0,874	2,25	15,2	3,12	81,5	0,006	0,004	1,28	0,004	0,00	0,004	0,168	0,05
SW-CHO-ZRC-046	4,3	8,9	5,10	4,88	8,61	0,830	73,0	0,323	1,27	0,129	0,049	0,13	0,149	0,249	-0,03
GW-CHO-RDB-047	4,4	9,2	5,31	3,97	7,91	1,33	62,0	0,063	0,007	0,751	0,030	0,05	0,009	0,140	0,03
GW-CHO-CHA-048	4,4	23,0	4,82	7,73	41,5	1,17	234	0,005	-0,001	#####	0,022	-0,01	-0,003	0,108	0,11
GW-CHO-ZCF-049	2,8	27,2	2,58	30,1	77,9	59,4	393	1,45	0,070	1,52	0,005	0,01	0,070	0,151	-0,03
GW-CHO-LWS-050	2,9	37,3	7,70	42,5	81,6	147	369	-0,003	0,001	1,53	0,005	-0,01	0,004	0,490	-0,03
GW-CHO-DCH-051	5,9	35,9	15,8	35,0	92,7	141	355	0,713	0,026	9,88	0,016	0,02	0,051	0,295	-0,03
GW-CHO-SAB-052	3,1	8,7	5,50	30,9	56,8	0,803	338	-0,003	0,002	7,36	0,023	-0,01	0,008	0,094	0,12
GW-CHO-CHS-053	5,0	19,6	2,65	12,0	52,5	0,652	275	0,005	0,049	0,424	0,005	-0,01	-0,003	0,101	0,18
GW-CHO-KPU-054	4,8	11,6	3,66	9,46	29,0	0,293	164	0,005	0,001	1,65	0,006	-0,01	0,011	0,177	0,16
GW-CHO-CHK-055	4,1	22,9	1,64	16,3	53,8	7,79	306	0,010	0,017	0,01	0,004	-0,01	-0,003	0,250	-0,03
GW-CHO-YAL-056	2,2	30,3	0,605	5,39	52,1	0,826	275	0,004	0,007	0,151	-0,003	-0,01	-0,003	0,455	-0,03

C. Trace elements (in mg/l, negative value: concentration is below detection limit)

Sample ID	Al	As	BO2	Ba	Be	Cd	Co	Cr	Cu	Li	Ni	Pb	Sc	SiO2	Sr	Ti	V	Zn
GW-CHO-DAL/1	0,004	-0,02	-0,01	0,046	-0,001	-0,002	-0,003	-0,003	-0,003	0,013	-0,003	-0,02	-0,001	42,0	0,140	-0,001	-0,003	0,442
GW-CHO-SEC-SCH-02	-0,003	-0,02	-0,01	0,047	-0,001	-0,002	-0,003	-0,003	0,003	0,011	-0,003	-0,02	-0,001	55,7	0,059	-0,001	0,008	3,41
GW-CHO-Kapa-BH-D-03	-0,003	-0,02	-0,01	0,082	-0,001	-0,002	-0,003	-0,003	0,004	0,008	-0,003	-0,02	-0,001	46,7	0,507	-0,001	0,009	0,021
GW-CHO-04																		
GW-CHO-Mukan-05	-0,003	-0,02	-0,01	0,023	-0,001	-0,002	-0,003	-0,003	0,019	0,008	-0,003	-0,02	-0,001	38,1	0,852	-0,001	-0,003	0,043
GW-CHO-Kampe-H.C-06	0,005	-0,02	-0,01	0,057	-0,001	-0,002	-0,003	-0,003	-0,003	0,005	-0,003	-0,02	-0,001	46,1	0,267	-0,001	-0,003	0,017
GW-CHO-saili-07	0,008	-0,02	-0,01	0,008	-0,001	-0,002	0,005	-0,003	-0,003	0,018	0,010	-0,02	-0,001	61,9	0,175	-0,001	-0,003	0,199
GW-CHO-Chilya-sch-08	0,003	-0,02	-0,01	0,041	-0,001	-0,002	-0,003	-0,003	-0,003	0,010	-0,003	-0,02	-0,001	35,8	0,285	-0,001	-0,003	0,083
GW-CHO-Sham-09	0,003	-0,02	-0,01	0,062	-0,001	-0,002	-0,003	-0,003	-0,003	0,003	-0,003	-0,02	-0,001	46,0	0,572	-0,001	-0,003	0,141
GW-CHO-Luim-10	-0,003	-0,02	-0,01	0,056	-0,001	-0,002	-0,003	-0,003	-0,003	0,015	-0,003	-0,02	-0,001	46,8	0,204	-0,001	0,004	0,010
GW-CHO-Kas-11A	0,004	-0,02	-0,01	0,059	-0,001	-0,002	-0,003	-0,003	-0,003	0,008	-0,003	-0,02	-0,001	48,7	0,344	-0,001	0,004	0,013
GW-CHO-Mula-sch-12	-0,003	-0,02	-0,01	0,110	-0,001	-0,002	-0,003	-0,003	-0,003	0,003	-0,003	-0,02	-0,001	54,6	0,309	-0,001	0,006	0,009
GW-CHO-Mwalu-Sch-13	-0,003	-0,02	-0,01	0,144	-0,001	-0,002	-0,003	-0,003	-0,003	0,015	-0,003	-0,02	-0,001	51,1	0,193	-0,001	0,059	0,029
GW-CHO-Likan-14	-0,003	-0,02	-0,01	0,068	-0,001	-0,002	-0,003	-0,003	-0,003	0,025	-0,003	-0,02	-0,001	38,7	0,558	-0,001	-0,003	2,43
GW-CHO-Mwachi-H.C-15	0,003	-0,02	-0,01	0,041	-0,001	-0,002	-0,003	-0,003	0,003	-0,003	-0,003	-0,02	-0,001	31,4	0,143	-0,001	0,015	0,694
S-CHO-River-16		-0,02	-0,01	0,075	-0,001	-0,002	0,003	0,003	0,013	-0,003	0,004	-0,02	0,001	13,3	0,045	0,064	0,012	0,014
GW-CHO-CHAM-17	-0,003	-0,02	-0,01	0,067	-0,001	-0,002	-0,003	-0,003	-0,003	0,004	0,004	-0,02	-0,001	65,2	0,140	-0,001	0,016	0,052
S-CHO-PAL-02	0,004	-0,02	-0,01	0,020	-0,001	-0,002	-0,003	-0,003	-0,003	-0,003	-0,003	-0,02	-0,001	18,3	0,381	-0,001	-0,003	0,004
SW-CHO-B-005	0,023	-0,02	-0,01	0,052	-0,001	-0,002	-0,003	-0,003	-0,003	-0,003	-0,003	-0,02	-0,001	12,8	0,098	0,001	-0,003	-0,003
GW-CHO-DAL-018	0,009	-0,02	-0,01	0,015	-0,001	-0,002	-0,003	-0,003	-0,003	0,013	-0,003	-0,02	-0,001	39,4	0,135	-0,001	-0,003	0,195
GW-CHO-SEC-019	0,003	-0,02	-0,01	0,079	-0,001	-0,002	-0,003	-0,003	-0,003	0,007	-0,003	-0,02	-0,001	46,0	0,104	-0,001	0,005	0,036
GW-CHO-KAP-020	-0,003	-0,02	-0,01	0,073	-0,001	-0,002	-0,003	-0,003	-0,003	0,008	-0,003	-0,02	-0,001	44,8	0,457	-0,001	0,008	0,008
GW-CHO-KAT-021	0,004	-0,02	0,01	0,098	-0,001	-0,002	-0,003	-0,003	-0,003	0,008	-0,003	-0,02	-0,001	42,8	0,319	-0,001	0,004	1,71
GW-CHO-MUK-022	0,003	-0,02	-0,01	0,022	-0,001	-0,002	-0,003	-0,003	-0,003	0,009	-0,003	-0,02	-0,001	35,0	0,958	-0,001	-0,003	0,244
GW-CHO-KAM-023	0,004	-0,02	-0,01	0,046	-0,001	-0,002	-0,003	-0,003	-0,003	0,003	-0,003	-0,02	-0,001	24,0	0,305	-0,001	-0,003	0,031
GW-CHO-SAI-024	0,005	-0,02	-0,01	0,050	-0,001	-0,002	-0,003	-0,003	-0,003	-0,003	-0,003	-0,02	-0,001	31,0	0,184	-0,001	-0,003	0,078
GW-CHO-CHI-025	0,004	-0,02	-0,01	0,040	-0,001	-0,002	-0,003	-0,003	-0,003	0,007	-0,003	-0,02	-0,001	34,4	0,270	-0,001	-0,003	0,179
GW-CHO-SHA-026	0,003	-0,02	-0,01	0,060	-0,001	-0,002	-0,003	-0,003	0,003	0,003	-0,003	-0,02	-0,001	41,3	0,548	-0,001	-0,003	0,206
GW-CHO-LUI-027	0,005	-0,02	-0,01	0,040	-0,001	-0,002	-0,003	-0,003	-0,003	0,012	-0,003	-0,02	-0,001	45,8	0,148	-0,001	0,003	0,013
GW-CHO-KAS-028	-0,003	-0,02	-0,01	0,056	-0,001	-0,002	-0,003	-0,003	-0,003	0,006	-0,003	-0,02	-0,001	45,2	0,295	-0,001	0,003	0,021
GW-CHO-MUL-029	0,003	-0,02	-0,01	0,093	-0,001	-0,002	-0,003	-0,003	-0,003	0,003	-0,003	-0,02	-0,001	51,3	0,263	-0,001	0,006	0,008
GW-CHO-MAL-030	-0,003	-0,02	-0,01	0,126	-0,001	-0,002	-0,003	-0,003	-0,003	0,014	-0,003	-0,02	-0,001	47,2	0,169	-0,001	0,060	0,023
GW-CHO-LIK-031	0,009	-0,02	-0,01	0,062	-0,001	-0,002	-0,003	-0,003	-0,003	0,025	-0,003	-0,02	-0,001	34,5	0,532	-0,001	-0,003	3,38
GW-CHO-MWA-032	0,004	-0,02	-0,01	0,130	-0,001	-0,002	-0,003	-0,003	-0,003	0,007	-0,003	-0,02	-0,001	22,6	0,162	-0,001	0,015	0,316
SW-CHO-RMW-033	0,014	-0,02	-0,01	0,074	-0,001	-0,002	-0,003	-0,003	-0,003	-0,003	-0,003	-0,02	-0,001	15,5	0,117	-0,001	-0,003	0,005
GW-CHO-CHA-034	0,028	-0,02	-0,01	0,055	-0,001	-0,002	-0,003	-0,003	-0,003	0,003	-0,003	-0,02	-0,001	52,0	0,135	0,001	0,011	0,023
GW-CHO-HOS-035	0,003	-0,02	-0,01	0,126	-0,001	-0,002	-0,003	-0,003	-0,003	0,014	-0,003	-0,02	-0,001	41,6	0,130	-0,001	-0,003	0,181
GW-CHO-HOS-036	0,004	-0,02	-0,01	0,052	-0,001	-0,002	-0,003	-0,003	-0,003	-0,003	-0,003	-0,02	-0,001	23,2	0,090	-0,001	-0,003	2,33
GW-CHO-SCH-037	0,005	-0,02	-0,01	0,066	-0,001	-0,002	-0,003	-0,003	-0,003	-0,003	-0,003	-0,02	-0,001	40,9	0,114	-0,001	0,003	1,38
SW-CHO-KAZ-038	0,018	-0,02	-0,01	0,064	-0,001	-0,002	-0,003	-0,003	-0,003	-0,003	-0,003	-0,02	-0,001	13,2	0,110	0,001	-0,003	-0,003
GW-CHO-KAZ-039	0,003	-0,02	-0,01	0,048	-0,001	-0,002	-0,003	-0,003	-0,003	0,015	-0,003	-0,02	-0,001	55,0	0,140	-0,001	0,005	0,005
GW-CHO-KAZS-040	0,005	-0,02	-0,01	0,080	-0,001	-0,002	-0,003	-0,003	-0,003	0,015	-0,003	-0,02	-0,001	36,2	0,175	-0,001	-0,003	0,241
GW-CHO-CPP-041	0,004	-0,02	-0,01	0,840	-0,001	-0,002	-0,003	-0,003	-0,003	-0,003	-0,003	-0,02	-0,001	23,8	0,422	-0,001	-0,003	3,63
SW-CHO-RGS-042	0,059	-0,02	0,03	0,076	-0,001	-0,002	-0,003	-0,003	-0,003	-0,003	-0,003	-0,02	-0,001	10,9	0,161	0,002	-0,003	0,003
GW-CHO-MBL-043	0,004	-0,02	-0,01	0,033	-0,001	-0,002	-0,003	-0,003	-0,003	-0,003	-0,003	-0,02	-0,001	45,0	0,079	-0,001	0,004	0,094
GW-CHO-KPS-044	-0,003	-0,02	-0,01	0,046	-0,001	-0,002	-0,003	-0,003	-0,003	-0,003	-0,003	-0,02	-0,001	26,3	0,080	-0,001	-0,003	0,007
GW-CHO-MUL-045	0,007	-0,02	-0,01	0,015	-0,001	-0,002	-0,003	-0,003	-0,003	0,012	-0,003	-0,02	-0,001	53,2	0,028	-0,001	-0,003	0,047
SW-CHO-ZRC-046	0,032	-0,02	-0,01	0,205	-0,001	-0,002	0,010	-0,003	-0,003	-0,003	-0,003	-0,02	-0,001	11,7	0,064	0,001	-0,003	-0,003
GW-CHO-RDB-047	0,044	-0,02	-0,01	0,074	-0,001	-0,002	-0,003	-0,003	-0,003	-0,003	-0,003	-0,02	-0,001	14,3	0,066	0,001	-0,003	0,058
GW-CHO-CHA-048	-0,003	-0,02	-0,01	0,008	-0,001	-0,002	-0,003	-0,003	-0,003	0,015	-0,003	-0,02	-0,001	39,3	0,184	-0,001	0,007	0,010
GW-CHO-ZCF-049	0,004	-0,02	-0,01	0,136	-0,001	-0,002	-0,003	-0,003	-0,003	0,003	-0,003	-0,02	-0,001	34,3	0,268	-0,001	-0,003	0,071
GW-CHO-LWS-050	0,004	-0,02	-0,01	0,060	-0,001	-0,002	-0,003	-0,003	-0,003	0,003	-0,003	-0,02	-0,001	24,7	0,337	-0,001	-0,003	0,024
GW-CHO-DCH-051	0,003	-0,02	-0,01	0,078	-0,001	-0,002	-0,003	-0,003	-0,003	0,011	-0,003	-0,02	-0,001	27,0	0,345	-0,001	-0,003	0,046
GW-CHO-SAB-052	-0,003	-0,02	-0,01	0,260	-0,001	-0,002	-0,003	-0,003	-0,003	0,009	-0,003	-0,02	-0,001	26,9	0,093	-0,001	-0,003	0,017
GW-CHO-CHS-053	0,003	-0,02	-0,01	0,143	-0,001	-0,002	-0,003	-0,003	-0,003	0,008	-0,003	-0,02	-0,001	46,6	0,130	-0,001	0,003	0,013
GW-CHO-KPU-054	-0,003	-0,02	-0,01	0,044	-0,001	-0,002	-0,003	-0,003	-0,003	0,004	-0,003	-0,02	-0,001	43,1	0,051	-0,001	-0,003	0,045
GW-CHO-CHK-055	0,003	-0,02	-0,01	0,147	-0,001	-0,002	-0,003	-0,003	-0,003	0,021	-0,003	-0,02	-0,001	45,2	0,115	-0,001	-0,003	0,024
GW-CHO-YAL-056	0,003	-0,02	-0,01	0,032	-0,001	-0,002	-0,003	-0,003	-0,003	0,003	-0,003	-0,02	-0,001	40,1	0,121	-0,001	-0,003	0,007

D. Stable isotopes

Sample number	Sampling date	Province	Longitude	Latidute	Name	δO 18	sd O18	δD	sd D	DE
P-CHO-D-01	18.12.2014	Lusaka	28,68307	-15,31892	DWA district office, Chongwe	-4,08	0,09	-12,9	0,4	20
P-CHO-D-02	29.12.2014	Lusaka	28,68307	-15,31892	DWA district office, Chongwe	-6,17	0,06	-32,5	0,2	17
P-CHO-D-03	06.01.2015	Lusaka	28,68307	-15,31892	DWA district office, Chongwe	-6,84	0,10	-39,5	0,4	15
P-CHO-D-04	16.01.2015	Lusaka	28,68307	-15,31892	DWA district office, Chongwe	-6,46	0,01	-41,0	0,2	11
P-CHO-D-05	21.01.2015	Lusaka	28,68307	-15,31892	DWA district office, Chongwe	-4,15	0,07	-26,5	0,1	7
P-CHO-D-06	05.02.2015	Lusaka	28,68307	-15,31892	DWA district office, Chongwe	-7,81	0,07	-50,1	0,1	12
P-CHO-D-07	12.02.2015	Lusaka	28,68307	-15,31892	DWA district office, Chongwe	-2,32	0,05	-3,7	0,0	15
P-CHO-D-08	19.03.2015	Lusaka	28,68307	-15,31892	DWA district office, Chongwe	-4,54	0,02	-22,9	0,3	13
P-CHO-D-09	30.03.2015	Lusaka	28,68307	-15,31892	DWA district office, Chongwe	-3,27	0,02	-14,2	0,3	12
P-CHO-D-10	02.04.2015	Lusaka	28,68307	-15,31892	DWA district office, Chongwe	-9,08	0,10	-57,4	0,3	15
P-CHO-D-11	14.04.2015	Lusaka	28,68307	-15,31892	DWA district office, Chongwe	-7,87	0,03	-49,16	0,20	14
P-CHO-D-12	23.04.2015	Lusaka	28,68307	-15,31892	DWA district office, Chongwe	-10,30	0,04	-65,99	0,12	16
S-CHO-B-01	25.06.2014	Lusaka	28,70249	-15,32308	Chongwe River Bridge GE	-2,93	0,18	-21,6	0,4	2
S-CHO-B-02	03.09.2014	Lusaka	28,70249	-15,32308	Chongwe River Bridge GE	-1,58	0,07	-15,3	0,4	-3
S-CHO-MWA-01	03.09.2014	Lusaka	28,93325	-15,45908	Chongwe River near Mwachilele	-3,30	0,05	-25,3	0,4	1
S-CHO-River-16	23/12/2014	Lusaka	28,93325	-15,45908	Chongwe River near Mwachilele	-5,88	0,02	-29,0	0,2	18
SW-CHO-NDO-01	10.03.2015	Lusaka	28,93139	-15,46902	Noel Chilima, Ndombwe	-4,71	0,05	-28,00	0,60	10
SW-CHO-CHI-02	10.03.2015	Lusaka	28,94403	-15,50042	Crispin Ngandu, Chikoloma Village	-4,84	0,04	-28,66	0,24	10
SW-CHO-CHI-04	10.03.2015	Lusaka	28,91489	-15,44187	Christopher Mwale, Chilonda Village	-4,62	0,07	-27,02	0,14	10
SW-CHO-RMW-03	10.03.2015	Lusaka	28,93325	-15,45908	Chongwe River neach Mwachilele	-4,76	0,04	-27,57	0,26	11
SW-CHO-RMW-04	18.03.2015	Lusaka	28,93325	-15,45908	Chongwe River neach Mwachilele	-4,30	0,07	-24,98	0,19	9
SW-CHO-CHA-01	19.03.2015	Lusaka	28,46300	-15,40609	Chalimbana River at old gauge plate	-5,84	0,10	-37,34	0,36	9
S-CHO-PAL-01	19.03.2015	Lusaka	28,53760	-15,4556	Palabana Spring	-6,76	0,02	-42,51	0,18	12
S-CHO-PAL-02	31.03.2015	Lusaka	28,53760	-15,4556	Palabana Spring	-6,74	0,07	-42,50	0,25	11
SW-CHO-B-005	30.03.2015	Lusaka	28,70247	-15,32308	Chongwe River Bridge GE	-3,54	0,09	-21,82	0,31	6
SW-CHO-RMW-033	01.04.2015	Lusaka	28,93325	-15,459083	Chongwe River at Mwachilele	-4,08	0,08	-25,28	0,35	7
SW-CHO-KAZ-038	30.03.2015	Lusaka	28,814961	-15,374203	Kazembe Bible College	-3,99	0,06	-24,49	0,12	7
SW-CHO-RGS-042	01.04.2015	Lusaka	28,508642	-15,224254	Chongwe River at Gauge 5_42	-3,88	0,06	-25,65	0,44	5
SW-CHO-ZRC-046	01.04.2015	Lusaka	28,437855	-15,183616	Chongwe River at ZRC Farm	-0,75	0,08	-11,07	0,33	-5
GW-CHO-CHI-01	03.09.2014	Lusaka	28,77955	-15,45433	Chilyabale School HP	-7,62	0,10	-49,2	0,4	12
GW-CHO-KAM-01	03.09.2014	Lusaka	28,76179	-15,39167	Kampekete Health Centre	-7,36	0,12	-46,7	0,4	12
GW-CHO-LIK-01	03.09.2014	Lusaka	28,85063	-15,47982	Likando Village HP 1	-7,41	0,08	-47,6	0,5	12
GW-CHO-MWA-01	03.09.2014	Lusaka	28,94499	-15,43718	Mwachilele Health Centre & School	-6,38	0,08	-42,3	0,6	9
GW-CHO-KAM-02	17.09.2014	Lusaka	28,76179	-15,39167	Kampekete Health Centre	-7,18	0,03	-46,3	0,3	11
GW-CHO-CTB-01	17.09.2014	Lusaka	28,80313	-15,40017	Chitentabunga Prim. School	-7,10	0,13	-46,4	0,4	10
GW-CHO-SHA-01	17.09.2014	Lusaka	28,81569	-15,38801	Shamakando Village HP	-6,74	0,08	-43,3	0,2	11
GW-CHO-KAB-01	17.09.2014	Lusaka	28,84188	-15,37759	Kabulanshishi School	-6,63	0,06	-44,2	0,4	9
GW-CHO-DAL/1	10.12.2014	Lusaka	28,65893	-15,32369	Daliyo Borehole	-7,41	0,07	-48,4	0,3	11
GW-CHO-SEC-SCH-02	10.12.2014	Lusaka	28,68044	-15,33630	Chongwe Secondary School	-6,84	0,08	-45,3	0,1	9
GW-CHO-Kapa-BH-D-03	10.12.2014	Lusaka	28,71806	-15,33665	Kapamangoma	-7,73	0,06	-49,6	0,1	12
GW-CHO-04	10.12.2014	Lusaka	28,61641	-15,34111	Katende	-7,25	0,08	-48,0	0,4	10
GW-CHO-Mukan-05	11.12.2014	Lusaka	28,71828	-15,38712	Mukankaulwa	-7,45	0,09	-48,7	0,2	11
GW-CHO-Kampe-H.C-06	11.12.2014	Lusaka	28,76304	-15,39129	Kampekete Health Center	-7,47	0,05	-47,8	0,1	12
GW-CHO-saili-07	11.12.2014	Lusaka	28,76598	-15,41136	Pa Saili Village	-7,79	0,03	-50,5	0,1	12
GW-CHO-Chilya-sch-08	11.12.2014	Lusaka	28,77955	-15,45433	Chilyabale School HP	-7,63	0,05	-49,8	0,1	11
GW-CHO-Sham-09	11.12.2014	Lusaka	28,73987	-15,49738	Shamboshi	-7,16	0,01	-46,0	0,1	11
GW-CHO-Luim-10	12.12.2014	Lusaka	28,82103	-15,50470	Luimba.B.School	-7,22	0,07	-46,0	0,3	12
GW-CHO-Kas-11A	12.12.2014	Lusaka	28,81893	-15,49574	Kasolo village	-7,50	0,01	-48,0	0,2	12
GW-CHO-Mula-sch-12	12.12.2014	Lusaka	28,80550	-15,56360	Mulalika Primary School	-6,93	0,07	-45,5	0,2	10
GW-CHO-Mwalu-Sch-13	12.12.2014	Lusaka	28,85352	-15,45451	Mwalumina Primary School	-7,16	0,08	-47,4	0,1	10
GW-CHO-Likan-14	12.12.2014	Lusaka	28,84791	-15,47172	Likando Village HP 2	-7,33	0,07	-47,5	0,5	11
GW-CHO-Mwachi-H.C-15	23/12/2014	Lusaka	28,94497	-15,43717	Mwachilele Health Centre	-6,37	0,06	-40,4	0,1	11
GW-CHO-CHAM-17	23/12/2014	Lusaka	28,89469	-15,33900	Chamulimba	-6,96	0,01	-44,3	0,1	11
GW-CHO-KAM-03	18.03.2015	Lusaka	28,76177	-15,391677	Kampekete Health Centre	-6,87	0,08	-43,24	0,15	12
GW-CHO-CHI-03	18.03.2015	Lusaka	28,77955	-15,45433	Chilyabale School HP	-7,28	0,08	-46,09	0,18	12
GW-CHO-DAL-018	30.03.2015	Lusaka	28,65893	-15,32369	Daliyo (Borehole)	-7,06	0,07	-45,11	0,19	11
GW-CHO-SEC-019	30.03.2015	Lusaka	28,67851	-15,336697	Chongwe Secondary School	-5,54	0,06	-35,15	0,48	9
GW-CHO-KAP-020	02.04.2015	Lusaka	28,71806	-15,33665	Kapamangoma B.H D	-7,40	0,09	-45,29	0,29	14
GW-CHO-KAT-021	02.04.2015	Lusaka	28,61641	-15,34111	Katende	-6,95	0,09	-44,02	0,44	12
GW-CHO-MUK-022	31.03.2015	Lusaka	28,71831	-15,387132	Mukankaulwa	-7,21	0,09	-45,48	0,16	12
GW-CHO-KAM-023	31.03.2015	Lusaka	28,76177	-15,391677	Kampekete H.C	-6,96	0,03	-42,47	0,20	13
GW-CHO-SAI-024	31.03.2015	Lusaka	28,76598	-15,41136	Saili Village	-7,04	0,05	-42,84	0,07	13
GW-CHO-CHI-025	31.03.2015	Lusaka	28,77955	-15,45433	Chilyabale	-7,36	0,09	-47,30	0,18	12
GW-CHO-SHA-026	02.04.2015	Lusaka	28,73987	-15,49738	Shamboshi	-6,81	0,06	-43,67	0,09	11
GW-CHO-LUI-027	01.04.2015	Lusaka	28,82103	-15,5047	Luimba. B. School	-6,95	0,07	-43,26	0,16	12
GW-CHO-KAS-028	01.04.2015	Lusaka	28,81893	-15,49574	Kasolo Village	-7,12	0,16	-44,62	0,36	12
GW-CHO-MUL-029	01.04.2015	Lusaka	28,80550	-15,5636	Mulalika. P. School	-6,78	0,07	-43,92	0,32	10
GW-CHO-MAL-030	01.04.2015	Lusaka	28,85352	-15,45451	Mwalumina. P. School	-7,09	0,09	-45,59	0,10	11
GW-CHO-LIK-031	01.04.2015	Lusaka	28,84791	-15,47172	Likando Village HP2	-6,93	0,13	-45,66	0,30	10
GW-CHO-MWA-032	01.04.2015	Lusaka	28,94497	-15,437167	Mwachilele H.C	-6,34	0,08	-42,99	0,19	8
GW-CHO-CHA-034	01.04.2015	Lusaka	28,89469	-15,339	Chamulimba	-6,70	0,03	-41,17	0,14	12
GW-CHO-HOS-035	30.03.2015	Lusaka	28,66843	-15,338973	Chongwe District Hospital	-7,23	0,01	-46,10	0,22	12
GW-CHO-HOS-036	30.03.2015	Lusaka	28,67043	-15,340031	Chongwe District Hospital Housing	-7,07	0,03	-44,43	0,12	12
GW-CHO-SCH-037	30.03.2015	Lusaka	28,67724	-15,334564	Klaus and Martina Weber	-3,90	0,09	-26,86	0,24	4
GW-CHO-KAZ-039	30.03.2015	Lusaka	28,82168	-15,370699	Kazembe Bible College	-6,81	0,11	-40,58	4,32	14
GW-CHO-KAZS-040	30.03.2015	Lusaka	28,83023	-15,340445	Kazembe Primary School	-6,76	0,03	-42,45	0,24	12
GW-CHO-CPP-041	31.03.2015	Lusaka	28,48125	-15,386358	Chalimbana Police Post	-7,33	0,04	-46,72	0,26	12
GW-CHO-MBL-043	01.04.2015	Lusaka	28,50844	-15,240333	Mwabula Village	-7,15	0,05	-46,74	0,13	10
GW-CHO-KPS-044	01.04.2015	Lusaka	28,47071	-15,265177	Kasisis Primary School	-6,68	0,05	-45,25	0,09	8
GW-CHO-MUL-045	01.04.2015	Lusaka	28,48470	-15,282557	Mulelasolo Farm	-6,82	0,06	-47,02	0,24	8
GW-CHO-RDB-047	01.04.2015	Lusaka	28,43990	-15,167111	ZRC Farm Borehole @ Dam	-0,48	0,03	-9,77	0,14	-6
GW-CHO-CHA-048	01.04.2015	Lusaka	28,49953	-15,155561	Chaminuka Lodge	-6,34	0,03	-44,31	0,33	6
GW-CHO-ZCF-049	02.04.2015	Lusaka	28,37572	-14,973812	Chisamba ZCF Compound	-6,15	0,07	-43,18	0,21	6
GW-CHO-LWS-050	02.04.2015	Lusaka	28,37670	-14,980837	Chisamba - Lukanga W&Sewerage	-6,28	0,06	-43,10	0,44	7
GW-CHO-DCH-051	02.04.2015	Lusaka	28,37622	-14,980557	District Council Headquaters	-6,38	0,07	-42,93	0,23	8
GW-CHO-SAB-052	02.04.2015	Lusaka	28,22023	-14,898193	Sable Quartz Farm	-7,28	0,09	-48,41	0,41	10
GW-CHO-CHS-053	02.04.2015	Lusaka	28,73209	-15,362462	Chisengo	-6,43	0,07	-43,34	0,35	8
GW-CHO-KPU-054	02.04.2015	Lusaka	28,72147	-15,367039	Kapuka B	-6,58	0,03	-44,57	0,10	8
GW-CHO-CHK-055	02.04.2015	Lusaka	28,68512	-15,375733	Chaka 1	-6,88	0,09	-45,65	0,38	9
GW-CHO-YAL-056	02.04.2015	Lusaka	28,72827	-15,493931	Chiyalusha D	-6,84	0,07	-43,89	0,29	11