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Groundwater Resources for Southern Province

**A Brief Description of Physiography,
Climate, Hydrology, Geology and
Groundwater Systems
of the Southern Province**



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This publication was produced under the technical co-operation project between the Governments of Zambia and the Federal Republic of Germany implemented by the Department of Water Affairs, Ministry of Energy and Water Development, Zambia and the Federal Institute for Geosciences and Natural Resources, Germany, and complements the hydrogeological map sheet series for the Southern Province.

Text, layout and graphics: Department of Water Affairs, Lusaka

Photographs: R. Bäuml, L. Chinjenge, H. Klinge, Ch. Neukum, J. Nkhoma, O. Silembo

Cover photo: Muckleneuk Hot Spring on Bruce Miller Farm (by Ch. Neukum)

Print Layout: Mariola Kosenko

Printed by: Printech Ltd, Lusaka

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First Edition, October 2007

Foreword

The Groundwater Resources for Southern Province Project was proposed and implemented by the Government of Zambia (GRZ) through the Department of Water Affairs (DWA) with support from the Federal Republic of Germany through the Federal Institute for Geosciences and Natural Resources (BGR). The project started in May 2005. The present Phase I covered a 30-month period ending October 2007. The project was implemented in order to fulfil the urgent need for groundwater resource assessment in the Southern Province. It was aimed at strengthening the capacities of the water sector in Zambia with special emphasis on groundwater by compiling a database and hydrogeological maps. The information generated is useful for regulation of groundwater development, use and management in the Province. Furthermore the project was intended to be a model for groundwater assessment in other provinces in the country.

The project was implemented in line with the National Water Policy which promotes integrated water resource management and resultant programmes such as the Water Resources Action Programme. It is also relevant to the Fifth National Development Plan and the 2030 Vision for Zambia and the Millennium Development Goals, all of which recognise the fact that the provision of safe drinking water is critical to economic growth and poverty eradication. The outputs of the project which include trained manpower, a groundwater database and hydrogeological maps will be useful to provincial and national planning

and regulation authorities, especially in view of the Water Resources Management Bill which, among other provisions, seeks to provide for the regulation of groundwater. Regulation of groundwater is not provided for by the current Water Act.

It is however notable that some challenges were met during the implementation of the project, namely, regional groundwater flow was not adequately covered due to insufficient number of boreholes, the north-western part of the Province was not mapped and uncertainty of existing groundwater data. Therefore care was taken in interpreting such data. With this in mind it is recommended that updating of the database and maps used in this project should be a continuous process in order to provide meaningful solutions.

A tool for groundwater resource management in Southern Province and Zambia has been placed in the hands of water resource managers, academics, politicians, water users and other interest groups but what remains is the challenge to put it to use and help to achieve the national goal of economic growth and poverty eradication through sustainable development and management of groundwater in the country.



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Prepared as a technical co-operation project between the governments of Zambia and the Federal Republic of Germany



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Executive Summary

According to the National Water Master Plan the south-western parts of Zambia extending from Mongu in Western Province to the Southern Province form the most drought-prone regions within Zambia. The tropical continental highland climate is characterised by a clear distinction between the cool and hot dry season lasting from May to October and the wet season between November and April. Rainfall totals are the lowest in the country with mean annual rainfall ranging from 650 mm to 800 mm. Furthermore, the distribution of rainfall during individual rainfall events and rainy seasons is very unpredictable. Due to these climatic conditions rain-fed agriculture is highly undependable.

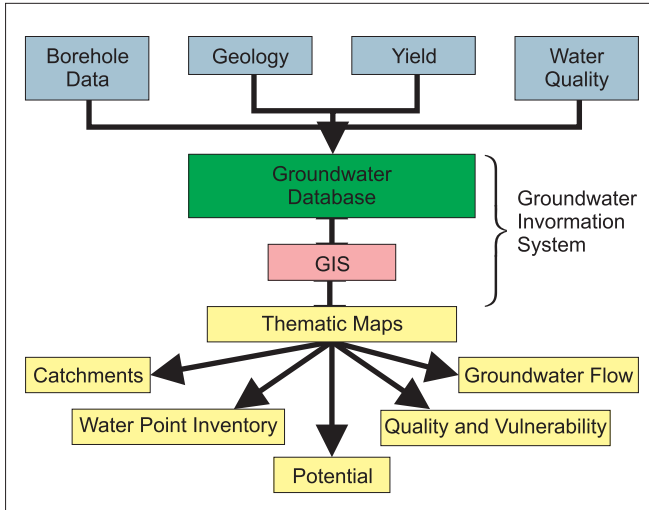
The Southern Province has a share in two of Zambia's major water courses, the Zambezi River including the Kariba reservoir at its southern and eastern boundaries and the Kafue River to its northern margins. But since distances and differences in elevation are large it is not economically feasible to distribute the surface water sources to the central areas of the Province. The discharge of most tributary rivers ceases during the prolonged dry periods. During this time, the large majority of the population of the Southern Province depends on water supply from small dams or groundwater. Groundwater constitutes the only reliable and safe water source available throughout the year, especially during periods of drought. Groundwater is stored underground, often available at much closer proximity compared to surface water on both surface and groundwater resources is required to regulate its use and to establish an integrated and sustainable management of the Nation's water resources. For underground water, this includes a comprehensive assessment of the groundwater resources and their current use, an improved understanding of the groundwater systems and their interactions with surface water as

well as a continuous and extended monitoring of groundwater levels and quality.

The Project "Groundwater Resources for Southern Province" was launched in May 2005 with the objectives to facilitate an effective groundwater resource planning and management in the Province and to strengthen the capacities in the Zambian water sector. The Project is carried out in the framework of the technical co-operation between the Governments of Zambia and the Federal Republic of Germany and implemented by the Department of Water Affairs (DWA), Ministry of Energy and Water Development, Zambia and the Federal Institute for Geosciences and Natural Resources, Germany.



As an integral part of this Project a professional groundwater information system at the DWA was developed consisting of a groundwater database and a Geographic Information System (GIS). The database stores information on over 3,000 water points including hand dug wells, boreholes, springs and unsuccessful groundwater exploration drill sites. The database includes the information of all major hydrogeological investigations carried out



Flowchart showing the concept of developing a groundwater information system.

since the mid-1970s and combines general information (e.g. location, type and purpose of water point) with comprehensive and detailed technical information on groundwater hydraulics, borehole design, geology and groundwater quality.

As part of this study three hydrogeological maps at scale 1 : 250,000 and another, more detailed map at scale 1 : 100,000 were developed. The design and legend of the maps follow international guidelines and can be adopted as a standard for groundwater maps of other regions. For future studies and exploration drillings, other thematic maps can readily be prepared at various scales.

This publication reviews the state of knowledge and provides references for further reading on the geography, climate, geology, hydrology and groundwater in the Southern Province. It accompanies the four hydrogeological maps together with a manual that provides detailed explanations for the use of the maps.

The groundwater related information assembled was assessed and interpreted in this study in order to identify groundwater systems and their potential.

About two thirds of the Province is made up of hard rocks that are more or less fractured, and the rest is covered by unconsolidated deposits that host potential porous aquifers. Most of the rock formations have been characterised as heterogeneous, i.e. their potential to host and produce groundwater is extremely variable. That seems to be one of the reasons why about one out of five boreholes drilled was unsuccessful during larger exploration campaigns in the past. Careful planning using the groundwater information system and possibly the use of advanced geophysical methods could considerably improve success rates during exploration.

The comprehensive statistical analysis of available hydrogeological data showed that the potential of groundwater in the Province is overall limited. In some areas, namely regions within the Karoo sandstones and basalts, the alluvial deposits of the Kafue Flats and the calc-silicate rocks in the Mazabuka/Magoye area, groundwater conditions are more favourable. The groundwater quality is overall good although concerns must be raised over microbiological contamination near major settlements due to poor sanitary conditions. In general, potential

groundwater production from aquifers is insufficient for larger development such as irrigation schemes. Despite these limitations extractable groundwater volumes are sufficient to assure long-term water supply to rural areas and smaller settlements if used sustainably.

The study has shown that groundwater in the Southern Province is a valuable but overall limited and vulnerable resource. The hydrogeological maps and this publication summarise the information on groundwater in the Southern Province. It is envisaged that the developed

groundwater information system and the groundwater maps will support efforts on exploring, managing and protecting the groundwater resources. It is of hope that the information gathered will be of great use to officials at the ministries on national and district level as well as to technicians of the commercial utilities, consultants and to the water sector as a whole. Finally the wish is expressed that the groundwater information system established for Southern Province can soon be extended to cover other Provinces and catchments.

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Introduction

Groundwater in the Southern Province – A valuable and vulnerable resource

The Southern Province has approximately 1.4 million inhabitants of which the large majority (83%) live in rural areas [5], [21]. The Province covers an area of approximately 85,500 km² and is bordered by the Zambezi River to the South, the Kariba reservoir to the east and the Kafue River to the north (Fig. 1). But despite these large freshwater sources at its margins the Province heavily depends on groundwater since runoff from most of the tributaries to the major rivers regularly ceases during the dry season.

The South of Zambia receives the lowest rainfall in the country with mean annual rainfall ranging from 650 mm to 800 mm. The climate is sub-tropical with a clear distinction between the cool and hot dry season lasting from May to October and the wet season between November and April. Rainfall totals and intra-seasonal distribution vary greatly from year to year. Due to these climatic conditions, the Southern Province is a drought-prone area and rain-fed agriculture is highly undependable.

Drinking water for the district centres and some smaller towns is provided by the Southern Water and Sewerage Company (SWSC). The district centres tap surface water sources (Zambezi River, Kariba reservoir and smaller dams) whereas some smaller towns, such as Gwembe, Nega-Nega and Chisekesi are supplied to 100 % from boreholes. For the large majority of the population that inhabits the vast and often remote rural areas groundwater constitutes the only reliable and safe water source available throughout the year.

To ensure the sustainable development and use of the Province's water resources, the increasing demand for groundwater in agriculture, commercial and domestic use needs to be regulated. This requires an integrated management of the water resources, which include both surface water and groundwater. Integrated Water Resources Management has accurately been defined by the Global Water Partnership Technical Advisory Committee [9] as "a process which promotes the coordinated



Figure 1: Project area: the Southern Province.

development and management of water, land and related resources, in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems".

The basis of such an integrated management is an assessment of the available quantities and qualities of surface and groundwater. Like elsewhere in the country, however, the knowledge base on the availability and quality of groundwater in the Southern Province is scanty. This lack of knowledge together with a shortage of

qualified staff at planning institutions has been identified as a major shortcoming to an effective management of this vulnerable resource.

Against this background, the project "Groundwater Resources for Southern Province" was launched in 2005. As a major accomplishment of the project, a comprehensive groundwater information system was established at the Department of Water Affairs including a water point database and a series of thematic maps showing groundwater usage and potential.

Rural Village in the Southern Province.



Physiography

Topography

The topography is visualised in Fig. 2 using a Digital Elevation Model (DEM). The elevation of the ground above sea level is displayed at 200 m intervals. Within the Province the altitude rises from approximately 400 m in the Zambezi valley to almost 1,400 m on the central plateau. The highest area with an altitude exceeding 1,500 m above sea level is formed by the Mabwetuba Hills in the south-eastern corner of the Mazabuka District, approximately 60 km in east-north-east direction of Gwembe. The lowest point within the Province is located at the junction of the Kafue and Zambezi rivers at 370 m above sea level.

The landscape of the Southern Province is dominated by the following three dominant topographic features:

1. The Choma-Kalomo Block in the centre of the Province;
2. The escarpment and the Zambezi valley ("graben") in the east;
3. The Kafue Flats in the north.

The Choma-Kalomo Block is part of the larger Central African Plateau and formed by ancient (Precambrian) basement rock. The elevation of the undulating surface ranges from 1,200 to 1,350 m above sea level.

In eastward direction, the elevation sharply drops along the escarpment from heights of about 1,000 m to circa 600 m above sea level in the Zambezi valley. The drop in altitude over this region varies between 20 and 150 m per kilometre. The rugged terrain is intersected by numerous smaller river valleys. The bottom of the valley that has geologically been described as a semi-graben system [22] is now filled by the Kariba reservoir.

The Kafue Flats form a vast floodplain with an altitude between 970 and 1000 m. The flats

cover an area of up to 60 km wide and 250 km long. The average gradient in eastward direction is as low as 10 cm per kilometre.

Vegetation

Large parts of the Province are classified as *miombo woodland*, which is a type of woodland dominated by semi-evergreen trees 15 to 21 m high with a well-developed grass layer. Most miombo is secondary re-growth as a result of extensive cultivation in the past. In the west, miombo woodlands have invaded into the Kalahari forming *miombo/Kalahari woodlands*.

Along the escarpment zone and within the Zambezi Valley *mopane woodland* is the predominant vegetation type. This is a one-storied woodland with an open canopy 6 to 18 m in height. Next to mopane woodland, scattered elements of *munga woodland* dominated by various species of acacia, dry forests, grassland and open woodland can be found.

Mopane woodland with patches of miombo woodland near Siavonga in the Zambezi Valley north of the Lake Kariba during the rain season (March).



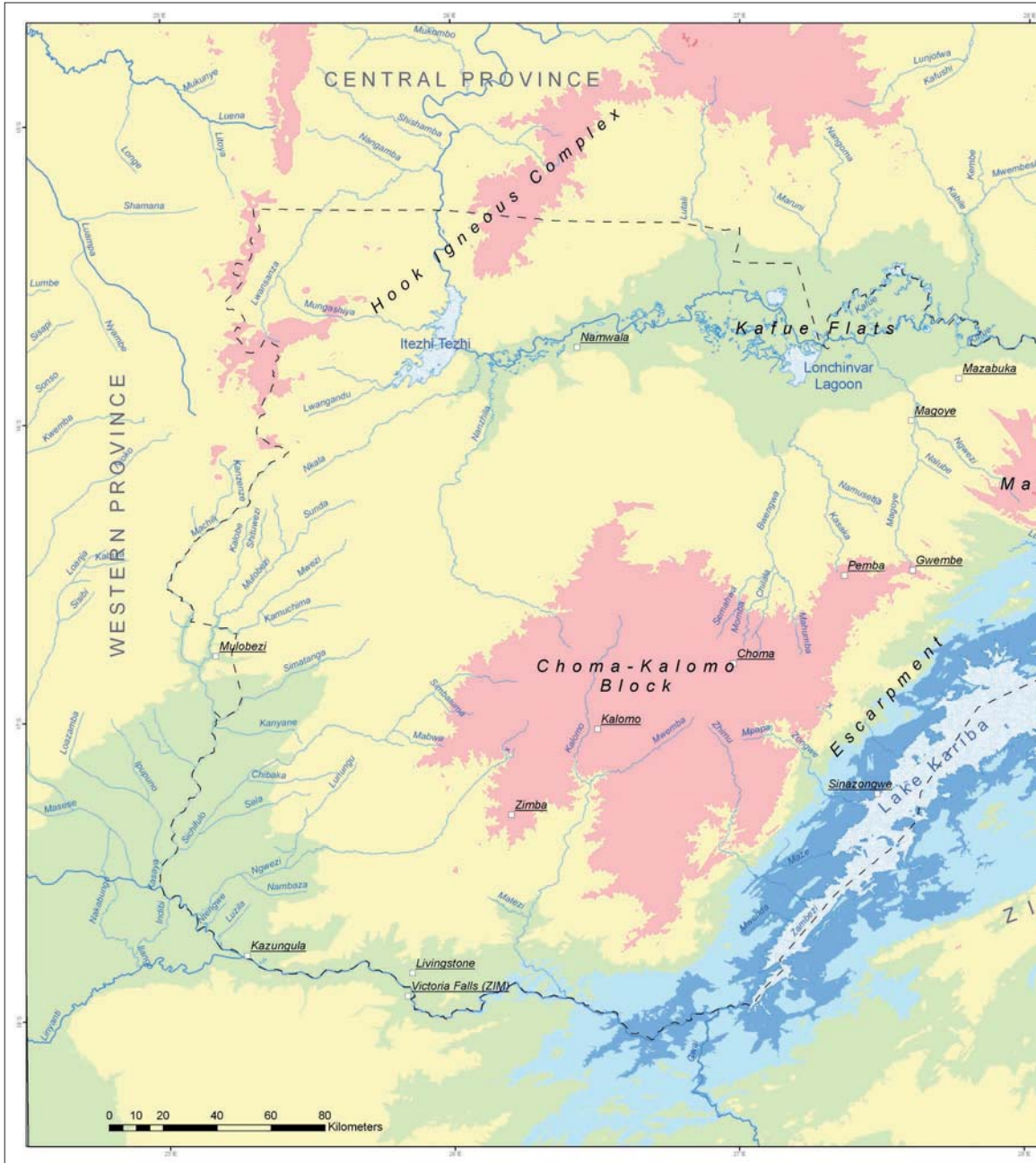
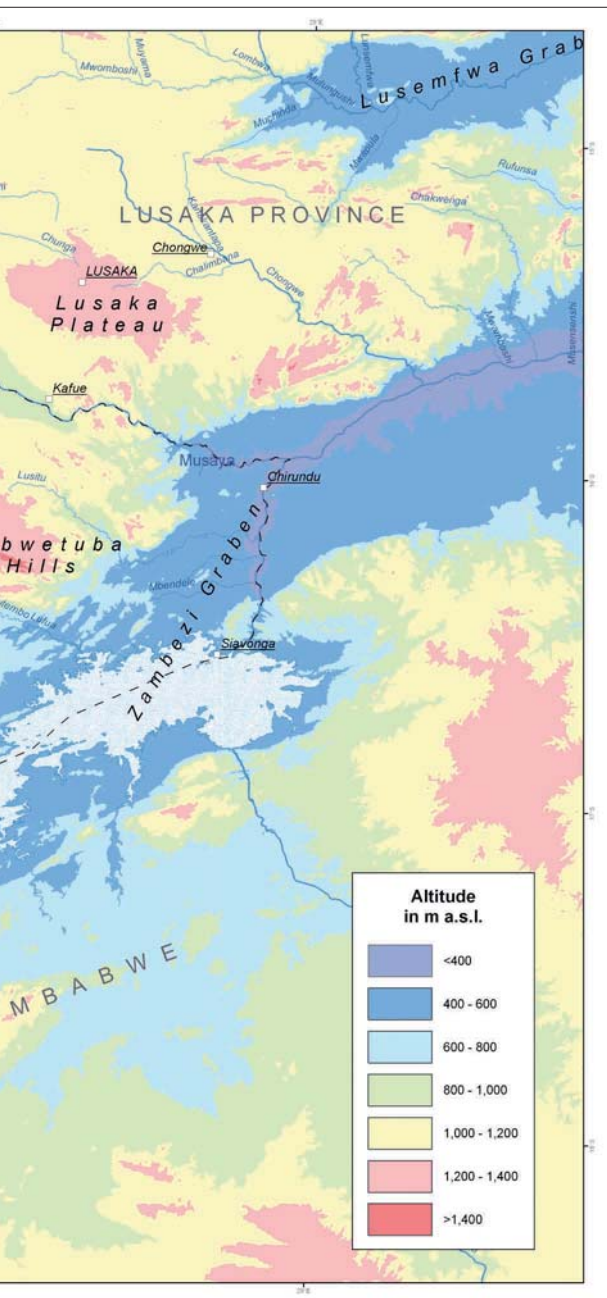


Figure 2: Digital Elevation Model (DEM) with elevation zones at 200 m-intervals.

Along the drainage lines *edaphic grassland* is predominant. The grassland can be divided into dambo grassland, riverine grassland, and floodplain grassland. These vegetations are associ-

ated with the streams and rivers, floodplains of the larger rivers, seasonally flooded freshwater swamps and some alkaline swamps [7].



Soils

Information on the distribution of soils is available in the *Zambian soil map* [19] at scale 1 : 3 million. The soil types classified as *acrisol*,

luvisol, *lithosol* and *arenosol* are dominant in the Southern Province. Gleysol, vertisol and fluvisol form less common soil units. The thickness of soils derived from borehole completion reports range from zero to six meters around a mean value of two meters.

Generally, a good correlation between soil units and the geological main subdivision can be observed. Common soils on metamorphic and magmatic rocks found within the Hook Igneous Complex in the northwest of the Province and the Choma-Kalomo Block are lithosols, acrisols, luvisols and ferralsols. On poorly drained rocks associated with the Muva Supergroup and granitic rocks of the Choma-Kalomo Block, gleysols are commonly developed. The rocks of the Katanga Supergroup are mainly covered by luvisols, acrisols and nitisols.

The Karoo sand-, silt- and mudstones in the Zambezi Valley are overlain by the more fertile luvisols and cambisols. The Kalahari sands are mainly covered by arenosols. These sandy-textured soils are often highly permeable and lack a significant soil profile development.

In waterlogged areas (floodplains) of the Kafue Flats gleysols are frequently developed. In grassland areas the clay-rich vertisols can be found.

Dambo surrounded by woodland.



Table 1: Soils in the Southern Province and the associated geology as well as the characteristic vegetation (in brackets). The soil code corresponds to the labels in the map above. Soil units according F.A.O./UNESCO classification [7].

Soil Code	Soil unit	Description	Associated geology	Area [%]
2	Lithosol, Ferric Acrisol, Ferric Luvisol	Shallow and gravelly soils derived from acid rocks, occurring in rolling to hilly areas, including escarpment (Miombo)	Magmatic and metamorphic rocks of the escarpment zone in the Zambezi Valley	13.7
3	Lithosol	Shallow soils derived from acid rocks occurring on hilly ranges (Miombo)	Magmatic and metamorphic rocks of the Hook Igneous and Basement Complex	0.5
8	Othic/xanthic Ferralsol, Ferric Acrisol	Association of strongly (60% map unit 7) and moderately (40% map unit 9) leached reddish to brownish clayey to loamy soils, derived from acid rocks (Miombo)	Isolated magmatic/metamorphic rocks in the Barotse Basin	0.4
9	Ferric Acrisol, Ferric Luvisol	Moderately leached reddish to brownish clayey to loamy soils, derived from acid rocks (Miombo)	Common soils on magmatic and metamorphic rocks of the Hook Igneous and Basement Complex	24.9
12	Chromic Luvisol, Orthic Acrisol, Eutric Nitosol	Moderately leached red to reddish clayey soils, derived from basic rocks, often in admixture with acid rocks (Munga)	Common soils of the Katanga Supergroup	15.6
19	Albic Arenosol, Ferralic Arenosol	Non or weakly podzolic sandy soils on Kalahari sands (Kalahari and Cryptosepalum)	Kalahari Group	19.5
21	Cambic Arenosol, Dystric Gleysol	Senanga-West floodplain soils (Miombo and termitary associated vegetation)	Cenozoic rocks	0.3
22	Dystric Gleysol	Hydromorphic sand plain soils or very poorly drained soils in large dambos (Grassland)	Muva Supergroup, Choma-Kalomo Batholith and Cenozoic rocks	2.0
25	Ferric Acrisol, Dystric Gleysol, Cambic Arenosol, Xanthic Ferralsol	Association of moderately to strongly leached reddish to yellowish loamy to clayey soils (40% map unit 8) (Miombo) and poorly drained soils in large depressions or valleys (60% map unit 29) (Termitary associated vegetation)	unspecific	1.6
27	Chromic/pellic Vertisol	Swamp soils (Mopane)	Mainly Cenozoic rocks	4.7
28	Pellic/chromic Vertisol	Kafue Flats clay soils (Grassland)	Alluvium, colluvium and laterite of the Kafue Flats	5.7
29	Dystric Gleysol, Humic Gleysol, Dystric Fluvisol	Floodplain soils (Termitary associated and grassland vegetation)	Katanga Supergroup and Cenozoic rocks	2.1
33	Orthic/chromic Luvisol, Eutric Cambisol	Gwembe valley soils (Mopane, Munga, Balakia)	Karoo Supergroup in the Zambezi Valley and adjacent escarpment zone	9.0

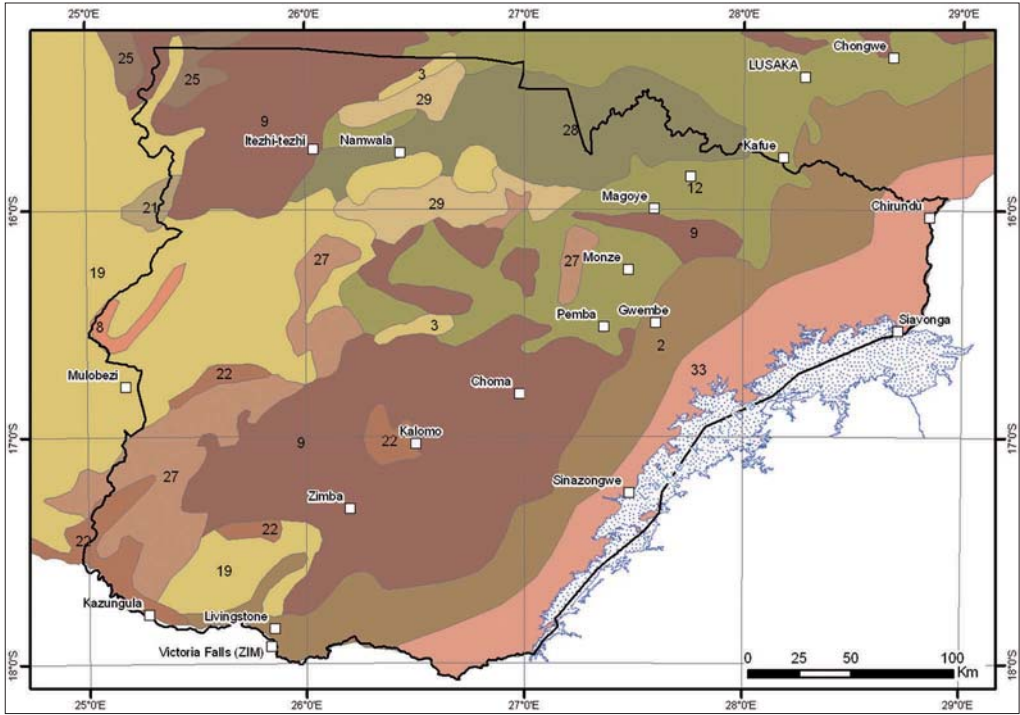


Figure 3: Soils of the Southern Province and adjacent areas in Zambia. Numbers represent individual soil units. Explanations to the soil codes are given in Tab. 1. (Modified after [19]).

Climate

Like for most of Zambia the climate in the Southern Province can be described as humid subtropical, with dry winters and hot summers, corresponding to Class Cwa according to the Köppen-Geiger classification. The Zambezi Valley experiences a hot, semi-arid Steppe climate with higher temperatures and lesser rainfall (Class Bhs). The weather conditions of the Zambian plateaus have also accurately been described as a tropical continental highland climate [20]. Due to the combined effect of low latitude (16 – 18°S), continental position and high elevation above sea level, the climate shows the combination of a clear division into a dry and a rainy season, the predominance of the diurnal cycle over the seasonal, and large daily ranges of temperature.

Landscape near Chikankata, Mazabuka District.



Commonly three seasons are distinguished:

1. Rainy season – a warm wet season from November to April
2. Cold season – a mild to cool, dry season from April to August
3. Hot season – a hot and dry season from September to November.

Temperature and Sunshine

The Meteorological Department of Zambia operates four meteorological stations in the Southern Province, namely at Choma, Kafue Polder, Livingstone and Magoye. Additionally there are, or temporarily existed, up to 50 voluntary stations [29].

The mean annual temperatures are subtropical with values ranging from 19.3 to 22.1°C (Tab. 2).

The mean monthly temperatures during the months of October/November are hot (22.5–26°C). The cold season is mild with mean monthly temperatures between 13.5 and 16.5°C. Daily minimum temperatures during this season often fall below 10°C. Due to the

continental position of the Province and the predominately high altitude, the temperature shows a large daily range. Due to its lower altitude, the Zambezi Valley experiences the highest temperatures during the hot season, and the mildest conditions during the cold season within the Province.

Table 2: Climatic parameters at stations in Southern Province and for Zambia (Source: [29], after data from Meteorological Department).

Station	Latitude	Longitude	Altitude	Temp.	Sunshine
	S	E	m asl	°C	hrs/day
Choma	16.850	26.067	1267	19.3	8.2
Kafue Polder	15.767	27.917	978	21.6	8.4
L/stone	17.867	25.883	987	22.1	8.6
Magoye	16.133	27.633	1018	21.3	n/a
Zambia				21.0	7.8

The Province receives above-average sunshine compared to the national average. Sunshine duration measured at stations in the Province and countrywide average at 8.4 and 7.8 hours per day, respectively.

Table 3: Long-term rainfall and evaporation at stations in Southern Province and for Zambia (Sources: MET, [29]).

Station	Rainfall	Rainfall days	Pan Evaporation 100%/75%	Actual Evaporation ¹⁾	PET ²⁾	Net Evaporation ³⁾	Runoff Coefficient ⁴⁾
	°mm	Day	mm	mm	mm	mm	%
Choma	796	83	1902/1427	667	1522	-726	17
Kafue Polder	767	68	2122/1592	677	1776	-1009	12
L/stone	697	76	2166/1625	637	1745	-1048	9
Magoye	720	67	1991/1493	674	1634	-914	6
Zambia	1001	97	2061/1546	816	1574	-573	18

¹⁾ calculated using Turc (1961) equation [27]

²⁾ Potential Evapotranspiration, calculated using (revised) Penman (1948) equation [23]

³⁾ Net evaporation = Rainfall – Potential Evaporation

⁴⁾ Runoff Coefficient = 1 – (Actual Evaporation/Rainfall).

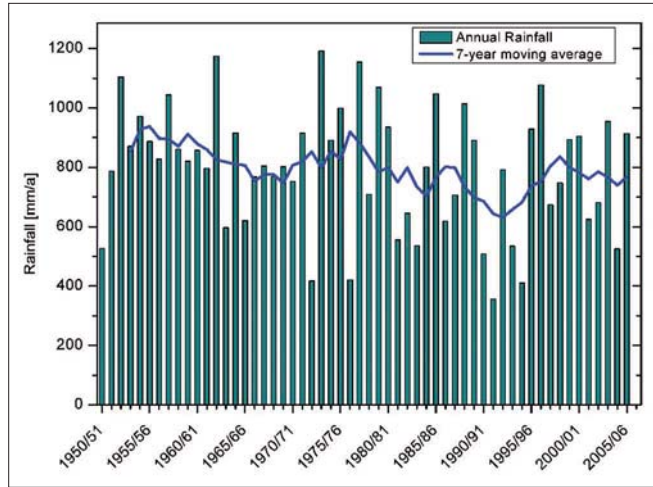


Figure 4: Long-term rainfall (since 1950) at Choma showing a large temporal variation (Source: Meteorological Department).

Rainfall

Annual rainfall and droughts

Mean seasonal rainfall from October to May at the four meteorological stations varies between 700 and 800 mm (Tab. 3). The number of rainfall days at the four stations varies noticeably between 67 and 83 days per year. Compared to Zambian means, the Province receives

200 to 300 mm less rainfall with 14 to 30 fewer rainfall days per year.

The regional rainfall distribution depicted in Fig. 6 shows that the seasonal rainfall gradually decreases from circa 800 mm in the north to below 650 mm in the south-western parts of the Province. The rainfall distribution ("isohyetal") map is based on stations with long-term data exceeding 25 years of records including stations from central and western Zambia and neighbouring countries. The average total rainfall for the Province calculated from the isohyetal map amounts to 757 mm.

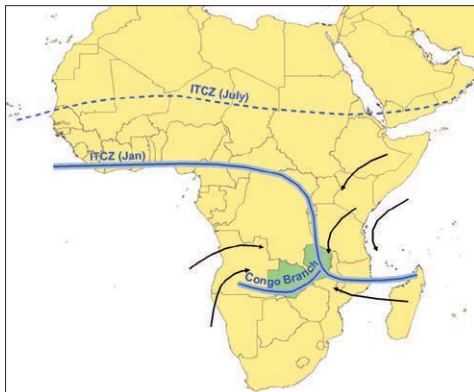


Figure 5: Approximate position of the ITCZ during the Southern Hemisphere winter (dashed line) and summer (thick line) and predominant wind directions during summer (arrows) (simplified after [20] and [25]).

The smooth contours shown in the rainfall distribution map conceal the high variability of rainfall. Rainfall in the Province is irregular and unreliable. In fact, the south-western parts of Zambia extending from Mongu in Western Province to Livingstone are known as the most drought-prone regions within Zambia [29].

The annual variation in rainfall at Choma since 1950 is shown in Fig. 4. The highest and lowest annual rainfall ever observed at Choma amounts to 1191 mm and 396 mm, respectively. The time-series of rainfall at Choma suggests a particular dry spell during the years 1990 to 1995. The driest individual rainy seasons occurred during 1972/73 (417 mm), 1976/77

(420 mm), 1991/92 (356 mm) and 1994/95 (411 mm). This corresponds well with regional occurrences of droughts which were reported for the periods 1946/47, 1965/66 1972/73, 1982/83, 1986-88, 1991/92 and 1994/95 and could be linked to major **El Niño** events [26].

Monthly rainfall

The annual variation of monthly rainfall is controlled by the clear distinction between the wet season during summer and the dry winter. The wet and dry season are separated from each other by a short pre-rainy season (September – November) and post-rainy period (April-May).

The rainy season in Zambia can be linked to the southward shift of the so-called Inter-Tropical Convergence Zone (ITCZ). During the winter months the ITCZ is situated over the Sahel re-

gion at about 15°N. The ITCZ shifts southwards following the apparent movement of the sun. During January the position of the ITCZ over eastern Africa is at 17°S. The trade winds of both hemispheres converge into the low pressure area over the ITCZ. The ITCZ is an area of pronounced convective activity and therefore associated with heavy tropical rain.

The monthly means for Choma are shown in Fig. 7. Over 90% of the seasonal rainfall is concentrated over the months from November to March. The highest individual monthly rainfall is encountered during the months of December, January or February. The three months have over 70% of the total rainfall. The winter months from June to August are practically without rain.

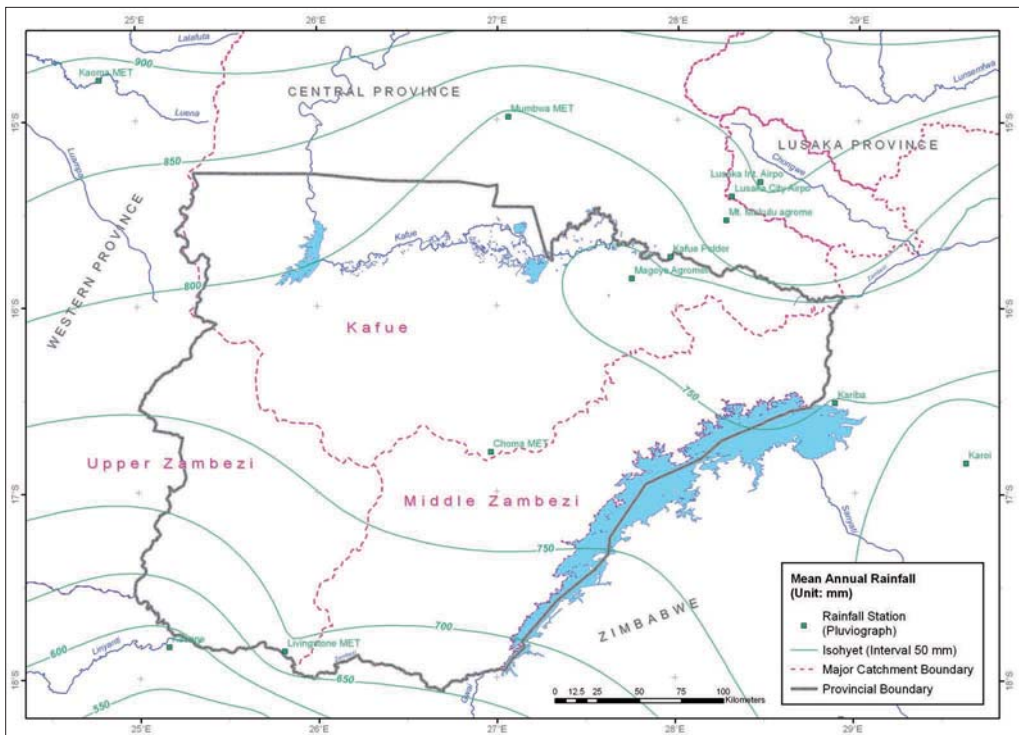


Figure 6: Isohyetal map of annual rainfall (Data Sources: Meteorological Department, Zambia & Department of Meteorological Services, Botswana).

Evaporation

Long-term Class-A pan evaporation at the four meteorological stations in the Southern Province varies between 1,902 mm and 2,166 mm (Tab. 3).

Evaporation from open water bodies such as lakes is often estimated by multiplying the pan evaporation by 0.75. Values corrected in such way range from 1,427 mm to 1,625 mm.

Potential evapotranspiration (PET) is the amount of water that could be evaporated and transpired if there was sufficient water available. PET is commonly determined using the Penman equation (1948) [23]. In the Water Resources Master Plan [29] values for PET obtained with a slightly revised version of the Penman approach range from 1,522 – 1,776 mm for stations situated in the Province. A similar estimate for PET of 1,784 mm is given by [2] for the Kafue Flats. The values

determined for PET are in the same order of magnitude but about 100 mm lower than the corrected pan evaporation.

Actual Evaporation from vegetated land surfaces (quantity of water that is actually removed due to the combined effect of evaporation and plant transpiration) is much lower than PET since surfaces and soils will gradually dry out between individual rainfall periods and markedly during the dry season. Annual actual evaporation estimated calculated from the empirical Turc (1961) equation [27] varies between 637mm and 677mm [29].

Net evaporation is defined as the difference between mean rainfall and potential evaporation and may be used as a measure for aridity. Due to high temperatures and the pronounced dry season, the net evaporation in the region takes always large negative values. The net

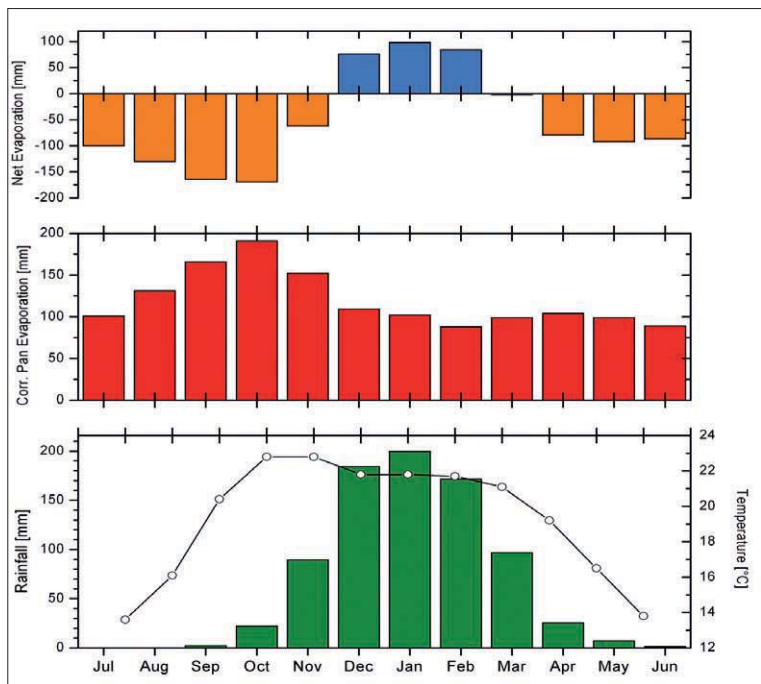


Figure 7: Seasonal variation of monthly mean temperature, rainfall and evaporation at Choma (Data Source: Meteorological Department).

evaporation is largest (i.e. least arid) on the plateau (Choma: -726 mm) and lowest (i.e. most arid) in the Zambezi Valley (Livingstone: -1,048 mm).

The seasonal variation of monthly rainfall, temperature, evaporation and net evaporation at Choma is depicted Fig. 7. It can be summarized as follows:

1. The highest (potential) evaporation (155 - 190 mm/month) is encountered during the hot season. Low potential evaporation (90 - 100 mm/month) occurs during the rainy months due to high humidity and during winter due to lower temperatures.
2. Actual evaporation can be assumed to peak during the rainy and post-rainy season when surfaces are wet and soils often become saturated with water.
3. Net evaporation is negative (i.e. PET exceeds rainfall) for all months except for December to February.

Hydrology

River and streams

The Southern Province is bordered by the Kasaya River, a minor tributary of the Zambezi, to the west, the Zambezi to the south, Lake Kariba to the east and the Lower Kafue River to the north. The Province lies entirely in the Zambezi river basin. The Kafue Catchment covers 46 % of the total area of the Province (85,150 km²). 51 % of the total area is part of catchments that drain directly into the Zambezi River, and the remaining 3 % are covered by Kariba Lake.

The two major river systems, the Zambezi and the Kafue rivers form together with the two Kafue tributaries Nanzhila and Kaleya the only perennial watercourses within the Province. Smaller rivers and streams are generally dry during the dry season (April to October). During the rainy season the flow of these minor rivers is generally intermittent or driven by rainfall events. Intermittent streams only flow during a few hours or days after a rainfall event.

Within the provincial area, the Kasaya (15,401 km²), Kalomo (6,309 km²) and Ngwezi (5,358 km²) rivers form the largest individual sub-catchments in the Zambezi basin. The largest sub-catchments of the Lower Kafue are the Nanzhila Catchment (7,134 km²) followed by the Bwengwa (2,510 km²), Magoye (2,281 km²) and Munyeke (2,271 km²) catchments.

Kafue River upstream of Itezhi Tezhi Dam.



Zambezi

The Zambezi Catchment is commonly divided into three major parts [2]:

1. the Upper Zambezi Catchment from its headwaters to the Victoria Falls,
2. the Middle Zambezi Catchment covering the area from the Falls to the Cahora Bassa Dam in Mozambique,
3. the Lower Zambezi Catchment downstream of the Cahora Bassa gorge in Mozambique.

The Southern Province shares approximately 625 km or 21.5 % of the total length (circa 2,900 km) of the Zambezi.

The Zambezi enters the Province on an eastward course near the town of Kazungula. Geologically, it exits the area covered by Kalahari sands and cuts its riverbed into the basaltic rocks of the Upper Karoo Group. After plunging down the Victoria Falls, and cascading down the Batoka and Devils gorges for a distance of approximately 120 km, the Zambezi flows into the vast Kariba Dam reservoir.

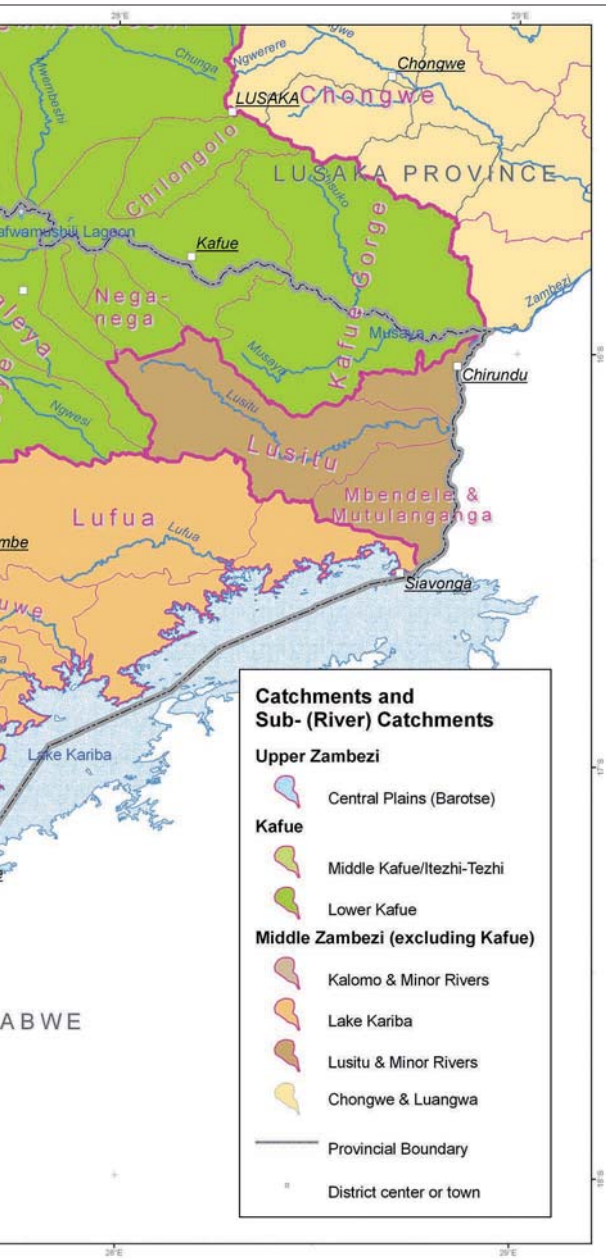
The area comprising the smaller rivers draining the Sinazongwe, Gwembe and Siavonga Districts as well as the Gwai (or "Gwayi"), Sengwa, and Sanyati rivers that originate from the Zimbabwean highlands is known as the *Gwembe Valley* [2], [18].



Figure 8: Major River Systems and catchments.

The average annual discharge of the Zambezi at the Kariba dam amounts to approximately 1,300 m³/s (Tab. 4). Under typical drought conditions the outflow at Kariba Dam reduces to

750 m³/s or 58 % of the average discharge. The lowest ever recorded outflow between 1953 and 1992 was 455 m³/s. The smaller Zambezi tributaries from the Gwembe Valley contribute



comparatively little to the overall runoff of the Zambezi. The mean annual discharge from these rivers is given as 232 m³/s by [2]. Between the confluence of the Linyanti and the Kariba Dam the average discharge, however, only increases by circa 140 m³/s. Consequently, a considerable amount of this inflow to the Zambezi,

however, is lost through evaporation from the Kariba reservoir.

Hydrographs of mean monthly discharge are shown in Fig. 10. At Victoria Falls the mean monthly discharge increases sharply from January to April. The mean date of arrival of the peak is April 19, with a standard variation of 19 days [2]. The maximum monthly discharge for April is 2,762 m³/s. The average minimum discharge of 337 m³/s occurs during October [28].

The hydrograph of monthly discharge at Lake Kariba is flattened out due to the storage capacity of the reservoir and possibly the regulated operation of the dam's turbines and spillway. The maximum monthly discharge still occurs during April but is sharply reduced compared to the river upstream. The maximum and minimum monthly outflow from the dam is 1,927 m³/s and 883 m³/s, respectively. The ratio between maximum and minimum discharge is hence 2.2, compared to 8.2 at Victoria Falls.

Unlike the Zambezi and Kafue rivers, the tributaries in the Gwembe Valley lack extensive storage reservoirs such as large dams and swamps. Runoff from the incised valleys

Victoria Falls towards the end of the rainy season.



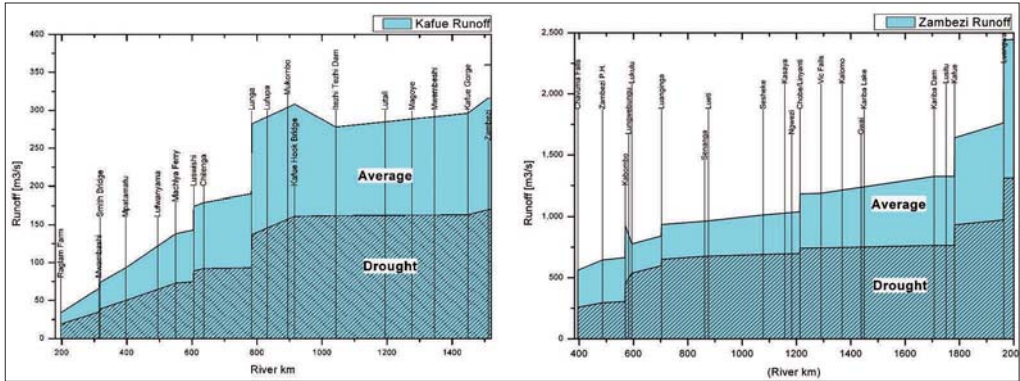


Figure 9: Annual runoff of the Zambezi (left) and Kafue River (right). Blue (non-hatched) area shows average runoff over the 30-year period between 1963 and 1992. Hatched area shows probable drought discharge with a return period of 10 years (Data Source: [28]).

therefore occurs as floods in response to major rainfall events. The cumulative discharge from the Gwai (54,610 km²), Sengwa (25,000 km²) and Sanyati Rivers (43,500 km²) peaks during February and totals more than 900 m³/s. Due to the lack of storage in the catchment the peak discharge occurs two months earlier than in the Zambezi.

Kafue River

The Kafue River forms the largest basin within the Middle Zambezi river system. Its watershed is entirely located on Zambian territory. On its downward course it passes through two large

floodplains, the Lukanga Swamps (2,600 km²) and the Kafue Flats (15,000 km²), and two large reservoirs created by the Itezhi Tezhi and the Kariba Gorge dams. The Kafue Catchment can be divided into the three following sections:

1. The Upper Kafue Catchment including the Kafue headwaters upstream of Lubungu and the large Lunga sub-catchment,
2. the Middle Kafue Catchment covering the area from the Lunga confluence to the Itezhi Tezhi Dam,
3. the Lower Kafue Catchment covering the Kafue Flats and the Kafue Gorge downstream of Itezhi Tezhi.

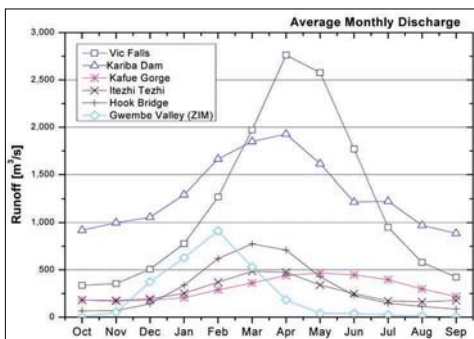


Figure 10 Average monthly discharge at selected gauging stations in the Kafue and Zambezi catchments (Data Source: [28]).

The Kafue originates from the plateau in the Copperbelt Province, an area with average rainfall well above 1100 mm. The river enters the Southern Province near the Kafue Hook Bridge approximately 35 km upstream of Itezhi Tezhi reservoir. At the reservoir outlet the river sharply turns in an eastward direction to enter the Kafue Flats, a floodplain with an area up to 60 km wide and 250 km long.

The average annual discharge of the Kafue River within the Province is between 250 and 300 m³/s. During drought conditions, the discharge downstream of Itezhi Tezhi is maintained at approximately 160 m³/s. Most of the

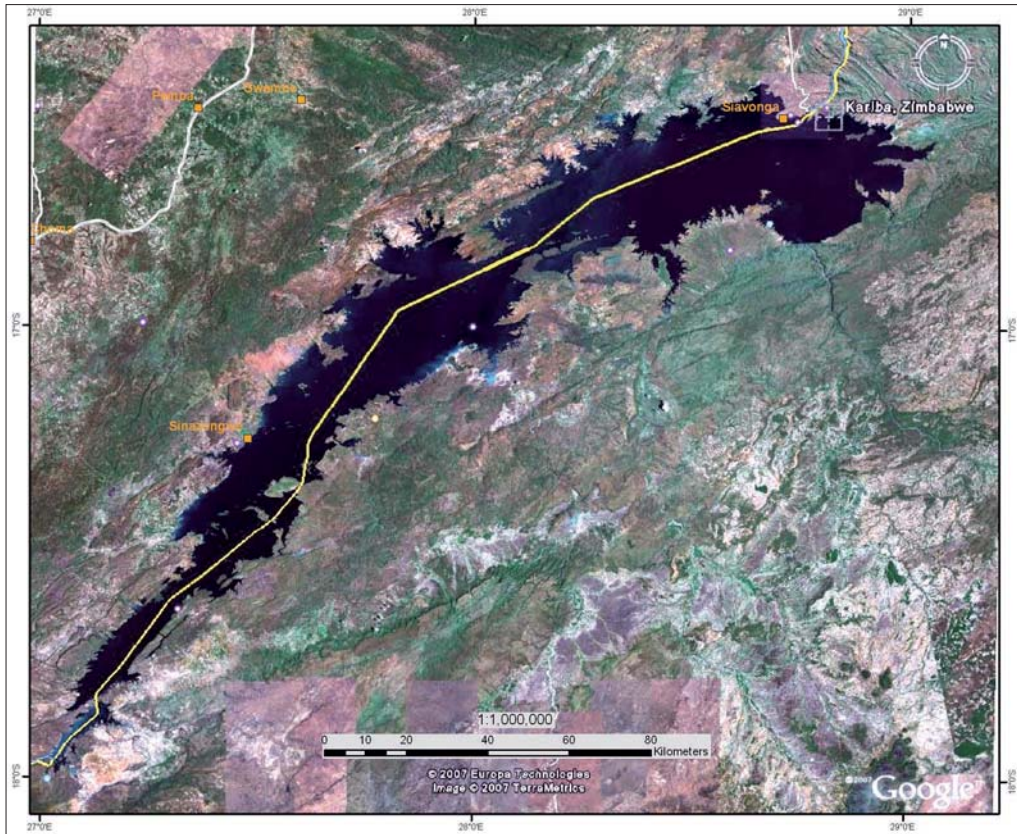
Table 4: Observed and statistical discharge at selected gauging stations for Southern Province for the period between 1953 and 1992 (Data Source: [28]).

Gauging Station	Catchment	Q	Q _D	Q _{Max}	Q ₉₅	Q ₁₈₅	Q ₂₇₅	Q ₃₅₅	Q _{Min}
Victoria Falls	Upper Zambezi	1187	744	3225	1766	777	449	316	298
Kariba Lake (Outflow)	Middle Zambezi	1299	756	6668	1083	904	729	482	455
Kafue Hook Bridge	Middle Kafue	308	161	1113	469	173	95	55	49
Itezhi Tezhi Dam (Outflow)	Middle Kafue	278	162	832	325	188	147	109	85
Kafue Gorge (Outflow)	Lower Kafue	296	163	574	402	253	177	123	100

Explanations:

- Q 30-years average discharge (1963-1992) in m³/s
- Q_D Probable average discharge of drought with a 10-year return period
- Q_{Max} Maximum discharge recorded
- Q₉₅ High discharge, exceeded on 95 days a year
- Q₁₈₅ Median discharge, exceeded on 185 days a year
- Q₂₇₅ Low discharge, exceeded on 275 days a year
- Q₃₅₅ Drought discharge, exceeded on 355 days a year
- Q_{Min} Minimum discharge recorded

Kariba Lake as seen from Google Earth at a distance of 200 km [10].



discharge of the Kafue River system is generated in the Upper Catchment. In the Middle and in particular the Lower Kafue Catchment, inflow from tributaries roughly equals evaporative losses from the dams and floodplains (Fig. 9).

The average monthly discharge at gauging stations at Hook Bridge, Itezhi Tezhi Dam and Kafue Gorge are depicted in Fig. 10. It should

be noted that the flow below Itezhi Tezhi is largely regulated through the regulation gate at the dam. The storage of flood waters in the Itezhi Tezhi Lake results in a delay of the arrival of the peak flow and a significant decrease in maximum monthly discharge from 774 m³/s at Hook Bridge to below 500 m³/s downstream of Itezhi Tezhi.

Table 5: Surface and catchment area as well as storage capacity of the three major reservoirs in Southern Province (Total capacity after [2]).

Reservoir	Catchment	Start of operation	Surface Area [km ²]	Catchment Area [km ²]	Total Capacity [mm ³]
Kariba	Middle Zambezi	1958	5350	663,880	160,000
Kafue Gorge	Lower Kafue	1972	800 ^{*)}	152,710	885
Itezhi Tezhi	Lower Kafue	1976	313	106,511	5,700

^{*)} Depending on degree of flooding values from 600 to 1,600 km² are reported.

Dams and reservoirs

Three large dams for hydropower generation are located in the Southern Province, the Kariba dam in the Middle Zambezi Catchment as well as the Itezhi Tezhi and Kafue Gorge dams in the Lower Kafue Catchment. The size of the surface and catchment areas of the three dam reservoirs are summarized in Tab. 5.

With a surface area of about 5,350 km² and a total capacity of 160 km³, the Kariba dam is the third largest reservoir in Africa after the Owen Falls (Victoria/Nile) and the Nasser reservoir (Nile). The reservoir is up to 30 km wide and 280 km long and regulated for hydropower generation. Net evaporative losses (evaporation – rainfall) from the reservoir have been estimated at 955 mm corresponding to approximately 13 % of the inflow into the dam.



The Kariba dam wall was built into an intrusion of granitic gneiss near Siavonga into which the Zambezi has incised a deep gorge.

The Kafue Gorge dam was completed in 1972 and hosts a hydropower station. The main purpose of the Itezhi Tezhi dam is to optimize inflow into the Kafue Gorge reservoir for an effective hydropower production and to minimize evaporation losses from the Kafue Gorge reservoir.

Springs

Unfortunately, springs in the Province have never been mapped systematically. A number of springs are known to exist in the Gwembe Valley along the escarpment. The locations of these springs are, however, often remote and difficult to access. They are associated with the various fracture and fault systems within the Karoo rocks, or occur at the contact between the Karoo and the Basement. Although some of the springs are perennial they are rarely

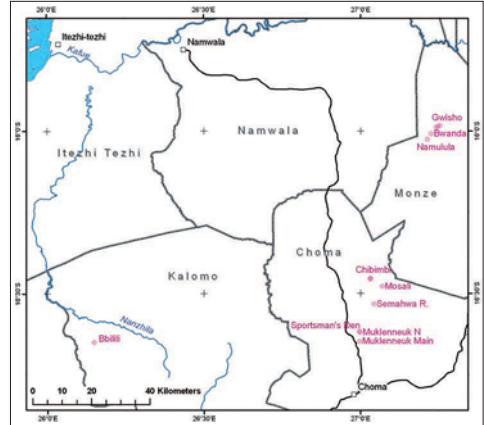


Figure 11: Location of hot springs in Southern Province.

used for water supply purposes. This may be related to the fact that springs are considered sacred places.

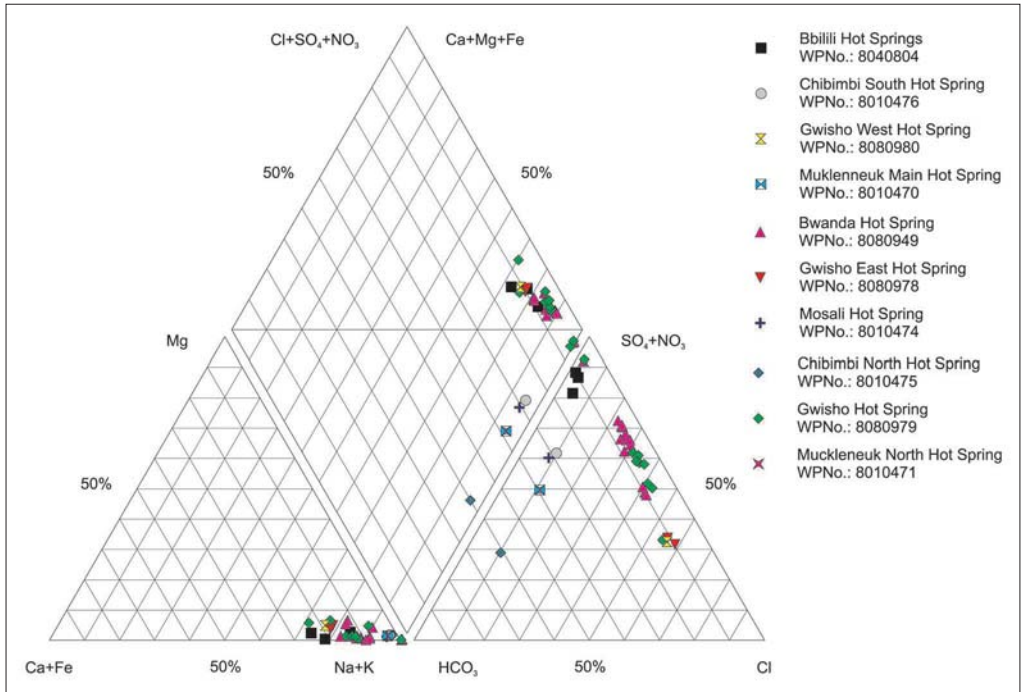


Figure 12: Piper diagram showing the major chemical composition of water from hot springs in Southern Province. The Bbilili springs are of the Na-SO₄ type, the Choma group of Na-SO₄/(HCO₃) type and the Lonchinvar group of the Na-SO₄/Cl (Data Source: [14]).

Zambia's hot and mineralised springs have been systematically investigated between 1971 and 1974 by [14]. Several important groups of hot springs can be found in the Southern Province, namely the Bbilili hot springs in Kalomo District, the hot springs north of Choma, the hot springs of Lochinvar National Park and the Longola hot spring near Itezhi Tezhi (Fig. 11).

The hot springs occur on major, probably deep faults within the Choma-Kalomo block or at the contact of Karoo sediments with Precambrian rocks. According to [14], the spring water is likely of meteoric origin, heated by deep cir-

ulation in fault zones, and enriched in minerals by dissolution of minerals from the rock adjacent to the faults during the prolonged passage.

The temperature of the springs varies between 40 and over 90°C, with the hottest springs found at Bwanda. Except for the Choma group of hot springs which has a comparatively low total content in dissolved minerals (TDS circa 500 mg/l), the thermal springs are highly mineralised (TDS>1000 mg/l). High levels of sulphate observed are usually associated with leaching of Karoo sediments.

Geology

Overview

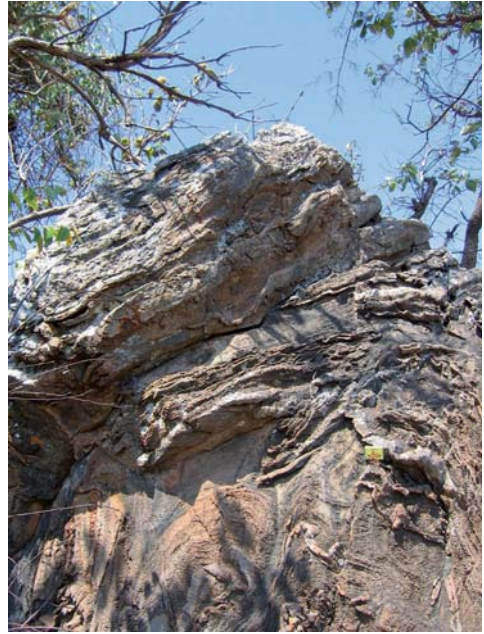
The geology of the Southern Province encompasses rocks of large variety which were formed over a long time range [6]. The oldest rocks have an age of around 1,400 million years and the youngest rocks were formed during the last thousands of years in an ongoing process.

Choma-Kalomo Block

The oldest rocks of the Southern Province are exposed within the Basement Complex and the overlying Muva Supergroup as well as the associated Choma-Kalomo Batholith which together form the Choma-Kalomo-Block. The suite comprises mainly metamorphic rocks like gneiss, granite-gneiss, amphibolites, quartzite, marble and calc-silicate rocks but also small outcrops of Karoo Supergroup sediments that were deposited during a later geological event (see below). Except for this minor occurrence of younger (Mesozoic) deposits the ages in the Choma-Kalomo Block are throughout Mesoproterozoic, i.e. between 900 and 1,600 Million years old.

Katanga Supergroup

The outcrops of the Katanga Supergroup in the Southern Province are restricted to the Zambezi Belt which occupies parts of the central and north-eastern Southern Province. These Neoproterozoic rocks are between 900 and 543 Million years old and have been deposited in a large scale rifting regime within a marine environment. Due to major tectonic events after their deposition (Lufilian Orogeny) they have undergone metamorphism of varying degree. The central to southern Zambezi Belt are occupied by metasedimentary rocks of various compositions: marble and calc-silicate rocks



Strongly folded calc-silicate rocks of the Katanga Supergroup.

alternating with regions of amphibolite-facies, kyanite, staurolith and locally sillimanite and garnet bearing schists and gneisses. The Kafue Rhyolith and the Nazingwe-Formation are the earliest Katanga deposits within a rifting environment and are metamorphosed up to amphibolite facies. All the Katanga rocks occur in sheets with varying deformation patterns, which are transported northeast-wards during the Lufilian Orogenesis [24], [13].

Hook Igneous Complex

The Hook Igneous Complex is located in the northwestern part of the Southern Province and consists mainly of granitoids with some metamorphic rocks like gneiss and migmatite. The granitoids are at large granites, but syenite, diorite, granodiorite, tonalite, monzonite, adamellite and, as minor intrusive rock, gabbros are also represented. A small outcrop of

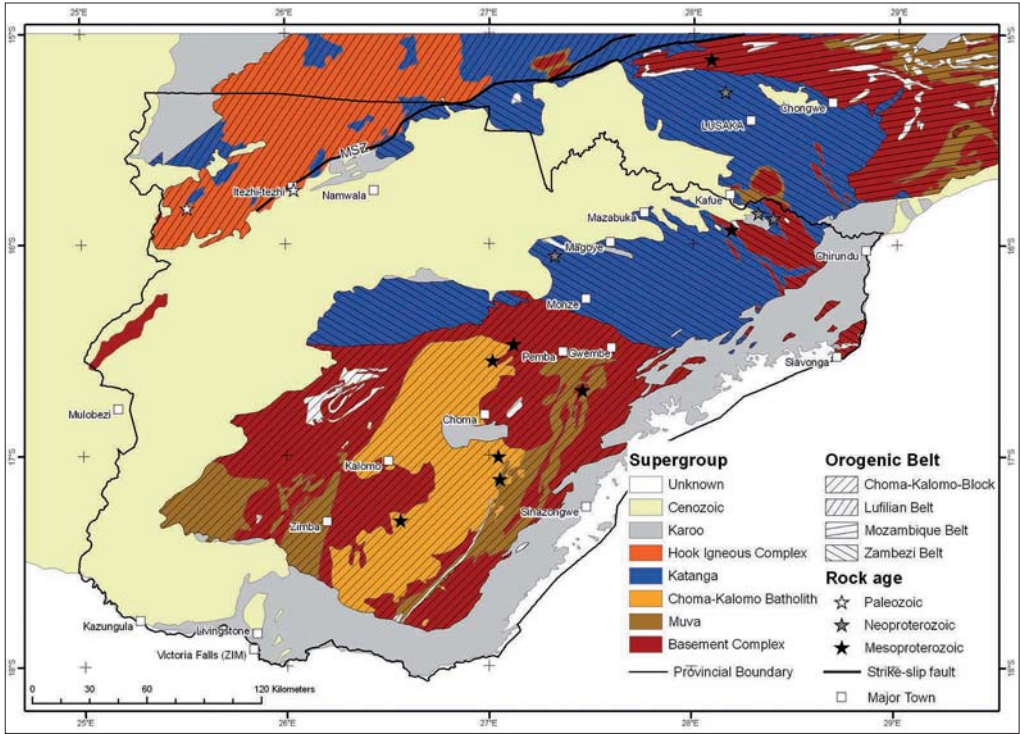


Figure 13: Geological map of the Southern Province with the main Orogenic Belts.

rhyolite represents the extrusive character of the magmatism occurring during the Lufilian Orogenesis along the Mwembeshi Shear Zone (MSZ), which is part of a large-scale shear zone transecting southern Africa.

Karoo Supergroup

The Karoo Supergroup deposits are related to rifting accompanied by the establishment of large-scale graben systems. The rifting is related to the break-up of Gondwanaland and commences at late Carboniferous time (circa 300 Million years ago) and continues until early Jurassic.

The sedimentary sequence of the Karoo Supergroup lies unconformably over older rocks. The Lower Karoo starts with the *Siankon-*

dobu Sandstone Formation, followed by the *Gwembe Coal Formation* and the *Madumabisa Mudstone Formation*. With the beginning of the Upper Karoo in early Triassic the *Escarpment Grit Formation* was deposited followed by the *Interbedded Sandstone and Mudstone Formation* and the *Red Sandstone Formation*. These clastic sediments are topped by the early Jurassic *Batoka Basalt Formation* which is the youngest member of the Karoo Supergroup [22], [30].

Cenozoic deposits

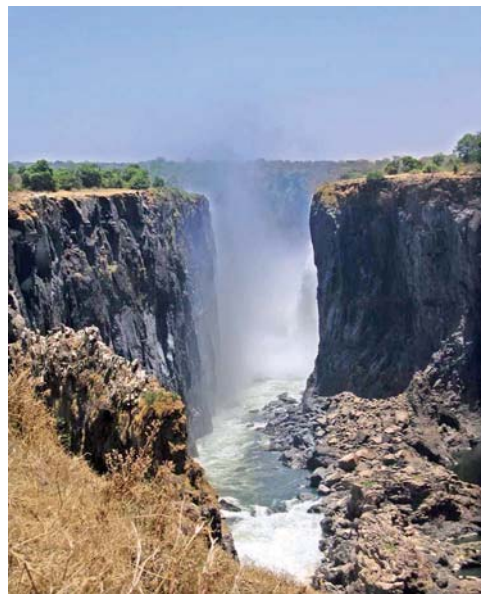
With an age of less than 20 Million years the Cenozoic deposits are the youngest sediments found in the Province. They consist of unconsolidated or semi-consolidated clastic sediments. These include alluvium and colluvium deposits



Outcrop of granitoidic rocks within the Hook Igneous Complex near Kafue River.

from the Kafue and Zambezi rivers and flood-plain material in a large variety of grain size distributions and terrace deposits of the Lake Kariba. The Neogene and Quaternary Kalahari group covers large areas of the western and southwestern part of the Southern Province. The Kalahari Group consists pre-dominantly of unconsolidated or semi-consolidated sand that was eroded, transported and deposited mostly by winds to form fossil dunes. These so-called *aeolian* deposits are characteristic for an arid to semi-arid environment. Gravel, silt and clay are minor deposits within the sequence [12].

The famous Victoria Falls are located in basaltic rocks of the Karoo Supergroup.



Water Supply and Sanitation

Water Supply and Use

Accurate information is required to improve the understanding of the water situation in the country. Zambia's current water resources use cannot be accurately determined since comprehensive water use data is generally not adequate due to poor data records kept by different users as well as the inadequate regulatory capacity to monitor the various water uses. This is true for both groundwater (which is not regulated) and surface water. The last comprehensive water use survey was carried out by the Water Resources Master Plan Study 1993 – 1996 which requires updating. Groundwater management regulations exist in the New Water Resources Management Bill which is yet to become law. The current Water Act empowers Government through the Water Development Board to control water allocations but the Board has little capacity to enforce the existing law.

The majority of the population in the Southern Province (1.4 million inhabitants in 2000) live

Maize field on the fluvial deposits of Zongwe River, Sinazongwe District.



Cattle drinking water from a small dam near Sinde, Kazungula District.

in rural areas. About 250,000 (17%) people live in peri-urban and low-cost areas.

Township water supply is dependent of both surface and groundwater. The Southern Water and Sewerage Company (SWASCO) which is the commercial water utility company in the Province currently supplies close to 20 million cubic meter to major towns (Source: SWASCO, 2006)

Only 41% of the population in peri-urban and low-cost areas has access to safe drinking water [21]. The main source of drinking water is provided by own connections in the households, followed by communal tabs and hand-pumps. Customers complain most frequently about the fact that not enough water is available, that distances between the dwellings and the water source are too large and that too much time is needed to fetch water.

In rural areas water supplied from groundwater is mostly provided by boreholes with hand-pumps or hand-dug wells that are often equipped with a bucket and windlass or a hand pump. Common depths of boreholes are in the range of 50 to 70 m. Hand-dug wells are shallow with depths ranging from a few meters to seldom above 20 m. Another water source

for domestic use is from the dry river beds of seasonal streams. In the wet season and few months (April to August) after the rainy season, the water in most of the seasonal streams is used for irrigation, gardening and livestock watering.

There are over 889 dams in the Province (Source: DWA). The majority of these hydraulic structures are earth dams apart from a few concrete dams constructed solely for township water supply in the major towns along the line of rail.

The Kafue Flats downstream of Itezhi Tezhi reservoir include wide wetlands and fertile alluvial plains which are a source of livelihood among villagers, small scale farmers and commercial irrigation plantations and farms. For the villagers the flood plains are grazing grounds for cattle and hunting ground for small animals. The Kafue Flats harbours Lochinvar and Blue Lagoon National parks. The Kafue Lechwe is adapted to the area and the area is also a sanctuary of a big variety of birds. The grassland offers thatching grass and clay for constructing rural domestic structures.

Lake water of Kariba Dam sustains irrigation, wildlife, domestic animals and a vibrant ecology of plant and animal life in the area. Irrigation methods used in rural areas are simple using buckets, watering cans etc. to grow, among others, vegetables, maize, citrus trees, rice, bananas and sugarcane.

Around 10 hectares around Lake Kariba are used for flood recession cropping [1]. In this type of farming, crops utilize the shallow water table and the water retained in the soil. The area which is seasonally flooded is used to grow crops at the end of the rainy season when the flooding subsides.

There are, on a commercial basis, some small irrigation schemes that were developed by government. These include Buleya Malima in Sinazongwe (62 ha of furrow irrigation),

Nkandabwe (12 ha) and Chiyabi and Siatwinda (12 ha) in the Gwembe valley.

On the plateau there is a huge irrigation scheme in Mazabuka town called the *Nakambala Sugar Estate*. This parastatal scheme was initiated by the Government to grow specific crops for throughput to the industries. Over 720,000 m³ of water per day is drawn from Kafue River for irrigating 13,413 ha of the sugarcane plantation [3].

Sanitation

The percentage of households in Southern Province with access to "improved sanitation" in 2003 was 40% whereas the national coverage was 65% according to the Millennium Development Goals Zambia Status Report [16]. The United Nations definition of "improved sanitation" used here assumes that facilities such as septic tank systems, pour flush latrines, simple pit or ventilated improved pit latrines are likely to be adequate, provided that they are not public.

Irrigation scheme along the Lower Kafue River.





Unsafe forms of water supply. From top to bottom: Women fetching water from loose sediments of riverbed, unprotected spring, improvised pumping of groundwater, unprotected shallow well.

Using the same definition, the ZVAC Survey [31] data shows that in 2007, the average percentage of households having access to sanitation in Southern Province is 48 % compared to 71% for Zambia. Nationwide, over 50% of households use traditional (simple) pit latrines while about 30% have no sanitary facility at all (Fig. 14).

Apart from low access to sanitation there is also low level of hygiene awareness and practice in the Province and these greatly contribute to high incidences of waterborne diseases such as diarrhoea and cholera.

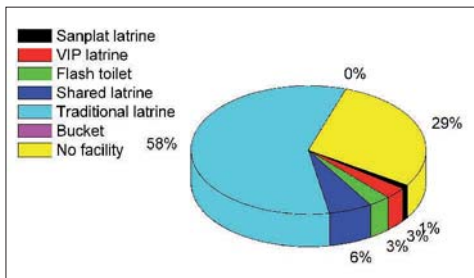


Figure 14: Percent distribution of households in Zambia by type of excreta disposal facility [31].

Groundwater Resources

Groundwater Systems and Potential

In order to identify the major groundwater systems, so-called "aquifers", of the Province the groundwater bearing rock formations were differentiated according to the rock type ("lithology") with respect to their regional distribution.

Using this approach, ten different groundwater systems with different lithology can be distinguished (Tab. 6). Unconsolidated ("loose") alluvial and Kalahari sediments covering the Kafue Flats and the western parts of the Province form the largest system with 35% of the total area. Other important systems in terms of surface area coverage are constituted by ancient (Precambrian) gneisses and undifferentiated basement rocks (20% of total area), acid to intermediate igneous rocks (mainly granites) of the Choma-Kalomo Block and the Hook Igneous Complex (15%), and the Karoo sandstone in the eastern portion of the Province (11%).

Almost two thirds of the aquifer systems of the Southern Province are formed by hard rock in which groundwater flow is associated with the occurrence and type of fracture and fault

systems. The intergranular systems within alluvium and Kalahari deposits are often characterised by interbedded layers of clay, silt, sand and gravel as a consequence of their complex depositional environment and history. As a result, they also host non-uniform, often discontinuous or layered aquifers.

Each groundwater system can be characterised according to their hydraulic properties, including

1. The transmissivity T , given in units of m^2/d , which can be considered a measure of the amount of water that can be transmitted through a rock formation.
2. The specific capacity q , given in units $L/s/m$, which is obtained by dividing the discharge of a pumped well by the stabilised drawdown observed during a pumping test.
3. The yield Q , given in L/s , which refers to the likely or characteristic yield that a well can produce from a rock formation.

Handpump, type India Mark II.



Table 6: Main groundwater systems and their lithology and occurrence.

No	System	Litho-Stratigraphical Description	Main Regional Occurrence	Surface Area [%]
1	Acid to intermediate igneous rock	Granitic rocks typically associated with the Choma-Kalomo Block and the Hook Igneous Complex, but also found within the Katanga Supergroup.	Throughout the Southern Province, predominant unit in the Choma-Kalomo area	15
2	Basalt	Basalt rock of mainly Upper Karoo Age	In the South between Kazungula, Livingstone and Zimba	4.5
3	Gneiss & undifferentiated metamorphic rock	Predominantly gneiss and granitic gneiss within the Basement, Katanga & Muva Supergroups	North-eastern areas of Southern Province, between Monze, Gwembe, Pemba and Choma and near Siavonga	20
4	Schist, shale & slate	Various schists of Precambrian age	Throughout the Southern Province	7.8
5	Quartzite	Quartzitic rocks of predominately Precambrian age	Throughout the Southern Province	<1
6	Carbonate & calc-silicate rock	Mainly calc-silicate rocks and marbles or dolomitic rocks of the Katanga Supergroup	Mazabuka District and area east of Mapanza	4.0
7	Mudstone	Karoo mudstones (mainly Madumabisa Mudstone Formation)	Escarpment zone of Siavonga, Gwembe and Sinazongwe Districts	1.6
8	Pre-Kalahari sand- and siltstone	Mostly Upper Karoo sand- and siltstones (Red Sandstone and Interbedded Sandstone and Mudstone Formations)	Escarpment zone of Siavonga, Gwembe and Sinazongwe Districts	11
9	Kalahari sandstone	Consolidated or semi-consolidated sandstone of the Kalahari Group	Western areas of the Province including Kazungula, Itezhi Tezhi and Namwala Districts	<1
10	Unconsolidated clastic sediments	Interbedded gravel, sand, silt and clay formed by alluvial deposits and unconsolidated Kalahari sediments	Kafue Flats and western areas of Southern Province	35

Descriptive statistical values of hydraulic parameters for each of the ten groups were obtained from the groundwater database (Tab. 7). As a major finding, the examined hydraulic parameters vary over a wide range even in areas with relatively uniform lithology, but particularly in areas where groundwater flow is controlled by zones of intense fracturing and faulting. This is reflected in the large values of standard deviation and coefficient of variation expressing the heterogeneity of the rock formations,

Values of transmissivity, specific capacity and yield given in Tab. 7 falling between the 25th to the 75th percentile can be considered typi-

cal since they apply to 50% of all boreholes for which the respective hydraulic information is available.

A comparatively low rate of success is reported for gneiss and undifferentiated basement rock (23% of dry boreholes), acid to intermediate igneous rocks (21% dry) and basalt (19% dry). Very few (<1%) unsuccessful boreholes are reported for the systems formed by unconsolidated sediments, Kalahari sandstone, quartzite as well as schists.

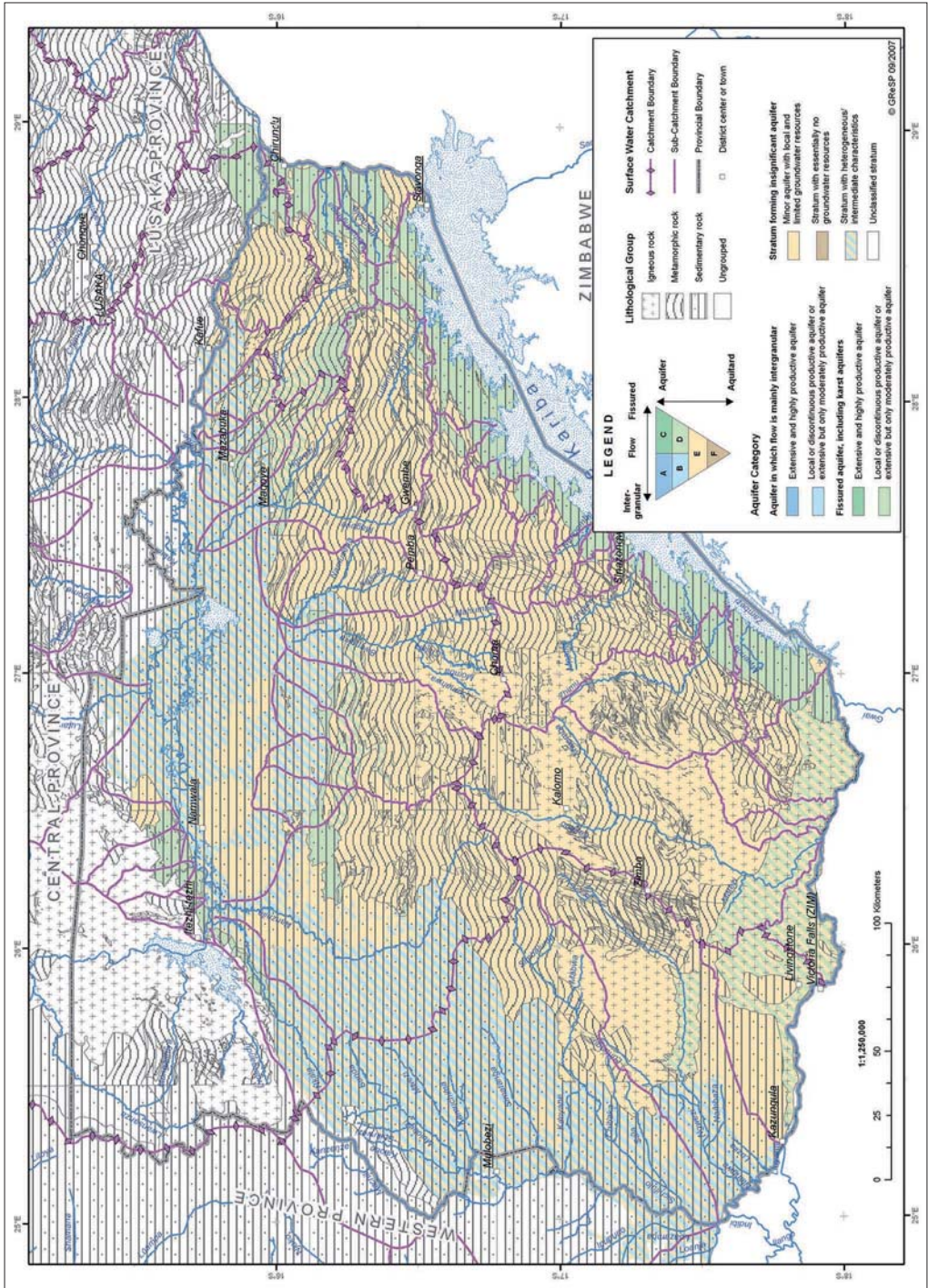


Figure 15: Lithology and potential of groundwater systems in the Southern Province.

Table 7: Descriptive statistics of aquifer characteristics: Transmissivity (T) in m²/day, Specific Capacity (q) in L/sec/min and Yield (Q) in L/sec.

No	System	Param.	n	Mean	Median	Stdev	CV [%]	Min	P25	P75	Max	Cate- gories
1	Acid igneous rock	q	97	0.30	0.034	2.37	778%	0.0045	0.015	0.073	23.33	E
		T	87	23.1	1.4	179.1	775%	0.15	0.56	2.6	1670	
		Q	157	0.56	0.31	0.71	126%	0	0.11	0.8	5	
2	Basalt	q	68	0.21	0.080	0.39	188%	0.0050	0.027	0.177	2.36	E - D
		T	65	30.5	5.5	100.1	328%	0.21	2.12	15.7	618	
		Q	89	0.70	0.60	0.67	95%	0	0.2	1.2	3.6	
3	Gneiss & undiff. metamorphic rock	q	47	0.16	0.044	0.28	171%	0.0017	0.017	0.175	1.32	E
		T	20	40.1	4.2	111.5	278%	0.09	0.52	21.0	500	
		Q	73	1.09	0.40	1.90	174%	0	0.1	1	9	
4	Schist, shale & slate	q	108	0.21	0.050	0.44	211%	0.0032	0.017	0.160	2.42	E
		T	67	21.6	2.9	40.3	187%	0.11	0.88	14.0	197	
		Q	116	1.19	0.80	1.41	119%	0	0.31	1.4	7	
5	Quartzite	q	34	0.20	0.028	0.55	272%	0.0053	0.009	0.075	2.67	E
		T	30	10.2	1.2	25.3	249%	0.14	0.44	5.3	120	
		Q	37	1.08	0.70	1.01	94%	0.1	0.3	1.7	5	
6	Carbonate & calc- silicate rock	q	20	0.44	0.059	1.33	301%	0.0034	0.021	0.218	6.00	E - D
		T	12	22.8	2.0	43.1	189%	0.19	0.50	14.0	121	
		Q	36	1.19	0.32	2.09	176%	0	0	1.2	10	
7	Mudstone (Karoo)	q	74	0.19	0.049	0.39	207%	0.0027	0.021	0.163	2.86	E
		T	32	34.1	3.0	69.3	203%	0.13	0.62	11.3	238	
		Q	147	1.59	0.90	2.13	134%	0	0.4	2	12	
8	Pre-Kalahari sand- and siltstone	q	67	0.50	0.167	1.00	198%	0.0070	0.058	0.418	5.71	D - E
		T	46	39.3	15.8	94.6	240%	0.18	2.33	38.7	628	
		Q	137	2.23	1.50	2.51	112%	0	0.6	3	15	
9	Kalahari sandstone	q	25	0.19	0.087	0.23	121%	0.0067	0.044	0.229	0.92	E - D
		T	25	15.7	5.8	22.1	141%	0.27	2.28	13.8	74	
		Q	25	0.81	0.80	0.41	51%	0.2	0.5	1.1	1.5	
10	Unconsolidated clastic sediments	q	61	0.26	0.074	0.80	311%	0.0028	0.027	0.235	6.15	E - B
		T	46	13.5	5.1	23.8	177%	0.11	1.09	14.8	120	
		Q	64	1.49	0.92	1.93	129%	0	0.4	1.6	10	

In summary, most aquifer systems of the Southern Province, especially those in the central areas that are formed by granitoid and basement rocks, have only limited potential and are only suitable for smaller withdrawals (e.g. private consumption or local rural water supply through hand pumps). In some areas, especially at the margins of the Province, groundwater systems with moderate potential can be found. These systems usually are formed by unconsolidated deposits or Karoo sandstone and basalt and may be sufficient for withdrawals for local water supply to smaller communities or for small-scale irrigation (Fig. 15). Wells with exceptional high yields ($Q > 10$ L/s), are rarely found regardless the aquifer lithology. Groundwater therefore is usually not suitable for larger development or for irrigation schemes. Locally, groundwater may be sufficient to supplement surface water-based irri-

gation systems along the major rivers and Lake Kariba or to facilitate small-scale irrigation.

Groundwater can overall be considered a reliable source for domestic and rural water supply for which comparatively small amounts of water (less than two cubic meters per hour) are needed. Groundwater exploration however is not without risks due to the heterogeneous nature of most groundwater systems. About one out of five boreholes drilled during larger exploration campaigns in the past was unsuccessful.

Regional Groundwater Flow

The groundwater contour map depicted in (Fig. 16) shows the general regional pattern of groundwater flow but is not suitable for larger-scale study areas due to the overall inconsis-

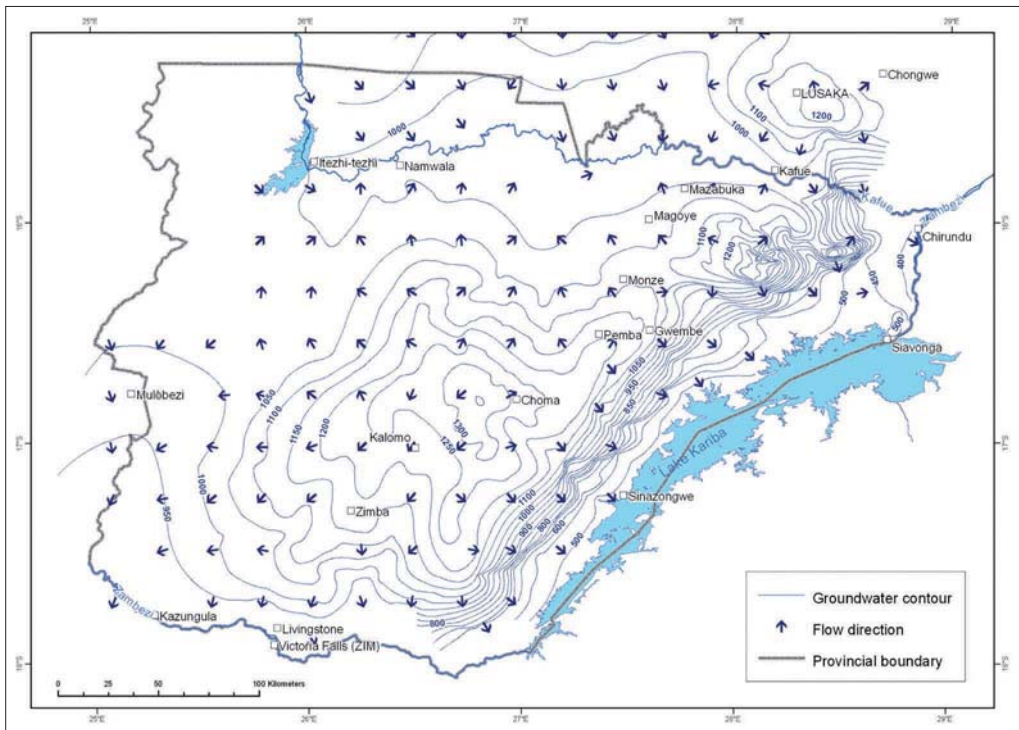


Figure 16: Groundwater contour map of the Southern Province and the adjacent north-eastern Lusaka area with indication of the groundwater flow directions. Water levels are given in meters above sea level.

ent quality of available groundwater level data. The map is based on 1,661 sites with water level measurements. The groundwater is flowing from three distinctive areas with high groundwater levels, namely the Choma-Kalomo Block, the Mabwetuba Hills area (hosting the highest point within the Southern Province) and the Lusaka Plateau, towards the major rivers Zambezi and Kafue and Lake Kariba. The groundwater gradient within the alluvial plain of the Kafue River is generally low and is directed towards the river course. In the westernmost part of the Province groundwater levels and flow directions are not predictable due to the lack of data. As a consequence to the similarity between surface slope and groundwater characteristics, rather steep groundwater gradients



Chemical water testing.

are characteristic for the escarpment zone in the direction of Lake Kariba.

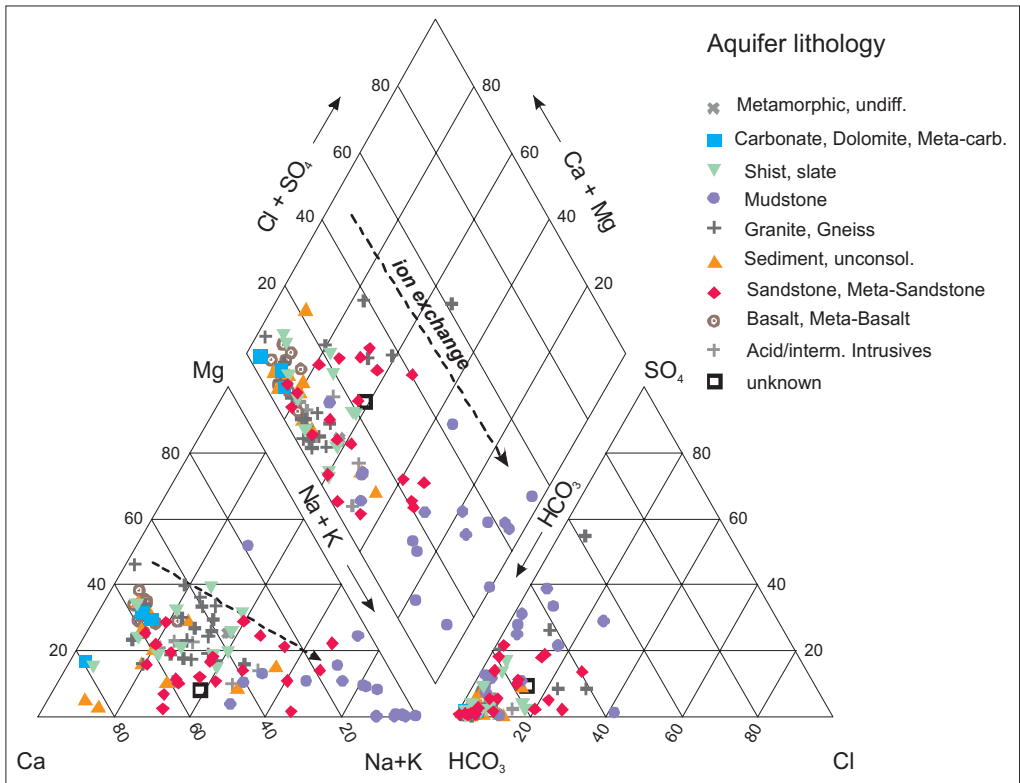


Figure 17: PIPER diagram showing major composition combining anion triangle (right) and cation triangle (left) to a rhombus (top). The grey arrow indicates trend of increasing impact of ion exchange processes within the aquifer.

Groundwater Quality

Overall chemical composition

The major anion (bicarbonate HCO_3 , sulphate SO_4 , chloride Cl , nitrate NO_3) and cation (sodium Na , potassium K , calcium Ca , magnesium Mg) composition of groundwater in Southern Province is typical for continental groundwater of primarily meteoric origin, shown by the accumulation of data in the left quarter (Ca/Mg-HCO_3) of the rhombus in the PIPER-Diagram (Fig. 17). The anion composition is strongly dominated by bicarbonate while calcium prevails in the cation composition although in certain host rocks such as mudstones dissolved sodium is dominant.

The chemical composition furthermore shows that most groundwater has temporary hardness which can be easily removed by conventional treatment of drinking water.



Fishing camp on Kafue River in Mazabuka.

Sources of groundwater contamination

The quality of groundwater in Southern Province is generally good although locally contamination may occur especially near urban centres mainly due to poor sanitary conditions. Usually households rely on unprotected shallow wells which are sometimes dug near pit

latrines. Poor on-site sanitation facilities and use of agro-chemicals are possible threats to groundwater quality in the Province. The need to protect the resource against contamination cannot be over-emphasised. Moreover, once contaminated it is difficult and costly to clean such water to the acceptable standard for drinking.



Unprotected shallow wells. Left: shallow well prone to contamination due to run-off. Right: shallow well as source of drinking water.

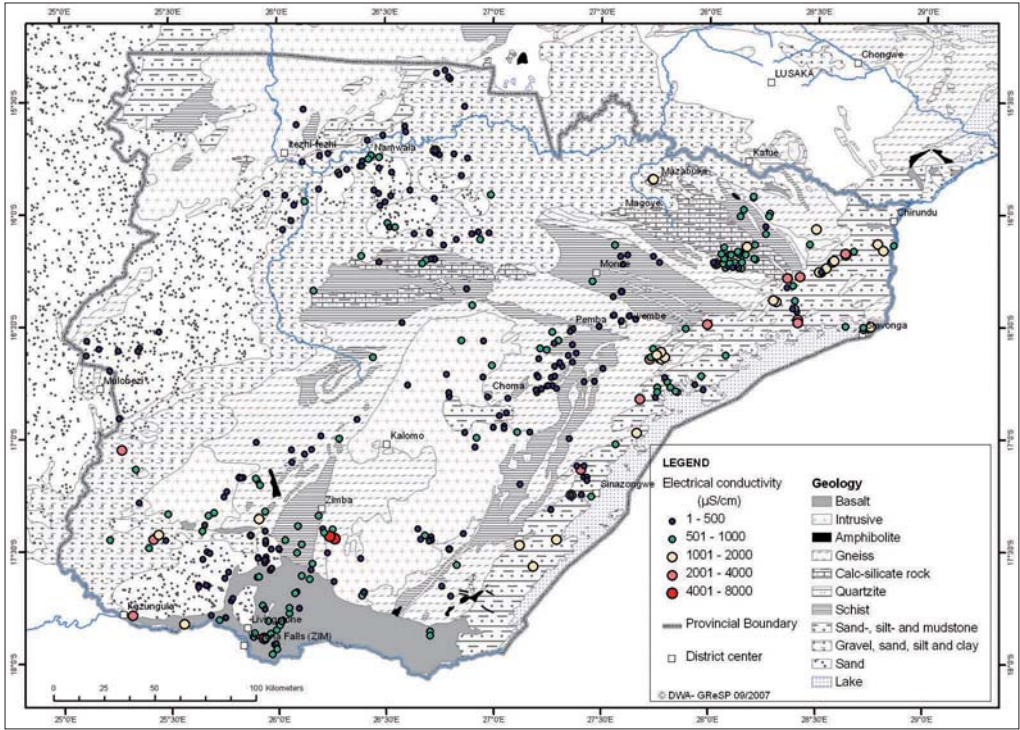


Figure 18: Regional distribution of salinity of groundwater expressed in electrical conductivity.

In addition to causing water contamination, poor sanitary conditions and poor hygiene practices contribute to the prevalence of waterborne diseases such as diarrhoea, dysentery and cholera in the Province, especially during the rainy season. Together with schistosomiasis, these waterborne diseases are mostly prevalent near rivers and reservoirs especially at fishing camps where there are often no sanitary facilities.

Untreated surface water from rivers and reservoirs is normally regarded as unsafe for drinking and probably for washing too. Improved sanitation and increased health and hygiene education in communities are required to address this situation.

Values of arsenic, manganese, sulphate and fluoride exceeding Zambian or the World Health Organisations' standards have been found at

individual sites but no clear distribution pattern could be recognized due to the limited amount of data. Fortunately, the occurrences seem to be only of local nature.

Turbid water unsuitable for human consumption (Kaleya River at Water Valley Farm, Mazabuka District).



A high sodium content (> 200 mg/l) was found in about 9% of the boreholes assessed. Most of these boreholes are located in the Zambezi Valley (covering Siavonga, Gwembe and Siavonga districts) and they are all associated with the mudstone type of lithology or with sandstone interbedded with siltstone and mudstone (Fig. 18). In addition, these water points have high electrical conductivity values (above 1000 S/cm) indicating higher salinity. Water with high salinity is unsuitable for irrigation since it may add to the salinity of soils. Soil salinity is a worldwide problem with increasing relevance especially in developing countries. The high sodium content commonly associated with soil salinisation may lead to a clogging of the clay mineral fraction in agricultural soil, leading to a strongly decreased water percolation and field capacity of soil.

Groundwater Vulnerability

Groundwater vulnerability describes the sensitivity of a groundwater system to contamination. Vulnerability maps are tools to assess the protection capacity of the geological sequence above the groundwater table. By using vulnerability maps for integrated water resources management, groundwater protection and management can be significantly improved.

In order to assess the groundwater vulnerability in the Southern Province the German GLA



Cattle farming near Batoka, Choma District.

- concept was applied [11]. The GLA-Method estimates the effectiveness of the unsaturated zone to protect groundwater from adverse effects (target 1 in Fig. 19). The unsaturated zone is herein subdivided into soil, unconsolidated deposits and hard rock. In practice, all layers between surface and groundwater table are considered which can be distinguished by their individual hydraulic properties. For large areas like the Southern Province only approximated vulnerability maps can be realized. More detailed investigations are necessary for the assessment of the groundwater vulnerability of smaller (larger-scaled) areas.

The vulnerability map is based on the regional model of groundwater levels which were used to estimate the thickness of the unsaturated zone. The thickness of the soil layer was assessed by analysing borehole completion re-

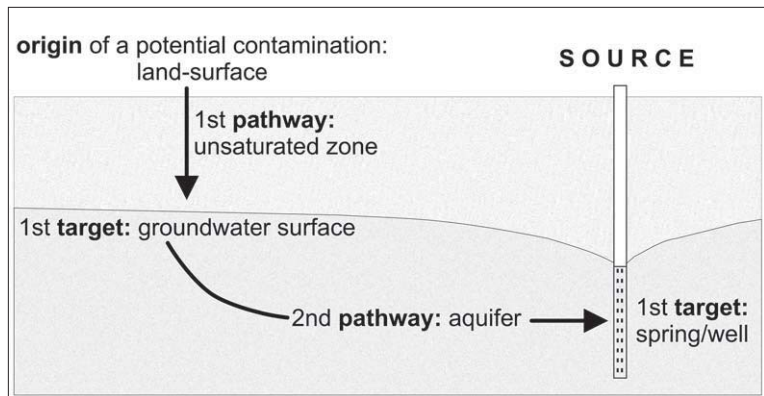


Figure 19: General concept of vulnerability mapping. Resource vulnerability considers target 1 and source vulnerability aims at target 2, after [32].

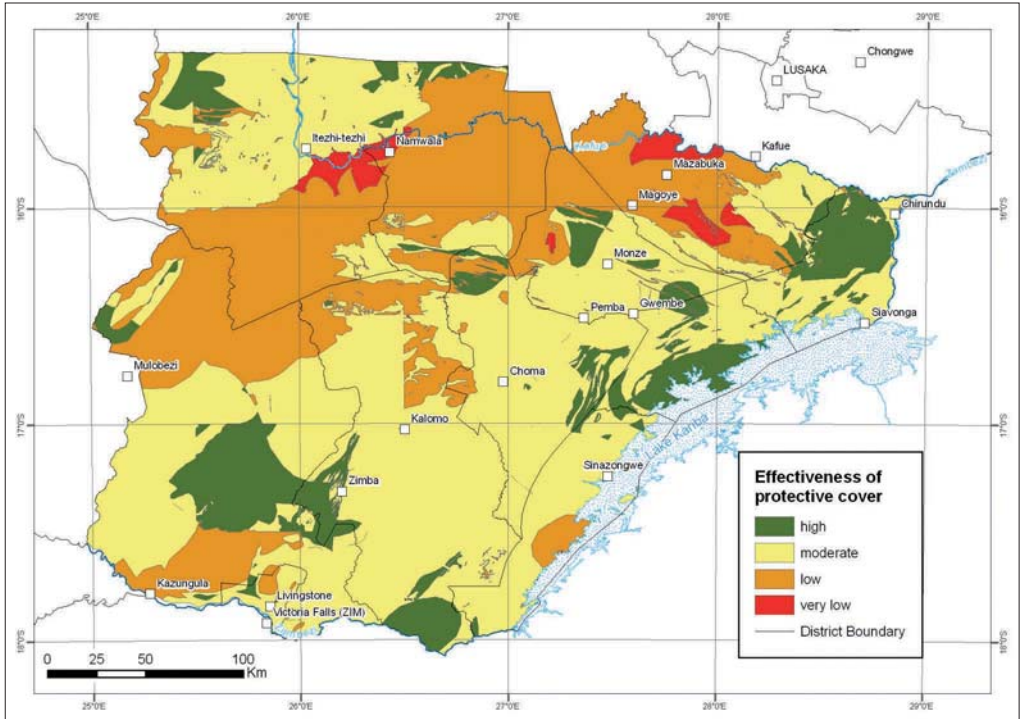


Figure 20: Map of Southern Province showing the generalised effectiveness of the protective cover with respect to groundwater contamination.

ports. Soil properties were estimated based on information contained in the Zambian soil map. The protective capacity of hard rocks above the groundwater table is estimated according to their lithological and structural characteristics.

Very low protective (very highly vulnerable) are, according to the applied method, some alluvial areas along the Kafue River with shallow groundwater tables. Low protective (highly vulnerable) covers are formed by the semi- to unconsolidated rocks of the Kafue Flats locally including the sediments of the Kalahari Group. Most of the igneous and metamorphic rocks of the Choma-Kalomo Block, the Hook Igneous Complex and the Katanga Supergroup are classified as moderately protective (vulnerable). The calc-silicate rocks of the Katanga Supergroup southeast of Magoye and Mazabuka are

an exception. These rocks are classified as low protective possibly due to their higher fracturing. Highly protective (low vulnerable) covers are associated with high depth of groundwater table and granitoids and metamorphic rocks. This is the case west of Zimba, southeast of Pemba and Gwembe, west of Chirundu and to a minor extent within the Hook Igneous Complex (Fig. 20).

In total, the vulnerability map distinguishes well between areas with semi- and unconsolidated rocks on one hand and with magmatic and metamorphic rocks on the other hand. The differences within the groups are mainly due to varying thicknesses of the unsaturated zone. This introduces the major source of uncertainty, as the interpolation of the available data gives only a rough approximation of the real and time-dependent distribution pattern.

Groundwater Maps

The only hydrogeological map available in Zambia prior to this study is at scale 1:1.5 million [15]. This map compiled in 1990 provides an appropriate classification of Zambia's aquifer systems and a very good general idea of overall hydrogeology at national scale. The groundwater information the map is based on, however, is largely taken from Chenov's report and data [4] and hence, somewhat outdated.

The hydrogeological maps developed in the framework of this project are at scales 1 : 250,000 (three sheets) and 1 : 100,000 (one sheet). The information displayed on the maps is drawn from all major groundwater studies that were carried out in the Province during recent years. Due to the larger scale compared

to the hydrogeological map of Zambia, these maps contain much more detailed information on groundwater related features. They are designed to display the groundwater systems and water points at catchment and sub-catchment scale. All information displayed is available in digitised format (ArcGIS feature classes). The maps cover more than 75% of the total Provincial area (Fig. 21).

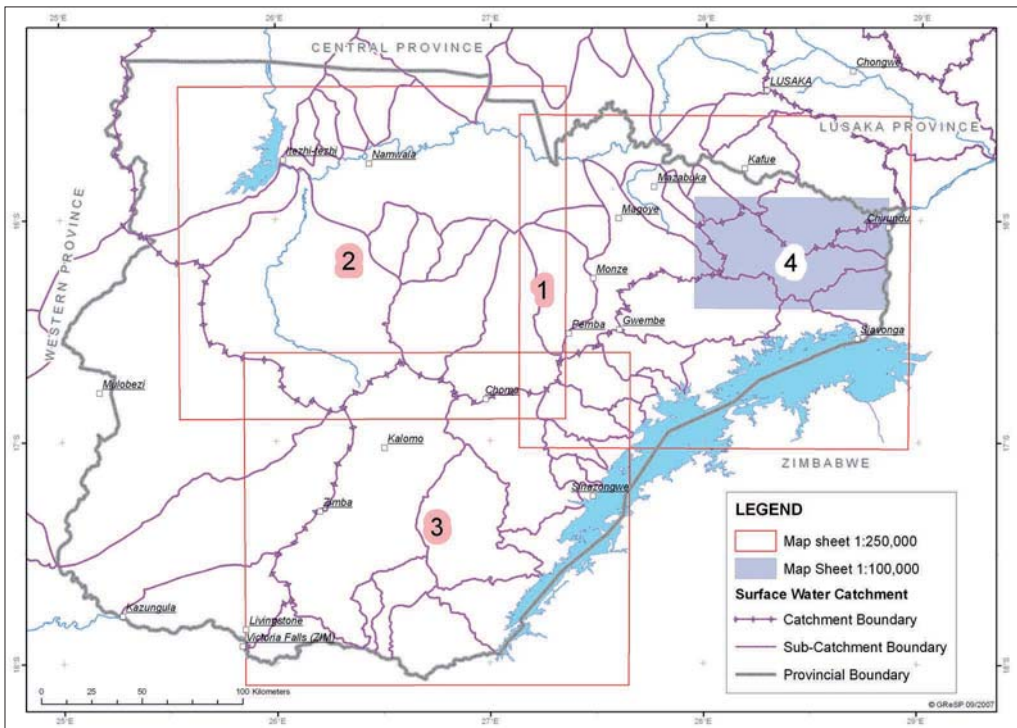


Figure 21: Available hydrogeological map sheets:

- | | |
|---|------------------------------------|
| 1. Northern Kariba Lake and Kafue Gorge | 1. Southern Kariba Lake and Kalomo |
| 2. Kafue Flats and Southern Tributaries | 2. Lusitu River. |

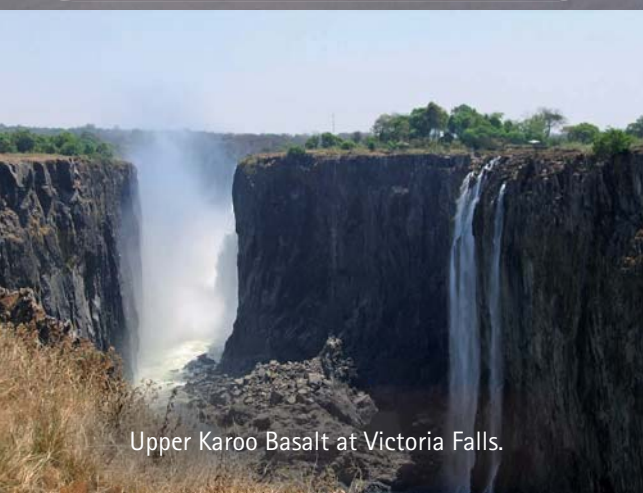
Rocks hosting major groundwater systems in the Southern Province



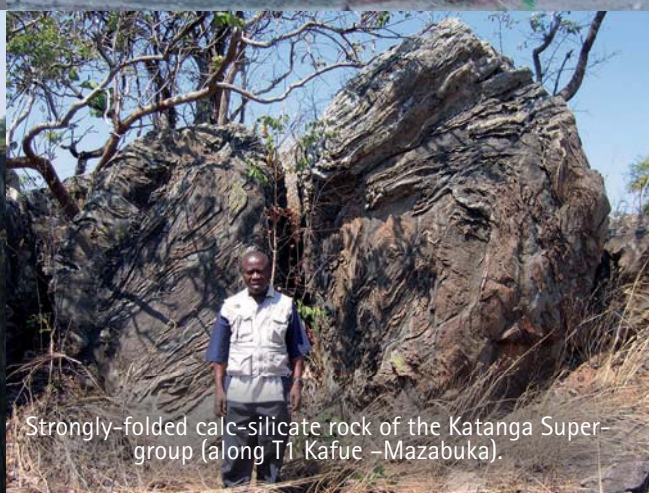
Madumabisa Mudstone with coal at Maamba Coal Mine.



Upper Karoo Sandstone (Siavonga Road, Lusitu River).



Upper Karoo Basalt at Victoria Falls.



Strongly-folded calc-silicate rock of the Katanga Supergroup (along T1 Kafue - Mazabuka).



Water tapped from river alluvium during the dry season.



Acid Igneous rock (along Chirundu Road).

Conclusions and Recommendations

In the framework of the project "Groundwater Resources for Southern Province" a professional and comprehensive groundwater information system for the Southern Province was developed at the Department of Water Affairs. The information system includes a groundwater database and a Geographic Information System (GIS) for hydrogeological mapping.

In the database, detailed technical data on water points in the Province is stored. Statistical information on aquifer characteristics of catchments or administrative units can be obtained straightforwardly and made available to groundwater consultants and planners. The published hydrogeological maps show the location of water points as well as the potential and distribution of major groundwater systems. On request, other thematic maps showing hydrological and groundwater information can be prepared for individual studies at various map scales using the established GIS. The available information is considered essential for the planning and preparation of upcoming groundwater investigations. It is therefore envisaged that the information system will be of great use and facilitate a more effective groundwater exploration and management in the near future.

In the database, a unique number has been allocated to each water point for identification purposes. This system could be used by authorities to register and administer all water points in a prescribed manner as stipulated by the Draft Water Resources Management Bill.

During this study, the need of harmonising data acquired during groundwater exploration became obvious. The regular submission of drilling records, water levels and abstraction data must be stronger promoted among stakeholders in the Water Sector. Even if no hydrogeologist or qualified consultant is available at a drill site a minimum set of data could



Remote rural settlement, Mazabuka District.

be collected by the person(s) on site including date and location of drilling, a sketch map, GPS co-ordinates, drill depth, borehole and casing diameter, depth of screens installed, static and pumped water levels and pumped yield. Data sheets to collect this information can be obtained through the project team at the Department of Water Affairs.

A continuous and extended groundwater monitoring of water tables and, in selected areas, groundwater quality is considered crucial for a future groundwater resource assessment and management. Continuous long-term monitoring is essential in order to identify possible impacts of climate change on water resources. Groundwater level observations can be used to identify trends in groundwater recharge, storage and availability. Groundwater quality monitoring can help to detect pollution or the potential gradual degradation of water quality.

About two thirds of all aquifers are hosted by hard rock formations; the remainder is largely formed by interbedded sediments comprising gravel, sand, silt or clay. Since these aquifers

are very heterogeneous, groundwater exploration is not a straightforward task, and the importance of modern siting methods is emphasized. About one out of five boreholes drilled during larger exploration campaigns in the past was unsuccessful. Careful siting using detailed structural analysis and advanced geophysical methods could considerably increase success rates and production rates during exploration drilling. Training of personnel in charge of groundwater development in geophysical field measurements and advanced evaluation methods is hence strongly recommended.

The comprehensive analysis of available hydrogeological data revealed that the potential of groundwater in the Province is overall limited despite the occurrence of some aquifers with more favourable groundwater conditions such as within the Karoo sandstone. Wells with exceptional high yields are rarely found regardless the aquifer lithology. Hence, the amount of water that can be produced from the rock bodies is generally insufficient for larger development or irrigation schemes. Despite these limitations extractable groundwater volumes in most areas should suffice for the supply to rural households and smaller settlements.

From a chemical point of view groundwater meets the national drinking water standards in most areas and hence, is well suitable for drinking water supply.

Some wells, in particular in the Gwembe Valley show increased salinity and may locally not be suitable for human consumption. Iron contents are also locally high (> 1 mg/l) but this causes

no immediate health threat. It is also advisable to test water for levels of arsenic, manganese, sulphate and fluoride since a few groundwater samples showed values exceeding the respective Zambian or WHO standards. However, no clear distribution pattern could be recognized due to the limited amount of data.

Potential contamination of groundwater by nitrate and agro-chemicals may occur in the vicinity of large irrigation schemes, but the investigation of local pollution sources was beyond the scope of this study. Especially the Kafue Flats whose effectiveness of protective cover has been identified as "low" to "very low" due to shallow groundwater tables may be vulnerable to such contamination.

Diarrhoea and dysentery cases (in 2005) were abundant especially in settlements near Lake Kariba, some district centres and generally in Monze District. The wide-spread occurrence of waterborne diseases near settlements hints at faecal contamination due to poor sanitary conditions. Consequently, continuous groundwater quality observations might be required near major settlements to monitor faecal contaminations and near large agricultural areas to assess contamination by nitrate, fertilizers or pesticides.

Suggested Further Reading:

The Technical Report available at the DWA includes a more comprehensive description of the physiography, climate, hydrology and groundwater systems as well as a full bibliography:

DWA/BGR – Department of Water Affairs & Federal Institute for Geosciences and Natural Resources (2007): The Groundwater Resources of Southern Province, Zambia (Phase 1).- by Bäuml R., Neukum Ch., Nkhoma J., & O. Silembo; Vol. 1 – Technical Report & Annex; Lusaka.

Acknowledgements

During Phase I the Project received valuable data and information from various institutions and individuals.

Special thanks are directed to the support and contributions from (in alphabetical order):

- Central Statistical Office for population data and administrative boundaries
- JICA and UNICEF for borehole (drilling) data
- Meteorological Department of Zambia and Department of Meteorological Services, Botswana for providing data on climate and rainfall
- Ministry of Health for information on Rural Health Centres and water borne diseases
- Mr. H. Mpamba, for data on his comprehensive research in the Gwembe Valley.
- NWASCO for the urban and peri-urban water supply and sanitation information system
- School of Mines, in particular Prof. I. Nyambe for geological maps and reports
- Southern Water and Sewerage Company for abstraction data

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