The Orange-Senqu River Commission (ORASECOM)

Sharing the Water Resources of the Orange-Senqu River Basin

Botswana | Lesotho | Namibia | South Africa

Contract No.: P-Z1-EAZ-048/CS/01

Preparation of Climate Resilient Water Resources Investment Strategy & Plan and Lesotho-Botswana Water Transfer Multipurpose Transboundary Project

GROUNDWATER REPORT

Component I and II

February 2020

FINAL REPORT

Report number: ORASECOM 006/2019

FC/02607.cdr

The Preparation of a Climate Resilient Water Resources Investment Strategy & Plan and the Lesotho-Botswana Water Transfer Multipurpose Transboundary project was commissioned by the Secretariat of the Orange-Senqu River Basin Commission (ORASECOM) with technical and financial support from the African Development Bank, NEDPAD-IPPF (Infrastructure Project Preparation Facility), the Stockholm International Water Institute (SIWI), the Climate Resilient Infrastructure Development Facility – UK Aid, and the Global Water Partnership-Southern Africa.

PREPARATION OF CLIMATE RESILIENT WATER RESOURCES INVESTMENT STRATEGY & PLAN AND LESOTHO-BOTSWANA WATER TRANSFER MULTIPURPOSE TRANSBOUNDARY PROJECT

COMPONENT I AND II

GROUNDWATER REPORT

Prepared for

Orange-Senqu River Commission (ORASECOM)

Von Willich LN, C nr Von Willich LN & Lenchen Avenue, Corporate 66 Office Park, Block A

Prepared by

in association with

PREPARATION OF CLIMATE RESILIENT WATER RESOURCES INVESTMENT STRATEGY & PLAN AND LESOTHO-BOTSWANA WATER TRANSFER MULTIPURPOSE TRANSBOUNDARY PROJECT

COMPONENT I AND II

GROUNDWATER REPORT

ORASECOM Document No. ORASECOM 006/2019

Date of Publication: February 2020

Authors: Karim Sami

Mookamedi Masie

Status: Final Report

APPROVALS

For the Consultants: ______________________

RS McKenzie Study Team Leader

Managing Director: WRP Consulting Engineers

____

C Muir Deputy Study Team Leader

For ORASECOM: ______________________

C Molosiwa

Executive Secretary: ORASECOM Secretariat

TABLE OF REPORTS

Reports submitted	ORASECOM Report No.[1]
Inception Report Components I and II	ORASECOM 010/2018
Inception Report Components III and IV	ORASECOM 011/2018
Preparation of climate resilient water resources investment strategy & plan Component I	
Core Scenario Update Report Component I	ORASECOM 003/2019
Core Scenario Supporting Report: Water Requirements and Return flows **Component I**	ORASECOM 004/2019
Core Scenario Supporting Report: Water Conservation, Water Demand management and Re-use Report **Component I**	ORASECOM 005/2019
Core Scenario Supporting Report: Ground Water Report **Component I**	ORASECOM 006/2019
Climate Change Report **Component I**	ORASECOM 007/2019
Review and assessment of existing policies, institutional arrangements and structures Component I	ORASECOM 008/2019
Optimized IWRMP Core Scenario economic approach Report Component **I**	ORASECOM 009/2019
Climate Resilient Water Resources Investment Plan Report **Component I**	ORASECOM 010/2019
System analysis Report Component I	ORASECOM 011/2019
Preparation of climate resilient water resources investment strategy & plan Component II	
Roadmap for IWRMP Operationalization Report Component II	ORASECOM 012/2019
Roadmap for IWRMP Operationalization Executive Summary	ORASECOM 012A/2019
Roadmap for IWRMP Operationalization: Appendix B Strategic Actions Concept Notes	ORASECOM 012B/2019
Roadmap for IWRMP Operationalization: Appendix C Core Scenario Concept Notes	ORASECOM 012C/2019
Climate Resilience Investment Plan (Brochure)	ORASECOM 012D/2019
Roadmap supporting Report: Strategic actions and TORs (Appendix A to Roadmap Report)	ORASECOM 013/2019
Lesotho-Botswana water transfer multipurpose transboundary project Component III Pre-feasibility Phase	
Pre-feasibility report Phase 1 Report Component **III**	ORASECOM 014/2019
Pre-feasibility report Phase 2 Report Component **III**	ORASECOM 015/2019

Reports submitted	ORASECOM Report No.[1]
Report A Phase 2: Dam on the Makhaleng River	ORASECOM 015A/2019
Report B Phase2: Water Conveyance System	ORASECOM 015B/2019
Report C Phase 2: Environmental and Social Assessment	ORASECOM 015C/2019
Report D Makhaleng River Ecological Water Requirements	ORASECOM 015D/2019
Lesotho-Botswana water transfer multipurpose transboundary project Component IV - Feasibility Phase	
Feasibility Study Interim Report Component IV	ORASECOM 016/2019
Feasibility Study Report Component IV : Volume **I** – Main Report	ORASECOM 017/2019
Feasibility Study Report Component IV : Volume **II** - Drawings	ORASECOM 017/2019
Geotechnical Investigation Report for the Dam on the Makhaleng River. Annexure A to Volume I – Main Report	ORASECOM 017A/2019
Survey Report Annexure B to Volume **I** – Main Report	ORASECOM 017B2019

EXECUTIVE SUMMARY

The Orange River basin is one of the largest river basins south of the Zambezi with a catchment area of approximately 1 million km^2. It encompasses all of Lesotho, a significant portion of South Africa, Botswana and Namibia. The Orange River originates in the Lesotho Highlands and flows in a westerly direction approximately 2 200 km to the west coast of South Africa and Namibia where the river discharges into the Atlantic Ocean.

Water scarcity is the main challenge in the basin and this requires a coordinated joint development, management and conservation of the water resources system.

The Republic of Botswana is an arid country faced with serious water constraints which will worsen with the expected effects of climate change. Botswana is predicted to experience chronic water shortages by about 2025, unless major new water source(s) is developed. Already Gaborone was critically hit by the 2015-2016 drought. As a consequence, the Governments of Botswana, Lesotho and South Africa signed a memorandum of agreement to undertake a reconnaissance study on the Lesotho to Botswana Water Transfer scheme (L-BWT) aimed at developing water in Lesotho and conveying it to Botswana and, on the way, supplying various users in Lesotho and South Africa. This reconnaissance study led to the selection of a technical option which included a new dam on the Makhaleng River in Lesotho and a piped conveyance system to Botswana. It is envisaged that eventually 150 million m^3/a will be pumped to Botswana with additional supplies for consumers along the route in Lesotho and South Africa.

The objective of the study is to update the Integrated Water Resources Management (IWRM) Plan validated in 2015 and propose an updated core scenario which includes the L-BWT project and to assist the Orange Sengu River Commission (ORASECOM) and the riparian countries in operationalizing the updated IWRM Plan.

The study is divided into two distinct parts:

- A climate resilient investment plan, based on the updated Water Resources Yield and Planning Model and the updated Core Scenario defined in the IWRM Plan of 2015 (Components I & II of the study); and
- The Lesotho-Botswana Water Transfer Project (Components III & IV of the study)

This report is part of Component I: Climate Resilient Water Resources Investment Plan. The specific task this report addresses is the assessment of the potential for better utilization of groundwater in the basin. The objective as stated in the Terms of Reference (TOR) is the

Quantification and mapping of potential groundwater volumes that could be considered in the core scenario, either for new developments or for substitution of surface water resources to obtain an improved utilization of groundwater in the basin.

Groundwater utilization within the Orange-Senqu River Basin, except for a few localities, is limited and has been attributed mainly to the low productivity of the aquifers within the basin. As part of the groundwater study component, an assessment of available hydrogeological data, from existing work already carried out in the basin was undertaken. The review and evaluation included:

- Assessment of the potential yield of the aquifer systems within each sub-catchment;
- Assessment of the potential volumes of groundwater in storage in each sub-catchment;
- State of current groundwater development and usage per sector within each sub catchment;
- Groundwater quality evaluated according to relevant water sector use standards (domestic, livestock, industrial, mining irrigation);
- The vulnerability of groundwater to over abstraction and contamination;
- Assessment of borehole yields (to determine whether aquifers can be economically exploited);
- Analysis of whether abstractions can impact on surface water resources;
- Identification of ecological or environmental limitations on abstraction.

A series of integrated maps of the basin or sub catchments which combine various spatial data sets were produced to highlight crucial aspects of the groundwater systems (aquifers) in the project area. Included are, aquifer distribution and aquifer sustainable yield (productivity) maps, groundwater quality maps and recharge distribution maps. The results of the groundwater resources quantification revealed the following;

Data Availability

The sources of data utilised for the study are shown in **Table E 1**. The South African Groundwater data is available the electronically on the NGA for over 200 000 boreholes. In Lesotho the data is available in spreadsheet format for limited data points, with coverage primarily in the lowlands. Relatively large amounts of data are available for Namibia, with sparse coverage in the western portion of Botswana. This variation in data coverage in different countries is problematic for data analysis and results in ‘border effects’ when interpreting conditions on both sides of international borders.

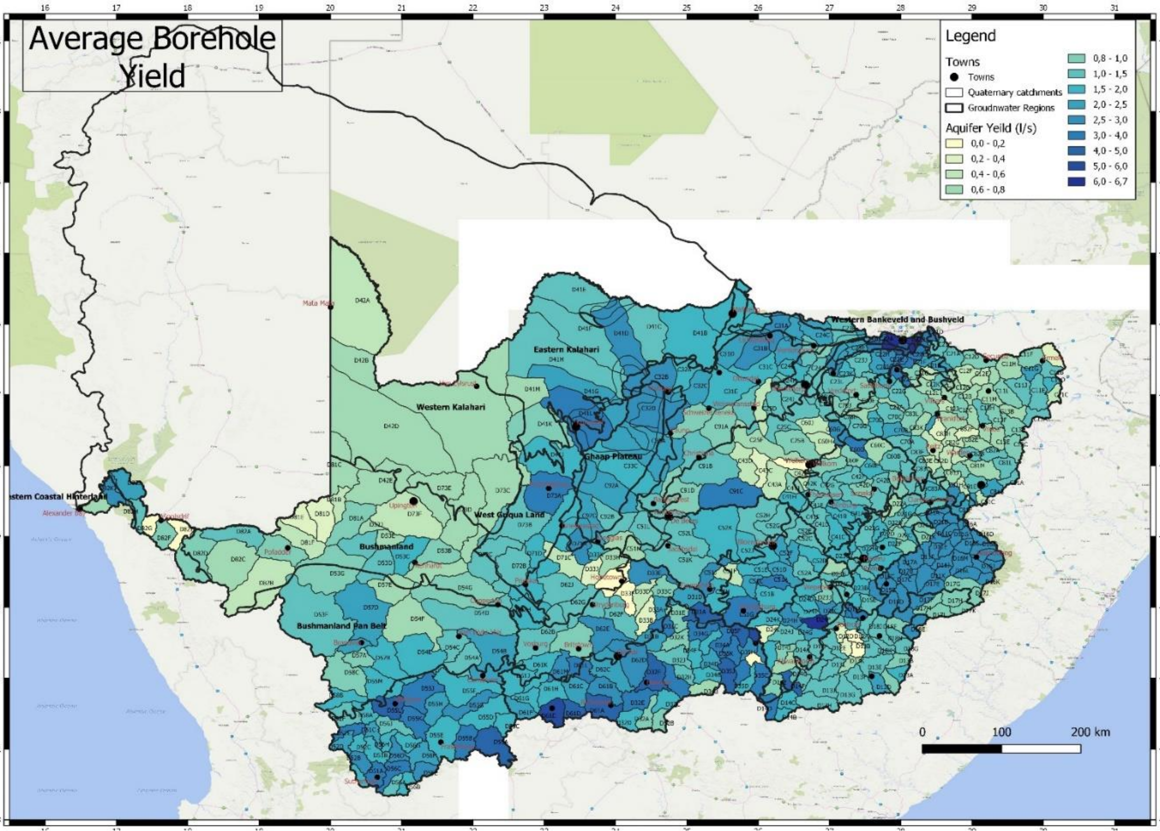
Table E1 Sources of data

Type of Data	Data	Source
Catchment delineation	Quaternary catchment boundaries.	WR2012. http://www.the-eis.com/ Namibia's One-Stop Shop for Environmental Information. Supported by Namibian Chamber of Environment, Department of Surveys and Mapping, Botswana
Groundwater discharge zones	Wetland location	National Freshwater Ecosystem Priority Area (NFEPA) atlas 2011
Population	Population and water source	Stats SA Lesotho State of Water Report Lesotho Bureau of Statistics Statistics, Botswana
Climatic data	Rainfall	WR2012
Geology	Lithology and structures	Council for Geoscience geological maps, Botswana Geoscience Institute (Geological Map of Botswana, BGI)
Soils	Soil maps	WR2012 Institute of Soil Climate and Water Ministry of Agricultural Development and Food Security
Hydrology	Flow data Baseflow	WR2012 GRA II (DWAF, 2006a)
Geohydrology	Harvest Potential Exploitation Potential Recharge Hydrochemistry Water levels Borehole yields	GRA II (DWAF, 2006a) GRA II (DWAF, 2006a) GRA II (DWAF, 2006a) ZQM database NGA NGA, Lesotho Borehole database (Excel 2020) Lesotho Springs Monitoring Database (Excel 2020) Department of Water and Sanitation Services, Botswana, (Borehole Archives) Groundwater in Namibia: An explanation to the Hydrogeological Map
Groundwater use	Licenced groundwater use Schedule 1 water use Livestock water use	WARMS Lesotho State of Water Report GRA II (DWAF, 2006a) WUC, Water Use Data (2013 to 2017) IWRM Plan for Namibia
Aquifer Vulnerability		Geology GIS coverage Soils ISCW coverage GRAII

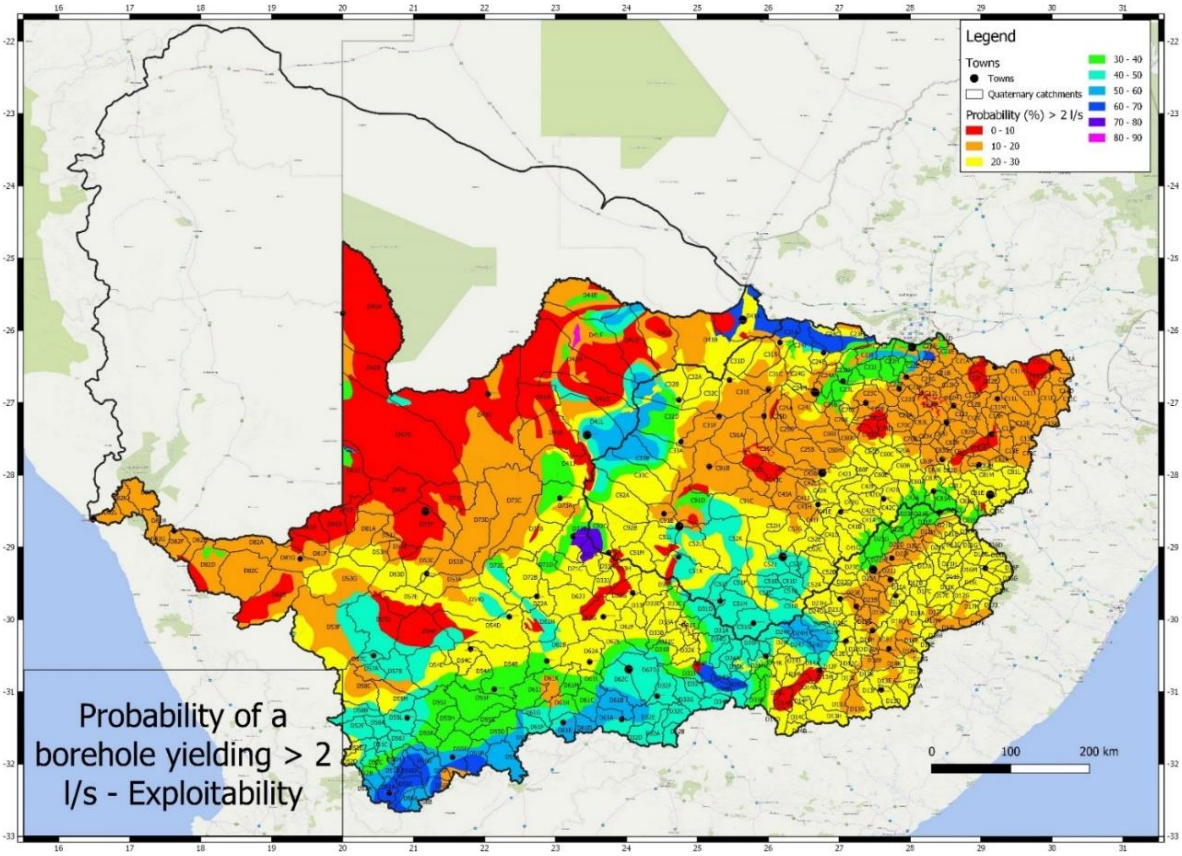
South Africa and Lesotho

Borehole Yields and Aquifer Productivity: Mean borehole yields are below 1 l/s in Bushmanland, the Western Kalahari and Namaqualand groundwater regions. In these groundwater regions, more than 80% of boreholes generally yield less than 2 l/s. Low yields are also encountered in the Southeastern Highveld. High yields of over 2 l/s are found in the Drakensberg highlands, the Western and Eastern Upper Karoo, Karst Belt and the Ghaap Plateau. The Highest yields of over 5 l/s are found in the Karst Belt (**Figure E1**). The yield characteristics for each groundwater region was also assessed in terms of the probability of obtaining a borehole of yield of more than 2 l/s as shown in (**Figure E2**). The map shows that the Karst Belt is the highest yielding aquifer region, with over 60% of boreholes yielding more than 10 l/s. On the Ghaap Plateau, more than 60% of boreholes yield more than 6 l/s whilst the Bushmanland has the poorest exploitability, with only 16% of boreholes yielding more than 2 l/s.

Note: Maps showing the groundwater related information for the entire Orange-Senqu basin are included in Appendix 16



E 1: Boreholes Yields, South Africa and Lesotho (see complete map Appendix 16)



E 2: Probability of a borehole yielding > 2 l/s, South Africa and Lesotho

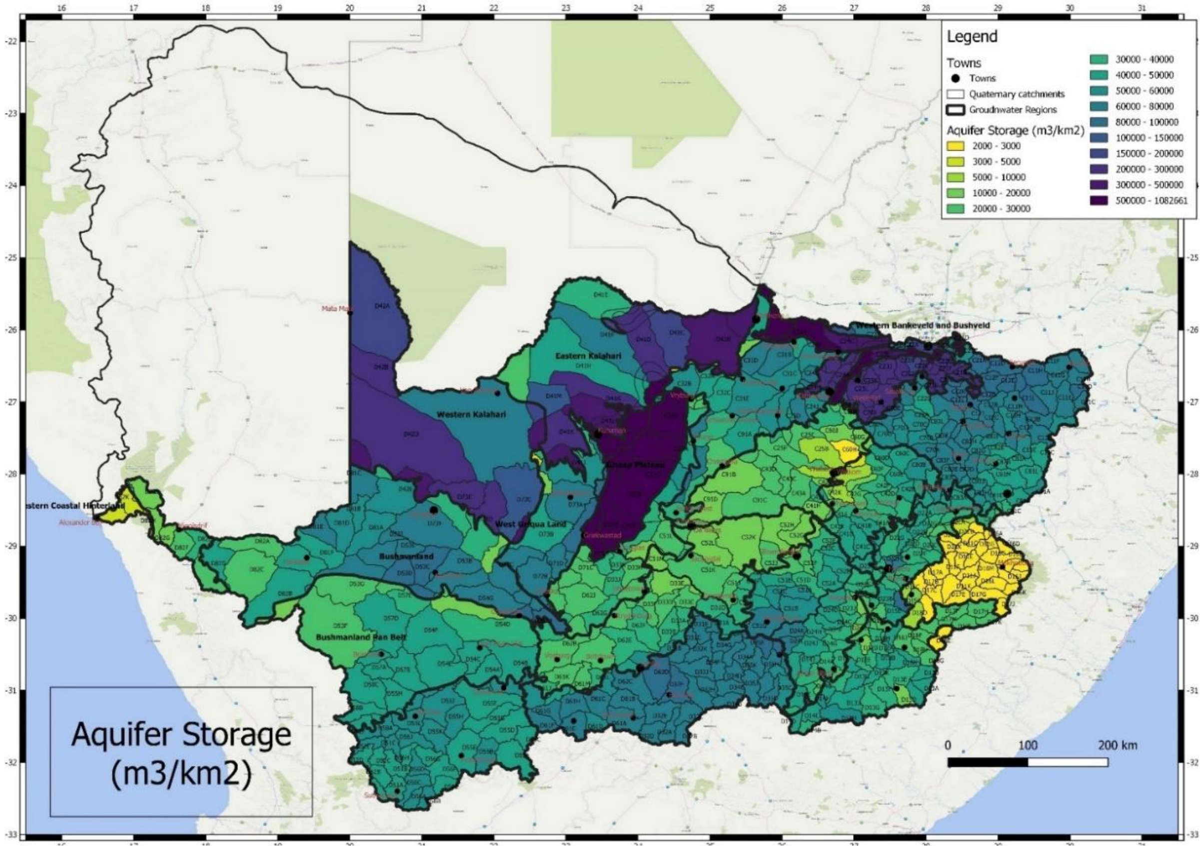
Volumes of Groundwater in Storage and Exploitation Potential (also map Appendix 16)

Volumes of groundwater held in storage in the different groundwater regions range from less than 3000 m^3/km^2 to over 500,000 m^3/km^2 for the basin **(Figure E3)**. Unless mining of groundwater is planned, the volume of groundwater held in aquifer storage is not indicative of the sustainable groundwater resources. The feasibility of abstracting the groundwater resource potential is limited by physical attributes of a particular aquifer system, such as permeability (aquifer productivity), access to drill sites, and economic factors, hence it is not possible to exploit all of the groundwater resource potential. The Groundwater Exploitation Potential is derived by the probability of drilling successful boreholes. The volume of water that may be abstracted from a groundwater resource may also be limited by anthropogenic and ecological and/or legislative considerations. They can relate to maintaining baseflow, avoiding sinkholes etc. The volume that can be sustainably abstracted is referred to as the Utilisable Groundwater Exploitation Potential and range from less than 300 $m^3/k^2/a$ to 25000 $m^3/km^2/a$ as shown in **Figure E4**.

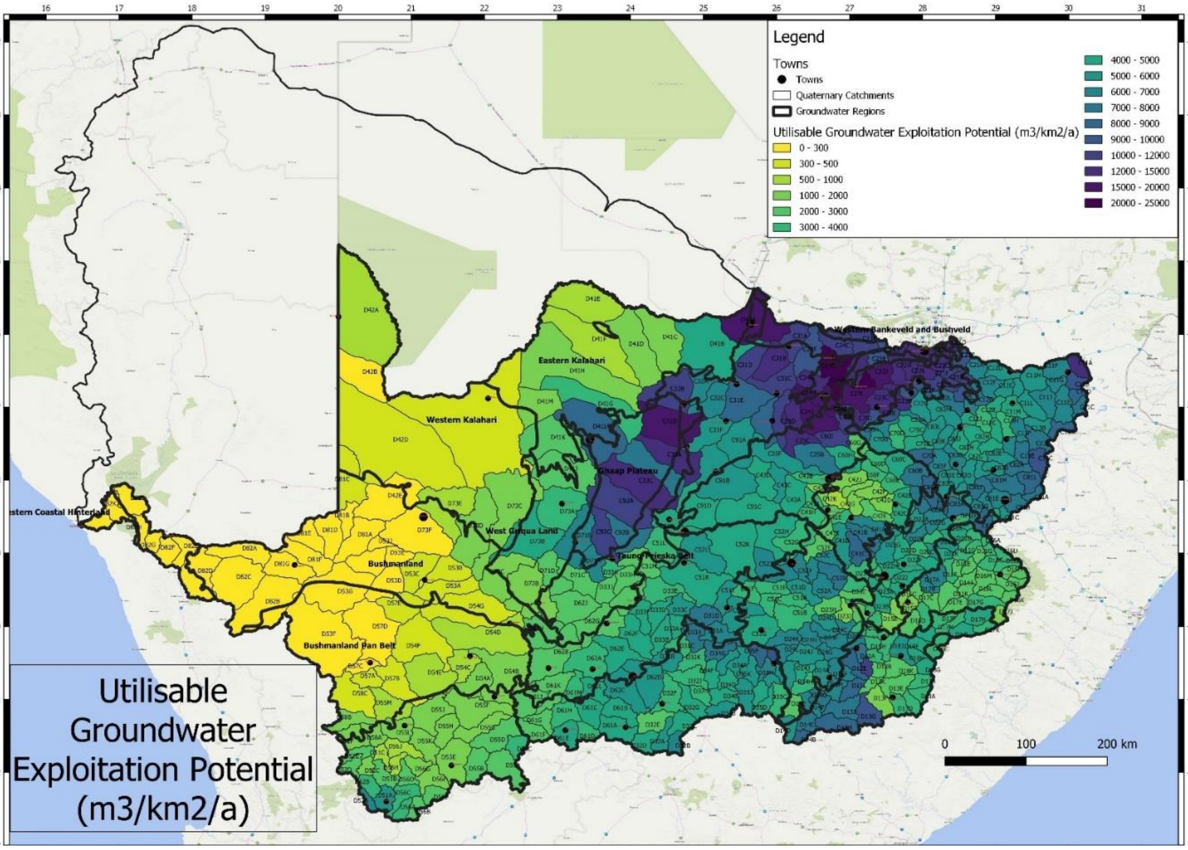
The data also shows that the largest volume of remaining allocable groundwater calculated as Utilisable Groundwater Exploitation Potential minus current legal water use is found in the Karst aquifers of the Ghaap Plateau in South Africa (**Figure E5**).

Potential for Base flow Reduction due to Groundwater Abstraction: One of the consequences of over abstraction of groundwater is a reduction of baseflow. Given the critical status of surface water resources in the Orange-Senqu Basin, the potential of groundwater abstraction to reduce baseflow, affecting environmental flows and the yield of dams, is an important factor to consider.

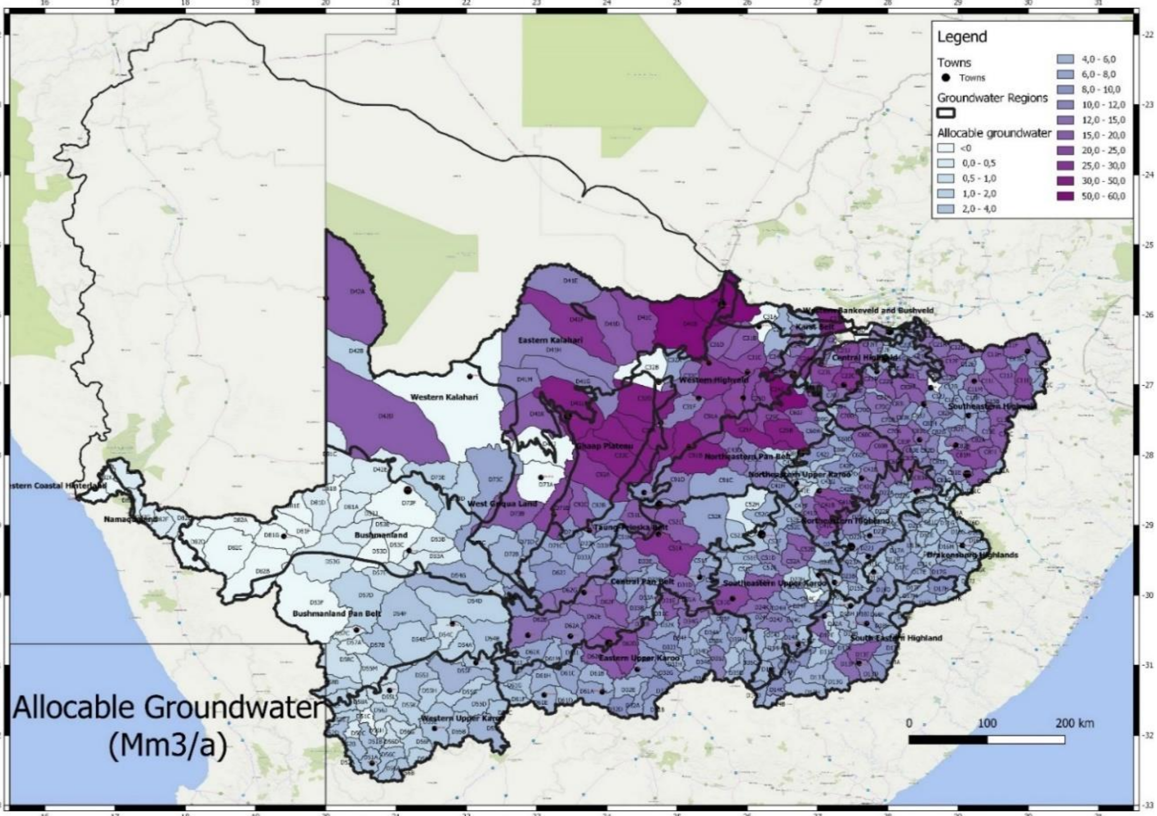
To quantify the potential of abstraction to reduce baseflow, a baseflow index was calculated by groundwater baseflow/groundwater recharge. The classification of risk based on this index is shown in **Figure E6** and rated as moderate to very high in the eastern part of the basin while it is very low to negligible for the rest of the basin. This suggests that the impact of future allocations on baseflow need to be investigated prior to large scale allocations. This impact can have a cumulative impact further down the basin.



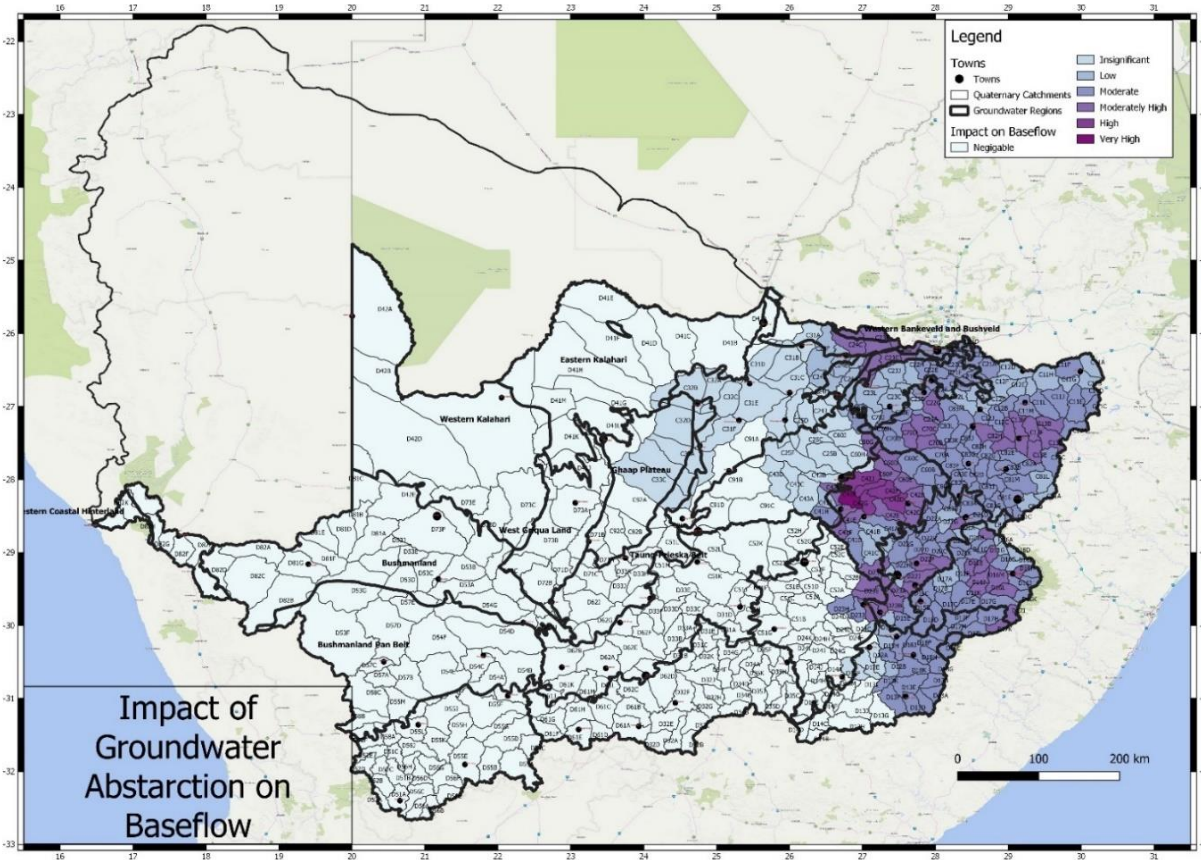
E 3: Aquifer Storage m³/km², South Africa and Lesotho (see complete map Appendix 16)



E 4:Utilisable Groundwater Exploitation Potential, South Africa and Lesotho (Appendix 16)



E 5: Allocable groundwater, South Africa and Lesotho

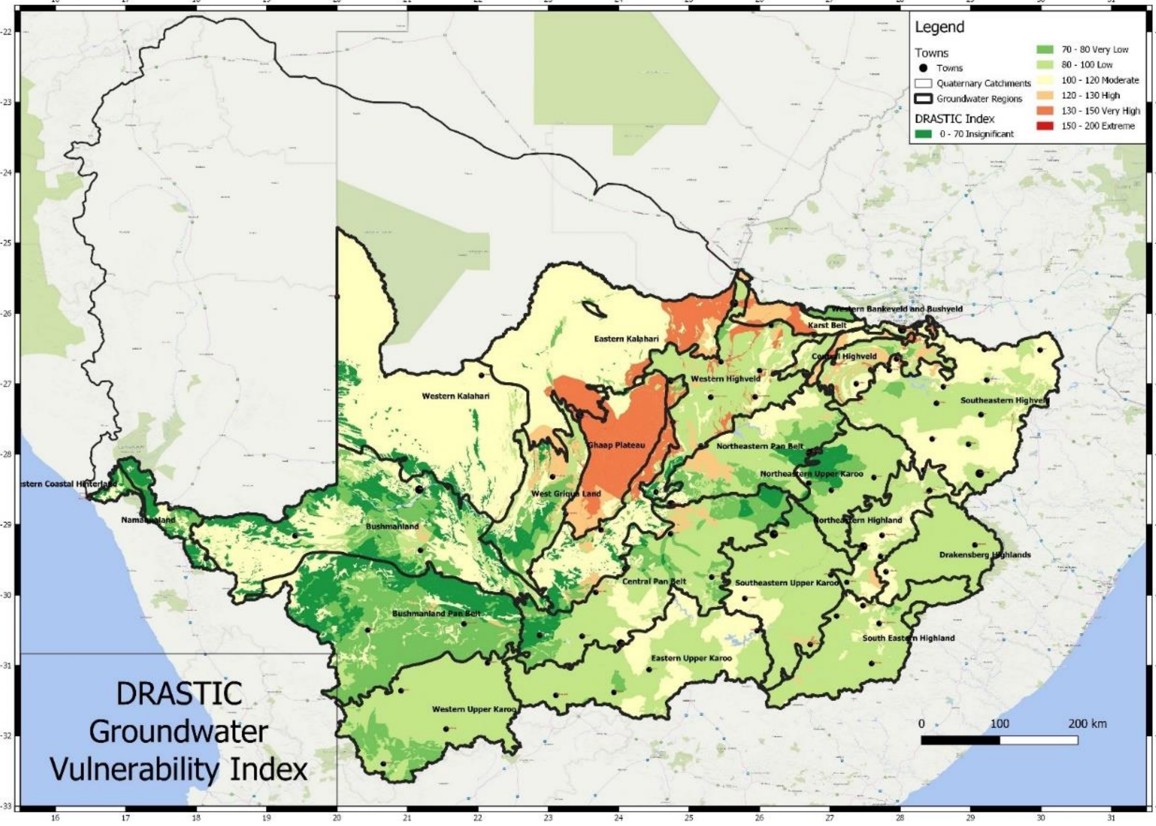


E 6: Impact of groundwater abstraction on baseflow, South Africa and Lesotho
Vulnerability of Groundwater to over Abstraction: (Also see Appendix 16)

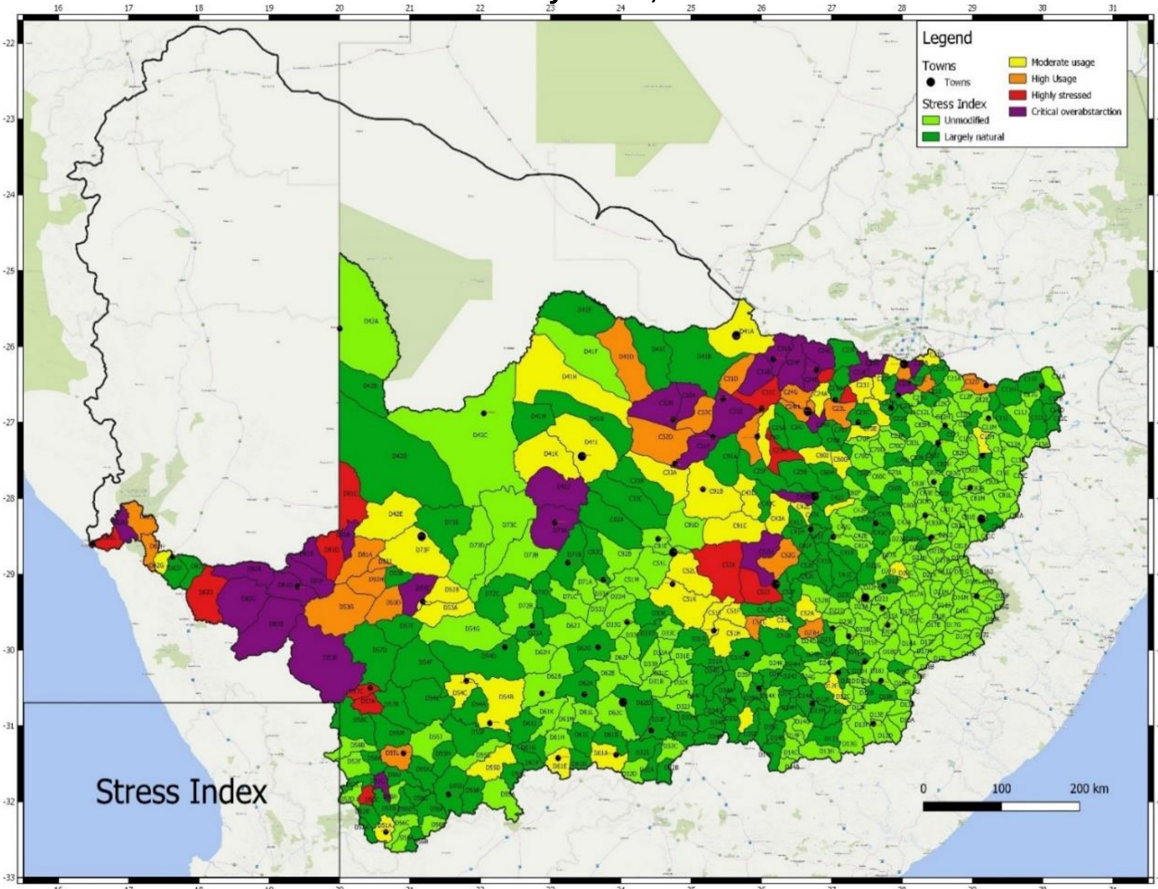
The vulnerability of groundwater to over abstraction was assessed through the use of stress indices defined as groundwater use relative to aquifer recharge. The stress index is shown in **Figure E 7** and indicates that groundwater resources are highly stressed in the Lower Orange basin and the Middle to lower Vaal.

Groundwater Pollution Vulnerability; Groundwater pollution vulnerability was considered in terms of the DRASTIC method of assessment of the intrinsic vulnerability of an aquifer to contamination from the surface. The results show that aquifers with high to extreme vulnerability are found in the dolomite aquifers of the Ghaap Plateau and the Karst Belt (**Figure E8**).

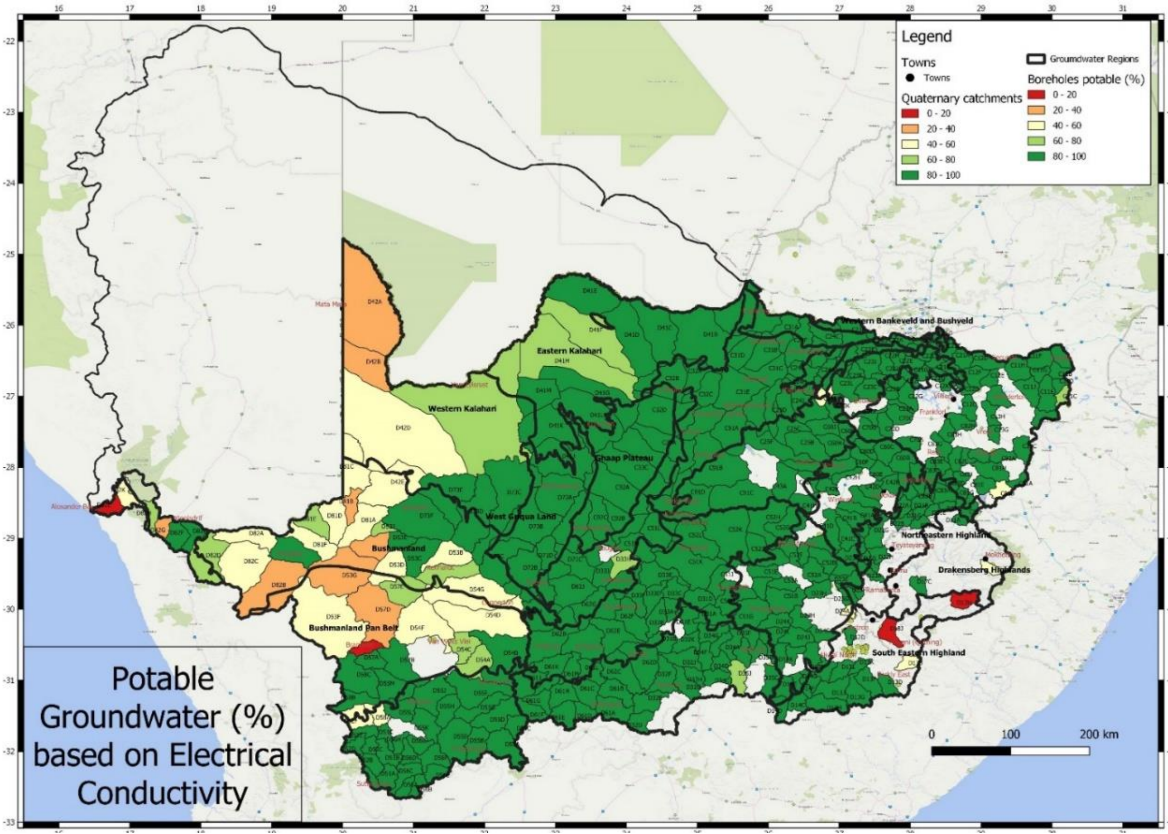
Limitations of Groundwater Quality on Use; Groundwater quality data was assessed in terms of applicable standards for potable water supply and irrigation. In terms of suitability for potable (potability index) supply, the percentage of boreholes that are potable declines to the west and north, reaching less than 10 percent in coastal Namaqualand (**Figure E9**) whilst for irrigation supply, the groundwater is of suitable quality across the basin, except in the Western Kalahari, Bushmanland, and Namaqualand (**Figure E10**).



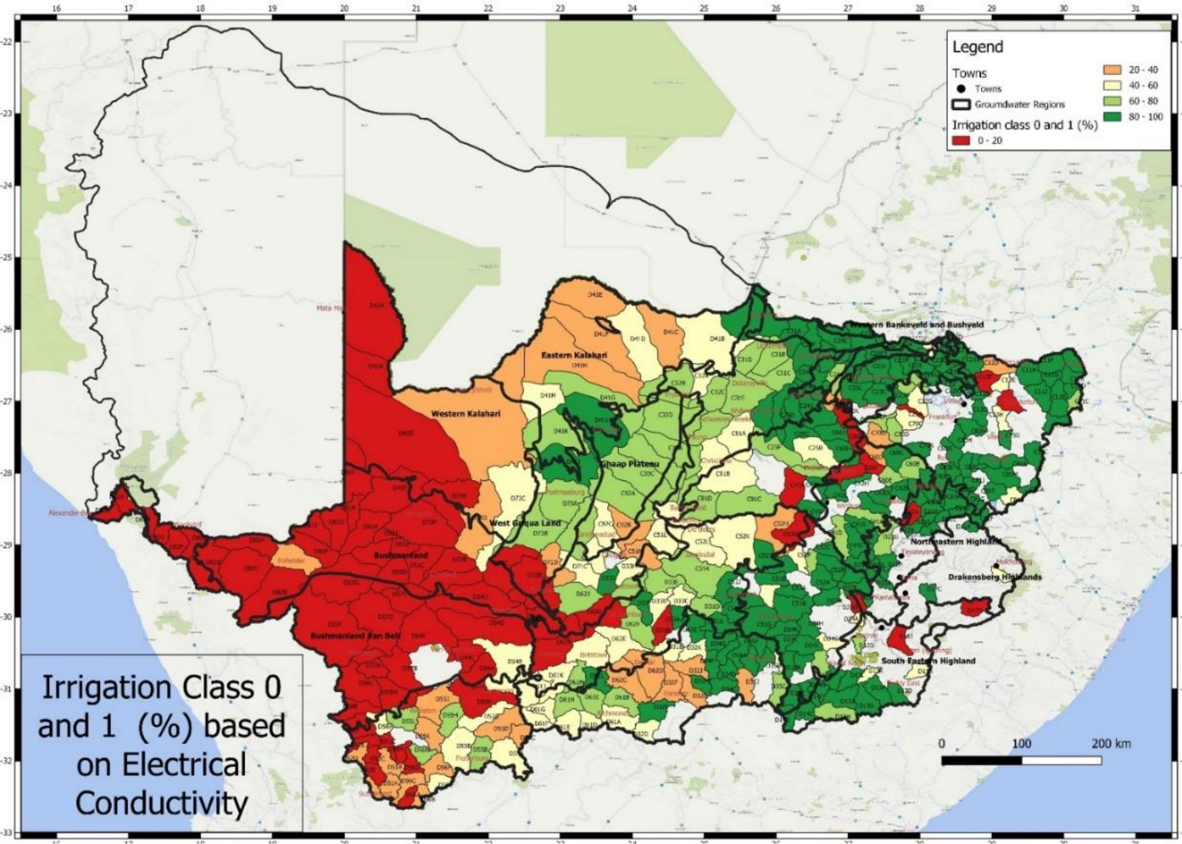
E 7: Groundwater Pollution Vulnerability Index, South Africa and Lesotho



E 8: Stress Index by Quaternary catchment, South Africa and Lesotho (See Appendix 16)



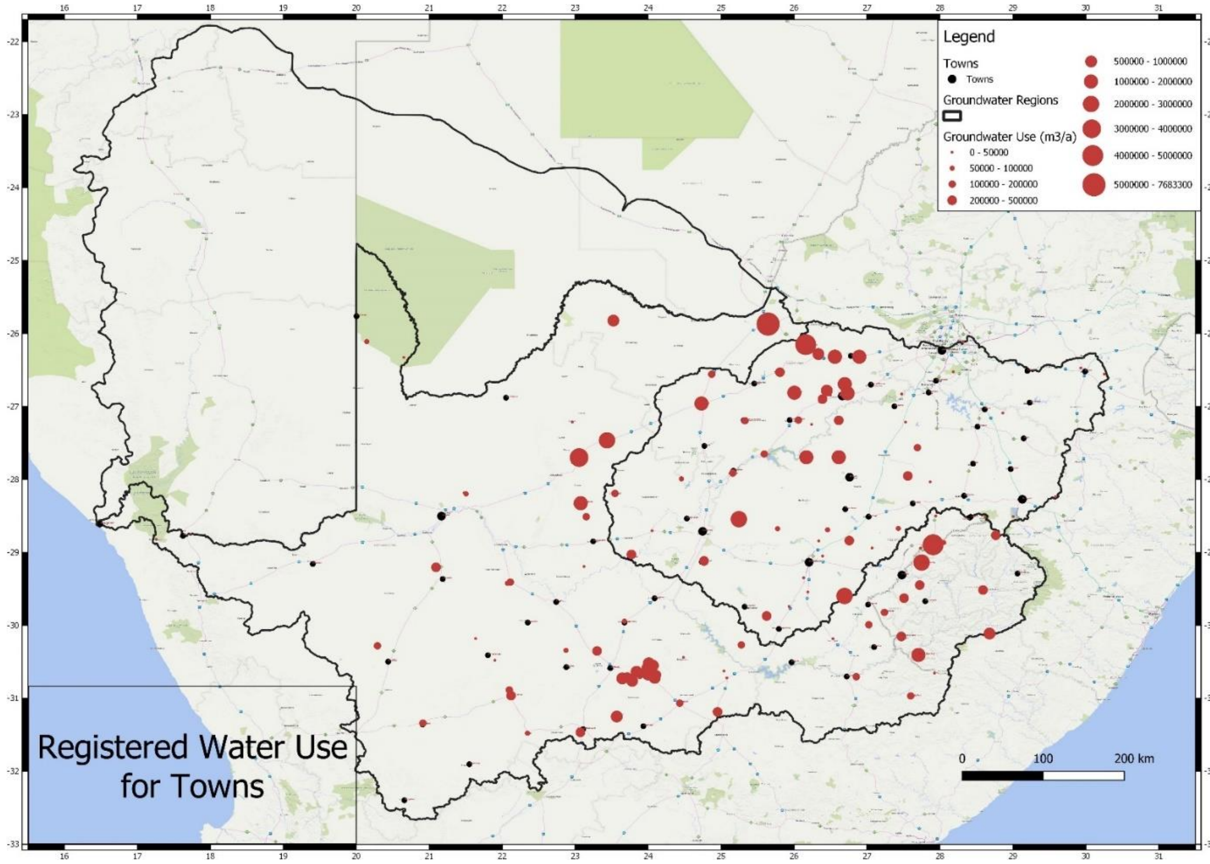
E 9: Percent potable groundwater in terms of electrical conductivity, South Africa and Lesotho (Also see Appendix 16)



E 10: Percent groundwater suitable for irrigation, South Africa and Lesotho

State of current groundwater development and usage

Many communities and towns in the catchment are solely or partially dependent on groundwater for municipal supply. Water supply schemes include industry dependent on a municipal water supply scheme. The towns utilising groundwater are shown **Figure E11**. The largest volumes of groundwater are used in the Karst Belt, the Western Highveld and Eastern Kalahari, the Ghaap Plateau and Central Pan Belt.



E 11: Registered Water Use for Towns, South Africa and Lesotho

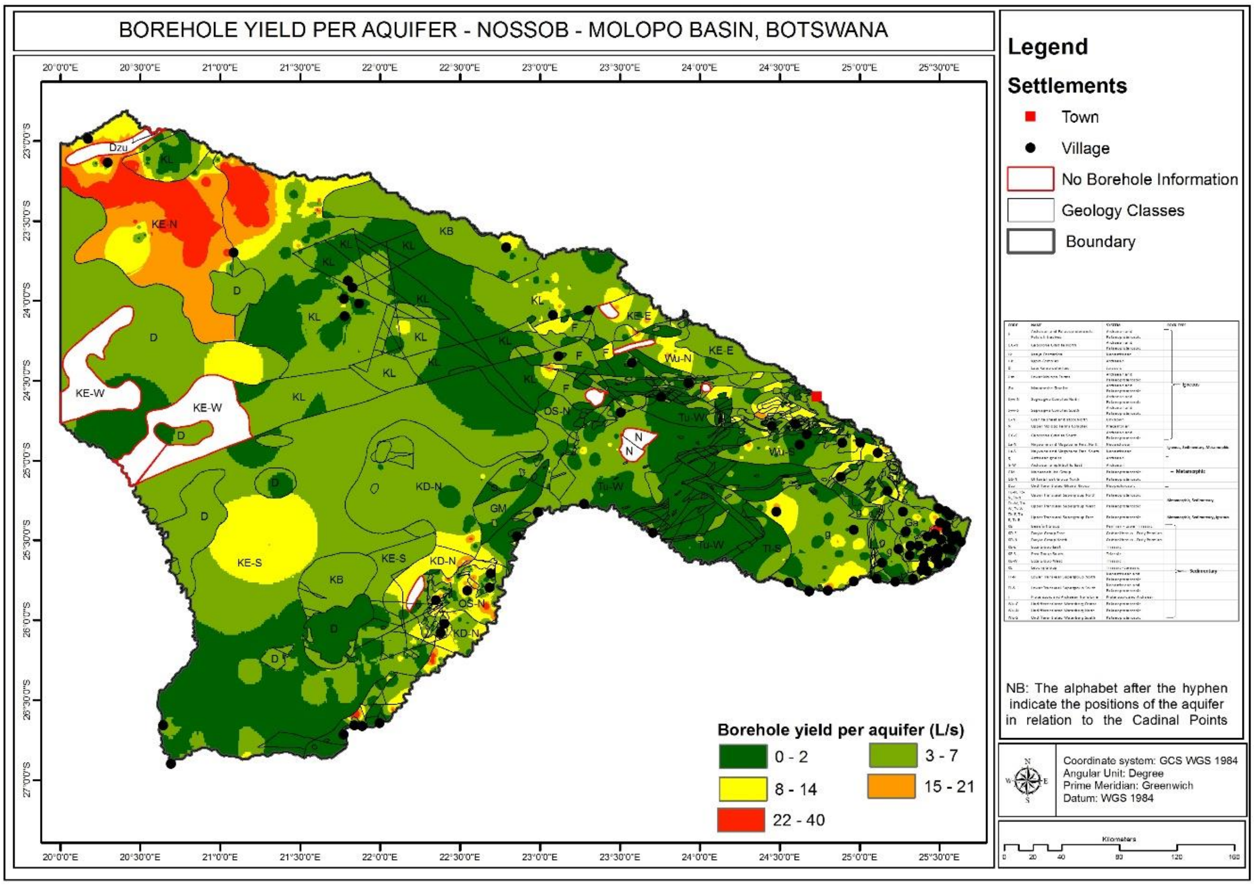
Botswana

Borehole Yields and Aquifer Productivity The average borehole yield of the fractured porous aquifers (Ecca and Lebung Groups) are 9 l /s and 4.7 l/s respectively (**Figure E12**) whilst borehole yields of fractured aquifers represented by the Upper Transvaal, Waterberg, Olifantshoek Beaufort, Nnywane and Mogobane hydrogeological units range from less than 1 to 10 l/s.

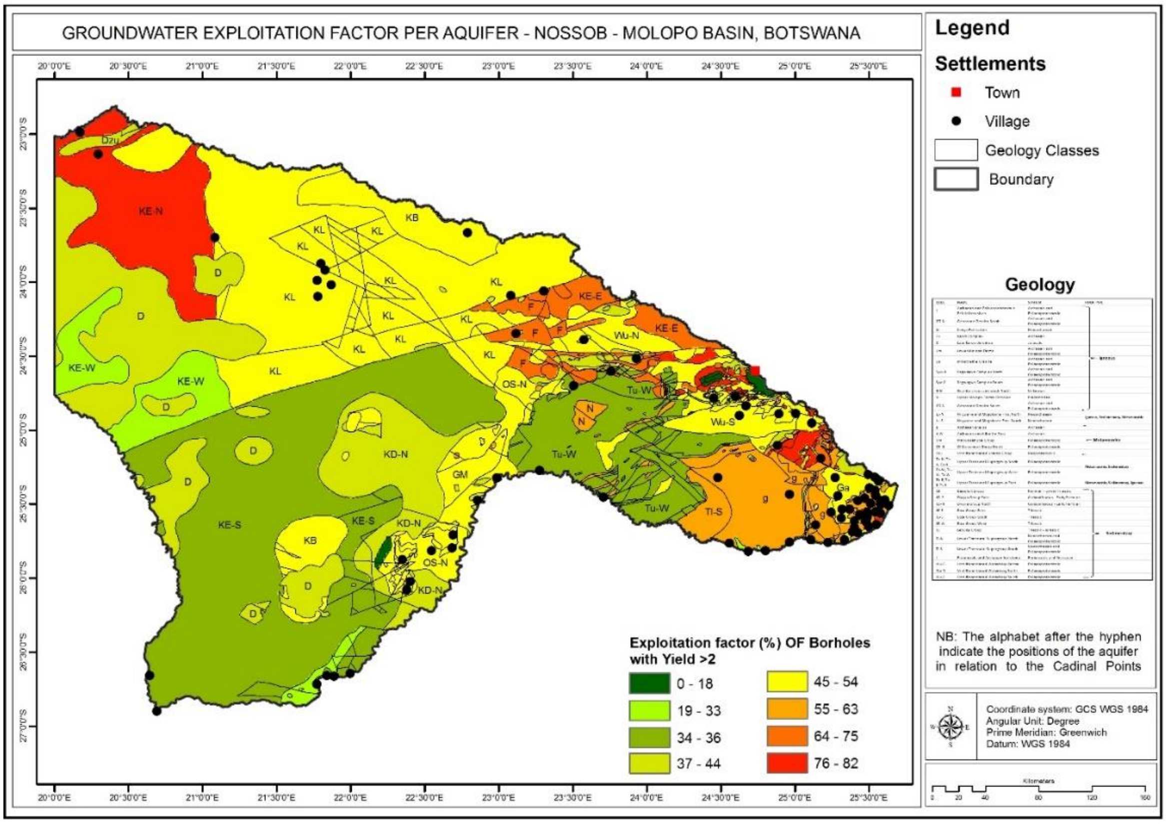
Yields of the fractured weathered aquifers (basement and post Karoo dolorites) are highly variable and range from 0 l/s to 7.7 l/s (with an average yield of 3.5 l/s). The Karsitc aquifer represented by rocks of the lower Transvaal Supergroup have average yields ranging from 6.6 to 10.7 l/s.

In terms of aquifer productivity, the Botswana part of the basin is largely underlain by moderately yielding aquifers with only about 13% of the basin underlain by aquifers with a productivity index of more than 60% i.e yield of more than 2 l/s. The most productive aquifers are found in Ecca North (Stampriet basin), Archaen Amphibolites East, Lower Transvaal North and Ecca East. (**Figure E13**).

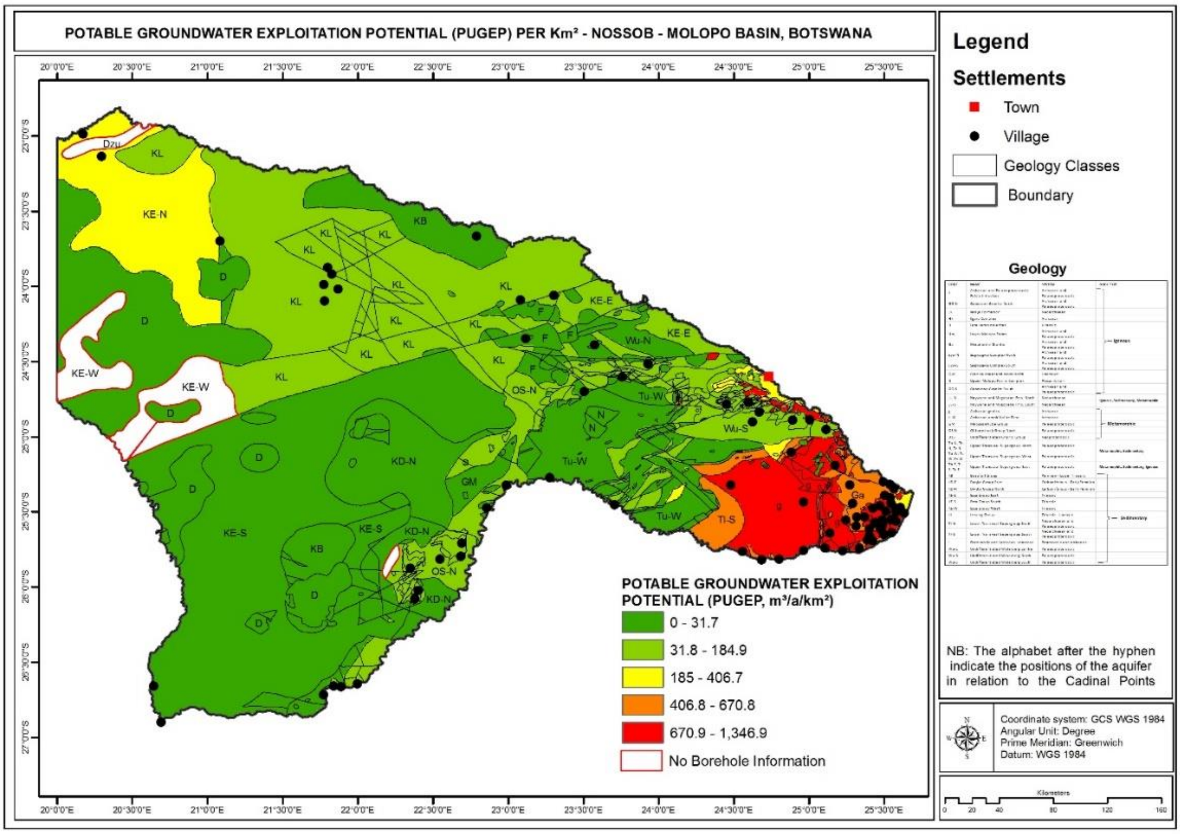
Groundwater Exploitation Potential Aquifers with highest potable groundwater exploitation potential (PUGEP) are Ecca North, Lebung and Lower Transvaal South. For the majority of the basin, with the exception of Ecca North, Lower Transvaal South, Upper Transvaal East and Lebung hydrogeologic units, there is very little scope for further development of potable groundwater resources as indicated by the allocable potable ground resource shown in **Figure E14.**



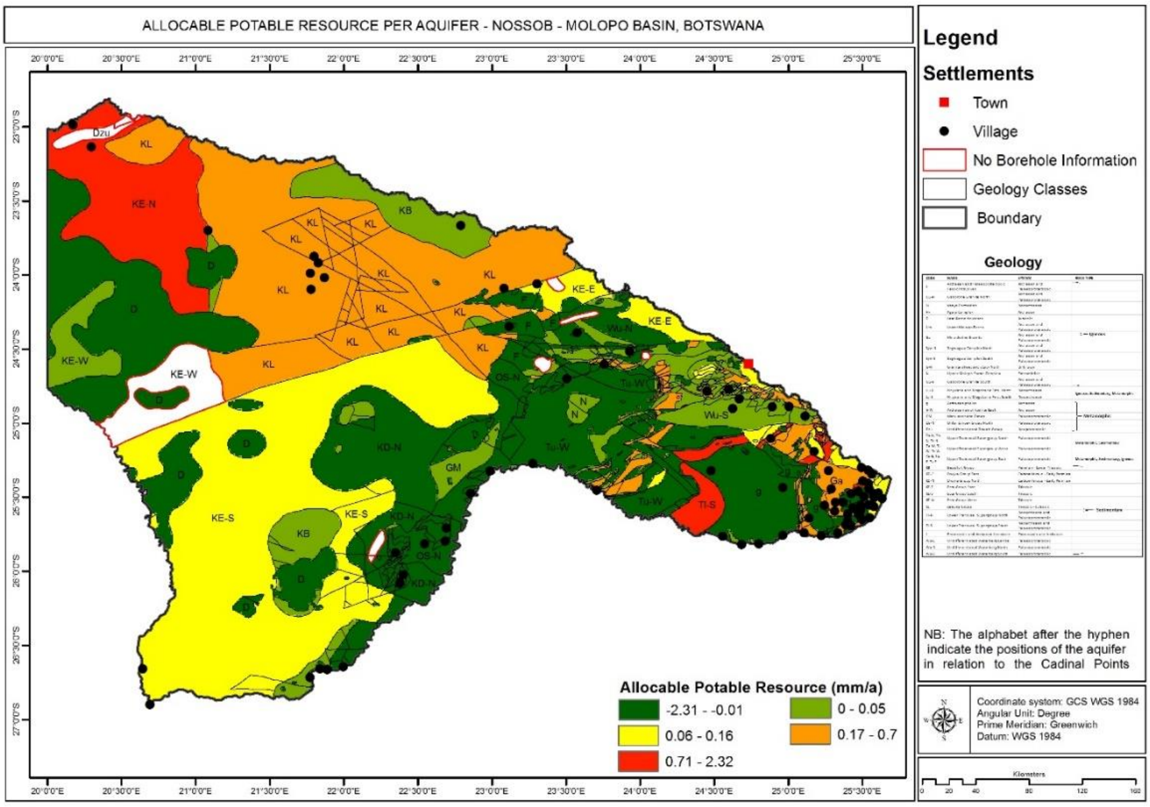
E 12: Average borehole yields, Botswana (see complete catchment in Appendix 16)



E 13: Aquifer productivity (% of boreholes yielding > 2 l/s (Botswana) (See Appendix 16)



E 14: Potable groundwater exploitation potential, Botswana ($m^3/km^2/a$)



E 15: Allocable potable groundwater resource, Botswana (Mm3/a)
Vulnerability of Groundwater to over Abstraction

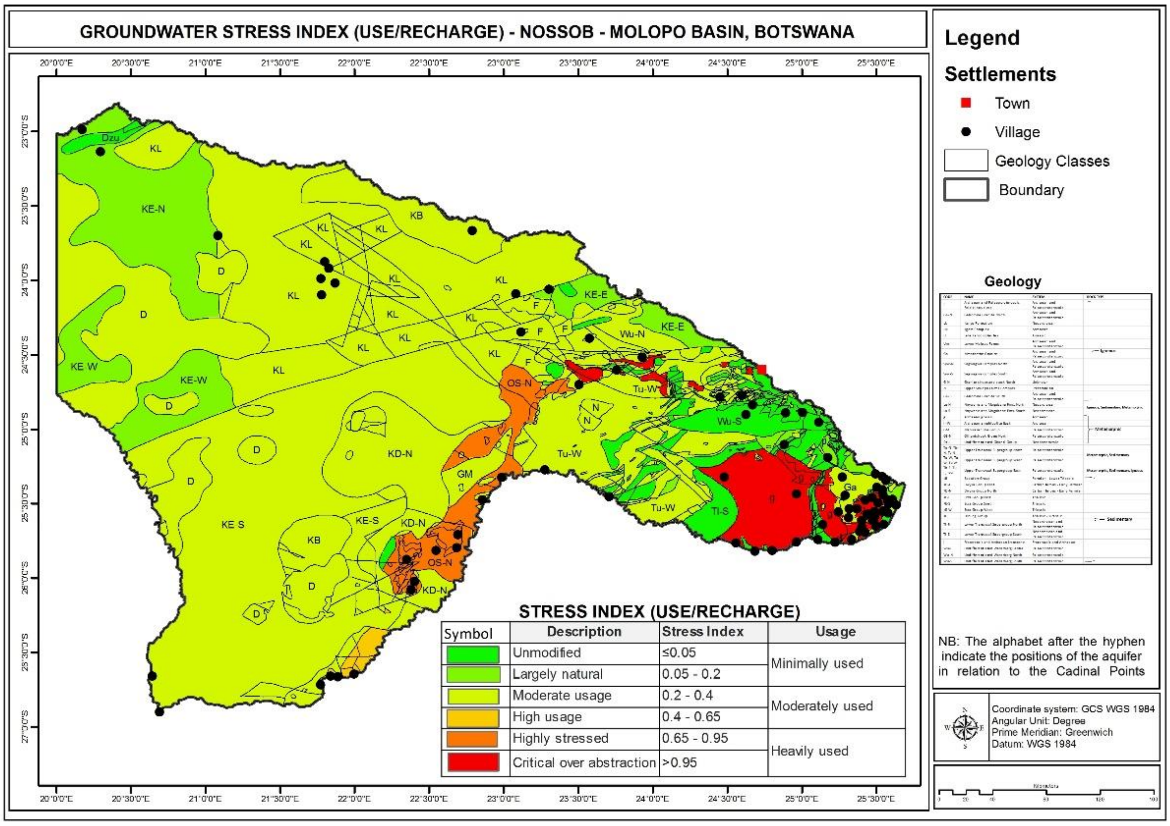
A groundwater stress index for the basin (Botswana) indicates that the areas underlain by Archean Gneiss (Goodhope water supply area) and the Olifanthoek North (Tsabong water supply area) are being over abstracted i.e. groundwater is highly stressed in these areas (**Figure E16**).

Groundwater Pollution Vulnerability

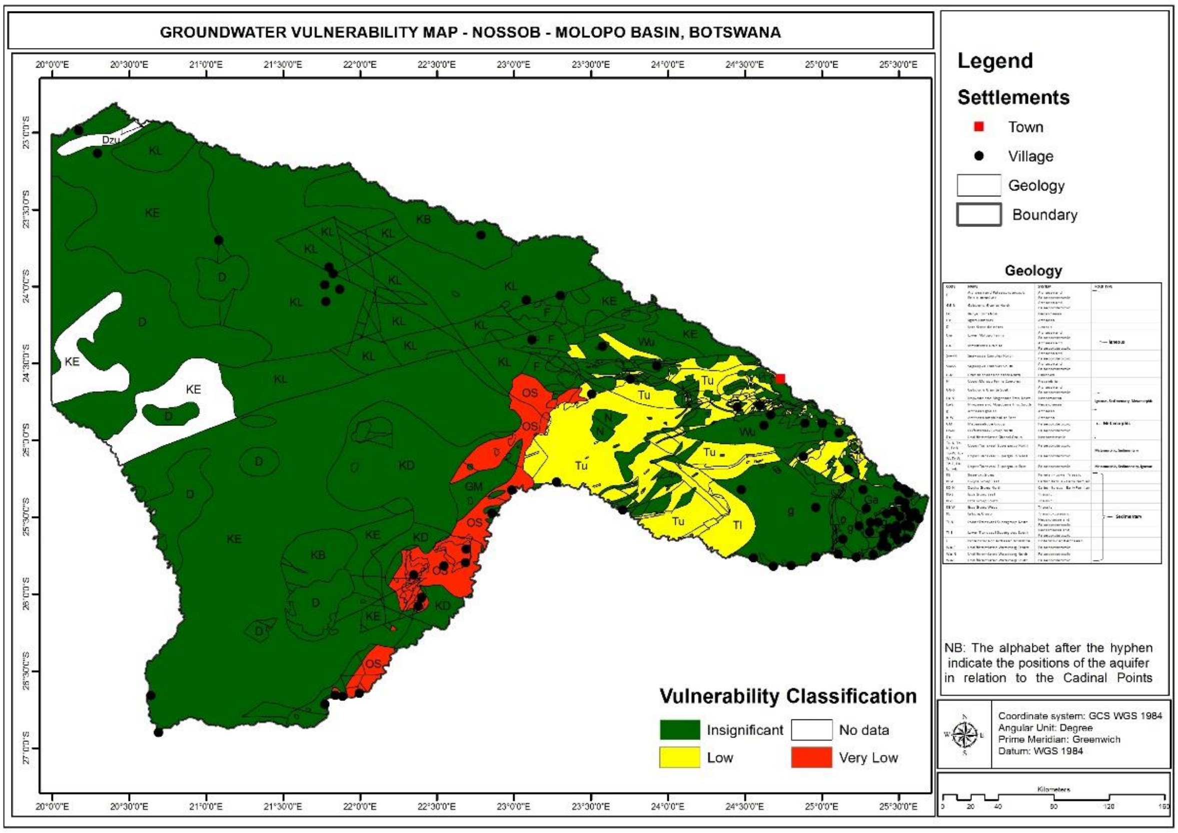
Aquifer vulnerability according to the DRASTIC index indicates that the majority of the basin has insignificant to low groundwater pollution vulnerability (**Figure E17**).

State of current groundwater development and usage

Data from Water Utilities Corporation indicates that the total groundwater use for domestic (demand centres) water supply is approximately 5.65 million m^3/a while the estimated livestock water use is 3.59 Mm^3/a.



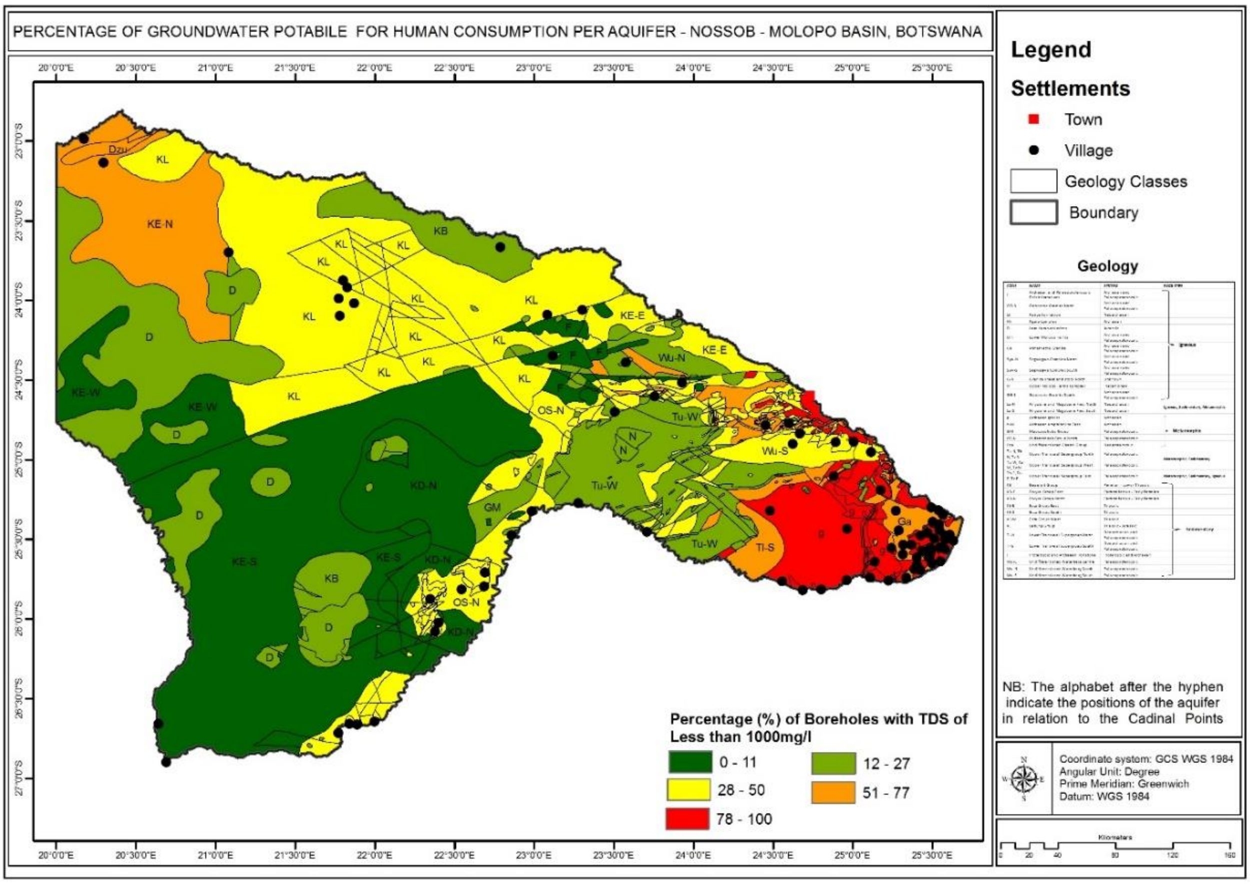
E 16: Stress Index, by aquifer unit, Botswana (Also see Appendix 16)



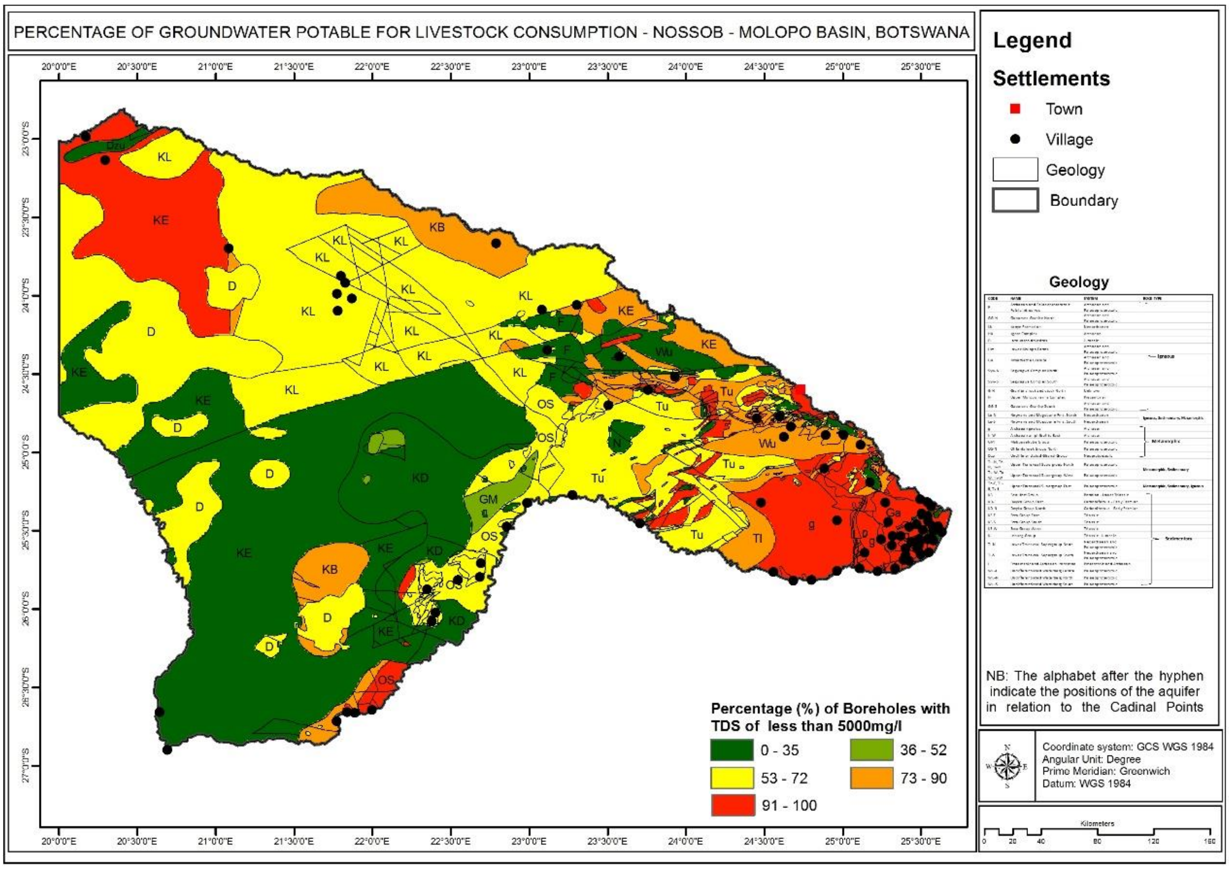
E 17: Groundwater Pollution Vulnerability Index, Botswana (Also see Appendix 16)

Limitations of Groundwater Quality on Use; Groundwater quality data was assessed for suitability for potable supply based on the drinking water quality specification for Botswana (BOS32:2015) and drinking water for livestock and poultry specification (BOS365:2010) based on total dissolved solids (TDS of less than 1000 mg/l for potable supply and TDS of less than 5000 mg/l for livestock.

In terms of groundwater suitability for human consumption (TDS <1000 mg/L), a large part of the basin is underlain by aquifers with groundwater which is not suitable for human consumption. Groundwater with the highest potability index (percentage of boreholes with TDS of less than 1000 mg/l) is predominantly found in the basement aquifers (78 to 100%), Upper Transvaal East (80%), Lower Transvaal South (77% and Ecca North (72%) with the lowest potability groundwater found in Dwyka North and Ecca South (**Figure E18**). In terms of suitability for livestock water supply (index i.e. percentage of boreholes with groundwater of TDS of less than 5000 mg/l) a relatively large part of the basin contains groundwater suitable for livestock consumption in terms of TDS (**Figure E19**).



E 18: Percent potable groundwater in terms of Total Dissolved Solids, Botswana



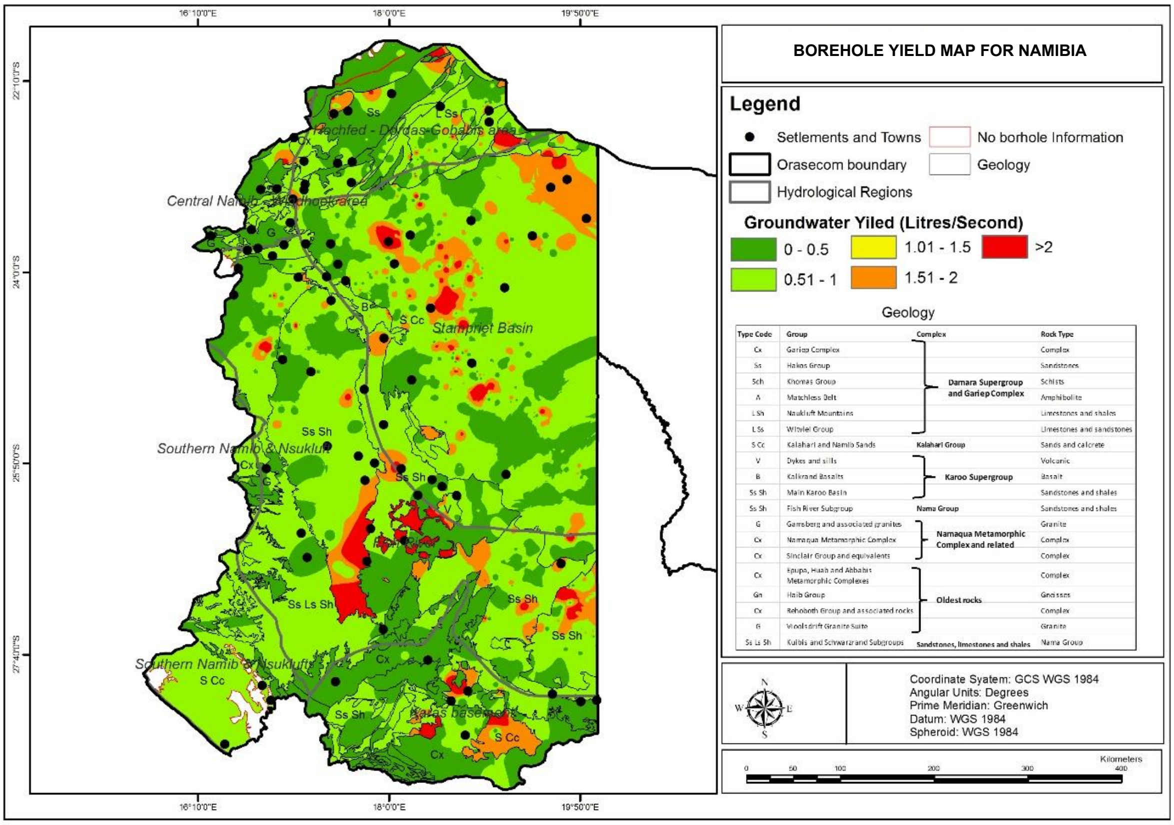
E 19: Percent groundwater suitable for livestock consumption in terms of TDS, Botswana

Namibia

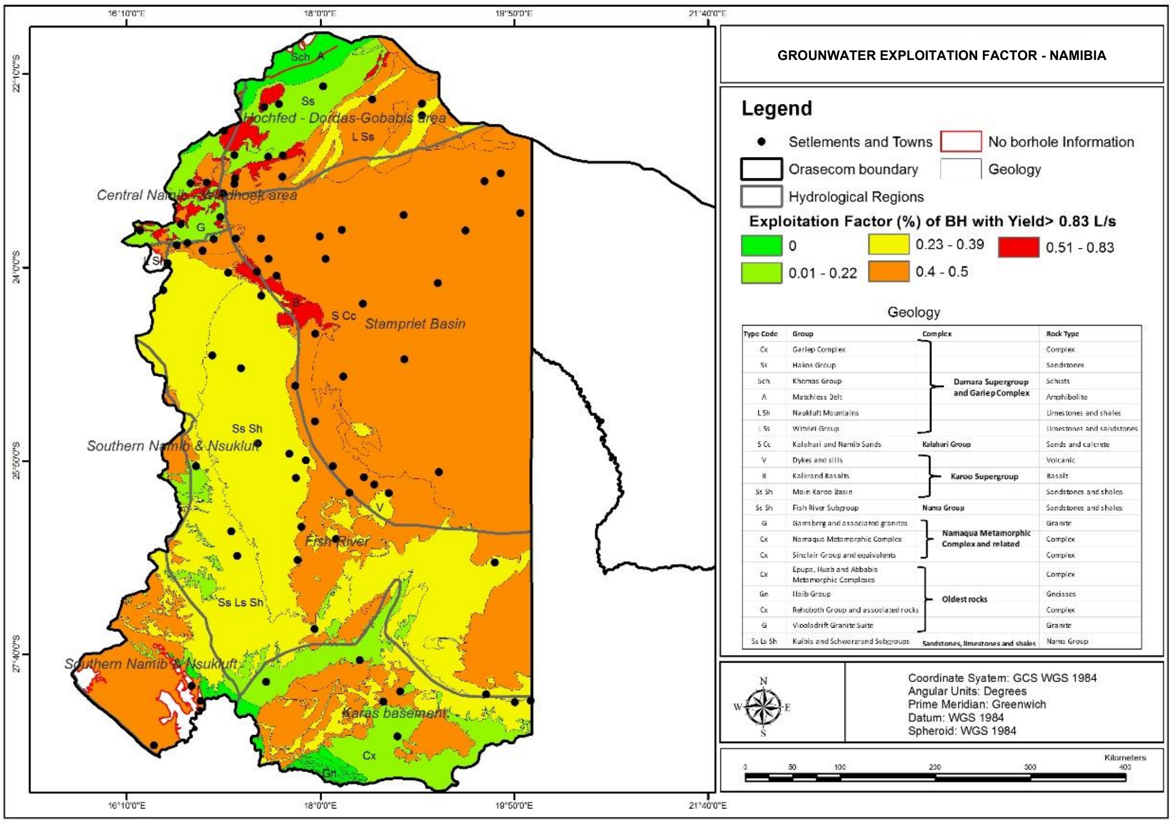
Borehole Yields and Aquifer Productivity

The Namibian part of the basin is underlain by low yielding aquifers with most boreholes yielding less than 1 l/s. Average borehole yields in fractured and fractured/weathered aquifers range from 0.33 (1.2 m^3/hr) to 1.28 l/s (4.6 m^3/hr) with the highest yielding boreholes found in the Rehoboth Group, Fish River Aroab and Stampriet Groundwater basins while the lowest yielding boreholes are found in the Karas basement groundwater basin (**Figure E20**).

In terms of the aquifer productivity (**Figure E21**) a high percentage of aquifers in the basin have low productivity (percentage of boreholes with yield of more than 0.83 l/s) with most of the groundwater basins having exploitation factors of 0 to 50% (average productivity factor ~10%). The data indicates that the Stampriet and Fish River Aroab Groundwater basins have the highest exploitation factors with the Karas basement groundwater basin having the lowest groundwater exploitation potential.

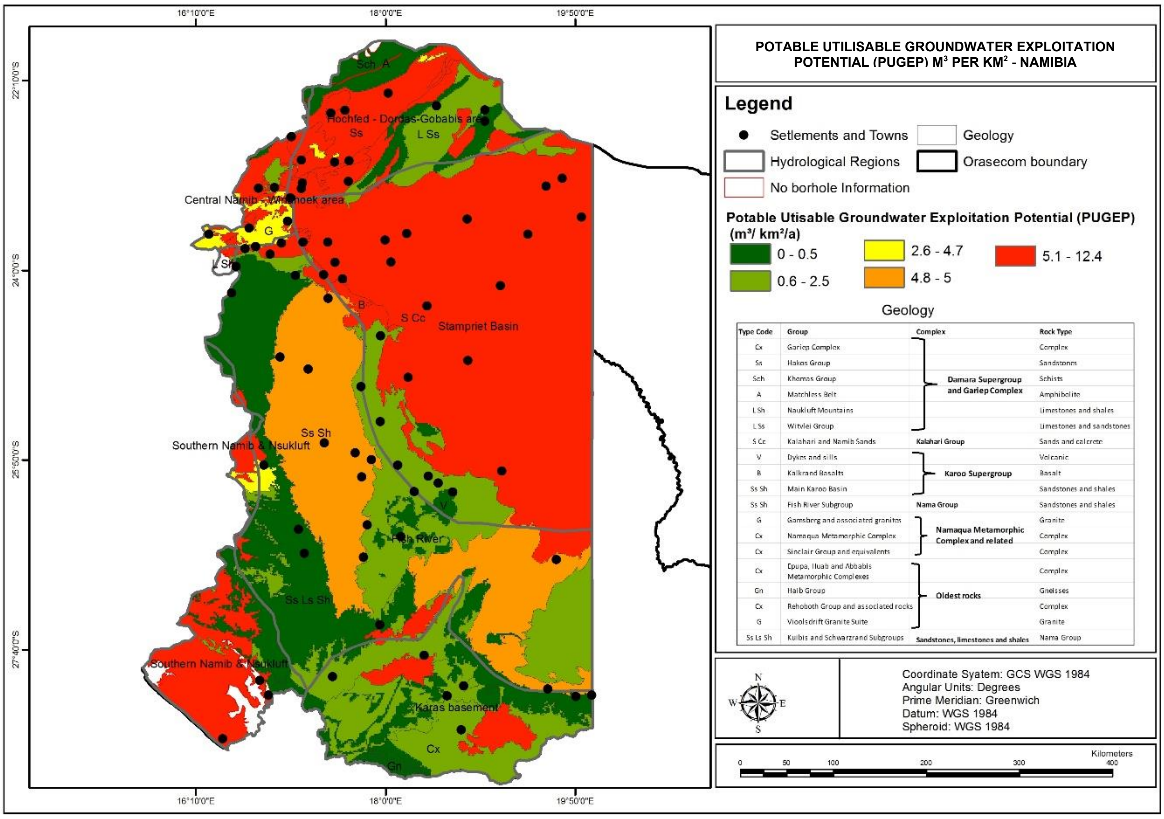


E 20: Average borehole yields, Namibia (also see Appendix 16)



E 21: Aquifer productivity (% of boreholes yielding > 0.83 l/s, Namibia (see Appendix 16)

Groundwater Exploitation Potential Aquifers with highest Potable Utilisable Groundwater Exploitation Potential (PUGEP) are Kalahari and Namib Sands, Main Karoo (Stampriet Basin) and the Fish River Sub Group. Aquifers with the lowest PUGEP being Namaqua Metamorphic Complex, Dykes and Sills, Epupa, Huab and Abbabis Metamorphic Complexes, Haib Group, Khomas Group and Vioolsdrift Granite Suite (**Figure E22**).

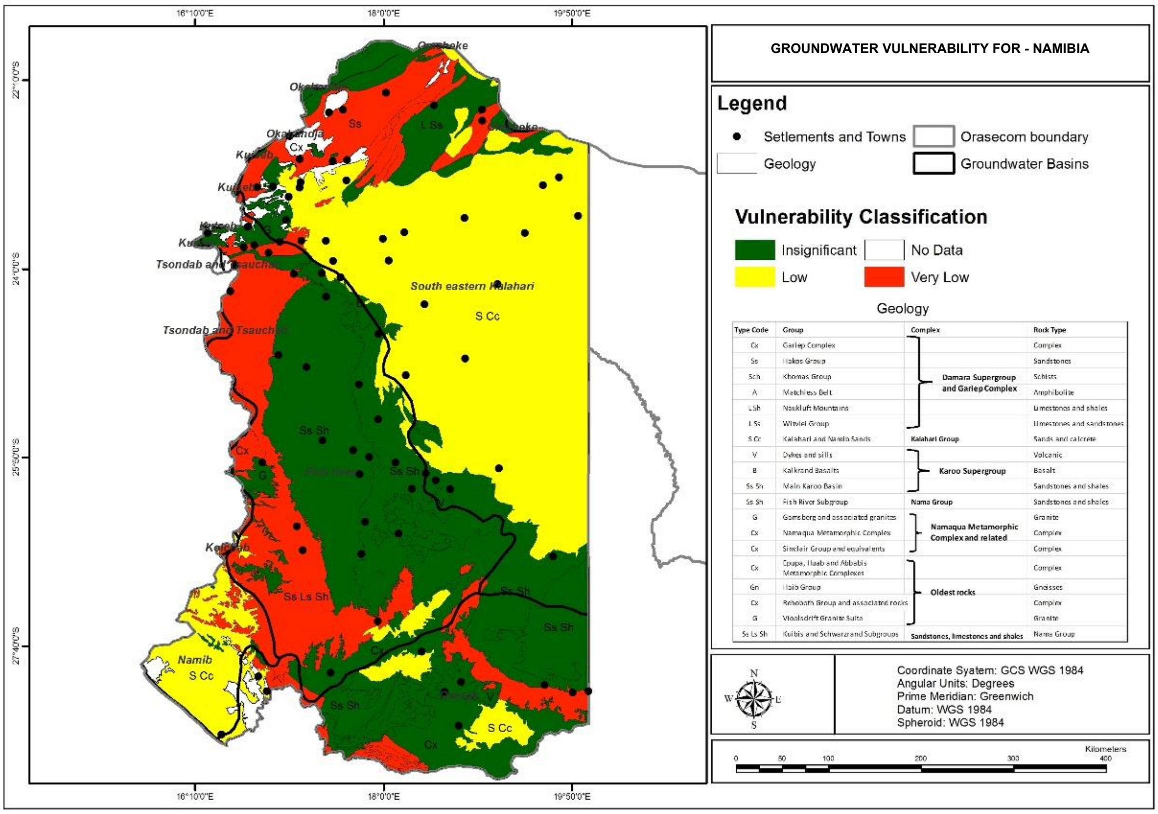


E 22: Potable Utilisable groundwater exploitation potential, Namibia (m^3/km^2/a)

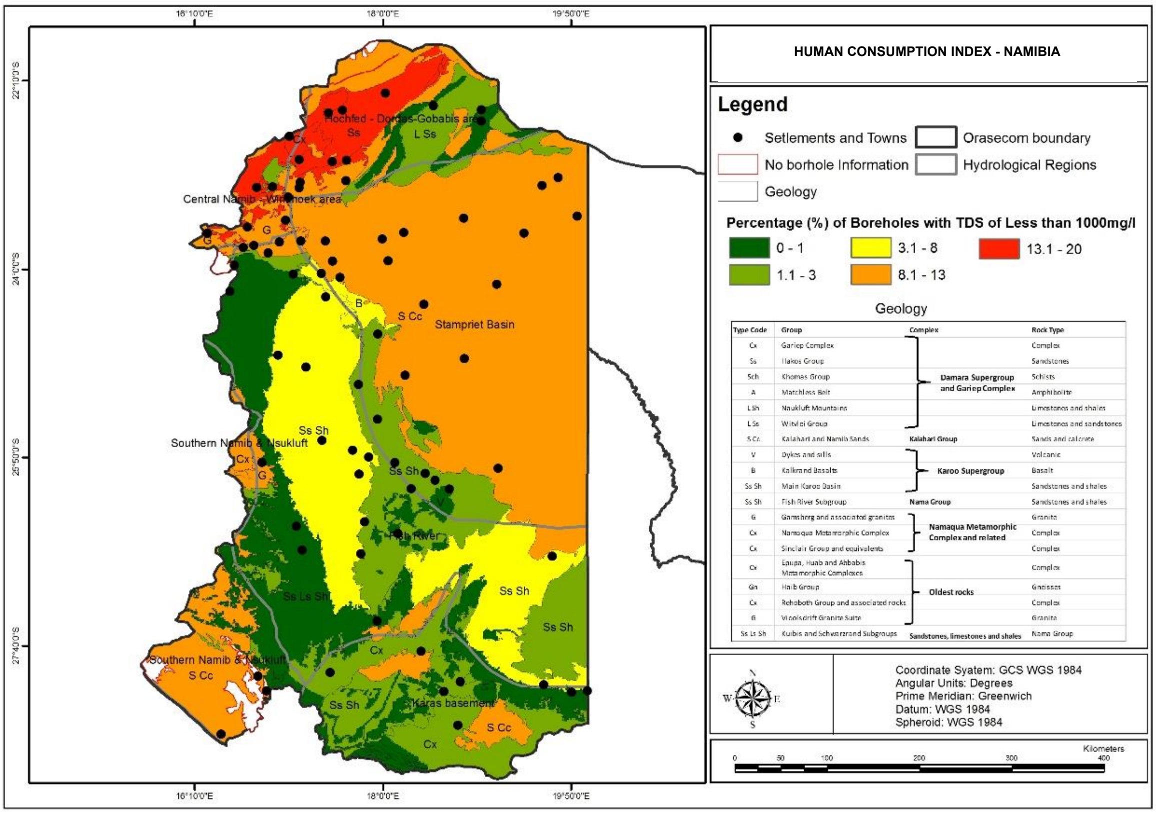
Groundwater Pollution Vulnerability

Aquifer vulnerability according to the DRASTIC index indicates that the majority of the basin has insignificant to low groundwater pollution vulnerability (**Figure E23**).

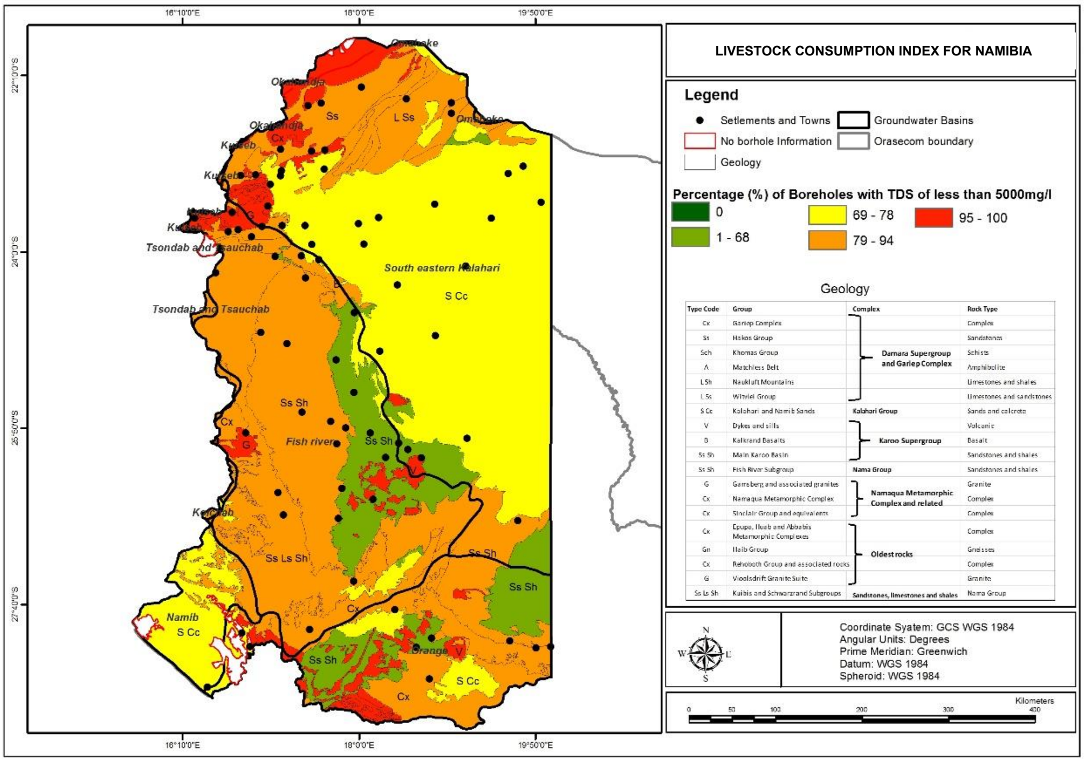
Limitations of Groundwater Quality on Use; Data indicates that the basin is dominated by aquifers with groundwater quality which is falls outside the Group A (Excellent Quality) range for potable use in terms of TDS (i.e TDS of less than 1000 mg/l) with potability indices of 0 to 20% (**Figure E24**), however a large part of the basin contains groundwater suitable for livestock consumption in terms of TDS with (79 to 100%, **see Figure E25**).



E 23: Groundwater Pollution Vulnerability Index, Namibia

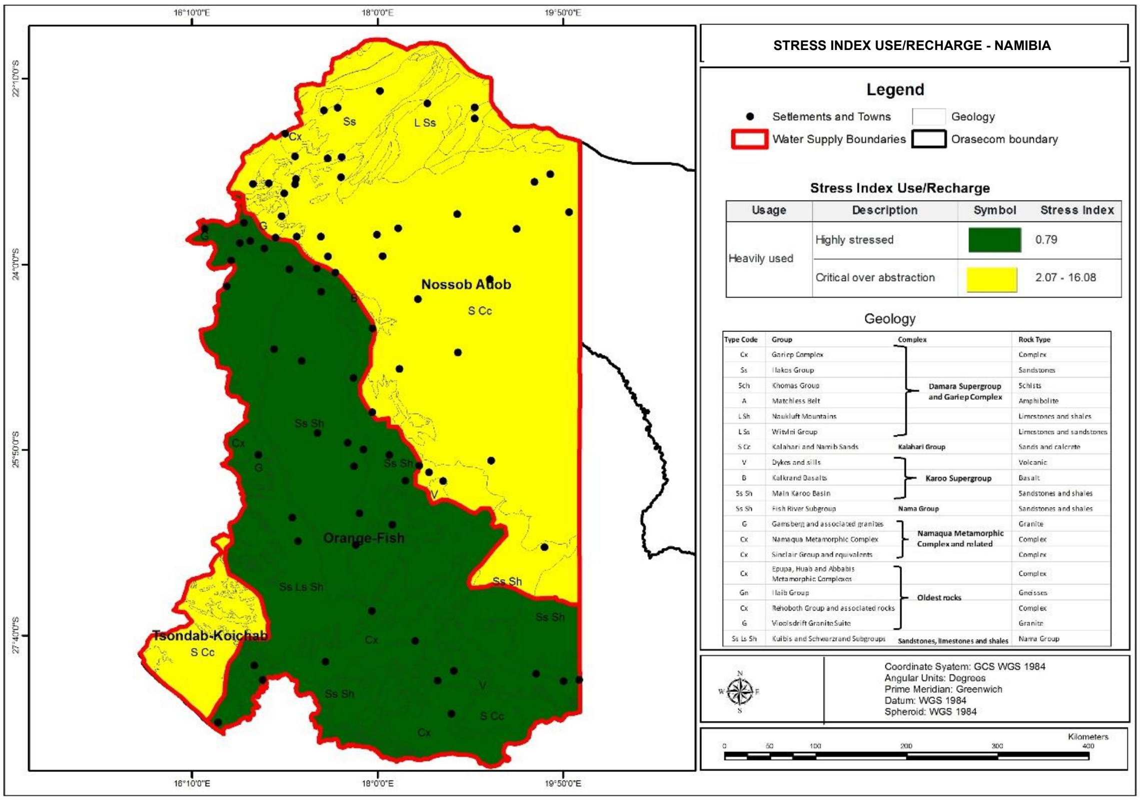


E 24: Percent potable groundwater in terms of TDS, Namibia



E 25: Percent suitable groundwater for livestock, in terms of TDS, Namibia Vulnerability of Groundwater to over Abstraction

A groundwater stress index for the basin indicates that the whole basin can be considered either as highly stressed or critically over abstracted particularly areas which fall under the Nossob-Auob water supply area (which includes the Stampriet basin) (**Figure E26**)



E 26: Stress Index, by water supply area, Namibia (Also see Appendix 16)

The potential for baseflow reduction for the Botswana and Namibian portions of the basin were taken as zero.

Data Limitations

There is a significant discrepancy in how the individual countries collect data, which complicates cross-border mapping and results in 'edge effects' at borders, or different classification. These problems can be summarised as:

- The National geological maps are based surficial geology in South Africa, Namibia and Lesotho, and mapped as pre-Kalahari Geology (sub-Kalahari Basement) in Botswana
- The same geological formations have different names across borders, and boundaries do not always align
- Borehole data coverage is dense in South Africa and Namibia, and sparse in Lesotho and the western portion of Botswana, making statistical characterisation difficult
- Low yielding boreholes do not appear to be incorporated into the Botswana and Lesotho databases, resulting in average and median yields being skewed towards higher yields, and resulting in discontinuities at borders

- South Africa manages groundwater based on groundwater management units, which are based on quaternary catchment boundaries, with the exception of the dolomites. Lesotho and Botswana define aquifers based on lithology while Namibia utilises groundwater drainage basins.

Conclusions

The flowing conclusions can be drawn, which have implications for the Core Scenario.:

South Africa

- Large volumes of groundwater (high CUGEP) are available in the South-eastern Highveld, Ghaap Plateau, Western Highveld, Eastern Upper Karoo, Central Highveld, South Eastern Highland, and Northeastern Pan Belt..
- Only in the Ghaap Plateau and the dolomites near Mafikeng do sufficient boreholes yield greater than 2 l/s to warrant economical abstraction. The dolomitic compartment near Mafikeng is known as the Grootfontein/Molopo dolomitic compartment.

Lesotho

- The Drakensberg Highlands consist of a fractured aquifer of low storage potential, although recharge is high, most of it is lost as interflow feeding and is not available to boreholes tapping the regional aquifer. In addition, they contribute to groundwater baseflow, hence abstraction would have a significant impact on baseflow
- The Northeastern Highlands GW Region (Lesotho Lowlands) have a somewhat higher percentage of high yielding boreholes and more aquifer storage than the southeastern highlands. Locally, the Northeastern Highland region is moderately stressed by existing abstraction.

Namibia and Botswana

- Namibia suffers from the over exploitation of groundwater resources and yields are low.
- Groundwater has a TDS greater than 1000 mg/l. Elevated nitrates occur throughout the basin.
- In Botswana high yields warrant local development of groundwater. The most readily exploitable aquifers are found in Ecca North (Stampriet basin), Archaen Amphibolites East, Lower Transvaal North and Ecca East.
- The highest UGEP is found in Ecca North, Lebung and Lower Transvaal South. The Ecca North is a transboundary aquifer shared with Namibia (Stampriet Basin), and the

Lower Transvaal South is a dolomitic transboundary aquifer shared with South Africa (Khakea-Bray aquifer). Both these transboundary aquifers are heavily utilised across the border

- A large part of the basin in Botswana is underlain by aquifers with groundwater of TDS greater than 1000 mg/l, with about 12% of the basin yielding groundwater which is 60% to 100 % suitable for human consumption.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABBREVIATIONS AND ACRONYMNS

AGRP	Average Groundwater Resource Potential
AMD	Acid mine drainage
DWA	Department of Water Affairs (RSA)
DWAF	Department of Water Affairs and Forestry (RSA)
DWS	Department Water and Sanitation
EC	Electrical conductivity
EF	Exploitability Factor
EFR	Environmental flow requirements
EWR	Environmental Water Requirement
GDP	Gross Domestic Product
GEF	Global Environmental Facility
GEP	Groundwater Exploitation Potential
GRA ll	Groundwater Resources Assessment Phase II
GRP	Groundwater Resource Potential
IAPP	International Association for Public Participation
IGRAC	International Groundwater Resources Assessment Centre
IPCC	International Panel for Climate Change
IVRS	Integrated Vaal River System
IWRM	Integrated Water Resources Management
L-BWT	Lesotho Botswana Water Transfer
LHDA	Lesotho Highlands Development Authority
LHWP	Lesotho Highlands Water Project
l/s	Litre per second
MAFS	Ministry of Agriculture and Food Security (Lesotho)
MAP	Mean Annual Precipitation
MAR	Mean Annual Runoff
MAWF	Ministry of Agriculture, Water and Forestry (Namibia)
MC	Management Centre (Botswana)
MEWR	Minerals, Energy and Water Resources (Botswana)

mm/a	Millimetres per annum
m^3/s	Cubic Meters per second
m^3/a	Cubic Meters per annum
MW	Megawatts
NWA	National Water Act
NAP	National Action Programme
NGA	National Groundwater Archive
NGO	Non-governmental organisation
ORASECOM	Orange Senqu River Commission
ORP	Orange River Project (Gariep and Vanderkloof dams and supply area)
PES	Present Ecological State
PF	Potability Factor
PGEP	Potable Groundwater Exploitation Potential
PUGEP	Potable Utilisable Groundwater Exploitation Potential
PWC	Permanent Water Commission
RSA	Republic of South Africa
SADC	Southern African Development Community
SADC-GIO	Southern African Development Community Groundwater Information Portal
SAP	Strategic Action Programme
TDA	Transboundary Diagnostic Analysis
TDS	Total dissolved solids
TTT	Technical Task Team
TOR	Terms of Reference
UGEP	Utilisable Groundwater Exploitation Potential
UNDP	United Nations Development Programme
VRS	Vaal River System
WARMS	Water Authorisation and Registration Management System
WASCO	Water and Sanitation Company
WC	Water Conservation
WDM	Water Demand Management

WR2012	Surface Water Resources of South Africa 2012
WMA	Water Management Area
WRYM	Water Resources Yield Model
WRPM	Water Resources Planning Model
WUC	Water Utilities Corporation (Botswana)

1 INTRODUCTION

1.1 Background

The Orange-Senqu River basin is one of the largest river basins south of the Zambezi with a catchment area of approximately 1 million km^2. It encompasses all of Lesotho, a significant portion of South Africa, Botswana and Namibia. The Orange-Senqu River originates in the Highlands of Lesotho and flows in a westerly direction approximately 2 200 km to the west coast of South Africa and Namibia where the river discharges into the Atlantic Ocean. See **Figure 1-1**.

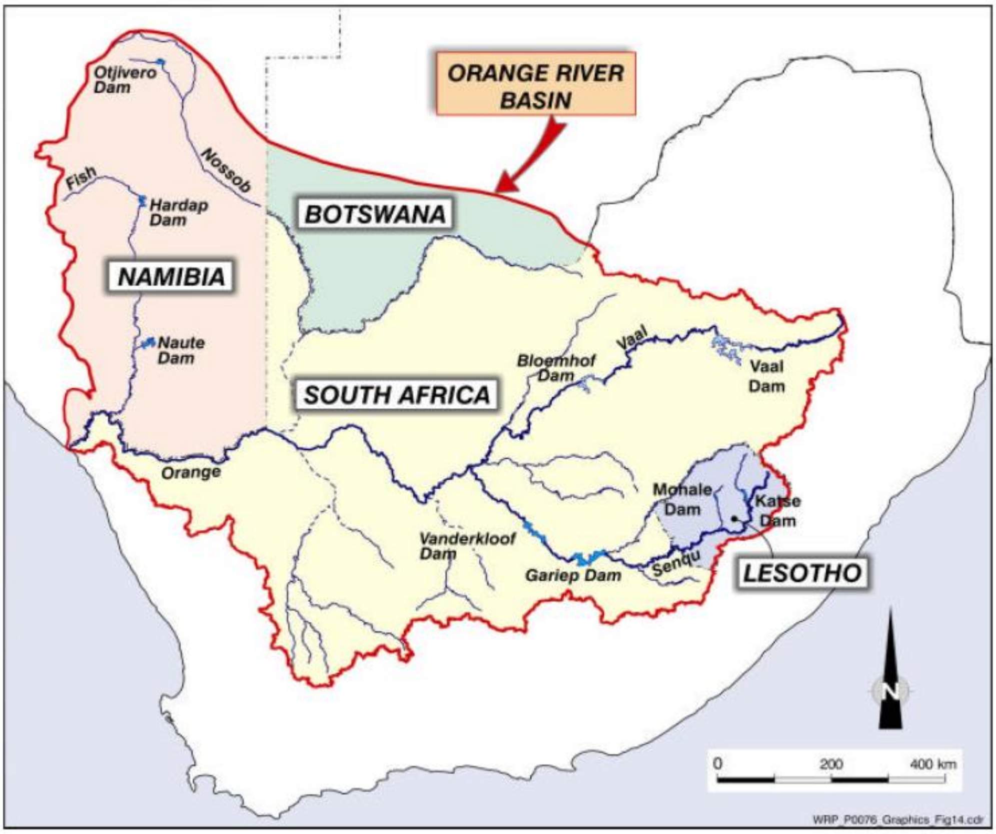


Figure 1-1 Orange-Senqu River Basin

There are however, three distinct hydrologically homogenous River basins in Lesotho, where each River basin has its clear source where it originates. These River basins, namely: Senqu, Mohokare and Makhaleng River basins all flow in the westerly direction and join together outside the border of Lesotho to form one large basin known as the Orange/Senqu River Basin.

It has been estimated that the natural runoff of the Orange-Senqu River basin is in the order of 11 300 million m^3/a, of which approximately 4 000 million m^3/a originates in the Senqu River basin in the Lesotho Highlands, 6 500 million m^3/a from the Vaal and Upper Orange river, with approximately 800 million m^3/a from the Lower Orange and Fish River (Namibia). The basin also includes a portion in Botswana and Namibia (north of Fish River) feeding the Nossob and Molopo rivers.

Southern Africa has fifteen (15) transboundary watercourse systems of which thirteen exclusively stretch over the Southern African Development Community (SADC) Member States. The Orange–Senqu is one of these thirteen transboundary water course systems. SADC member states embrace the ideals of utilizing the water resources of these transboundary watercourses for the regional economic integration and for the mutual benefit of riparian states. The region has demonstrated a great deal of goodwill and commitment towards collaboration on water issues. Thus, SADC has adopted the principle of basin–wide management of the water resources for sustainable and integrated water resources development.

To enhance the objectives of integrated water resources development and management in the region, the Orange–Senqu River Basin Commission (ORASECOM) was established in November 2000.

ORASECOM was established by the Governments of the four States (South Africa, Lesotho, Botswana and Namibia) for managing the transboundary water resources of the Orange-Senqu River basin and promoting its beneficial development for the socio-economic wellbeing and safeguarding the basin environment. This led to the development of a basin level Integrated Water Resources Management (IWRM) Plan adopted in February 2015 by the ORASECOM Member States. The IWRM plan provides a strategic transboundary water resources management framework and action areas, and serves as a guiding and planning tool for achieving the long-term development goals in the basin. A key aspect of the transformative approach for strengthening cooperation has been identified as the need for joint project implementation that provides a mutually inclusive transboundary benefit.

The IWRM Plan recommends strategies and measures for promoting sustainable management of the water resources of the basin and defines strategic actions that will ensure and enhance water security, considering the long term socio-economic and environmental demands on the water resources of the basin. The Lesotho to Botswana Water Transfer Scheme, a major component of this study, was not included in the 2015 IWRM Plan as one of the strategic actions.

The Orange-Senqu River basin is a highly complex and integrated water resource system, characterized by a high degree of regulation and major inter-basin transfers to manage the discrepancy between the location of relatively abundant precipitation and the location of greatest water requirements. The infrastructure involves storage and transmission of water, to water demand centres that are in some cases located outside of the basin.

Figure 1.2 provides approximate values of the natural run-off in the Orange-Senqu River basin. These figures highlight the variable and uneven distribution of runoff from east to west in the basin. The figures refer to the natural runoff which would have occurred had there been no developments or impoundments in the catchment. The actual runoff reaching the river mouth is considerably less than the natural values and are estimated to be in the order of half the natural values.

The difference is due mainly to the extensive water utilisation in the Vaal River basin, most of which is for domestic and industrial purposes. Several major transfer systems are used to bring water into the Upper Vaal River catchment to support the high water requirements, in particular those within the Gauteng area as well as for several Power Stations. Large volumes of water are also used to support extensive irrigation and some mining demands along the Orange River downstream of the Orange/Vaal confluence, as well as significant irrigation developments in the Eastern Cape, supplied through the Orange/Fish Tunnel. In addition to the water demands, evaporation losses from the Orange River and the associated riparian vegetation account for 500 to 1 000 million m^3/a, depending upon the flow in the river.

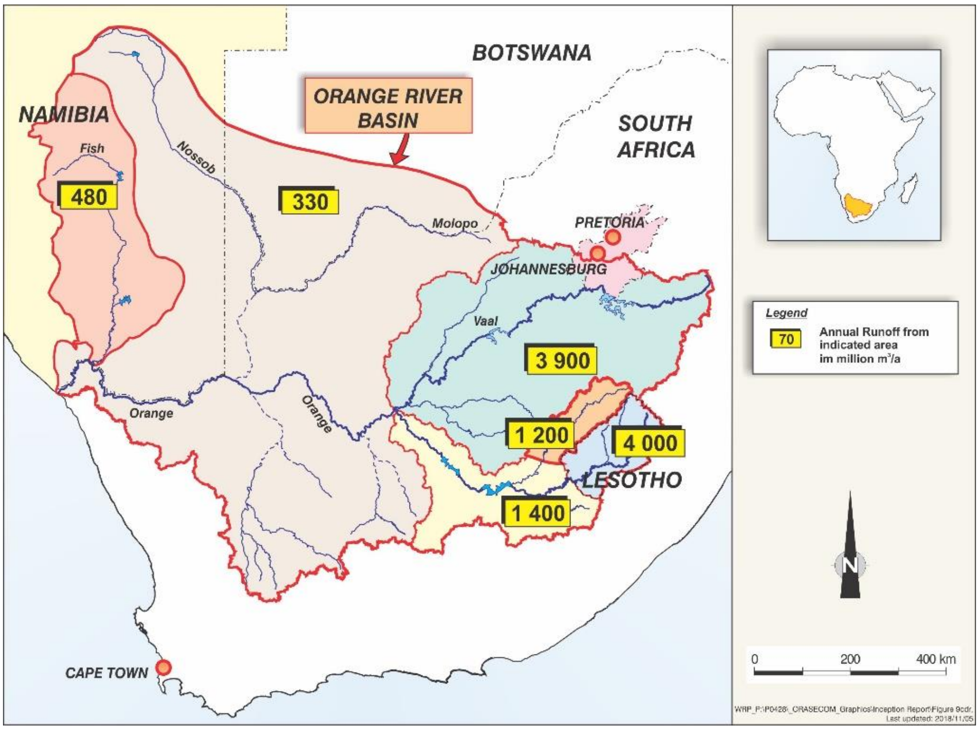


Figure 1-2: Approximate Natural Run-off in the Basin

Water scarcity is the main challenge in the basin, and this requires a coordinated joint development, management and conservation of the water resources of the system. The climate in the basin varies from relatively temperate in the eastern source areas, to hyper-arid in the west. As shown in **Figure 1.3**, average annual precipitation decreases from more than 1000 mm/a in the source areas of the basin to less than 50 mm/a at the mouth. This varies considerably from year to year. Much of the rainfall occurs as intense storms, which can be highly localised. The temporal and spatial distribution of precipitation within any particular year can be considerable.

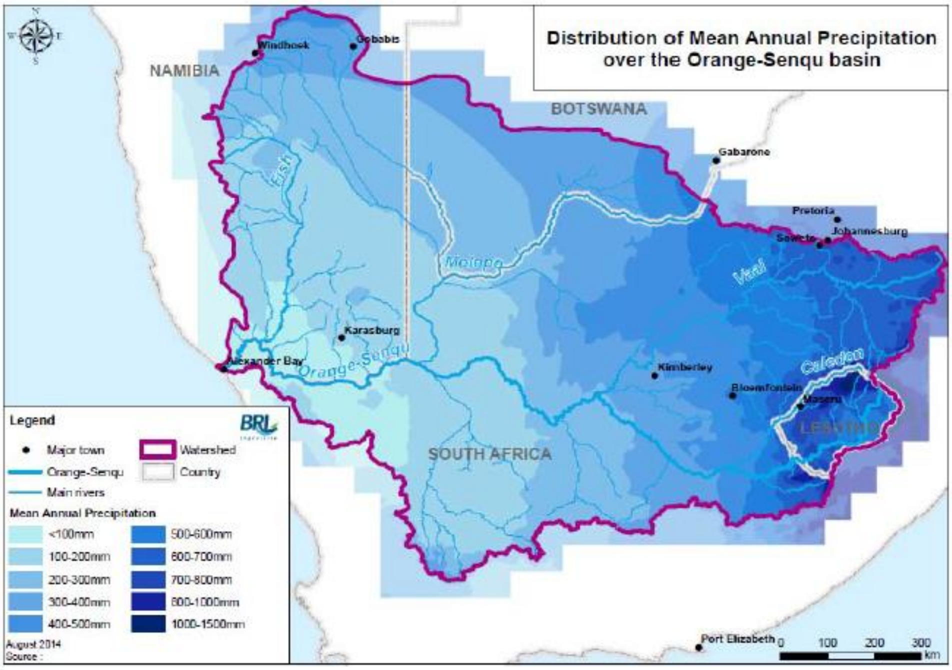


Figure 1-3 Distribution of Mean Annual Precipitation

In **Figure 1.4** it is evident that evaporation increases from south-east to north-west reaching a maximum of more than 1 650 mm/a in the west. Even in the cooler and wetter parts of the basin, evaporation in most cases exceeds precipitation. Temperature and evaporation follow a similar distribution with the coolest temperatures in the Lesotho Highlands and the hottest in the western Kalahari.

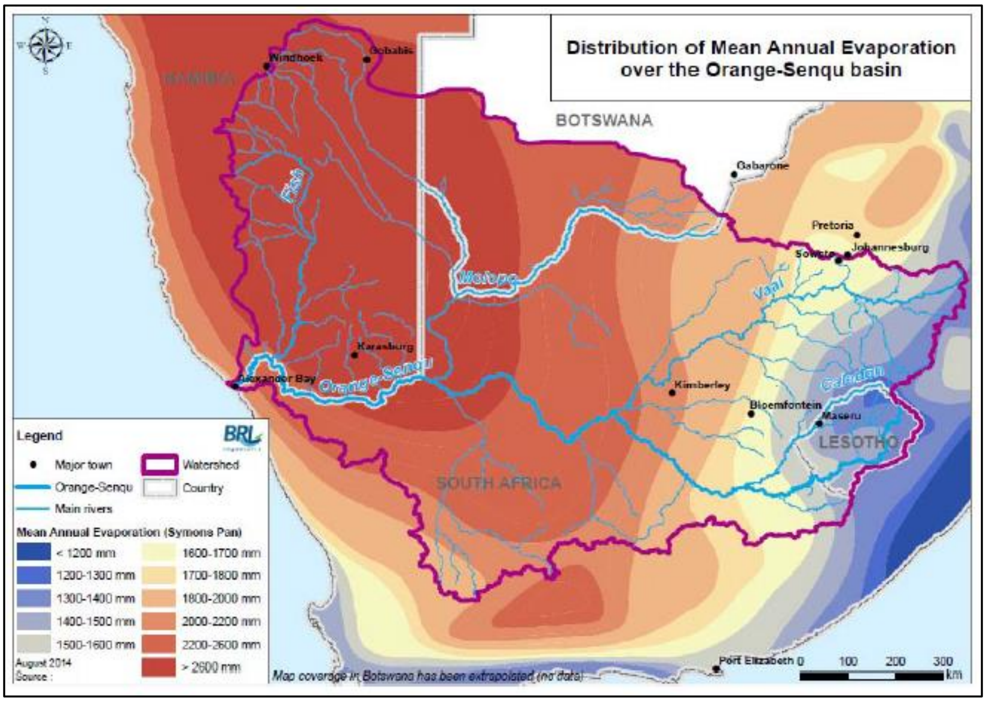


Figure 1-4: Distribution of Mean Annual Evaporation

It is generally accepted that Southern Africa will be highly impacted by climate change. Consequently, there are concerns around the changes in precipitation and temperature due to climate variability and climate change. This study therefore aims to enhance investment in transboundary water security and to build resilience to climate change into the implementation of the strategic projects and actions described in the IWRM Plan.

The Republic of Botswana is an arid country faced with serious water constraints which will worsen with the expected effects of climate change. Botswana will experience chronic water shortages by about 2025, unless major new water sources are developed. Already Gaborone was critically hit by the 2015-2016 drought.

As a consequence, the Governments of Botswana, Lesotho and South Africa signed a Memorandum of Agreement to undertake a reconnaissance study on the Lesotho to Botswana Water Transfer scheme (L-BWT) aimed at developing water in Lesotho and conveying it to Botswana and, on the way, supplying various users in Lesotho and South Africa. This reconnaissance study led to the selection of a technical option which included a new dam on the Makhaleng River in Lesotho and a piped conveyance system to Botswana. It is envisaged that eventually 150 million m^3/a will be pumped to Botswana with additional supplies for consumers along the route in Lesotho and South Africa.

1.2 Objective of the Assignment

The objective of the study is to update the IWRM Plan endorsed in 2015 and propose an updated core scenario which includes the L-BWT project and to assist ORASECOM and the riparian countries in operationalizing the updated IWRM Plan. This will be met through three outputs:

- Preparing a climate resilient investment plan for the Orange-Senqu River Basin based on the updated core scenario;
- Operationalizing ten priority actions selected from the updated IWRM Plan; and
- Studying at pre-feasibility level the L-BWT, and at feasibility level the dam included in this study.

The study was therefore divided into two distinct parts:

- A climate resilient investment plan, based on the updated Water Resources Yield and Planning Model and the updated Core Scenario defined in the IWRM Plan of 2015 (Components I & II of the study); and
- The Lesotho-Botswana Water Transfer Project (Components III & IV of the study)

The four components referred to above are:

- Component I: Climate Resilient Water Resources Investment Plan;
- Component II: Operationalisation of the Integrated Water Resources Management Plan;
- Component III: Pre-feasibility study of the Lesotho to Botswana Water Transfer Project;
- Component IV: Feasibility Study of the Dam on Makhaleng River in Lesotho.

1.2.1 Climate Resilient Investment Plan (Components I and II)

The high level of variability in precipitation due to climate variability and change, defines the need to optimize and implement efficient water resources development and management in the basin. The development of new infrastructure to meet increasing water demands, even if technically and environmentally feasible, is both expensive and complex. Economic considerations of water use have been identified as a key part in the planning and optimum use of what will become an increasingly scarce and expensive resource. Projections of future water demand and associated infrastructure development must be based on balanced considerations of economic, social, and environmental factors. The integration of water resources yield analysis, water resources development planning and economic optimization will ensure the development of short, medium- and long-term solutions to address basin water resources development challenges.

The assignment will include water resource studies in the Botswana, Lesotho and Namibian parts of the basin and the updating of inputs from the RSA Reconciliation Strategy Studies with more recent results from the Reconciliation Strategy Maintenance Studies as well as other recent water resource related studies conducted for the basin. This will establish comprehensive basin wide analyses which will be integrated with economic analyses to determine the optimized and most efficient development options, as part of setting the long-term development investment strategy and plan for the basin.

Components I & II will thus address the water resources investment plan and the operationalization of the updated IWRM Plan with the following outputs:

- Update the Core Scenario of the IWRM Plan to include the Lesotho-Botswana Water Transfer Scheme and any other new projects that are identified;
- Estimate the Climate Change Effects on the updated Core Scenario;
- Optimise the IWRM Plan Core Scenario through an economic approach;
- Develop a Financial Strategy for the Core Scenario;
- Update the basin wide investment plan approved by ORASECOM by including new projects considering climate change effects;
- Undertake a comprehensive assessment of existing policies, legal institutional arrangements and structures;
- Select 10 strategic actions and develop Terms of Reference and cost estimates for each; and
- Prepare a road map for operationalization of ten strategic actions contained in the Integrated Water Resource Management Plan.

1.2.2 Lesotho-Botswana Water Transfer (L-BWT) Project (Components III and IV)

The south eastern urban complex of Botswana centred around the capital city, Gaborone, has experienced rapidly increasing growth over the last few decades, and is expected to continue doing so. Its water demands have long outstripped local bulk water resources, which have already been supplemented from sources in the north-east of the country. The country has experienced several severe drought spells that have, in the recent past, led to water restrictions. Despite several concerted efforts to alleviate the water shortage challenges, indications are that the water sources will not be adequate to meet the growing demand as early as 2025.

The solution for addressing the water security challenges lies in the need for increasing the efficient use of existing infrastructure, developing additional water resources and improving the management systems, based on water resources availability and use.

A Reconnaissance Study to identify possible water resources was completed in October 2015, which outlined various options of water sources and conveyance routes to supply water from Lesotho to Botswana. The various sources covered by the study include the Lesotho Highlands Water Project, the Makhaleng River and the Senqu/Orange in the south of Lesotho. The preferred supply scheme recommended in the Reconnaissance Study is a dam on the Makhaleng River, and a conveyance system to bring the water from Lesotho, across South Africa to Botswana.

A Pre-feasibility Study is required to determine water demands up to 2050 for specified areas in Botswana, Lesotho and South Africa, from available relevant information in all countries, and to investigate suitable dam site(s) by analysing the Makhaleng catchment hydrology, determining the size of dam(s) on the basis of topography, geology, yield, sedimentation, hydropower generation and water demands for specific areas in Botswana, Lesotho and South Africa.

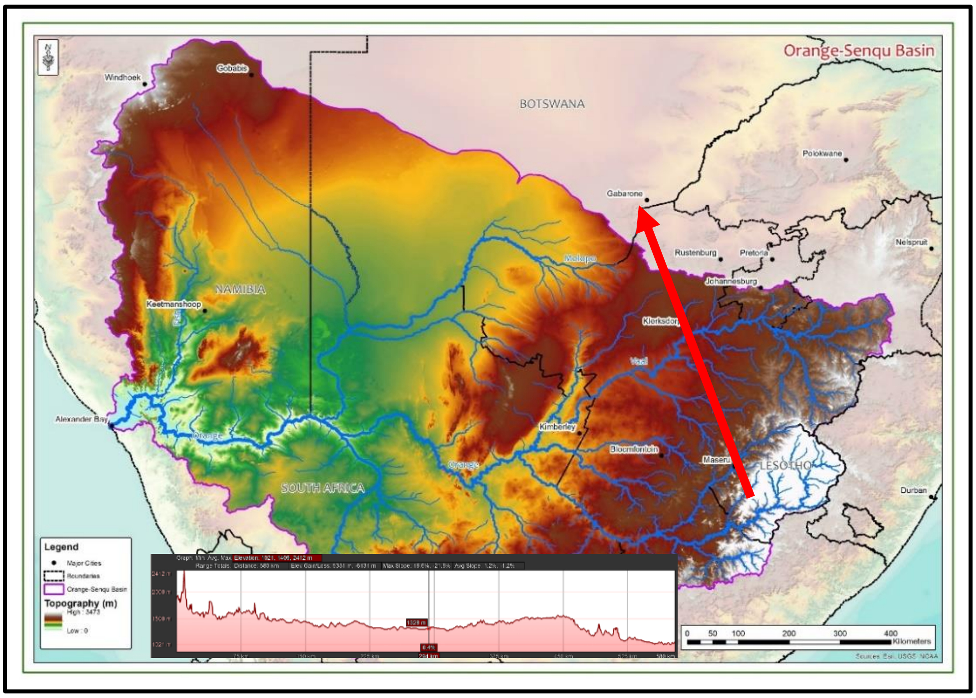


Figure 1-5: Orange Senqu basin topographical map showing the possible Lesotho Botswana Water Transfer Project

For the conveyance system, the study is only required to investigate pipeline options along the shortest route, to either Gaborone or Lobatse in Botswana, preferably along existing road servitudes. Depending on the results and recommendations from the Pre-feasibility Study, a Feasibility Study for the dam on the Makhaleng River will follow, but this depends on a final decision by the client. In **Figure 1.5** the topographic map of the catchment is shown with the Lesotho to Botswana water transfer project overlain.

Components III & IV of this study will thus focus on the Lesotho-Botswana Water Transfer Multipurpose Trans-boundary Project (L-BWT) and will address:

Component III - Phase 1

- Undertake a validation of the water requirements for irrigation in Lesotho, the demand in South Africa along the pipeline route, and the demand in Botswana;
- Undertake an assessment of the water resource being the Makhaleng catchment;
- Do the dam site selection; and
- Do the conveyance route selection.

Component III - Phase II

- Conduct a pre-feasibility study of a dam on the Makhaleng River;
- Conduct a prefeasibility study of the conveyance pipeline from Makhaleng to Gaborone/Lobatse;
- Evaluate environmental and social impacts;
- Undertake an economic assessment of the dam and the Lesotho-Botswana conveyance pipeline; and
- Undertake a multi-criteria analysis (MCA) of the options.

Component IV - Feasibility of the Makhaleng Dam (Depending on results from the Pre-Feasibility Study)

- A hydrological analysis including climate change effects;
- A Feasibility Study of the Makhaleng Dam:
- An Economic social and financial analysis update; and
- A project implementation plan.

1.3 Purpose of this Report

This Report addresses Component I, the development of a climate resilient water resources investment plan, **Task 1b3** was defined as the Assessment of the potential for better utilizing the groundwater in the basin.

1.3.1 Objective of Study

The objective as stated in the TOR is the Quantification and mapping of potential groundwater volumes that could be considered in the core scenario, either for new developments or for substitution of surface water resources to obtain an improved utilization of groundwater in the basin.

To meet this objective, it was imperative that the large volume of data available in the basin be interpreted in a quantitative manner to assess the resource volume, current allocations, and the volumes of groundwater that remain available, as well as areas already or soon to be in crisis. Many reports exist which discuss groundwater in a qualitative manner, and do not utilise the wealth of data in a manner to quantify resources to water managers.

1.3.2 Methodology

As per the TOR, groundwater utilization within the Orange-Senqu River Basin, except for a few localities, is limited and has been attributed mainly to the low productivity of the aquifers within the basin. As part of the groundwater study component, an assessment of available hydrogeological data, mainly from existing work already carried out which will include the groundwater recharge work done for ORASECOM between February and September 2018.

- Assessment of the potential volumes of groundwater in storage in each sub-catchment;
- Assessment of the potential yield of the aquifer systems within each sub-catchment;
- State of current groundwater development and usage per sector within each sub catchment;
- Groundwater quality evaluated according to relevant water sector use standards
- (domestic, industrial, mining, irrigation, livestock);
- The vulnerability of groundwater to over abstraction and contamination;
- Assessment of borehole yields (to determine whether aquifers can be economically exploited);
- Analysis of whether abstractions can impact on surface water resources;
- Identification of ecological or environmental limitations on abstraction.

The analysis is based on available hydrogeological data from different groundwater studies conducted within the Orange-Senqu Basin, research organizations and consulting firms as well as interviewing groundwater experts within the River Basin States. Data sources include reports and data held by government departments of the river basin states (e.g. Department of Water Affairs, Geological Survey Departments etc.), ORASECOM, SADC Groundwater Information Portal (SADC-GIP), SADC-Groundwater Management Institute, UNESCO IHP and

International Groundwater Resources Assessment Centre (IGRAC). Crucial data sets that were used for resource assessment include:

- Aquifer storage;
- Aquifer hydraulic parameters and borehole yield characteristics;
- Groundwater quality;
- Water level data;
- Recharge and aquifer yield potential;
- Groundwater usage data.

A series of integrated maps of the basin or sub catchments which combine various spatial data sets and highlight crucial aspects of the groundwater systems (aquifers) in the project area were produced. Included are basin wide simplified geological and structural maps, aquifer distribution and aquifer sustainable yield (productivity) maps, groundwater quality maps and recharge distribution maps. The results of the groundwater resources investigation were ultimately be used to/for:

- Reconciliation of current and projected water demands vs sustainable groundwater resources (aquifer yield);
- Evaluation of any existing over abstraction by stress indices, and water levels;
- Determine whether groundwater can meet projected demands, or whether it can only be used to supplement peak demands or for conjunctive use, or by temporary mining until other sources are developed;
- Evaluate the impacts of abstractions on surface water resources;
- Evaluate water quality limitations on development;
- Determining whether groundwater can be considered in the core scenario, either for new developments, for augmentation and conjunctive use (e.g. injection of surface water into aquifers to reduce evaporation), or for substitution of surface water resources as well as recommendations on how and where groundwater resources of the basin can be better utilized.

1.3.3 Outcomes/ Deliverables

Section in the Core Scenario update and optimization report covering:

- Potential quantities and quality groundwater that could be considered in the core scenario either for new developments or for substitution or conjunctive use with of surface water resources in line with spatial unit of analysis utilized by the surface water resource analysis;

- Recommendations on how and where groundwater resources of the basin can be better utilized;
- Identification of constraints, looking at both quantity and quality, such as remaining allocable groundwater, aquifer storage and the impact during droughts, borehole yields, existing infrastructure;
- Groundwater Report;
- Inputs to the Core Scenario Update Report.

1.4 Sources of Data

The sources of data utilised for the study are shown in **Table 1-1**, and the number of data points is shown in. A very large fraction of this data falls within the ORASECOM basin and has been utilised.

The South African Groundwater data is available on the electronically on the NGA for over 200 000 boreholes. In Lesotho the data is available in spreadsheet format for limited data points (**Figure 1-2**), with coverage primarily in the lowlands. Relatively large amounts of data are available for Namibia, with sparse coverage in the western portion of Botswana. This variation in data coverage in different countries is problematic for data analysis and results in 'border effects' when interpreting conditions on both sides of international borders.

Table 1-1 Literature sources and databases accessed during this study

Type of Data	Data	Source
Catchment delineation	Quaternary catchment boundaries.	WR2012 (RSA and Lesotho). http://www.the-eis.com/ Namibia's One-Stop Shop for Environmental Information. Supported by Namibian Chamber of Environment, Department of Surveys and Mapping (Botswana)
Groundwater discharge zones	Wetland location	National Freshwater Ecosystem Priority Area (NFEPA) atlas 2011
Population	Population and water source	Stats SA Lesotho State of Water Report Lesotho Bureau of Statistics Statistics, Water Utilities Corporation Water Accounts (Botswana)
Climatic data	Rainfall	WR2012, Department of Meteorological Services (Botswana)
Geology	Lithology and structures	Council for Geoscience geological maps (RSA and Lesotho), Botswana Geoscience Institute (Geological Map of Botswana, BGI)

		Groundwater in Namibia: An explanation to the Hydrogeological Map
Soils	Soil maps	WR2012 Institute of Soil Climate and Water Ministry of Agricultural Development and Food Security (Botswana) http://www.the-eis.com/ **(**Namibia)
Hydrology	Flow data Baseflow	WR2012 GRA II (DWAF, 2006a)
Geohydrology	Harvest Potential Exploitation Potential Recharge Hydrochemistry Water levels Borehole yields	GRA II (DWAF, 2006a) GRA II (DWAF, 2006a) GRA II (DWAF, 2006a) ZQM database NGA NGA, Lesotho Borehole database (Excel 2020) Lesotho Springs Monitoring Database (Excel 2020) Department of Water and Sanitation Services, Botswana, (Borehole Archives) Groundwater in Namibia: An explanation to the Hydrogeological Map SADC Hydrogeological Map Data base (Botswana and Namibia)
Groundwater use	Licenced groundwater use Schedule 1 water use Livestock water use	WARMS – South Africa Lesotho State of Water Report GRA II (DWAF, 2006a) WUC, Water Use Data (2013 to 2017) IWRM Plan for Namibia (August 2010)
Aquifer Vulnerability		Geology GIS coverage Soils ISCW coverage GRAII Groundwater Pollution Vulnerability Map (Botswana)

Table 1-2 Summary of borehole data available electronically in SADC

	Location	Compl. year	Depth	SWL	Yield	F	NO3	TSD	EC
All	334660	272647	278751	196110	148714	38371	39824	33840	42922
Angola	No data								
Botswana	5957	5164	5492	5197	4305	4826	3533	5121	4791
DR Congo	No data								
Lesotho	120	120	120	57	85	0	0	0	0
Madagascar	2755	0	1106	1200	16	0	0	0	2511
Malawi	985	603	967	975	890	394	324	499	698
Mauritius	No data								
Mozambique	7225	3412	5456	6063	5351	0	177	0	94
Namibia	53569	53560	35828	26061	31487	20830	23558	27912	22297
South Africa	226356	189552	193098	130239	90267	11684	11688	0	11737
Seychelles	No data								
Swaziland	3074	2380	2576	2076	2714	471	516	23	587
Tanzania	2299	28	2203	1601	1494	105	28	28	135
Zambia	15088	1664	14837	13205	2365	61	0	257	72
Zimbabwe	17232	16164	17068	9436	9740	0	0	0	0

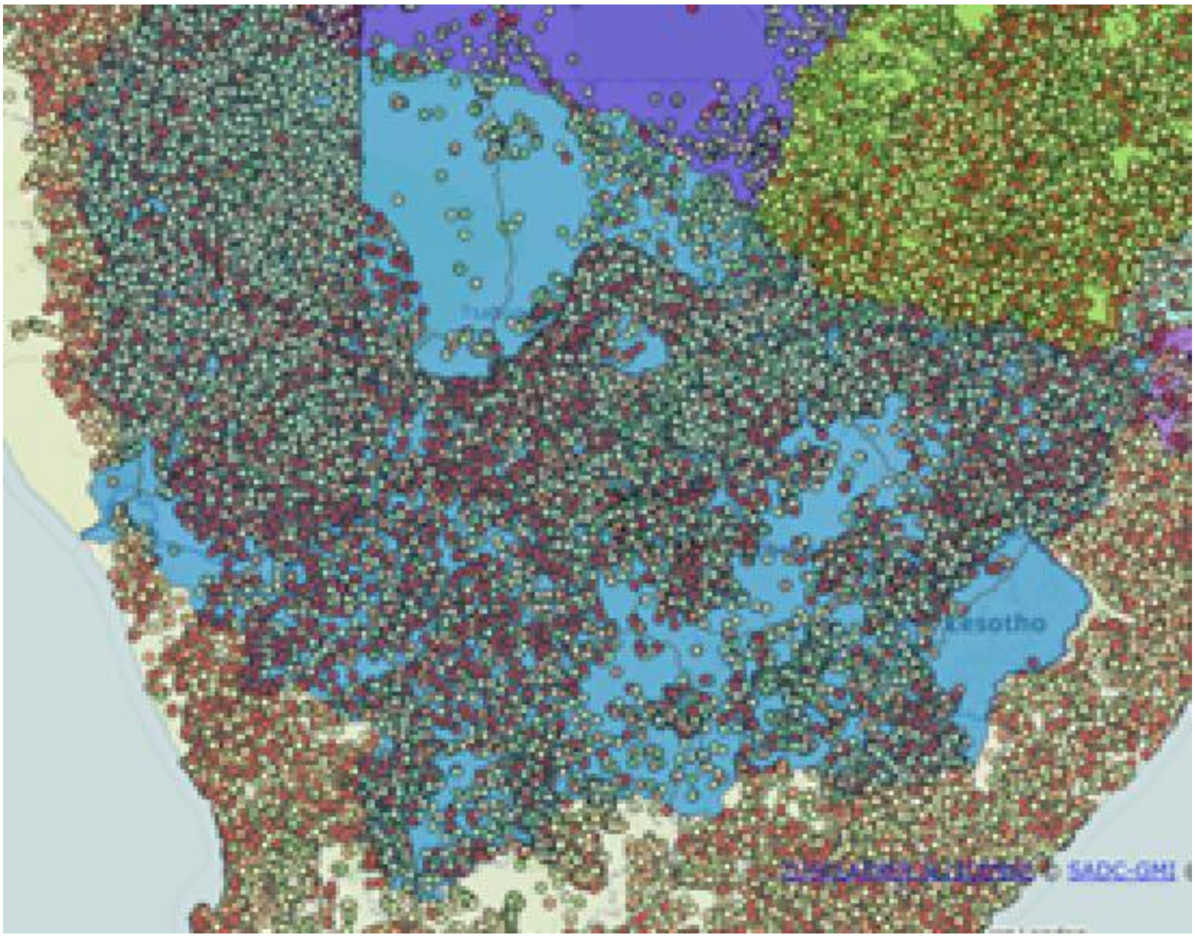


Figure 1-6 Available borehole yield data with Orange-Senqu basin shown in blue

1.5 Outline of this Report

The report outline is provided below.

Chapter 1: Introduction

This Chapter provides general background to the project, study area and purpose of the report, as well as the data sources available.

Chapter 2: Evaluation of Data and Methods

Chapter 2 discusses the data sets utilised, the methodologies utilised, and the rationale for modification to existing data sets.

Chapter 3: Study Area Description

This chapter provides a physical description of the catchment including climate, soils, land cover, population, groundwater use, geology and groundwater regions.

Chapter 4: Groundwater Resources in the study area, South Africa and Lesotho

This chapter describes the groundwater resources in terms of aquifer type, borehole yields, recharge, aquifer storage, groundwater resources, baseflow, groundwater use and stress index, groundwater quality, the groundwater reserve, remaining groundwater resources, aquifer vulnerability and the potential impact of groundwater abstraction on baseflow.

Chapter 5: Groundwater Resources in the study area, Botswana

This chapter describes the groundwater resources in terms of aquifer type, borehole yields, recharge, aquifer storage, groundwater resources, baseflow, groundwater use, stress index, groundwater quality, remaining groundwater resources and aquifer vulnerability.

Chapter 6: Groundwater Resources in the study area, Namibia

This chapter describes the groundwater resources in terms of aquifer type, borehole yields, recharge, aquifer storage, groundwater resources, baseflow, groundwater use stress index, groundwater quality, remaining groundwater resources and aquifer vulnerability

Chapter 7: Summary and conclusions

Chapter 8: References

2 EVALUATION OF DATA AND METHODOLOGIES

2.1 Approach

Several factors affect utilisation and exploitation of groundwater on a large scale and these need to be evaluated when assessing groundwater resources. These factors are:

- Borehole yield
- Aquifer storage
- Groundwater quality
- Recharge and Exploitability
- Existing Groundwater use
- Legislative considerations, protecting against sinkhole formation, conserving important groundwater dependant ecosystems, avoiding excessive drawdown, maintaining baseflow to rivers

The basic unit of evaluating the above factors was considered to be the Quaternary catchment, of which 496 exist in Primary catchments C, D covering South Africa and Lesotho. For Botswana and Namibia the Basic unit of analysis was the Litho-Hydrogeological Unit.

Catchments were overlain over Groundwater regions to delineate units of analysis; hence many Quaternary (South Africa and Lesotho) catchments are subdivided into units based on variations in geology, hence integrating hydraulic boundaries with geological boundaries and variations.

Criteria utilised to disaggregate catchments include:

- Nature of the aquifers (primary, secondary dolomitic, alluvial etc.).
- Groundwater depth.
- Lithology as it affects borehole yields and groundwater quality.
- Topography.
- Groundwater quality
- Recharge and available groundwater resources

Each subunit was then analysed in terms of aquifer storage, groundwater use, recharge, water quality, baseflow, borehole yield, aquifer vulnerability.

The objective was to:

- Identify water users in each subunit, including towns, industrial, mining and major irrigation users as well as deriving an estimate of rural water use (Schedule 1, South Africa and Lesotho and) and livestock water users.

- Identify groundwater stress based on use and available resources
- Identify water quality problem areas both in terms of natural constituents that hinder some uses and contamination. This was done by listing the percentage or number of samples falling into various water quality categories.
- Define catchments with significant unutilised groundwater resources
- Define surface groundwater interaction areas in terms of quantifying the volumetric contribution of baseflow to rivers.

2.2 Groundwater Regions

South Africa has been subdivided into groundwater regions (Vegter, 2001) with a corresponding number. The regions are based on:

- Geological age.
- Similar lithology.
- Structural terranes
- Physiography
- Climate.

The subdivision in the Orange Senqu basin into groundwater regions is shown in **Table 2-1** and **Figure 2-1**. These regions did not cover countries other than South Africa but have been extended to cover Lesotho. Entries in **Bold** are new and have been added to the original groundwater regions and have been defined for this project. Namibia has also been divided into groundwater basins as shown in **Table 2-2** and **Figure 2-2**. No groundwater regions have been delineated for Botswana and for this study, the area was subdivided into Litho-Hydrogeologic regions as shown in **Table 2-3** and **Figure 2-3**.

Groundwater regions to not always correlate across borders because of different aquifers being used by different countries. In Namibia, the Stampriet Karoo aquifer is used in the western Kalahari basin (24). In South Africa, the overlying sedimentary Kalahari aquifer is used (23), hence they are mapped as different regions with differing properties. In Botswana, the mapped geology is based on the underlying pre-Kalahari geology.

Table 2-1 Groundwater Regions, South Africa and Lesotho

Geology	Dominant Lithology	Region Name	Region number	Country
Swazian and Mokolian crystalline rocks	Metasedimentary and metavolcanics	Bushmanland	26	South Africa Namibia
	Metasedimentary and metavolcanics	Namaqualand	27	South Africa Namibia
Ventersdorp and Karoo Lava Regions	Basalt	**Drakensberg Highlands**	**65**	**Lesotho**
	Andesite, dacite, quartz porphyry, agglomerate etc.	Western Highveld	18	South Africa
Vaalian Strata	Shale, quartzite, andesite	Western Bankeveld and Bushveld	9	South Africa Botswana
	Dolomite and chert	Karst Belt	10	South Africa Botswana
	Dolomite, chert, limestone, shale	Ghaap Plateau	24	South Africa Botswana (minor)
Vaalian-Mokolian strata	Banded ironstone, mudstone, shale, dolomite	West Griqualand	25	South Africa
Namibian Strata	Quartzite, arkose, arenite, limestone, phyllite, schist and other metamorphics	Richtersveld or Far Northwestern Coastal Hinterland	54	South Africa Namibia
Carbo-Triassic strata	Shale, sandstone, coal, mudstone, sandstone	Eastern Highveld	28	South Africa
	Shale, dolerite	North eastern Pan Belt	30	South Africa
	Shale, dolerite	Central Pan Belt	31	South Africa

Geology	Dominant Lithology	Region Name	Region number	Country
	Sandstone, shale, mudstone, siltstone capped by basalt	Northeastern Highland	32	South Africa Lesotho
	Tillite, shale	Bushmanland Pan belt	34	South Africa
	Mudstone, shale, sandstone	Northeastern upper Karoo	33	South Africa
	Mudstone, shale, sandstone	**South Eastern upper Karoo**	**66**	**South Africa** **Lesotho**
	Shale, sandstone, mudstone	Western Upper Karoo	37	South Africa
	Mudstone, shale, sandstone	Eastern Upper Karoo	38	South Africa
Composite Regions	Granite gneiss, shale, quartzite, conglomerate, andesite and sedimentaries	Central Highveld	17	South Africa
	Gravel, sandstone, clay covering various lithologies	Eastern Kalahari	22	South Africa Botswana
	Mudstone, shale, sandstone	Western Kalahari	23	South Africa Botswana
	Andesite, dacite, quartz porphyry, breccia, shale, sandstone, tillite	Taung-Prieska Belt	29	South Africa
	Sandstone, shale, mudstone, siltstone capped by basalt	South eastern Highland	39	South Africa Lesotho

Table 2-2 Groundwater Regions, Namibia

Group	Dominant Lithology	Groundwater Basin
Fish River Sub Group	Sandstones and shales	Fish River Aroab
Kuibis and Schwarzrand Subgroups	Sandstones, limestones and shales	Fish River Aroab
Epupa, Huab and Abbabis Metamorphic Complexes	Gneisses and granites	Hochfeld-Dordabis-Gobabis
Gamsberg and associated granites	Granite	Hochfeld-Dordabis-Gobabis
Hakos Group	Sandstones	Hochfeld-Dordabis-Gobabis
Khomas Group	Schists	Hochfeld-Dordabis-Gobabis
Matchless Belt	Amphibolite	Hochfeld-Dordabis-Gobabis
Rehoboth Group and associated rocks	Granites	Hochfeld-Dordabis-Gobabis
Sinclair Group and equivalents	Granites	Hochfeld-Dordabis-Gobabis
Witvlei Group	Limestones and sandstones	Hochfeld-Dordabis-Gobabis
Dykes and sills	Basalt and Dolerite	Karas Basement
Haib	Gneisses	Karas Basement
Namaqua Metamorphic Complex	Gneisses	Karas Basement
Vioolsdrift Granite Suite	Granites	Karas Basement
Gariep Complex	Schists and amphibolites	Southern Namib and Naukluft
Naukluft Mountains	Limestones and shales	Southern Namib and Naukluft
Kalahari and Namib Sands	Sands and calcrete,	Stampriet Basin
Kalkrand Basalts	Basalt	Stampriet Basin
Main Karoo Basin	Sandstones and shales	Fish River Aroab, Stampriet

Table 2-3 Groundwater Regions, Botswana

Lithostratigraphic Unit	Dominant Lithology	Litho-Hydrogeological Unit (Groundwater Basin
Ecca	Interbedded coal, carbonaceous siltstone and mudstone and white and poorly cemented sandstone	Ecca North
Ecca	Interbedded coal, carbonaceous siltstone and mudstone and white and poorly cemented sandstone	Ecca East
Ecca	Interbedded coal, carbonaceous siltstone and mudstone and white and poorly cemented sandstone	Ecca South
Ecca	Interbedded coal, carbonaceous siltstone and mudstone and white and poorly cemented sandstone	Ecca West
Beaufort	Pale grey, non-carbonaceous siltstone and mudstone	Beaufort
Dwyka	Assorted glacial deposits including diamictite, very thinly laminated siltstone (varvite) and sandstone	Dwyka East
Dwyka	Assorted glacial deposits including diamictite, very thinly laminated siltstone (varvite) and sandstone	Dwyka North
Dwyka South	Assorted glacial deposits including diamictite, very thinly laminated siltstone (varvite) and sandstone	Dwyka South
Gaborone Granite	Granite	Gaborone Granite North
Gaborone Granite	Granite	Gaborone Granite South
Granite Sheet and Stock	Granite	Granite Sheet and Stock
Kanye Formation	Homogeneous felsite	Kanye Formation
Kgoro Complex	Diorite	Kgoro Complex
Late Karoo Dolerites	Dolerite	Late Karoo Dolerites
Lebung	Orange, red or white sandstone, with reddish siltstone increasingly common downwards the bottom	Lebung
Lower Molopo	Undifferentiated Ultrabasic Rocks	Lower Molopo
Lower Transvaal	Basal quartzite (Black Reef Quartzite), dolomitic limestone, chert, minor limestone, ironstone, variably carbonaceous siltstone and shale	Lower Transvaal North

Lithostratigraphic Unit	Dominant Lithology	Litho-Hydrogeological Unit (Groundwater Basin
Lower Transvaal	Basal quartzite (Black Reef Quartzite), dolomitic limestone, chert, minor limestone, ironstone, variably carbonaceous siltstone and shale	Lower Transvaal South
Mabua Sehube	Metamorphosed arkosic sandstone, limestone, shale, mudstone, ironstone	Mabua Sehube
Mmathethe Granite	Granite	Mmathethe Granite
Nnywane and Mogobane	Rhyolitic volcanics, breccio-conglomerate, siltstone, sandstone, mudstone and shale	Nnywane and Mogobane Formation N
Nnywane and Mogobane	Rhyolitic volcanics, breccio-conglomerate, siltstone, sandstone, mudstone and shale	Nnywane and Mogobane Formation South
Olifanthoek	White to reddish quartzite with minor shale	Olifanthoek North
Olifanthoek	White to reddish quartzite with minor shale	Olifanthoek South
Proterozoic and Archaen Ironstone	Ironstone	Proterozoic and Archaen Ironstone
Segwagwa	Syenite	Segwagwa North
Segwagwa	Syenite	Segwagwa South
Undifferentiated Waterberg	Reddish siliciclastic sedimentary rocks, mostly sandstone and conglomerate	Undifferentiated Waterberg North
Undifferentiated Waterberg	Reddish siliciclastic sedimentary rocks, mostly sandstone and conglomerate	Undifferentiated Waterberg Central
Undifferentiated Waterberg	Reddish siliciclastic sedimentary rocks, mostly sandstone and conglomerate	Undifferentiated Waterberg South
Undifferentiated Ghanzi	Weakly metamorphosed purple-red to greenish grey, siliciclastic sedimentary rocks, mostly quartzites	Undifferentiated Ghanzi
Upper Molopo	Norite	Upper Molopo
Upper Transvaal	Interbedded reddish quartzite, shale, variably manganiferous and carbonaceous siltstone with chert, dolomite, ironstone, andesitic volcanics and breccia	Upper Transvaal North
Upper Transvaal	Interbedded reddish quartzite, shale, variably manganiferous and carbonaceous siltstone with chert, dolomite, ironstone, andesitic volcanics and breccia	Upper Transvaal West

Lithostratigraphic Unit	Dominant Lithology	Litho-Hydrogeological Unit (Groundwater Basin
Upper Transvaal	Interbedded reddish quartzite, shale, variably manganiferous and carbonaceous siltstone with chert, dolomitese, ironstone, andesitic volcanics and breccia	Upper Transvaal East
Archaen Gneiss	Banded, quartzofeldspathic gneiss	Archaen Gneiss
Archaen Amphibolites	Amphibolite	Archaen Amphibolites East
Archaen Amphibolites	Amphibolite	Archaen Amphibolites West
Archaean and Palaeoproterozoic Felsites	Felsite	Archaean and Palaeoproterozoic Felsites

2.3 Catchments

The basic unit of analysis used for South Africa and Lesotho was the Quaternary catchment, as defined in WR2012. Large units of Geology, soils and groundwater regions were intersected with Quaternary catchments to define hydraulically connected units of similar property.

The study area covers Primary Drainage Regions C and D for South Africa and Lesotho, and Tertiary Drainage Regions Z10 and Z20 for Botswana and Namibia. For Namibia and Botswana, the basic unit of analysis was the litho-hydrogeologic unit (**Figures 2-2 and 2-3**).

2.4 Borehole Yield

Borehole yield data is important to assess the exploitability of groundwater resources in an economical manner, as opposed to assessing availability from aquifer storage and recharge only.

The prospects of utilising aquifers for water supply can be assessed from the yield distribution of boreholes within hydrogeologically defined regions. The basic homogenous region is termed a lithostratigraphic unit and the available data as indicated in **Table 2-1 to 2-3** allowed such an analysis to be undertaken for all 4 countries.

A yield of more than 2 l/s is generally considered to be the margin at which a motorised pump and reticulation system become viable, hence yields were analysed in terms of mean and median yields, as well as the percentage of boreholes yielding more than 0.5, 2 and 5 l/s. However, for the Namibian part of the basin, productive boreholes were taken as boreholes yielding more than 0.83 l/s (3 m^3/hr) into order to be consistent with the hydrogeological map of Namibia of 2011.

2.4.1 South Africa and Lesotho

A National groundwater map of South Africa was compiled by Vegter (1995) and it did not cover adjacent countries. The data on which this map is based is now over 20 years old hence it was considered preferable to gather all the borehole data in the NGA for the basin and reclassify the yield distributions. The same lithostratigraphic map units were utilised, however the data was also interpreted by Quaternary catchment.

Lesotho has a 1:300 000 Hydrogeology map, however it is of a qualitative nature hence not useful for an analysis of groundwater availability or exploitability. Borehole data was used to characterise the yield distributions, which were merged with South African data where units cross national borders.

2.4.2 Namibia and Botswana

Namibia and Botswana have a 1:1000 000 hydrogeology maps, as these maps are of a qualitative nature, borehole data was used to characterise the yield distributions, per litho-hydrogeologic unit in each country.

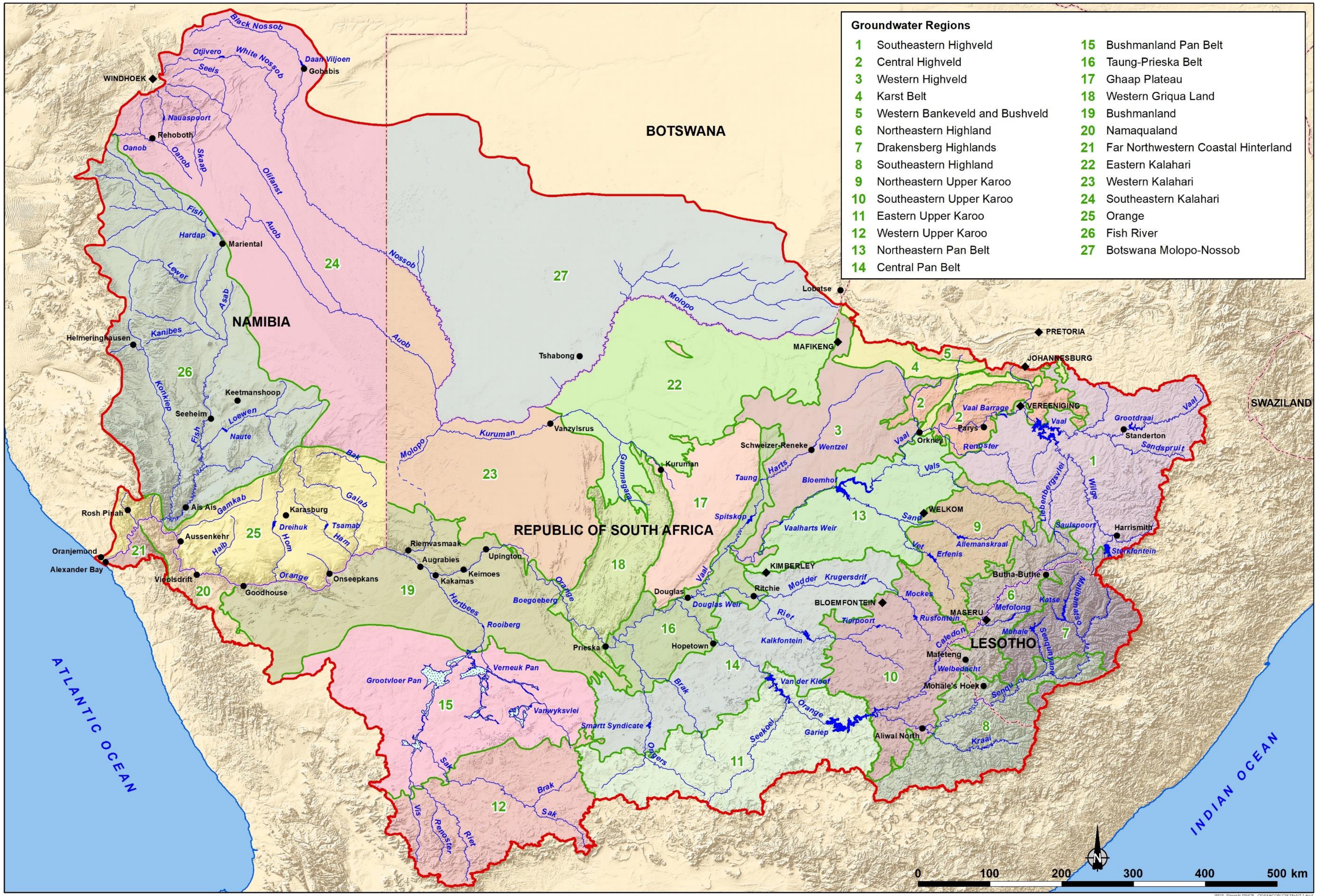


Figure 2-1 Groundwater Regions, ORASECOM Basin

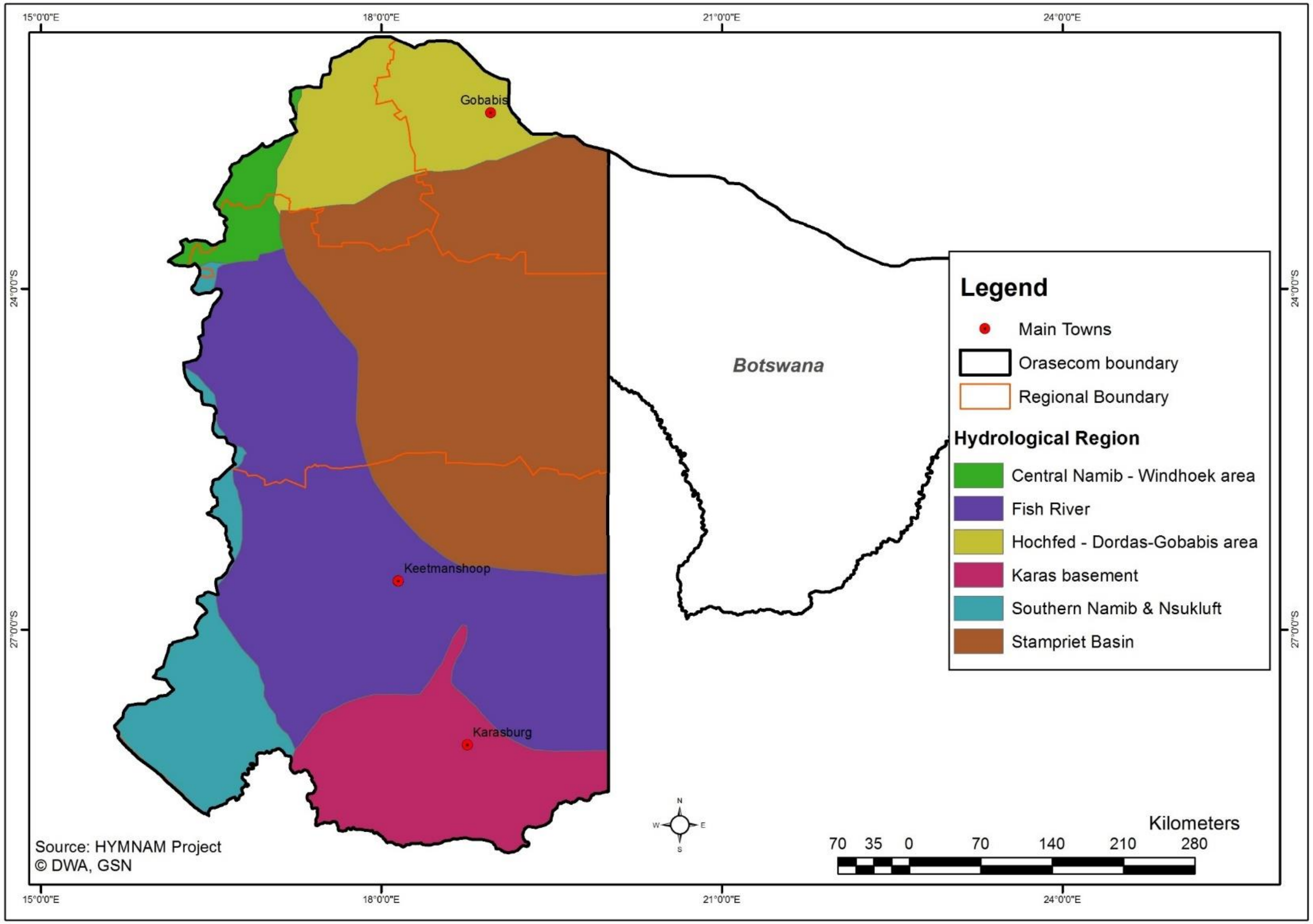


Figure 2-2 Groundwater Basins, Namibia

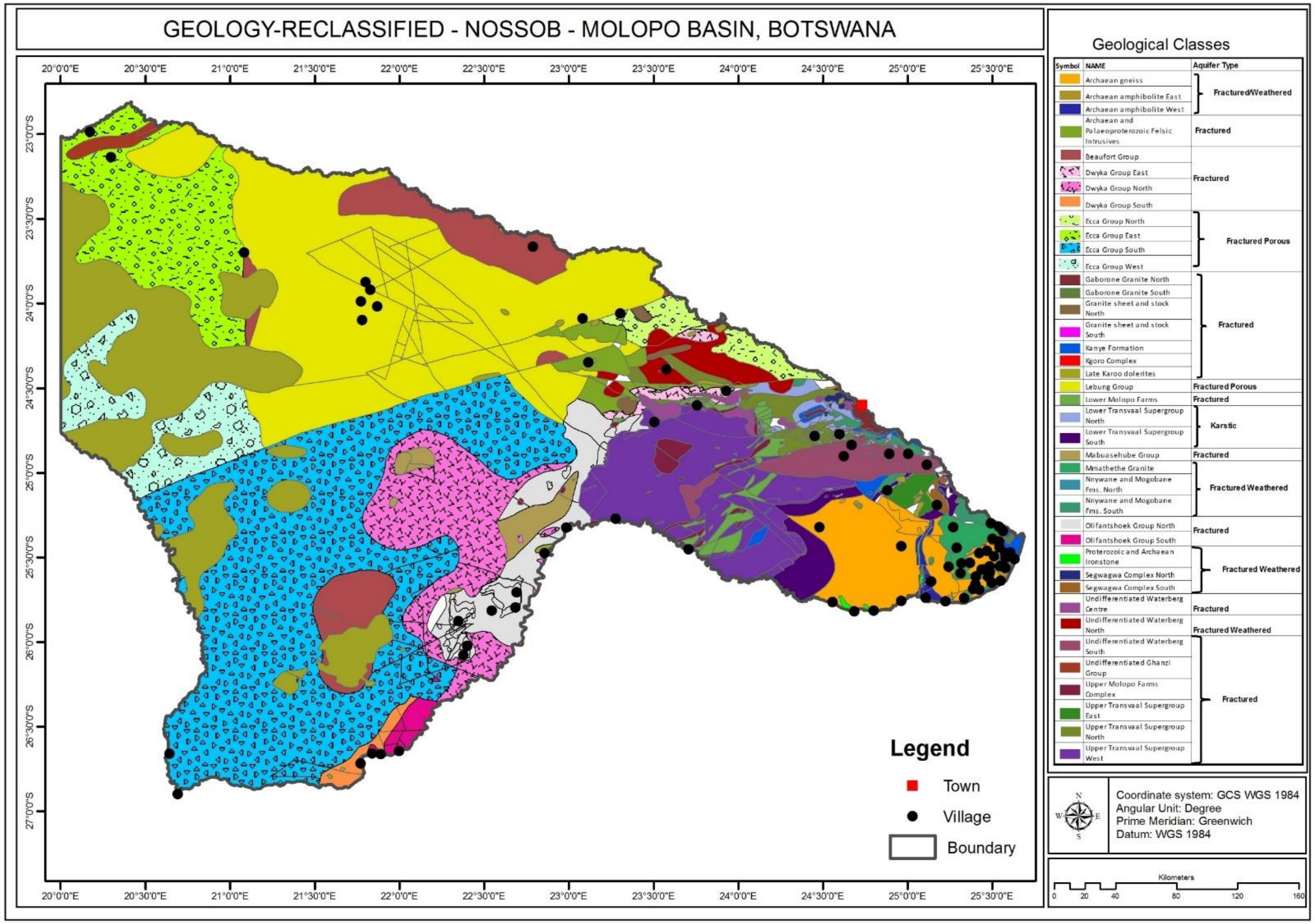


Figure 2-3 Litho-Hydrogeological Units (Groundwater Basins), Botswana

2.5 Groundwater Use

2.5.1 South Africa

2.5.1.1 Irrigation

Groundwater use was obtained from the WARMS database. It has to be noted that WARMS is not indicative of actual use but a measure of legal or authorized water use registration which is legally protected.

2.5.1.2 Livestock

WARMS does not include livestock water use. Livestock water use was obtained from GRAII.

2.5.1.3 Industry and Mining

Groundwater use was obtained from WARMS. Water use for power generation is included as industry.

2.5.1.4 Water Supply

Groundwater use was obtained from WARMS. Not all water schemes are registered on WARMS. Where no data exists on WARMS, but a water use is recorded in GRAII, the GRAII figure was utilized. The detailed data from the Lower Orange EWR study was used in preference to WARMS for the Lower Orange.

2.5.1.5 Schedule 1

WARMS does not include Schedule 1 water use, which is private small scale water use for domestic purposes. Schedule 1 water use for the Lower Orange was obtained from the Lower Orange EWR Report (DWS, 2016), where it forms a large component of groundwater use.

2.5.2 Lesotho

Water use by Urban Councils was obtained from the Lesotho State of Water Report. Water use was allocated to the appropriate Quaternary catchment. The total groundwater use is 4.12 million m^3/a.

For rural groundwater use, the volume of surface water pumped was divided by population served by functioning water systems in rural areas (699 270 people of a total rural population of 1 624 806). The consumption was 26-50 l/c/d. Based on this water use figure, it was then assumed that all this population served are served by surface water. The remainder of the population (925 535) was assumed to use groundwater (whether boreholes with motorized or hand pumps or springs) and was allocated a usage of 25 l/c/d. The groundwater use for the district was then apportioned by the area of each Quaternary catchment underlying the District. A total groundwater use of 8.45 million m^3/a was obtained for rural water use. This water use was assumed equivalent to the South African Schedule 1 water use.

1100 ha are under irrigation. This was assumed to be based on surface water.

2.5.3 Namibia

Groundwater use data by sector was obtained from the IWRM plan for Namibia (2010) and indicates, that total groundwater use in the Orange-Senqu Basin within Namibia is over 40 million m^3/a with highest water users being livestock and irrigation respectively.

2.5.3.1 Irrigation

Irrigation groundwater use in the basin is estimated as 12.95 million m^3/a with the highest use of 12.5 million m^3/a occurring in the Nossob-Auob water supply area.

2.5.3.2 Livestock

The total groundwater use for livestock is estimated to be about 22.5 million m^3/a (IWRM Plan for Namibia) with the highest use of 13.1 million m^3/a occurring in the Nossob-Auob groundwater supply area (part of the Stampriet basin).

2.5.3.3 Mining

There is no mining groundwater use in the Namibian part of the basin.

2.5.3.4 Municipal Water Supply

Domestic groundwater water supply for municipal water supply and rural water supply in the basin is relatively low estimated as 3.5 million m^3/a (NAMWATER) and 1.1 million m^3/a for rural water supply.

2.5.4 Botswana

2.5.4.1 Irrigation and Mining

There is no irrigation or mining groundwater use in the Botswana part of the basin.

2.5.4.2 Livestock

An estimate of possible abstraction for livestock use was made based on livestock population density data from the 2015 Botswana Agricultural Census per -Litho-Hydrogeological Unit. The total groundwater water use for livestock watering was estimated as 3.59 million m^3/a.

2.5.4.3 Water Supply

Domestic groundwater use data was obtained from the Water Utilities Corporation (WUC) records for the period 2013 to 2017 and indicates the total domestic groundwater use is about 5.65 million m^3/a.

2.6 Groundwater Resources Assessment

2.6.1 GRA Methodologies

GRAII is a data set using hydrogeological, geological, hydrological and water use data to produce groundwater resource potential information for planning purposes. GRA II calculates a Groundwater Resource Potential (GRP) as an estimate of the maximum volume (m^3) of groundwater that is potentially available for abstraction on an annual basis under pristine aquifer (i.e. no abstraction) and normal rainfall conditions. It does not consider the practicalities or feasibility of abstracting the water in terms of the number and/or spacing of production boreholes. It uses the following basic algorithm:

$AGRP = [R_e + (S_v / D_i)] - B_f$ .... Eq (1)

Where R_e = Mean Annual Potential Recharge (m^3 / a.

S_v = Mean Volume of Water stored in Aquifer (m^3). The upper 5m to 10 m (i.e. below the water table) of aquifer was considered to be feasibly abstractable over a given period of time.

D_i = Drought Index

B_f = Mean Annual contribution to River Baseflow.

The Drought Index or Di is used to assess the number of years required to bridge cycles of negligible or no aquifer recharge from rainfall, where groundwater abstracted will almost entirely be removed from aquifer storage. It is equal to the 20th Percentile of annual rainfall / Median Annual Rainfall.

The Groundwater Resource Potential only takes into consideration the volumes of water held in aquifer storage and the recharge from rainfall. The feasibility of abstracting this water is limited by many factors due mainly due to the physical attributes of a particular aquifer system, economic and/or environmental considerations. One of the most important of these is the inability to establish a network of suitably spaced production boreholes to ‘capture’ all the available water in an aquifer system or on a more regional scale.

The factors limiting the ability to develop such a network of production boreholes, includes the low permeability or transmissivity of certain aquifer units, accessibility of terrain to drilling rigs, unknown aquifer boundary conditions etc.

An Exploitability Factor (EF) was used to downscale the Groundwater Resource Potential (GRP) and derive a Groundwater Exploitation Potential (GEP). An Exploitability Factor was developed from the probability of drilling a borehole with a yield of > 2 l/s for South Africa, Lesotho and Botswana while for Namibia a yield of 0.83 l/s was used (in line with hydrogeological map of Namibia). This generates Exploitation factors of 0.2 in low yielding aquifers to 0.6 in high yielding aquifers

The Groundwater Exploitation Potential or GEP, which is the portion of the GRP that can practically be abstracted, is defined as follows:

GEP = GRP * EF .... Eq. (2).

Groundwater quality is one of the main factors restricting the development of available groundwater resources. Although there are numerous problems associated with groundwater quality, some of which are relatively easily remediated, high concentration of total dissolved solids (TDS), nitrates (NO_3 and NO_2) and Fluoride (F) are considered to be the most common and serious problems associated with water quality on a regional scale.

The proportion of potable groundwater or Potability Factor (PF) for each Quaternary catchment and litho-hydrogeologic unit (Botswana and Namibia) using available data for total dissolved solids, nitrate, fluoride potassium, sodium, sulphate and calcium concentrations in the water was utilised to calculate a Potable Groundwater Exploitation Potential (PGEP). Groundwater classified as poor or unacceptable was considered not to be potable.

The Potable Groundwater Exploitation Potential (PGEP) is estimated using the Potability Factor (probability of drilling borehole with a TDS meeting specified criteria) as follows:

PGEP = GEP * PF .... Eq. (3)

The volume of water that may be abstracted from a groundwater resource may ultimately be limited by anthropogenic, ecological and/or legislative considerations, which ultimately is a management decision that will reduce the total volume of groundwater available for development – referred to as the Utilisable Groundwater Exploitation Potential (UGEP). In South Africa, legislative restrictions are imposed on the volumes of groundwater available for utilisation by the requirements of the ‘Groundwater Component’ of the Reserve as stipulated in the National Water Act (1998). Other aspects such as protection against the hazards of saline intrusion or sinkhole formation, conserving important groundwater dependant ecosystems, avoiding excessive drawdown, maintaining baseflow to rivers etc. can all be factored in using this approach.

The groundwater requirements of the ecological reserve are catered for by prescribing a fixed-level below which the water level may not decline. This approach reduces the volume of groundwater held in aquifer storage that is available for abstraction and is especially important during droughts where aquifer losses (abstraction) often exceed aquifer gains (recharge).

The Utilisable Groundwater Exploitation Potential (UGEP) is derived by replacing the S_v term in eq. 1 with a S_{vr} term, which is the groundwater held in storage in the allowable water level drawdown, varying from 0-10 m depending on the catchment so that:

UGEP = $([R_e + (S_{vr} / D_i)] – B_f)$* EF (eq. 4)

Where S_{vr} = aquifer storage in the depth of maximum drawdown

Groundwater storage, a fundamental basis to derive S_v was based on values of Storativity for the weathered zone and fractured zone. The depth of the weathered and fractured zones was determined from water strike frequency per Groundwater region where data was available and borehole depth where water strike data is not available. To take into account variations in weathered thickness, the slope factor was utilised, and saturated weathered thickness was multiplied by the slope factor to calculate weathered aquifer storage by:

Weathered storage ($S_{vweathered)}$ = $S_{weathered}$ * Thickness of saturated weathered zone * slope factor (eq. 5)

2.6.2 Assessment of Assumptions

An examination of eq.1 shows that calculations of GRP and GEP are based on:

- Estimates of aquifer storage
- Estimates of recharge
- Estimates of baseflow utilised

It is assumed the depth of weathered zone, exploitation, potability and slope factors are correct since they are based on physical data.

It is also evident from eq. 1 that AGRP will ALWAYS be higher than recharge when there is no baseflow.

2.6.2.1 Aquifer Storage

A perusal of the GRAII database for the study area, sorting for the 5 highest and 5 lowest storativity values (ignoring zero values for large parts of Lesotho) illustrates the problems with storativty values in GRAII, which appear to have never been verified by a simple analysis of extreme values. The upper range is considered to be too high, as known storage in the dolomite is of the order of 0.02-0.03. This situation is made worse when it is considered that the entire catchment is not underlain by dolomite. In comparison, storativities in basalt are of the order of 0.001. Limited storativity data is available for Namibia and Botswana

Due to limited-availability of storativity data for Namibia and Botswana and the large amount of questionable data in the GRAII database (South Africa and Lesotho). It was decided to calculate storativities using an S-curve equation:

Storativity = $a/(1+e^{(c+(SWL*b))})$ …. eq. (5)

Where:

a, b, and c are parameters to define the upper limit of storativity, the 'break point' of the curve where the rate of decline in S stabilises with depth. The break point of the curve was calibrated to match the depth of the weathered zone. The a, b and c parameters were calibrated for each groundwater region. The SWL (Static water level) was calculated for the weathered zone by:

SWL = (weathered zone thickness- static water level)/ (3+static water level)

So that the SWL used to determine storativity was approximately at the weighted mean saturated thickness.

Table 2-4 Comparison of Storativty in GRAII and this study (RSA, and Lesotho)

Catchment	Geology	GRAII Weathered Zone S	GRAII Fractured Zone S	Recalculated Weathered Zone S	Recalculated Fractured Zone S
C24C	Dolomite, shale	0.087944	0.003656	0.001-0.019	0.00000258-0.00027
C31A	Dolomite, tillite, conglomerate	0.077076	0.003270	0.002-0.0278	0.00001-0.0007
C23F	Dolomite, shale	0.062883	0.002532	0.0039-0.017	0.0000687-0.0003
C21D	Arenite, dolomite	0.051996	0.002190	0.002-0.028	0.0000123-0.00075
C24F	Dolomite, andesite	0.048570	0.002048	0.0026-0.032	0.0000278-0.0015
D22F	arenite	0.000014	0.000001	0.00257	0.000155
D17L	Basalt, arenite	0.000013	0.000000	0.00265	0.000266
D21L	Basalt, arenite	0.000010	0.000000	0.00264	0.0001
D21B	Basalt, arenite	0.000008	0.000000	0.0013-0.00255	0.000025-0.00014
D18J	Basalt, mudstone	0.000004	0.000000	0.0044	0.000266

For the fractured zone, the following equation was used:

SWL = (fractured zone thickness/ (3+weathered zone thickness)

Where catchments cut across more than 1 groundwater region, the storativity calculations were area weighted. The corrected S values for South Africa and Lesotho are shown in **Table 2-4**.

2.6.2.2 Baseflow

An assessment of baseflow is shown in **Table 2-5**.

Table 2-5 Comparison of Baseflow and AGRP from GRAII and this study (South Africa and Lesotho)

Catchment	Geology	GRAII Baseflow For AGRP Mm^3/a	GRAII Groundwater baseflow Mm^3/a	GRAII Total baseflow Mm^3/a	GRAII Recharge Mm^3/a	GRAII AGRP Mm^3/a	This study AGRP Mm^3/a
C24C	Dolomite, shale	21.57	21.55	21.74	53.58	618.60	131.92
C31A	Dolomite, tillite, conglomerate	0.85	0.85	0.95	34.90	585.01	161.99
C23F	Dolomite, shale	22.90	22.97	22.97	57.22	427,21	101.38
C21D	Arenite, dolomite	4.17	4.20	5.18	17.49	128.69	40.52
C24F	Dolomite, andesite	8.88	8.86	11.07	54.46	537.86	186.86
D22F	arenite	5.62	5.62	23.46	32.99	27.55	17.08
D17L	Basalt, arenite	5.32	5.29	25.80	28.89	23.85	9.78
D21L	Basalt, arenite	2.66	2.62	17.00	21.02	18.79	7.67
D21B	Basalt, arenite	4.91	4.94	36.27	37.58	33.09	3.52
D18J	Basalt, mudstone	7.34	4.56	30.18	43.06	36.43	17,64

It is clear that when the AGRP was calculated, only the groundwater baseflow was utilised in eq 1. However, the entire volume of recharge was utilised, much of which is lost as interflow, especially in steep catchments. This will result in overestimates of AGRP, especially in catchments with a significant volume of interflow (**Table 2-5**).

AGRP was recalculated using the corrected storativities and the correct baseflow using eq.1.

2.6.2.3 Aquifer recharge

The estimation of recharge is one the most important components for groundwater resource evaluation. During the Lower Orange EWR study, it was found that when GRAII recharge is plotted against rainfall, it was observed that below 150 mm/a of rainfall, a wide scatter of recharge can be observed and numerous zero values (**Figure 2-4**). Consequently, recharge was plotted versus rainfall for each groundwater region to derive rainfall recharge relationships (**Figure 2-5**). These relationships were then used to estimate recharge when recharge in GRA II was given as less than 1 mm/a. This required correcting recharge for 78 of 178 quaternary units and recharge increased from 396 million m^3/a in GRAII to 480 Mm^3/a for the study by the removal of zero values. The recharge values were validated against water levels, as it was not possible that abstraction occurs, and water levels fluctuate and are stable with zero recharge.

The corrected recharge values from the Lower Orange EWR study were utilised for this study to recalculate groundwater resources.

Recharge values for the Botswana part of the basin are based estimates from studies conducted by various projects in area and for Namibia a recharge value of 0.1 mm per annum was applied.

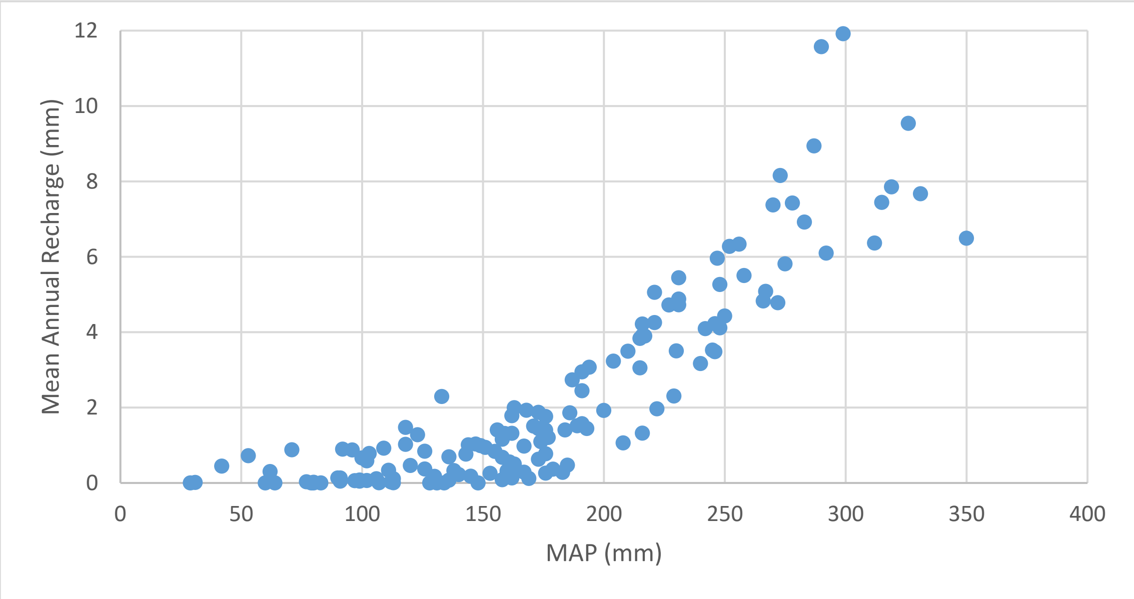
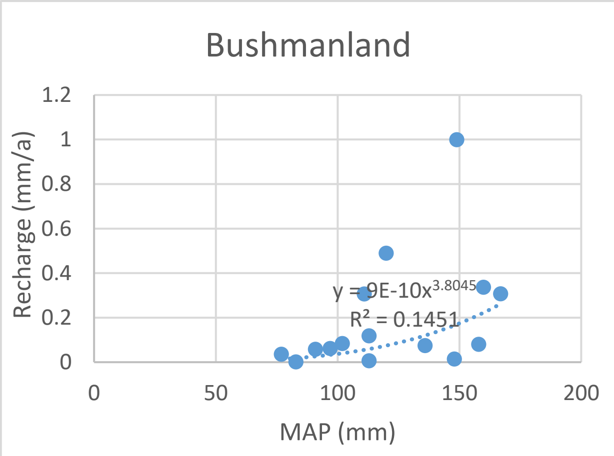
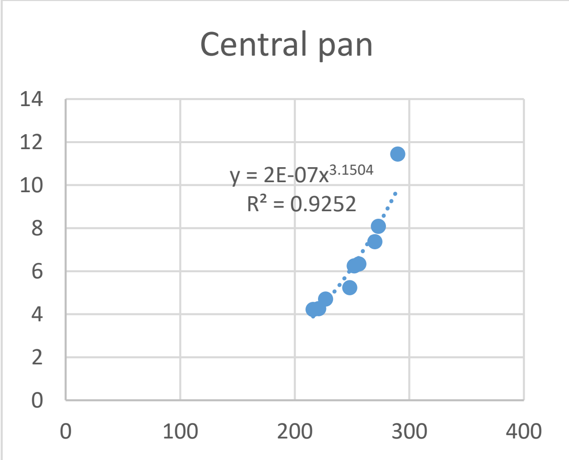
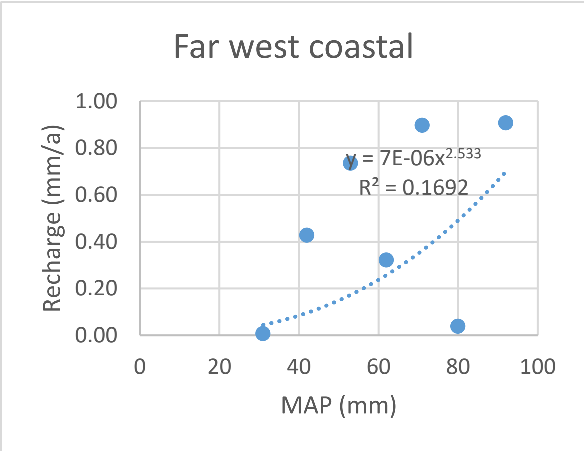
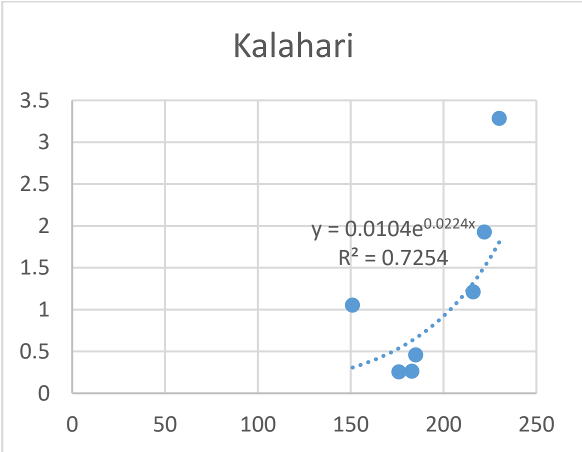


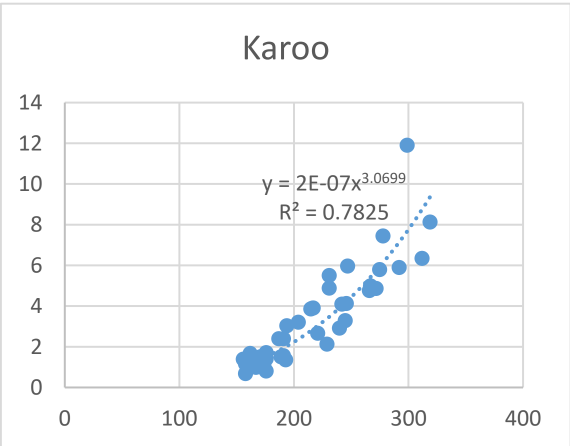
Figure 2-4 Rainfall vs GRAII recharge

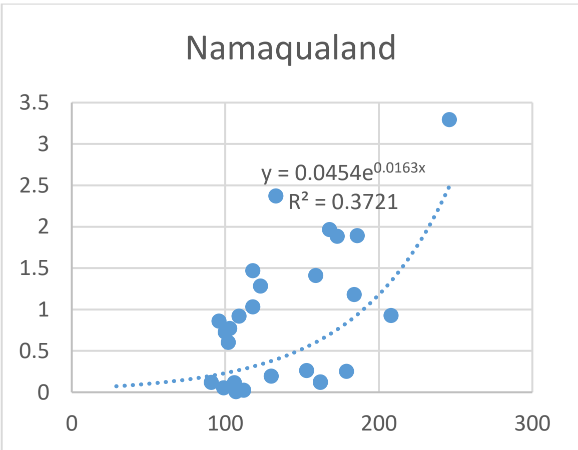

Bushmanland
Recharge (mm/a)
1.2
1
0.8
0.6
0.4
0.2
0
0
50
100
150
200
MAP (mm)
y = 9E-10x^3.8045
R² = 0.1451


Central pan
14
12
10
8
6
4
2
0
0
100
200
300
400
y = 2E-07x^3.1504
R² = 0.9252


Far west coastal
Recharge (mm/a)
1.00
0.80
0.60
0.40
0.20
0.00
0
20
40
60
80
100
MAP (mm)
y = 7E-06x^2.533
R² = 0.1692


Kalahari
3.5
3
2.5
2
1.5
1
0.5
0
0
50
100
150
200
250
y = 0.0104e^0.0224x
R² = 0.7254


Karoo
14
12
10
8
6
4
2
0
0
100
200
300
400
y = 2E-07x^3.0699
R² = 0.7825


Namaqualand
3.5
3
2.5
2
1.5
1
0.5
0
0
100
200
300
y = 0.0454e^0.0163x
R² = 0.3721

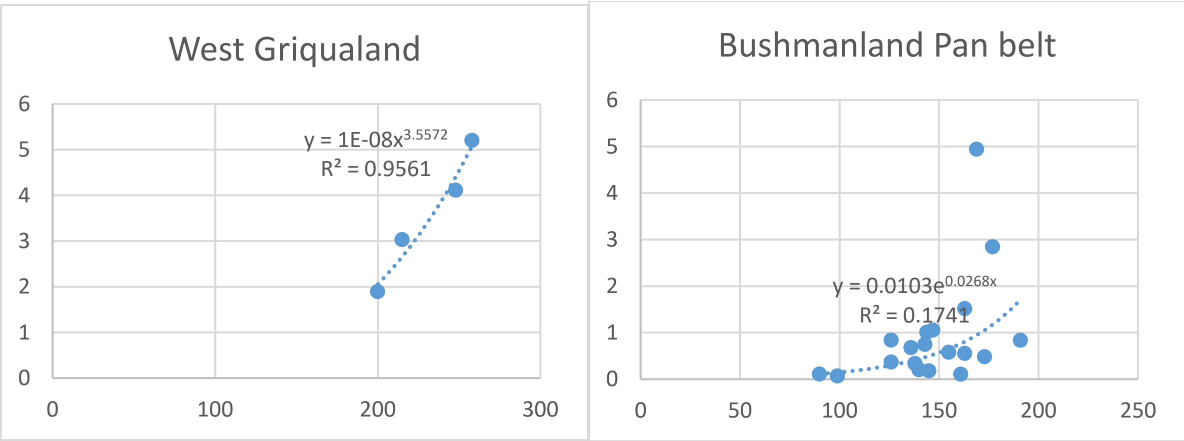


Figure 2-5 Relationship between MAP (mm/a) and Recharge (mm/a) per groundwater region (RSA)

The ORASEOM Transboundary aquifer recharge study (2018) found that GRAII recharge figures for Lesotho are a large overestimate. The observed baseflows do not support such large recharge volumes. This can be attributed to the GRAII results being based on the Chloride method, which assumes that all Cl from precipitation ends up in groundwater. This assumption is not valid in the area as surface runoff is high. The Cl method therefore overestimates the Cl load to groundwater, hence increasingly overestimates recharge with increasing volumes of surface runoff. The error was found to increase from 10-80% with increasing proportions of surface runoff. It can be concluded that the Cl method cannot be applied in catchments where surface runoff is significant.

The results show that catchments underlain by basalt generate proportionally more runoff than those underlain by sedimentary rocks. The basalt aquifers also generate a higher proportion of baseflow. In the basalt catchments, over 90% of baseflow originates as interflow, and doesn't pass through the regional aquifer. This implies that over 90% of recharge is not accessible as a groundwater resource, resulting in the low borehole yields and limited groundwater resources in the basaltic Highlands. In the drier sedimentary lowlands, the bulk of recharge percolates to the regional aquifer.

Regional rainfall-recharge relationships were developed for the Highlands and Lowlands, and the mean annual recharge figures calibrated to stream flows were utilised in preference to GRAII.

2.6.3 Conclusions

Due to the errors and incorrect conceptualisations in GRAII, it was not considered of value to repeat and disseminate these errors by reproducing them for this study. The following procedure was adopted:

- Storativity (S) was recalculated for each groundwater region, and the highest and lowest value in each region was verified
- Only the groundwater stored in the upper 5 m to 10 m of the aquifer, whether the weathered or fractured zone or a combination of the two) was utilised in equation 1.
- The static water level used to calculate S was the weighted mean depth of the saturated weathered and fractured zone
- Total baseflow was used including interflow, since the recharge values in GRAII include recharge that drives interflow
- Where corrected recharge values were available, these were used in preference to GRAII.

Groundwater resources were then calculated utilising eq. 1-4, and a verification was included so that Exploitation Potential AGEP does not exceed recharge. If this occurred, GEP was defaulted to 95% of recharge.

2.7 Aquifer Pollution Vulnerability

Some aquifers are susceptible to contamination from surface due to shallow groundwater tables, thin soil cover, coarse soils with low clay content and unconfined aquifer conditions. Fractured aquifers allow rapid entry and migration of contaminants via preferred pathways and have the potential to contaminate vast areas along the fracture network.

Groundwater vulnerability was considered in terms of the DRASTIC method of assessment of the intrinsic vulnerability of an aquifer to contamination from the surface. The method considers various factors which control the vulnerability of an aquifer to contamination from surface.

The DRASTIC Approach to aquifer vulnerability assessment is based on superimposing various layers of data with prescribed ratings. The final outcome/rating is then used to categorise the level of vulnerability. Higher ratings are associated with aquifers that have higher vulnerability and susceptibility to contamination from the surface. The term DRASTIC originates from the following layers:

D - Depth to groundwater

R - Recharge rate (net recharge)

A - Aquifer media; Obtained from the Geological maps

S - Soil media; obtained from the soils data set, (WR2012, RSA) intersected with geology

T – Topography; obtained from GRAII and from a 20 m DTM

I - Impact on vadose zone; obtained from the Geological maps

Each of these layers is assigned a value based on a rating (r) and a weight (w). These layers are adjusted by a weighting factor and summed to calculate the DRASTIC index. The DRASTIC formula for groundwater in South Africa according to Lynch *et al*. (1994) is as follows:

DRASTIC INDEX = DrDw + RrRw+ ArAw+ SrSw+ TrTw+ IrIw

Depth to groundwater (Dw)

Recharge (Rw)

Aquifer media (Aw)

Soil media (Sw)

Topography (% slope) (Tw)

Impact of vadose zone (Iw)

The weights of each of the above-mentioned terms are shown in **Table 2-6**.

Table 2-6 DRASTIC Ratings and Weighting

Depth to groundwater (mbgl)	Rating	Weighting	Recharge (mm/a)	Rating	Weighting	Aquifer	Rating	Weighting
<1.5	10		0 - 5	1		Karstic (dolomite)	10	
1.5 to 4.5	9		5 - 10	3	4	Intergranular	8	3
4.5 to 9	7		10 - 50	6		Fractured	6	
9 to 15	5	5	>50	8		Fractured and weathered	3	
15 to 22.5	3							
22.5 to 30	2							
>30	1							
Topography Slope rating (%)	**Rating**	**Weighting**	**Impact of vadose zone**	**Rating**	**Weighting**	**Soil**	**Rating**	**Weighting**
0-2	10		Gneiss, Basalt, Dolorite, schist/amphibolite	3		Loamy Medium Sand (LmS)	6	
2-6	9	1	Mudstone/shale, sandstone/shale	3	5	Sand	10	2
6-12	5		Karoo (Sandstone)	5		sandy clay (Sacl)	5	
12-18	3		Granite, amphibolite, felsite, Seynite, Norite	6		sandy clay loamy (SaClLm)	5	
			Dolomite	10		sandy loamy (Salm)	6	
			Quartzite	8				
			Kalahari (sand)	10				

A DRASTIC index below 80 is considered low vulnerability to insignificant, and a rating of above 130 is a high vulnerability to extreme (**Table 2-7**).

Table 2-7 DRASTIC Indices Classification

DRASTIC INDEX	**Vulnerability**
0-70	Insignificant
70-80	Very Low
80- 100	Low
100 – 120	Moderate
120-130	High
130 - 150	Very High
150 -200	Extreme

2.8 Quantifying Groundwater Stress

The concept of stressed water resources is often addressed and needs to be defined quantitatively. The groundwater stress index is used to reflect water availability versus groundwater used. The Stress Index for an assessment area is defined as follows:

Stress Index = Groundwater use/Recharge.

In calculating the Stress Index, the variability of annual recharge is taken into account in the sense that not more than 65% of average annual recharge should be allocated on a catchment scale without caution and monitoring.

Although the total recharge is used, it is preferable to use aquifer recharge, the portion of recharge that enters the regional aquifer after losses to interflow above the regional aquifer. Aquifer recharge is the resource available to boreholes. In wet mountain catchments, recharge is high but most recharge is lost as interflow and little groundwater is available to boreholes due to a low aquifer recharge.

Stress index can be used to describe the status of the aquifer (**Table 2.8**)

Table 2-8 Classification of groundwater by stress

Usage	Description	Stress Index
Minimally used	Unmodified	≤0.05
	Largely natural	0.05 - 0.2
Moderately used	Moderate usage	0.2 - 0.4
	High usage	0.4 - 0.65
Heavily used	Highly stressed	0.65 - 0.95
	Critical over abstraction	>0.95

2.9 Environmental Water

In South Africa a component of Groundwater is considered the groundwater component of the Reserve and is not available for allocation. The Reserve is mandated under the Water Act of 1998 and protected under this Act. This component is to protect baseflows and environmental flows, and a Basic Human Need Reserve to reserve groundwater for people who do not at present have a legally protected water supply.

The data was obtained from the National Integrated Water Information System (NIWIS), and the recently completed Lower Orange Ecological Water Requirements Report (DWS, 2016), which has not yet been uploaded on the NIWIS.

In Lesotho, some Quaternary catchments, Botswana and Namibia a reserve has not been set.

2.10 Allocable Groundwater

Allocable groundwater was considered to be the difference between aquifer recharge, the reserve and current legally protected groundwater use (Licenced water use, groundwater use under a General Authorisation, and Schedule 1 water use). The following formula was applied:

Allocable Groundwater = Recharge – Reserve – Authorised water use

Where no Reserve has been set, the following formula was applied:

Allocable Groundwater = Aquifer Recharge – Authorised water use

2.11 Groundwater Quality

2.11.1 South Africa and Lesotho

Over 39500 groundwater quality analyses were available. These were filtered to remove multiple analyses over time from a single site to avoid weighing averages based on data from 1 site. The following parameters were selected for analysis:

- TDS and EC: These are an indicator of salinity, which is a problem over large areas of the catchment
- Fluoride: Excessive fluoride is a problem over large areas of the catchment due to the basaltic/magmatic composition of much of the geology
- Nitrates: Dry land nitrate loading occurs over large parts of the more arid reaches of the basin.
- Metals: All data on metals were sorted from minimum to maximum concentrations. Where maximums exceed recommended guidelines the metal was selected for further analysis. These metals found to be a risk include arsenic and molybdenum and iron.

2.11.2 Namibia and Botswana

The following parameters were selected for analysis for Namibia and Botswana.

- TDS
- Fluoride
- Nitrates

The data resource used for the parameters above was obtained from the SADC Hydrogeological map that unfortunately did not contain data on metals as given for RSA and Lesotho in Section 2.11.1.

3 CATCHMENT AREA DESCRIPTION

3.1 Study Area

The study area encompasses the entire ORASECOM area, which is the basin of the Orange River. The Orange River is an international resource, shared by four countries being Lesotho, South Africa, Botswana and Namibia. Numerous administrative districts are located with the basin (**Figure 3-1**).

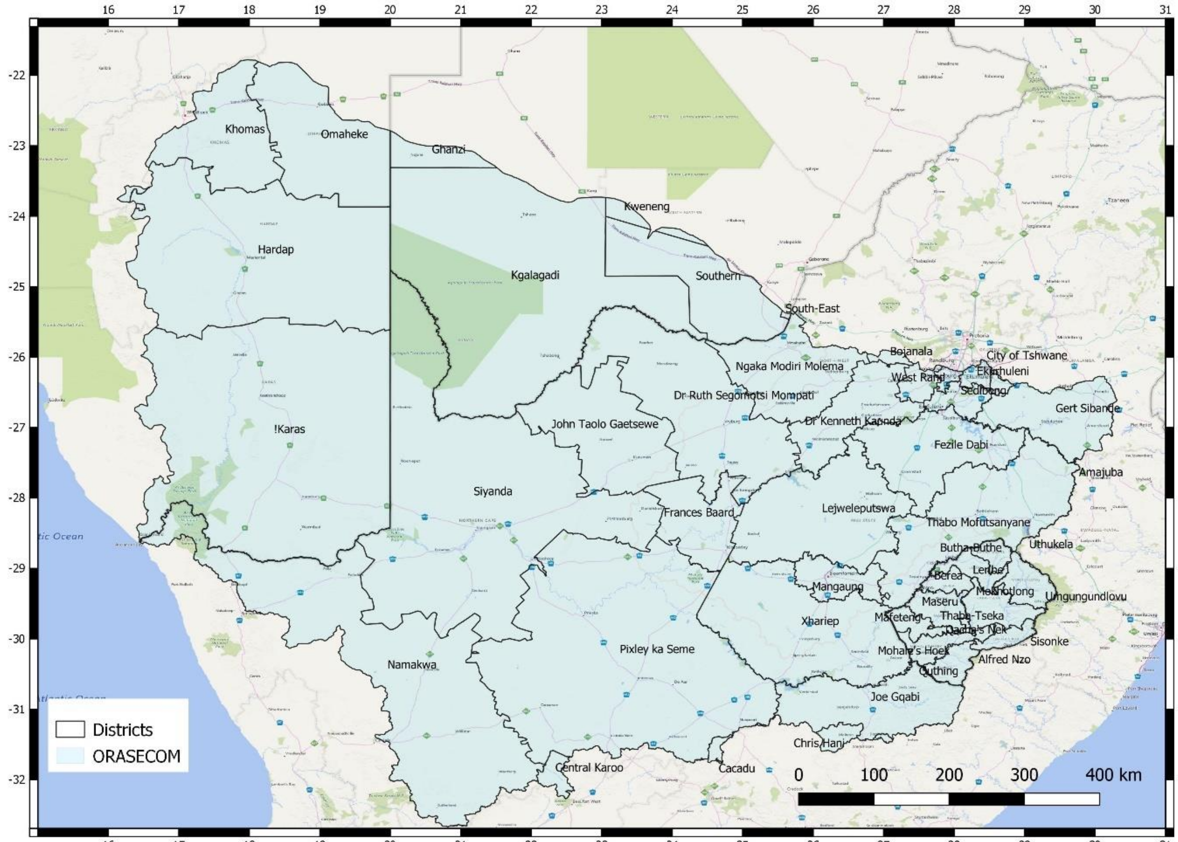


Figure 3-1 Location of ORASECOM Area and District/ Municipalities

The Orange-Senqu River Basin consists of:

- The Senqu River originating in the highlands of Lesotho
- Botswana in the North-eastern part of the Basin (Molopo and Nossob)
- The Fish River in Namibia
- and the largest area situated in South Africa.

3.2 Physiography

The headwaters of the Orange River rise at an altitude of about 3,300 metres above sea level on a dissected plateau formed by the Lesotho Highlands that extends from the Drakensberg escarpment in the east to the Maluti Mountains in the west. The main source of the Orange River is officially recognized as the Senqu River, which rises near the plateau's eastern edge. The Seate (Khubedu) headwater rises near Mount-aux-Sources to the north. Still farther north is the Malibamatso headwater, one site of the Lesotho Highland Project. The Lesotho headwaters flow over the turf soil that covers Drakensberg lava and cut through the lava to expose underlying sedimentary rocks; material eroded from these rocks contributes to heavy silt deposits further down the river's course.

After entering South Africa southwest of Lesotho, the river flows south and west through more open country, where sandstones, shales, and mudstones appear on the surface and where dolerite outcrops form small hills and flat-topped mountains. Near Aliwal North the river has eroded a broad valley some 50 km wide and more than 300 m deep. The river's channel, however, varies greatly in both width and depth because of dolerite outcrops that sometimes narrow it to 1,000 or 1500 m. The river receives the Caledon as a tributary at the head of the Gariep Reservoir. From the Gariep Dam the Orange swings to the northwest to its confluence with the Vaal River. The Vaal River, which rises in Mpumalanga province, flows west through the major population and industrial core of South Africa before turning south and joining the Orange River near the town of Douglas. The Orange then turns southwest and flows over calcrete and tillite (glacial clayey deposit). At Prieska it makes another sharp bend to the northwest, and this marks the beginning of its middle course. Quartzites and ironstones form a "barrier zone" through which the river has cut deep gorges. At Upington the river—by then flowing westward—spreads out over a granite surface. In this area the Orange River splits up into innumerable channels, between which are islands of varying length; and the river attains its greatest width, which may reach nearly four miles in places. About 60 km downstream from Upington, however, the riverbed is suddenly narrowed to about 700 m.

Some 30 km below Kakamas the Orange River—again flowing in several channels—forms the Augrabies Falls. There, after descending in a series of rapids, the river plunges into a deep pool. The river flows through an almost vertical-sided gorge for about 16 km, emerging again into more open country. The lower course of the river, from the Augrabies Falls to the sea, is sometimes called the Gorge Tract. Where the rock surface is soft, the river valley is generally open. Where the river traverses harder igneous rock, however, it is confined between almost vertical cliffs more than 300 m high in places. Some of the Orange's most rugged passages are found in the last section of the river, as it flows along the Richtersveld before turning west to the Namib coastal desert.

The Orange River reaches the sea a few km north of Alexander Bay. The mouth is less than 5 km wide and is nearly closed by sandbars, which are widely breached during high floods.

The gap in the southern end of the bars is maintained by the outflow of water from the river mouth during low tides and by the tidal inflow at high tides.

3.3 Climate

The rainfall patterns in the Orange basin have a direct effect on the river's rate of flow. In Lesotho, above the confluence with the Caledon, the rainfall average increases from 500 to 1400 mm/a annually in the Highlands of Lesotho (**Figure 1-3**); and, combined with the melted winter snows of the highland areas, this small area contributes nearly 60 percent of the Orange River's total annual flow. From the Caledon to the Vaal annual rainfall decreases from 500-300 mm/a, and below the Vaal confluence it decreases to below 50 mm/a at the Orange river mouth.

The amount of rainfall reaching the river as runoff decreases from about 16 percent in Lesotho to less than 0.5 percent in the lower Orange catchment. Conversely, summer maximum temperatures increase from east to west, the high exceeding 30° C on an average 5 days per year in Lesotho and 150 days per year in the west. The result of these phenomena is a tremendous increase in the rate of evaporation from east to west. Waters lost to evaporation may amount to 12 times the total precipitation in the lower course of the Orange River, and the potential storage capacity of reservoirs in the drier regions may be reduced by up to 60 percent.

S-pan evaporation decreases eastwards, towards the Lesotho Highlands, and is at its maximum in the coast and southwards from a high of over 2600 mm/a in the north to 1700 mm/a on the west coast and 1200 mm/a in the highlands of Lesotho (**Figure 1-4**).

3.4 Vegetation

The basin is characterised by major Bioregions, which are depicted in **Figure 3-2.** The main vegetation types found are:

- **Drakensberg Grassland Bioregion** vegetation covering the Highlands of Lesotho.
- **Highveld Grassland Bioregion** which covers the Lesotho Lowlands and the Northeastern highveld of South Africa.
- **Dry Highveld Bioregion** that covers a N-S section from Mafikeng in the north through Bloemfontein to the Orange River in the south.
- **Eastern Kalahari Bioregion** comprising bushveld, thornveld and shrubland, and is found in the east from Douglas to Groblershoop on the Orange River north into Botswana.
- **Inland Saline** vegetation consisting of southern Kalahari, Bushmanland, Highveld and Namaqualand saltpans.
- **Kalahari Duneveld** and bushveld found in the northern region of the Kalahari panhandle, extending into Botswana and Namibia.

- **Namaqualand Hardeveld** consisting of Hardeveld and Blomveld, covers large parts of Namaqualand, extending into Namibia.
- **Namaqualand Sandveld** consisting Duneveld and sandy grassland, covers the bulk of the coast of Namaqualand.
- **Richtersveld** consisting of succulents and shrubs cover the edges of the Orange River near its mouth.
- **Southern Namib Desert** occupying the border region of the Orange River bordering Namibia.
- **Trans-escarpment Succulent Karoo** vegetation found in the south of catchment the escarpment region north of Sutherland.
- **Upper Karoo Bioregion** vegetation covering the southern portion of the catchment, which gives way to Bushmanland vegetation to the north as the MAP decreases.

3.5 Soils

Soil cover is an important consideration for groundwater recharge and aquifer vulnerability to contamination. The majority of area is covered by Arenosols: generally, of a loamy sand or coarser texture with a depth of at least 100 cm from the soil surface (**Figure 3-3**). They contain less than 35% (by volume) rock fragments or other coarse fragments within 100 cm from the soil surface.

Large areas are covered by soils with minimal development, which are usually shallow and stablished on hard rock.

Of significance is soil texture. Soil texture plays an important role in controlling soil permeability. Soil texture is shown in (**Figure 3-4**) for South Africa and Lesotho.

Large parts of the catchment are underlain by sandy soil textures, making them vulnerable to contamination.

3.6 Land cover

The eastern portion of the catchment is cover ed grassland and extensive cultivation. Extensive tracts of bare ground exist in the Lesotho Highlands (figure 3-6). The central portion is largely covered by low shrubland used for grazing and bushland. Grasslands exist in the Kalahari as part of the Kgalagadi Transfrontier National Park.

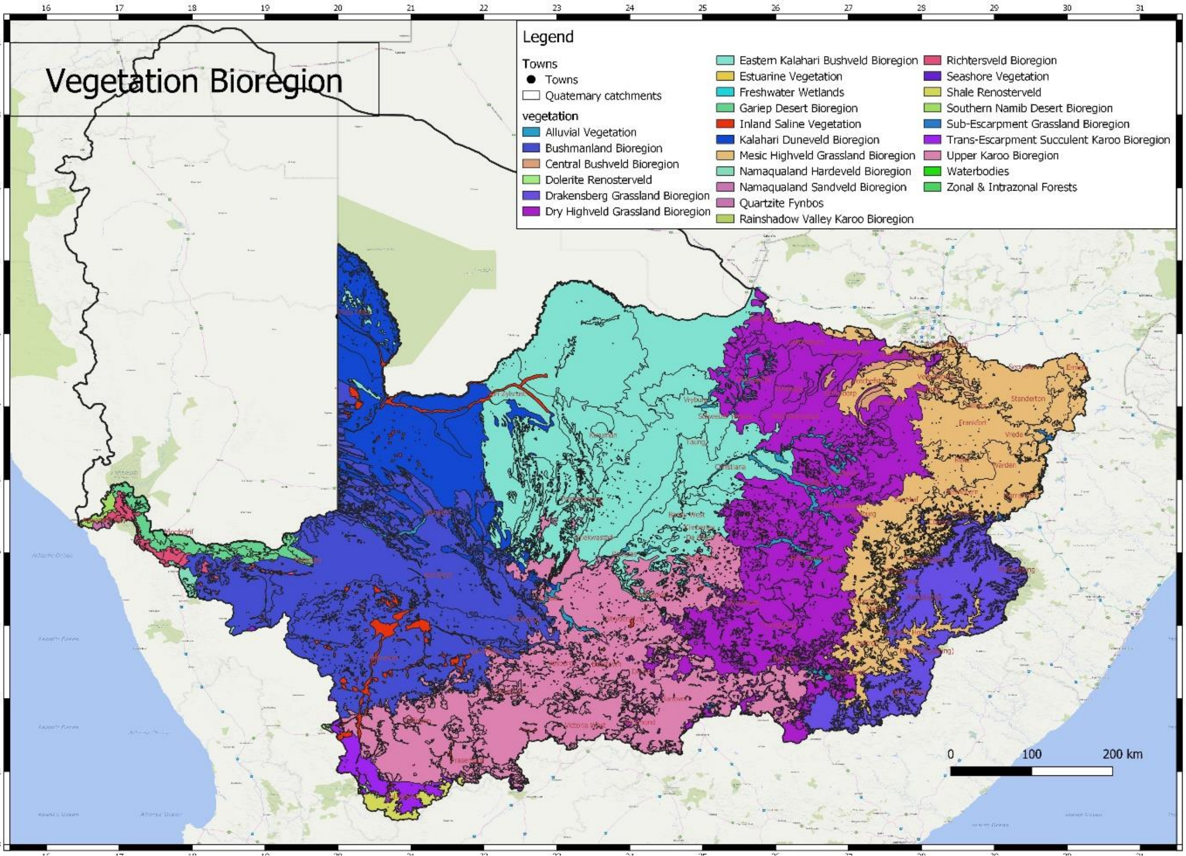


Figure 3-2 Major regions, RSA and Lesotho (No data for Botswana and Namibia)

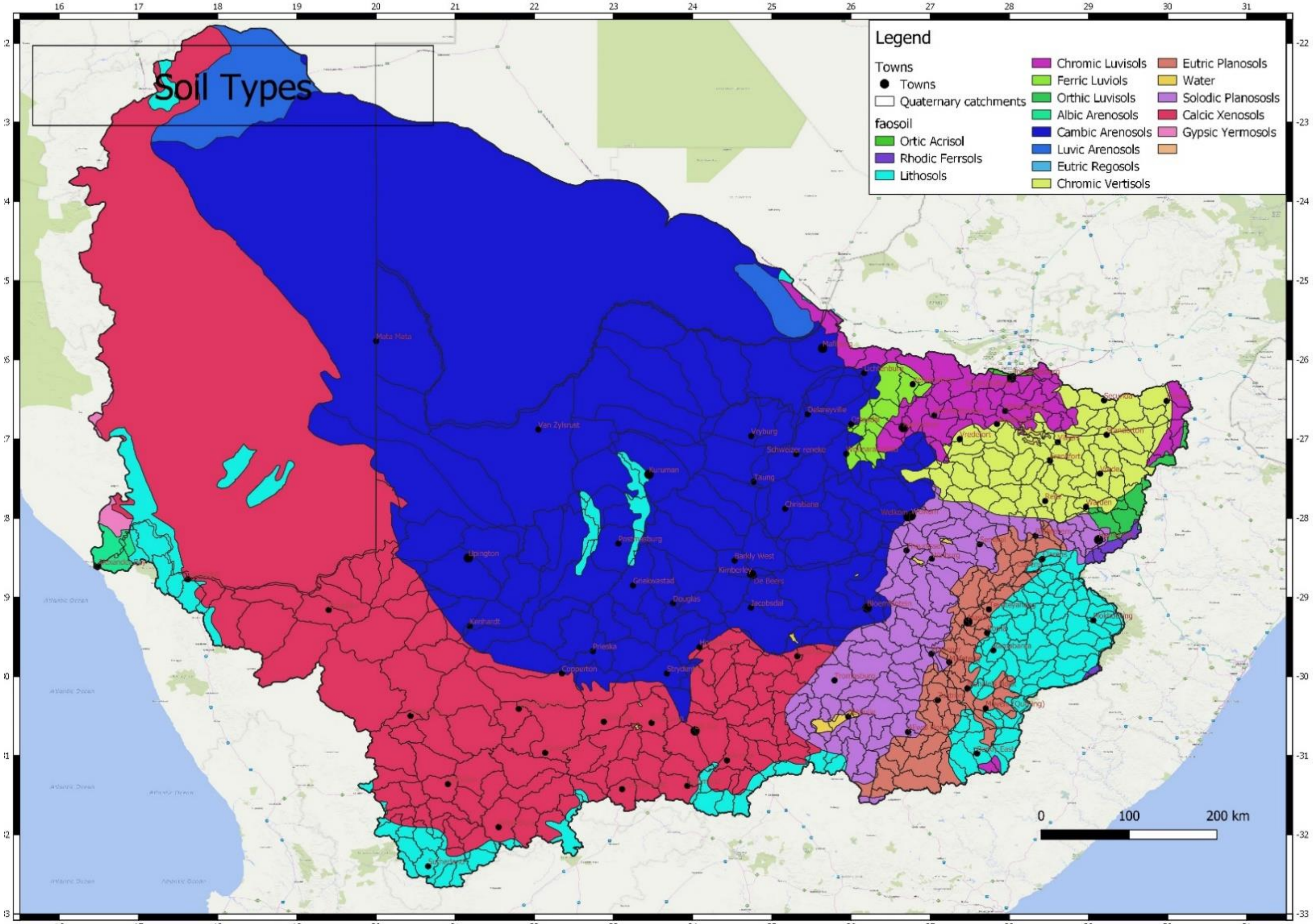


Figure 3-3 Soil Types (see Appendix 16)

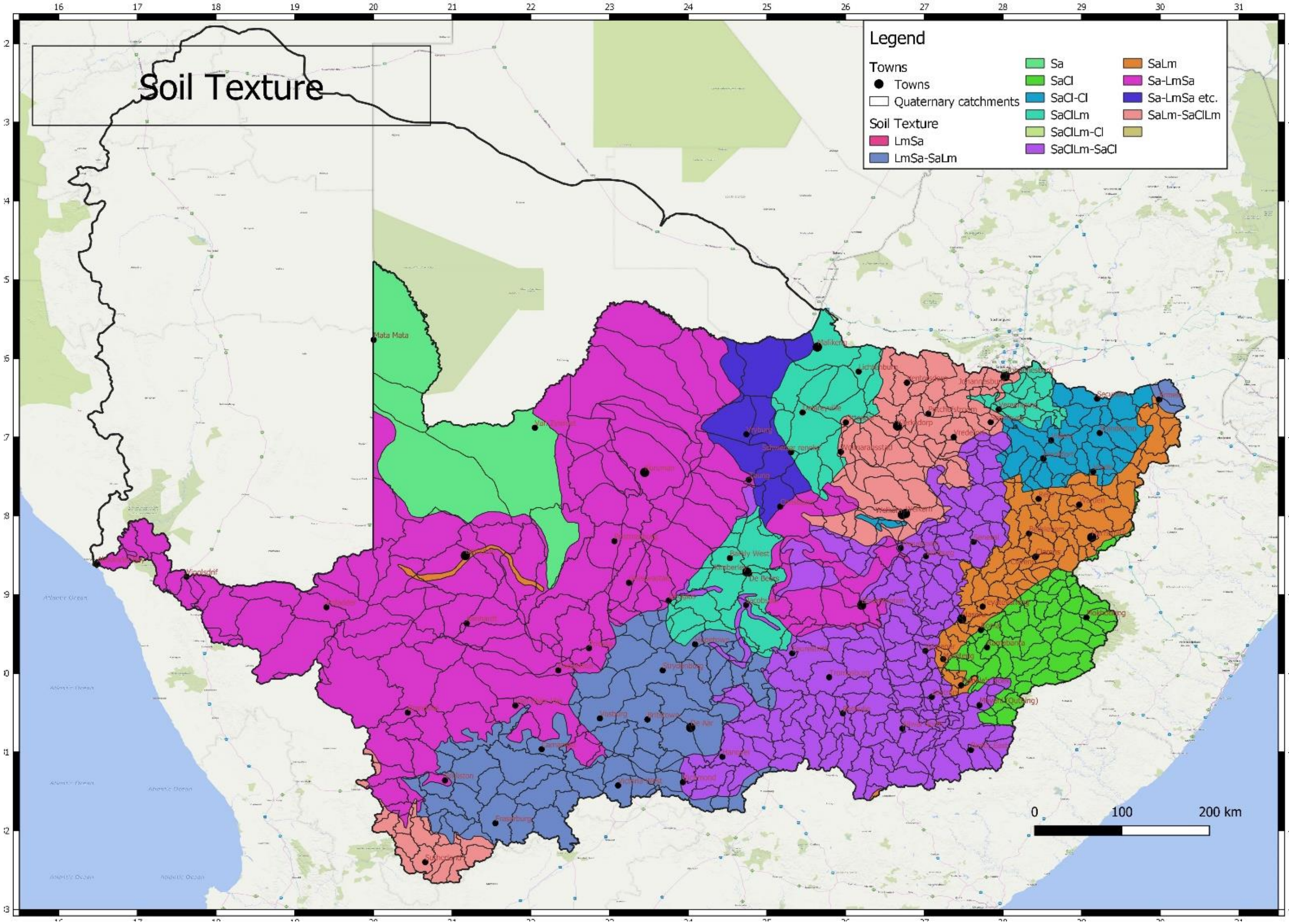


Figure 3-4 Soil Texture RSA and Lesotho

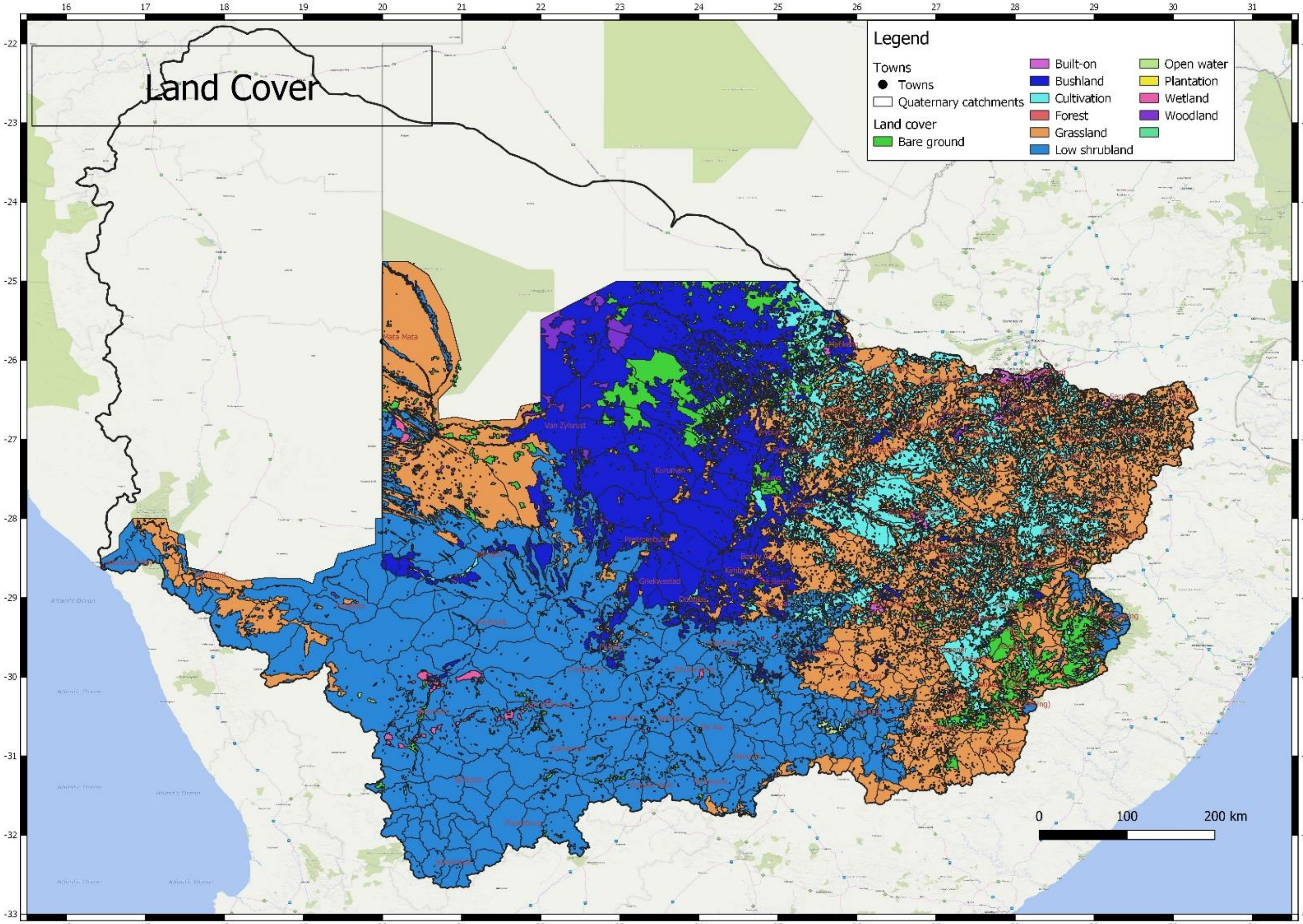


Figure 3-5 Land cover RSA and Lesotho

3.7 Geology, South Africa and Lesotho

Very diverse lithostratigraphic units, varying in age from Swazian Age to Quaternary, underlie the basin. The lithologies cover the broad spectrum of intrusive and extrusive igneous rocks, sedimentary and metamorphic rocks, and unconsolidated sediments.

The geologic units present are shown in **Figure 3-6** and are grouped by potentially similar hydrogeological environments in groundwater regions (**Table 2-1**).

The following geological units were identified:

- **Swazian age supracrustal rocks:** These rocks are found in the Kraaipan Group. They underlie the **Eastern Kalahari Groundwater Region** outcropping in places. They extend into the **Western Highveld Groundwater Region.**
- **Archean Gneiss and Granitoids:** Swazian age migmatites, granite-gneiss and Gneiss are found in the **Central Highveld Groundwater Region, the Western Highveld and in the Eastern Kalahari.** These include the Halfway House Granite, underlying larges parts of Johannesburg.
- **Marydale Group:** These rocks include the Prieskapoort Group and Doornfontein subgroups and the Draghoender Gneiss and are found in **the Bushmanland Groundwater Region.** They area greenstone belt 2910 – 3000 Mega-annum or million annum (Ma) in age and is located from 20 km SSW of Prieska up to the vicinity of Copperton and Marydale. It is at the southwestern edge of the Kaapvaal craton and forms a narrow belt of discontinuous outcrops under Tertiary cover extending for about 100 km in a SE direction. It is sub-divided into the Prieskapoort and Doornfontein Subgroups. They form part of the Namaqualand Metamorphic Province and occur as a compound syncline that is steeply folded and highly metamorphosed to greenstone level.
- **Witswatersrand Supergroup:** These rocks include the Dominion and Central Rand Groups and, the Hospital Hill, Government Hill, Jeppestown and Turfontein subgroups. They are located in the **Central Highveld and Western Highveld Groundwater Regions** in the vicinity of Johannesburg and are well known for gold mining.
- **Ventersdorp Supergroup:** The Kameeldoorns conglomerate Formation and quartz porphyry of the Makwassie Formation, Amalia Group and are found in the **Central and Western Highveld Groundwater Regions.** Andesite of the Klipriviersberg Group is found the **Central and Southeastern Highveld Groundwater Regions.** Quartz porphyry of the Kareefontein Formation is found in the **Western Highveld and Eastern Kalahari Groundwater Regions**. Tuff and andesite of The Hartswater Group is found in the **Western Highveld and Taung-Prieska Groundwater Regions**. The Richie Group quartz porphyry and Sodium Group outcrops SE of Prieska in the **Taung Prieska Groundwater Region** and consists of volcanic grits and tuffs, lavas, arkose, porphyry, limestone, chert. It rests on a floor of Randian intrusive granite and is 2640 Ma in age. The Zeekoebaart Formation is exposed south of Boegoeberg dam and consists almost entirely of volcanic andesite and dacite, with some porphyry, tuff and breccia. It has limited exposure related to extensive erosion, and the rocks are only encountered in 2 – 5 very small isolated inliers

between Prieska and Douglas. The Allanridge and Bothaville Formations is 2600 Ma and outcrop near Vryburg and west of Kimberley.

- **Transvaal ironstones, sediments and volcanics in the Northern province:** These rocks are found near Vryburg, Prieska and Morokweng. The 2640 Ma Vryburg Formation overlies the Ventersdorp rocks in Griqualand West. The Asbestos Hills banded ironstones and Koegas Subgroup are 2500 - 2400 Ma in age and form the Asbestos Hills and the Kuruman Hills. The Makganyene Formation was deposited over a regional unconformity cut deeply down into the Koegas Subgroup rocks. The Ongeluk Formation is overlain over another unconformity over the Makganyene Formation and is 22200 Ma. They are found in the **Eastern Kalahari, Western Kalahari, Ghaap Plateau, West Griqualand, Bushmanland, Taung Prieska Groundwater Regions.**
- **Ghaap Group dolomite:** These rocks form the Ghaap plateau and are 2600 - 2500 Ma in age. They are a significant aquifer hence have been separated from the remainder of the Transvaal Group ironstones and other sedimentary rocks. The bulk of the dolomitic outcrop occurs over quaternary catchments D71A, B and C92C and stretches across the WMA boundary into the Lower Vaal WMA. A further narrow strip of dolomite, approximately 50 km long and less than 5km wide outcrops in a roughly north-west to south-east orientation along the Doringberg Fault, west of Peiring. The main body of the outcrop is located in catchment D72B and lie in The **Ghaap Plateau Groundwater Region.**
- **Transvaal sediments, dolomites and volcanics in the Pretoria Group of the Transvaal basin:** Timeball Hill shale and Hekpoort andesite are found in the **Northeastern Pan Belt, Western Bankeveld and the Central and Southeast Groundwater Regions**. These are overlain by the Black Reef quartzite and Malmani dolomites in the **Karst Belt Groundwater Region**. Upper Transvaal sediments are found the **Central Highveld, South Eastern Highveld, Northeastern pan Belt, Western Bankeveld Groundwater Regions**
- **Kheis tectonic Sub Province:** Schist and arenites of the Dagbreek and Sultanaoord Formations are found in **West Griqualand, Bushmanland and the Eastern Kalahari Groundwater Regions.**
- **Olifantshoek Supergroup:** The lower part of this grouping consists of clastic sediments and volcanic rocks, which grade upward to rudaceous sediments. These rocks are encountered west of Postmasburg and east of Olifantshoek and build the foothills of the Langeberg, Korannaberg and Eselberg. They form a prominent north trending mountain range from Boegoeberg northward to the Korannaberg. They form the Brusland subgroup and Matsap Formation. They overlie Transvaal Supergroup rocks in the **West Griqualand Groundwater Regio and Eastern Kalahari Groundwater Region** with a regional unconformity and are about 1900 Ma in age.
- **Namaqua-Natal Province:** The region consists of metamorphic rocks formed or metamorphosed between 2000 - 1000 Ma. These rocks range from an assembly of compact sedimentary and volcanic rocks, to extrusive and intrusive rocks including homogenous granites to migmatites and gneisses. The area underlain by the Namaqualand-Natal Province is situated near the Orange River between Prieska to Upington and Springbok. It consists of:
  - Early Mokolian age (2000 Ma) sediments and volcanics that are metamorphosed.

- Intrusive and extrusive rocks formed during rifting and subduction (1600 - 1200 Ma) and subsequently metamorphosed.
- Syn and post tectonic granitoids formed between 1200 - 1000 Ma.

It has been divided into sub-terranes based on marked changes in lithology across structural discontinuities:

- **Richtersveld sub province:** The rocks are 2000 Ma and consist of low to medium grade metamorphosed extrusive and intrusive rocks along the Namibian border. Thrusts or shears bound the sub province. It consists of volcano-sedimentary rocks of the Orange River Group and intrusive granitoid of the Vioolsdrift Suite.
- **Bushmanland Terrane:** The Terrane consists of granitic gneisses and medium to high-grade deformation of sedimentary and volcanic rocks. The northern boundary of this Terrane is the Richtersveld sub province and in the east, it abuts against the Kakamas Terrane at the Hartbees River Thrust. It consists of basement gneisses of 2050 - 1700 Ma, mixed sedimentary and volcanic metamorphosed rocks of 1900 - 1200 Ma, and syn and post tectonic Namaqua age intrusive granites and charnokites. It underlies the **Namaqualand groundwater Region**
- **Kakamas Terrane:** The terrane consists of metamorphosed sedimentary rocks and subsequent granitic intrusions. It lies to the east of the Bushmanland Terrane and is bounded in the east by the Boven Rugzeer shear zone. It stretches from the Onseepkans area south 200 km to Kenhardt- Putsonderwater. High-grade metamorphism characterises the rocks of the Terrane.
- **Areachap Terrane:** This Terrane consists of a NNW trending belt of medium grade 1300 Ma metamorphosed rocks of sedimentary and volcanic origin, and subsequent 1000 Ma granitic intrusions and are found in the **Bushmanland Groundwater Region**.
- **Kaaien Terrane:** This Terrane forms the eastern margin of the Namaqua-Natal Province and consists of deformed quartzite and volcano sedimentary rocks. It is bounded in the west by the Brakbosch shear zone and in the east by the Dabep Thrust. The Brulpan Group build the Skeurberg to the west of the Langeberg and consists of schists found in the Western **Kalahari Groundwater Region.** The Zonderhuis and Leerkrans Formations are found across both Regions.
- **Koras Group:** The Koras Group lies in the Kaaien Terrane; however, because it consists of relatively undeformed and unmetamorphosed rocks, it is considered a separate geological unit. It lies unconformably over the metamorphic rocks to the east and north of Upington and post-dates the shear zone, which marks the boundary of the Kaaien Terrane. It is 1180 Ma in age. It is found in the **Western Kalahari Groundwater Region**

- **Namibian Successions and intrusives:** These rocks are grouped into the Richtersveld Suite, the Gariep Supergroup and the Nama and Vanrhynsdorp Groups, and are intruded by granites. The Richtersveld Suite consists of felsic rocks intruded into rocks of the Vioolsdrift Suite and Orange River Group. The Gariep Supergroup are a meta-volcanic and sedimentary succession that fill a tectonic belt running from Kleinsee to Namibia. They have been extensively deformed and are about 700 Ma in age. The Nama and Vanrhynsdorp Groups were deposited in foreland basins and are separated from The

Gariep Belt geographically. They underly the **Bushmanland, Far Northwestern Coastal Hinterland, Western Kalahari, Bushmanland Pan Belt and Namaqualand Groundwater Regions**

- **The Karoo Supergroup is represented for its entire succession:** It consists of a thick succession of sedimentary rocks ranging from mudrocks through coarser varieties (sandstones, conglomerates) to diamictites and rhythmites. They are capped by basalt. Karoo or Jurassic dolerite is common throughout the sequence and frequently intrudes older rocks. They have been subdivided based on the following considerations:
  - **Dwyka Tillite:** This massive tillite consists of highly compacted diamictite and is separated from the remainder of the Karoo Supergroup, as it is a poor aquifer of low permeability and storage. It outcrops in the **Central and Western and Southeastern Highveld, The Eastern and Western Kalahari, Bushmanland, Namaqualand, Taung-Prieska Belt, the Northeastern, Central and Bushmanland Pan Belts Groundwater Regions**, hence is very ubiquitous across the Basin,
  - **Carbonaceous Ecca Group shales:** The Prince Albert and Whitehill Formations form thick sequences of black carbonaceous shale with the highest fracking potential where they underlie other Karoo rocks. They have been separated from the remainder of the Ecca Group due to their often-poor water quality. They are found in the **Western and central and Southeastern Highveld, Western Kalahari, Taung Prieska, Northeastern Central and Bushmanland Pan Belts, and the Northeastern Upper Karoo Groundwater Regions.**
  - **Other Ecca Group shales and sandstones:** Ecca Group rocks are of marine origin and are often more saline than Karoo rocks that are younger in the Sequence. Consequently, they are treated separately. Ecca sandstones and mudstones are found in the **Western and Eastern Upper Karoo Groundwater Regions**
  - **Beaufort Group rocks**: Are of fluviatile and generally of continental origin. Their salinity is related to low recharge rather than connate marine water like in the Ecca. They're found in the **South Eastern Highveld, Central Pan Belt, Northeastern, Southeastern, Eastern and Western Upper Karoo, South Eastern and Northeastern Highlands, The Northeastern and Southeastern and Eastern Upper Karoo Groundwater Regions**
  - **Molteno, Elliot and Clarens Formations:** The sandstones and mudstones are found in the S**outheastern Highveld, Northeastern and Southeastern Highlands, The Northeastern and Southeastern Upper Karoo Groundwater Regions**
  - **Drakensberg Basalts: These are found in the Southeastern Highveld, the Northeastern and Southeastern and Drakensberg Highlands.**
- **Sutherland Suite:** This 66 Ma Cretaceous dome structure is an intrusion consisting of volcanic breccia, carbonatite, trachyte and olivine melilite. Water quality can be poor, but it is of geohydrological relevance due to the fracturing it induced in the surrounding Beaufort Group rocks during intrusion. Since this one intrusion only occurs in the Beaufort Group, it is grouped with the Beaufort Group.
- **Quaternary and Tertiary dune deposits**, consisting of "Kalahari red sands", occupy the extreme northern part of the basin bordering on Namibia. These dune deposits are of

considerable thickness and comprise fine aeolian sands with occasional coarser gravel deposits. These are found as far east as the **Western Highveld Groundwater Region**, but largely overly the **Eastern and Western Kalahari Groundwater Regions**. They also overly parts of the **Ghaap Plateau, West Griqualand, Bushmanland, Taung Prieska, Central and Bushmanland Pan Belts Groundwater Regions.**

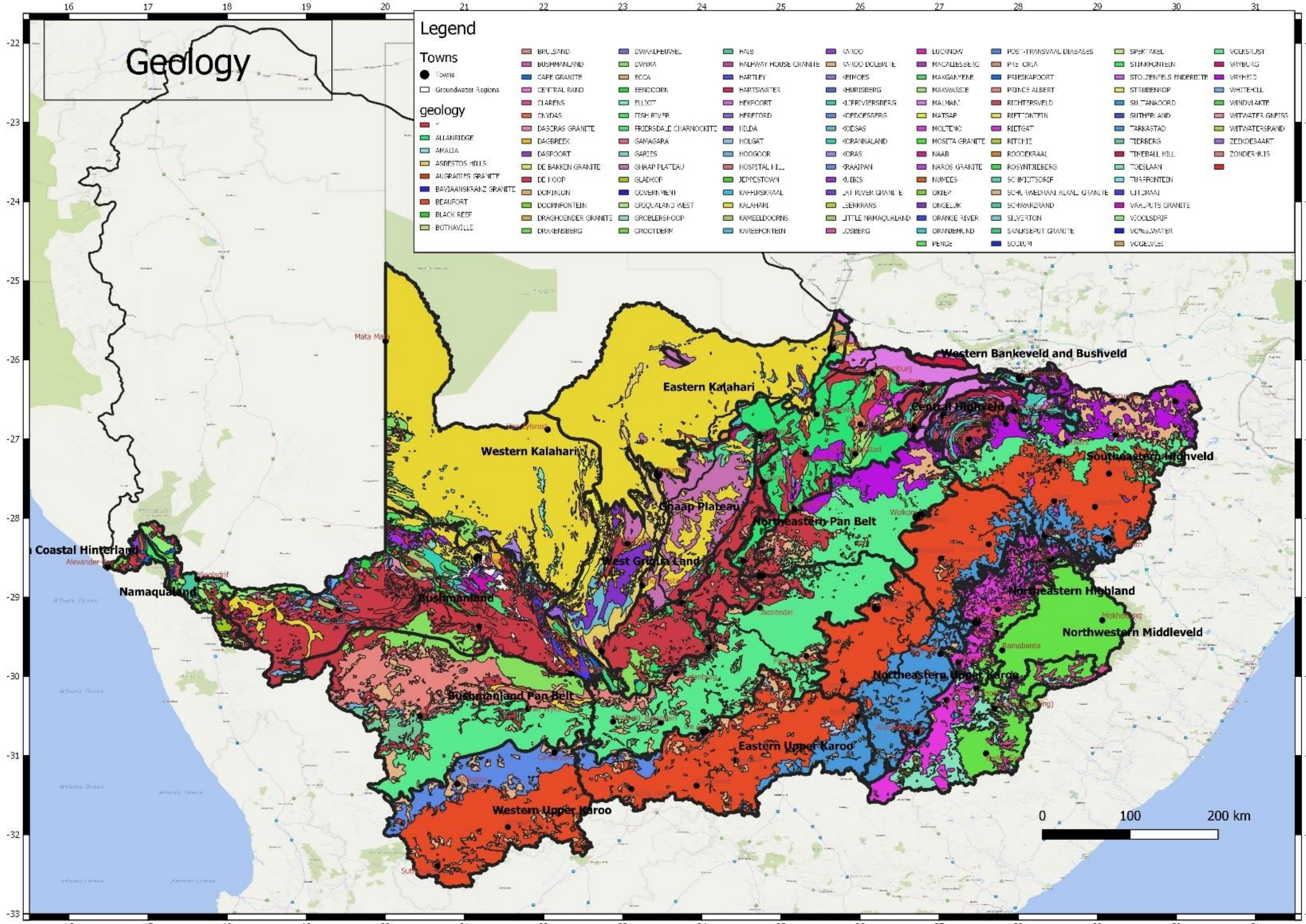


Figure 3-6 Geology and groundwater regions , South Africa and Lesotho (see entire basin Appendix 16)

3.8 Geology, Namibia

The geologic units present are shown in **Figure 3-7** and the general geology is described below per groundwater basin.

- **Hochfeld-Dordabis-Gobabis Area,** The Damara Super Group rocks predominate in this groundwater basin and are mainly made up of rocks of the Matchless Suite Group (amphibolite and schists). Pre-Damara intrusive and metamorphic rocks belonging to the Sinclair and Rehoboth Groups (granites) as well as the Epupa, Huab and Abbabis Metamorphic Complexes (gneisses and granites) are also found in this basin. Other groups of rocks found in this basin are the Hakos Group (Sandstones), Khomas Group (schists) and the Witvlei Group (limestones and sandstones)

- **Stampriet Artesian Basin**

The Northern boundary is defined by sub-outcrops of the Karoo strata. The succession rests on the Kamtsas Formation and on the Nama group. The North-east part of this basin consists of sandstones with artesian groundwater that may be found under the Kalkrand Basalts. Younger Kalkrand Basalt occurs in the North-west and the Kalahari sequence deposits are also present in this area. Groundwater occurs in the Nossob and Auob sandstones of the Ecca Group which are divided by shale layers and overlain by the Rietmond shale and sandstone.

- **Fish River-Aroab Basin**

The Fish River-Aroab basin is mostly dominated by sedimentary rocks of clastic origin i.e. sandstone and shales of the Fish River Subgroup and sandstones, limestones and shales of the Kuibis and Schwarzrand Subgroups.

- **Southern Namib and Naukluft**

The geology of the Sothern Namib-Naukluft Groundwater basin consists of fractured and karstified dolomites and limestones of the Naukluft Mountains Group and Schists and amphibolites of the Gariep Group.

- **Karas Basement**

The geology of the Karas Basement groundwater basin consists of gneisses of Haib Group and the Namaqua Metamorphic Complex as well as granites of the Vioolsdrift Granite Suite. Dolerites sills and dykes are also found in the Karas basement groundwater basin.

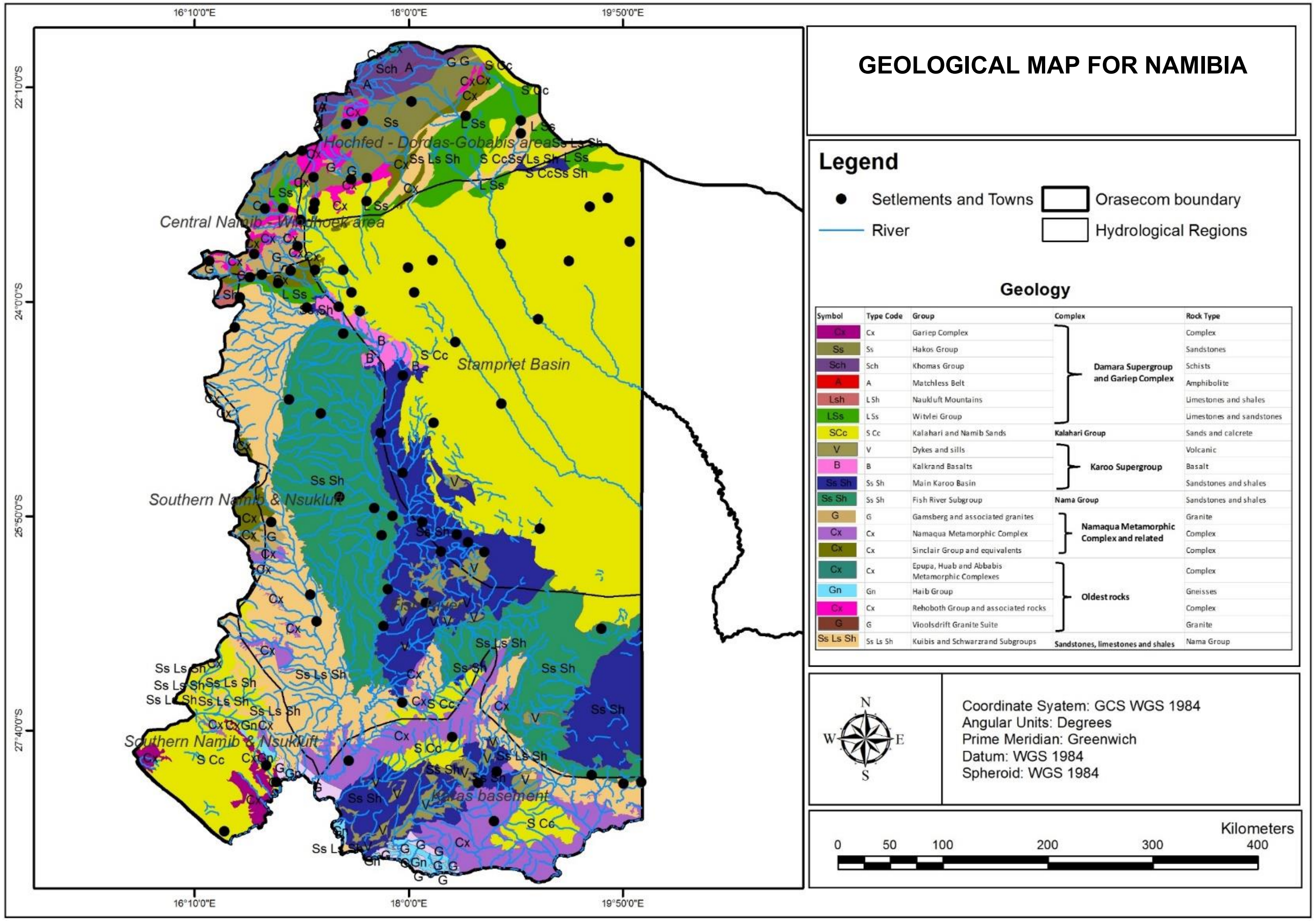


Figure 3-7 Geology and groundwater basins, Namibia (see entire basin Appendix 16)

3.9 Geology, Botswana

The geologic units present are shown in **Figure 3-8** and the general geology is described below.

- **Beaufort Group,** comprises of thin purple/reddish fine to medium grained sandstone, and dark grey mudstone/siltstone near its base, with the bulk of the group comprising of grey, purple-brown non carbonaceous mudstone. The Beaufort group has limited groundwater potential both in terms of yield and groundwater quality.
- **Lebung Group,** the Lebung Group is made up of two formations, the Ntane Sandstone Formation and the Mosolotsane Formation. Orange, red or white sandstone comprises the Ntane Formation while the Mosolotsane (Dongdong) Formation consists of basal conglomeratic sandstone, greenish-yellow sandstone interbedded with red-brown siltstones and reddish-brown mudstone. Sandstones of the Ntane Formation comprise the main aquifer of the Lebung group is arguably Botswana's principal aquifer. The Mosolotsane basal sandstone occasionally form aquifers with poor groundwater quality.
- **Ecca Group,** the Ecca Group in the basin is divided into two formations being the Kobe and Otshe Formations. The consists of an interbedded sequence of coal, carbonaceous siltstone and mudstone and white poorly cemented sandstones. Sandstones of the Otshe Formation which is the Equivalent of the Aoub Formation in Namibia forms the main aquifer in the Ecca Group.
- **Dwyka Group,** consists primarily of tillite, with quartzite/granite clasts in a sandstone matrix, purple mudstones (rythmites/varvites) and purple siltstones. The Dwyka Group which is the basal unit of the Karoo Supper Group unconformably overlies the Olifantshoek Supergroup rocks.
- **Olifantshoek Supergroup,** rocks comprise of white to reddish quartzite with minor shale
- **Upper Transvaal,** comprises of interbedded reddish quartzite, shale, variably manganiferous and carbonaceous siltstone, chert, dolomite, ironstone, andesitic/felsic volcanics and breccia.
- **Lower Transvaal,** the lower Transvaal is made up of basal quartzite (Black Reef Quartzite), dolomitic limestone, chert, minor limestone, ironstone, variably carbonaceous siltstone and shale
- **Undifferentiated Waterberg,** consists of reddish siliciclastic sedimentary rocks, mostly sandstone and conglomerate.
- **Nnywane and Mogobane,** rocks of this formation consist of Rhyolitic volcanics, breccio-conglomerate, siltstone, sandstone, mudstone and shale

- **Mabua Sehube**, consists of Metamorphosed arkosic sandstone, limestone, shale and mudstone
- **Dolerite** Sills and intrusions
-
- **Basement Rocks,** which occur in eastern part of the Botswana part of the basin consist of granite, norite, quartzofeldspathic gneiss, amphibolite, felsite and syenite

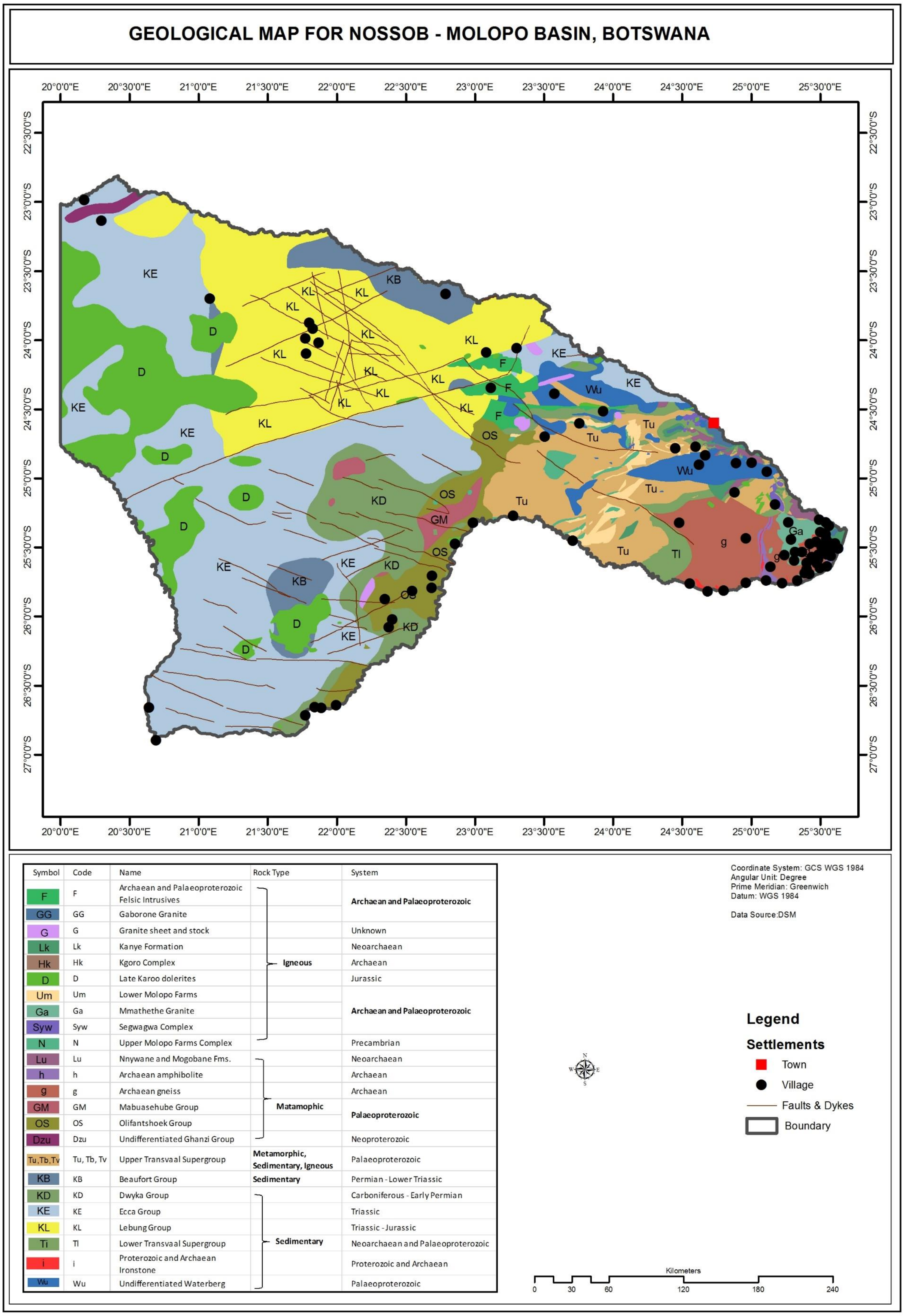


Figure 3-8 Geology, Botswana (see entire basin Appendix 16)

4 GROUNDWATER RESOURCES IN THE STUDY AREA, SOUTH AFRICA AND LESOTHO

4.1 Aquifer types

Four aquifer types can be distinguished in the Basin: namely Intergranular, Intergranular and Fractured (weathered and fractured), Fractured (Structural), and Karst (**Figure 4-1**):

- **Intergranular aquifers:** These primary aquifers principally occur in the Kalahari and are associated with unconsolidated deposits of Kalahari sand. These can be moderately to high yielding, and yield up to 5 l/s (18 m^3/hr)
- **Intergranular and fractured aquifers:** Secondary fractured and weathered aquifers are found in the sedimentary, metamorphics and granitic intrusives where water levels are above the depth of weathering. They are found in the wetter and eastern half of the Basin, and along the Orange River close to the western margin of the basin. Weathering gives rise to low to moderately yielding aquifers where groundwater is stored in the interstices in the weathered saturated zone and in joints and fractures of competent rocks. Borehole yields are largely in the 0.1-0.5 l/s (0.36 to 1.8 m^3/hr) and 0.5 -2 l/s (1.8 to 7.2 m^3/hr) classes, except on the west coast and near the Lower Orange mouth where yields are below 0.1 l/s.
- **Fractured aquifers:** Fractured aquifers are common in the Western half of the catchment and in the Drakensberg highlands. The yield of fractured rock aquifers is structurally controlled, as permeability is a function of post-depositional events and associated with faults, fractures, dykes and lithological contacts. Groundwater is found below the weathered zone. The dimension and intensity of fracturing and faulting is highly variable and greatly influences borehole yield.
- **Karstic aquifers:** Karstic aquifers are found on the Ghaap plateau and the Karst Belt. Karstic aquifers develop in chemically soluble rocks such as dolomite and are characterised by a network of conduits that allow for turbulent flow of groundwater. They are the highest yielding aquifers in the region and yield often exceeds 5 l/s (18 m^3/hr).

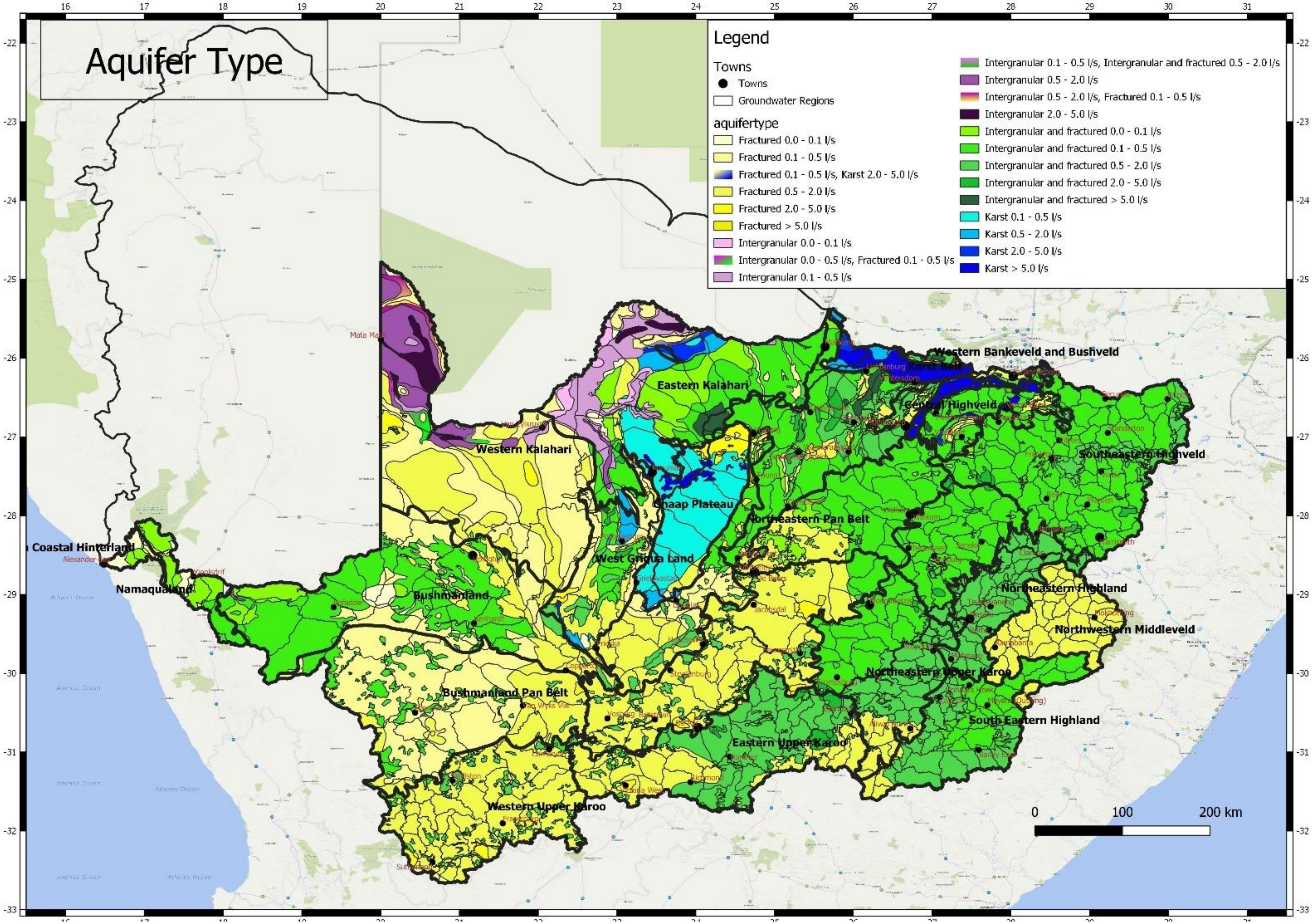


Figure 4-1 Aquifer type, South Africa and Lesotho

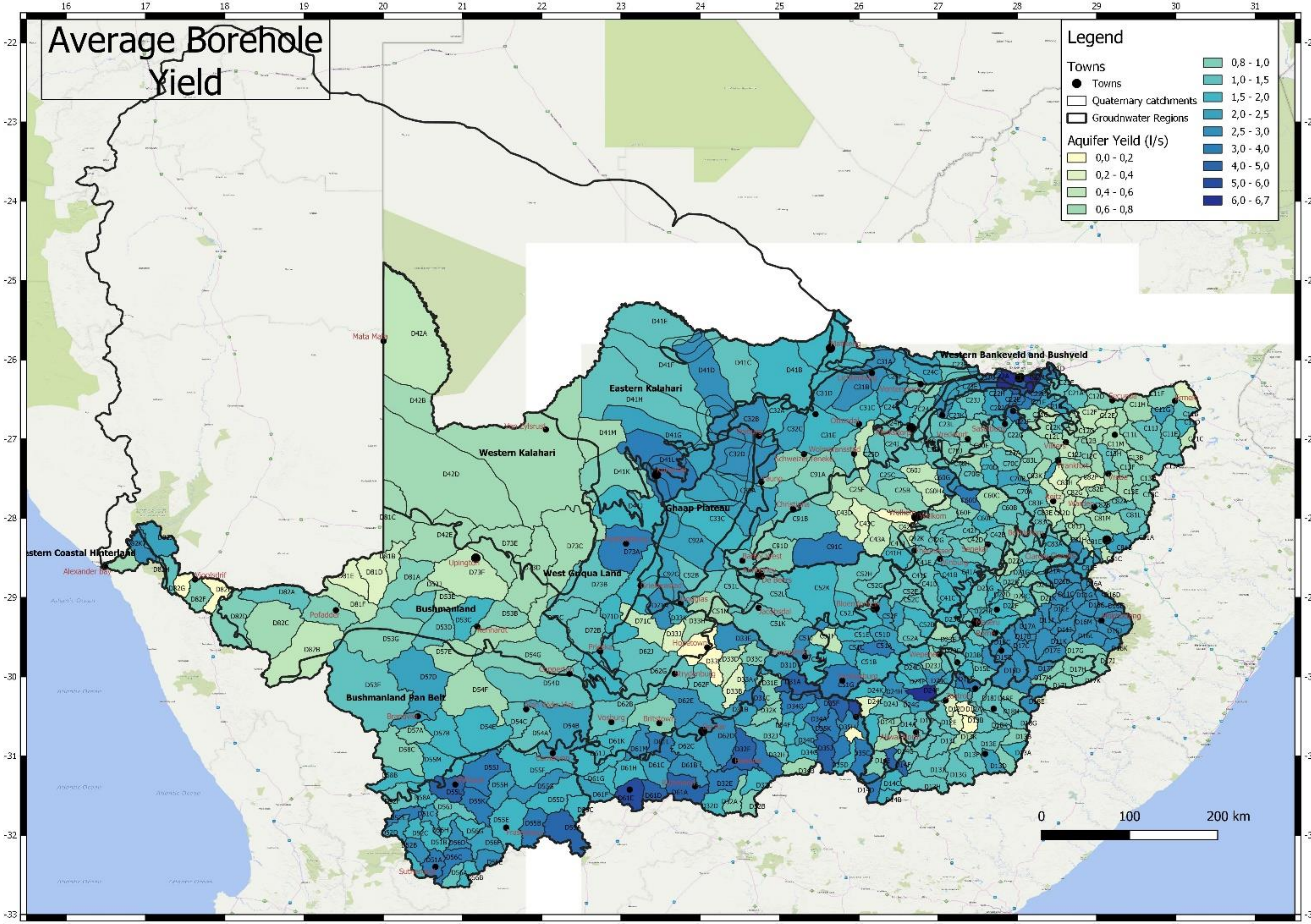


Figure 4-2 Borehole yields, South Africa and Lesotho (see entire basin Appendix 16)

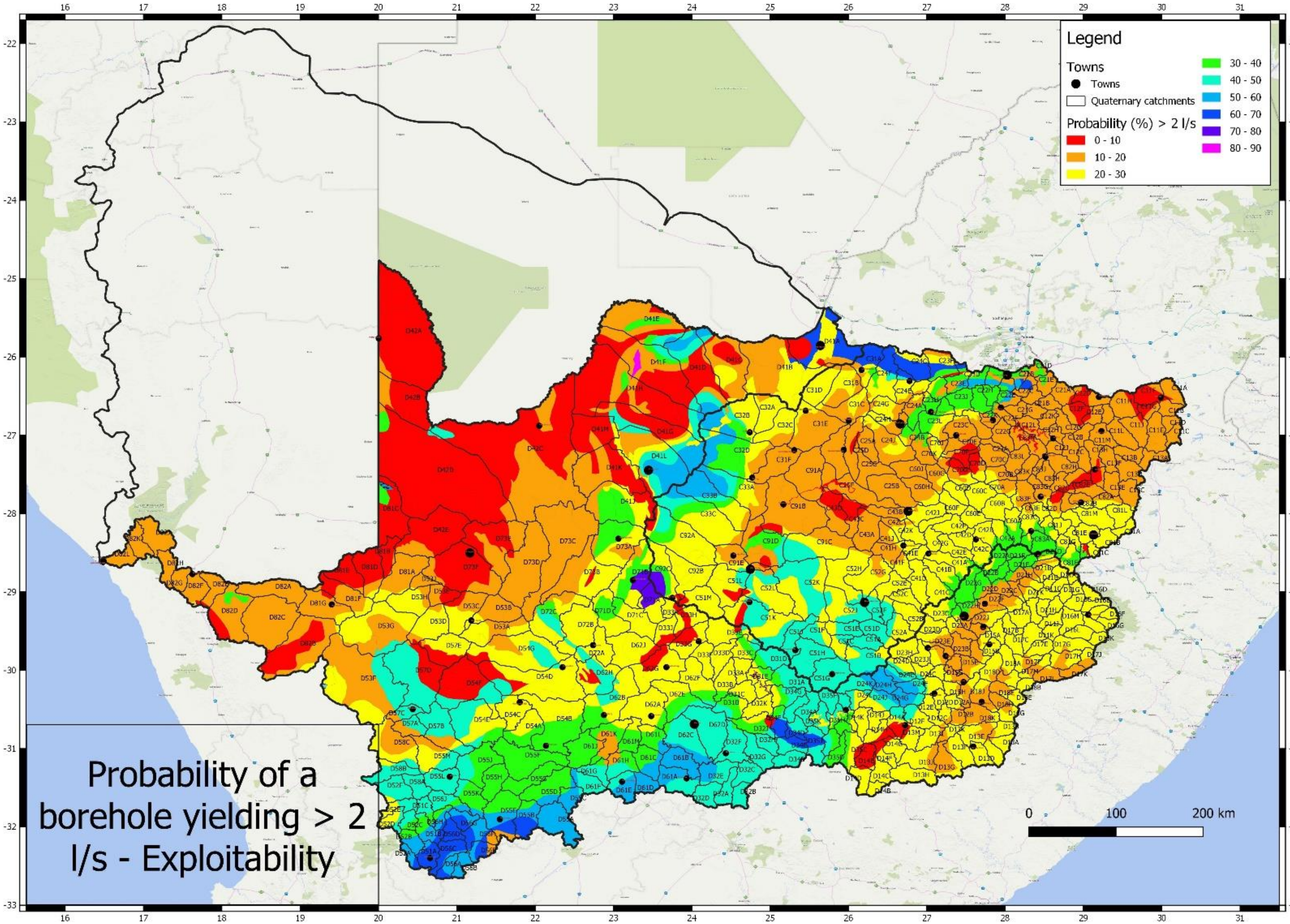


Figure 4-3 Probability of a borehole with a yield of > 2 l/s, South Africa and Lesotho (see entire basin Appendix 16)

4.2 Borehole yield

Average borehole yields per Quaternary catchment are shown in **Figure 4-2**. Mean borehole yields are below 1 l/s in Bushmanland, the Western Kalahari and Namaqualand. In these groundwater regions, more than 80% of boreholes generally yield less than 2 l/s. Low yields are also encountered in the Southeastern Highveld. High yields of over 2 ls/ are found in the Drakensberg highlands, the Western and Eastern Upper Karoo and the Ghaap Plateau. The Highest yields of over 5 l/s are found in the Karst Belt.

The probability of achieving a borehole with a yield > 2 l/s was mapped by Vegter (1995), but only for South Africa. This limitation to South Africa and the data being pre-1995, suggested that the map needed to be revised with all the additional data of the past 25 years. Yield data was obtained for 40 000 boreholes in Lesotho and South Africa and was analysed by Quaternary catchment (**Figure 4-3**). Yield characteristics for each groundwater region are shown in **Table 4-1**.

The Karst Belt is the highest yielding aquifer region, with 20% of boreholes yielding more than 10 l/s. On the Ghaap Plateau, 20% of boreholes yield more than 6 l/s. Bushmanland has the poorest exploitability, only 16% yielding more than 2 l/s.

4.3 Recharge

Recharge is shown in **Figure 4-4** for each Quaternary catchment. Recharge exceeds 150 mm/a in the Drakensberg Highlands and declines towards the west, being less than 2 mm/a in the Western Kalahari, Bushmanland. Bushmanland Pan Belt and Namaqualand.

When aquifer recharge is plotted, by excluding the recharge component that is lost as interflow and not accessible to boreholes, a slightly different pictures emerges. Aquifer recharge is still below 2 mm/a in the western portion since interflow does not occur or is minor. In the Drakensberg highlands, however. Aquifer recharge is only 6-10 mm/a since most recharge is lost as interflow due to low storativity of the rocks. Consequently, groundwater resources are very limited despite the high rainfall and recharge. Aquifer recharge is shown in **Figure 4-5**.

Table 4-1 Borehole yields in groundwater regions, South Africa and Lesotho

Groundwater Region	Number of boreholes	Average yield (l/s)	Median yield (l/s)	% of yields >5 l/s	% of yields >2 l/s	% of yields > 0.5 l/s	80th percentile (l/s)
Bushmanland	1797	1.19	0.50	3.7	16.5	50.3	1.59
Bushmanland Pan Belt	1387	2.26	0.80	12.1	30.9	65.4	3.00
Central Highveld	2646	2.05	0.90	6	25.9	70.6	2.52
Central Pan Belt	1155	2.18	1.00	11.2	34.9	70.8	3.40
Eastern Kalahari	3060	2.11	0.64	8.5	22.3	59.6	2.14
Eastern Upper Karoo	1004	3.79	1.50	22.9	45.1	75	5.14
Far Northwestern Coastal Hinterland	24	1.87	1.33	7.5	32.2	74	2.88
Ghaap Plateau	1442	4.36	1.50	25	46.8	77	6.00
Karst Belt	957	7.43	2.00	27	50.8	80.3	10.00
Namaqualand	35	1.42	0.75	7.3	17.7	60.6	1.60
Northeastern Highland	622	2.28	0.80	5	31.6	68.6	2.98
Northeastern Pan Belt	561	1.12	0.60	2.9	16.7	57.7	1.77
Northeastern Upper Karoo	797	1.80	0.83	6.8	25.9	65.9	2.53
South Eastern Highland	993	1.53	0.70	5.7	23.1	62.4	2.50
Southeastern Highveld	4375	1.12	0.60	2.6	15	57	1.60
Southeastern Upper Karoo	925	2.48	1.26	12.2	34.9	75.7	3.43
Taung-Prieska Belt	550	1.78	0.75	7.7	25.4	60.5	2.50
West Griqua Land	1000	2.13	0.76	8	24.3	65	2.50
Western Bankeveld and Bushveld	207	2.41	0.88	9.8	26.3	71.9	2.52
Western Highveld	5361	1.38	0.76	3.9	20.5	66.2	2.00
Western Kalahari	2371	1.15	0.52	1.8	9.9	53.6	1.21
Western Upper Karoo	1031	3.46	1.36	19.3	42.1	77.8	4.50
Drakensberg Highlands	240	1.44	0.74	4.2	23.5	63.6	2.53

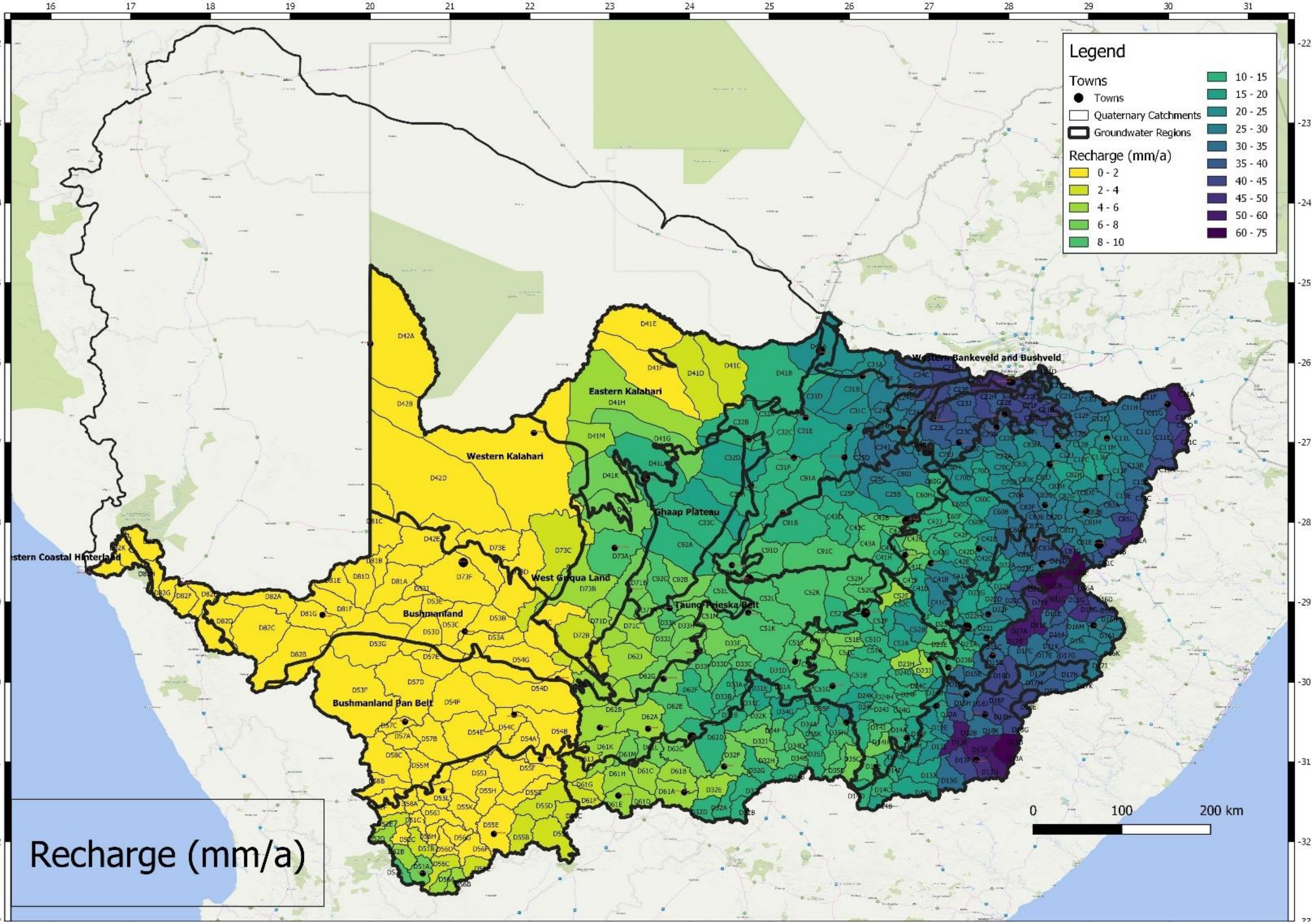


Figure 4-4 Recharge, South Africa and Lesotho

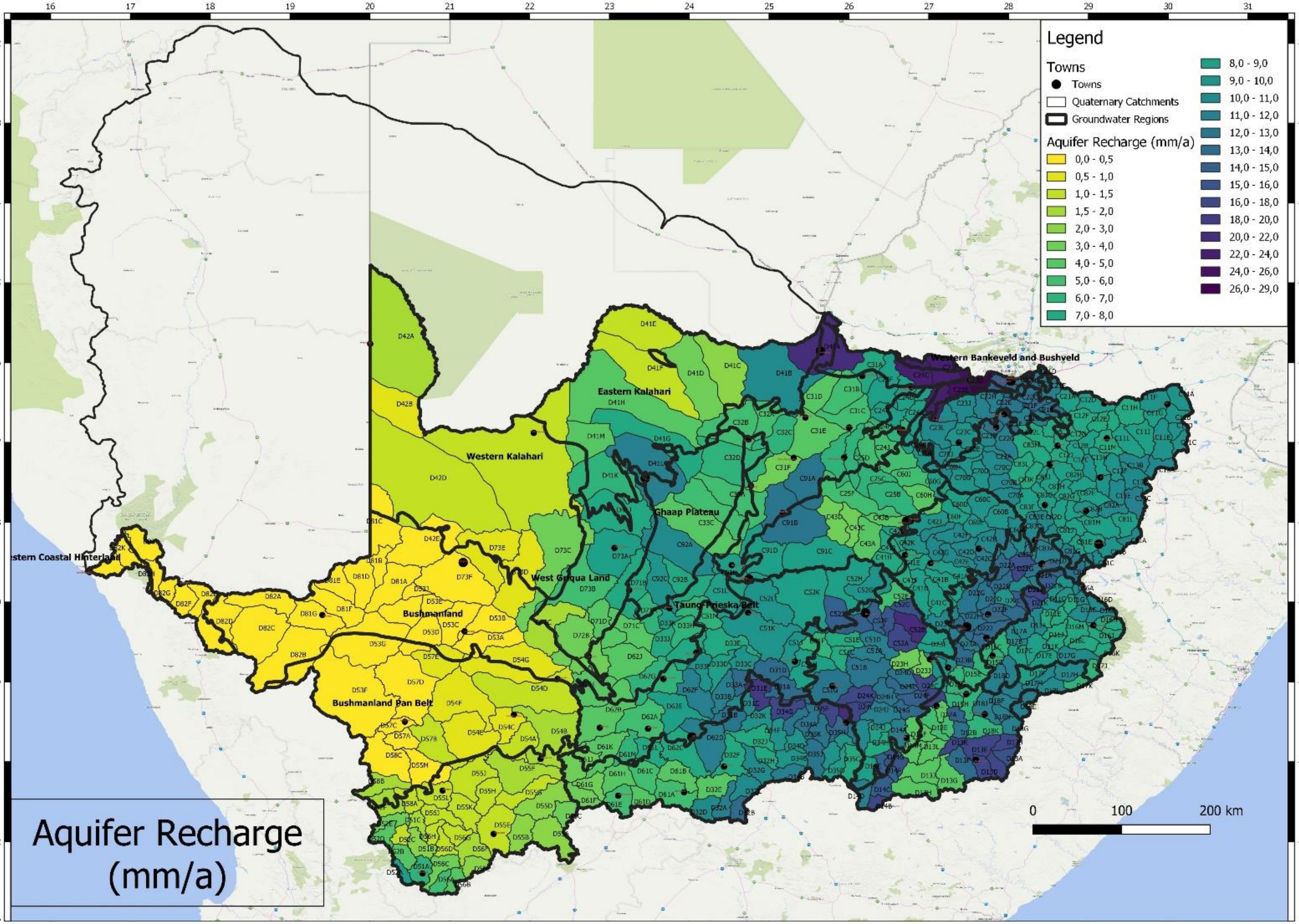


Figure 4-5 Aquifer recharge, South Africa and Lesotho

4.4 Groundwater Storage

In fractured rock aquifers the number of water-bearing fractures generally decreases with depth, resulting in a corresponding decline in aquifer storativity with depth. Whether groundwater storage is in fractures only or in fractured as well as weathered rock, also affects storage, since weathered zones have higher pore space. Consequently, two types of aquifer storage exist: weathered storage and fractured zone storage. The weathered zone is normally a relatively thin zone (5-40 m). In addition, an interstitial overburden such as the Kalahari can add 200 m or more of intergranular storage.

The upper surface of the weathered (or intergranular) aquifer is taken as the static water level. This zone is characterised by a large number of relatively low-yielding water-strikes. The fractured zone lies below the zone of weathering and is normally much thicker than the weathered zone.

Unless mining of groundwater storage is planned, the volume of water that may be abstracted from an aquifer is not indicative of the sustainable groundwater resources. It was assumed that the upper 5m of the saturated thickness can be feasibly be abstracted over a given period of time between recharge events. The volume of groundwater stored in this 5m aquifer zone was estimated, in a similar manner to GRAII.

4.4.1 Storativity

Calculations of aquifer storage are directly dependent on estimates of storativity. Storativities were calculated per Quaternary, or sub quaternary, where a Quaternary catchment cuts across more than one Groundwater region. Storativity data per region is summarized in **Table 4-2**.

Table 4-2 Storativites per Groundwater Region, South Africa and Lesotho

	Minimum Storativity		Maximum Storativity		Average	
Groundwater Region	Weathered	Fractured	Weathered	Fractured	Weathered	Fractured
Bushmanland	2.80E-04	7.94E-06	2.33E-03	3.90E-04	9.70E-04	4.00E-05
Bushmanland Pan Belt	2.10E-04	7.72E-07	1.41E-03	8.00E-05	7.50E-04	1.00E-05
Central Highveld	2.89E-03	6.87E-05	9.29E-03	1.13E-03	6.36E-03	2.80E-04
Central Pan Belt	3.90E-04	7.88E-07	2.16E-03	6.00E-05	1.38E-03	3.00E-05
Eastern Great Karoo	1.37E-03	4.46E-05	1.37E-03	4.00E-05	1.37E-03	4.00E-05
Eastern Kalahari	5.70E-04	3.98E-06	1.69E-02	3.54E-03	5.01E-03	3.50E-04
Eastern Upper Karoo	1.10E-03	6.45E-06	2.74E-03	1.20E-04	1.76E-03	6.00E-05
Far Northwestern Coastal Hinterland	1.10E-04	4.31E-06	1.70E-04	1.00E-05	1.40E-04	1.00E-05
Ghaap Plateau	1.82E-03	4.23E-05	1.39E-02	2.52E-03	1.05E-02	1.36E-03
Namaqualand	2.30E-04	1.26E-06	1.46E-03	6.00E-05	8.70E-04	2.00E-05

	Minimum Storativity		Maximum Storativity		Average	
Groundwater Region	**Weathered**	**Fractured**	**Weathered**	**Fractured**	**Weathered**	**Fractured**
Northeastern Highland	1.76E-03	2.44E-05	6.07E-03	7.17E-03	2.58E-03	3.30E-04
Northeastern Pan Belt	4.40E-04	2.97E-06	2.39E-03	7.00E-05	1.51E-03	2.00E-05
Northeastern Upper Karoo	6.30E-04	1.18E-05	2.50E-03	1.80E-04	1.67E-03	6.00E-05
Southeastern Highland	1.66E-03	1.80E-05	4.43E-03	2.70E-04	2.94E-03	1.10E-04
Southeastern Highveld	1.60E-03	9.71E-06	4.05E-03	1.40E-04	3.14E-03	5.00E-05
Taung-Prieska Belt	3.20E-04	3.37E-07	2.30E-03	6.00E-05	1.05E-03	1.00E-05
West Griqua Land	1.40E-04	3.27E-06	1.83E-03	1.60E-04	1.11E-03	5.00E-05
Western Bankeveld and Bushveld	2.66E-03	3.56E-06	1.18E-02	1.20E-04	6.26E-03	4.00E-05
Western Highveld	4.00E-05	3.43E-09	3.47E-03	1.70E-04	1.92E-03	4.00E-05
Western Kalahari	1.51E-03	4.98E-05	5.82E-03	5.40E-04	3.74E-03	2.20E-04
Western Upper Karoo	8.30E-04	9.40E-06	1.64E-03	1.20E-04	1.31E-03	3.00E-05
Karst Belt	4.80E-03	6.01E-06	3.82E-02	4.30E-03	2.21E-02	9.00E-04
Drakensberg Highlands	4.30E-04	1.26E-06	2.98E-03	2.90E-04	1.14E-03	3.00E-05
Southeastern Upper Karoo	1.27E-03	2.63E-05	2.16E-03	1.00E-04	1.64E-03	5.00E-05

4.4.2 Saturated Thickness

Saturated thicknesses of the weathered and fractured zone per Groundwater Region are shown in **Table 4-3**. Groundwater storage in the weathered and fracture zone is shown in **Figures 4-6** and **4-7**. Total aquifer storage is shown in **Figure 4-8**. Storage is high in the weathered zones of the dolomites and the intergranular Kalahari groundwater regions (**Figure 4-5**). Total storage is low in the basalts of the Drakensberg Highlands and Highest in the dolomites of the Karst Belt and Ghaap Plateau (**Figure 4-8**).

Storage in the upper 5 m of the aquifer is shown in **Figure 4-9**.

Table 4-3 Saturated thickness per Groundwater Region, South Africa and Lesotho

	Minimum		Maximum		Average	
Groundwater Region	**Weathered**	**Fractured**	**Weathered**	**Fractured**	**Weathered**	**Fractured**
Bushmanland	14.0	122.0	82.3	199.7	58.6	162.1
Bushmanland Pan Belt	14.0	111.7	72.4	169.7	53.6	125.7
Central Highveld	11.1	119.8	44.6	214.8	29.4	150.4
Central Pan Belt	6.2	74.7	55.7	199.2	20.6	119.1
Eastern Great Karoo	39.1	73.9	39.1	73.9	39.1	73.9
Eastern Kalahari	11.0	118.7	110.0	263.3	69.2	190.6
Eastern Upper Karoo	10.3	65.7	53.0	133.1	36.7	82.1
Far Northwestern Coastal Hinterland	14.4	94.1	19.0	187.7	17.0	140.7
Ghaap Plateau	41.8	112.4	92.4	254.8	60.1	142.1

	Minimum		Maximum		Average	
Groundwater Region	**Weathered**	**Fractured**	**Weathered**	**Fractured**	**Weathered**	**Fractured**
Namaqualand	13.4	101.5	55.8	199.1	27.6	177.4
Northeastern Highland	0.0	1.6	24.6	158.2	12.4	103.9
Northeastern Pan Belt	1.7	91.8	39.2	205.9	12.9	156.1
Northeastern Upper Karoo	1.7	65.7	46.8	205.9	19.1	114.2
Southeastern Highland	0.0	73.5	39.4	144.7	10.3	118.6
Southeastern Highveld	8.6	88.6	43.9	188.2	19.5	151.8
Taung-Prieska Belt	4.8	112.4	60.4	149.4	34.9	130.9
West Griqua Land	25.4	112.4	92.4	222.6	56.8	152.6
Western Bankeveld and Bushveld	17.5	162.3	53.7	224.1	25.4	190.5
Western Highveld	4.8	112.8	110.0	224.1	34.0	149.4
Western Kalahari	25.4	153.8	88.7	222.6	59.3	184.1
Western Upper Karoo	16.3	73.7	60.1	135.4	37.4	128.1
Karst Belt	13.6	123.2	104.2	224.1	30.8	170.4
Drakensberg Highlands	0.0	120.0	16.3	123.5	0.8	120.1
Southeastern Upper Karoo	5.8	82.0	30.6	139.4	20.3	98.1

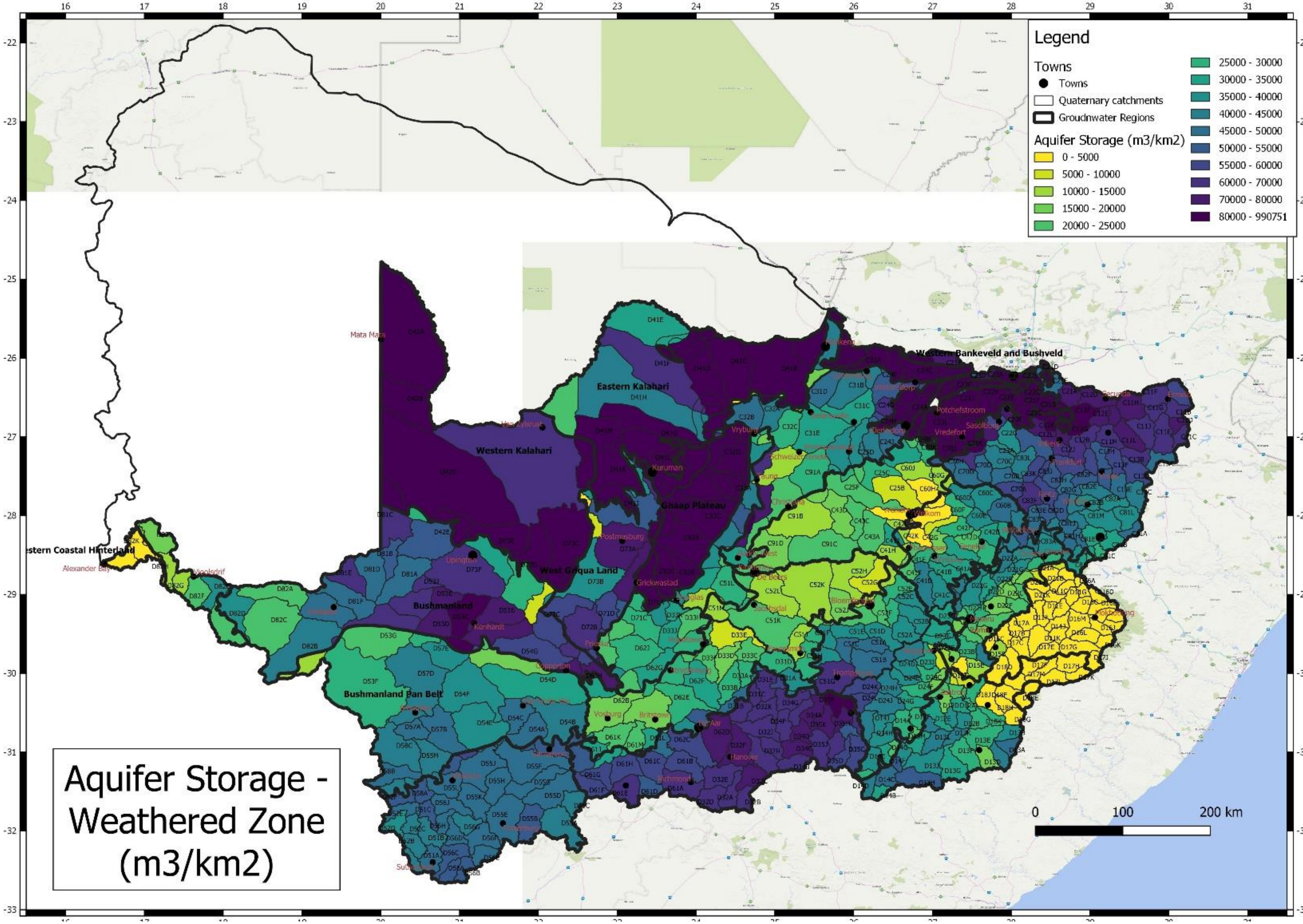


Figure 4-6 Aquifer storage in the weathered zone, South Africa and Lesotho

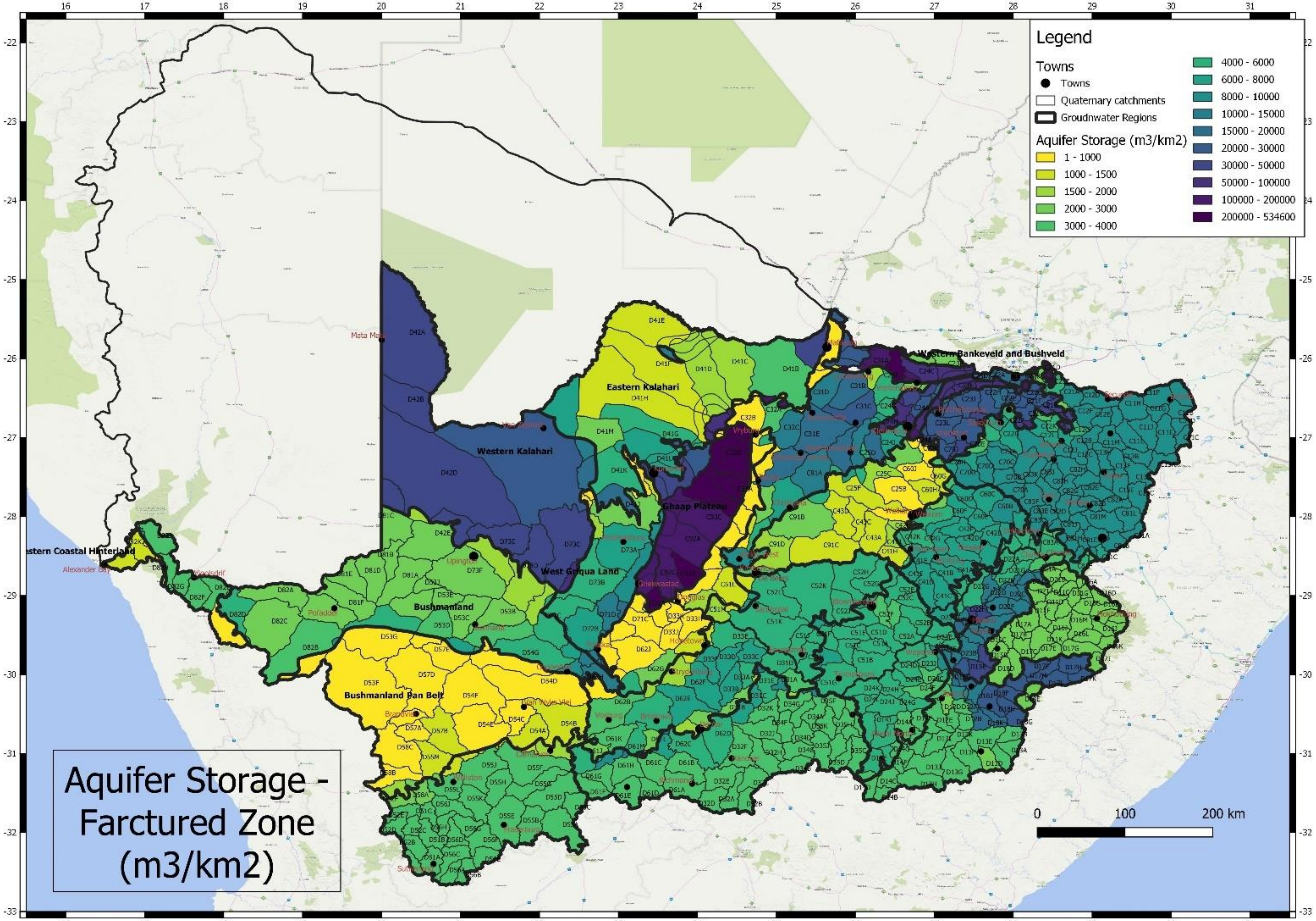


Figure 4-7 Aquifer storage in the fractured zone, South Africa and Lesotho

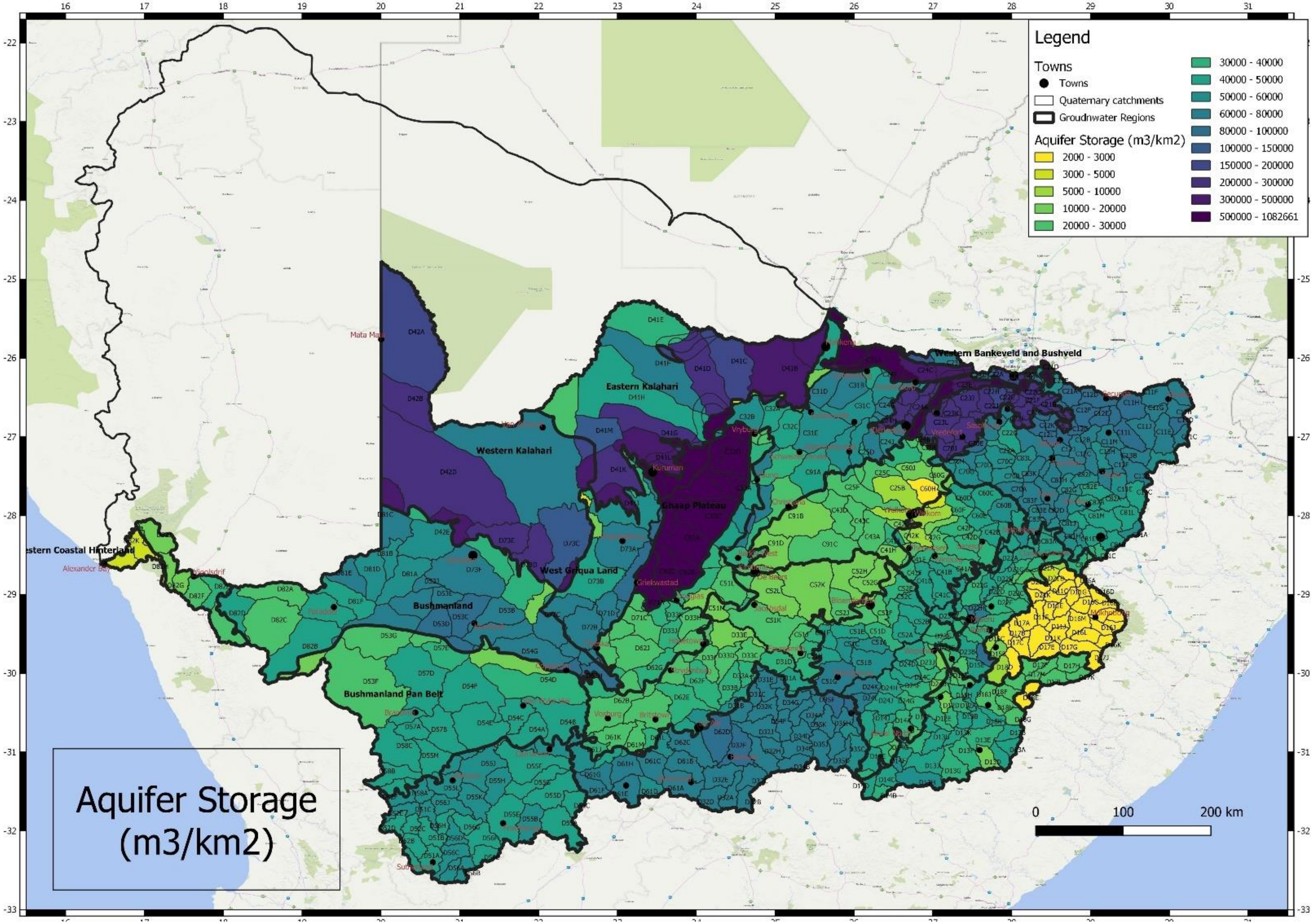


Figure 4-8 Aquifer storage, South Africa and Lesotho (see entire basin Appendix 16)

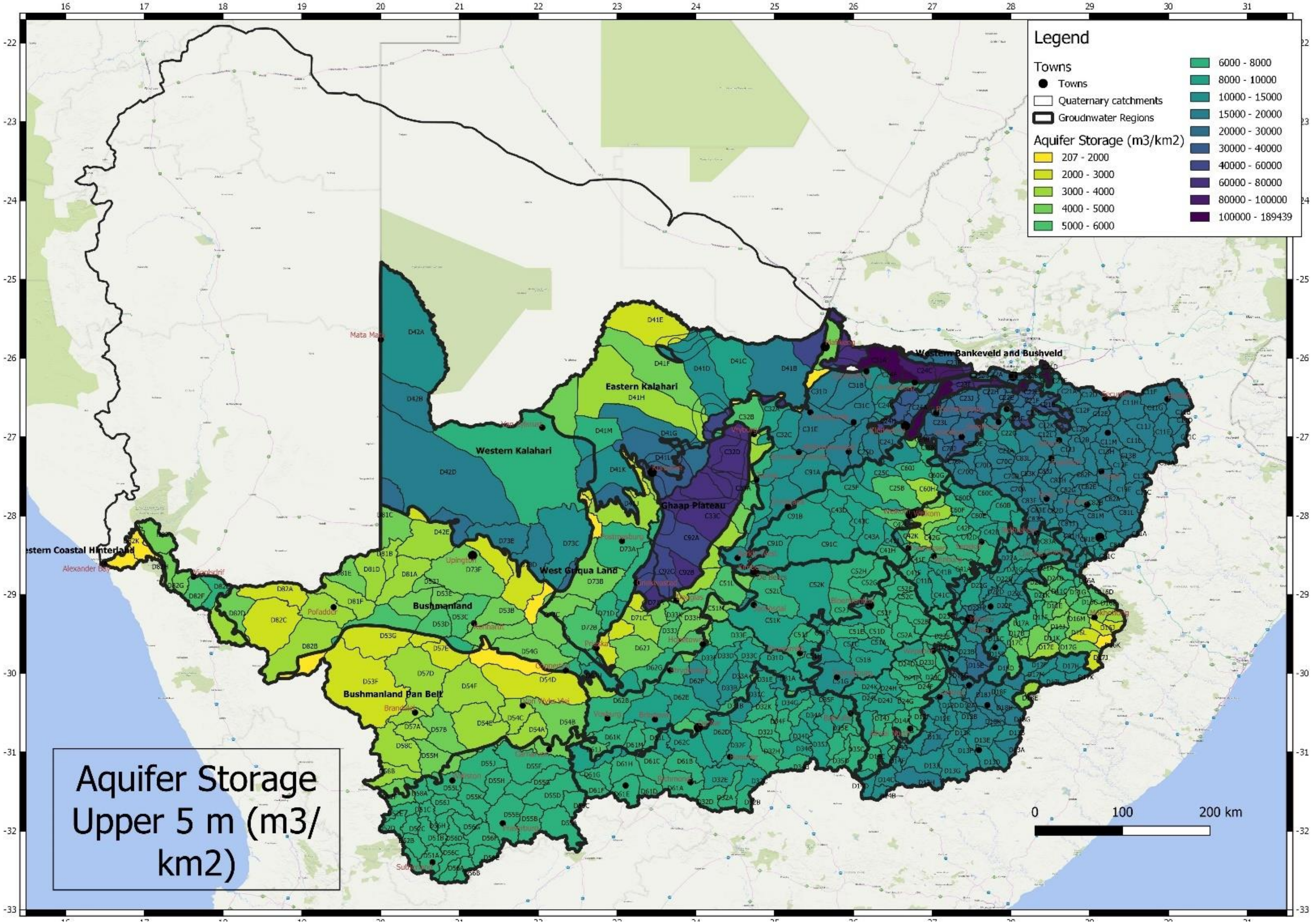


Figure 4-9 Aquifer storage in the upper 5 m of the aquifer, South Africa and Lesotho

4.5 Baseflow

Baseflow can be considered to consist of the portion of subsurface water which contributes to the low flow of streams. This can originate as either from the regional groundwater body (groundwater baseflow), that portion of the total water resource that can either be abstracted as ground water or surface water, or via perched aquifers, high lying springs, excess recharge that is not accepted by the aquifer, processes that can be lumped as interflow. In catchments with significant relief and geological heterogeneities, a large part of the baseflow fraction originates as interflow and never passes through the regional aquifer, and hence does not form part of the groundwater resources.

Baseflow to maintain instream flows cannot therefore be simply attributed to discharge from the regional aquifers, since a large fraction could originate as interflow from: subsurface discharge with a rapid turnover time seeping from shallow fractures outcropping on steep slopes; from perched water tables; or from highland springs above the regional valley bottom aquifer. This often occurs due to geological discontinuities; hence they are not necessarily in contact with the regional aquifer. Baseflow can be subdivided into interflow not originating from the regional groundwater body and therefore not accessible by boreholes, and groundwater baseflow.

The distribution of baseflow is shown in **Figure 4-10**. It is evident that a large proportion of baseflow is generated in the Drakensberg Highlands of Lesotho. When only the groundwater component of baseflow (groundwater baseflow) is considered (**Figure 4-11**), the contribution from the Drakensberg Highlands is much less, since most baseflow is generated as interflow and only a small proportion enters the regional aquifer. Consequently, recharge is high, but recharge to the aquifer is low and groundwater baseflow is a small component of baseflow.

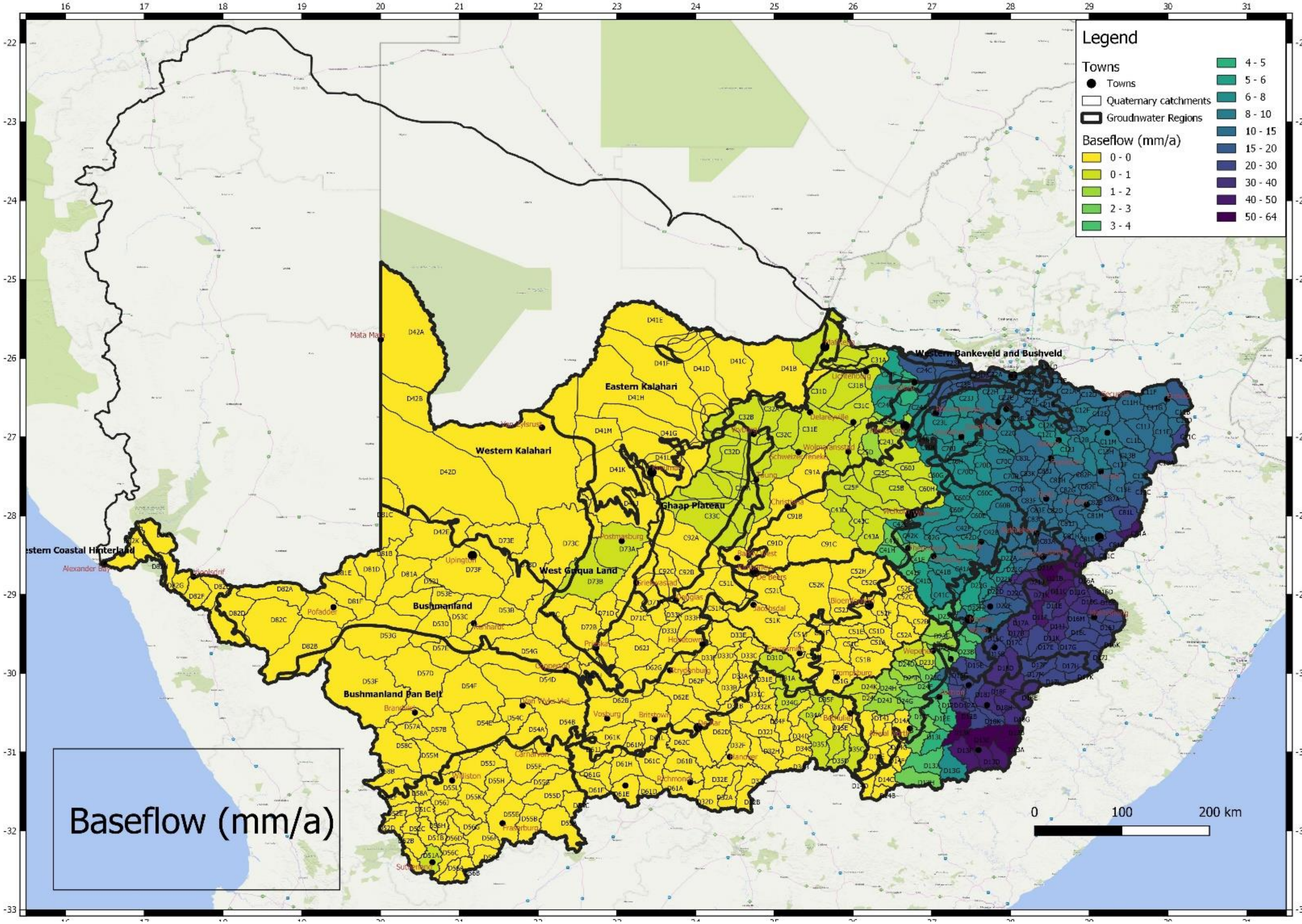


Figure 4-10 Baseflow, South Africa and Lesotho (see entire basin Appendix 16)

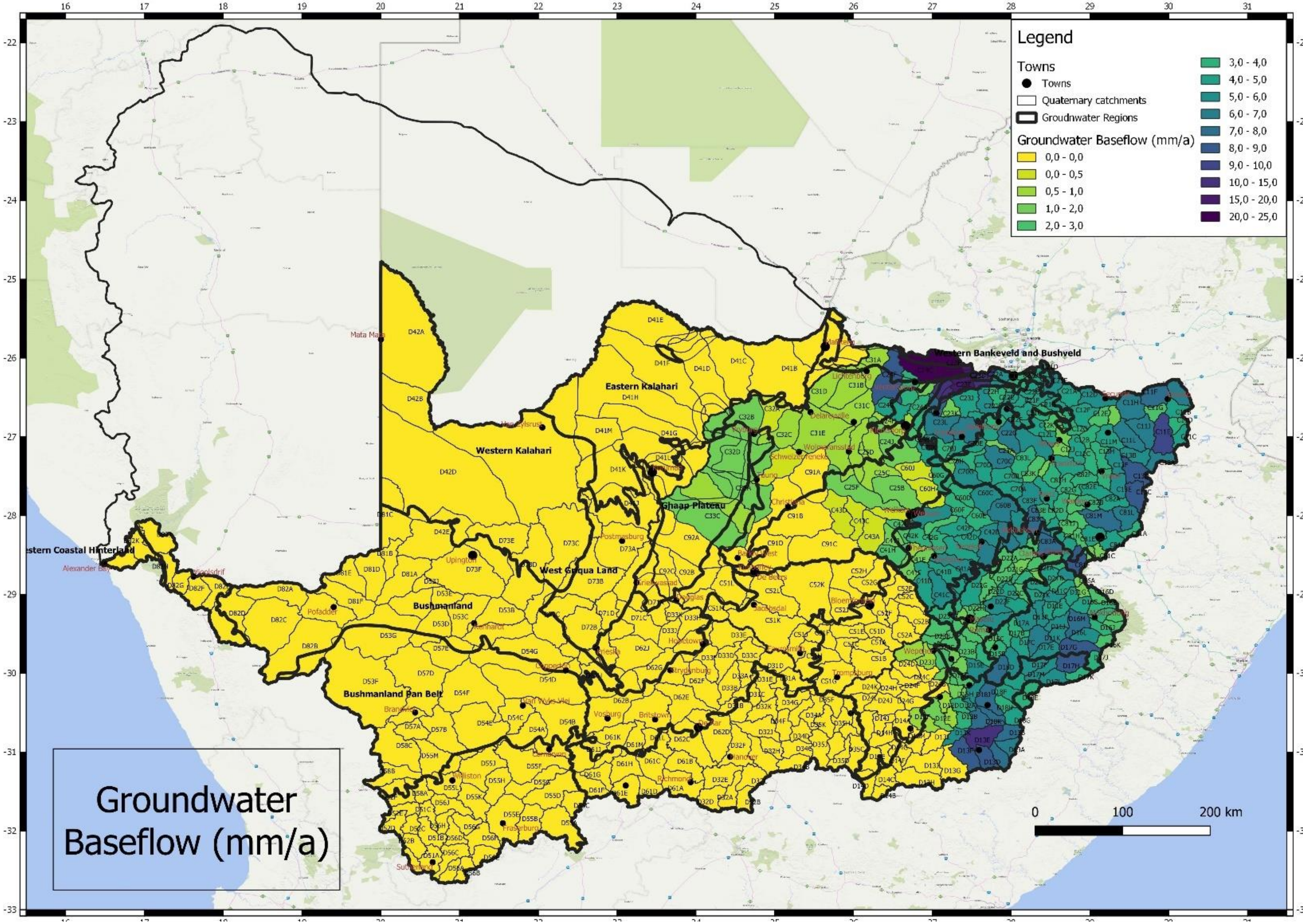


Figure 4-11 Groundwater baseflow, South Africa and Lesotho (see entire basin Appendix 16)

4.6 Groundwater Resources

4.6.1 Groundwater Resource Potential

Assuming that the upper 5m (i.e. below the water table) of aquifer storage can feasibly be abstracted over a given period of time, the groundwater resource potential was calculated using eq 4, with the storage volumes calculated from the revised storativity data. Calibrated recharge from the Lower Orange Environmental Water Requirement (EWR) study and ORSECOM transboundary aquifer project were used where available.

If the saturated thickness of the weathered zone is less than 5m, the volume of water stored was estimated using the weathered zone storativity only. Where the saturated is equal to zero, the volume of water stored is estimated using the fractured zone storativity only. If the thickness of the saturated weathered zone exceeds 5 m, then a combination of both storativities were used.

Groundwater Resource Potential, incorporating recharge, baseflow and storage is shown in **Figure 4-12**. Groundwater Resource Potential is highest in the dolomites of the Ghaap Plateau and Karst Belt, and lowest in the western part of the basin.

4.6.2 Groundwater Exploitation Potential

The feasibility of abstracting the groundwater resource potential is limited by physical attributes of a particular aquifer system, such as permeability, access to drill sites, and economic factors, hence it is not possible to exploit all of the groundwater resource potential. The Groundwater Exploitation Potential, factoring in permeability and the probability of drilling successful boreholes, is shown in **Figure 4-13**.

4.6.3 Utilisable Groundwater Exploitation Potential

The volume of water that may be abstracted from a groundwater resource may also be limited by anthropogenic and ecological and/or legislative considerations. They can relate to maintaining baseflow, avoiding sinkholes etc. The volume that can be sustainably abstracted is referred to as the Utilisable Groundwater Exploitation Potential (UGEP). It was calculated assuming zero drawdown of storage where groundwater baseflow exists to maintain baseflow, and other maximum drawdown levels were taken from GRAII. The UGEP is shown **Figure 4-14**.

.

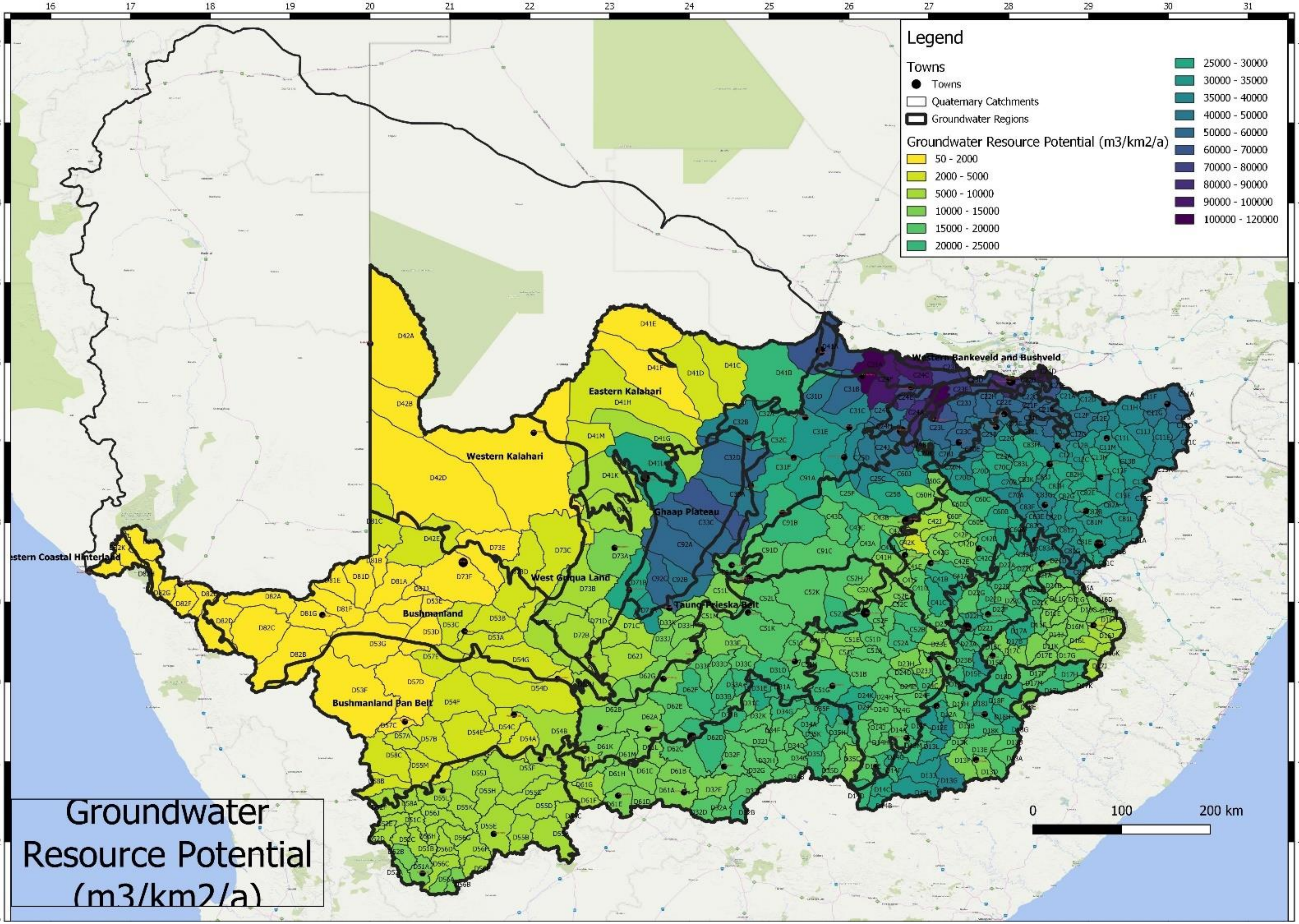


Figure 4-12 Groundwater Resource Potential, South Africa and Lesotho

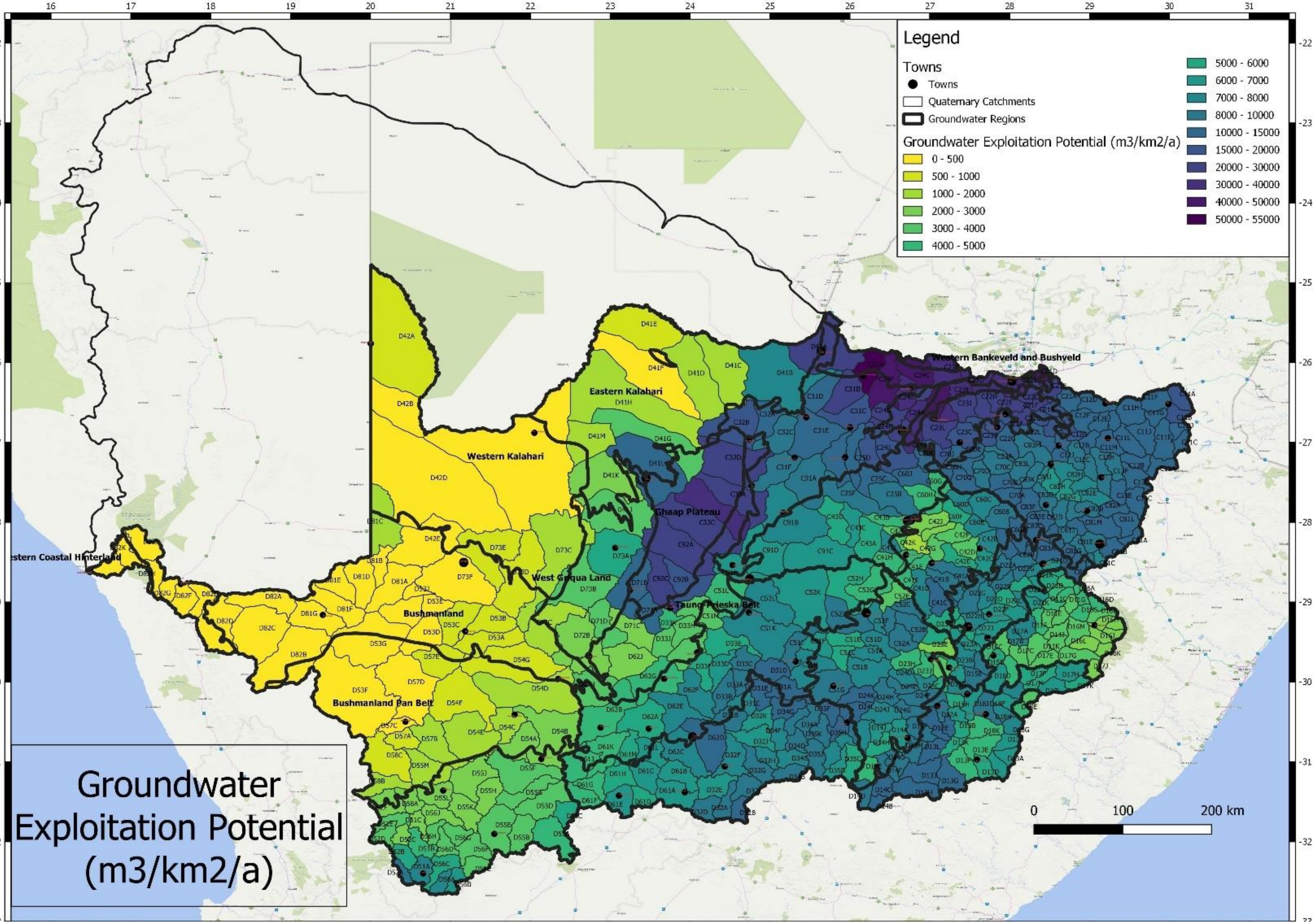


Figure 4-13 Groundwater Exploitation Potential, South Africa and Lesotho

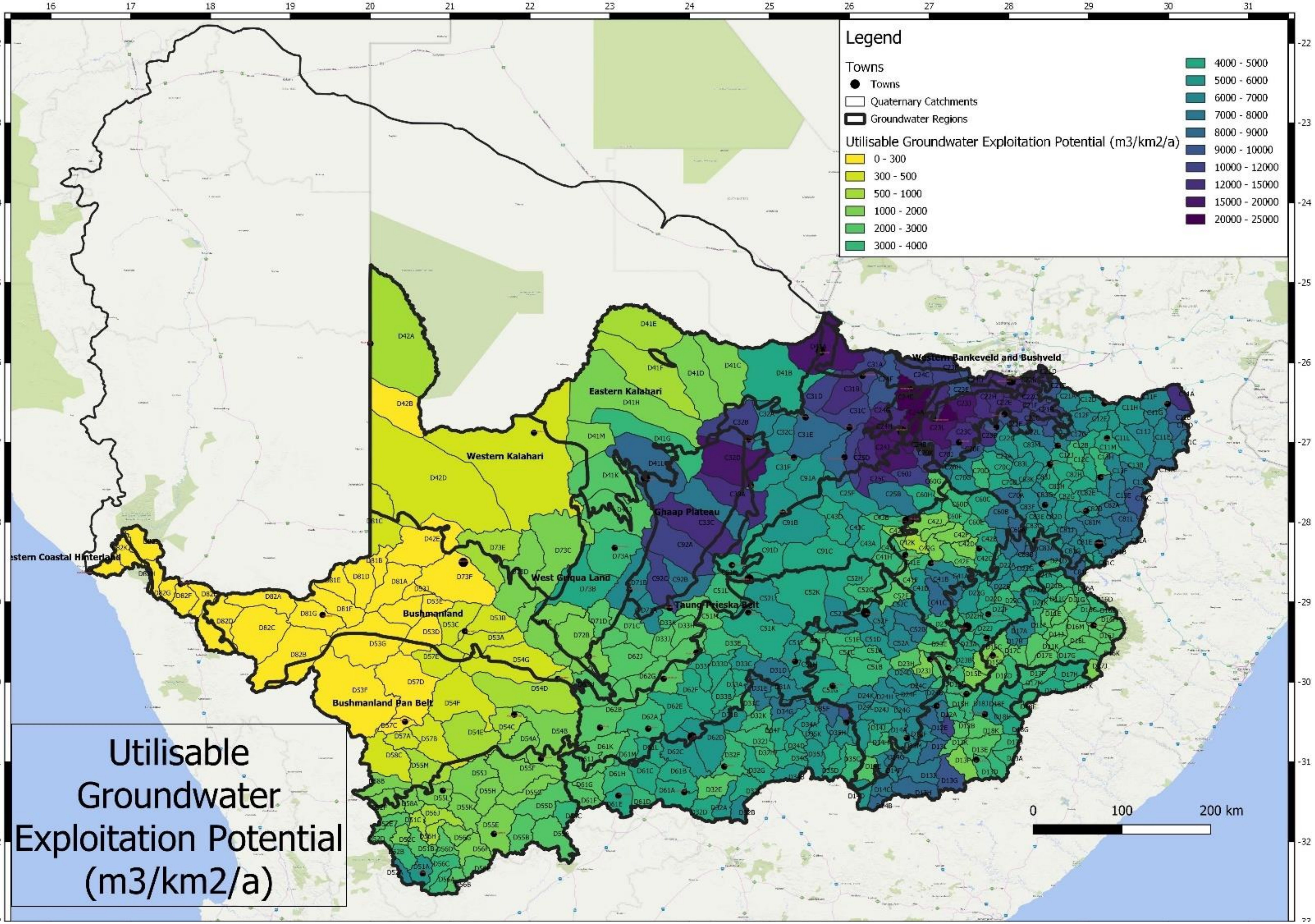


Figure 4-14 Utilisable Groundwater Exploitation Potential, South Africa and Lesotho (see entire basin Appendix 16)

4.7 Groundwater Quality

4.7.1 Potability standards and Irrigation standards

Over 39500 groundwater quality analyses were available for South Africa and Lesotho. These are for 21559 individual monitoring points. For boreholes with a time series of analyses, the most recent water quality was used to avoid weighting analyses based on one borehole site.

All hydrochemical data were collated and were assessed for potable use and irrigation by using the Guidelines for Water Quality (**Table 4-4**). Classes 0-2 were considered potable. Class 0 is considered the Target Water Quality Range.

Table 4-4 Guidelines for Water Quality, South Africa and Lesotho

Analyses	Unit	Classification				
		Class 0 IDEAL	Class I GOOD	Class II MARGINAL	Class III POOR	Class IV UNACCEPTABLE
Domestic						
pH		5.5 - 9.5	4.5-5.5 and 9.5-10	4-4.5 and 10-10.5	3-4 and 10.5-11	< 3 or > 11
Conductivity	mS/m	< 70	70 - 150	150 - 270	270 - 450	> 450
TDS	mg/l	< 450	450 - 1000	1000 - 2400	2400 - 3400	> 3400
Total Hardness	$CaCO_3$	< 200	200 - 300	300 - 600	> 600	
Calcium	mg/l	< 80	80 - 150	150 - 300	> 300	
Copper	mg/l	< 1	1 - 1.3	1.3 - 2	2 - 15	> 15
Iron	mg/l	< 0.5	0.5 - 1	1 - 5	5 - 10	> 10
Magnesium	mg/l	< 70	70 - 100	100 - 200	200 - 400	> 400
Manganese	mg/l	< 0.1	0.1 - 0.4	0.4 - 4	4 - 10	> 10
Potassium	mg/l	< 25	25 - 50	50 - 100	100 - 500	> 500
Sodium	mg/l	< 100	100 - 200	200 - 400	400 - 1000	> 1000
Chloride	mg/l	< 100	100 - 200	200 - 600	600 - 1200	> 1200
Fluoride	mg/l	< 0.7	0.7 - 1	1 - 1.5	1.5 - 3.5	> 3.5
Nitrate NO_3 - N	mg/l	< 6	6 - 10	10 - 20	20 - 40	> 40

Analyses	Unit	Classification				
		Class 0 IDEAL	Class I GOOD	Class II MARGINAL	Class III POOR	Class IV UNACCEPTABLE
Nitrite NO_2 - N	mg/l	< 6	6 - 10	10 - 20	20 - 40	> 40
Orthophosphate (PO_4 as P)	mg/l	< 0.1	0.1 - 0.25	0.25 - 1	> 1	
Sulphate (SO_4)	mg/l	< 200	200 - 400	400 - 600	600 - 1000	> 1000
MPN *E. coli*	/100ml	0	0 - 1	1 - 10	10 - 100	> 100
Irrigation						
Conductivity	mS/m	< 40	40 - 90	490-270	2740-540	> 540

4.7.2 Electrical Conductivity

The data indicates that Electrical Conductivity (EC) varies between 2 to over 20 000 mS/m and that EC is highly variable, with boreholes of Class 0 located in close proximity to boreholes of Class 4.

Groundwater in the Bushmanland Pan Belt, Bushmanland, the Western Kalahari, Namaqualand and the Far Northwestern Coastal Hinterland is generally of Class 3 or 4, Poor to Unacceptable. The percent of boreholes which are Ideal and Good for potable water (Class 0 and 1), and Marginal water quality for emergency or short-term potable use (Class 2) in each Quaternary is shown in **Figure 4-15**. The fraction of boreholes that are potable (potability index) declines to the west and north, reaching less than 10 percent in coastal Namaqualand.

The groundwater quality in terms of suitability for water supply and irrigation is shown in **Figures 4-15** and **4-16**.

Groundwater is of suitable quality for water supply across the basin, except in the Western Kalahari, Bushmanland, and Namaqualand.

It should also be noted that variations in water quality guidelines exist amongst the member states. For this reason it was decided that international al guidelines be adopted to define potability.

The presence of dissolved solids in water may affect its taste (1). The palatability of drinking water has been rated by panels of tasters in relation to its TDS level as follows: excellent, less than 300 mg/litre; good, between 300 and 600 mg/litre; fair, between 600 and 900 mg/litre; poor, between 900 and 1200 mg/litre; and unacceptable, greater than 1200 mg/litre (1). Water with extremely low concentrations of TDS may also be unacceptable because of its flat, insipid taste. No health-based guideline value for TDS has been proposed WHO/SDE/WSH/03.04/16.

Health effects related to TDS are minimal at concentrations below 2000 - 3 000 mg/l TDS. The total dissolved solids (TDS) is a measure of the amount of various inorganic salts dissolved in water. The TDS concentration is directly proportional to the electrical conductivity (EC) of water. Since EC is much easier to measure than TDS, it is routinely used as an estimate of the TDS concentration.

For most natural waters electrical conductivity is related to the dissolved salt concentration by a conversion factor ranging from 5.5 - 7.5. The average conversion factor for most waters is 6.5. The conversion equation is as follows:

EC(mS/m at 25EC) x 6.5 = TDS(mg/l)

Based on this information, a threshold of 1200 mg/l TDS or 185 mS/m EC was selected as the threshold for potability (see **Appendix 16** for combined maps on water quality).

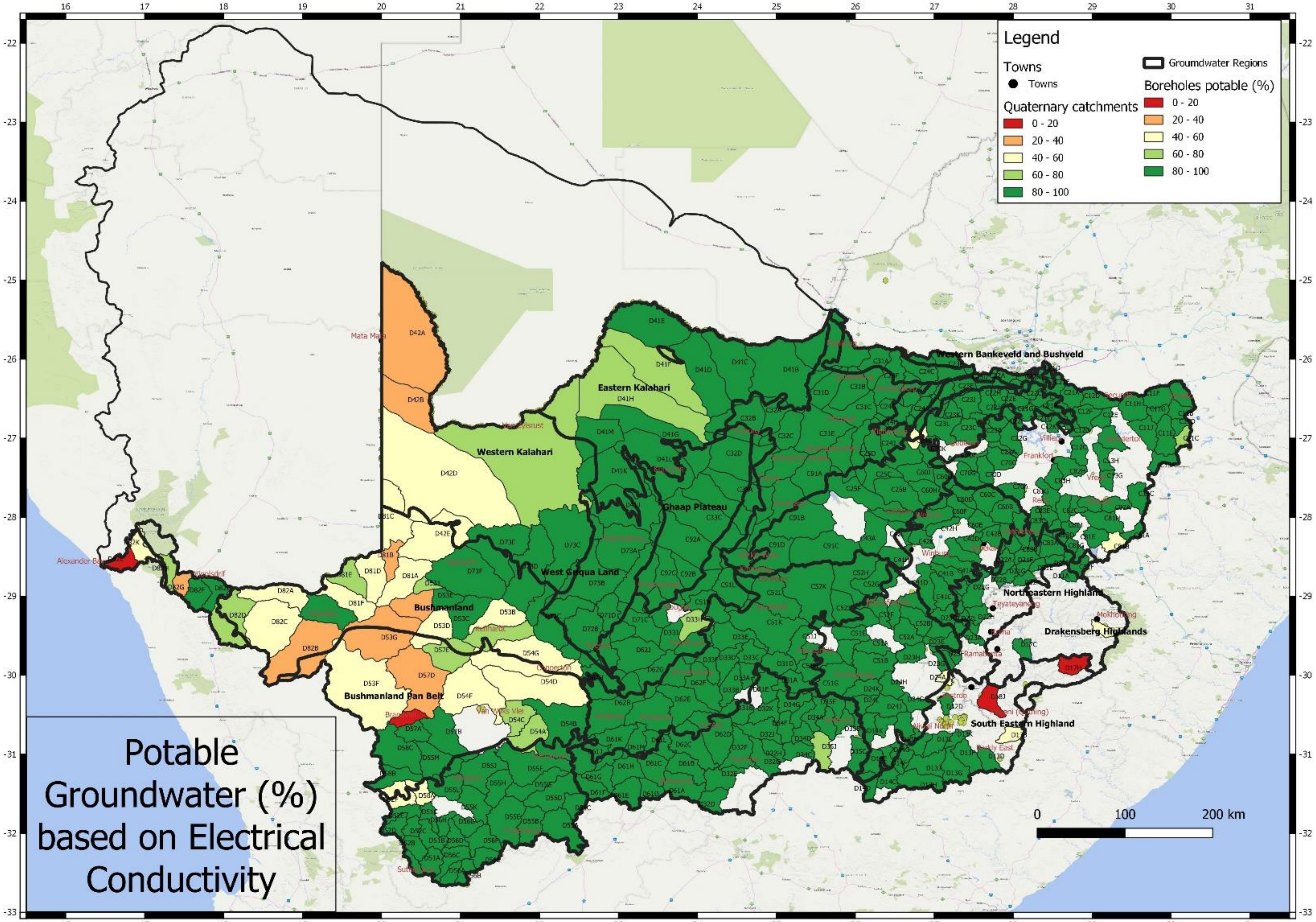


Figure 4-15 Percent potable groundwater per Quaternary catchment in terms of electrical conductivity, South Africa and Lesotho (see entire basin Appendix 16)

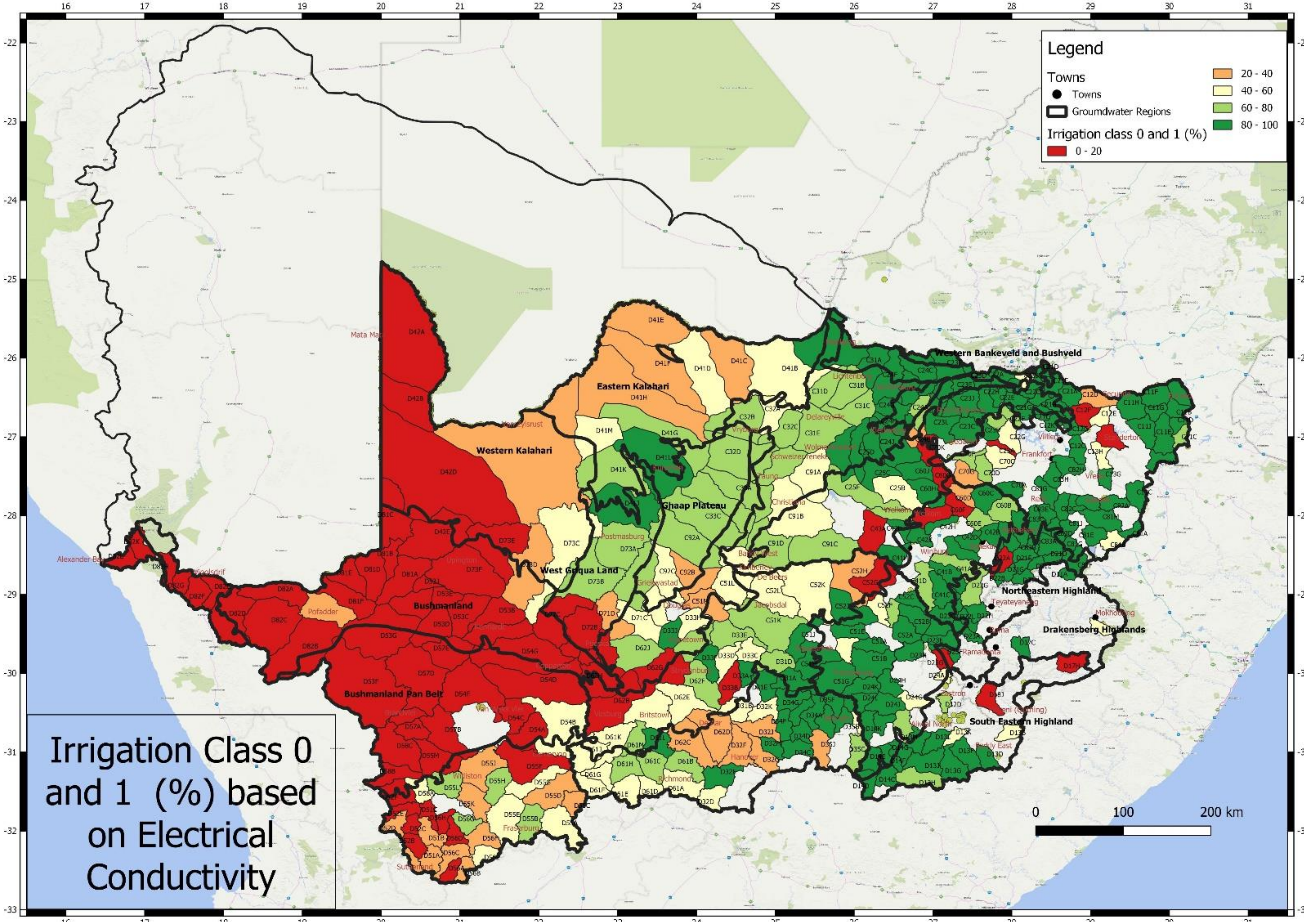


Figure 4-16 Percent groundwater suitable for irrigation per Quaternary catchment, South Africa and Lesotho

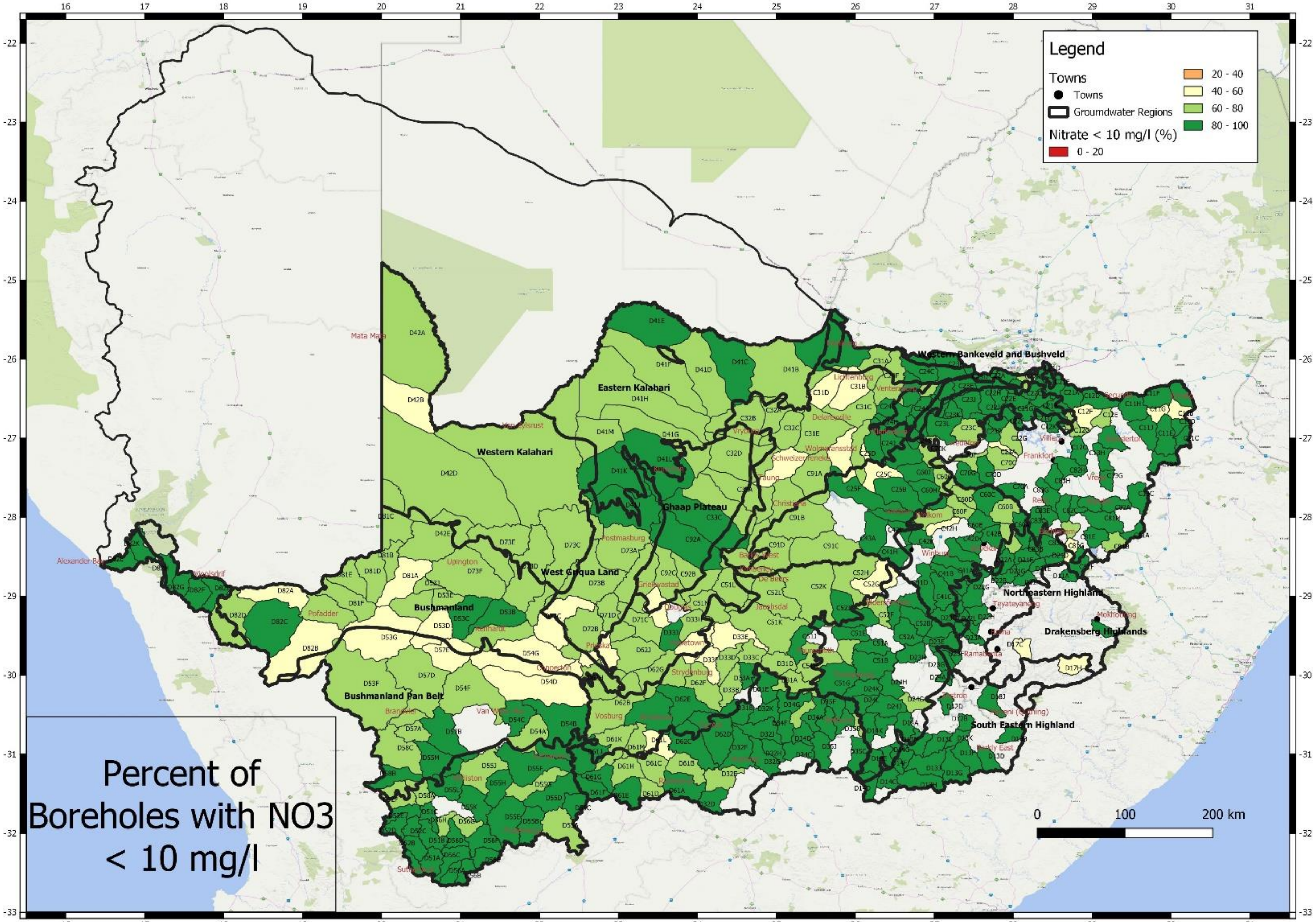


Figure 4-17 Percent potable groundwater per Quaternary catchment in terms of nitrates, South Africa and Lesotho

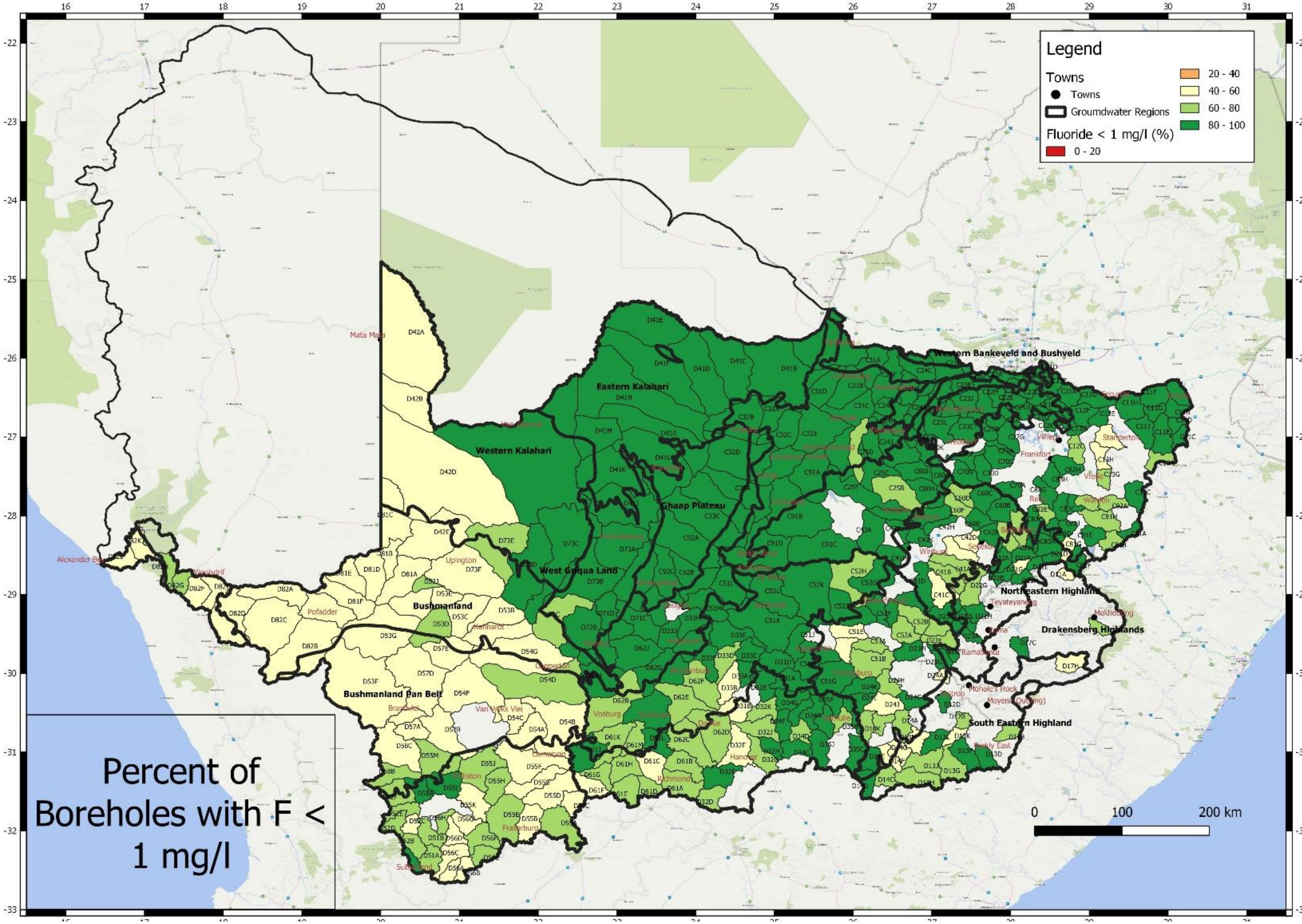


Figure 4-18 Percent potable groundwater per Quaternary catchment in terms of fluoride, South Africa and Lesotho

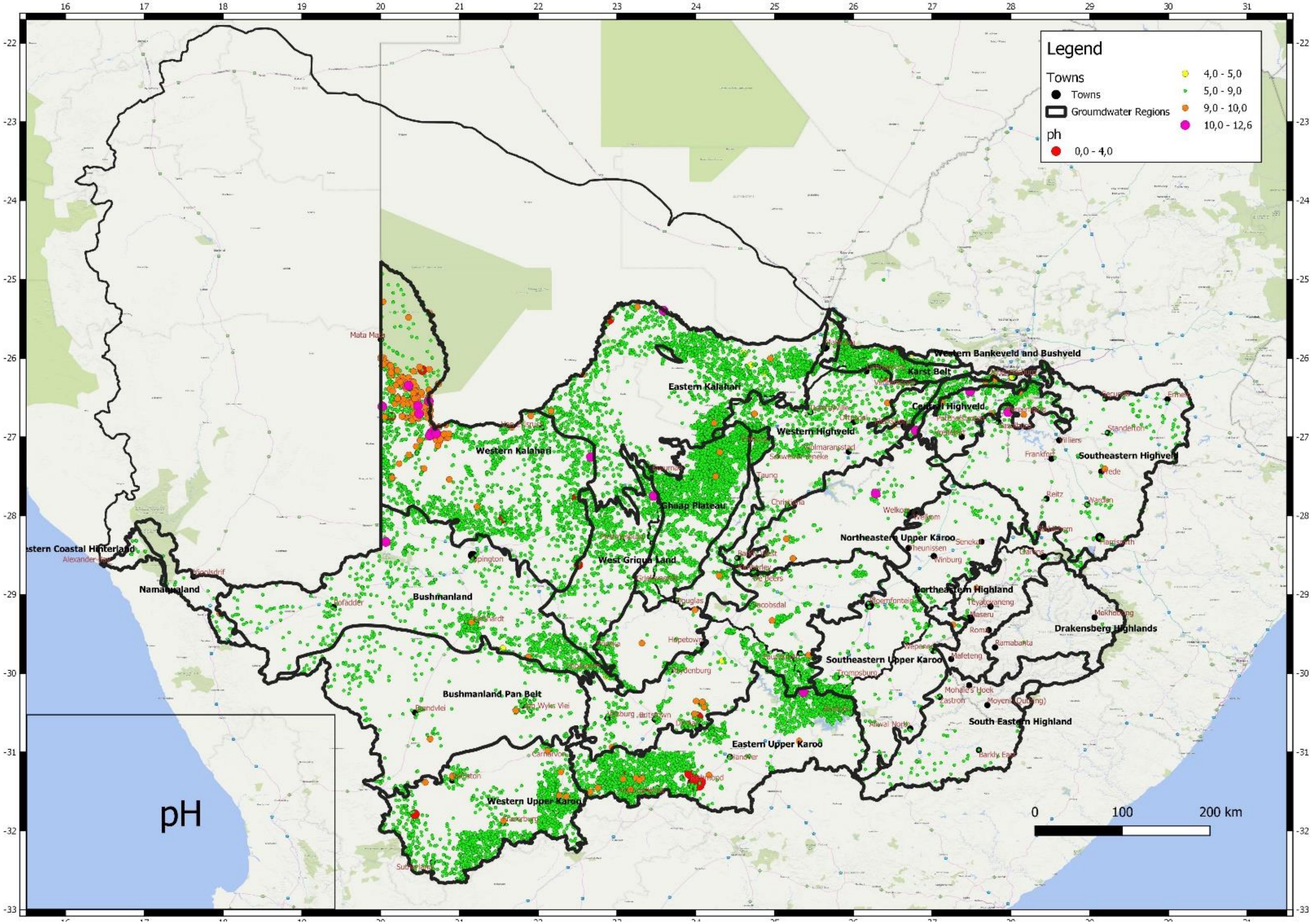


Figure 4-19 pH of groundwater, South Africa and Lesotho

4.7.3 Nitrates

Figure 4-17 shows the faction of boreholes with potable groundwater in terms of nitrates (<10 mg/l) in each Quaternary catchment. Elevated nitrates are found throughout the basin. Groundwater in the Eastern and Western Kalahari, Bushmanland and Namaqualand show elevated nitrates with only 40 - 70% of boreholes yielding potable water (**Figure 4-16**).

4.7.4 Fluorides

The Percent of boreholes with potable groundwater in terms of fluoride concentration (<10 mg/l) is shown in **Figure 4-18**. Groundwater in the western Kalahari, Bushmanland, the Bushmanland Pan Belt and Namaqualand show elevated fluorides, with only 40-60% of boreholes yielding potable water.

4.7.5 pH

The Water Quality Range for Ideal or Good quality water pH is5-9. Marginal quality extends the pH range down to 4 and to 10.5. Below 4 toxic effects associated with dissolved metals are likely to occur. Above 9, the probability of toxic effects associated with deprotonated species increases sharply. The areas of occurrence of acidic waters (pH <5) and that of very basic water (pH>9) is shown in **Figure 4-19**. Acid waters are rare and where present, their probability of occurrence is low (<10%). Basic ground water is found in the Bushmanland Pan belt, Taung-Prieska, and the Western Kalahari.

4.7.6 Metals

The following metals were found to occur at above the Target Water Quality Range: Arsenic (As), Molybdenum (Mo), Iron (Fe) and Boron (B).

4.7.6.1 Arsenic

There are about 24 As-bearing minerals commonly found in hydrothermal veins, ore deposits. Most primary As minerals are sulphides, of which arsenopyrite is the most common. Most Arsenic bearing minerals occur in sulphide rich mineralised areas in close association with Cd, Pb, Ag, Au, Sb, P, W and Mo. Arsenic is one of a suite of incompatible elements that do not fit easily into the lattices of common rock-forming minerals. It is common in geothermal springs that leach continental rocks. Because arsenic is an incompatible element, it accumulates in differentiated magmas, and commonly found at higher concentrations in volcanic rocks of intermediate (andesites) to felsic (rhyolites) composition than in mafic (basaltic/doleritic) rocks. It is only found in sedimentary rocks, such as the Karoo, where argillaceous rocks with sulphide mineralisation under reducing conditions, such as black carbonaceous shales.

The Target Water Quality Guideline Range is 0 - 10 ug/l and should never exceed 200 ug/l, which would result in serious health risk (DWAF, 2006b).

The frequency of As occurrence over 50 ug/l is shown in **Figure 4-20**. The high concentration of As across the Bushmanland Pan belt and the Central Pan Belt coincides with the outcrop of carbonaceous Ecca shale, where it would be expected. The presence of significant occurrences of As in the eastern Western Upper Karroo and the Eastern Upper Karroo cannot be explained by the sandstone and mudstone geology, which does not contain As minerals. However, AS could be an indicator of upwelling of deeper groundwater from the underlying carbonaceous shales.

High concentrations occur in the Karst Belt and Central Highveld, which can be attributed to mining and industrial activity.

4.7.6.2 Molybdenum

Molybdenum is a strongly chalcophile or siderophile metallic element forming several minerals but is more widely present at trace levels in association with organic matter and sedimentary sulphide minerals, notably in black shale.

Mo behaves incompatibly and is only sparingly incorporated in major rock-forming silicates. In sediments, Mo tends to follow Cu in its behaviour and is strongly complexed by organic matter. Black shale is therefore, enriched in Mo. Unlike most metals, Mo is mobile under alkaline conditions, and finds particular application in reconnaissance exploration in arid environments. Consequently, Mo can be an indicator of groundwaters in contact with carbonaceous shales. **Figure 4-21** shows the frequency of occurrence of Mo above 0.07 mg/l. The presence of significant occurrence of Mo in the Western and Eastern Upper Karoo, without any geological sources, suggests that there is potentially upwelling groundwater from deeper aquifers in contact with carbonaceous shales.

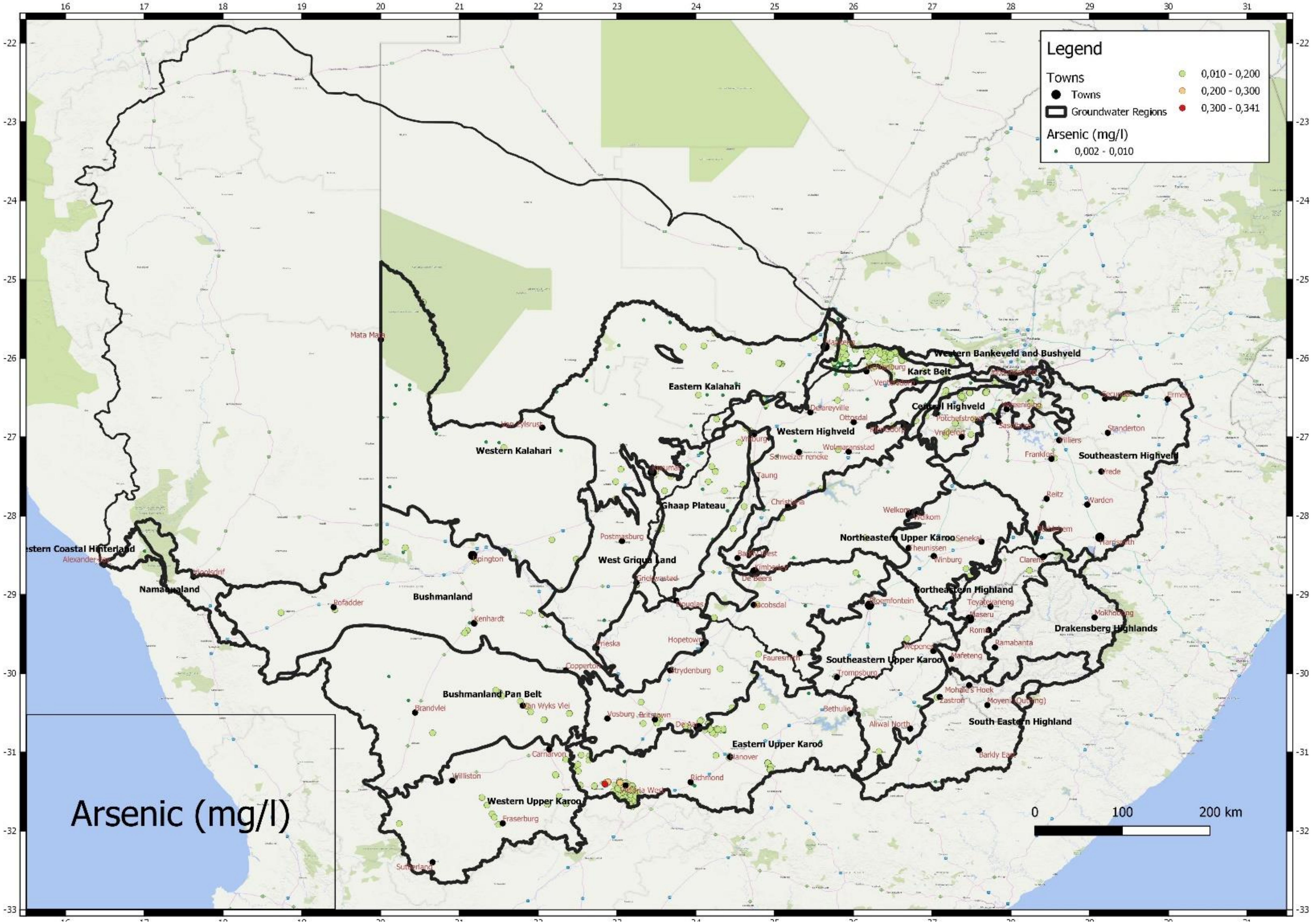


Figure 4-20 Arsenic in groundwater, South Africa and Lesotho

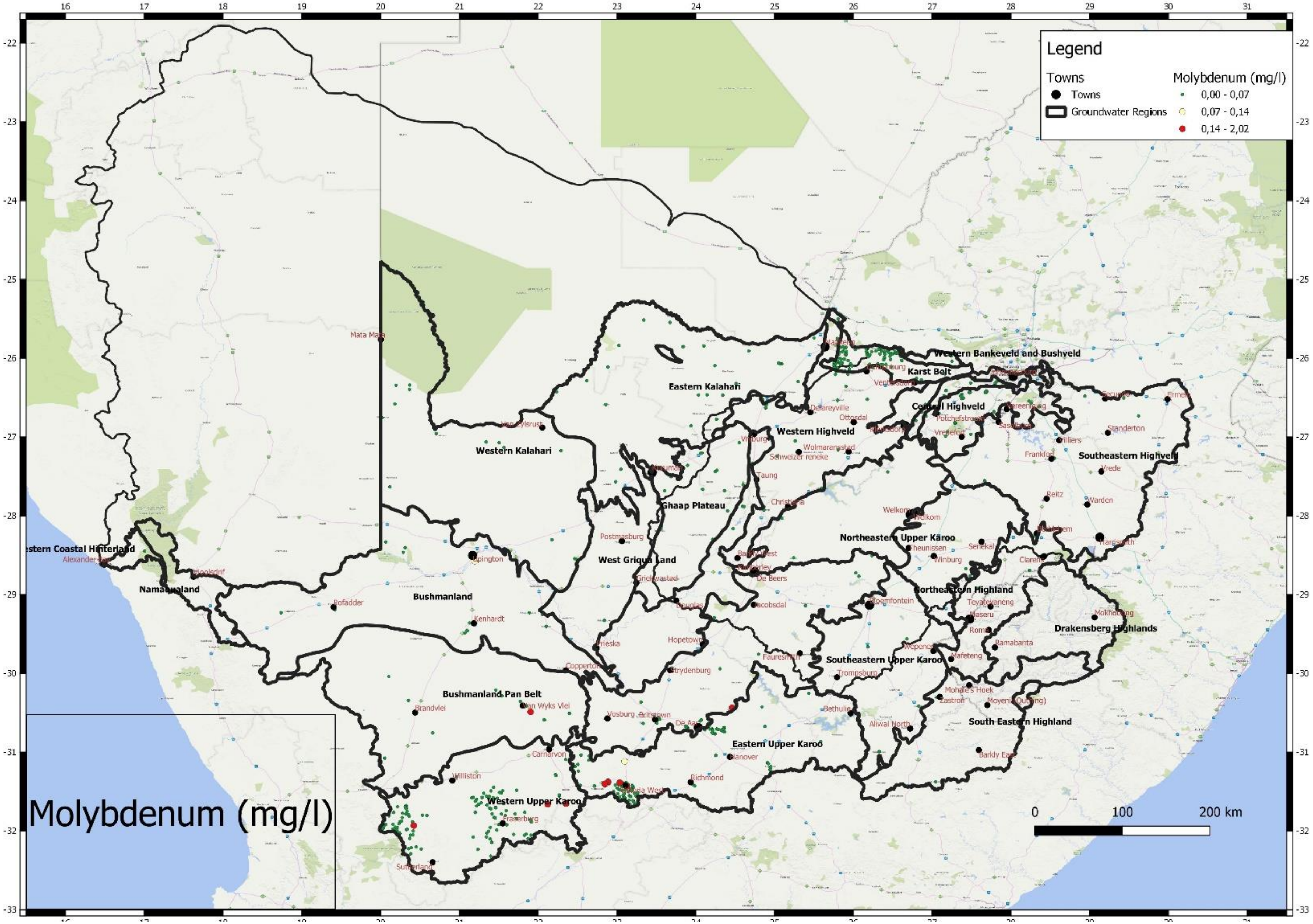


Figure 4-21 Molybdenum in groundwater, South Africa and Lesotho

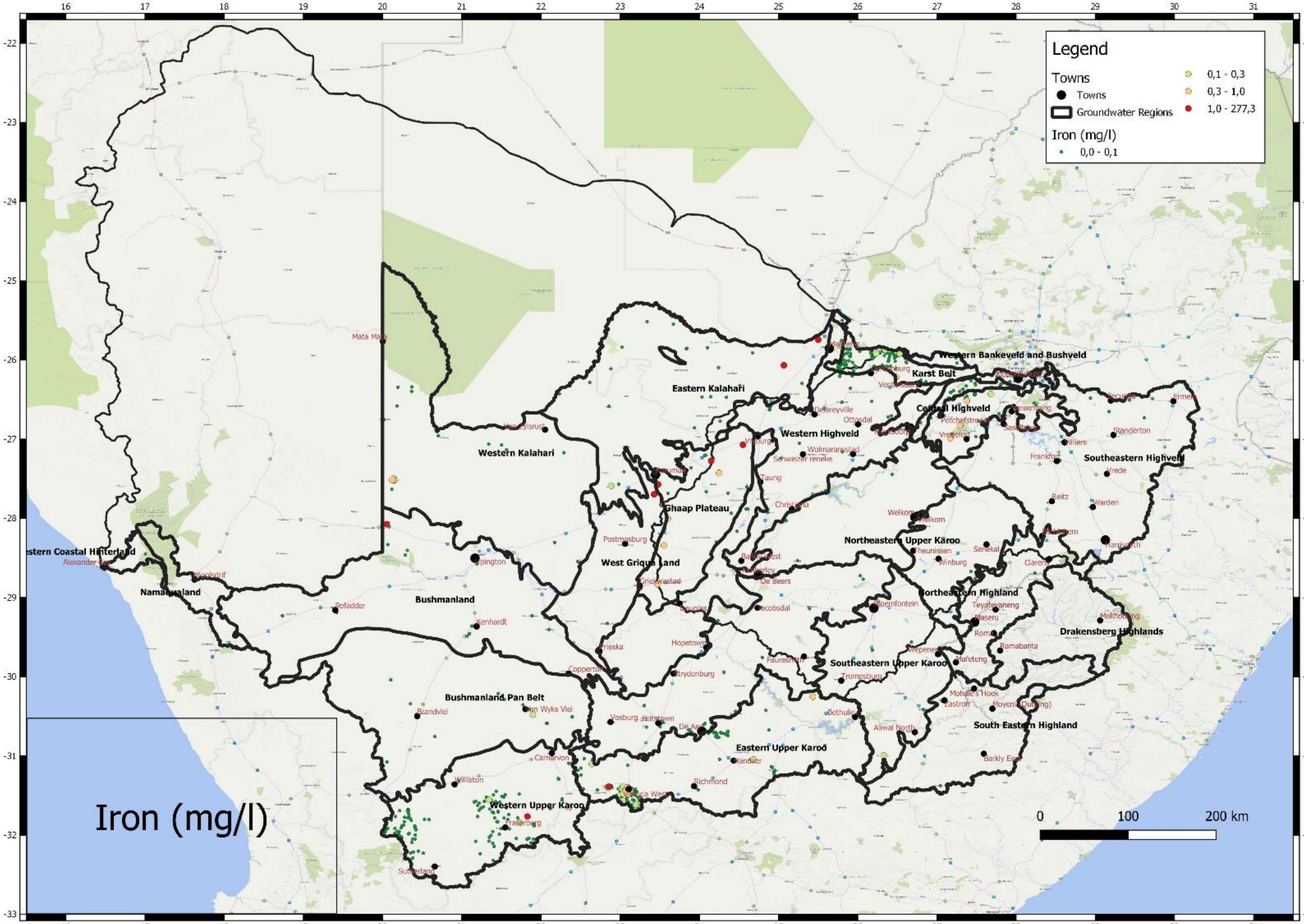


Figure 4-22 Iron in groundwater, South Africa and Lesotho

4.7.6.3 Iron

In water, iron can be present as dissolved ferric iron, Fe (III), as ferrous iron, Fe (II) or as suspended iron hydroxides. The major effects of the presence of iron in domestic water are aesthetic, but in some cases distribution systems may also be affected. Health effects may occur at extremely high concentrations. Excessive ingestion of iron may result in haemochromatosis, wherein tissue damage occurs as a consequence of iron accumulation. The extreme unpalatability of such water would probably prevent consumption. Further, iron in the distribution system promotes proliferation of iron-oxidising bacteria which oxidise ferrous iron to ferric iron, and manifest as slimy coatings in plumbing when the iron concentration of the water in the distribution system approaches 0.3 mg/l. Effects are predominantly aesthetic, such as the staining of enamelled surfaces of baths, hand basins and lavatory cisterns/bowls and laundry. Iron causes discolouration of water supplies when present at low concentrations in association with aluminium.

High iron concentrations are found in the Western and Eastern Upper Karoo and the Ghaap Plateau (**Figure 4-22**).

4.8 Groundwater Use

The data and methodology adapted for groundwater use quantification are given in **Section 2.4**. It is important to note that actual use may not equate to registered use, as some users over abstract relative to their allocation, some users do not use their entire allocation to safeguard future use, while many non-registered users exist. These users do not have their use legally safe guarded, hence their water use is allocable to other users.

4.8.1 Water Supply

Many communities and towns in the catchment are solely or partially dependent on groundwater for municipal supply. Water supply schemes include industry dependent on a municipal water supply scheme. Water use per Quaternary catchment is shown in **Figure 4-23**.

The towns utilising groundwater are shown in **Figure 4-24**. Volumes are registered lawful volumes, and not actual use. Some small towns and villages utilising groundwater do not have a registered water use. Since the purpose of the data is to determine allocable groundwater volumes, towns that do not have water use licence need to be allocated one from the remaining allocable groundwater. If actual use were listed, allocating licences in future would result in double accounting if actual unauthorised water use were included with licenced volumes.

4.8.2 Rural water supply

In addition to formal groundwater supply, a large segment of the population is dependent on boreholes and springs. These users were considered Schedule 1 domestic groundwater users. Data for municipal use and schedule 1 per Quaternary catchment is shown in **Figure 4-25**.

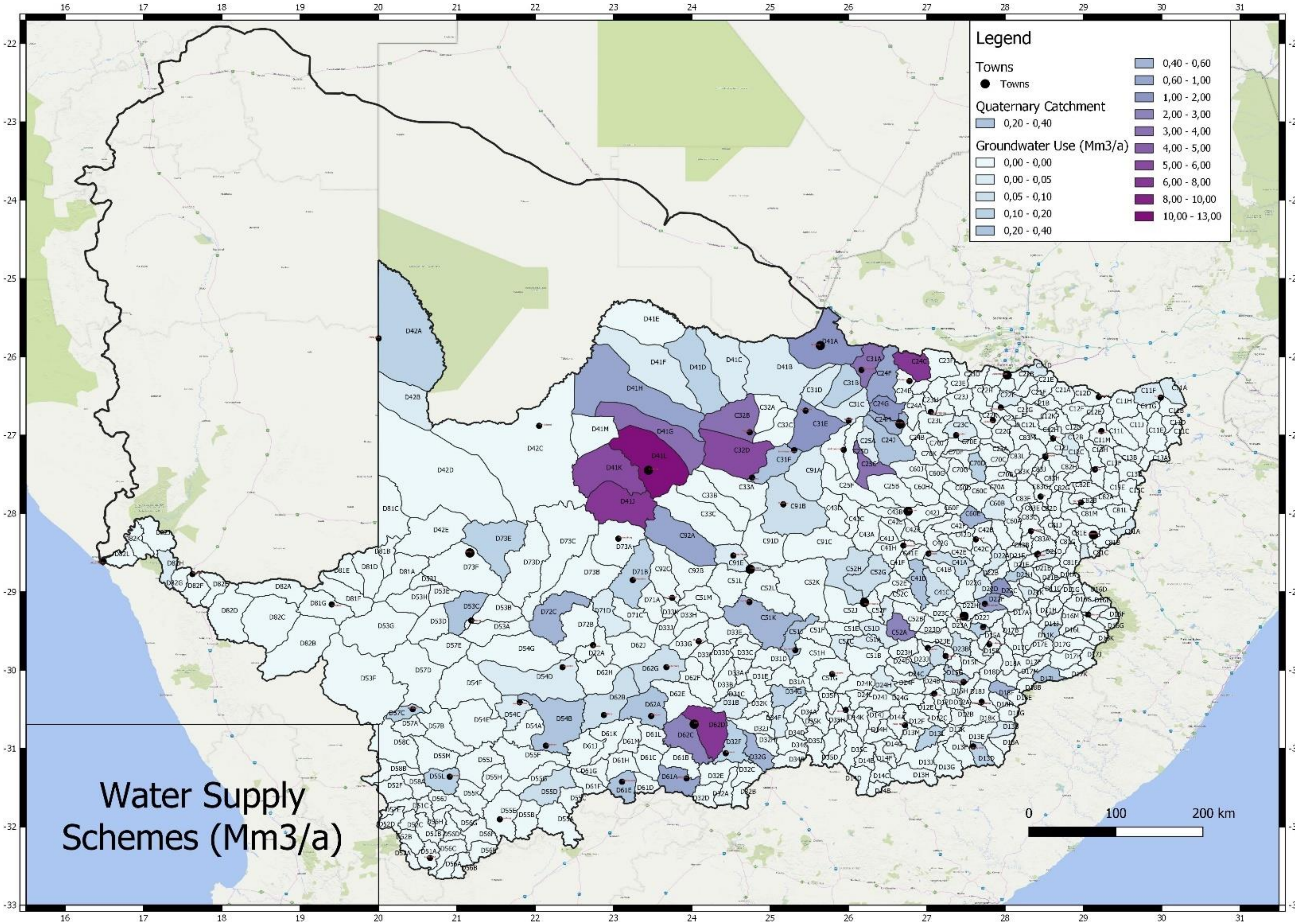


Figure 4-23 Water use by water supply schemes, South Africa and Lesotho

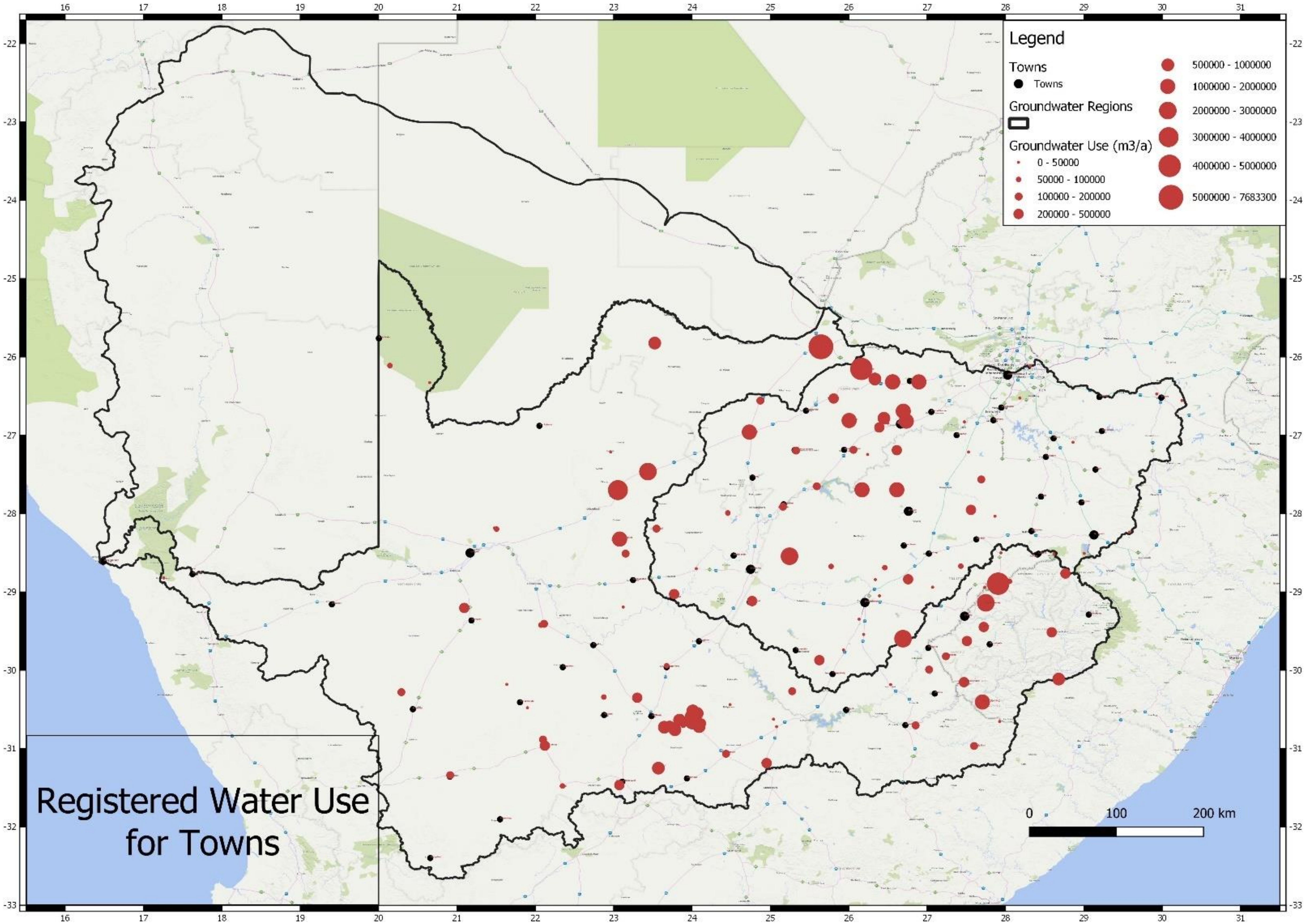


Figure 4-24 Lawful registered water use for Towns, South Africa and Lesotho

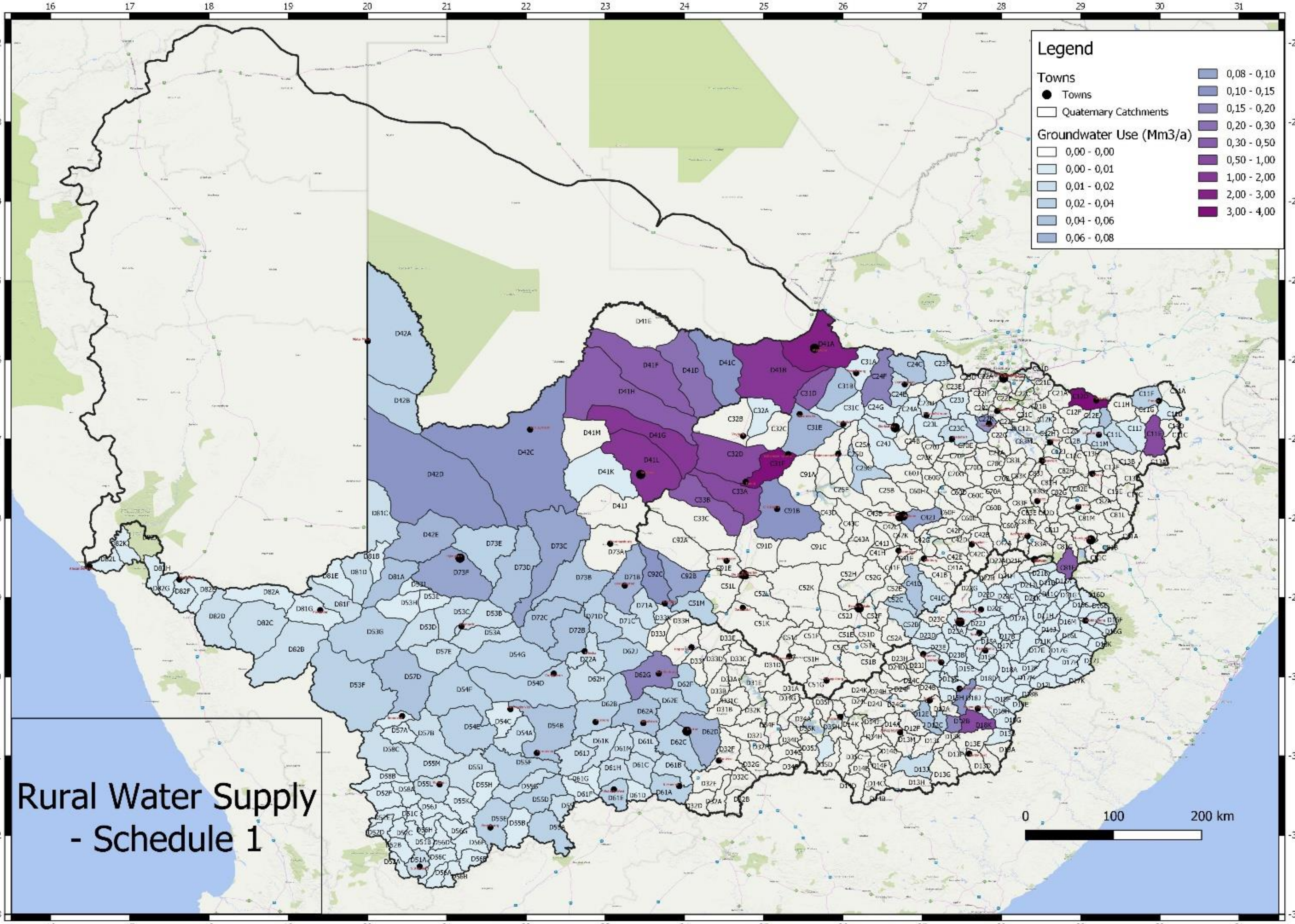


Figure 4-25 Water use for rural water supply, South Africa and Lesotho

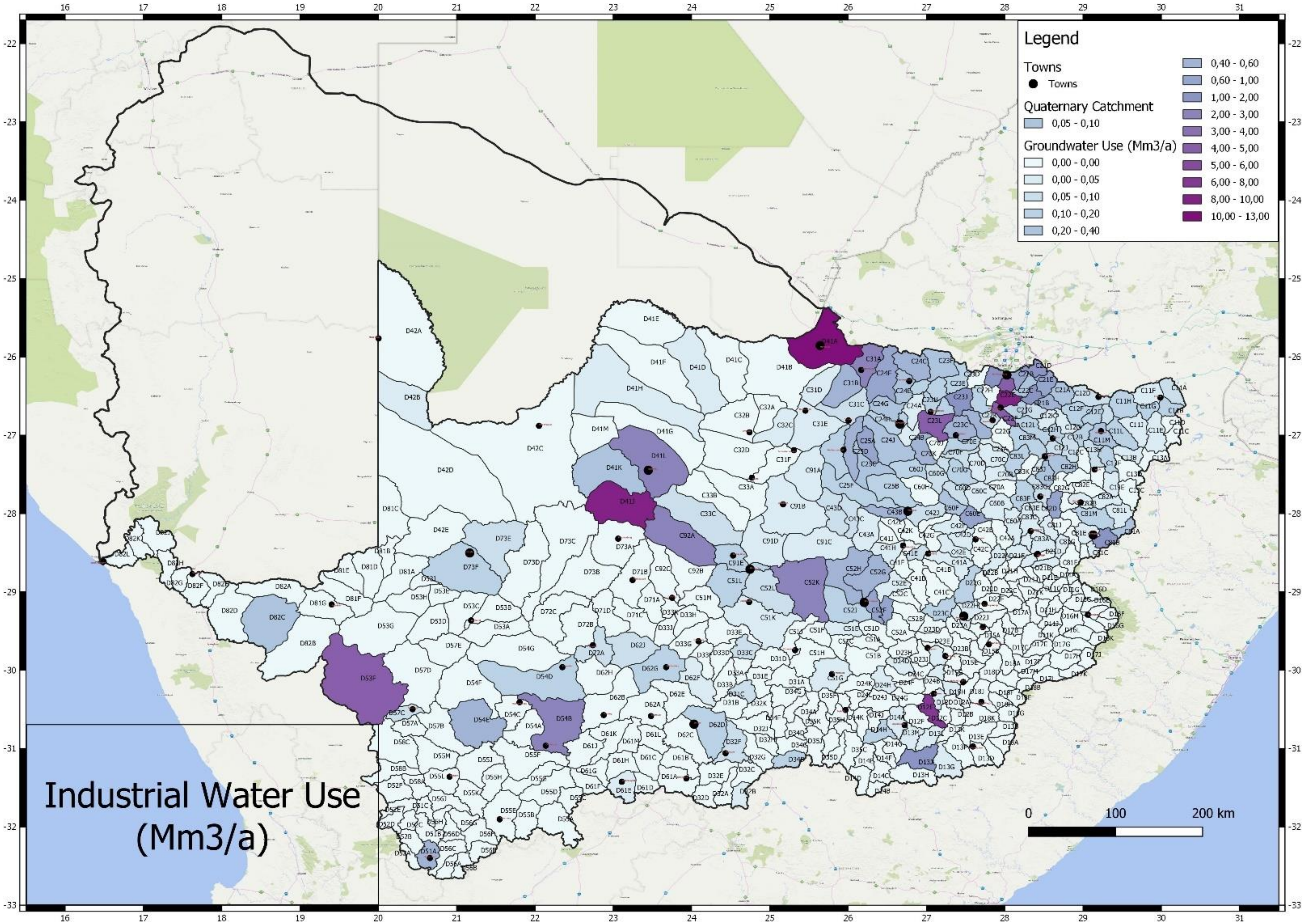


Figure 4-26 Industrial groundwater use, South Africa and Lesotho

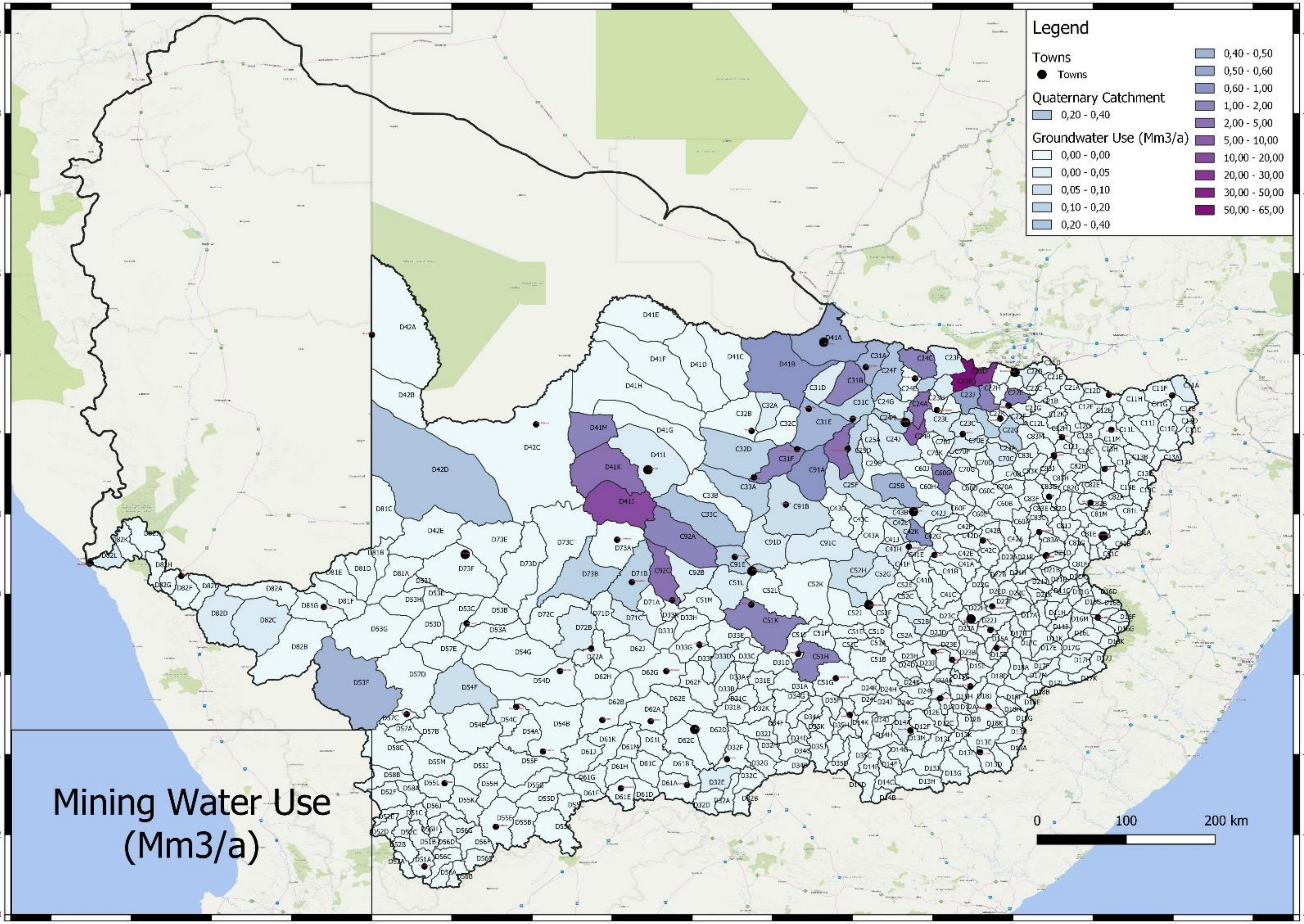


Figure 4-27 Groundwater use for mining, South Africa and Lesotho

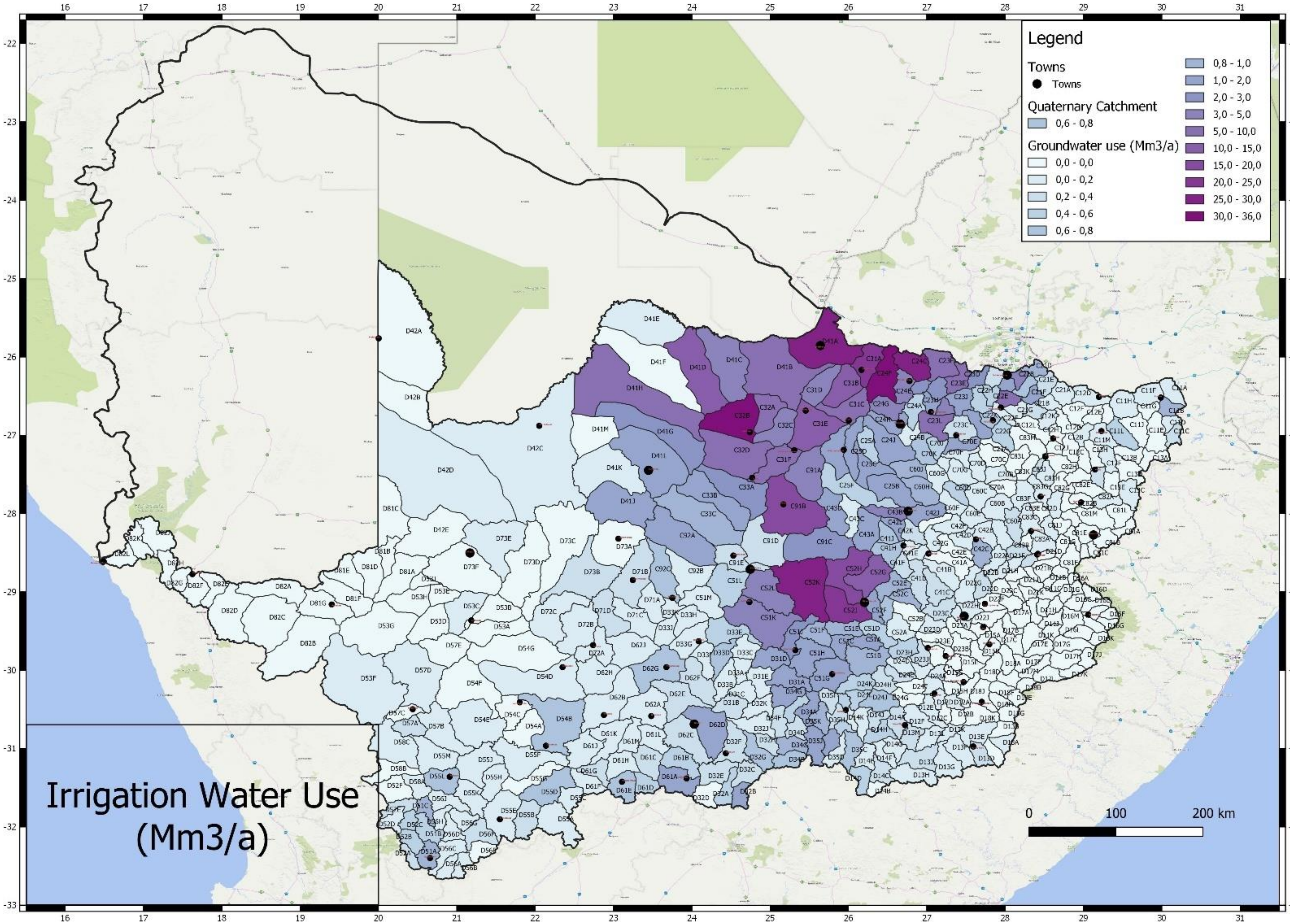


Figure 4-28 Groundwater use for irrigation, South Africa and Lesotho

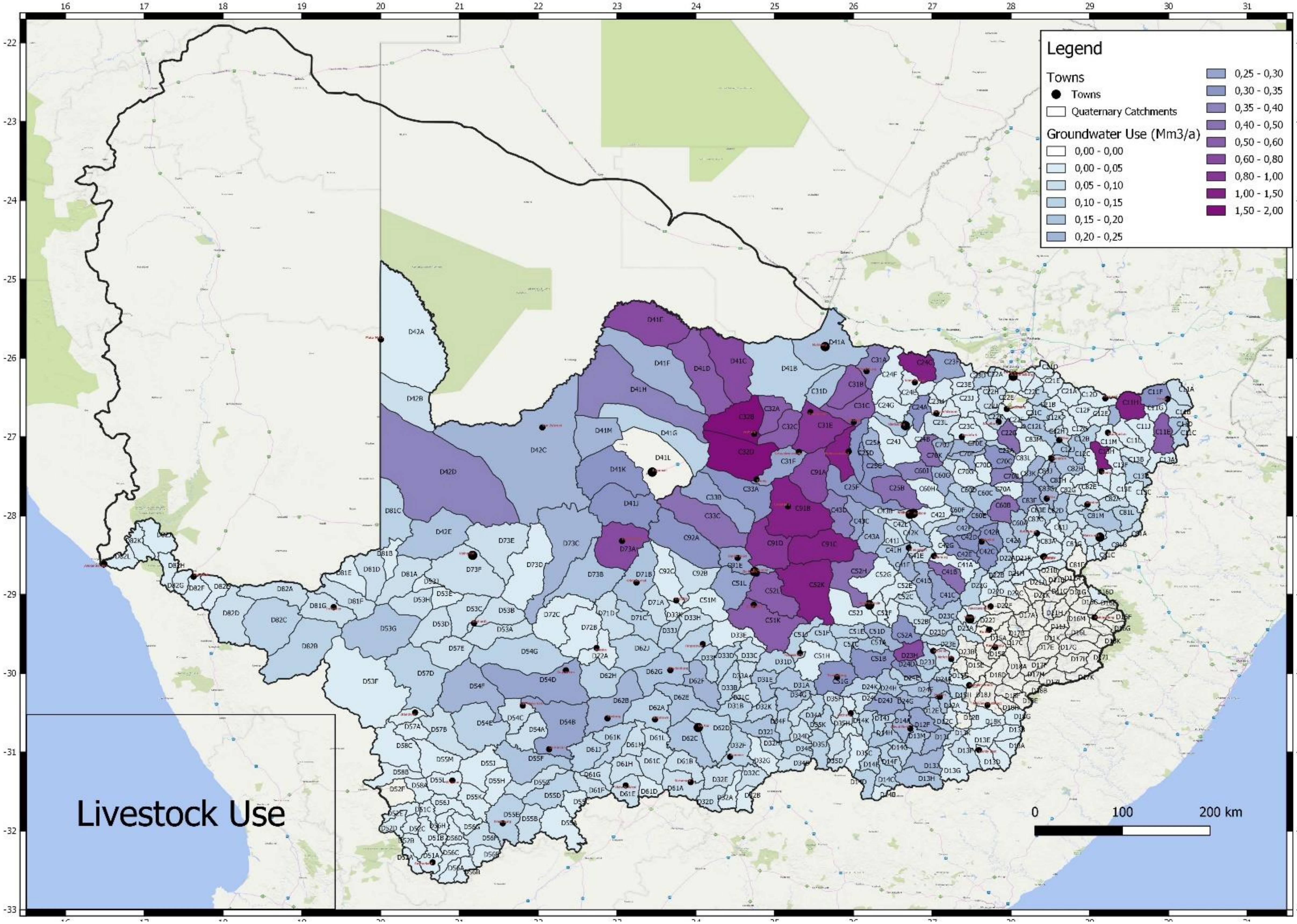


Figure 4-29 Groundwater use for livestock, South Africa and Lesotho

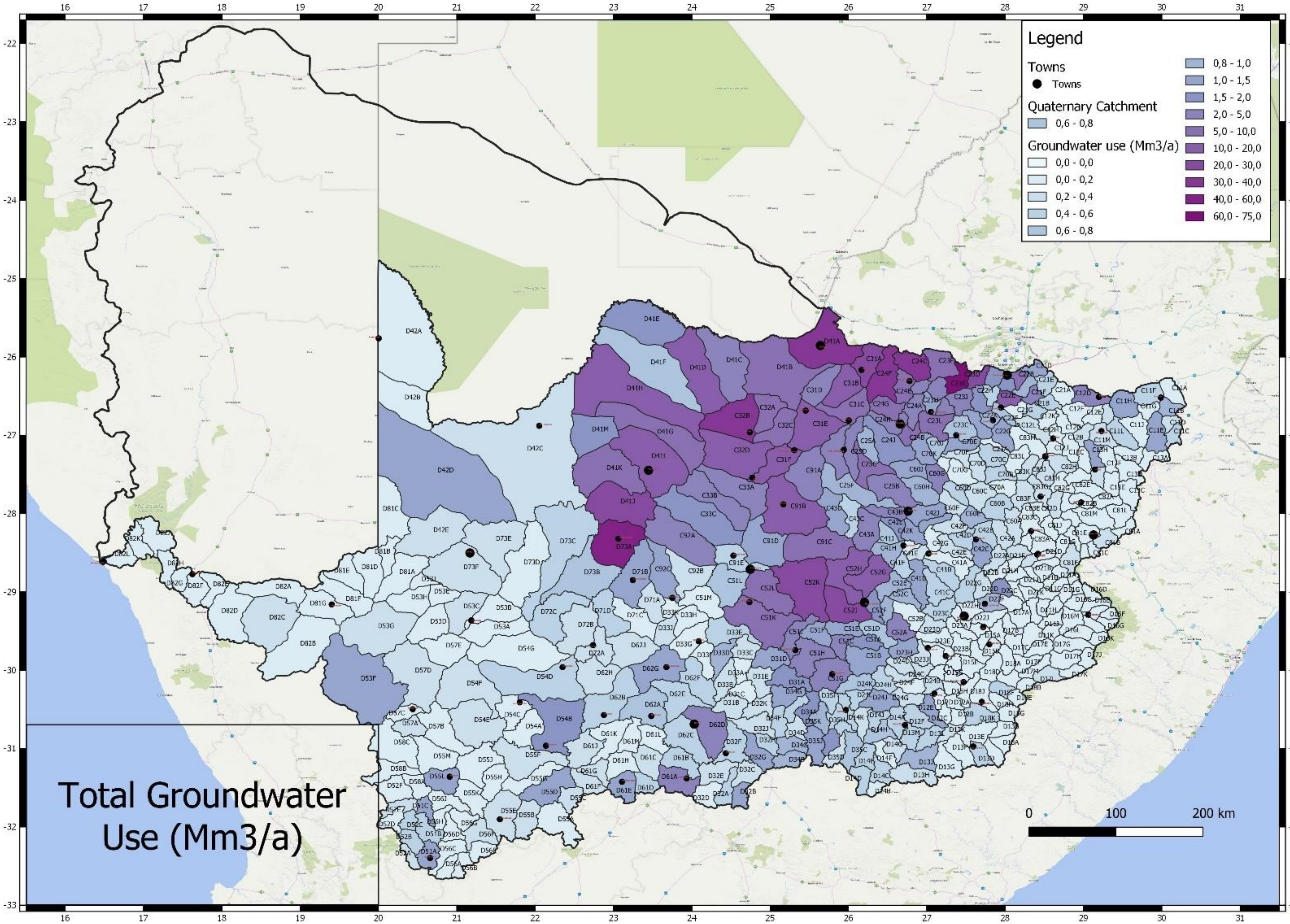


Figure 4-30 Total groundwater use, South Africa and Lesotho

4.8.3 Industrial

Industrial water use from own supply is shown in **Figure 4-26**. For Lesotho, data from WASCO lumps industrial water use with urban supply

4.8.4 Mining

Groundwater use for mining is shown in **Figure 4-27**.

4.8.5 Irrigation and livestock

Groundwater use for irrigation and livestock is shown in **Figures 4-28** and **4-29**.

4.8.6 Total Groundwater Use

Total groundwater use is shown in **Figure 4-30**. The largest volumes of groundwater are used in the Karst Belt, the Western Highveld and Eastern Kalahari, the Ghaap Plateau and Central Pan Belt.

Groundwater use relative to available resources in the catchment is shown in **Table 4-5**. Abstraction exceeds aquifer recharge in the Karst Belt due to licences for mine dewatering in the West Rand and Far West Rand. It is unlikely that this entire allocation is still being abstracted once dewatering of the dolomites was achieved. Abstraction also exceeds aquifer recharge in the Far Northwestern Coastal Hinterland. This is due to boreholes drilled in the vicinity of the Orange River, and it is most likely those alluvial aquifers are recharged by the Orange river.

Table 4-5 Groundwater use and resources, South Africa and Lesotho

Groundwater Region	Use (Mm^3/a)	Recharge (Mm^3/a)	Aquifer Recharge (Mm^3/a)	Groundwater Exploitation Potential (Mm^3/a)	Utilisable Groundwater Exploitation Potential (Mm^3/a)	Potable Utilisable Groundwater Exploitation Potential (Mm^3/a)
Bushmanland	3.36	23.08	23.08	26.88	17.47	7.48
Bushmanland Pan Belt	5.44	31.12	31.12	43.69	22.82	7.64
Central Highveld	79.09	503.04	152.62	328.92	192.81	173.03
Central Pan Belt	96.05	355.44	355.44	278.88	180.41	137.50
Drakensberg Highlands	0.16	677.38	155.88	69.64	51.80	46.54
Eastern Kalahari	90.39	281.94	272.33	190.51	142.70	110.76
Eastern Upper Karoo	29.99	325.65	325.65	278.70	167.35	135.76
Far Northwestern Coastal Hinterland	0.16	0.13	0.13	0.05	0.04	0.01
Ghaap Plateau	33.23	236.64	149.69	414.82	209.41	187.82
Karst Belt	148.28	261.16	137.41	302.37	104.89	92.05
Namaqualand	0.22	0.82	0.82	0.57	0.46	0.12
Northeastern Highland	6.77	399.57	173.17	117.35	75.66	68.11
Northeastern Pan Belt	46.72	369.93	185.25	206.96	153.92	106.94
Northeastern Upper Karoo	14.55	306.82	171.96	117.43	78.35	65.19
South Eastern Highland	8.14	746.96	224.04	176.24	116.69	100.10
Southeastern Highveld	26.33	1368.53	421.64	518.16	300.04	253.23
Southeastern Upper Karoo	43.97	327.20	315.28	202.20	137.17	114.63
Taung-Prieska Belt	12.24	150.98	120.70	174.32	97.36	77.26

Groundwater Region	**Use (Mm^3/a)**	**Recharge (Mm^3/a)**	**Aquifer Recharge (Mm^3/a)**	**Groundwater Exploitation Potential (Mm^3/a)**	**Utilisable Groundwater Exploitation Potential (Mm^3/a)**	**Potable Utilisable Groundwater Exploitation Potential (Mm^3/a)**
West Griqua Land	68.38	105.90	105.73	81.68	62.62	49.83
Western Bankeveld and Bushveld	14.47	44.86	24.61	42.35	12.37	12.18
Western Highveld	148.94	542.70	221.38	482.76	288.58	240.62
Western Kalahari	4.39	86.70	86.70	31.18	34.48	16.43
Western Upper Karoo	9.35	71.19	71.19	116.54	65.04	45.87
TOTAL	**890.63**	**7217.73**	**3725.82**	**4202.21**	**2512.43**	**2049.10**

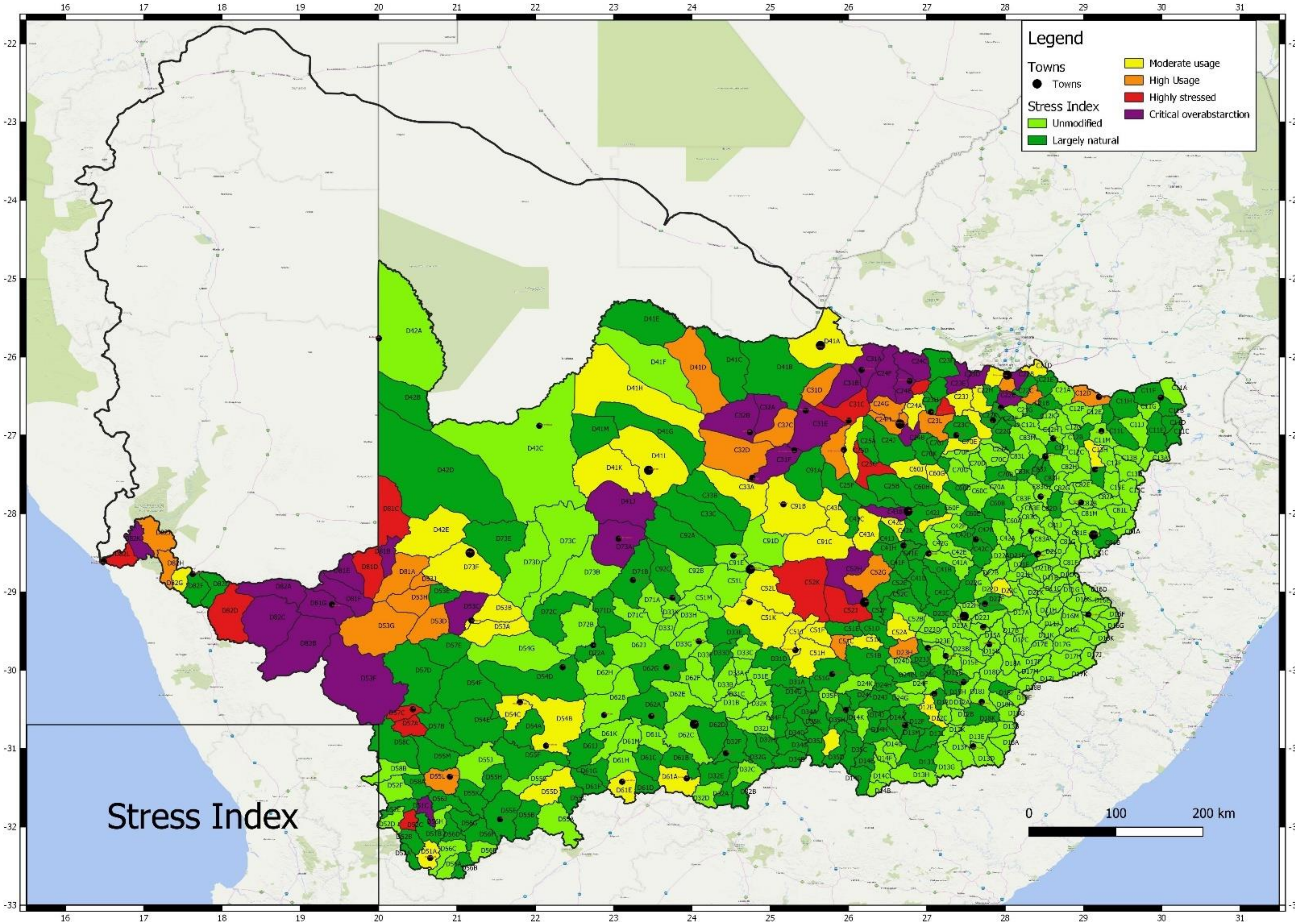


Figure 4-31 Stress Index by Quaternary catchment, South Africa and Lesotho (see entire basin Appendix 16)

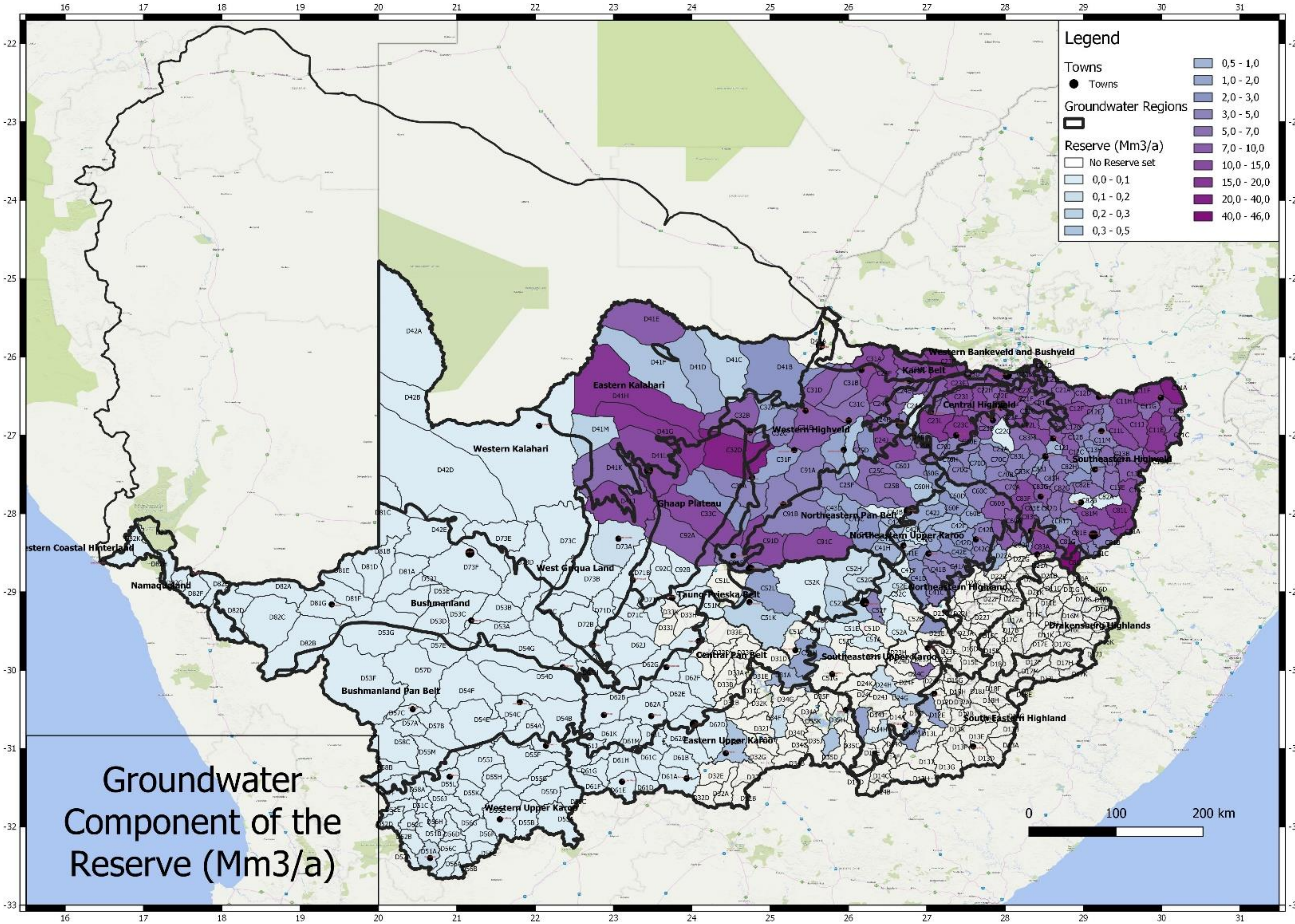


Figure 4-32 Groundwater component of the Reserve, South Africa and Lesotho

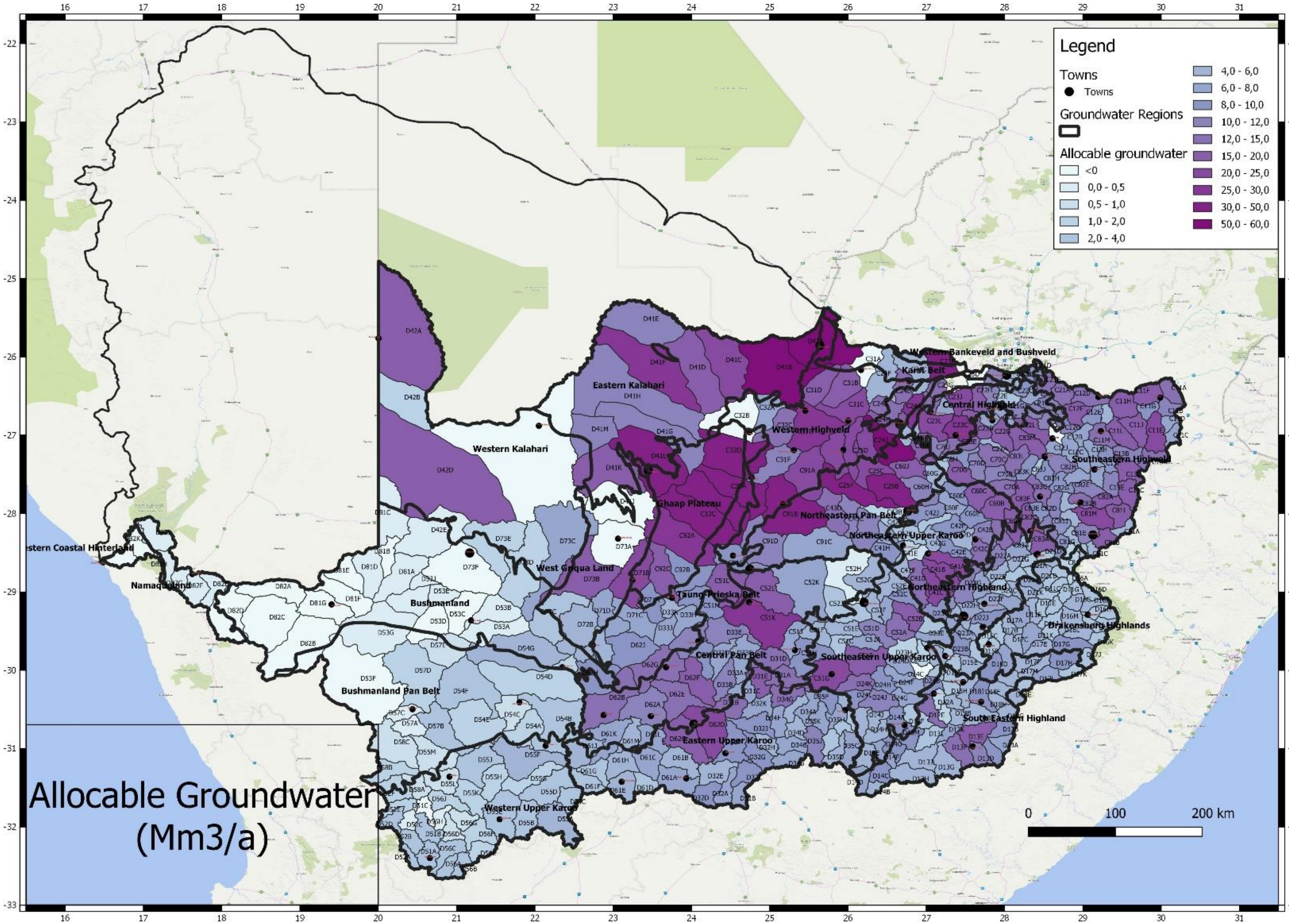


Figure 4-33 Allocable Groundwater, South Africa and Lesotho (see entire basin Appendix 16)

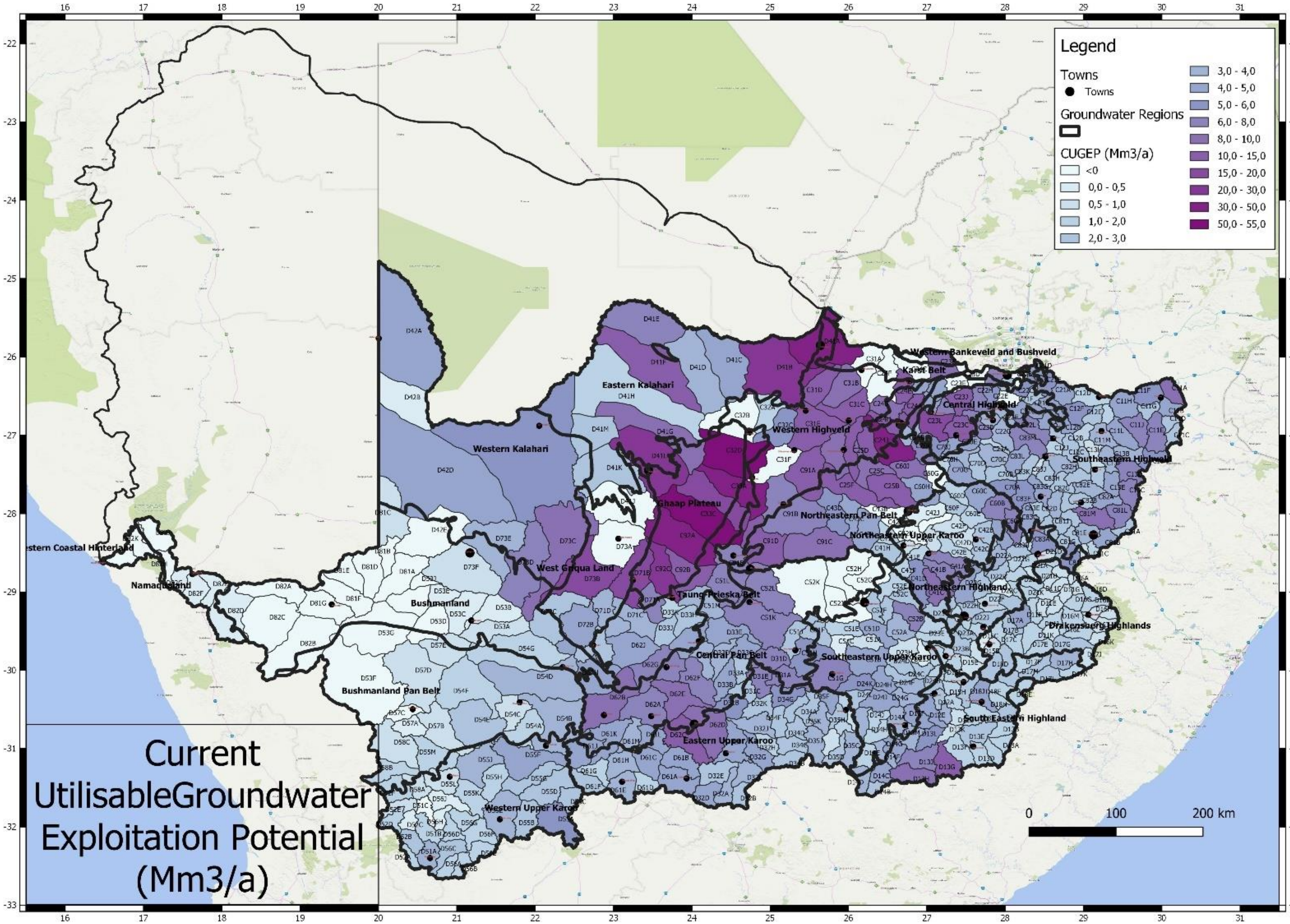


Figure 4-34 Current Utilisable Groundwater Exploitation Potential, South Africa and Lesotho (see entire basin Appendix 16)

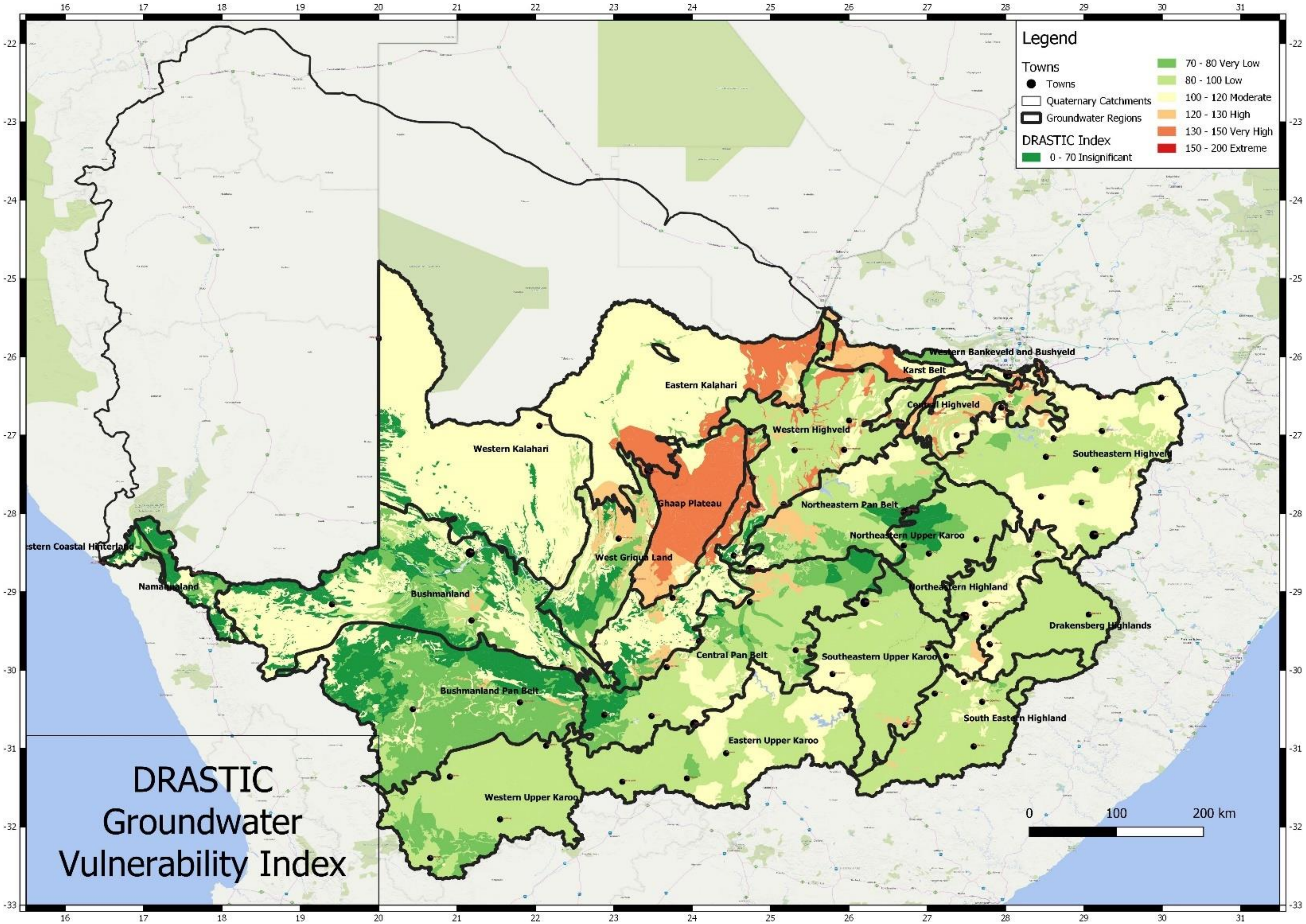


Figure 4-35 Aquifer vulnerability, South Africa and Lesotho

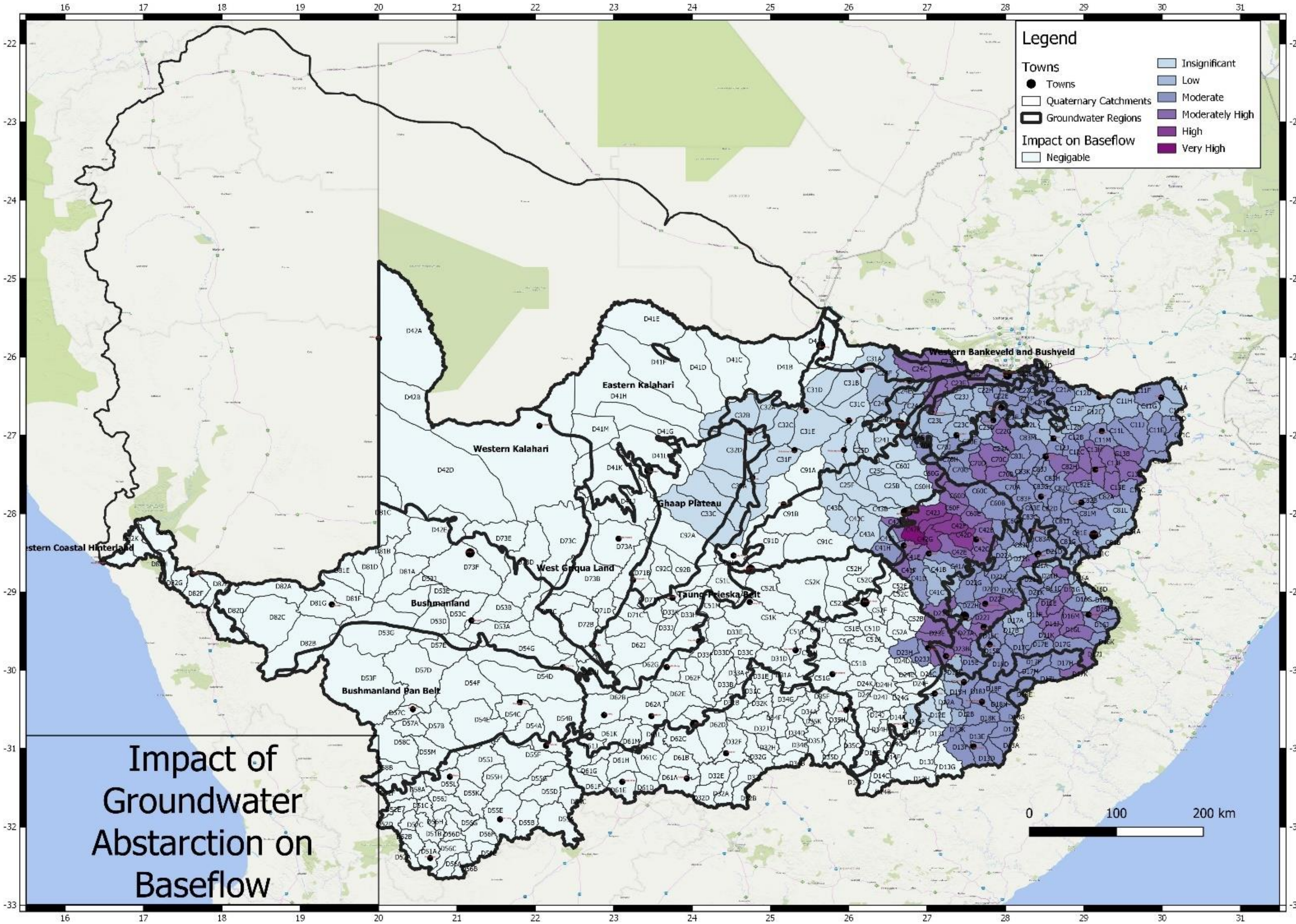


Figure 4-36 Risk of baseflow reduction, South Africa and Lesotho

4.9 Groundwater Stress Index

Groundwater use is more meaningful when assessed relative to available groundwater resources. The best measure of groundwater resources is aquifer recharge; hence a stress index is defined as groundwater use relative to aquifer recharge. Aquifer stress does not imply actual stress since usage is based on water use allocations. The actual allocation may not be used in its entirety. It implies that over allocation exists. Stress index is shown in **Figure 4-31**.

4.10 Groundwater Reserve

The Groundwater Reserve in **Figure 4-32**. No Reserve has been set for Lesotho and large parts of upper Orange River Catchment.

4.11 Remaining Groundwater resources

The remaining allocable groundwater resources can be considered in two ways:

1. The remaining groundwater that can be legally allocated. This volume was calculated according to the methodology in 2.10. The volume per Quaternary catchment is shown in **Figure 4-33** and is termed Allocable Groundwater. This does not consider whether the water can be economically exploited, merely the volume of recharge, current legal water allocations and the Reserve
2. The volume of groundwater than can practically or economically be abstracted. This was calculated as the Utilisable Groundwater Exploitation Potential minus current legal water use. This is termed the Current Utilisable Groundwater Exploitation Potential. The volumes per Quaternary catchment are shown in **Figure 4-34**.

4.12 Aquifer Vulnerability

Aquifer vulnerability according to the DRASTIC index is shown in **Figure 4-35** and shows that aquifers with high to extreme vulnerability are found in the dolomite aquifers of the Ghaap Plateau and the Karst Belt**.** The methodology is described in **Section 2.6**.

4.13 Impact of Abstraction on Baseflow

One of the consequences of over abstraction of groundwater is a reduction of baseflow. Given the critical status of surface water resources in the Orange-Senqu Basin, the potential of groundwater abstraction to reduce baseflow, affecting environmental flows and the yield of dams, is an important factor to consider.

To quantify the potential of abstraction to reduce baseflow, a baseflow index was calculated by groundwater baseflow/groundwater recharge. The classification of risk based on this index is shown in **Table 4-6** and **Figure 4-36**.

Table 4-6 Risk of Baseflow Reduction

Baseflow Index	Risk of Baseflow Reduction
0	Negligible
0-0.1	Insignificant
0,1-0.2	Low
0.2-0.4	Moderate.
0.3-0.5	Moderately High
0.5-0.7	High
0.7-0.8	Very High

In the drier dolomitic groundwater regions, such as the Ghaap Plateau, the potential impact on baseflow is mapped as low since the impact occurs on dolomitic 'eyes' who discharge is significant on a local level but low over a much wider groundwater region where no perennial baseflow exists. Impact assessment at a much finer interval is necessary.

5 GROUNDWATER RESOURCES IN THE STUDY AREA, BOTSWANA

5.1 Aquifer types

The main litho-hydrogeologic units in the Botswana part of the Basin are shown in **Figure 5-1**. Four main aquifer types can be distinguished in the basin: namely Fractured Porous (Intergranular and Fractured), Fractured Weathered, (weathered and fractured), Fractured (Structural), and Karstic (**Table 5-1**).

- **Fractured Porous aquifers:** Fractured porous Aquifers are found in the Karoo Super Group Sandstones represented by the Ntane (Lebung Group) and the Otshe Sandstone (Ecca Group) Formations. Water levels are below the depth of weathering (i.e below 50 m). They are found in northern and central parts of the Botswana part of the Basin and underlie about 54% of the Basin. The average borehole yield in the Ecca Group aquifer is 9 l /s (32 $m^{3/}$hr) whilst the average yield of the Lebung Group aquifer (Ntane sandstone aquifer) is about 4.7 l/s (~17 m^3/hr), It has to be noted that there is a vast area (Kalahari Transfrontier Park) in the project underlain by the Ecca Group with no borehole information.

- **Fractured aquifers are** represented by the Upper Transvaal (Interbedded reddish quartzite, shale, and carbonaceous siltstone with chert, dolomite, ironstone, andesitic volcanics and breccia), Waterberg (reddish sandstone and conglomerate) and the Olifantshoek rocks (mostly sandstone and conglomerate) Beaufort (non-carbonaceous siltstone, mudstone and thin limestone), Dwyka group (assorted glacial deposits including diamictite, very thinly laminated siltstone and sandstone) Nnywane and Mogobane Formations (Rhyolitic volcanics, breccio-conglomerate, siltstone, sandstone, mudstone and shale).

- **Fractured Weathered aquifers:** Fractured weathered aquifers in the study area are predominantly represented by igneous, and metamorphic rock units of Archaean and Precambrian age (basement rocks) and Post Karoo Dolerite Intrusions.

- **Karstic aquifers** are represented by Lower Transvaal Super Group Rocks (Basal quartzite (Black Reef Quartzite), dolomitic limestone, chert, minor limestone, ironstone, variably carbonaceous siltstone and shale) and covers about 2 % of the basin area.

- The **porous aquifers**, are represented by alluvial and Kalahari bed aquifers which are not well mapped in the geological map of Botswana and were therefore not included in the current analysis. These aquifers are generally saline and low yielding though they are occasionally fresh.

The fractured and fractured weathered aquifers cover about 44% of the basin.

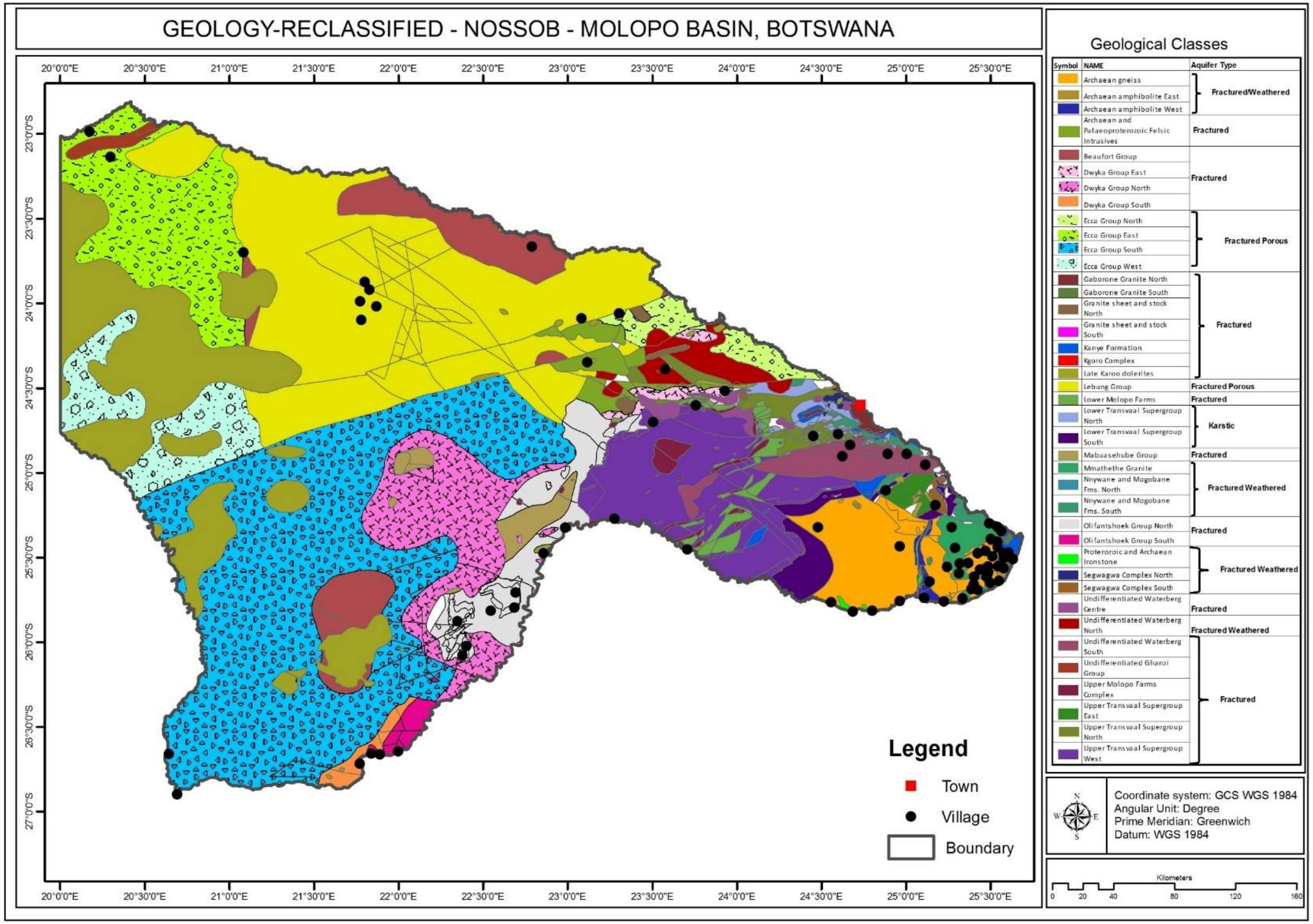


Figure 5-1 Litho-Hydrogeologic Units, Botswana

Table 5-1 Summary of Aquifer Information, Botswana

Litho Hydrogeologic Unit	Main Lithology	Aquifer Type
Ecca North (Otshe Sandstone)	Interbedded coal, carbonaceous siltstone and mudstone and white and poorly cemented sandstone	Fractured Porous
Ecca East (Otshe Sandstone)	Interbedded coal, carbonaceous siltstone and mudstone and white and poorly cemented sandstone	Fractured Porous
Ecca North South (Otshe Sandstone)	Interbedded coal, carbonaceous siltstone and mudstone and white and poorly cemented sandstone	Fractured Porous
Ecca North West (Otshe Sandstone)	Interbedded coal, carbonaceous siltstone and mudstone and white and poorly cemented sandstone	Fractured Porous
Beaufort	Pale grey, non-carbonaceous siltstone and mudstone	Fractured
Dwyka East	Assorted glacial deposits including diamictite, very thinly laminated siltstone (varvite) and sandstone	Fractured
Dwyka North	Assorted glacial deposits including diamictite, very thinly laminated siltstone (varvite) and sandstone	Fractured
Dwyka South	Assorted glacial deposits including diamictite, very thinly laminated siltstone (varvite) and sandstone	Fractured
Gaborone Granite North	Granite	Fractured
Gaborone Granite South	Granite	Fractured
Granite Sheet and Stock	Granite	Fractured
Kanye Formation	Homogeneous felsite	Fractured
Kgoro Complex	Diorite	Fractured

Litho Hydrogeologic Unit	Main Lithology	Aquifer Type
Late Karoo Dolerites	Dolerite	Fractured
Lebung (Ntane Sandstone)	Orange, red or white sandstone, with reddish siltstone increasingly common downwards the bottom	Fractured Porous
Lower Molopo Complex	Undifferentiated Ultrabasic Rocks	Fractured
Lower Transval North	Basal quartzite (Black Reef Quartzite), dolomitic limestone, chert, minor limestone, ironstone, variably carbonaceous siltstone and shale	Karstic
Lower Transvaal South	Basal quartzite (Black Reef Quartzite), dolomitic limestone, chert, minor limestone, ironstone, variably carbonaceous siltstone and shale	Karstic
Mabua Sehube	Metamorphosed arkosic sandstone, limestone, shale, mudstone, ironstone	Fractured
Mmathethe Granite	Granite	Fractured Weathered
Nnywane and Mogobane Formation North	Rhyolitic volcanics, breccio-conglomerate, siltstone, sandstone, mudstone and shale	Fractured Weathered
Nnywane and Mogobane Formation South	Rhyolitic volcanics, breccio-conglomerate, siltstone, sandstone, mudstone and shale	Fractured Weathered
Olifanthoek North	White to reddish quartzite with minor shale	Fractured
Olifanthoek South	White to reddish quartzite with minor shale	Fractured
Proterozoic and Archaen Ironstone	Ironstone	Fractured Weathered
Segwagwa North	Syenite	Fractured Weathered
Segwagwa South	Syenite	Fractured Weathered
Undifferiated Waterberg North	Reddish siliciclastic sedimentary rocks, mostly sandstone and conglomerate	Fractured Weathered

Litho Hydrogeologic Unit	Main Lithology	Aquifer Type
Undifferentiated Waterberg Central	Reddish siliciclastic sedimentary rocks, mostly sandstone and conglomerate	Fractured
Undifferiated Waterberg South	Reddish siliciclastic sedimentary rocks, mostly sandstone and conglomerate	Fractured
Undifferiated Ghanzi	Weakly metamorphosed purple-red to greenish grey, siliciclastic sedimentary rocks, mostly quartzites	Fractured
Upper Molopo	Norite	Fractured
Upper Transvaal North	Interbedded reddish quartzite, shale, variably manganiferous and carbonaceous siltstone with chert, dolomite, ironstone, andesitic volcanics and breccia	Fractured
Upper Transvaal West	Interbedded reddish quartzite, shale, variably manganiferous and carbonaceous siltstone with chert, dolomite, ironstone, andesitic volcanics and breccia	Fractured
Upper Transvaal East	Interbedded reddish quartzite, shale, variably manganiferous and carbonaceous siltstone with chert, dolomitese, ironstone, andesitic volcanics and breccia	Fractured
Archaen Gneiss	Banded, quartzofeldspathic gneiss	Fractured/Weathered
Archaen Amphibolites East	Amphibolite	Fractured/Weathered
Archaen Amphibolites West	Amphibolite	Fractured/Weathered
Archaean and Palaeoproterozoic	Felsite	Fractured

5.2 Borehole yield

Average borehole yields per litho-hydrogeologic unit in the basin are shown in **Figure 5-2** while **Figure 5-3** indicates the aquifer productivity index i.e. percentage of boreholes with yield of more than 2 litres per second (l/s). Borehole yields statistics are given in **Table 5-2**.

Mean borehole yields for Ecca North, Ecca East and Ecca South are 18.6 (67 m^3/hr), 4.9 (18 m^3/hr) and 3 (11 m^3/hr) l/s respectively. The yields of the Ecca north aquifer are among the highest yielding aquifers in the Botswana. Yields of boreholes completed in Ecca west are not known as there is no borehole information for this aquifer in the project area. The Lebung Group which is represented by the Ntane Sandstone Formation in the study has an average borehole yield of 4.7 l/s (17 m^3/hr). Boreholes completed in the Dwyka and Beoufrd Groups have average borehole yields of 3 l/s (11 m^3/hr) and 2.7 l/s (10 m^3/hr) respectively which are higher than what is reported in previous study reports.

The fractured/weathered aquifers found in Archaen Gneiss, Archaen Amphibolites, Mmathethe Granite, Nnywane and Mogobane Formation , Segwagwa Formation and Undifferentiated Waterberg have an average borehole yield of 3.5 l/s (13 m^3/hr) with the highest borehole yields found in Undifferentiated Waterberg, Archaen Gneiss, Segwagwa Formation (Syenite) and Nnywane/Mogobane Formations (Rhyolitic volcanics, breccio-conglomerate, siltstone, sandstone, mudstone and shale

Fractured aquifers have average borehole yield of 3 l/s with the highest yielding boreholes found in the Upper Transvaal and Olifanthoek and Kanye Formation (**Table 5-2**).

Karstic aquifers found in the Lower Transvaal Super Group have an average borehole yield 6 l/s (22 m3/hr).

5.3 Recharge

Recharge is shown in **Figure 5-4** for each Litho-Hydrogeological Unit. Recharge values for the Ecca, Lebung and, Waterberg, Transvaal and Olifanthoek aquifers are based on information from hydrogeological studies conducted in these aquifer units by the Departments of Water Affairs and Geological Survey which indicates that recharge is mostly less 0.3 mm/a for a large portion of the study area. Recharge for the fractured (mostly basement complex) aquifers was taken as 2 mm/a-based on results of groundwater recharge estimation study GRES 1 study.

Table 5-2 Borehole Yield Summary, Botswana

Litho-Hydrogeologic Unit	No BHs	Average yield (l/s)	Median yield (l/s)	% Q >5 l/s	% Q >2 l/s	% Q > 0.5 l/s	Aquifer Type
Beaufort	18	2.7	2.4	27.8	50.0	66.7	Fractured
Dwyka East	9	2.1	0.8	5.6	33.3	66.7	Fractured
Dwyka North	55	2.8	1.6	25.5	41.8	56.4	Fractured
Dwyka South	15	4.3	0.8	12.5	18.8	50.0	Fractured
Gaborone Granite North	70	1.3					Fractured
Gaborone Granite South	12	3.0	3.0	16.7	58.3	75.0	Fractured
Granite Sheet and Stock	8	0.0	0.0	0.0	0.0	0.0	Fractured
Kanye Formation	6	4.5	3.7	50.0	50.0	100.0	Fractured
Kgoro Complex	0						Fractured
Late Karoo Dolerites	23	1.7	1.4	0.0	26.1	73.9	Fractured
Lower Molopo	12	1.7	0.8	8.3	33.3	50.0	Fractured
Mabua Sehube	6	2.5	3.1	0.0	66.7	66.7	Fractured
Olifanthoek South	45	4.7	1.8	40.6	40.6	65.6	Fractured
Undifferentiated Ghanzi	0						Fractured
Upper Molopo	10	3.3	3.4	30.0	60.0	90.0	Fractured
Archaean and Paleo Proterozoic Felsites	18	3.2	3.2	11.1	66.7	83.3	Fractured
Olifanthoek North	214	5.9	2.1	42.5	50.0	57.9	Fractured
Upper Transvaal North	20	4.3	1.0	35.0	45.0	50.0	Fractured
Upper Transvaal West	91	2.1	0.6	11.0	31.9	50.6	Fractured
Upper Transvaal East	5	3.2	2.5	20.0	60.0	80.0	Fractured
Ecca North	61	18.6	23.8	70.5	82.0	85.3	Fractured Porous

Litho-Hydrogeologic Unit	No BHs	Average yield (l/s)	Median yield (l/s)	% Q >5 l/s	% Q >2 l/s	% Q > 0.5 l/s	Aquifer Type
Ecca East	16	4.9	3.0	31.3	68.8	81.3	Fractured Porous
Ecca South	206	3.0	0.8	21.4	33.5	55.5	Fractured Porous
Ecca West	0						Fractured Porous
Lebung	220	4.7	2.0	27.0	44.0	61.5	Fractured Porous
Mmathethe Granite	47	2.8	0.8	14.9	48.9	70.2	Fractured Weathered
Nnywane and Mogobane Formation N	2	5.5	5.5	50.0	50.0	50.0	Fractured Weathered
Nnywane and Mogobane Formation South	12	2.7	1.5	16.7	41.7	58.8	Fractured Weathered
Proterozoic and Archaen Ironstone	4	1.6	1.4	0.0	30	50	Fractured Weathered
Segwagwa North	5	1.6	0.8	0.0	40.0	60.0	Fractured Weathered
Segwagwa South	3	5.3	3.0	33.3	66.7	66.7	Fractured Weathered
Undifferentiated Waterberg North	34	4.7	1.7	26.5	47.1	67.7	Fractured Weathered
Undifferentiated Waterberg Central	19	2.8	2.2	10.5	63.2	79.0	Fractured Weathered
Undifferentiated Waterberg South	47	4.9	2.1	31.9	51.1	76.6	Fractured Weathered
Archaen Gneiss	83	4.1	3.3	31.7	58.5	74.4	Fractured Weathered
Archaen Amphibolites East	5	3.4	4.5	20.0	80.0	80.0	Fractured Weathered
Archaen Amphibolites West	5	2.9	2.2	0.0	60.0	100.0	Fractured Weathered
Lower Transvaal North	4	6.4	3.8	25.0	75.0	100.0	Karstic

Litho-Hydrogeologic Unit	No BHs	Average yield (l/s)	Median yield (l/s)	% Q >5 l/s	% Q >2 l/s	% Q > 0.5 l/s	Aquifer Type
Lower Transvaal South	52	5.3	2.7	30.8	53.9	67.3	Karstic

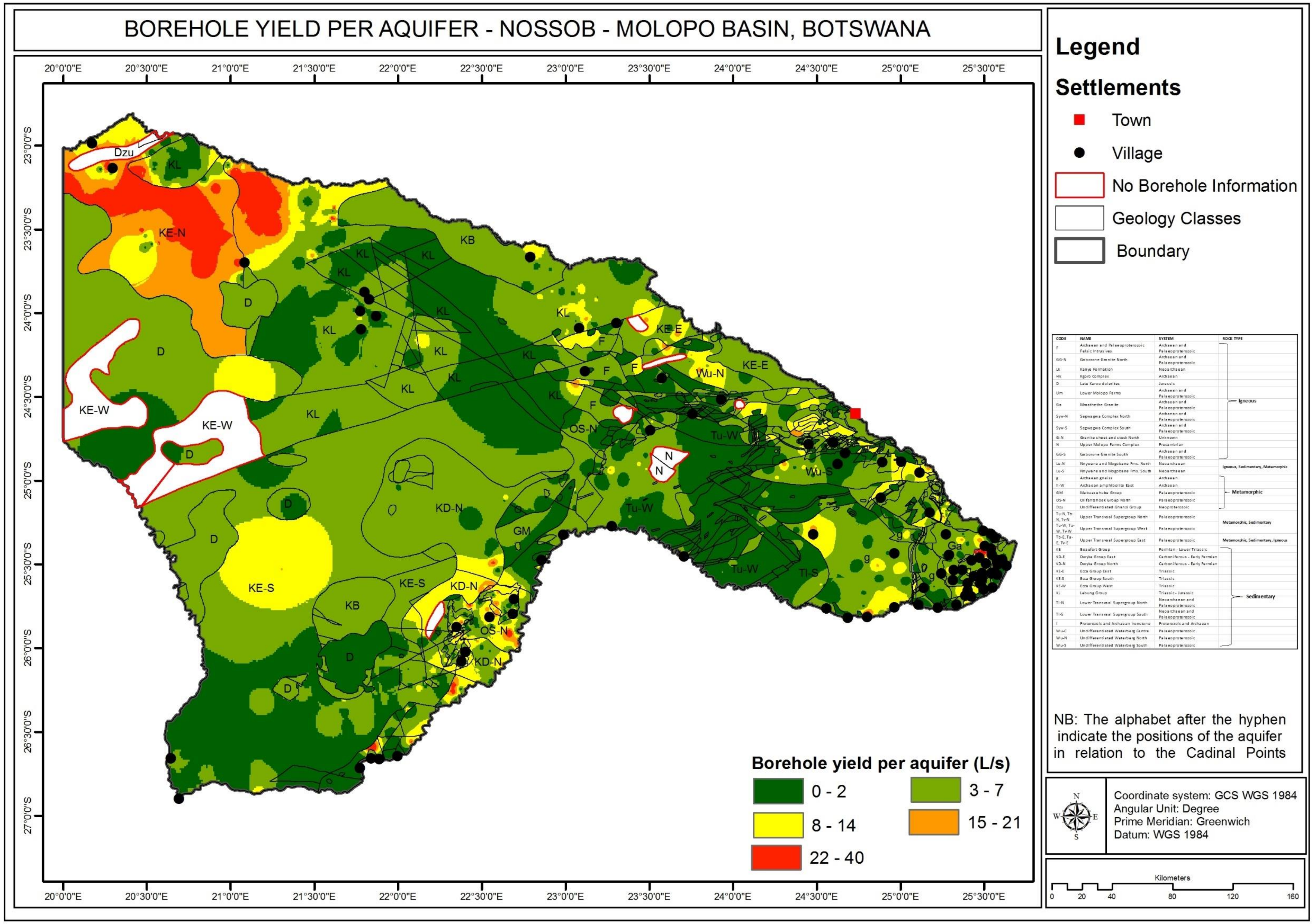


Figure 5-2 Borehole yields, Botswana (See entire basin Appendix 16)

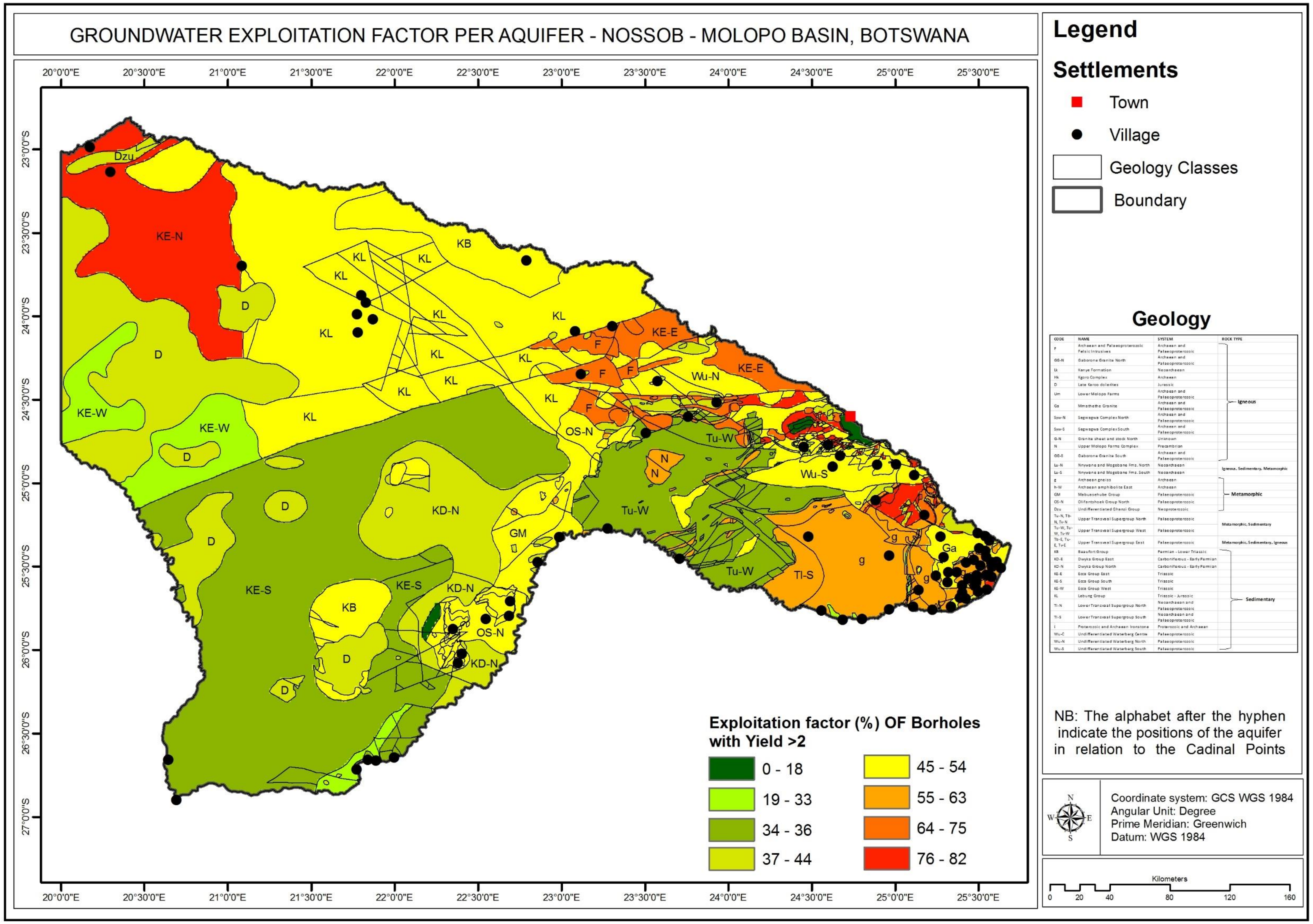


Figure 5-3 Aquifer productivity index (exploitation factor), Botswana

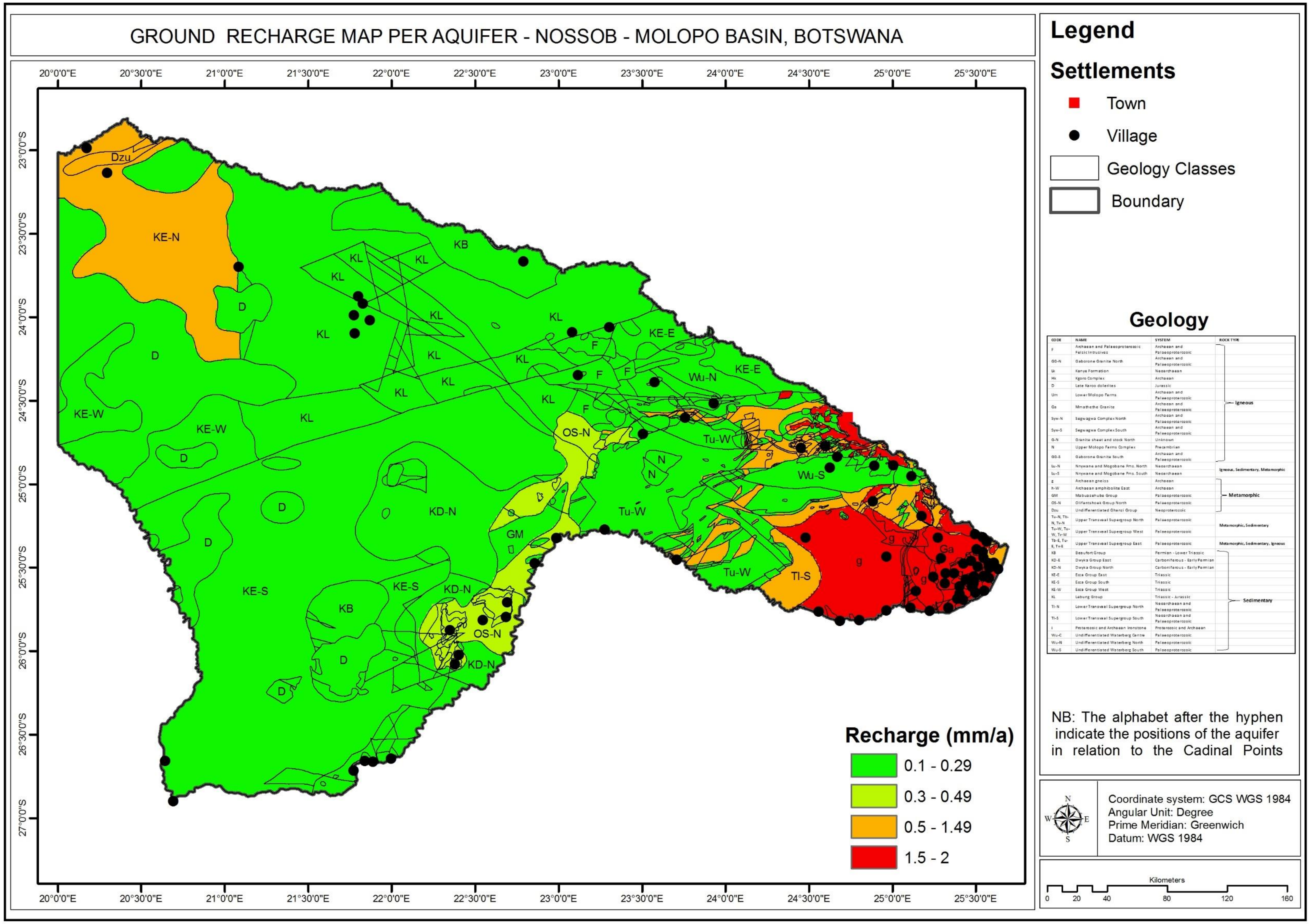


Figure 5-4 Aquifer recharge, Botswana

5.4 Groundwater Storage

In fractured rock aquifers the number of water-bearing fractures generally decreases with depth, resulting in a corresponding decline in aquifer storativity with depth. Whether groundwater storage is in fractures only or in fractured as well as weathered rock, also affects storage, since weathered zones have higher pore space. Consequently, two types of aquifer storage exist: weathered storage and fractured zone (fractured porous) storage. The Weathered Zone is normally a relatively thin zone (5-50 m).

Since the majority of aquifers in the Botswana part of the basin have water levels below the weathered zone (below 50 m) and mostly below Kalahari Beds, the volume of groundwater stored in the weathered zone was taken as zero and groundwater storage was calculated only for the fractured zone.

5.4.1 Storativity

Calculations of aquifer storage are directly dependent on estimates of storativity. Calculated storativity values used for estimation of groundwater volumes per aquifer unit is summarized in **Table 5-3.**

Table 5-3 Storativity per Litho-Hydrogeological Unit, Botswana

Litho-Hydrogeological Unit	Sy (Weathered)	Ss (Fractured)	Average	Litho-Hydrogeological Unit	Sy (Weathered)	Ss (Fractured)	Average
Ecca North	5.82E-05	1.77E-03	9.12E-04	Nnywane/Mogobane Formations North	4.26E-04	9.86E-04	7.06E-04
Ecca East	4.55E-05	4.27E-03	2.16E-03	Nnywane/Mogobane Formations South	3.12E-03	3.61E-03	3.37E-03
Ecca South	1.02E-03	3.47E-03	2.24E-03	Olifanthoek North	3.94E-04	3.95E-03	2.17E-03
Ecca West	7.46E-03	7.46E-03	7.46E-03	Olifanthoek South	1.16E-03	1.30E-03	1.23E-03
Beaufort	1.88E-05	4.64E-03	2.33E-03	Proterozoic and Archaen Ironstone	3.04E-03	4.35E-03	3.69E-03
Dwyka East	1.63E-04	3.63E-03	1.90E-03	Segwagwa Formation North	5.34E-05	5.21E-03	2.63E-03
Dwyka North	2.01E-04	2.10E-03	1.15E-03	Segwagwa Formation South	2.50E-03	1.10E-02	6.76E-03
Dwyka South	1.11E-03	3.11E-03	2.11E-03	Undifferentiated Waterberg North	2.68E-05	3.10E-03	1.56E-03
Gaborone Granite North	1.71E-05	6.68E-03	3.35E-03	Undifferentiated Waterberg Central	1.41E-05	3.10E-03	1.56E-03
Gaborone Granite South	9.72E-04	5.79E-03	3.38E-03	Undifferentiated Waterberg South	1.05E-04	3.03E-03	1.57E-03
Granite Sheet and Stock	3.59E-04	6.23E-03	3.29E-03	Undifferentiated Ghanzi	7.46E-03	3.92E-03	5.69E-03
Kanye Formation	3.84E-04	2.20E-03	1.29E-03	Upper Molopo Complex	1.14E-05	3.92E-03	1.96E-03
Kgoro	7.46E-03	7.46E-03	7.46E-03	Upper Transvaal North	8.27E-05	3.86E-03	1.97E-03
Late Karoo Dolerites	2.05E-04	4.97E-03	2.59E-03	Upper Transvaal West	4.37E-05	3.86E-03	1.95E-03
Lebung	3.77E-05	3.86E-03	1.95E-03	Upper Transvaal East	1.70E-04	1.69E-03	9.30E-04
Lower Molopo	5.21E-05	4.42E-03	2.24E-03	Archaen Gneiss	8.23E-04	4.97E-03	2.89E-03
Lower Transvaal North	3.27E-05	1.30E-03	6.68E-04	Archaen Amphibolites East	1.43E-03	6.15E-03	3.79E-03
Lower Transvaal South	1.43E-03	4.35E-03	2.89E-03	Archaen Amphibolites West	1.38E-03	1.81E-03	1.59E-03
Mabua Sehube	2.52E-05	4.48E-03	2.25E-03	Archaean and Palaeoproterozoic Units	4.03E-05	3.32E-03	1.68E-03
Mmathethe Granite	4.02E-03	9.94E-03	6.98E-03				

5.4.2 Saturated Thickness

Saturated thicknesses of the weathered and fractured zone per Litho-Hydrogeological Unit are shown in **Table 5-4** and the calculated total aquifer storage (m^3) and aquifer storage per km^2 is shown in **Figures 5-5** and **5-6** respectively. Storage is highest in the fractured /porous aquifer zones of the Ecca and Lebung Groups and lowest in fractured basement aquifers (igneous and metamorphic aquifers).

Table 5-4 Saturated thickness per Litho-Hydrogeological Unit, Botswana

Litho-Hydrogeological Unit	Average Weathered Saturated Thickness (m)	Average Fractured/Porous Saturated Thickness (m)	Litho-Hydrogeological Unit	Average Weathered Saturated Thickness (m)	Average Fractured/Porous Saturated Thickness (m)
Ecca Group North	0.00	110	Nnywane and Mogobane Formation North	0.00	101
Ecca Group East	0.00	39	Nnywane and Mogobane Formation South	0.00	27
Ecca Group South	0.00	51	Olifanthoek North	0.00	57
Ecca Group 4 West	Unknown		Olifanthoek South	0.00	58
Beaufort Group	0.00	34	Proterozoic and Archaen Ironstone	0.00	47
Dwyka Group East	0.00	49	Segwagwa Formation North	0.00	45
Dwyka Group North	0.00	87	Segwagwa Formation South	0.00	88
Dwyka Group South	0.00	57	Undifferentiated Waterberg North	0.00	31
Gaborone Granite North	0.00	9	Undifferentiated Waterberg Central	0.00	22
Gaborone Granite South	0.00	20	Undifferentiated Waterberg South	0.00	64
Granite Sheet and Stock	0.00	14	Undifferentiated Ghanzi	Unknown	
Kanye Formation	0.00	61	Upper Molopo Complex	0.00	55
Kgoro Complex	Unknown		Upper Transvaal North	0.00	67
Late Karoo Dolerites	0.00	49	Upper Transvaal West	0.00	46

Litho-Hydrogeological Unit	Average Weathered Saturated Thickness (m)	Average Fractured/Porous Saturated Thickness (m)	Litho-Hydrogeological Unit	Average Weathered Saturated Thickness (m)	Average Fractured/Porous Saturated Thickness (m)
Lebung Group	0.00	45	Upper Transvaal East	0.00	40
Lower Molopo Complex	0.00	37	Archaen Gneiss	0.00	30
Lower Transval North	0.00	100	Archaen Amphibolites East	0.00	15
Lower Transvaal South	0.00	36	Archaen Amphibolites West	0.00	85
Mabua Sehube	0.00	122	Archaean and Palaeoproterozoic Units	0.00	54
Mmathethe Granite	0.00	44			

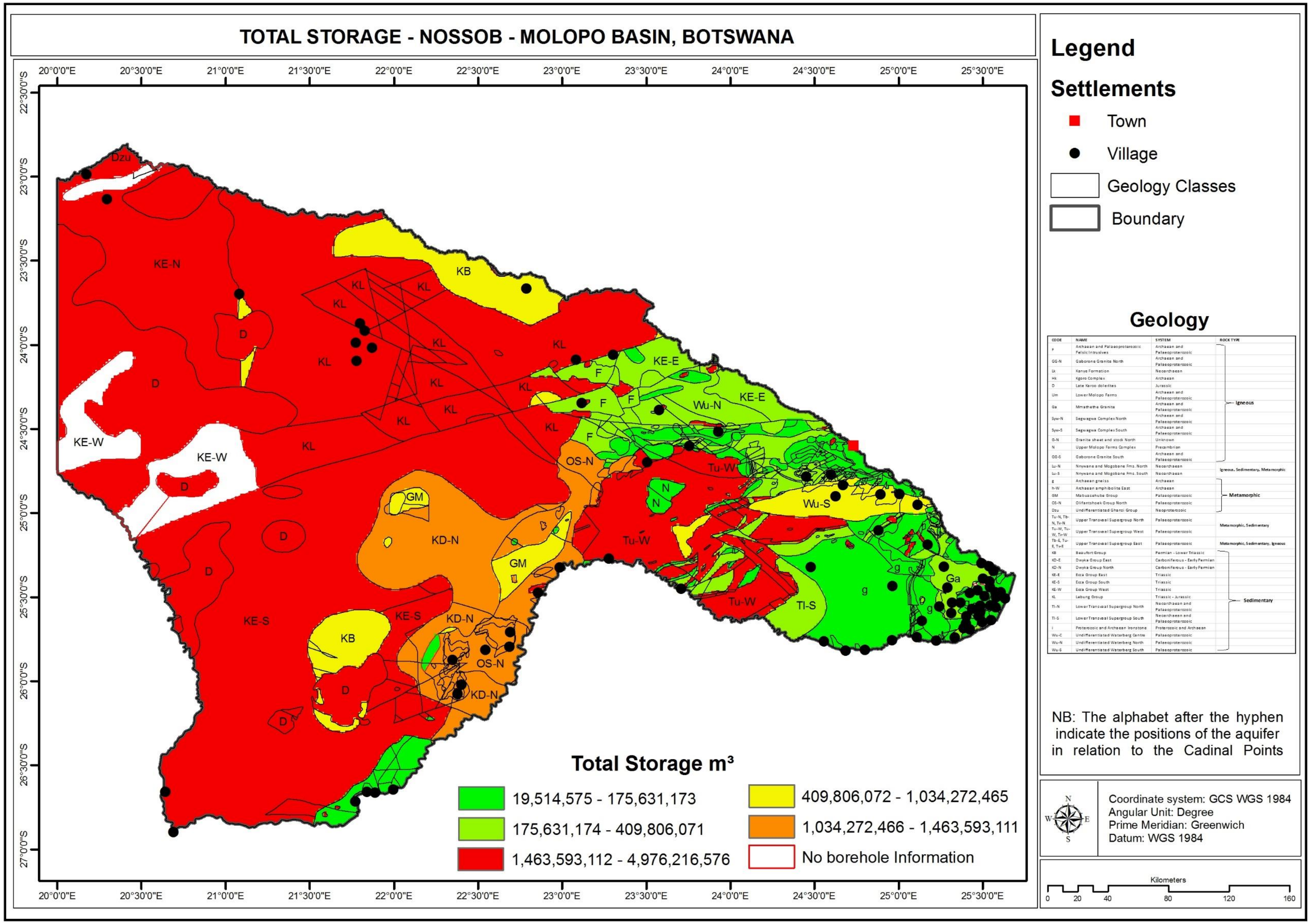


Figure 5-5 Total aquifer storage in the different aquifer systems, Botswana

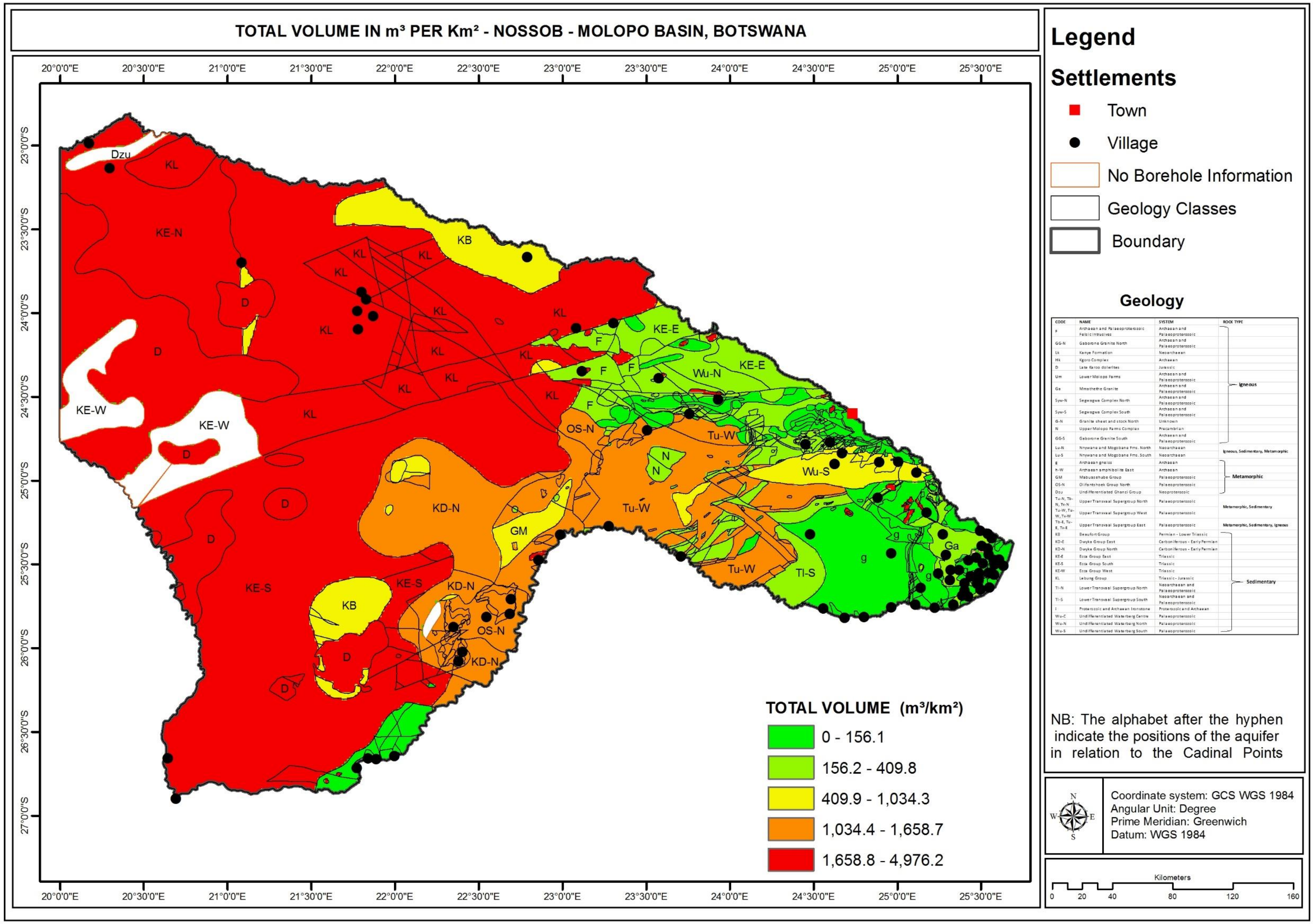


Figure 5-6 Aquifer storage m³/km², Botswana (see entire basin Appendix 16)

5.5 Baseflow

On the Botswana part of the Basin, baseflow was considered as zero as there are no streams feed by groundwater.

5.6 Groundwater Resources

5.6.1 Groundwater Resource Potential

Assuming that the upper 10 m (i.e. below the water table) of aquifer storage can feasibly be abstracted over a given period of time, the groundwater resource potential was calculated using eq 1. As indicated previously, the volume of water stored in the aquifer was estimated using the fractured storativity only.

Groundwater Resource Potential, incorporating recharge, drought index and storage in the upper 10 m of the aquifer is shown in **Figure 5-7**. Groundwater Resource Potential is highest in the Karoo, Transvaal and Olifanthoek aquifers and lowest in the eastern part of the basin which is mostly underlain by basement aquifers (see **Figure 5-7**) and **Table 5-5**.

5.6.2 Groundwater Exploitation Potential

The Groundwater Exploitation Potential, factoring in the probability of drilling successful boreholes in a particular aquifer is shown in **Figure 5-8**. This indicates that the aquifers with the highest exploitation potential are the Lebung, Ecca and the Upper Transvaal while aquifers with lowest potential in the basement aquifers.

5.6.3 Utilisable Groundwater Exploitation Potential

The volume of water that may be abstracted from a groundwater resource may also be limited by anthropogenic and ecological and/or legislative considerations. They can relate to maintaining baseflow, avoiding excessive drawdown etc. The volume that can be sustainably abstracted is referred to as the Utilisable Groundwater Exploitation Potential (UGEP). It was calculated assuming an annual maximum drawdown of 2 m and is shown in **Figure 5-9**.

5.6.4 Potable Utilisable Groundwater Exploitation Potential

The volume of water that may be abstracted from a groundwater resource may also be limited by groundwater quality, anthropogenic and ecological and/or legislative considerations. They can relate to maintaining baseflow, providing groundwater which meets certain quality standard.

The potable utilisable groundwater exploitation potential (PUGEP) was calculated by multiplying the Utilisable Groundwater Exploitation Potential (UGEP) by the potability index (suitability for human consumption) i.e. the probability of obtaining groundwater with total dissolved solids value of less than 1000 mg/l per Litho-Hydrogeological Unit as shown **Figure 5-10**. This indicates that aquifers with highest Potable Utilisable Groundwater Exploitation Potential are Lebung and Ecca (North) while aquifers with lowest PUGEP are Beaufort, Dwyka and Ecca (South).

Table 5-5 Groundwater Resources Potential, Botswana

Litho Hydrogeologic Unit	Exp Factor Fraction of BH with Q> 2 l/s	Potability Factor (Fraction of BH with TDS<1000 mg/l	Potability Factor (Livestock Consumption, Fraction of BH with TDS <5000 mg/l	(Average Groundwater Resources Potential) AGRP (m^3/a)	Groundwater Exploitation Potential (GEP, m^3/a)	Utilisable Groundwater Exploitation Potential (UGEP, m^3/a)	Potable Utilisable Groundwater Exploitation Potential (PUGEP, m^3/a)	PUGEP (Mm^3/a)	Livestock Groundwater Exploitation Potential (LPUGEP, m^3/a)	LPUGEP, (m^3/a)
Ecca North	0.82	0.72	0.95	6,604,084	5,403,341	3,911,236	2,819,728	2.82	3729318	3.73
Ecca East	0.71	0.35	0.82	1,571,719	1,109,448	433,715	153,076	0.15	357177	0.36
Ecca South	0.34	0.04	0.30	17,373,021	5,982,725	1,970,660	78,201	0.08	594326	0.59
Ecca West				7,736,154	0	0	0	0.00	0	0.00
Beaufort	0.50	0.22	0.72	4,167,131	2,083,566	627,033	139,341	0.14	452857	0.45
Dwyka East	0.33	0.44	0.89	410,037	136,665	44,366	19,718	0.02	39437	0.04
Dwyka North	0.42	0.11	0.32	3,003,843	1,256,153	494,381	52,594	0.05	157781	0.16
Dwyka South	0.19	0.35	0.82	368,189	69,521	23,754	8,384	0.01	19562	0.02
Gaborone Granite North	0.17	1.00	1.00	553,732	94,925	64,608	64,608	0.06	64608	0.06
Gaborone Granite South	0.58	1.00	1.00	371,056	216,449	153,174	153,174	0.15	153174	0.15
Granite Sheet and Stock	0.00	0.00	1.00	1,042,446	0	0	0	0.00	0	0.00
Kanye Formation	0.50	0.67	1.00	454,973	227,487	155,347	103,564	0.10	155347	0.16
Kgoro Complex				106,613	0	0				0.00
Late Karoo Dolerites	0.26	0.20	0.52	12,545,567	3,261,847	962,501	192,500	0.19	500500	0.50
Lebung	0.44	0.35	0.61	20,665,912	9,111,788	3,700,803	1,306,166	1.31	2249508	2.25
Lower Molopo	0.33	0.42	1.00	2,115,253	705,084	480,806	200,336	0.20	480806	0.48

Litho Hydrogeologic Unit	Exp Factor Fraction of BH with Q> 2 l/s	Potability Factor (Fraction of BH with TDS<1000 mg/l	Potability Factor (Livestock Consumption, Fraction of BH with TDS <5000 mg/l	(Average Groundwater Resources Potential) AGRP (m^3/a)	Groundwater Exploitation Potential (GEP, m^3/a)	Utilisable Groundwater Exploitation Potential (UGEP, m^3/a)	Potable Utilisable Groundwater Exploitation Potential (PUGEP, m^3/a)	PUGEP (Mm^3/a)	Livestock Groundwater Exploitation Potential (LPUGEP, m^3/a)	LPUGEP, (m^3/a)
Lower Transvaal North	0.75	0.33	0.67	201,372	151,029	71,233	23,744	0.02	47489	0.05
Lower Transvaal South	0.54	0.77	0.90	2,641,014	1,422,084	973,942	750,747	0.75	872489	0.87
Mabua Sehube	0.67	0.17	0.50	956,013	637,374	193,773	32,296	0.03	96887	0.10
Mmathethe Granite	0.50	0.67	0.92	2,804,583	1,402,292	844,418	562,945	0.56	774050	0.77
Nnywane and Mogobane Formation North	0.50	1.00	1.00	500,942	250,471	232,567	232,567	0.23	232567	0.23
Nnywane and Mogobane Formation South	0.42	0.92	0.92	563,522	234,801	185,138	169,710	0.17	169710	0.17
Olifanthoek North	0.48	0.42	0.70	3,660,122	1,750,493	704,949	295,488	0.30	493887	0.49
Olifanthoek South	0.41	0.44	0.90	238,568	97,813	59,275	26,218	0.03	53576	0.05
Proterozoic and Archaen Ironstone	0.25	1.00	1.00	204,993	51,248	38,867	38,867	0.04	38867	0.04
Segwagwa North	0.40	0.50	0.75	228,079	91,232	66,324	33,162	0.03	49743	0.05
Segwagwa South	0.67	1.00	1.00	412,480	274,987	159,943	159,943	0.16	159943	0.16
Undifferentiated Waterberg North	0.47	0.21	0.35	1,049,319	493,797	169,023	34,799	0.03	59655	0.06
Undifferentiated Waterberg Central	0.63	0.47	0.89	1,125,996	711,156	105,989	50,205	0.05	94832	0.09

Litho Hydrogeologic Unit	Exp Factor Fraction of BH with Q> 2 l/s	Potability Factor (Fraction of BH with TDS<1000 mg/l	Potability Factor (Livestock Consumption, Fraction of BH with TDS <5000 mg/l	(Average Groundwater Resources Potential) AGRP (m^3/a)	Groundwater Exploitation Potential (GEP, m^3/a)	Utilisable Groundwater Exploitation Potential (UGEP, m^3/a)	Potable Utilisable Groundwater Exploitation Potential (PUGEP, m^3/a)	PUGEP (Mm^3/a)	Livestock Groundwater Exploitation Potential (LPUGEP, m^3/a)	LPUGEP, (m^3/a)
Undifferentiated Waterberg South	0.51	0.35	0.90	3,115,148	1,590,714	208,656	73,030	0.07	187790	0.19
Undifferentiated Ghanzi				1,269,736	0	0		0.00	0	0.00
Upper Molopo	0.60	0.22	0.22	498,088	298,853	94,681	21,040	0.02	21040	0.02
Upper Transvaal North	0.44	0.60	0.80	1,435,302	637,912	364,854	218,912	0.22	291883	0.29
Upper Transvaal West	0.33	0.27	0.62	5,563,136	1,854,379	590,519	159,241	0.16	364927	0.36
Upper Transvaal East	0.60	0.80	1.00	562,078	337,247	282,876	226,301	0.23	282876	0.28
Archaen Gneiss	0.59	0.84	0.93	1,126,777	659,577	485,074	408,172	0.41	449581	0.45
Archaen Amphibolites East	0.80	1.00	1.00	81,314	65,051	45,290	45,290	0.05	45290	0.05
Archaen Amphibolites West	0.60	1.00	1.00	479,554	287,732	252,664	252,664	0.25	252664	0.25
Archaean and Palaeoproterozoic Felsites	0.67	0.00	0.17	167,532	0	0	0	0.00	0	0.00
			Total (m^3)	107,975,399	42,959,241	19,152,440	9,106,730		13994148	
			Total (million m^3)	107.98	42.96	19.15	9.11	9.11	13.99	13.99

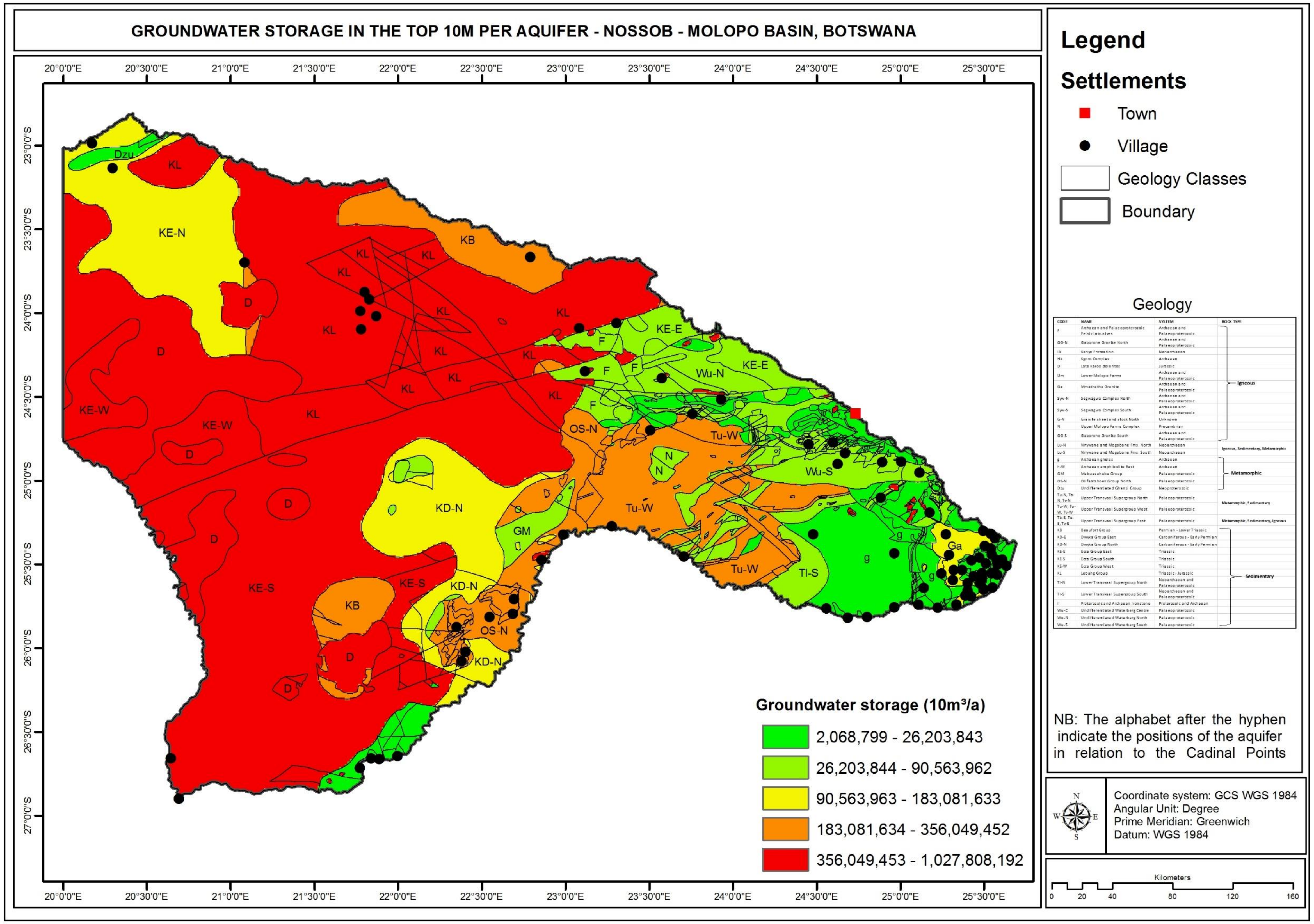


Figure 5-7 Groundwater Resource Potential, Botswana

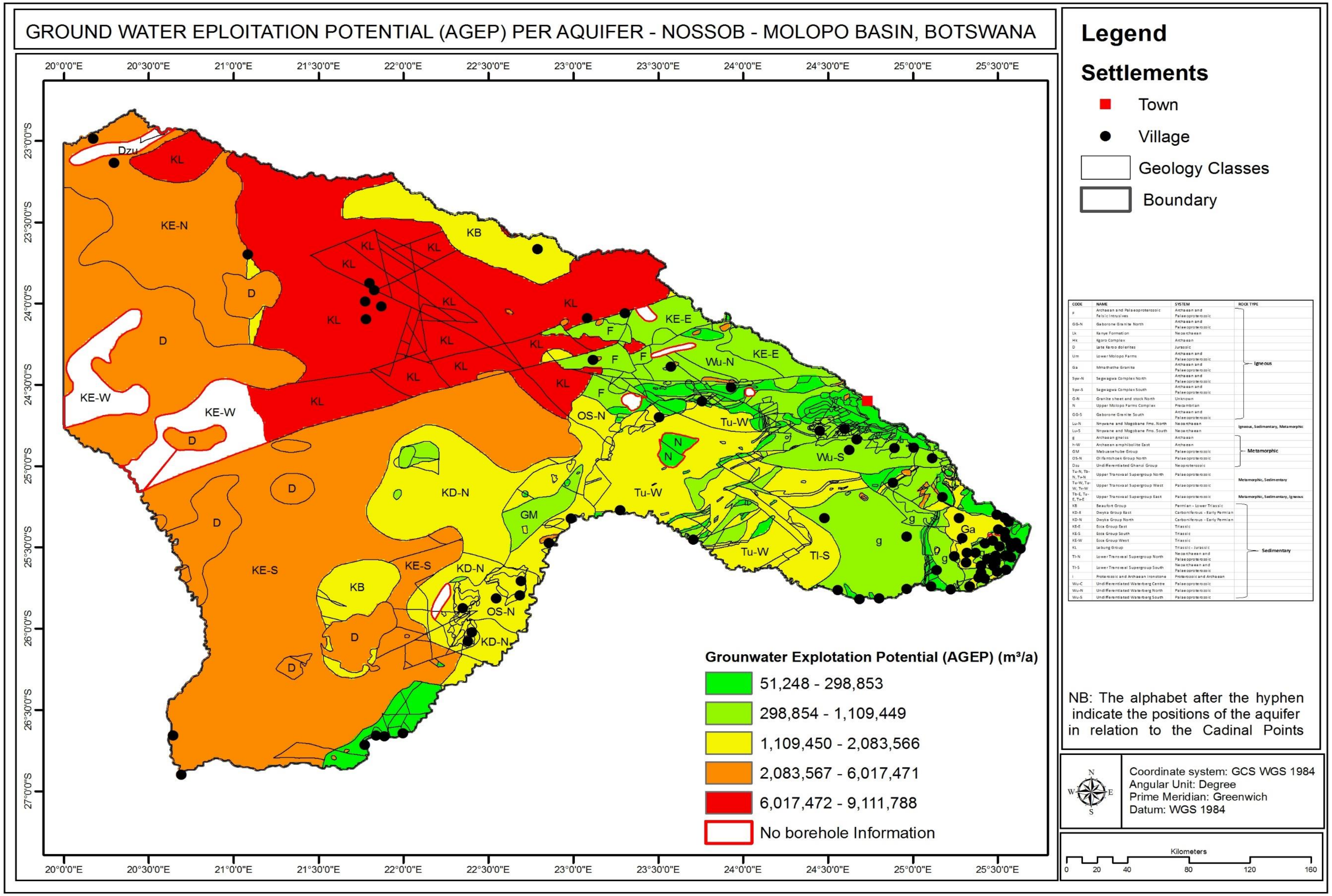


Figure 5-8 Groundwater Exploitation Potential, Botswana

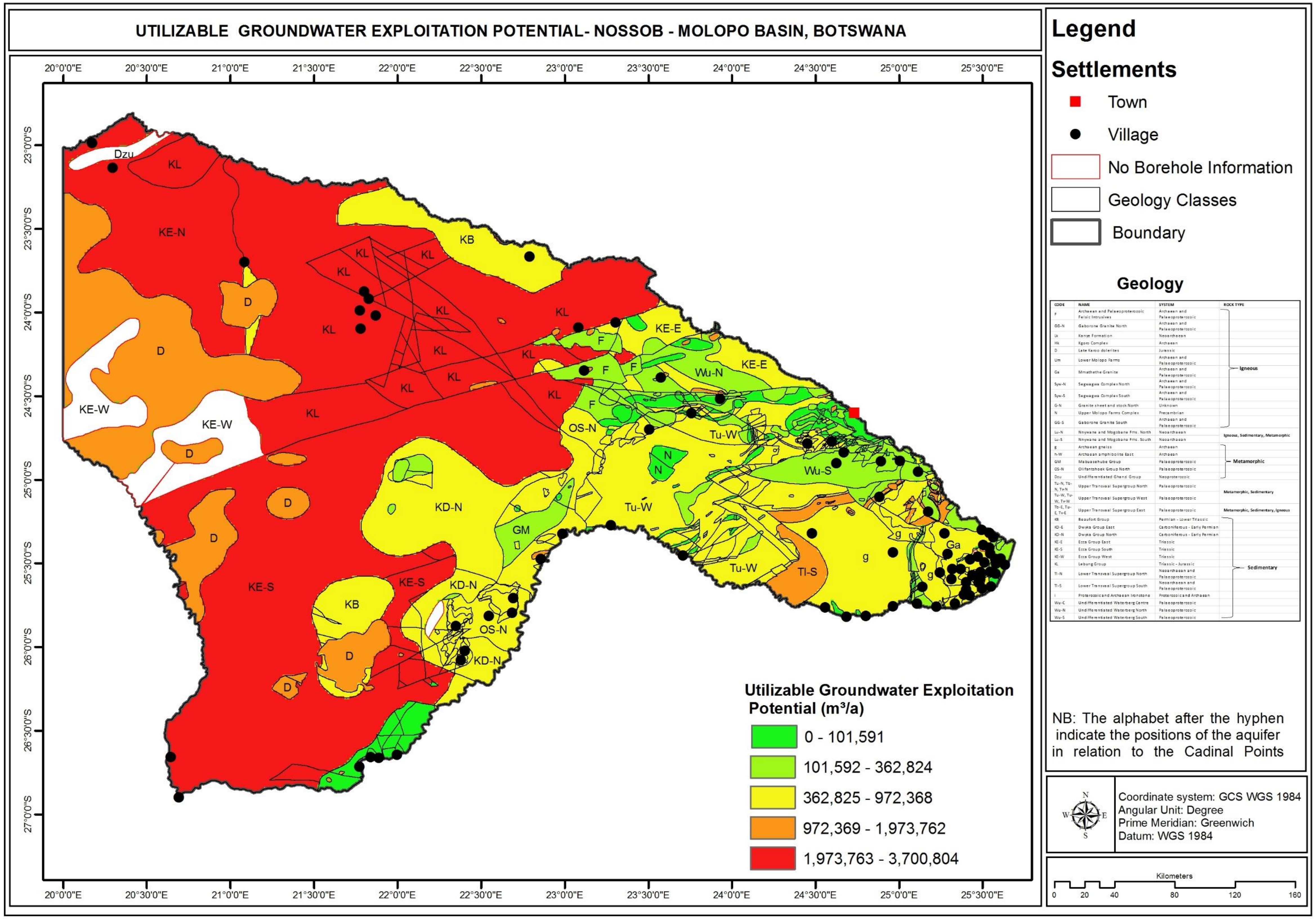


Figure 5-9 Utilisable Groundwater Exploitation Potential, Botswana (see entire basin Appendix 16)

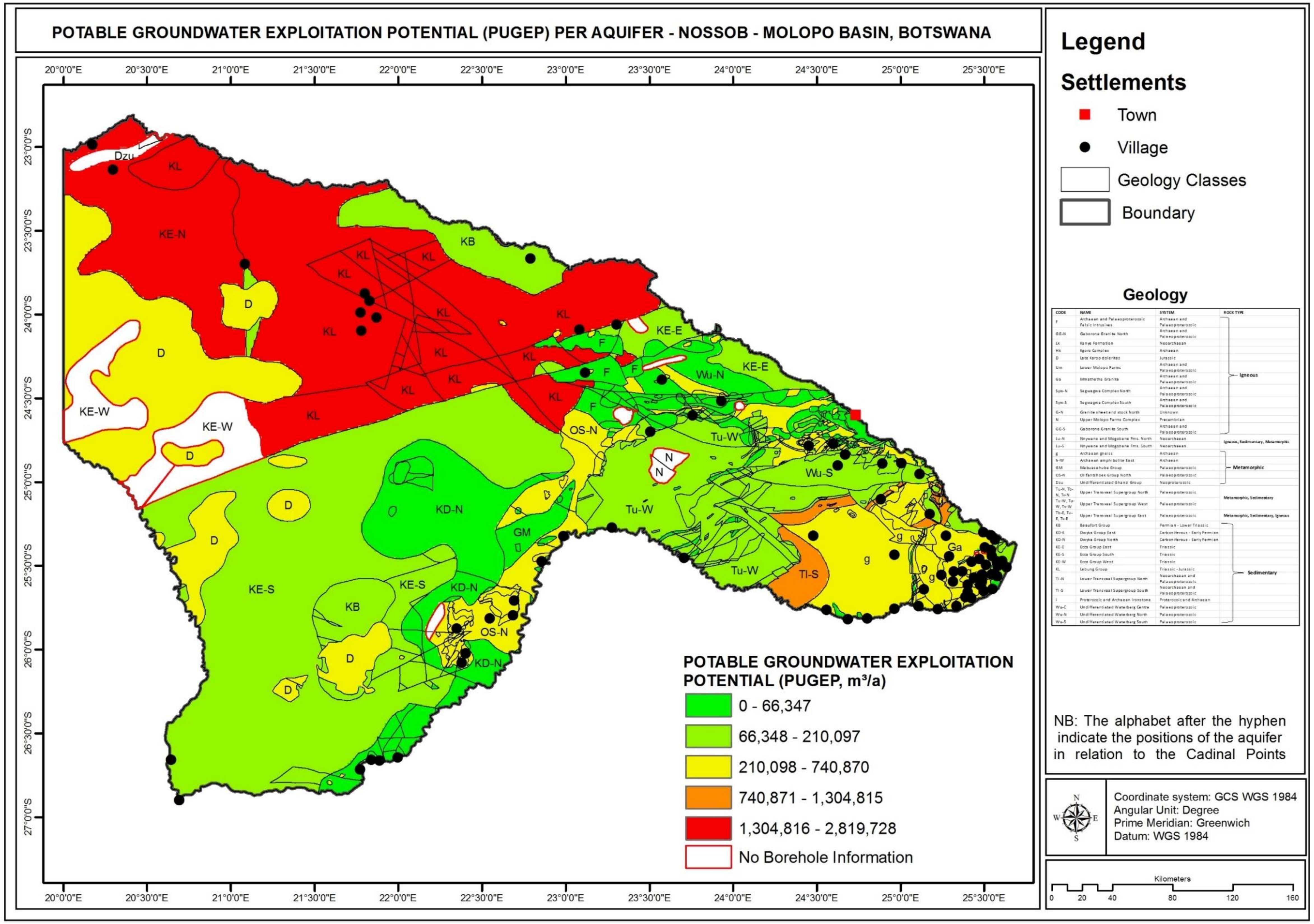


Figure 5-10 Potable Utilisable Groundwater Exploitation Potential, Botswana

5.7 Groundwater Quality

5.7.1 Potability and Livestock standards

Groundwater quality data is available for 1210 boreholes in the form of total dissolved solids (TDS), electrical conductivity, a few cases of nitrate and fluoride. These data was used to calculate the potability index per Litho-Hydrogeological unit based on the drinking water quality standard for Botswana (BOS32:2015) and suitability for livestock consumption i.e. TDS of less than 5000 mg/l.

5.7.2 Total Dissolved Solids

The data indicates that the Total Dissolved Solids (TDS) varies between less than 1000 mg/l to over 60,000 mg/l as shown in **Figure 5-11**. The potability index i.e. percentage of boreholes with groundwater of TDS of less than 1000 mg/l is shown in **Figure 5-12.**

Figure 5-12 indicates that the highest percentage of boreholes with groundwater which is suitable for human consumption (potable use) are found in basement aquifers (78 to 100%) followed by Ecca North (51 to 77%) with the Beaufort, Dwyka and Ecca (South) aquifers having very low potability indices (0 to 27%).

Groundwater quality in terms of suitability for livestock water supply (index i.e. percentage of boreholes with groundwater of TDS of less than 5000 mg/l) is shown in **Figure 5-13** and indicates that a relatively large part of the basin contains groundwater suitable for livestock consumption in terms of TDS.

It should also be noted that variations in water quality guidelines exist amongst the member states. For this reason, it was decided that international al guidelines be adopted to define potability. A threshold of 1200 mg/l TDS or 185 mS/m EC was thus selected as the threshold for potability. A detailed description is given in **Section 4.7.2**. (see **Appendix 16** for combined maps on water quality).

.

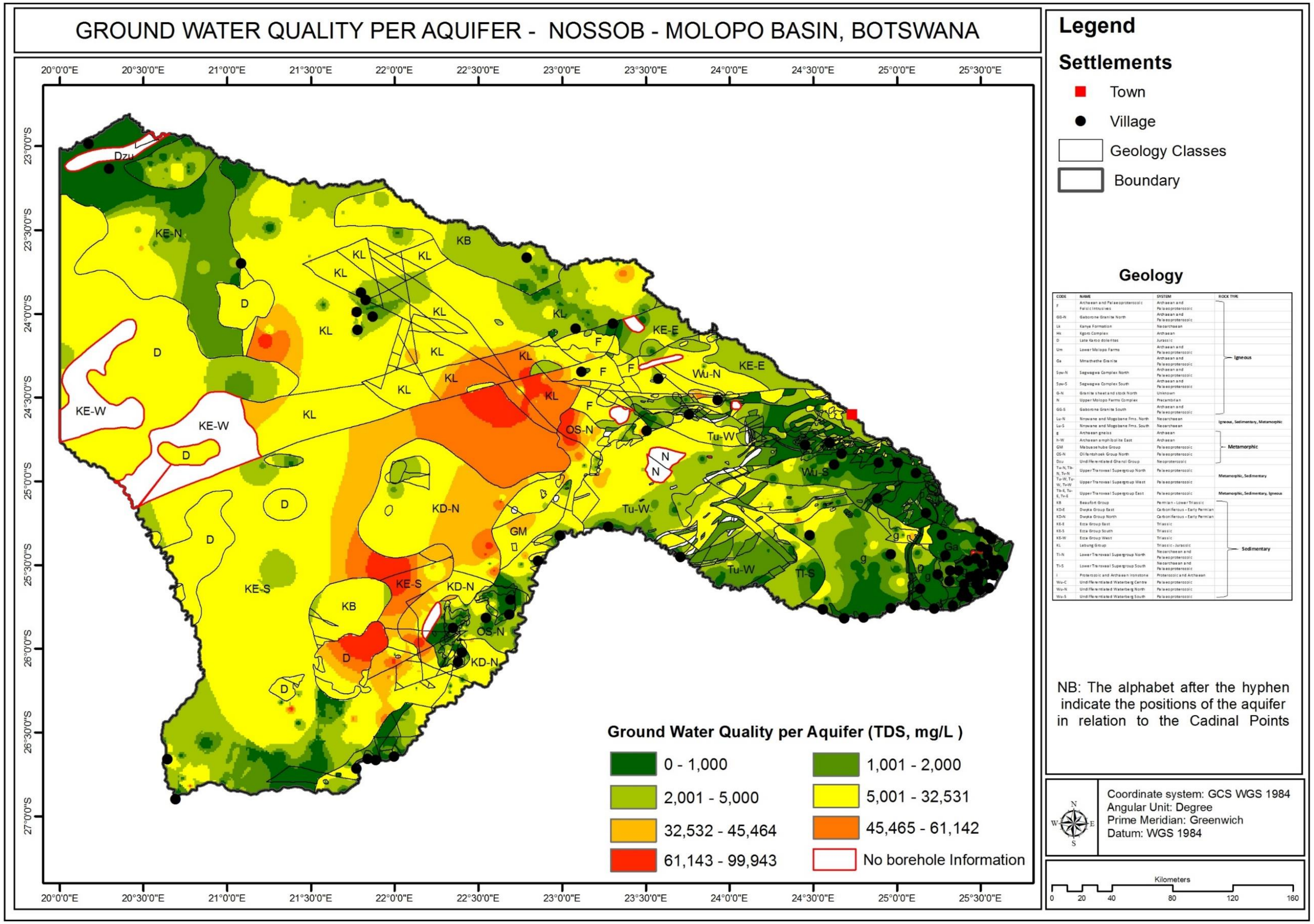


Figure 5-11 TDS Distribution per Lithostratigraphic Unit, Botswana

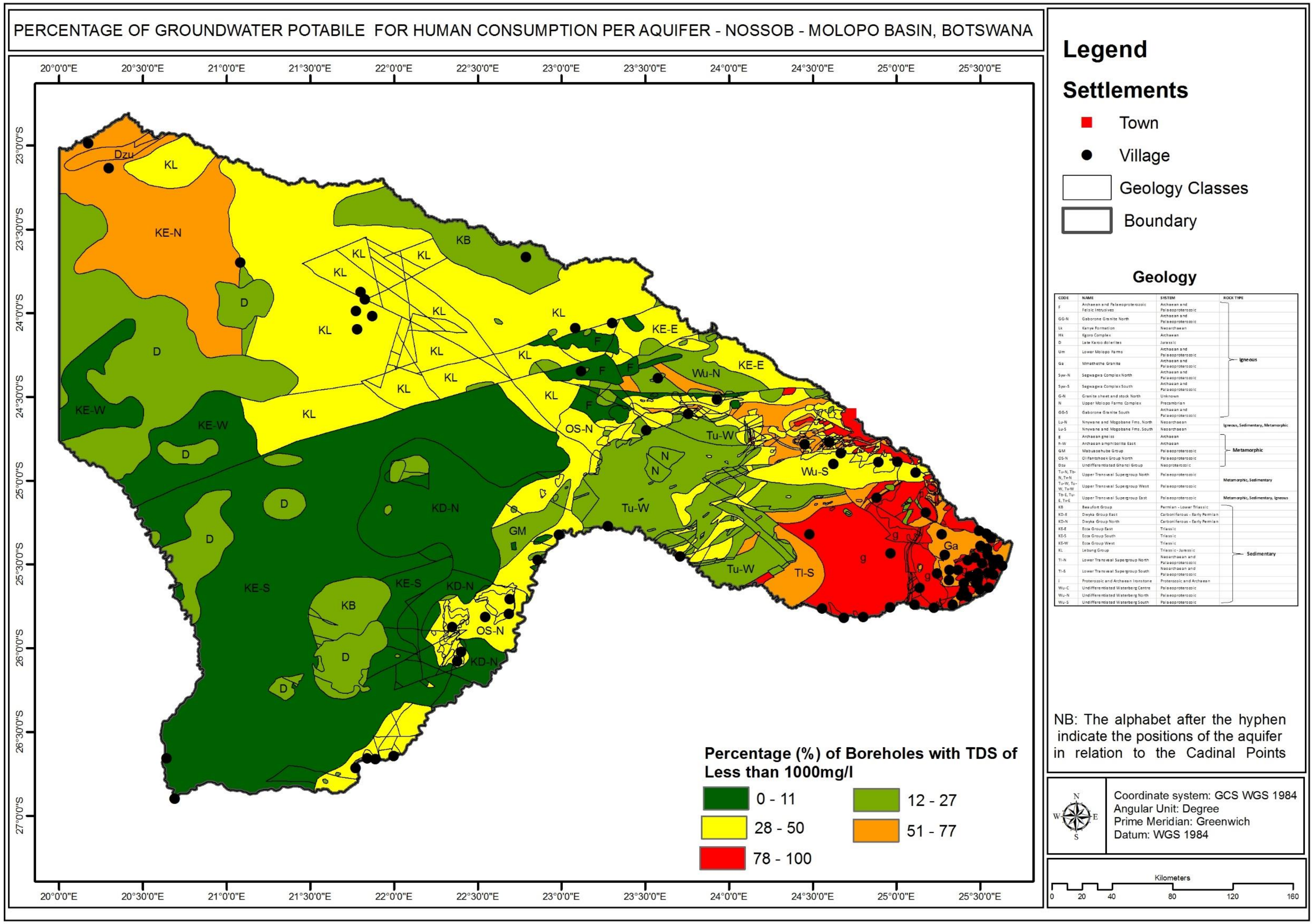


Figure 5-12 Percent of boreholes with groundwater suitable for human consumption, in terms of TDS, Botswana

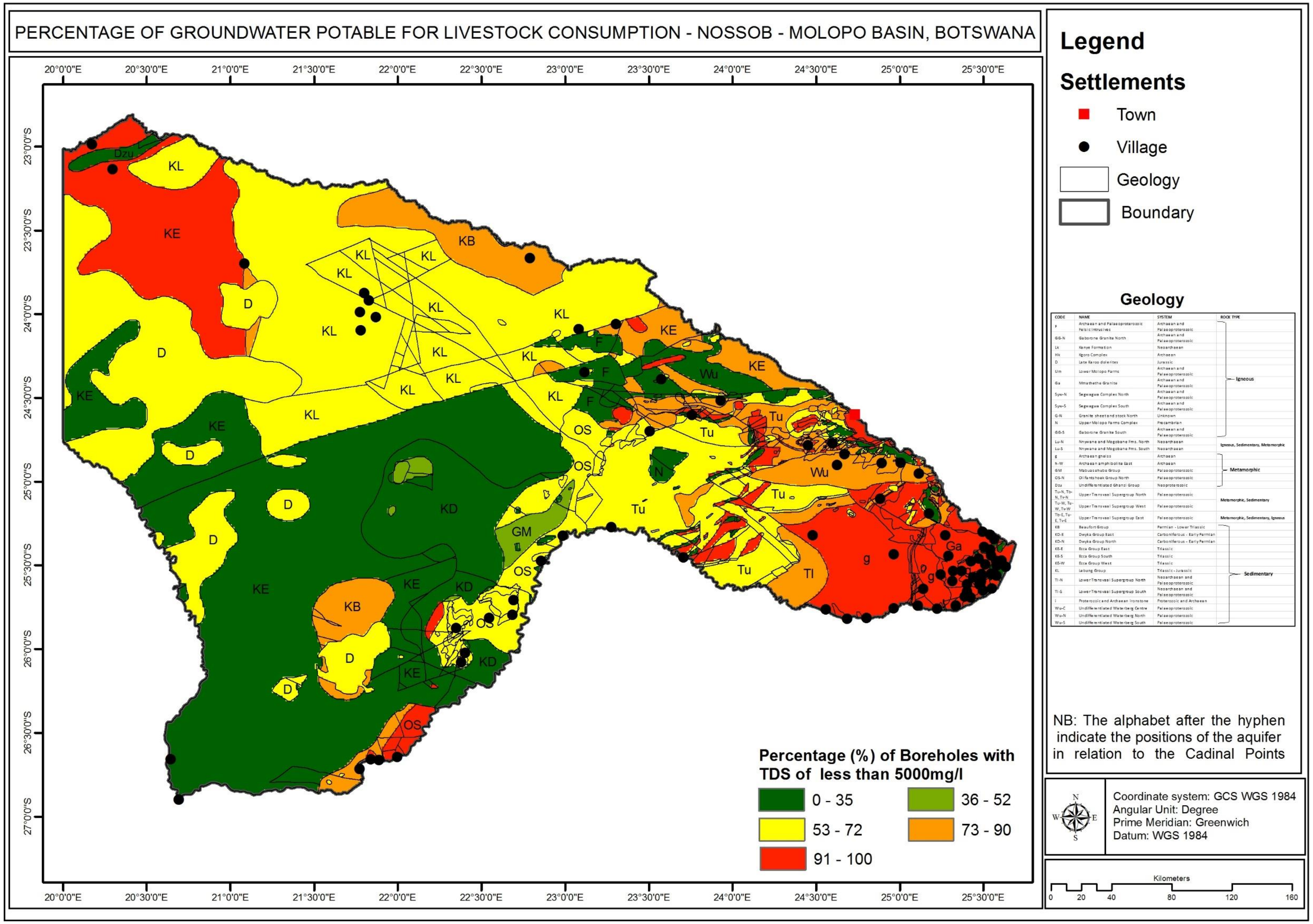


Figure 5-13 Percent of boreholes with groundwater suitable for livestock consumption in terms of TDS, Botswana

5.7.3 Nitrates

Very limited data for nitrates was available for the Botswana part of the basin, however the available data indicates most of the boreholes (~ 84%) have nitrate content of less than 50 mg/l which is the BOS32:2015 limit for potable supply.

5.7.4 Fluorides

Available data on fluoride indicate that about 76 % of boreholes have potable water in terms of fluoride (fluoride <1.5 mg/l)

5.8 Groundwater Use

Domestic groundwater use data was obtained from Water Utilities Corporation records for the period 2013 to 2017. Other ground water use data is not available, however the Department of Water Affairs, Water Apportionment Board water rights records indicate that the allocated annual quantity for the whole basin is 1.92 million cubic meters mainly for livestock use. It is important to note that actual use may not equate to allocated use, as some users over abstract relative to their allocation, some users do not use their entire allocation, while many non-registered users exist.

5.8.1 Water Supply

The majority of communities and towns in the catchment are solely dependent on groundwater for domestic supply. Water use data per Litho-Hydrogeologic Unit based on data from WUC is shown in **Table 5-6** which indicates relatively low usage which is a reflection of the sparse population in the basin and limited groundwater resources.

5.8.2 Mining and Industrial Use

There are no mines and industries on the Botswana part of the basin as such there is no groundwater use for these activities.

5.8.3 Livestock

An estimate of possible abstraction for livestock use was made based on livestock population density data from the 2015 Botswana Agricultural Census per litho-Litho-Hydrogeological Unit as shown in **Table 5-6**.

5.8.4 Total Groundwater Use

Total groundwater use is shown in **Table 5-6**. Abstraction exceeds aquifer recharge in the Undifferentiated Waterberg Central (Kanye Water Supply Area) and Archaen Gneiss (Goodhope Water Supply Area) aquifers.

Table 5-6 Groundwater use and resources, Botswana

Litho-Hydrogeological Unit	Total Estimated Livestock (Cattle, Sheep and Goats) Use (MM^3/a)	Total Use Domestic Use (MM^3/a)	Total use (MM^3/a)	Groundwater Recharge (MM^3/a)	Groundwater Exploitation Potential (MM3/a)	Potable Utilisable Groundwater Exploitation Potential (Mm^3/a)	Allocable Potable Resource (MM^3/a)
Ecca Group North	0.24	0.26	0.5	4.32	5.4	2.82	2.32
Ecca Group East	0.05	0	0.05	0.38	1.11	0.15	0.1
Ecca Group South	0.77	0.11	0.88	2.81	6.02	0.08	-0.8
Ecca Group West	0.13	0	0.13	2.4	Unknown	Unknown	Unknown
Beaufort Group	0.14	0	0.14	0.53	2.08	0.14	0
Dwyka Group East	0.02	0	0.02	0.06	0.18	0.03	0.01
Dwyka Group North	0.20	0	0.2	0.73	1.26	0.05	-0.15
Dwyka Group South	0.02	0	0.02	0.07	0.07	0.01	-0.01
Gaborone Granite North	0.01	0	0.01	0.33	0.09	0.06	0.05
Gaborone Granite South	0.00	0.08	0.08	0.24	0.22	0.15	0.07
Granite Sheet and Stock	0.01	0	0.01	0.64	Unknown	Unknown	Unknown
Kanye Formation	0.02		0.02	0.27	0.23	0.1	0.08

Litho-Hydrogeological Unit	Total Estimated Livestock (Cattle, Sheep and Goats) Use (MM^3/a)	Total Use Domestic Use (MM^3/a)	Total use (MM^3/a)	Groundwater Recharge (MM^3/a)	Groundwater Exploitation Potential (MM3/a)	Potable Utilisable Groundwater Exploitation Potential (Mm^3/a)	Allocable Potable Resource (MM^3/a)
Kgoro Complex	0.00	0	0	0.06	Unknown	Unknown	Unknown
Late Karoo Dolerites	0.41	0	0.41	1.49	4.56	0.27	-0.14
Lebung Group	0.73	0.31	1.04	5.33	9.11	1.31	0.27
Lower Molopo Complex	0.04		0.04	1.27	0.71	0.2	0.16
Lower Transvaal North	0.02	0	0.02	0.07	0.15	0.02	0
Lower Transvaal South	0.04	0	0.04	1.6	1.42	0.75	0.71
Mabua Sehube	0.03	0	0.03	0.12	0.48	0.02	-0.01
Mmathethe Granite	0.03	0.34	0.36	1.41	1.4	0.56	0.2
Nnywane/Mogobane Formations North	0.01	0	0.01	0.46	0.25	0.23	0.22
Nnywane/Mogobane Formations South	0.01	0.06	0.07	0.41	0.23	0.17	0.1
Olifanthoek North	0.13	0.59	0.72	0.93	1.75	0.3	-0.42
Olifanthoek South	0.02	0.04	0.06	0.12	0.08	0.02	-0.04
Proterozoic and Archaen Ironstone	0.00	0	0	0.14	0.05	0.04	0.04
Segwagwa Formation North	0.00	0	0	0.15	0.09	0.03	0.03

Litho-Hydrogeological Unit	Total Estimated Livestock (Cattle, Sheep and Goats) Use (MM^3/a)	Total Use Domestic Use (MM^3/a)	Total use (MM^3/a)	Groundwater Recharge (MM^3/a)	Groundwater Exploitation Potential (MM3/a)	Potable Utilisable Groundwater Exploitation Potential (Mm^3/a)	Allocable Potable Resource (MM^3/a)
Segwagwa Formation South	0.00	0.02	0.02	0.2	0.27	0.16	0.14
Undifferentiated Waterberg North	0.05		0.05	0.19	0.49	0.03	-0.02
Undifferentiated Waterberg Central	0.02	2.34	2.36	0.11	0.71	0.05	-2.31
Undifferentiated Waterberg South	0.06		0.06	0.21	1.59	0.07	0.01
Undifferentiated Ghanzi	0.01		0.01	0.98	Unknown	Unknown	Unknown
Upper Molopo Complex	0.02	0	0.02	0.07	0.3	0.02	0
Upper Transvaal North	0.04	0.18	0.22	0.67	0.64	0.22	0
Upper Transvaal West	0.23		0.23	0.82	1.85	0.16	-0.07
Upper Transvaal East	0.01		0.01	0.45	0.45	0.3	0.29
Archaen Gneiss	0.01	1.32	1.33	0.75	0.66	0.41	-0.92
Archaen Amphibolites East	0.00		0	0.05	0.07	0.05	0.05
Archaen Amphibolites West	0.01		0.01	0.41	0.29	0.25	0.24
Archaean and Palaeoproterozoic Units	0.05		0.05	0.17	0.66	0	-0.05

5.9 Groundwater Stress Index

Groundwater use is more meaningful when assessed relative to available groundwater resources. The best measure of groundwater resources is aquifer recharge; hence a stress index is defined as groundwater use relative to aquifer recharge (Groundwater stress index). A groundwater stress index for the basin (Botswana) is given in **Figure 5-14** and indicates that the areas underlain by Archean Gneiss (Goodhope water supply area) and the Olifanthoek North (Tsabong water supply area) are being over abstracted i.e. high to heavily used.

5.10 Groundwater Reserve

No Reserve has been set for Botswana.

5.11 Allocable Groundwater Resources

The allocable groundwater resources were calculated as the Potable Utilisable Groundwater Exploitation Potential minus current water use. This was termed the allocable potable groundwater resource and is shown **Table 5-6**. This indicates the majority of the basin with exception Ecca North, Lower Transvaal South, Upper Transvaal East and Lebung hydrogeologic units have very little scope for further development of potable groundwater resources.

5.12 Aquifer Vulnerability

Aquifer vulnerability according to the DRASTIC index is shown in **Figure 5-15** and indicates that the majority of the basin has insignificant to low groundwater pollution vulnerability**.**

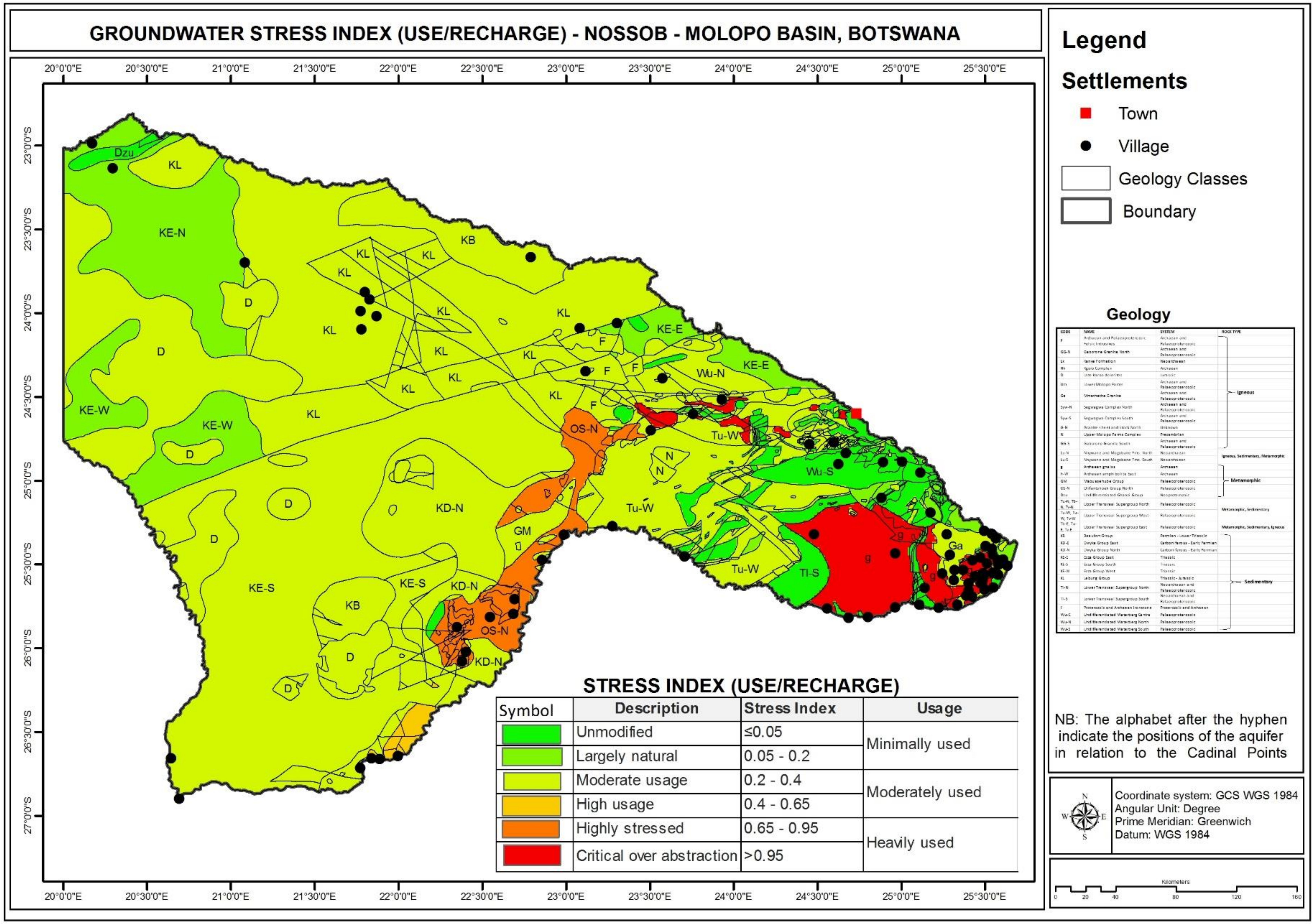


Figure 5-14 Stress Index, Botswana (see entire basin Appendix 16)

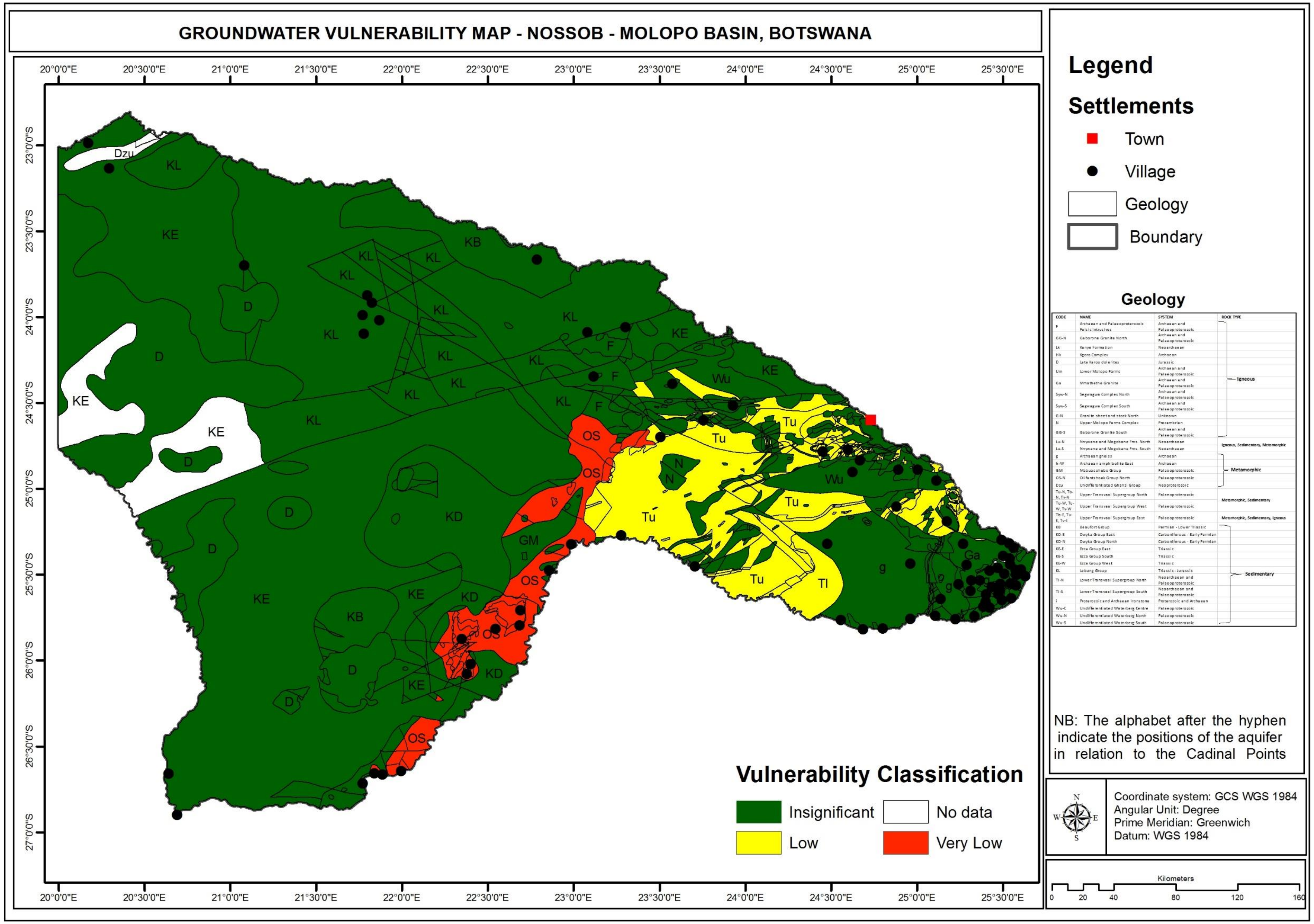


Figure 5-15 Groundwater Pollution Vulnerability Map, Botswana (see entire basin Appendix 16)

6 HYDROGEOLOGY NAMIBIA

6.1 Aquifer types

Three main aquifer types that can be distinguished in the Namibian part of the basin: namely Porous (Intergranular), Porous Fractured, Fractured Weathered, (weathered and fractured), and Karstic (**Figure 6-1** and **Table 6-1**):

- **Porous and Porous Fractured aquifers:** Porous aquifers are represented by the Kalahari and Namib Sands Group and while the Main Karoo Basin (Aoub and Nossob Sandstone) has porous fractured aquifers. The porous and porous fractured aquifers are found in the eastern and southeastern part of the study area The average borehole yield in the Kalahari aquifer is 1.1 l/s (~4 $m^{3/}$hr) while the average borehole yield of the Main Karoo Basin (Aoub and Nossob Formations) is 1.28 l/s (4.6 m^3/hr).

- **Fractured and weathered aquifers** are found in the majority of the basin and represented by gneisses, granites, schists, amphibolites, sandstones, dolerite dykes and sills, basalts and limestones which are found in Karas basement, Fish River-Aroab, Hochfeld-Dordabis-Gobabis and Stampriet Basin. Average borehole yields in fractured/weathered aquifer range from 0.1 l/s (0.36 m^3/hr) to 1.46 l/s (5.9 m^3/hr) with the highest yielding boreholes found in the Rehoboth Group, Kalkrand Basalt and Fish River Sub Group while the lowest yielding boreholes are found in the Vioolsdrift Granite Suite.

- **Karstic aquifers are** represented by limestones of the Naukluft Mountains Group. The groundwater potential of the Naukluft Mountains Group is unknown as there is no borehole information in this group however, they are reported to have low groundwater potential.

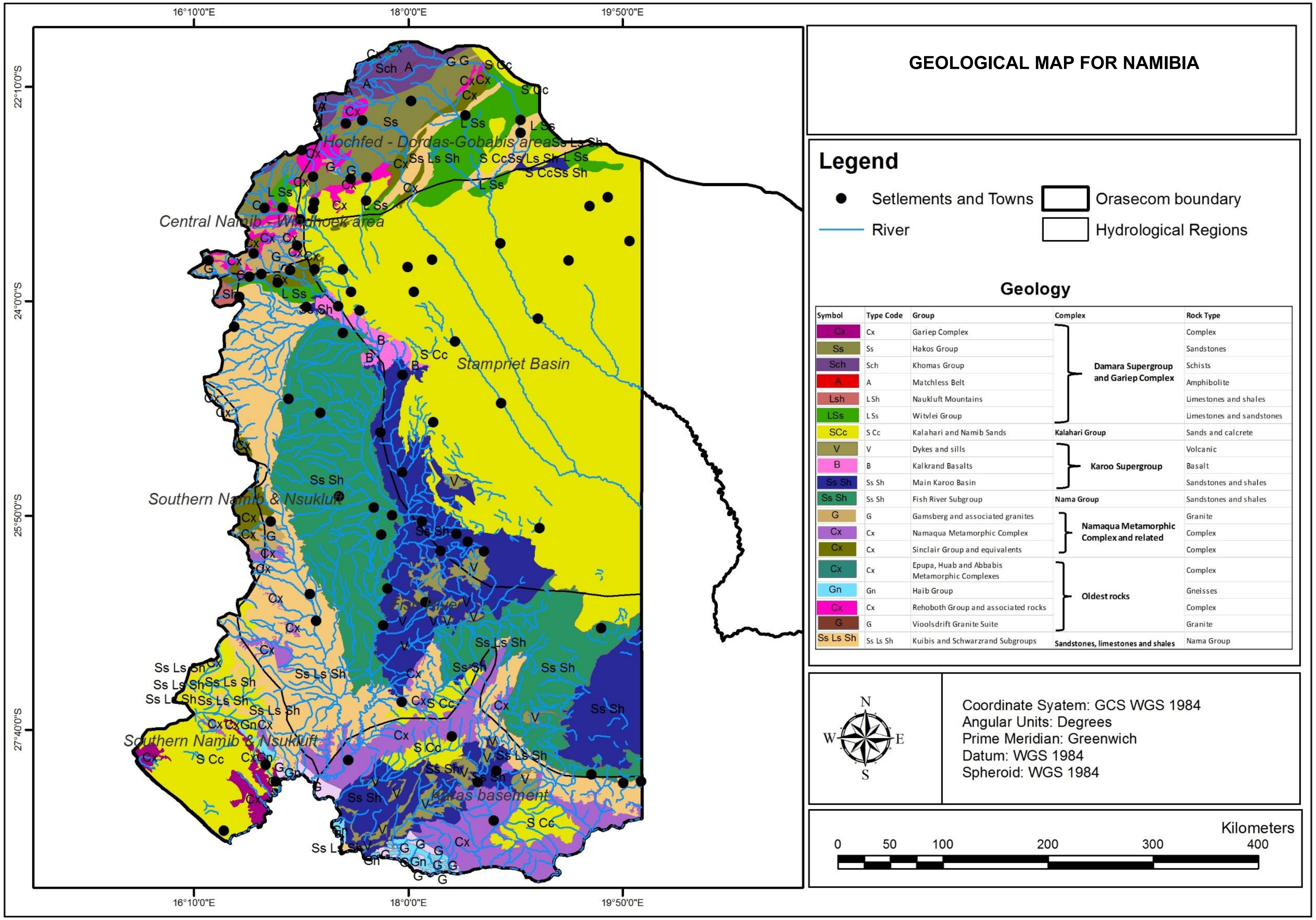


Figure 6-1Geology of the Groundwater Basins, Namibia

Table 6-1 Summary of Aquifer Information, Namibia

Group	Rock Type	Groundwater Basin	Weathered / Porous Thickness (m)	Saturated Weathered/ Porous Thickness (m)	Saturated Fractured Thickness (m)	Average Yield (l/s)	Aquifer Type
Fish River Sub Group	Sandstones and shales	Fish River Aroab	30.78	20.61	71.28	0.98	Fractured and Weathered
Kuibis and Schwarzrand Subgroups	Sandstones, limestones and shales	Fish River Aroab	26.35	18.84	58.42	0.92	Fractured and Weathered
Epupa, Huab and Abbabis Metamorphic Complexes	Gneisses and granites	Hochfeld-Dordabis-Gobabis	0.00	0.00	40.00	0.60	Fractured
Gamsberg and associated granites	Granite	Hochfeld-Dordabis-Gobabis	34.33	25.16	51.00	0.26	Fractured and Weathered
Hakos Group	Sandstones	Hochfeld-Dordabis-Gobabis	21.00	13.50	82.67	0.72	Fractured and Weathered
Khomas Group	Schists	Hochfeld-Dordabis-Gobabis	29.50	17.50	48.05	0.35	Fractured and Weathered
Matchless Belt	Amphibolite	Hochfeld-Dordabis-Gobabis	Unknown	Unknown	Unknown	Unknown	Fractured and Weathered
Rehoboth Group and associated rocks	Granites	Hochfeld-Dordabis-Gobabis	0.00	0.00	45.88	1.65	Fractured and Weathered
Sinclair Group and equivalents	Granites	Hochfeld-Dordabis-Gobabis	28.70	19.40	47.50	0.82	Fractured and Weathered

Group	**Rock Type**	**Groundwater Basin**	**Weathered / Porous Thickness (m)**	**Saturated Weathered/ Porous Thickness (m)**	**Saturated Fractured Thickness (m)**	**Average Yield (l/s)**	**Aquifer Type**
Witvlei Group	Limestones and sandstones	Hochfeld-Dordabis-Gobabis	36.30	24.00	48.77	0.87	Fractured and Weathered
Dykes and sills	Basalt and Dolerite	Karas Basement	38.43	28.86	44.00	0.69	Fractured and Weathered
Haib	Gneisses	Karas Basement	22.07	19.07	0.00	0.13	Weathered
Namaqua Metamorphic Complex	Gneisses	Karas Basement	28.55	14.80	56.53	0.41	Fractured and Weathered
Vioolsdrift Granite Suite	Granites	Karas Basement	19.65	14.65	0.00	0.10	Weathered
Gariep Complex	Schists and amphibolites	Southern Namib and Naukluft	Unknown	Unknown	Unknown	Unknown	Fractured
Naukluft Mountains	Limestones and shales	Southern Namib and Naukluft	Unknown	Unknown	Unknown	Unknown	Karstic
Kalahari and Namib Sands	Sands and calcrete	Stampriet Basin	32.91	20.90	66.32	1.10	Porous and Fractured
Kalkrand Basalts	Basalt	Stampriet Basin	29.67	19.78	62.67	1.46	Fractured and Weathered
Main Karoo Basin	Sandstones and shales (Aoub and Nossob Formation)	Stampriet Basin	28.15	16.52	46.54	1.28	Porous and Fractured

6.2 Borehole yield

Average borehole yields in the five groundwater basins are shown in **Figure 6-2** while **Figure 6-3** indicates the aquifer productivity index i.e. percentage of boreholes with yield of more than 0.83 litres per second (l/s). Borehole yield summary data is given in **Table 6-2**.

The data indicates that a vast portion of the groundwater basins is dominated by relatively low yielding boreholes with the majority of boreholes having yields ranging between 0.33 l/s (1.2 m^3/hr) 1.2 to 1.28 l/s (4.6 m^3/hr). The highest yielding boreholes are found the Stampriet (Aoub and Nossob) and Fish River Aroab basins with the lowest yields found in Karas Basement groundwater basin. In terms of the aquifer productive index, (see **Figure 6-3**), the majority of the basin shows a low productivity factor (percentage of boreholes with yield of more than 0.83 l/s) with most of the groundwater basins having exploitation factors of 0 to 50% (average productivity factor ~10%). The data indicates that the Stampriet Groundwater basin has the highest exploitation factor with the Karas basement Groundwater basin having the lowest groundwater exploitation potential.

6.3 Recharge

Recharge in Namibia is known to be low though it not well constrained and for this study it was assumed to be 0.1mm/a for the whole basin. However, it has to be noted that higher recharge occurs during years of exceptionally high rainfall and some areas have higher groundwater recharge than others.

Table 6-2 Borehole Yield Summary, Namibia

Group	Groundwater Basin	Number of boreholes	Average yield (l/s)	**Average Yield (Groundwater Basin, l/s)**	Median yield (l/s)	% Q >5 l/s	% Q >2 l/s	% Q > 0.5 l/s	Aquifer Type
Fish River Sub Group	Fish River Aroab	146	1.0	0.95	0.6	1.4	11.0	56.8	Fractured and Weathered
Kuibis and Schwarzrand Subgroups	Fish River Aroab	96	0.9		0.6	1.0	10.4	56.3	Fractured and Weathered
Epupa, Huab and Abbabis Metamorphic Complexes	Hochfeld-Dordabis-Gobabis	1	0.6	0.75					Fractured
Gamsberg and associated granites	Hochfeld-Dordabis-Gobabis	8	0.3		0.1	0.0	0.0	25.0	Fractured and Weathered
Hakos Group	Hochfeld-Dordabis-Gobabis	20	0.7		0.4	0.0	15.0	30.0	Fractured and Weathered
Khomas Group	Hochfeld-Dordabis-Gobabis	4	0.4		0.4	0.0	0.0	50.0	Fractured and Weathered
Matchless Belt	Hochfeld-Dordabis-Gobabis	0							Fractured and Weathered
Rehoboth Group and associated rocks	Hochfeld-Dordabis-Gobabis	6	1.7		1.3	0.0	50.0	50.0	Fractured and Weathered
Sinclair Group and equivalents	Hochfeld-Dordabis-Gobabis	26	0.8		0.8	0.0	0.0	69.2	Fractured and Weathered
Witvlei Group	Hochfeld-Dordabis-Gobabis	88	0.9		0.6	1.1	9.1	58.0	Fractured and Weathered
Dykes and sills	Karas Basement	9	0.6	0.33	0.8	0.0	0.0	55.6	Fractured and Weathered
Haib	Karas Basement	3	0.1		0.2	0.0	0.0	0.0	Weathered
Namaqua Metamorphic Complex	Karas Basement	34	0.4		0.3	0.0	0.0	29.4	Fractured and Weathered
Vioolsdrift Granite Suite	Karas Basement	2	0.1		0.0	0.0	0.0	0.0	Weathered
Gariep Complex	Southern Namib and Naukluft	0		Unknown (Reported Low)					Fractured

Group	Groundwater Basin	Number of boreholes	Average yield (l/s)	**Average Yield (Groundwater Basin, l/s)**	Median yield (l/s)	% Q >5 l/s	% Q >2 l/s	% Q > 0.5 l/s	Aquifer Type
Naukluft Mountains	Southern Namib and Naukluft	0							Karstic
Kalahari and Namib Sands (Stapriet Basin)	Stampriet Basin	492	1.1	1.28	0.8	2.0	14.0	59.8	Porous and Fractured
Kalkrand Basalts	Stampriet Basin	12	1.5		1.3	0.0	25.0	91.7	Fractured and Weathered
Main Karoo Basin	Stampriet Basin (Aoub and Nossob)	88	1.3		0.8	3.4	13.6	63.6	Porous and Fractured

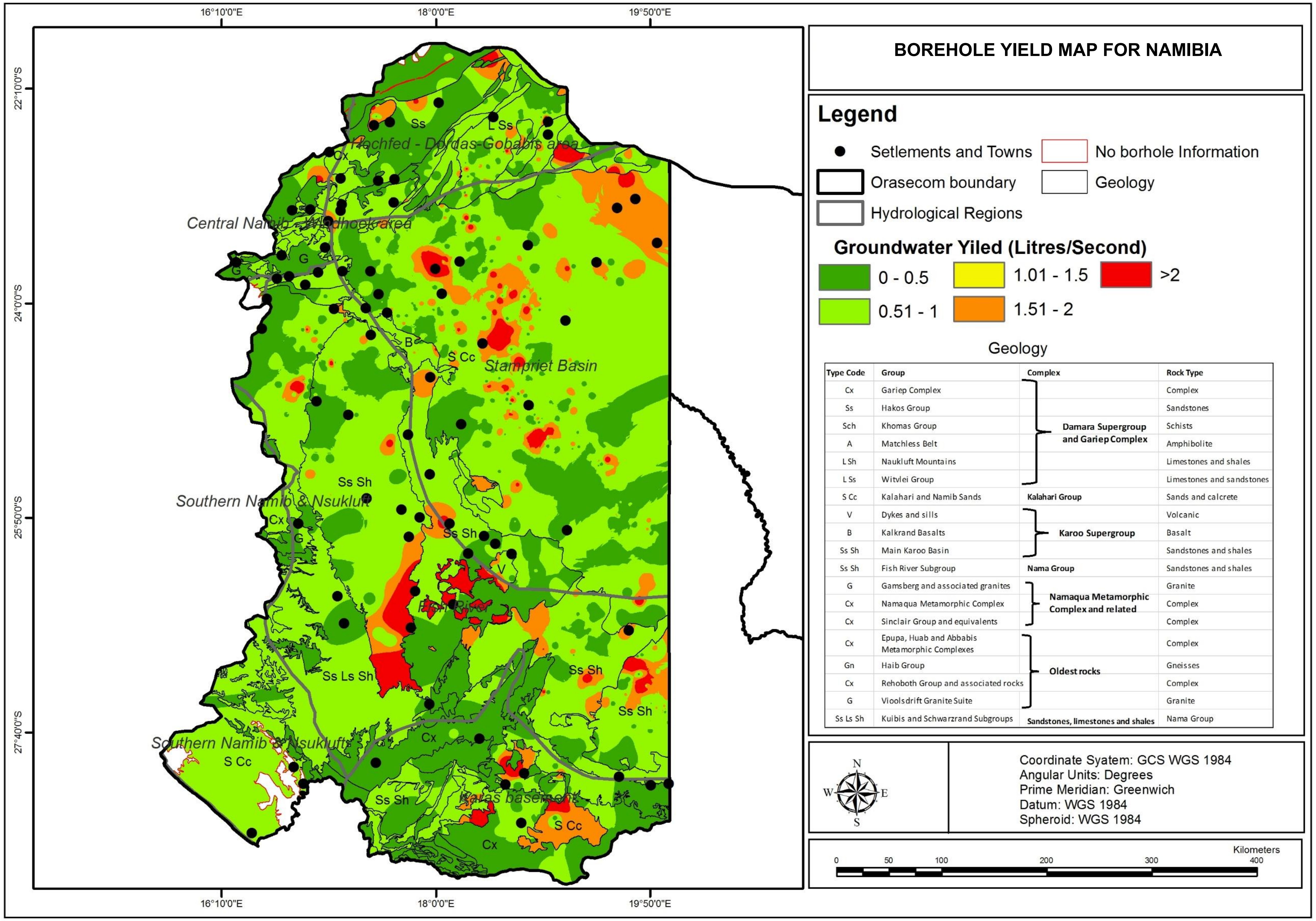


Figure 6-2 Borehole yields, Namibia (See entire basin Appendix 16)

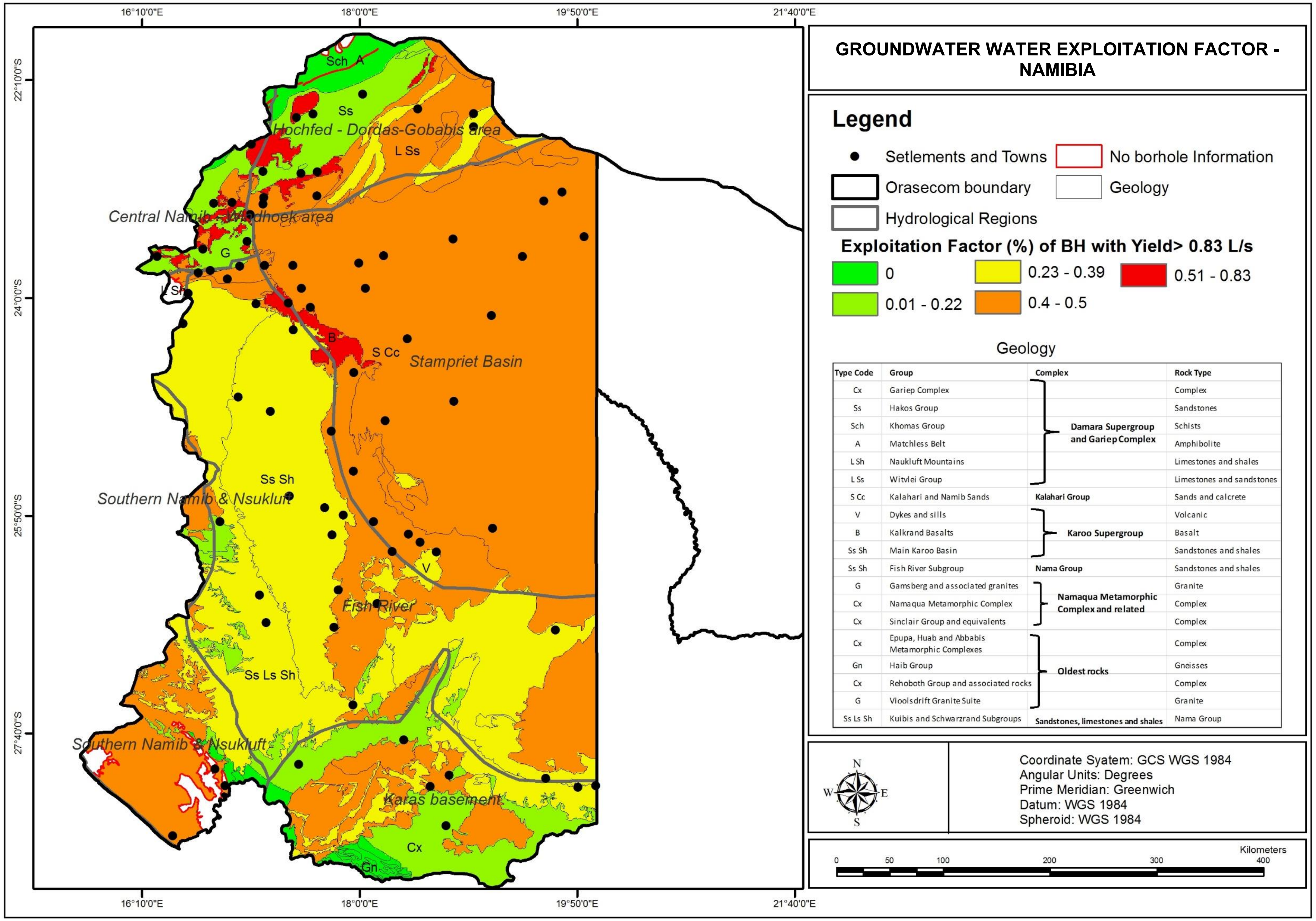


Figure 6-3 Aquifer productivity index (exploitation factor), Namibia

6.4 Groundwater Storage

In fractured rock aquifers the number of water-bearing fractures generally decreases with depth, resulting in a corresponding decline in aquifer storativity with depth. Whether groundwater storage is in fractures only or in fractured as well as weathered rock, also affects storage, since weathered zones have higher pore space. Consequently, two types of aquifer storage exist: weathered storage and fractured zone storage. The Weathered Zone is normally a relatively thin zone (5-50 m). For the Namibian part of the study boreholes with a depth of less than 50 m were taken as having groundwater storage in the weathered zone only while boreholes with depth of more than 50 m were taken as having groundwater stored in both the weathered and fractured zone.

6.4.1 Storativity

Calculations of aquifer storage are directly dependent on estimates of storativity. The calculated storativity values used for estimation of groundwater volumes per aquifer unit is summarized in **Table 6-3**.

6.4.2 Saturated Thickness

Saturated thicknesses of the weathered and fractured zone per Litho-Hydrogeological Unit are shown in **Table 6-1** and the calculated total aquifer storage (m^3) and aquifer storage per m^3/km^2 is shown in **Figures 6-4** and **6-5** respectively. Storage is highest in the Kalahari -Namib sands (Stampriet basin) Kuibis and Schwarzrand Subgroups (Fish River- Fish River Aroab Groundwater Basin) and lowest in the Epupa, Huab and Abbabis Metamorphic Complexes (Karas Basement groundwater basin).

Table 6-3 Storativity per Litho-Hydrogeological Unit, Namibia

Group	Dominant Rock Type	Groundwater Basin	Sy (Weathered/Porous)	Ss (Fractured)	Average
Fish River Subgroup	Sandstones and shales	Fish River Aroab	3.46E-03	3.20E-04	1.89E-03
Kuibis and Schwarzrand Subgroups	Sandstones, limestones and shales	Fish River Aroab	4.11E-03	5.78E-04	2.34E-03
Epupa, Huab and Abbabis Metamorphic Complexes	Gneisses and granites	Hochfeld-Dordabis-Gobabis	2.34E-03	4.20E-03	3.27E-03
Gamsberg and associated granites	Granite	Hochfeld-Dordabis-Gobabis	3.37E-03	3.98E-04	1.88E-03
Hakos Group	Sandstones	Hochfeld-Dordabis-Gobabis	4.49E-03	4.80E-04	2.49E-03
Khomas Group	Schists	Hochfeld-Dordabis-Gobabis	3.32E-03	5.90E-04	1.95E-03
Matchless Belt	Amphibolite	Hochfeld-Dordabis-Gobabis	Unknown	Unknown	Unknown
Rehoboth Group and associated rocks	Granites	Hochfeld-Dordabis-Gobabis	2.79E-03	2.81E-03	2.80E-03
Sinclair Group and equivalents	Granites	Hochfeld-Dordabis-Gobabis	2.75E-03	7.25E-04	1.74E-03
Witvlei Group	Limestones and sandstones	Hochfeld-Dordabis-Gobabis	2.89E-03	3.66E-04	1.63E-03
Dykes and sills	Basalt and Dolerite	Karas Basement	3.08E-03	3.53E-04	1.72E-03
Haib	Gneisses	Karas Basement	5.09E-03	2.62E-03	3.86E-03
Namaqua Metamorphic Complex	Gneisses	Karas Basement	2.45E-03	6.26E-04	1.54E-03
Vioolsdrift Granite Suite	Granites	Karas Basement	4.55E-02	3.27E-02	3.91E-02
Gariep Complex	Schists and amphibolites	Southern Namib and Naukluft	Unknown	Unknown	Unknown

Group	Dominant Rock Type	Groundwater Basin	Sy (Weathered/Porous)	Ss (Fractured)	Average
Naukluft Mountains	Limestones and shales	Southern Namib and Naukluft	Unknown	Unknown	Unknown
Kalahari and Namib Sands	Sands and calcrete	Stampriet Basin	3.12E-03	3.09E-04	1.71E-03
Kalkrand Basalts	Basalt	Stampriet Basin	3.33E-03	1.88E-04	1.76E-03
Main Karoo Basin	Sandstones and shales	Stampriet Basin	3.45E-03	6.68E-04	2.06E-03

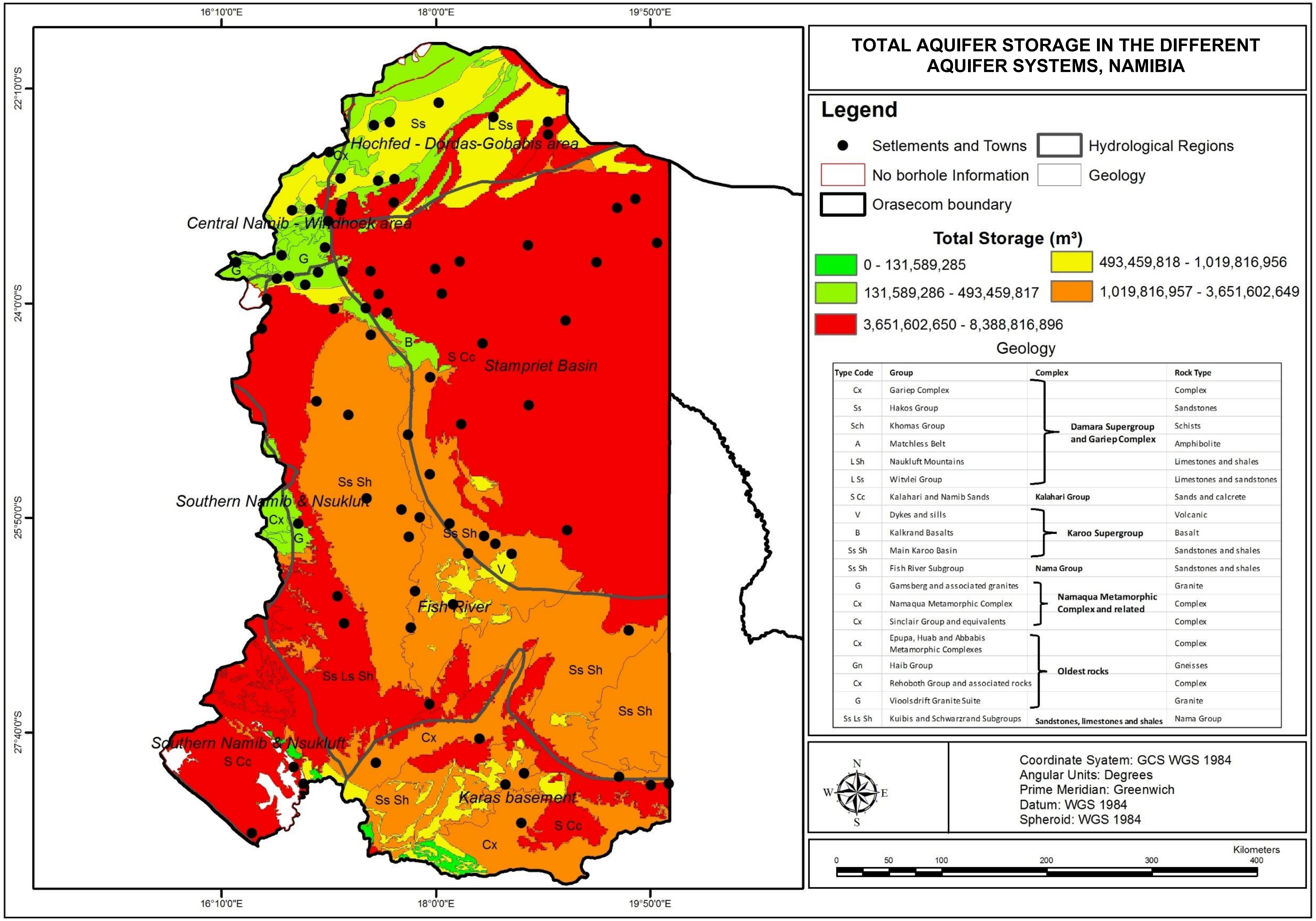


Figure 6-4 Total aquifer storage in the different aquifer systems, Namibia

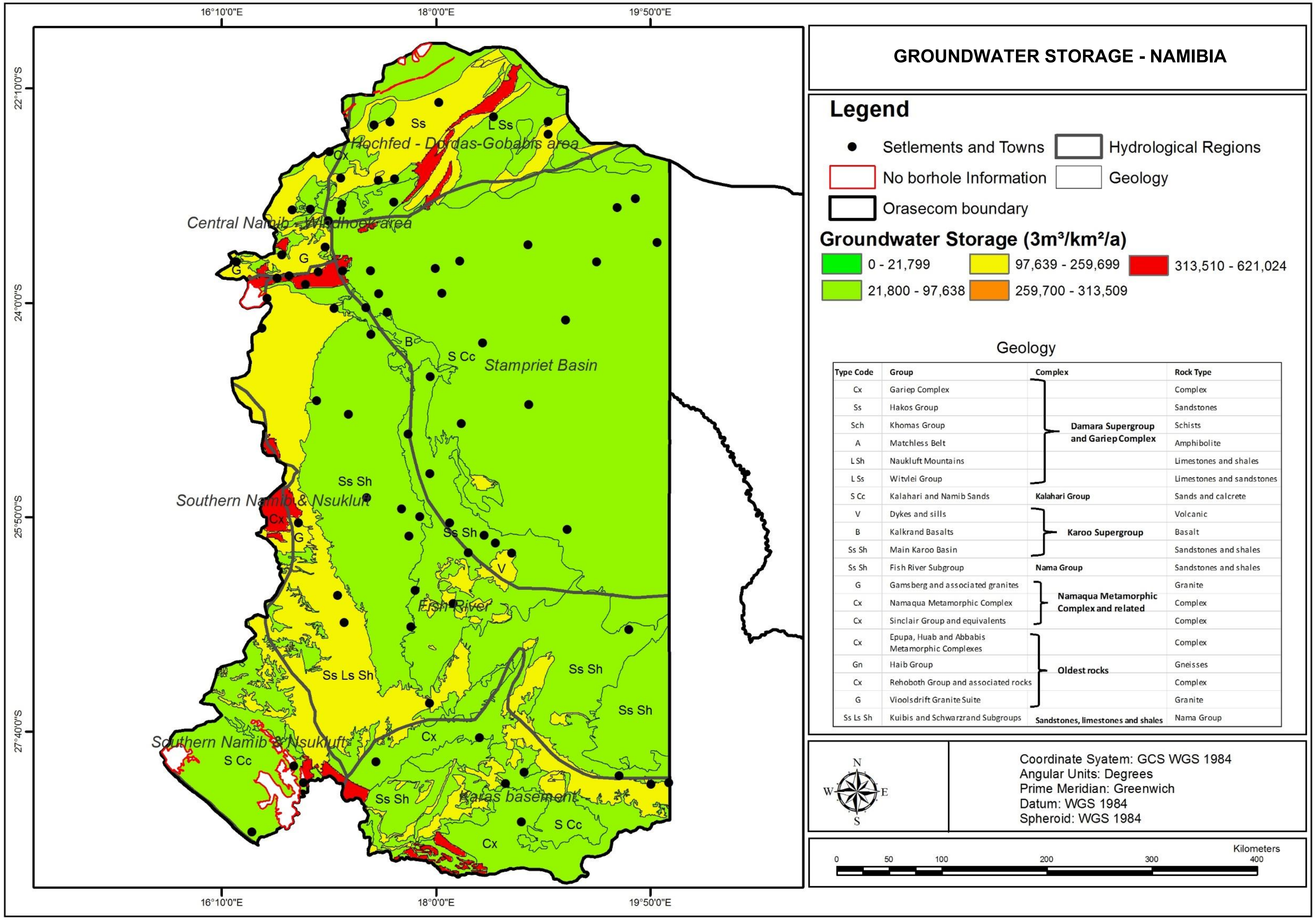


Figure 6-5 Aquifer storage m³/km², Namibia (see entire basin Appendix 16)

6.5 Baseflow

On the Namibian part of the Basin, baseflow was considered as zero.

6.6 Groundwater Resources

6.6.1 Groundwater Resource Potential

Assuming that the upper 5 m (i.e. below the water table) of aquifer storage can feasibly be abstracted over a given period of time, the groundwater resource potential was calculated using eq 1. The volume of water stored in the aquifer was estimated using both the weathered fractured zone storativity.

Groundwater Resource Potential, incorporating recharge, drought index and storage in the upper 5 m of the aquifer is shown in **Figure 6-6** and summarised in **Table 6-4**. Storage is highest in the Kalahari -Namib sands (Stampriet basin) Kuibis and Schwarzrand Subgroups (Fish River- Fish River Aroab Groundwater Basin) and lowest in the Epupa, Huab and Abbabis Metamorphic Complexes (Karas Basement groundwater basin).

6.6.2 Groundwater Exploitation Potential

The feasibility of abstracting the groundwater resource potential is limited by physical attributes of a particular aquifer system, such as permeability, access to drill sites, and economic factors, hence it is not possible to exploit all of the groundwater resource potential. The Groundwater Exploitation Potential, factoring in the probability of drilling successful boreholes (yield of more than 0.83 l/s) in a particular aquifer is shown in **Figure 6-7**. This indicates that the aquifers with the highest groundwater exploitation potential are the Kalahari and Namib Sands, Main Karoo Basin, Kuibis and Schwarzrand Subgroups and Witvlei Group while it is lowest in the Epupa, Huab and Abbabis Metamorphic Complexes, Haib Group, Khomas Group and Vioolsdrift Granite Suite.

6.6.3 Utilisable Groundwater Exploitation Potential

The volume of water that may be abstracted from a groundwater resource may also be limited by anthropogenic and ecological and/or legislative considerations. This can relate to maintaining baseflow, avoiding excessive drawdown etc. The volume that can be sustainably abstracted is referred to as the Utilisable Groundwater Exploitation Potential (UGEP). It was calculated assuming an annual drawdown of 2 m with no recharge and is shown in **Figure 6-8**. Aquifers with the highest utilisable groundwater exploitation potential are the Kalahari and Namib Sands (Stapriet Basin), Fish River Sub-Group, Main Karoo Basin, and Kuibis and Schwarzrand Subgroups. Aquifers with the lowest utilisable groundwater potential being the

Epupa, Huab and Abbabis Metamorphic Complexes, Haib Group, Khomas Group and Vioolsdrift Granite Suite.

6.6.4 Potable Utilisable Groundwater Exploitation Potential

The volume of water that may be abstracted from a groundwater resource may also be limited by groundwater quality, anthropogenic and ecological and/or legislative considerations. They can relate to, providing groundwater which meets certain quality standards. The potable utilisable groundwater exploitation potential (PUGEP) was calculated by multiplying the Utilisable Groundwater Exploitation Potential (UGEP) by the potability index (suitability for human consumption) i.e. the probability of obtaining groundwater with total dissolved solids value of less than 1000 mg/l per as shown in **Figure 6-9**. This indicates that aquifers with highest Potable Utilisable Groundwater Exploitation Potential are Kalahari and Namib Sands (Stampriet Basin) and the Fish River Sub-Group while most the aquifers within the basin have very low potable utilisable groundwater exploitation potential. Aquifers with lowest PUGEP being Namaqua Metamorphic Complex, Dykes and Sills, Epupa, Huab and Abbabis Metamorphic Complexes, Haib Group, Khomas Group and Vioolsdrift Granite Suite.

.

Table 6-4 Groundwater Resources Potential, Namibia

Group	Groundwater Basin	Ex. Factor fraction of BH with Q> 0.83 l/s	Potability Factor (fraction of BH with TDS<1000 mg/l	Potability Factor (Livestock Consumption, fraction of BH with TDS <5000 mg/l	(Average Groundwater Resources Potential) AGRP (m^3/a)	Average Groundwater Exploitation Potential (AGEP, m^3/a)	Utilisable Groundwater Exploitation Potential (UGEP, m^3/a)	Potable Utilisable Groundwater Exploitation Potential (PUGEP, m^3/a)	PUGEP (million m^3/a)	Livestock Groundwater Exploitation Potential (LPUGEP, m^3/a)	LPUGEP, (million m^3/a)
Kalahari and Namib Sands (Stampriet Basin)	Stampriet Basin	0.45	0.12	0.77	32,513,526	14,631,087	6,465,605	775,873	0.78	4,978,516	4.98
Fish River Sub Group	Fish River Aroab	0.38	0.08	0.90	13,032,258	4,952,258	2,106,786	173,160	0.17	1,890,335	1.89
Main Karoo Basin	Stampriet Basin	0.44	0.02	0.65	10,446,315	4,596,379	1,956,460	39,129	0.04	1,271,699	1.27
Kuibis and Schwarzrand Subgroups	Fish River Aroab	0.30	0.01	0.86	13,430,207	4,029,062	1,612,643	16,126	0.02	1,386,873	1.39
Witvlei Group	Hochfeld-Dordabis-Gobabis	0.39	0.03	0.92	2,613,434	1,019,239	463,132	13,894	0.01	426,082	0.43
Sinclair Group and equivalents	Hochfeld-Dordabis-Gobabis	0.42	0.12	0.92	1,288,171	541,032	251,817	30,218	0.03	231,672	0.23
Rehoboth Group and associated rocks	Hochfeld-Dordabis-Gobabis	0.50	0.17	1.00	1,099,392	549,696	243,200	41,344	0.04	243,200	0.24
Namaqua Metamorphic Complex	Karas Basement	0.12	0.03	0.85	4,102,708	492,325	240,941	7,228	0.01	204,800	0.20
Kalkrand Basalts	Stampriet Basin	0.83	0.08	0.83	615,011	510,459	219,991	17,599	0.02	182,593	0.18
Hakos Group	Hochfeld-Dordabis-Gobabis	0.15	0.20	0.90	3,572,124	535,819	206,682	41,336	0.04	1,860,135	1.86
Dykes and sills	Karas Basement	0.22	0.00	1.00	1,626,427	357,814	156,702	0	0.00	156,702	0.16
Gamsberg and associated granites	Hochfeld-Dordabis-Gobabis	0.13	0.13	1.00	1,193,985	155,218	66,744	8,677	0.01	66,744	0.07
Epupa, Huab and Abbabis	Hochfeld-Dordabis-Gobabis	0.00	0.00	1.00	45,910	0	0	0	0.00	0	0.00

Group	Groundwater Basin	Ex. Factor fraction of BH with Q> 0.83 l/s	Potability Factor (fraction of BH with TDS<1000 mg/l	Potability Factor (Livestock Consumption, fraction of BH with TDS <5000 mg/l	(Average Groundwater Resources Potential) AGRP (m³/a)	Average Groundwater Exploitation Potential (AGEP, m³/a)	Utilisable Groundwater Exploitation Potential (UGEP, m³/a)	Potable Utilisable Groundwater Exploitation Potential (PUGEP, m³/a)	PUGEP (million m³/a)	Livestock Groundwater Exploitation Potential (LPUGEP, m³/a)	LPUGEP, (million m³/a)
Metamorphic Complexes											
Khomas Group	Hochfeld-Dordabis-Gobabis	0.00	0.00	1.00	1,282,628	0	0	0	0.00	0	0.00
Haib	Karas Basement	0.00	0.00	1.00	396,108	0	0	0	0.00	0	0.00
Vioolsdrift Granite Suite	Karas Basement	0.00	0.00	1.00	4,147,808	0	0	0	0.00	0	0.00
Matchless Belt	Hochfeld-Dordabis-Gobabis	Unknown	Unknown		116,731				0.00		
Gariep Complex	Southern Namib and Naukluft	Unknown	Unknown		598,380				0.00		
Naukluft Mountains	Southern Namib and Naukluft	Unknown	Unknown		119,634				0.00		
				Total (m³)	92,240,757.36	32,370,387.39	13,990,704.20	1,164,585.47		12,899,351.00	
				Total (Mm³)	92.24	32.37	13.99	1.16	1.16	12.90	12.90

The Average Groundwater Resource Potential (AGRP) for Namibia is given in **Figure 6-6** with the Average Groundwater Exploitation Potential (AGEP, m³/a) in **Figure 6-7**.

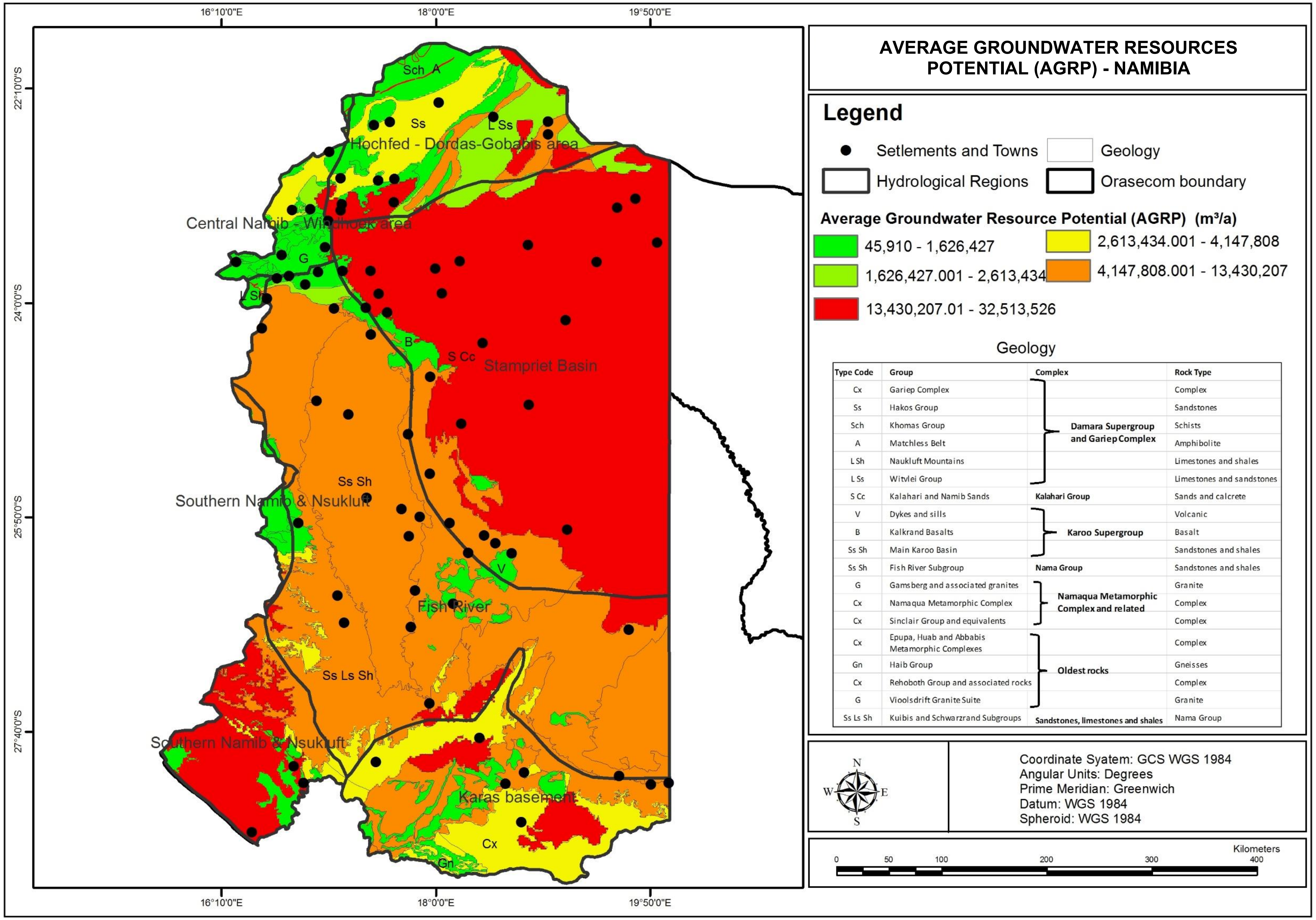


Figure 6-6 Groundwater Resource Potential, Namibia

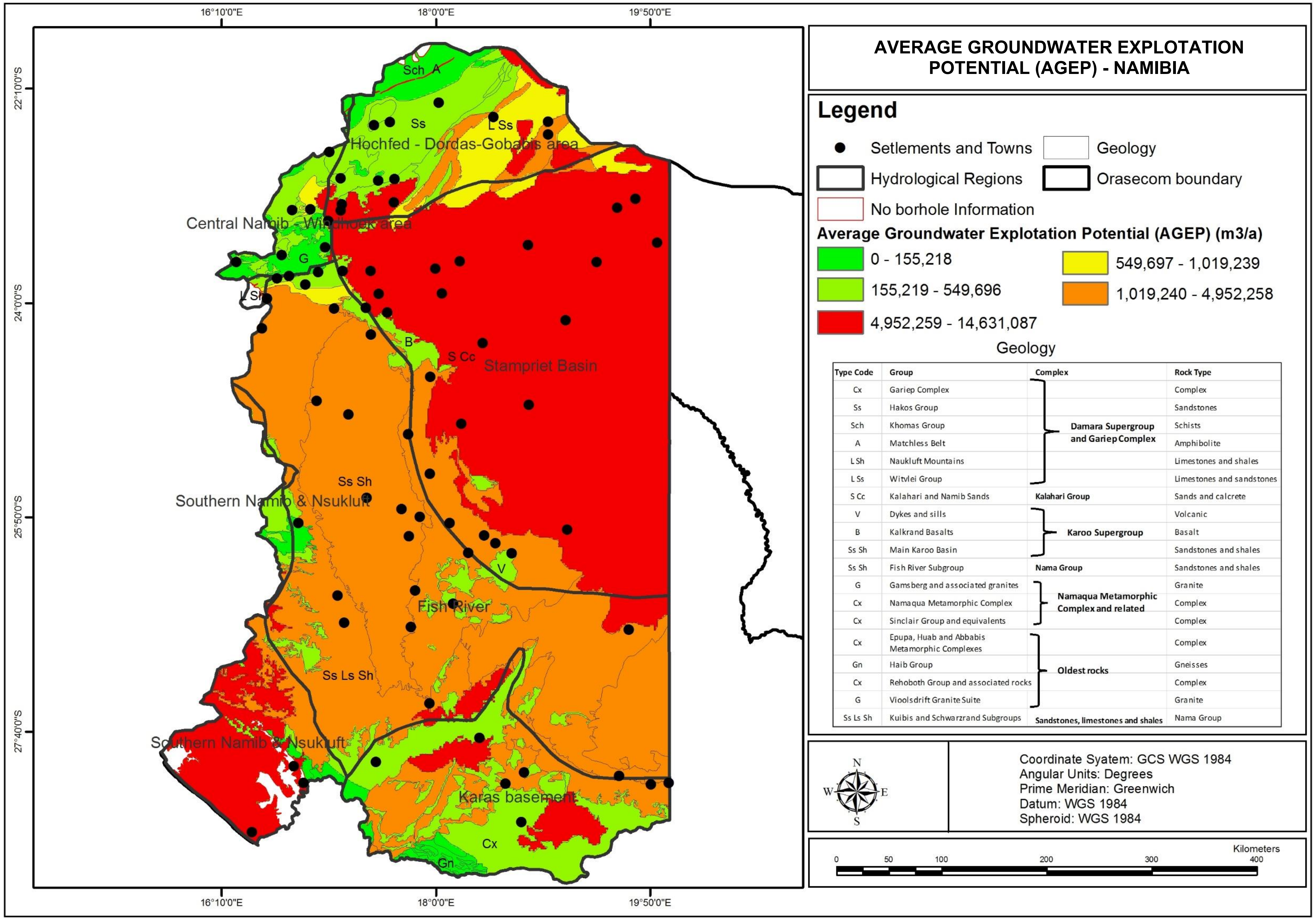


Figure 6-7 Groundwater Exploitation Potential, Namibia

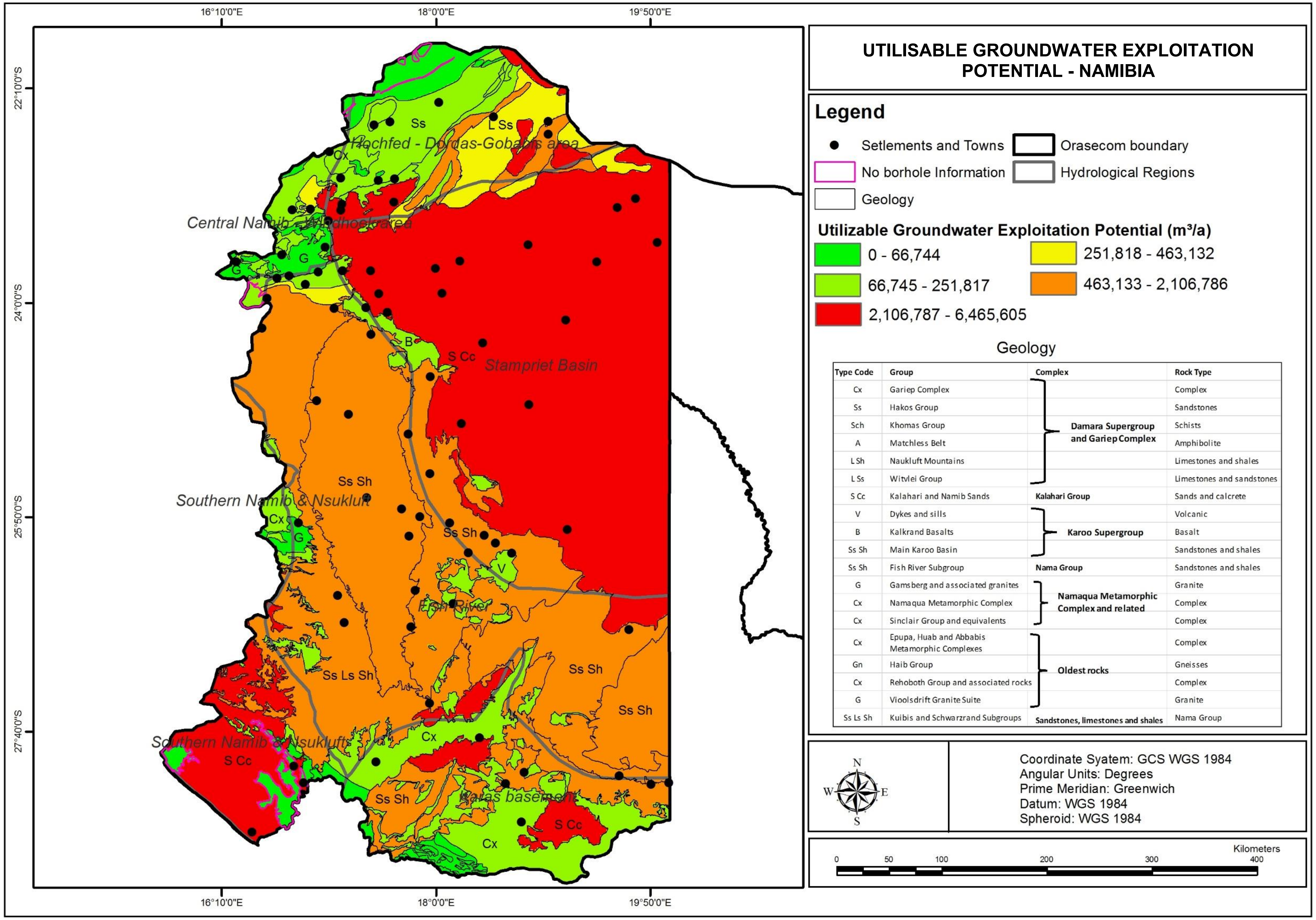


Figure 6-8 Utilisable Groundwater Exploitation Potential, Namibia (see entire basin Appendix 16)

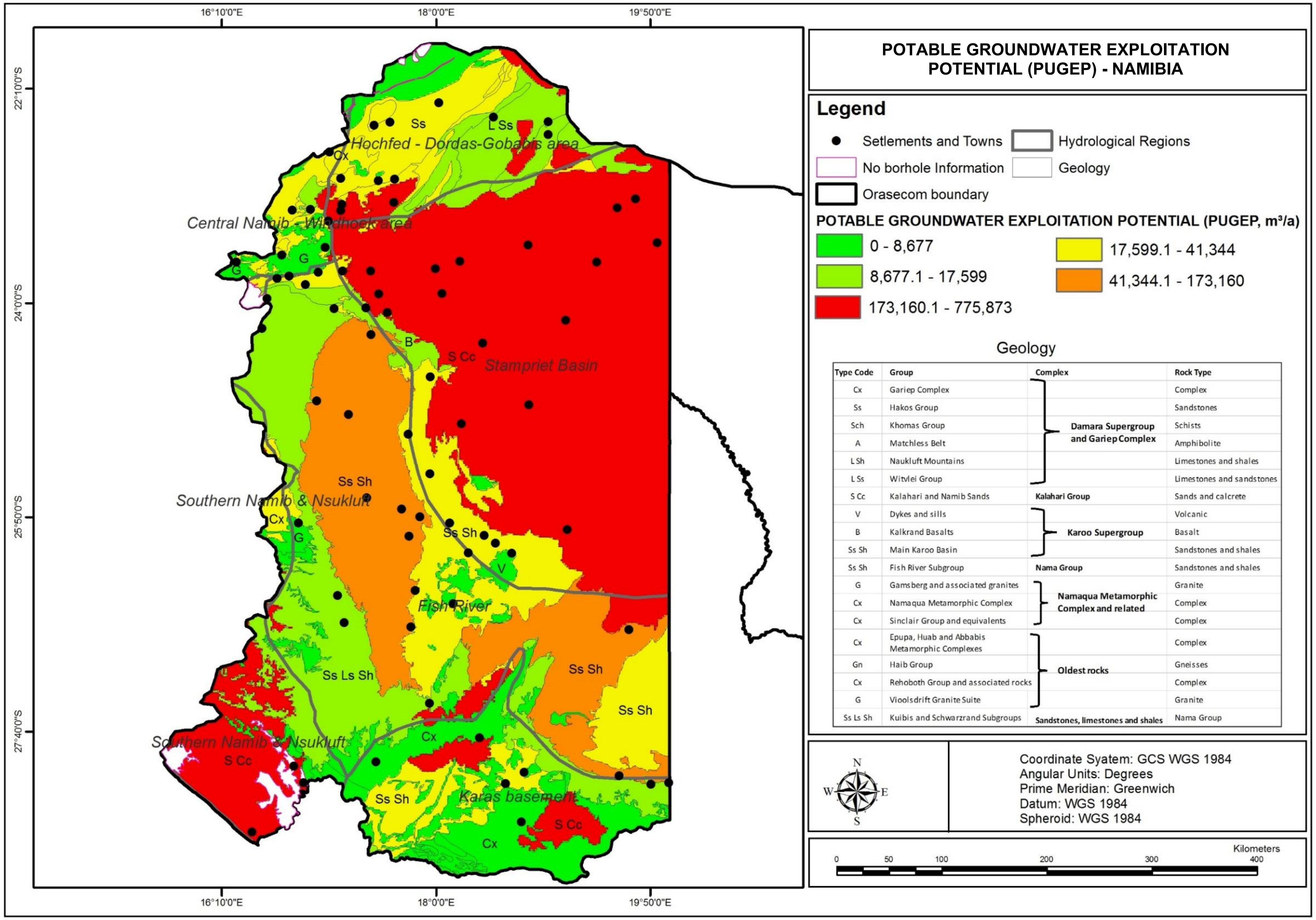


Figure 6-9 Potable Utilisable Groundwater Exploitation Potential, Namibia

6.7 Groundwater Quality

6.7.1 Potability and Livestock standards

Groundwater quality data is available for 1210 boreholes in the form of total dissolved solids (TDS), electrical conductivity, nitrate and fluoride. These data were used to calculate the potability index per Litho-Hydrogeological unit based on the drinking water quality and suitability for livestock consumption i.e. TDS of less than 5000 mg/l.

6.7.2 Total Dissolved Solids

The data indicates that the Total Dissolved Solids (TDS) varies between less than 1000 mg/l to over 15,000 mg/l as shown in **Figure 6-10.** The potability index i.e. percentage of boreholes with groundwater of TDS of less than 1000 mg/l is shown in **Figure 6-11**.

Figure 6-11 indicates that basin is dominated by groundwater which is falls outside the Group A (Excellent Quality) range for potable use in terms of TDS (i.e TDS of less than 1000 mg/l) with potability indices of 0 to 22%. However, most of the groundwater falls within the Group B class water (Good Quality).

Groundwater quality in terms of suitability for livestock water supply (i.e. percentage of boreholes with groundwater of TDS of less than 5000 mg/l) is shown in **Figure 6-12** and indicates that a large part of the basin contains groundwater suitable for livestock consumption in terms of TDS (79 to 100%).

.

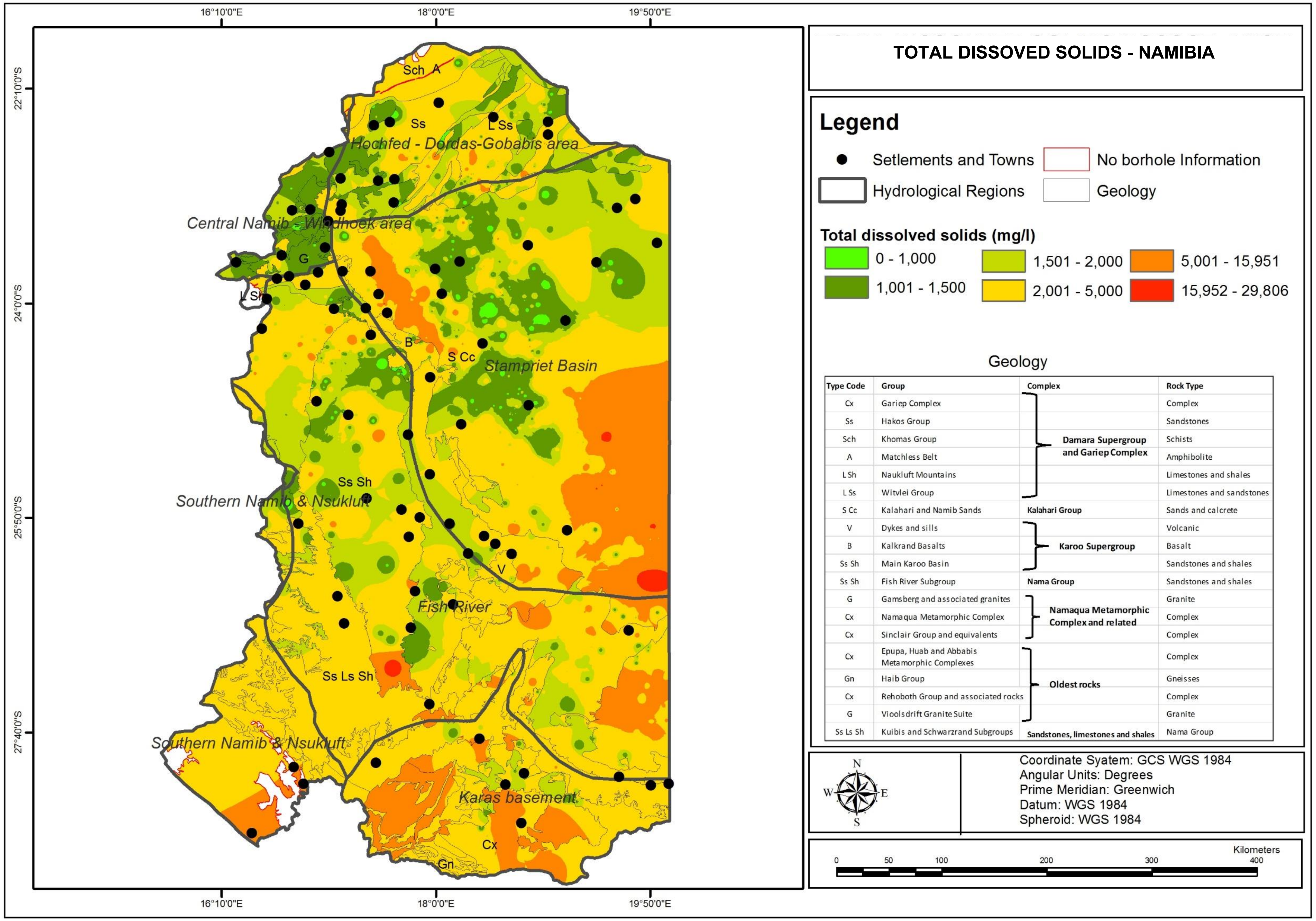


Figure 6-10 TDS Distribution per Groundwater Basin, Namibia

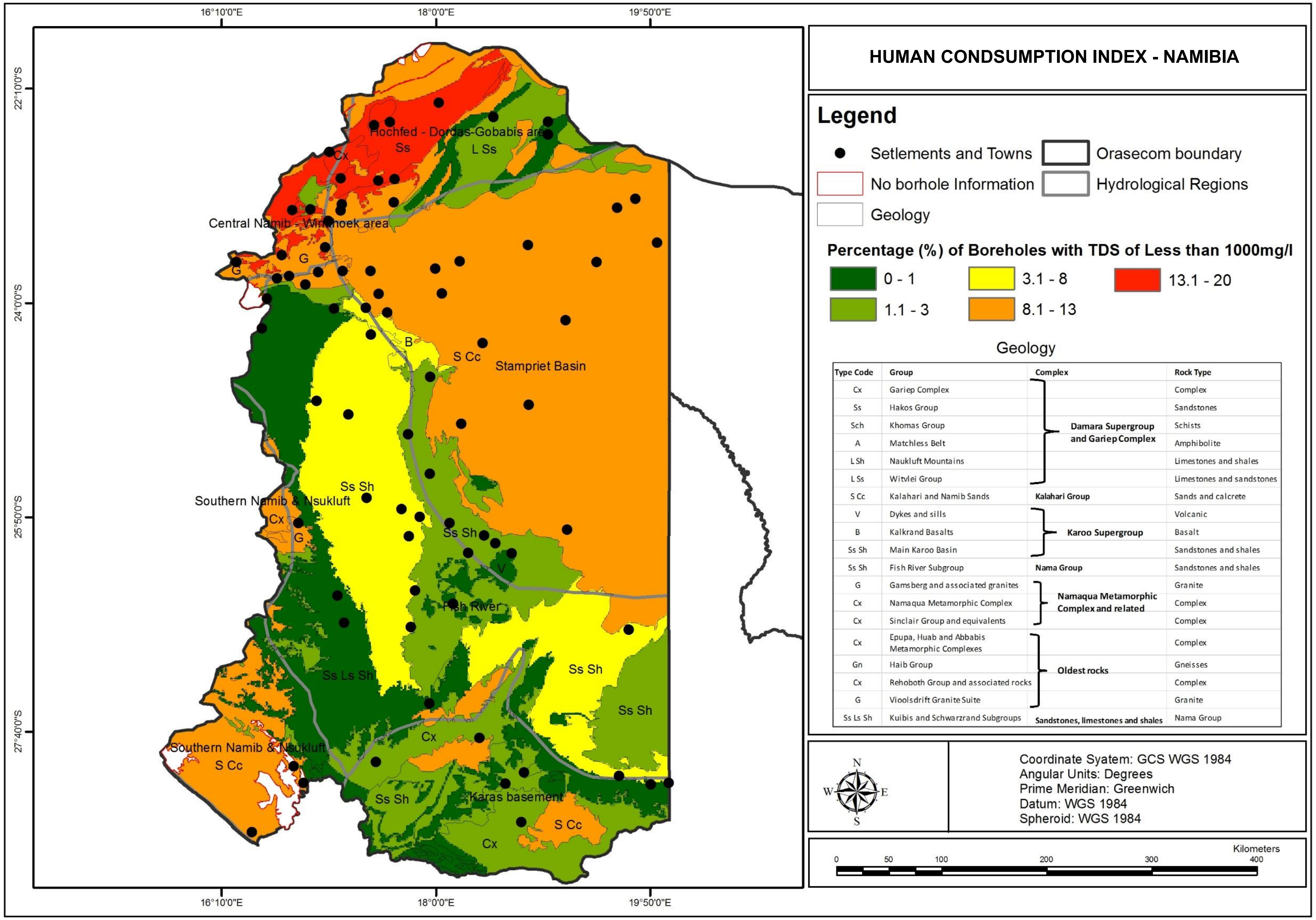


Figure 6-11 Percent of boreholes with groundwater suitable for human consumption, Namibia

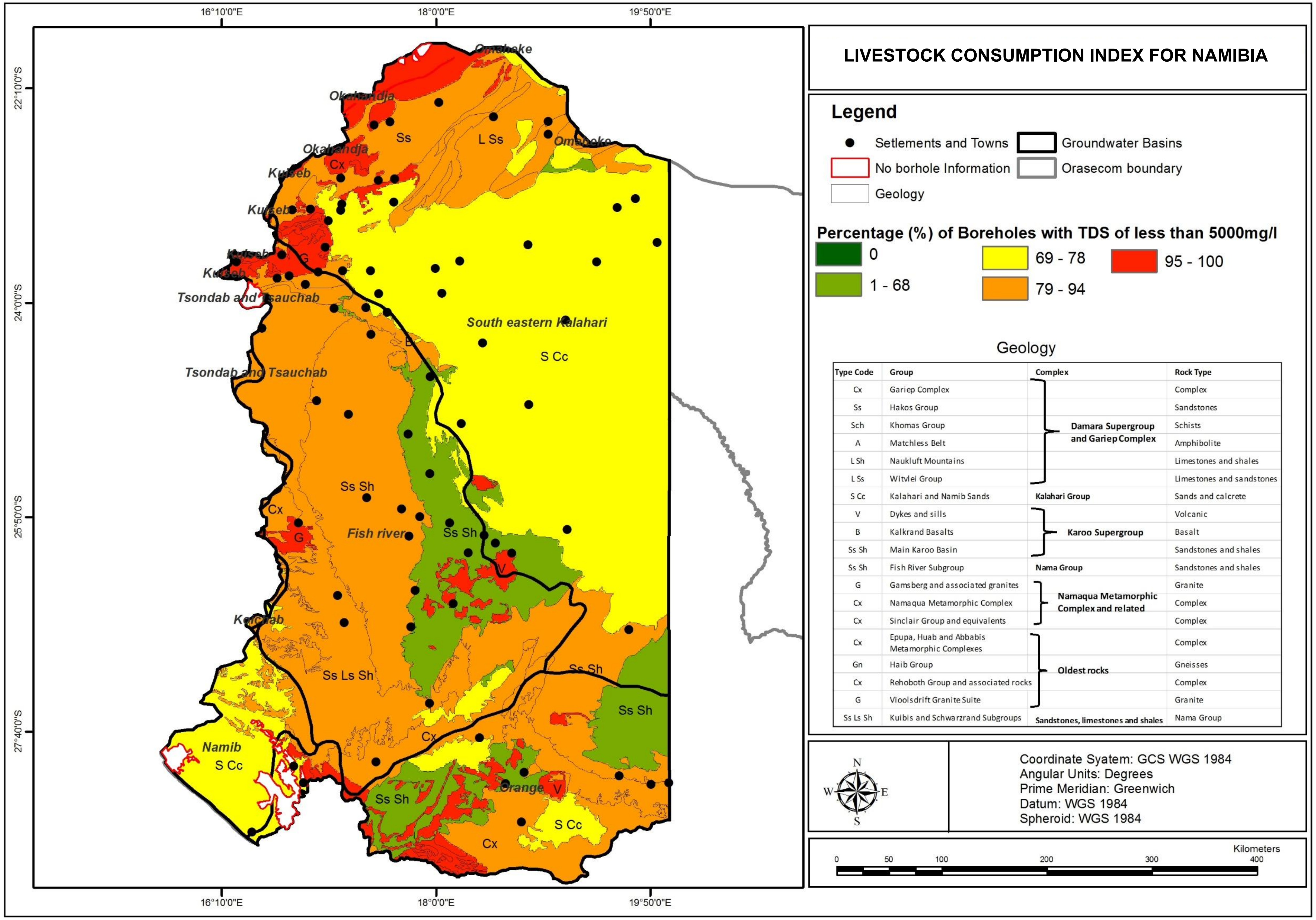


Figure 6-12 Percent of boreholes with groundwater suitable for livestock consumption, Namibia

6.7.3 Nitrates

Figure 6-13 shows the nitrate distribution within each groundwater basin. Elevated nitrates are found throughout the basin with most of the groundwater having nitrates concentration of between 50 to 143 mg/l.

6.7.4 Fluorides

The fluoride concentration within each groundwater basin is shown in **Figure 6-14** indicates that most of the groundwater basins have fluoride concentrations of less than 1.5 mg/l with exception of Karas Basement, Southern Namib and the south-eastern parts of the Stampriet and Fish River Aroab Groundwater basins where elevated fluorides are found.

.

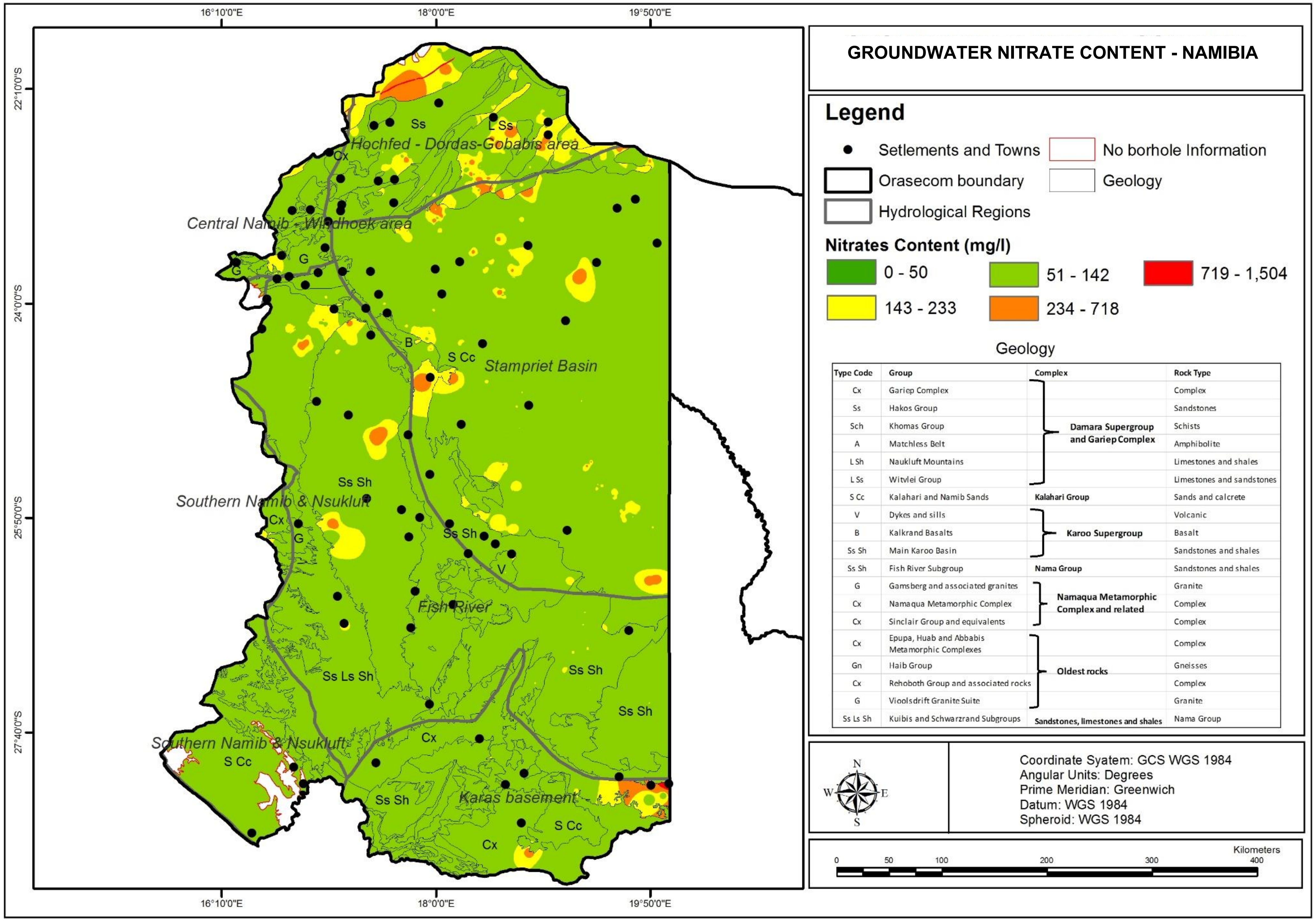


Figure 6-13 Nitrate Distribution, Namibia

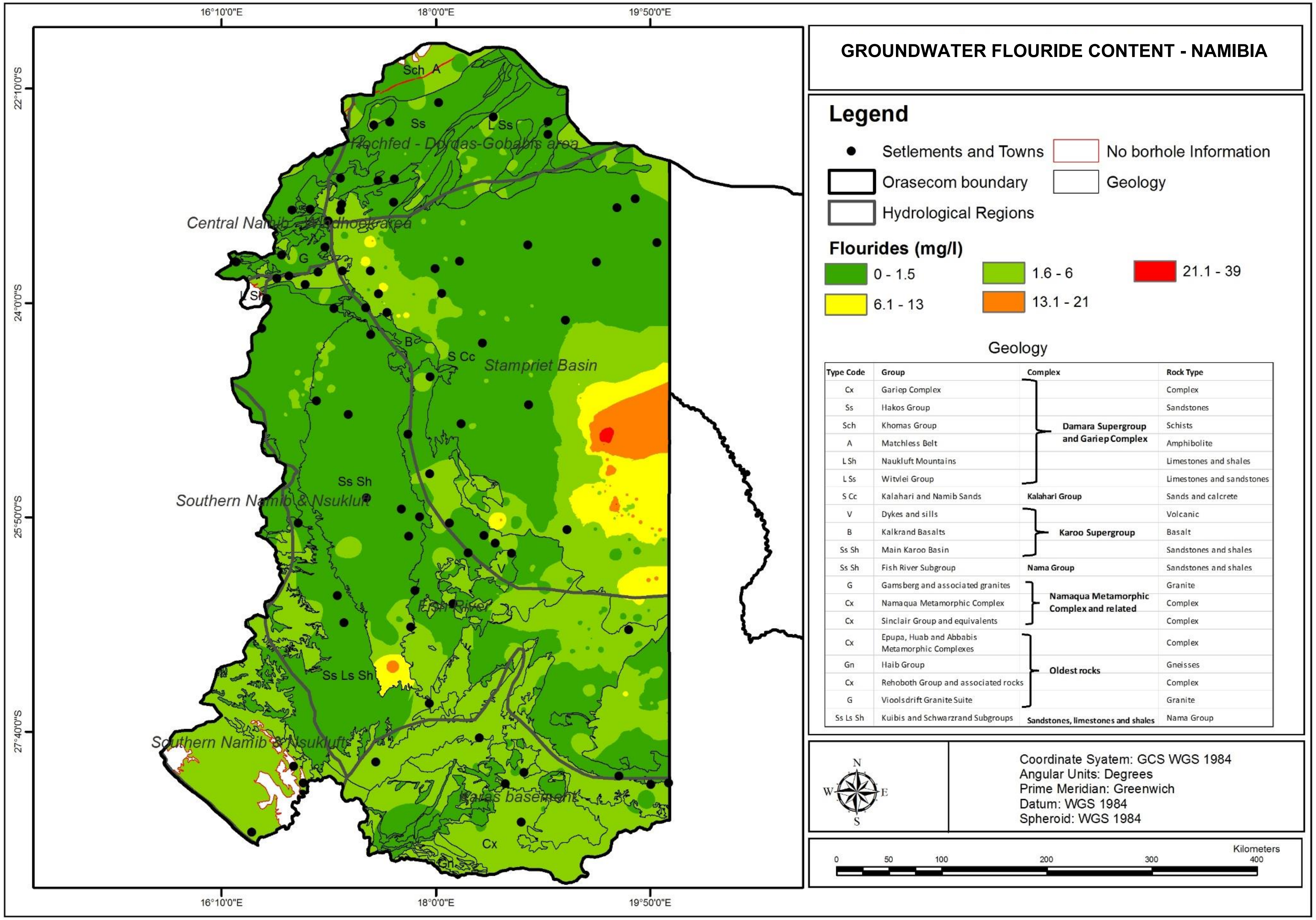


Figure 6-14 Fluoride Distribution, Namibia

6.8 Groundwater Resources Use

Groundwater use data by sector was obtained from the IWRM plan for Namibia (August 2010) as summarised in **Table 6-5**. This data although it is over 10 years old indicates, that total groundwater use in the basin is over 40 million cubic meters per annuum with highest water users being livestock and irrigation respectively.

6.8.1 Water Supply

A large part of the basin is dependent on groundwater supply for municipal and rural supply. Groundwater use data per water supply basin based on data from the IWRM plan for Namibian is shown in **Table 6-5** which indicates relatively low usage compared to livestock and irrigation supply.

6.8.2 Mining and Industrial Use

There is no mining groundwater use in the Namibian part of the basin.

6.8.3 Livestock

The total groundwater use for livestock is estimated to be about 22.5 million cubic meters per annum (IWRM Plan for Namibia) with highest use of 13.1 million m^3 occurring in the Nossob-Auob groundwater supply area which is part of the Stampriet basin.

6.8.4 Irrigation

Irrigation groundwater use in the basin is estimated as 12.95 MCM.

6.8.5 Total Groundwater Use

Total groundwater use is shown in **Table 6-5**.

.

Table 6-5 Groundwater use and resources, Namibia

Litho-Hydrogeological Unit	Groundwater Basin	Water Supply Region	NAMWATER (2008), (m^3)	Adjusted Livestock Demand 2009 (With Losses), (m^3)	Irrigation (2008), (m^3)	Mining (m^3)	Local Authorities (m^3)	Rural Water Supply (m^3)	Total (m^3)
Fish River Sub Group	Fish River Aroab								
Kuibis and Schwarzrand Subgroups	Fish River Aroab								
Dykes and sills	Karas Basement								
Haib	Karas Basement	Orange-Fish	1,098,725	7,630,940	516,000	-	-	374,882	9,620,547
Namaqua Metamorphic Complex	Karas Basement								
Vioolsdrift Granite Suite	Karas Basement								
Main Karoo Basin	Fish River Aroab								
Epupa, Huab and Abbabis Metamorphic Complexes	Hochfeld-Dordabis-Gobabis								
Gamsberg and associated granites	Hochfeld-Dordabis-Gobabis	Nossob-Auob	1,021,456	13,086,017	12,431,400	-	-	647,857	27,186,730
Hakos Group	Hochfeld-Dordabis-Gobabis								

Litho-Hydrogeological Unit	Groundwater Basin	Water Supply Region	NAMWATER (2008), (m^3)	Adjusted Livestock Demand 2009 (With Losses), (m^3)	Irrigation (2008), (m^3)	Mining (m^3)	Local Authorities (m^3)	Rural Water Supply (m^3)	Total (m^3)
Khomas Group	Hochfeld-Dordabis-Gobabis								
Matchless Belt	Hochfeld-Dordabis-Gobabis								
Rehoboth Group and associated rocks	Hochfeld-Dordabis-Gobabis								
Sinclair Group and equivalents	Hochfeld-Dordabis-Gobabis								
Witvlei Group	Hochfeld-Dordabis-Gobabis								
Kalahari and Namib Sands (Stapriet Basin)	Stampriet Basin								
Kalkrand Basalts	Stampriet Basin								
Gariep Complex	Southern Namib and Naukluft	Tsondab-Koichab	1,372,668	1,794,796	-	-	-	26,171	3,193,635
Naukluft Mountains	Southern Namib and Naukluft								
		Grand Total	**3,492,849**	**22,511,753**	**12,947,400**	**0**	**0**	**1,048,910**	**40,000,912**

Table 6-6: Groundwater Resource Potential, Namibia

Litho-Hydrogeological Unit	Groundwater Basin	Water Supply Region	Total use (MM^3/a)	Recharge (MM^3/a)	Groundwater Exploitation Potential (MM^3/a)	Potable Utilisable Groundwater Exploitation Potential (Mm^3/a)	Allocable Potable Resource	Livestock Groundwater Exploitation Potential (LPUGEP, m^3/a)
Fish River Sub-Group	Fish River Aroab	Orange-Fish	9.62	12.19	14.43	0.24	-9.38	4.91
Kuibis and Schwarzrand Subgroups	Fish River Aroab							
Dykes and sills	Karas Basement							
Haib	Karas Basement							
Namaqua Metamorphic Complex	Karas Basement							
Vioolsdrift Granite Suite	Karas Basement							
Main Karoo Basin	Fish River Aroab							
Epupa, Huab and Abbabis Metamorphic Complexes	Hochfeld-Dordabis-Gobabis	Nossob-Auob	27.19	13.16	17.95	0.93	-26.25673	7.99
Gamsberg and associated granites	Hochfeld-Dordabis-Gobabis							
Hakos Group	Hochfeld-Dordabis-Gobabis							
Khomas Group	Hochfeld-Dordabis-Gobabis							
Matchless Belt	Hochfeld-Dordabis-Gobabis							
Rehoboth Group and associated rocks	Hochfeld-Dordabis-Gobabis							
Sinclair Group and equivalents	Hochfeld-Dordabis-Gobabis							
Witvlei Group	Hochfeld-Dordabis-Gobabis							
Kalahari and Namib Sands (Stapriet Basin)	Stampriet Basin							
Kalkrand Basalts	Stampriet Basin							

Litho-Hydrogeological Unit	Groundwater Basin	Water Supply Region	Total use (MM^3/a)	Recharge (MM^3/a)	Groundwater Exploitation Potential (MM^3/a)	Potable Utilisable Groundwater Exploitation Potential (Mm^3/a)	Allocable Potable Resource	Livestock Groundwater Exploitation Potential (LPUGEP, m^3/a)
Gariep Complex	Southern Namib and Naukluft	Tsondab-Koichab	3.19	0.2		Unknown	Unknown	Unknown
Naukluft Mountains	Southern Namib and Naukluft							

Litho-Hydrogeological Unit	Total Estimated Livestock (Cattle, Sheep and Goats) Use (MM^3/a)	Total Use Domestic Use (MM^3/a)	Total use (MM^3/a)	Recharge (MM^3/a)	Groundwater Exploitation Potential (MM3/a)	Potable Utilisable Groundwater Exploitation Potential (Mm^3/a)	Allocable Potable Resource (MM^3/a)
Dykes and sills				0.48	0.36	0.00	
Epupa, Huab and Abbabis Metamorphic Complexes				0.02	0.00	0.00	
Fish River Sub Group				3.67	4.95	0.17	
Gamsberg and associated granites				0.34	0.16	0.01	
Gariep Complex				0.17	Unknown	Unknown	
Haib				0.11	0.00	0.00	
Hakos Group				0.83	0.54	0.04	
Kalahari and Namib Sands (Stampriet Basin)				9.83	14.63	0.78	

Litho-Hydrogeological Unit	**Total Estimated Livestock (Cattle, Sheep and Goats) Use (MM^3/a)**	**Total Use Domestic Use (MM^3/a)**	**Total use (MM^3/a)**	**Recharge (MM^3/a)**	**Groundwater Exploitation Potential (MM3/a)**	**Potable Utilisable Groundwater Exploitation Potential (Mm^3/a)**	**Allocable Potable Resource (MM^3/a)**
Kalkrand Basalts				0.18	0.51	0.02	
Khomas Group				0.37	0.00	0.00	
Kuibis and Schwarzrand Subgroups				3.36	4.03	0.02	
Main Karoo Basin				2.95	4.60	0.04	
Matchless Belt				0.00	Unknown	Unknown	
Namaqua Metamorphic Complex				1.48	0.49	0.01	
Naukluft Mountains				0.03	Unknown	Unknown	
Rehoboth Group and associated rocks				0.33	0.55	0.04	
Sinclair Group and equivalents				0.43	0.54	0.03	
Vioolsdrift Granite Suite				0.14	0.00	0.00	
Witvlei Group				0.83	1.02	0.01	

6.9 Groundwater Stress Index

Groundwater use is more meaningful when assessed relative to available groundwater resources. The best measure of groundwater resources is aquifer recharge; hence a stress index is defined as groundwater use relative to aquifer recharge (Groundwater stress index). A groundwater stress index for the Namibian part of the basin) is given in **Figure 6-15** and indicates that groundwater in the Namibian part of the basin is highly stressed or critically over abstracted.

6.10 Remaining Allocable Groundwater resources

The remaining allocable groundwater resources was calculated as the Potable Utilisable Groundwater Exploitation Potential minus current water use and is shown **Table 6-5**. This indicates the majority of the basin has very little scope for further development of potable groundwater resources.

6.11 Aquifer Vulnerability

Aquifer vulnerability according to the DRASTIC index is shown in **Figure 6-16** and indicates that the majority of the basin has insignificant to low groundwater pollution vulnerability**.**

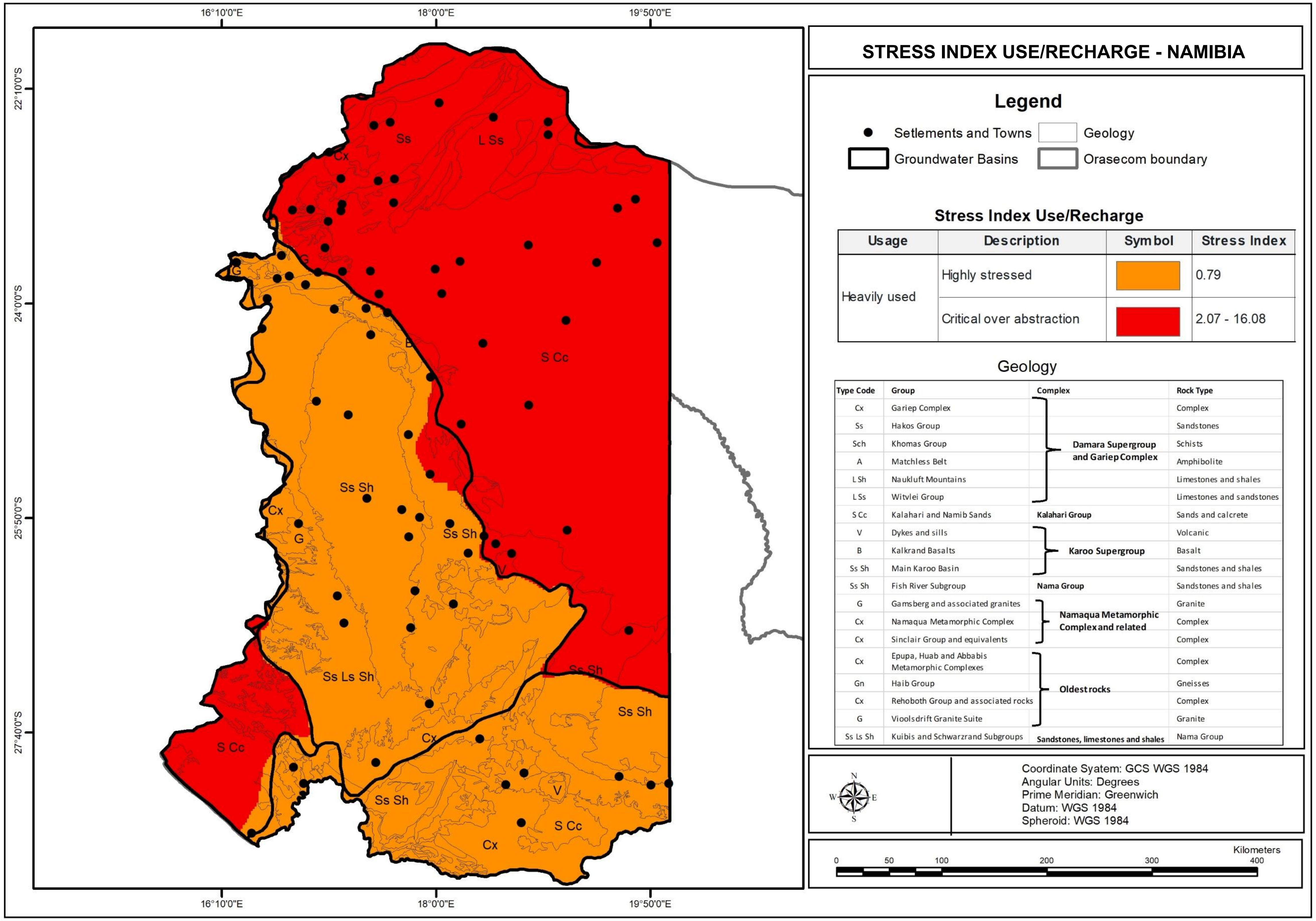


Figure 6-15 Stress Index, Namibia

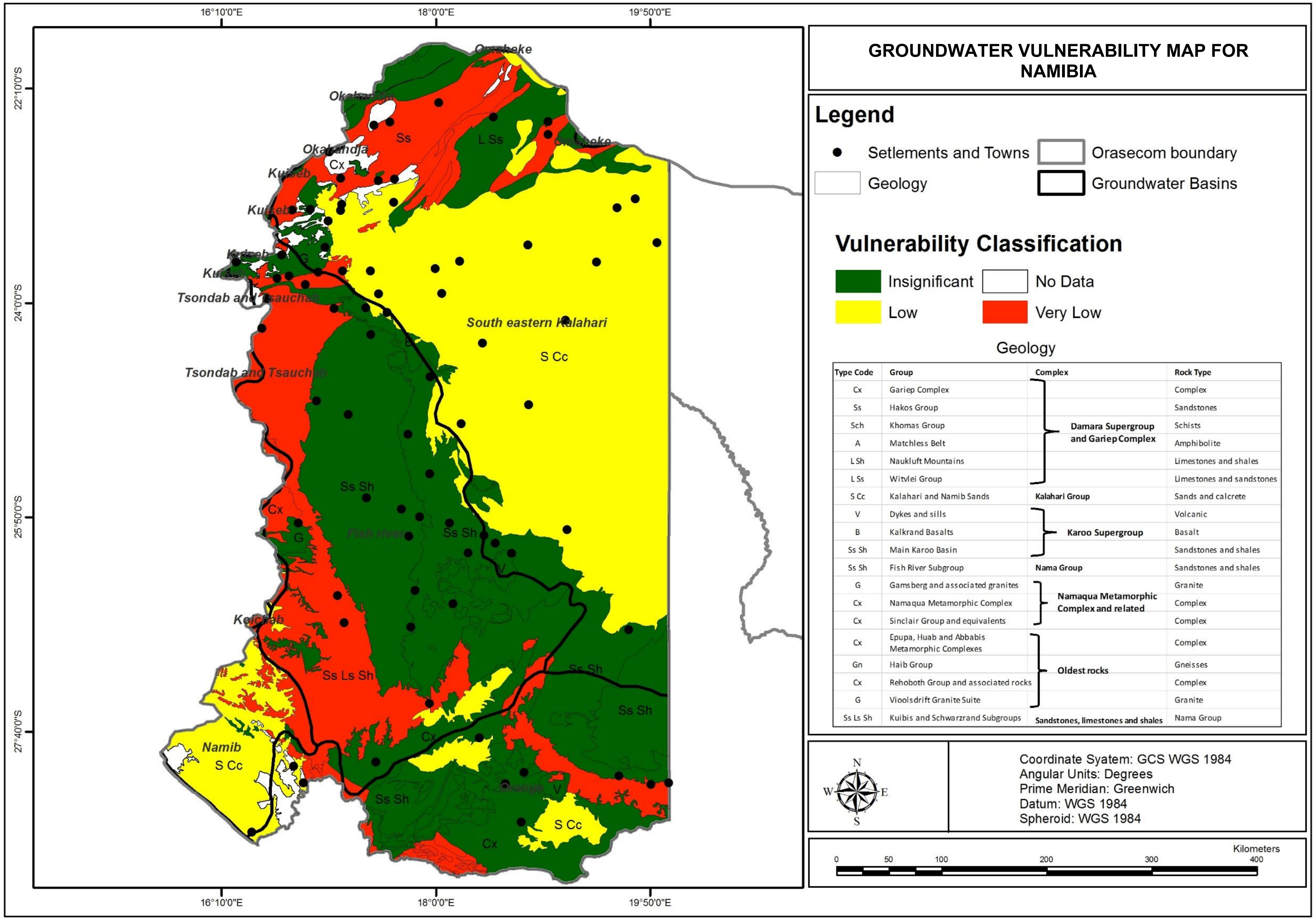


Figure 6-16 Groundwater Pollution Vulnerability Map, Namibia (see entire basin Appendix 16)

7 SUMMARY AND CONCLUSIONS

The objective of the Groundwater Report is the Quantification and mapping of potential groundwater volumes that could be considered in the core scenario, either for new developments or for substitution of surface water resources to obtain an improved utilization of groundwater in the basin.

7.1 Data Limitations

There is a significant discrepancy in how the individual countries collect data, which complicates cross-border mapping and results in 'edge effects' at borders, or different classification. These problems can be summarised as:

- The National geological maps are based surficial geology in South Africa, Namibia and Lesotho, and on sub-Kalahari Basement in Botswana
- The same geological formations have different names across borders, and boundaries do not always align
- Borehole data coverage is dense in South Africa and Namibia, and sparse in Lesotho (Figure 7-1), where it is concentrated in the Lowlands, and the western portion of Botswana, making statistical characterisation difficult
- Low yielding boreholes do not appear to be incorporated into the Botswana and Lesotho databases, resulting in average and median yields being skewed towards higher yields, and resulting in discontinuities at borders
- South Africa manages groundwater based on groundwater management units, which are based quaternary catchment boundaries, with the exception of the dolomites. Lesotho and Botswana define aquifers based on lithology, and Namibia utilises groundwater drainage basins.
- Groundwater recharge, and consequently exploitation potential methodologies vary across borders resulting in cross border 'edge effects. In South Africa, recharge as based on nation wide based on the Chloride method during the GRAII study. This was modified in the Lower Orange due to underestimation in naturally saline environments. In Lesotho, the results from GRAII were a large over estimate, which the Chloride Method tends to do in areas with high surface runoff. These were corrected and calibrated against baseflow volumes during ORASECOM (2018). The Namibia and Botswana recharge estimates are national planning values, that seem lower than South African values across the border.

- Multi-layered aquifers like the Stampriet between Botswana, Namibia and South Africa, and the Eastern and Western Kalahari region between South Africa and Botswana are multi-layered aquifers. South Africa considers the upper Kalahari as a leaky weathered zone, and as a porous weathered zone aquifer in the Stampriet basin. Botswana and Namibia to do utilise the Kalahari, hence map the underlying fractured aquifer. This results in discrepancies in storage and yield estimates
- The quantification of groundwater use remains to be a problem. Problems found are that groundwater use is recorded as licenced use rather than an actual use, many groundwater users are not recorded, rural water use is undocumented and needs to be estimated.

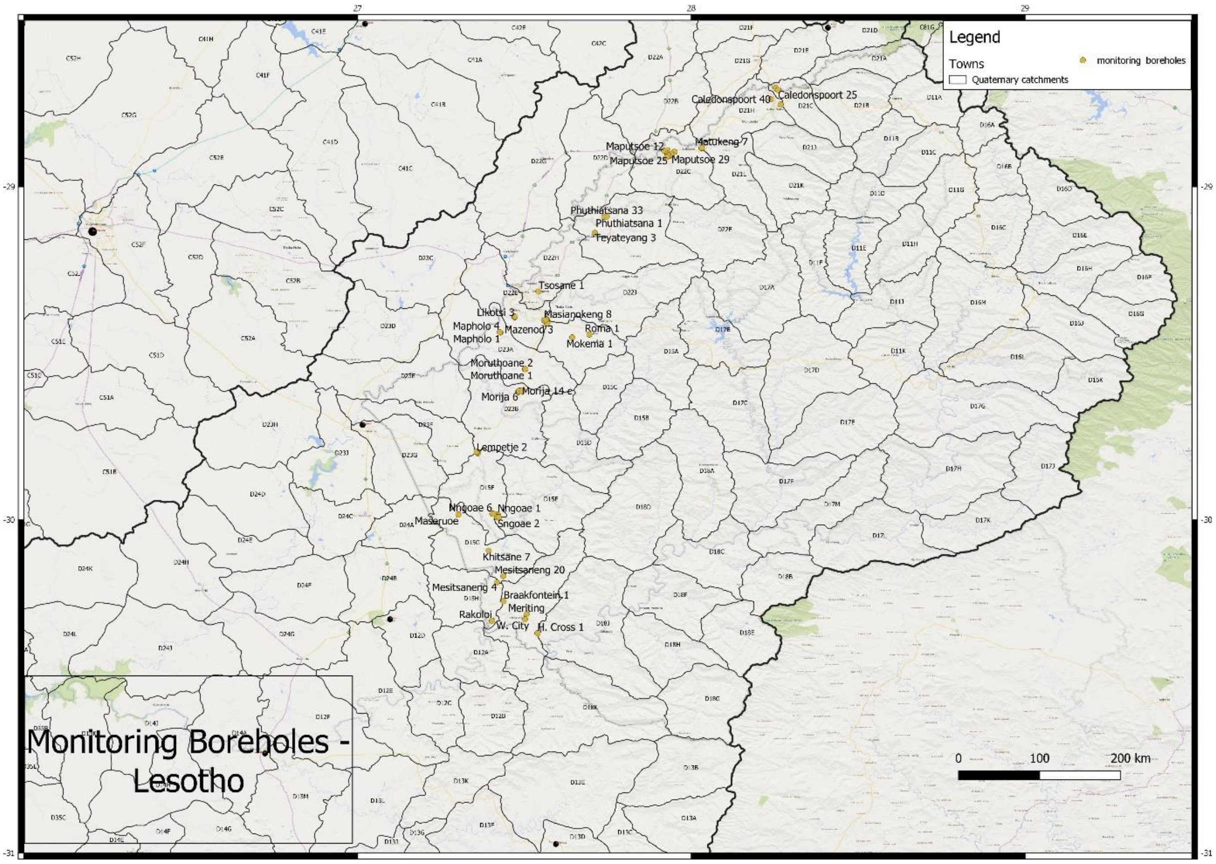


Figure 7-1 Borehole monitoring network in Lesotho

7.2 Summary

- Large errors were found in aquifer storage estimates in the South Africa GRAII database, which have been revaluated.
- The baseflow utilised when calculating groundwater resources for GRAII was only the groundwater baseflow component and ignored the significant loss of recharge to the

interflow component, resulting in large errors in the groundwater balance. The Average Groundwater Resource Potential was recalculated

- The study found that recharge estimates for the arid regions of South Africa and for Lesotho had large errors, since they cannot be reconciled with the water balance. Revised groundwater recharge was developed for the ORASECOM Transboundary project which are calibrated against the water balance. These were used to recalibrate the hydrology including surface-subsurface interactions. These were utilised for this study.
- The Upper Vaal is also a major source of baseflow. Currently no calibrated hydrology including interactions between groundwater and surface water exists for this important basin
- Groundwater resources are highly stressed in the Lower Orange basin, and the Middle to lower Vaal (**Figure 4-31**).
- The largest volume of remaining allocable groundwater can be found in the Karst aquifers of the Ghaap Plateau in South Africa. A map of current utilisable Groundwater Exploitation Potential, which accounts for current use, is shown in **Figure 4-34.** It indicates the remaining groundwater resources per Quaternary catchment
- In the upper reaches of the Vaal and Orange-Senqu basins, groundwater abstraction can have a moderate to high impact on baseflow. This suggests that the impact of future allocations on baseflow need to be investigated prior to large scale allocations. This impact can have a cumulative impact further down the basin.
- The Botswana part of the basin is largely underlain by relatively moderately yielding aquifers with about 13% of the basin underlain by aquifers with a productivity index of more than 60%. The most productive aquifers are found in Ecca North (Stampriet basin), Archaen Amphibolites East, Lower Transvaal North and Ecca East
- In terms of suitability for human consumption (TDS <1000 mg/L) again a large part of the basin is underlain by aquifers with groundwater which is not suitable for human consumption without treatment with about 12% of the basin yielding groundwater which is 60% to 100 % suitable for human consumption. Groundwater with the highest potability index is predominantly found in the basement aquifers (78 to 100%), Upper Transvaal East (80%), Lower Transvaal South (77% and Ecca North (72%) with the lowest potability groundwater found in Dwyka North (11% and Ecca South (0.04%).
- Aquifers with highest potable utilisable groundwater exploitation potential (PUGEP) are Ecca North, Lebung and Lower Transvaal South

- Majority of the basin with exception Ecca North, Lower Transvaal South, Upper Transvaal East and Lebung hydrogeologic units have very little scope for further development of potable groundwater resources
- Areas underlain by Archean Gneiss (Goodhope water supply area) and the Olifanthoek North (Tsabong water supply area) are being over abstracted i.e. high to heavily used.
- The Namibian part of the basin is largely underlain low yielding aquifers with most boreholes having yields of less than 1 l/s.
- The Namibian part of the basin is dominated by groundwater which is not suitable for potable use without treatment in terms of TDS (i.e TDS of less than 1000 mg/l) with potability indices of 0 to 22%. However, a large part of the basin contains groundwater suitable for livestock consumption in terms of TDS (79 to 100%).
- Elevated nitrates are found in groundwater throughout the basin in Namibia
- Data indicates that for the majority of the Namibian part of the basin there is little scope for development of large-scale groundwater use schemes for potable use. However, a large part of the basin has potential for development of groundwater for livestock water use

7.3 Conclusions

The flowing conclusions can be drawn, which have implications for the Core Scenario.:

South Africa

- Large volumes of groundwater (high CUGEP) are available in the South-eastern Highveld, Ghaap Plateau, Western Highveld, Eastern Upper Karoo, Central Highveld, South Eastern Highland, and Northeastern Pan Belt (**Figure 4-34**).
- Only in the Ghaap Plateau and the dolomites near Mafikeng do sufficient boreholes yield greater than 2 l/s to warrant economical abstraction. The dolomitic compartment near Mafikeng is known as the Grootfontein/Molopo dolomitic compartment (**Figure 7-1)**.

Lesotho

- The Drakensberg Highlands consist of a fractured aquifer of low storage potential, although recharge is high, most is lost as interflow feeding and is not available to boreholes tapping the regional aquifer. In addition, they contribute to groundwater baseflow, hence abstraction would have a significant impact on baseflow
- The Northeastern Highlands GW Region (Lesotho Lowlands) have a somewhat higher percentage of high yielding boreholes and more aquifer storage than the southeastern

highlands. Locally, the Northeastern Highland region is moderately stressed by existing abstraction.

Namibia and Botswana

- Namibia suffers from the over exploitation of groundwater resources and yields are low.
- Groundwater has a TDS greater than 1000 mg/l. Elevated nitrates occur throughout the basin.
- In Bostwana. yigh yields warrant local development of groundwater. The most readily exploitbale aquifers are found in Ecca North (Stampriet basin), Archaen Amphibolites East, Lower Transvaal North and Ecca East.
- The highest CUGEP is found in Ecca North, Lebung and Lower Transvaal South (**Figure 7-1)**. The Ecca North is a transboundary aquifer shared with Namibia (Stampriet Basin), and the Lower Transvaal South is a dolomitic transboundary aquifer shared with South Africa (Khakea-Bray aquifer). Both these transboundary aquifers are heavily utilised across the border
- A large part of the basin in Botswana is underlain by aquifers with groundwater of TDS greater than 1000 mg/l, with about 12% of the basin yielding groundwater which is 60% to 100 % suitable for human consumption.

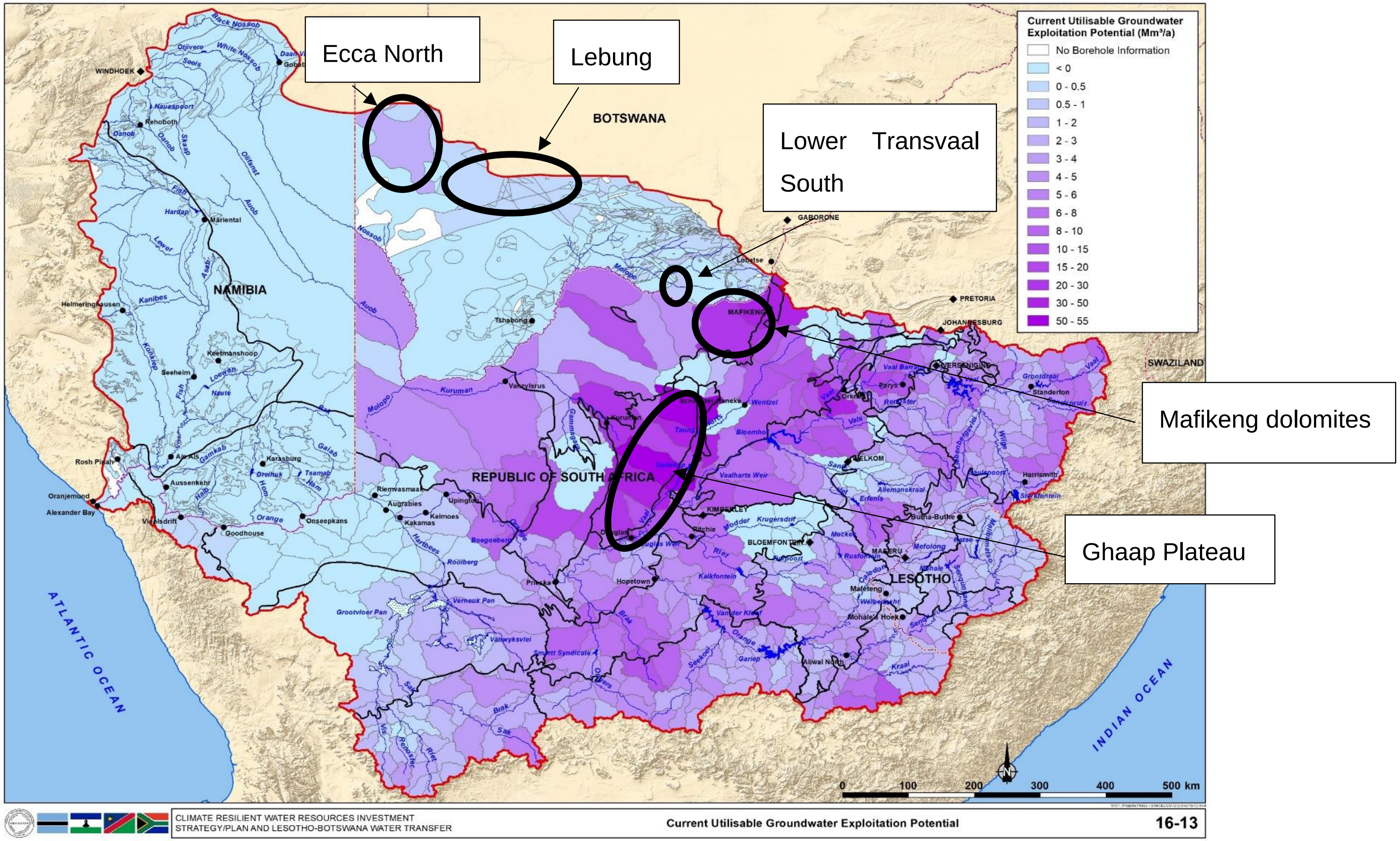


Figure 7-2 Potential zones for large scale groundwater development

8 REFERENCES

Department of Water Affairs, Botswana, 2008 Matsheng Groundwater Development Project, Final Report, Prepared Water Resources Consultants, Botswana

Department of Water Affairs Namibia, Ministry of Agriculture, Water and Rural Development, the Geological Survey of Namibia, Ministry of Mines and Energy; the Namibia Water Corporation and the Federal Institute for Geoscience and Natural Resources Germany, First edition December 2001, Unrevised second edition January 2011, Groundwater in Namibia an explanation to the Hydrogeological Map

Department of Water and Sanitation, South Africa, October 2016. Determination of Ecological Water Requirements for Surface water (river, estuaries and wetlands) and Groundwater in the Lower Orange WMA. Groundwater EWR report. Prepared by: WSM Leshika Consulting (Pty) Ltd.. DWS Report No: RDM/WMA06/00/CON/COMP/0416.

Department of Water Affairs and Forestry (DWAF). 2006. Groundwater Resource Assessment Phase II (GRA II): Task 1D Groundwater Quantification. Version 2: Final. Prepared by DWAF, SRK, GEOSS and CSIR. Project 2003-150.

Department of Water Affairs and Forestry (DWAF). 2006. Groundwater Resource Assessment Phase II (GRA II): Task 2C Groundwater Planning Potential Version 1: Final. Prepared by CSIR, SRK, GEOSS and CSIR. Project 2003-150.

Department of Water Affairs and Forestry (DWAF). 2006. Groundwater Resource Assessment Phase II (GRA II): Task 3b. Groundwater Surface water Interaction Version 1: Final. Prepared by WSM Leshika. Project 2003-150.

Department of Water Affairs and Forestry (DWAF), South Africa. 1996b. South African water quality guidelines. Volume 1: Domestic Use.

Department of Water Affairs and Forestry (DWAF). 1998. Quality of Domestic Water Supplies. Volume 1: Assessment Guide. Second Edition. Water Research Commission No: TT 101/98.

http://www.the-eis.com/ Namibia's One-Stop Shop for Environmental Information. Supported by Namibian Chamber of Environment

IWRM PLAN FOR NAMIBIA, The Assessment of Resources Potential and Development Needs (August 2010)

Japan International Cooperation Agency - JICA (2002). The Study on the Groundwater Potential Evaluation and Management Plan in the Southeast Kalahari (Stampriet) Artesian Basin in the Republic of Namibia – Final Report

ORASECOM, March 2018. Groundwater Recharge in the Karoo Sedimentary and Khakhea/Bray Dolomitic Aquifers. Prepared by: WSM Leshika Consulting (Pty) Ltd.. Report No 002/2018.

ORASECOM 010/2010. Joint Basin Survey-1. Setting the baseline water resources quality in 2010

ORASECOM 005/2009 Groundwater Review of the Molopo-Nossob Basin for Rural Communities Including Assessment of National Databases at the Subbasin Level for Possible Future Integration Report No. ORASECOM/005/2009, Geotechnical Consulting Services (Pty) Ltd In Association With Continental Consultants (Pty) Ltd, July 2009

ORASECOM, 2008. Preliminary Transboundary diagnostic Analysis, Orange-Senqu River basin. April, 2008 20) ORASECOM 006/2009. Feasibility Study of the Potential for Sustainable Water Resources Development in the Molopo-Nossob Watercourse. Groundwater Report. ORASECOM. Report No: 006/2009

ORASECOM 004/2007. Review of Groundwater Resources in the Orange River Catchment. Report No. ORASECOM 004/2007

Review of Groundwater Resources in the Orange River Catchment, 2007, Prepared by WRP Consulting Engineers, Jeffares and Green, Sechaba Consulting, WCE Pty Ltd, Water Surveys Botswana (Pty) Ltd

SADC, 2009. Transboundary Water Management in SADC Orange-Senqu River Awareness Kit (OS-RAK). Final Report

Stampriet, Transboundary Aquifer Assessment, Governance of Groundwater Resources in Transboundary Aquifers (GGRETA) - Phase 1, Technical Report, 2016, Prepared by the International Hydrological Programme of the United Nations Educational, Scientific and Cultural Organization

Statistics Botswana, 2015**,** Botswana Agricultural Census Report

UNDP/GEF. 2008. Preliminary Diagnostic Analysis adopted by ORASECOM in April 2008. Main Report

Water Quality in the Orange River, 2007, Prepared by WRP Consulting Engineers, Jeffares and Green, Sechaba Consulting, WCE Pty Ltd, Water Surveys Botswana

Water Research Commission, June 2001. Groundwater Development in South Africa and an Introduction to the Hydrogeology of Groundwater Regions. Prepared by: JR Vegter. WRC report No: TT 134/00

Water Research Commission 1995. Groundwater Resources of South Africa: An Explanation of a Set of National Groundwater Maps. Prepared by: JR Vegter, Report No. TT 74/95.