REPORT

DEL-2: Aquifer Mapping Studies Progress Report

Aquifer Mapping Technologies for Zambia: Groundwater Data Availability Report for Nyimba District

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PROJECT BACKGROUND

The United Nations Environment Programme (UNEP) requires a consulting firm to offer technical assistance in the development of a groundwater management plan to support climate change adaptation in the Republic of Zambia. This technical assistance will include technology transfer to support decision-making, tools and methodologies for aquifer mapping; and knowledge management.

This Aquifer Mapping Technologies for Zambia: Groundwater Data Availability Report for Nyimba District report, prepared by OneWorld Sustainable Investments, is submitted to UNEP. The report constitutes Deliverable 2 under this contract.

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1

Introduction

1.1| Overview

This Draft Preliminary Assessment is Deliverable 2 under of the project "*Provision of Technical Assistance for Aquifer mapping technologies for Zambia*", commissioned by the United Nations Environment Programme (UNEP). The Technical Assistance will enable the development of a groundwater management plan to support climate change adaptation in the Republic of Zambia through, *inter alia*:

i) technology transfer to support decision-making;

ii) tools and methodologies for aquifer mapping; and

iii) knowledge management.

The delivery of the project will take place over five phases, as shown in Figure 1 below.

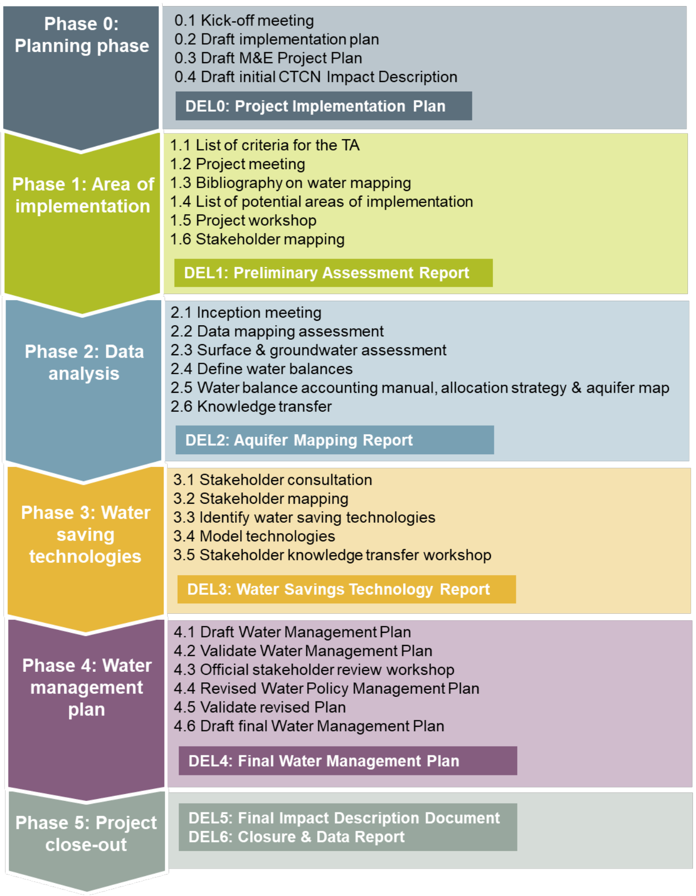

Figure 1: Phased Project Delivery Approach

1.2| Structure of the report

Following this introductory section, **Section 2** provides a background and general hydrological overview of Zambia. **Section 3 presents the analysis of availability, completeness and quality of data on Nyimba**. **Section 4** captures and presents analysis of the data status quo in Nyimba and presents the outline for the way forward.

Additional sections include:

Appendix 1 – outline of revised methodology.

2

Status of Groundwater in Zambia: Overview

2.1| Background

Ground water represents an essential part of Zambia's climate change adaptation strategies; offering essential livelihood resources and mechanisms. Its strategic importance will probably intensify under climate change and human development (population growth, urbanization) in future. Groundwater constitutes the most important buffer and reserve of water during surplus periods as well as a source of water for streams and/or direct withdrawals in times of shortage. However, there are major gaps in the knowledge of groundwater resources in Zambia with inadequate knowledge on the groundwater resources in both quantity and quality for the current, short, and long-term periods with significant uncertainty regarding the impact of climate change on groundwater resources and groundwater-dependent ecosystems in Zambia.

A surface water crisis is being experienced in most parts of Zambia. The situation has worsened due to the drying up of surface water resources which much of the population depends on. The reduced amount of rainfall being received because of climate change has negatively affected the water levels of highly dependent surface water resources. This has led to women and children walking long distances as far as 5 km to have access to clean and safe water. As a result, the focus has shifted towards harnessing groundwater resources for various uses. However, the challenge has been the identification of local aquifers across the country especially in rural areas, particularly in the Eastern Province. In trying to address the water shortage, the government, civil society, and cooperating partners have been drilling boreholes but experiencing more dry boreholes because there is inadequate information in aquifer identification and characterisation. This has led to the loss of resources through dry boreholes as was recorded in Kalomo, Kazungula, Ngabwe and Mwense districts by the Department of Water Resources Development (DWRD).Through Aquifer Mapping an accurate and comprehensive micro-level picture of groundwater in Zambia will be known and this will enable a robust groundwater management plan at the appropriate scale to be devised and implemented for this common pool resource. This will in turn achieve drinking water security, improved irrigation facility and sustainability in water resources development in rural and peri-urban parts of Zambia. The aquifer mapping programme will help in the planning of suitable adaptation strategies that are climate resilient in economic growth centers. The aquifer mapping approach can help integrate groundwater availability with ground water accessibility and quality aspects in the context of climate change. Furthermore, statistics have shown that there is a strong correlation between economic growth, industrial growth, and water consumption. Therefore, to achieve the much-needed economic growth there is a need to enhance good health through the provision of safe drinking water, promote agriculture irrigation and adapt groundwater management strategies that are climate resilient. Thus, aquifer mapping needs to be initiated in order to identify aquifers in the areas and produce large scale maps (taking into account any existing data and hydrogeological maps). Based on this, the identified aquifers should then be developed into well fields for multipurpose use.

The communication and implementation of the provision of technical assistance for aquifer mapping technologies for Zambia is designed to ensure that stakeholder inputs are considered at all critical points within the project development cycle. This will ensure that stakeholders retain ownership of the aquifer mapping process, that the process is aligned with the needs and context of the relevant stakeholders and is tailored to be implemented in a way that considers capacity needs potential. This report therefore provides an evaluation of the proposed aquifer system of Nyimba in Eastern Province as agreed through a stakeholder engagement process with DWRD. The report presents a view of groundwater-related data availability, quality and completeness – as of October 2023.

2.2| General hydrology of Zambia

Zambia is covered by two major drainage systems – the Zambezi and the Congo. The Zambezi River system drains generally north to south and ultimately south-east to the Indian Ocean. The Congo River has its headwaters in Zambia; it drains in a northerly direction and ultimately west to the Atlantic Ocean. In accordance with the Water Resources Management Act, Number 21, 2011, the two main river systems covering the country have been delineated into six catchments – three in the Zambezi and three in the Congo River systems.

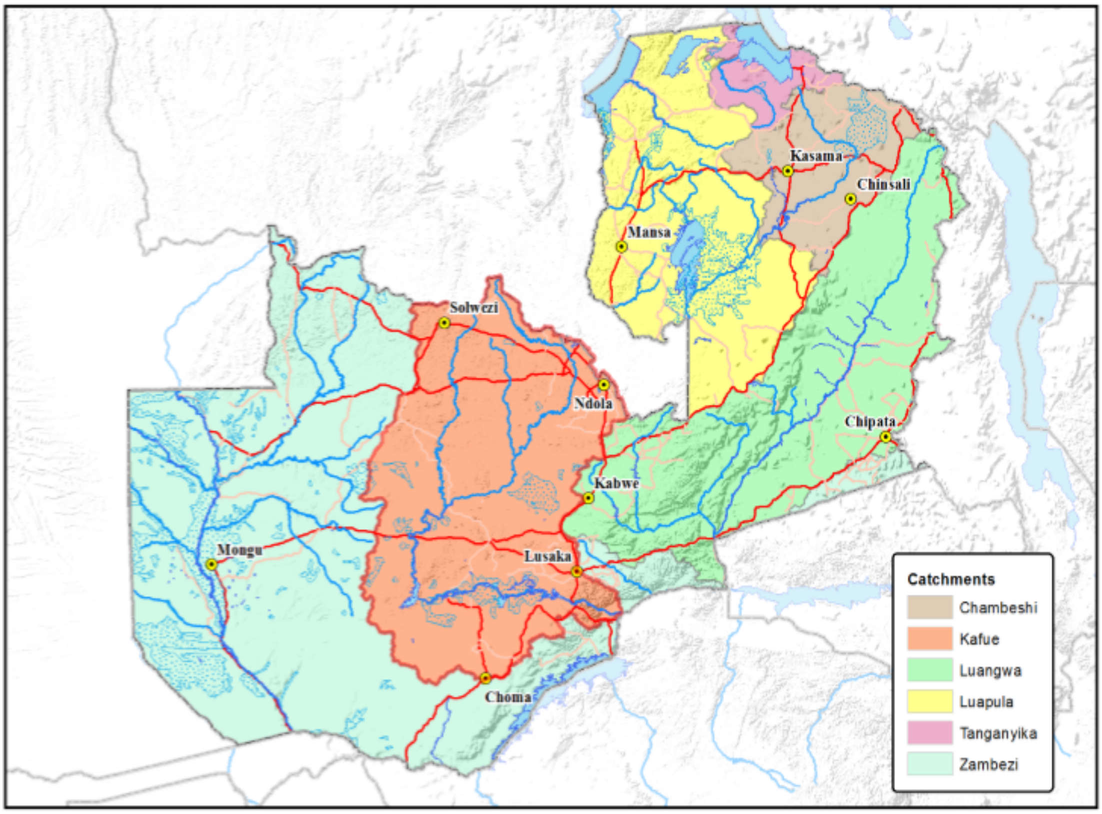

Figure 2: Zambia's hydrological catchments (Source: NWRS, 2021)

The catchments in the Zambezi River system comprise Zambezi main stem, Kafue, and Luangwa. In the Congo River system the catchments comprise Chambeshi, Luapula and Lake Tanganyika. Due to its enormous size, the Zambezi in Zambia is further delineated into Upper Zambezi Sub-catchment and Lower Zambezi Sub-catchment. In the same manner, Kafue has been further delineated into Upper Kafue Sub-Catchments and Lower Kafue Sub-Catchment. Figure 2 presents the official catchments in Zambia.

3

Groundwater Resource Data

3.1| Data availability – national perspective

The most comprehensive national assessment of groundwater resources for Zambia, to date, was done by Chenov (1978) who quantified the hydraulic properties of 862 boreholes through out Zambia. In additional, a network of 500 observation boreholes were established covering almost the whole country with the exception of Senanga District and the area west of the Zambezi River. This was the first attempt at establishing a hydrogeological map for Zambia of which three maps at a scale of 1:1,000,00,000 were produced that include:

- a depth to groundwater level,
- groundwater level fluctuation,
- and groundwater quality.

The weakness in this dataset is that it lacked spatial coordinates as this was before GPSs were commonly available. This work was later complimented further by the Japan International Cooperation Agency (JICA) water resources master plan (YEC, 1995) whose objective was to formulate a plan for water resources development to support the water supply and agriculture sector.

Through the Masterplan an assessment on available water resources, use, demand and modelled water use scenarios under different conditions including climate change was conducted. The data collected was archived at the Department of Water Affairs typically in hard copy. Several other initiatives have taken place since (at a local or regional scale), through the Ministry of Local Government, Ministry of Health, Zambia Environmental Management Authority and Development Partners such as UNICEF (United Nations Childrens Education Fund), KfW (German Development Bank) and JICA (Japan International Cooperation Agency) and Federal Institute for Geosciences and Natural Resources (BGR). However, in 2005, a hydrogeological database software called GeODin® was integrated as part of the cooperation project, Groundwater Resources for the Southern Province (GReSP), involving the Department of Water Affairs (DWA) and BGR. Through this database, a strong effort was made to collect groundwater in various formats (excel, word or access database) and type (digital or hardcopy) into one system. GeODin® would thus serve as the tool for effective groundwater management and development of groundwater resources. It composes general information such as water point information, water point type, water source, catchment, basin block (i.e., sub-catchment), and administrative information, water user, well construction information and data record information as well as the owner and location of a borehole. It also captures the hydrogeological information such as type of aquifer, yield, borehole profile, purpose of the borehole, groundwater quality and the availability of the groundwater resources. The database can be linked to a Geographic Information System (GIS) to visualize groundwater information for stakeholders, policy makers and the public.

Naturally, after the setup of WARMA, GeODin® was adopted as the Groundwater Information Management System (GrIMS). As of December 2019, there are about 31,000 water points captured in the database (Tena et al., 2019), which are organized within hydrological units (six catchments and 35 sub-catchments, referred to as basin blocks). The data entered into the database were assembled from the following sources:

- Results of the groundwater resources inventory commissioned by the UNESCO/NORAD Water Research Project and the National Council for Scientific Research (Chenov, 1978);
- Borehole completion and construction reports from projects commissioned by the Ministry of Energy and Water Development (MEWD) and the Japan International Cooperation Agency (JICA) between 1986 and 2003;
- Water Point questionnaires collected by the Water Point Inventory Community Management & Monitoring Unit (CMMU) between the early and mid-1990's under supervision of the two former ministries in the water sector, namely the Ministry of Energy and Water Development (MEWD) and Ministry of Local Government and Housing (MLGH);
- Results of the water supply and sanitation project commissioned by the Ministry of Local Government and Housing (MLGH) & the German Development Bank (KfW) from 2010 to2011;
- Data of drilling of rural water supply boreholes funded by UNICEF between 2002 and 2015;
- Borehole completion reports at the Department of Water Affairs (DWA), particularly from the groundwater drilling works in the Gwembe Valley between 2001 and 2014 that were funded by the Seventh-day Adventist Church;
- Data collected from groundwater mapping and groundwater quality surveys prepared by the GReSP project from 2005 to 2017;
- Data collected from MLGH (various District Council Offices) between 2010 and 2014;
- Data collected from Ministry of Health 2015, and
- Data collected from private drillers from 2012 onwards.

Out of all water points, about 24,000 water points have general and basic hydrological information. based on data extracts from WARMA availed to the consultants. Figure 3 shows the number of boreholes, and available attribute records for water quality, lithology, pump yields, Static water level and hydraulics in the six catchments. The highest number of boreholes is in Kafue Catchment at 11,610 and the lowest is Lake Tanganika Catchment. Table 1, shows that the data on lithology is rather poor with just 2% of the 24,343 having data. Except for static water level records, cumulative attribute information are less than 10% of the database. Furthermore, the database provided only has static water level taken at the time of drilling. The static water is the rest water level before any pumping activities. Both Figure 3 and Table 2 highlight the uneven distribution of data across the catchments. It should be highlighted that there has been some effort in the last few years to drill and install additional observation borehole across the country (L. Museteka, personal communication). Table 3, outlines the distribution of the boreholes, range of the static water table, timing of static water table records and depth. The records have a static water level at the time of drilling from as far back as 1900 up to 2020 but no time series data. Upload of time series data has not commenced (L. Museteka, personal communication).

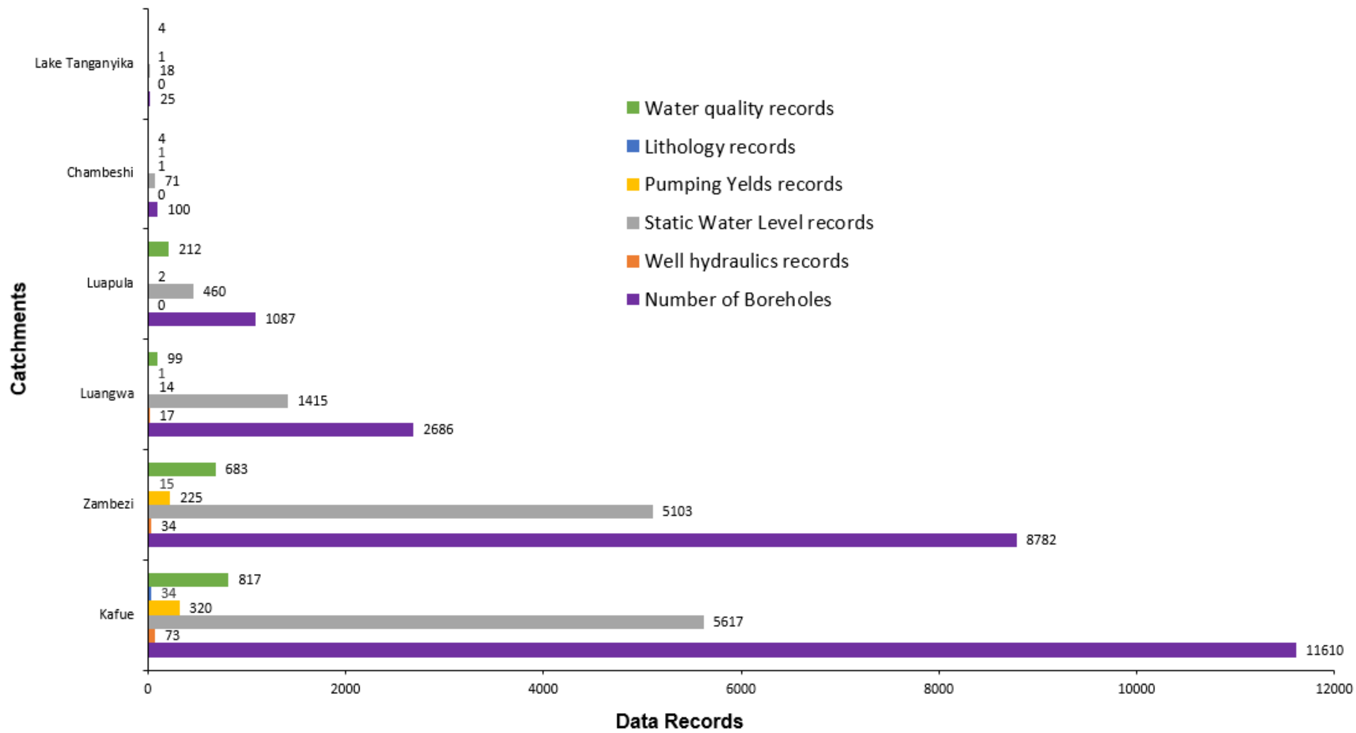

Figure 3: Distribution of numbers of boreholes and attributes (water quality, lithology, pump yields, Static water level, hydraulics) across the six catchments of Zambia.

Table 1: Number of boreholes and percentage distribution of attributes (water quality, lithology, pump yields, Static water level, hydraulics) across the six catchments of Zambia

Catchment	Number of boreholes	Well hydraulics records	Static Water Level records	Pumping Yield records	Lithology records	Water quality records
Chambeshi	153	0.00%	67.3%	3.27%	0.65%	7.19%
Kafue	11,610	0.63%	48.4%	2.76%	0.29%	7.04%
Lake Tanganyika	25	0.00%	72.0%	4.00%	0.00%	16.00%
Luangwa	2,686	0.63%	52.7%	0.52%	0.04%	3.69%
Luapula	1,087	0.00%	42.3%	0.18%	0.00%	19.50%
Zambezi	8,782	0.39%	58.1%	2.56%	0.17%	7.78%
Grand Total	24,343	0.51%	52.2%	2.33%	0.21%	7.50%

Table 2: Distribution of Groundwater use across the six catchments.

Water use	Chambeshi	Kafue	Lake Tanganyika	Luangwa	Luapula	Zambezi	Grand Total
Commercial	12	261	4	108	51	172	608
Domestic	89	6932	8	929	717	3596	12271
Exploratory		16				3	19
Aquaculture		2					2
Gardening		39		1	1	20	61
Industry	2	87		6		38	133
Irrigation		444		165	2	79	690
Livestock		122		3		23	148
Observation		53				54	107
Unknown use	3	1117		301	74	855	2350
Rural Water Supply	36	2258	12	2252	231	2009	6798
Water Supply	7	201		8	5	72	293
Grand Total	149	11532	24	3773	1081	6921	23480

3.2| Data completeness and quality

The data available in GeODin® varies widely in quality. For example, when reviewing and evaluating collected data it was observed that the emphasis of the information obtained from the past groundwater projects was focused on the works, e.g., type and diameter of casing, cost and expenditure, tools and machinery etc. rather than on the documentation of the hydro-geological situation and results obtained when drilling and completing the boreholes. Most of datasets in the database did not even include the lithology (geology) in which the borehole was drilled. Water quality information is very limited and rather simply defined quantitatively as fresh or saline. The lack of time series data makes it difficult to appreciate the dynamics of the aquifer systems under various stresses such as climate variability. However, there is still some information that could be used for in-depth analysis within some acceptable assumptions.

In order to use the current GEODIN database it will need to be used collaboratively with the SADC Hydrogeological Map and Borehole Database (HGM). SADC HGM has quite consistent records for Zambia with more than 15,000 records for hydrogeological information and water quality data. In addition the database captures and presents global estimates from Döll and Fiedler (2008), coupled with formulae to compute groundwater availability based on area and precipitation Ponce (2006), summarised in Table 4. Furthermore WARMA has adapted the GEODIN database to include a water permits component.

Table 3: Distribution of boreholes attributes for yields and the static water level (SWL) over the catchments

Catchment	Basin Block	Number of boreholes	Minimum SWL	Maximum SWL	Minimum of Date SWL	Maximum of Date SWL	Minimum yield (L/S)	Maximum yield (L/S)	Average Depth
Chambeshi	Upper Chambeshi	100	3.47	50	1986-02-20	2020-09-15	1	2	55.3
	Lower Chambeshi	53	8	65	2018-08-14	2019-11-15	1	1	56.0
Kafue	Itezhi-Tezhi	19	1.5	38.22	1993-12-07	2020-08-26	3	24	52.5
	Kafue Flats	9121	0	134	1900-01-01	2021-01-22	1	75	55.2
	Kafue Gorge	325	0.2	90	1976-01-01	2020-11-25	1	6	58.4
	Kafue Headwaters	7	10	28	2018-10-14	2019-11-11	0	0	65.8
	Kafulafuta	243	3	51	1995-04-11	2020-08-28	1	5	49.9
	Lufupa	239	0.5	44.92	2009-02-04	2019-07-04	1	1	59.0
	Lufwanyama	12	6.12	33	2018-11-25	2020-07-15	1	1	61.3
	Lukanga/Upper Kafue	590	0.9	59	1994-04-12	2020-12-11	1	35	58.3
	Lunga	221	0.5	120	2009-02-07	2019-08-27	1	2	48.8
	Mpatamatu	528	1	150	1991-09-07	2019-12-24	1	50	48.2
	Smith's Bridge	305	4	55	2017-10-24	2019-12-23	1	50	49.0
Lake Tanganyika	Lake Tanganyika	25	6.69	65.58	2006-07-09	2019-10-25	1	1	63.7
Luangwa	Lower Luangwa	447	0.56	73.96	1991-12-03	2020-07-24	1	4	51.4
	Lukusashi	209	1	65	1994-01-15	2020-08-26	1	1	53.6
	Lunsemfwa	1223	0.22	73	1993-03-20	2020-12-18	1	50	59.9
	Middle Luangwa	12	3.31	25	2019-02-15	2019-08-20	1	1	55.2
	Upper Luangwa	795	0.52	35.2	1999-03-02	2020-07-28	0	0	53.6

Catchment	Basin Block	Number of boreholes	Minimum SWL	Maximum SWL	Minimum of Date SWL	Maximum of Date SWL	Minimum yield (L/S)	Maximum yield (L/S)	Average Depth
Luapula	Lake Bangweulu	196	4	110.05	2006-10-15	2019-11-08	1	3	53.6
	Lake Mweru	222	1.44	39.42	2008-11-29	2019-04-09	5	5	48.7
	Luela	464	0.5	70	2006-11-05	2019-10-23	1	1	51.2
	Mansa/Luongo	142	2.3	50	1900-01-20	2019-07-20	3	3	59.3
	Wantipa/Lake Mweru	63	0	48	2008-11-26	2019-07-21	1	1	54.7
Zambezi	Barotse Floodplain	1045	-0.7	57	2009-05-17	2019-10-22	0	120	48.7
	Cahora Bassa	11	2.4	20	2000-10-09	2019-08-20	1	1	61.7
	Chongwe	3888	0	140	1900-01-20	2025-09-20	0	80	59.8
	Kabompo	513	0.1	44	2009-02-09	2021-11-20	1	1	51.3
	Kariba Dam	1073	0.5	60	1978-11-01	2020-10-22	1	5	60.4
	Lusitu	201	0.8	37.6	1978-11-01	2020-09-22	1	6	48.3
	Middle Luangwa	1	7.7	7.7	1900-01-00	1900-01-00	0	0	#DIV/0!
	Sesheke	576	-38.2	53	2019-03-16	2019-12-09	0	100	49.2
	Victoria Falls	792	-36.13	60	1978-11-01	2020-10-24	0	100	54.4
	Watopa	450	0	50	1994-12-01	2019-10-25	0	50	49.3
	Zambezi Headwaters	232	0	14.1	2009-03-24	2019-09-26	0	1	45.3

Table 4: Available data in the SADC HGM database and estimates of recharge

Groundwater resources	Surface area (km^2)	Ref.	Recharge (mm/yr)	Ref.	Groundwater availability (km^3/yr)	Ref.
1. Porous/intergranular	283,978	HGM 2019	60	DF 2008	*6.8*	Po 2006
2. Fissured	262,427	HGM 2019	60	DF 2008	*6.3*	Po 2006
3. Karst	24,889	HGM 2019	60	DF 2008	*0.6*	Po 2006
4. Low permeability	205,503	HGM 2019	60	DF 2008	*4.9*	Po 2006

The issue of data quality and completeness calls for a more discussion within the water sector in order to standardisation of borehole drilling reports/forms, pumping test, water quality assessments in consultation with the Zambia Bureau of Standards (ZABS) coupled with capacity building activities at different levels.

4

Nyimba District – Groundwater data status

Nyimba District in Eastern Province is part of the Lower Luangwa Catchment. Table 5, provides a summary of available data for which out the 103 data points:

- only 80 records provide detail on static water levels,
- 27 distinct counts on borehole depth,
- and 4 distinct counts on the aquifer system being exploited (lithology).

The district has limited records on abstraction and water quality. With only one borehole having water quality and discharge information. The challenge identified is the a very limited information/ detail relating to borehole hydraulics (hydraulic conductivity and storativity), and the lack or limited availability of time series data.

Table 5: Summary of groundwater attributes for the Lower Luangwa Catchment

Basin Block: Lower Luangwa Districts	Count of Water point type	Distinct Count of Static water level [m]	Distinct Count of Total depth of borehole [m]	Distinct Count of Main aquifer lithology	Distinct Count of Quality of water	Distinct Count of Pumping rate [l/s]
Chilanga	1	1	1	1	1	1
Chongwe	2	1	2	1	1	2
Luangwa	167	63	91	14	2	1
Lusaka	2	2	2	1	2	2
Nyimba	103	80	27	4	1	1
Petauke	12	12	11	3	1	1
Rufunsa	159	86	93	7	2	3
Grand Total	446	245	227	31	10	11

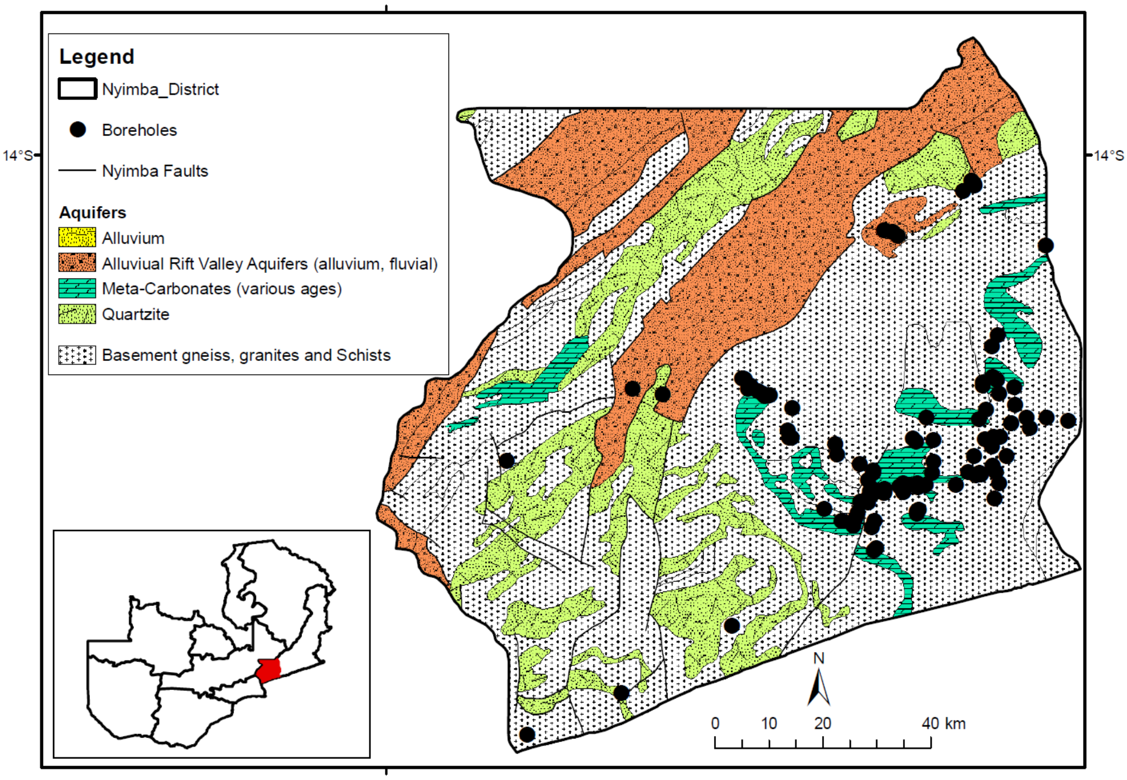

Figure 4: Spatial distribution of the boreholes in Nyimba District, Eastern Province, Zambia

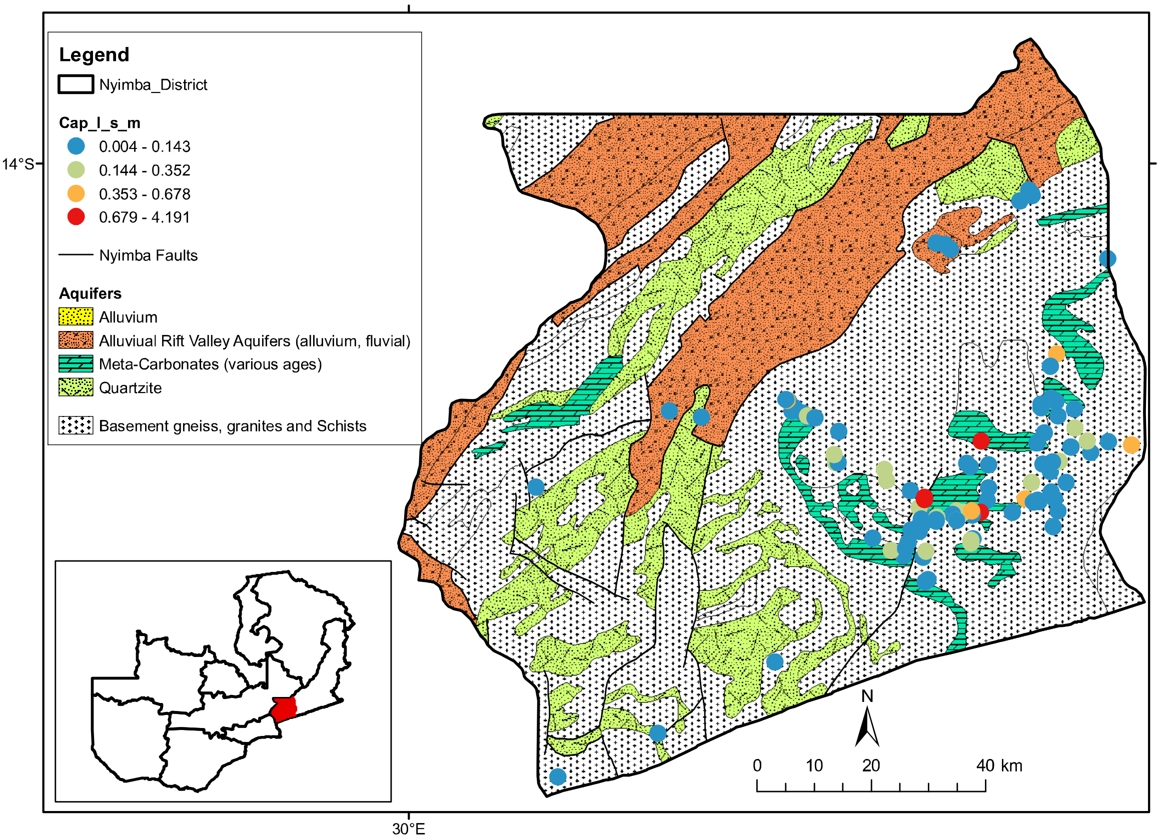

Figure 5: Specific Discharge of borehole based the JICA master plan

Figure 4 provides a spatial distribution of the boreholes for Nyimba District. Majority of the borehole are around the administrative centre at Nyimba town. These boreholes are hosted in a basement rock system with associated discharge rates of not more than 5 L/s.

Figure 5, shows the specific discharge of the boreholes. The specific discharge information was based on data from the JICA master plan on hydraulic properties and some recent drilled boreholes from consultants - but not available in the WARMA database. Specific discharge indicates the important role of the fracture system on the hydrogeological properties of the aquifer system.

4.1| Way forward

Based on the overview analysis on available information from the WARMA database and digitised data from the JICA master plan, the following is recommended:

- Hydrogeological modelling of the basement aquifer system is only possible on the basis of acceptable assumptions. These need to be declared and agreed upon with the stakeholders.
- The hydrogeological modelling process can only be done in a steady state condition.
- A hydro census is recommended so that a current status of the boreholes can be captured. However, the record available can be used as a starting point. An updated project methodology and list is data required is available as appendix 1 and 2.
- Even though a detailed geological map (1:50,000) is not available for Nyimba, the JICA master plan should be explored for lithological thickness and geometry where possible.

5

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6

Appendix 1

Updated Hydrogeological Mapping for Nyimba

Based on the stakeholder engagement meetings in Lusaka, the Zambian government indicated that 1:100 000 geological maps were available for the Nyimba area. This represents a significant improvement on the 1: 1 500 000 scale that the current hydrogeological model by BGR and the UPGro Groundwater Atlas (*Figure 6*). This mapping approach will need to be mindful of the improved scale mapping by BGS of the Kafue Flats at a scale of 1 : 250 000 in 2007 (*Figure 7*).

At the stakeholder engagement meeting in Nyimba, it was indicated that certain groundwater resource data was available and that additional data, particularly aquifer parameters, could be collected by the Zambian contingent through their own funding. It is envisaged that this would include a hydrocensus, possible water quality tests, and possible test pumping of existing groundwater resources. The data is considered to be "scattered" at this point, and effort will need to be invested in collecting as much as possible by both the project technical and the Zambian team. The aim of collecting the groundwater resource data is to be able to run statistics on key parameters in order to refine not only the scale of the current geohydrological mapping initiatives but also improve the classification of aquifers into yield classes, similar to that conducted in South Africa (*Figure 8*). It should be noted that the data set is critical to generate a meaningful response.

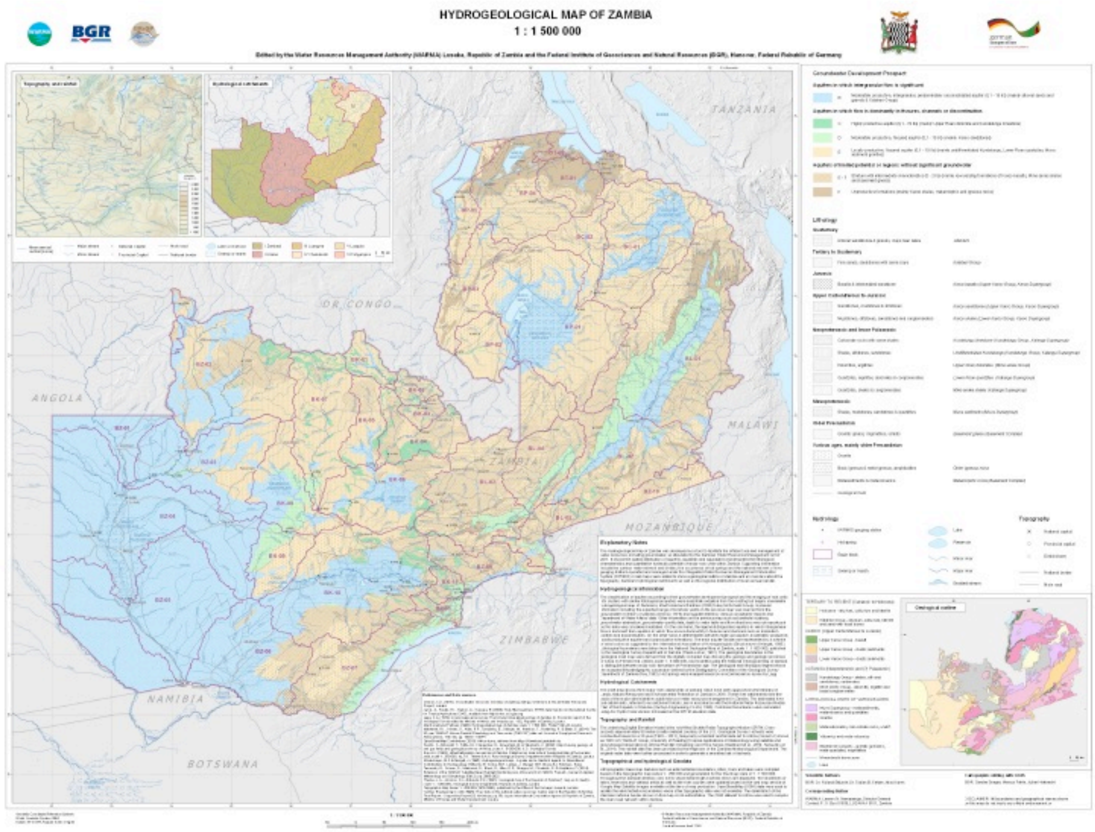

Figure 6 Groundwater map of Zambia by the Federal Institute for Geosciences and Natural Resources [BGR - Bundesanstalt für Geowissenschaften und Rohstoffe].

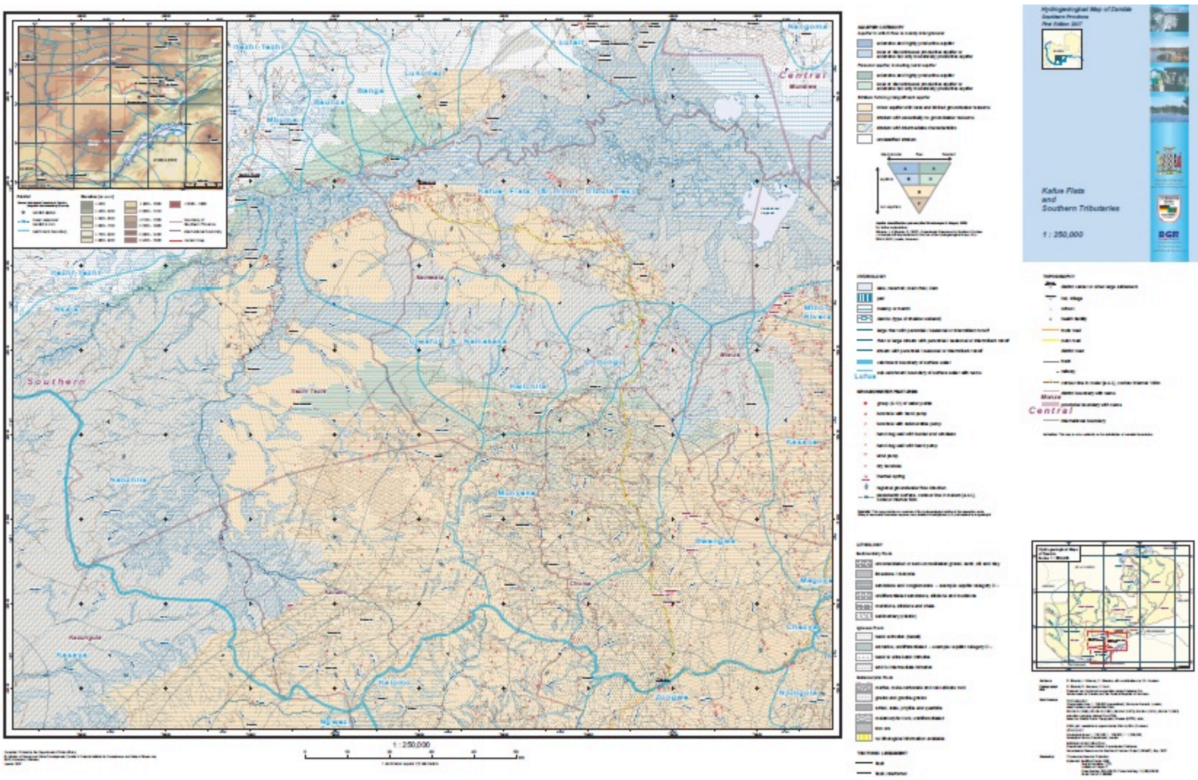

Figure 7 An example of BGS mapping of the Kafue Flats

Aquifer type	Principal groundwater occurence Borehole yield class (median l/s) (excluding dry boreholes) 0.0 - 0.1	0.1 - 0.5	0.5 - 2.0	2.0 - 5.0	> 5.0
Intergranular	a1	a2	a3	a4	a5
Fractured	b1	b2	b3	b4	b5
Karst	c1	c2	c3	c4	c5
Intergranular and fractured	d1	d2	d3	d4	d5

Figure 8 An example of the South African aquifer yield classes used for mapping aquifers.

Development of Recharge Tool

A programme to estimate recharge was developed by Gerrit Von Tonder and Yongxin Xu in 2000 under the guidance of Eddie Van Wyk to apply various methodologies to estimating recharge. This is typically project or area-specific and has allowance for the following methods:

- Chloride Method
- Isotopes
- Saturated Volume Fluctuation (SVF)
- Cumulative Rainfall Departure (CRD)
- EARTH Model
- Baseflow
- Qualified Guess

The Chloride, Isotope, SVF, CRD and Earth model are all methodology specific and directly transferable to the Zambian context. It is also unlikely that there will be sufficient data to run these more data hungry methodologies.

The Qualified guess and baseflow methods are both spatially dependant and present the most achievable assessment of recharge but will need to be adapted where possible to the Zambian context. In addition to the listed methodologies, a desktop review of the Thornwaite, Aplis, and other new methodologies (post 2000) will be considered for compatibility. The WHYMAP recharge mapping will also be considered for applicability. (Possible data source includes HydroATLAS-Zambia - Home (weebly.com))

It is proposed that the necessary permissions are sought to adapt this tool to the Zambian context, particularly of relevance is the qualified guess approach, which allows for informed estimates in data-scarce settings.

Relevant to the tool adaption, the data that would be beneficial from the Zambian government would be geology, soil maps, topography, and rainfall if available. In the event that rainfall is not available, then satellite remote sensing could be considered. This recharge approach can then be considered in the water balance determination.

Determining basic aquifer parameters

Please note – this subsection is to be undertaken by the Department of Water Resources Development at national level and from Nyimba. It has no financial implications for this project. It is included here because it is integral to the progress of the project.

Key activities will include determining basic aquifer parameters, to be developed in conjunction with this project:

- A groundwater hydrocensus (location of all boreholes, users and uses)
- Pump test measurements (helps define basic aquifer parameters)
- Water quality measurements

Water Balance:

The water balance approach can then be undertaken by developing an assessment of inputs and outputs to the groundwater store. The basic water balance approach remains:

Inflow = Outflow + Δ Storage

Or a combination of these variables.

Estimates of inflow (to the aquifer) can be developed by evaluating rainfall and recharge. Outflows can be evaluated by obtaining data on groundwater abstraction. The change in storage can then be determined, also verified / calibrated against water level changes in the aquifer.

<u>Rainfall</u>

Given the paucity of measured rainfall data in Zambia and especially more remote sites such as Nyimba, remote sensing by satellite provides the most tractable means of obtaining rainfall inputs. We propose using the Climate Hazards Group InfraRed Precipitation with Station data (CHIRPS) datasets. CHIRPS is a 35+ year quasi-global rainfall data set. Spanning 50°S-50°N (and all longitudes) and ranging from 1981 to near-present, CHIRPS has a resolution of 0.05° and is quite suitable for an application at Nyimba. *Figure 9* gives a large-scale example for Africa at a 5-day accumulated value.

Team colleagues at the University of Zambia and stakeholder representation also suggest the TAMSAT series, which gives a similar product but specifically for Africa.

<u>Outflows</u>

These will be determined by borehole pump data, obtained by local stakeholders at Nyimba.

The critical assumption here is that such data exists in various formats, that it can be collated and made available to the project within the time scope of this project and this component of the project will be funded by the Zambian stakeholders (Department of Water Resources and Development). This was the gist of the outcomes of stakeholder meetings in Lusaka and Nyimba (21 – 23 August 2023).

<u>Change in Storage</u>

Similar to the approach above for outflows, the change in storage in the aquifer can be obtained from pump data and water level data, such as it exists. From such data, basic aquifer parameters can be determined.

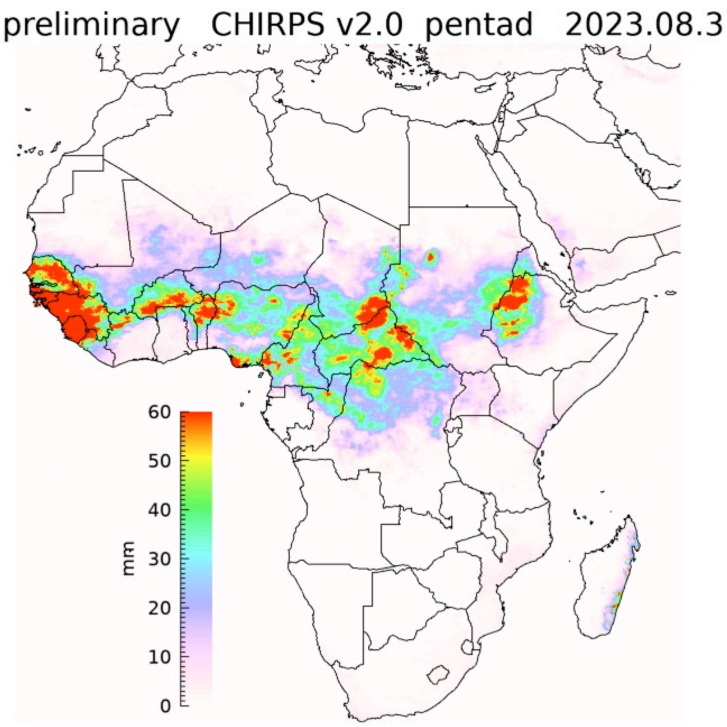

Figure 9 An image of a pentad (5-days) accumulated rainfall for Africa from the CHIRPS remotely sensed data (Source: Climate Hazards Center, University of Santa Barbera, California).

Request for data

- Borehole data sets
    - WARMA data
    - Regional data sets and borehole reports
        - Agriculture
        - World vision
        - Nyimbe province
        - Other
- 1: 100 000 Geology and cross sections
- Airbourne magnetic survey
- Rainfall and evaporation data (there are no stations in Nyimbe, but all stations in proximity)
- A surface water impoundment coverage, and rivers coverage
- Water quality data

The following GIS layers would be beneficial for the data analysis:

- Topography
- Soils
- Quaternary catchment boundaries
- River flows / baseflow
- Existing BGR geohydrological mapping
- Cities, towns, villages, communities, and settlements boundaries
- Roads

Summary and Conclusions

The Government of Zambia wants and expects methodologies for aquifer mapping that have wide applicability to other areas of Zambia (also strongly articulated feedback from the Lusaka workshop). We believe the above approach attempts to meet the needs of the stakeholders, has practicability, especially regarding the resources required for aquifer mapping, and achieves outcomes for a water balance approach. Key risks include the availability of borehole, groundwater and pump test data from Zambia and Nyimba, with government commitments to fund and undertake that component of the study.