REFINEMENT OF STRATEGIC GROUNDWATER SOURCE AREAS OF SOUTH AFRICA

WP11446

GAP ANALYSIS REPORT

RDM/NAT00/02/CON/SWSA/0224

September 2024

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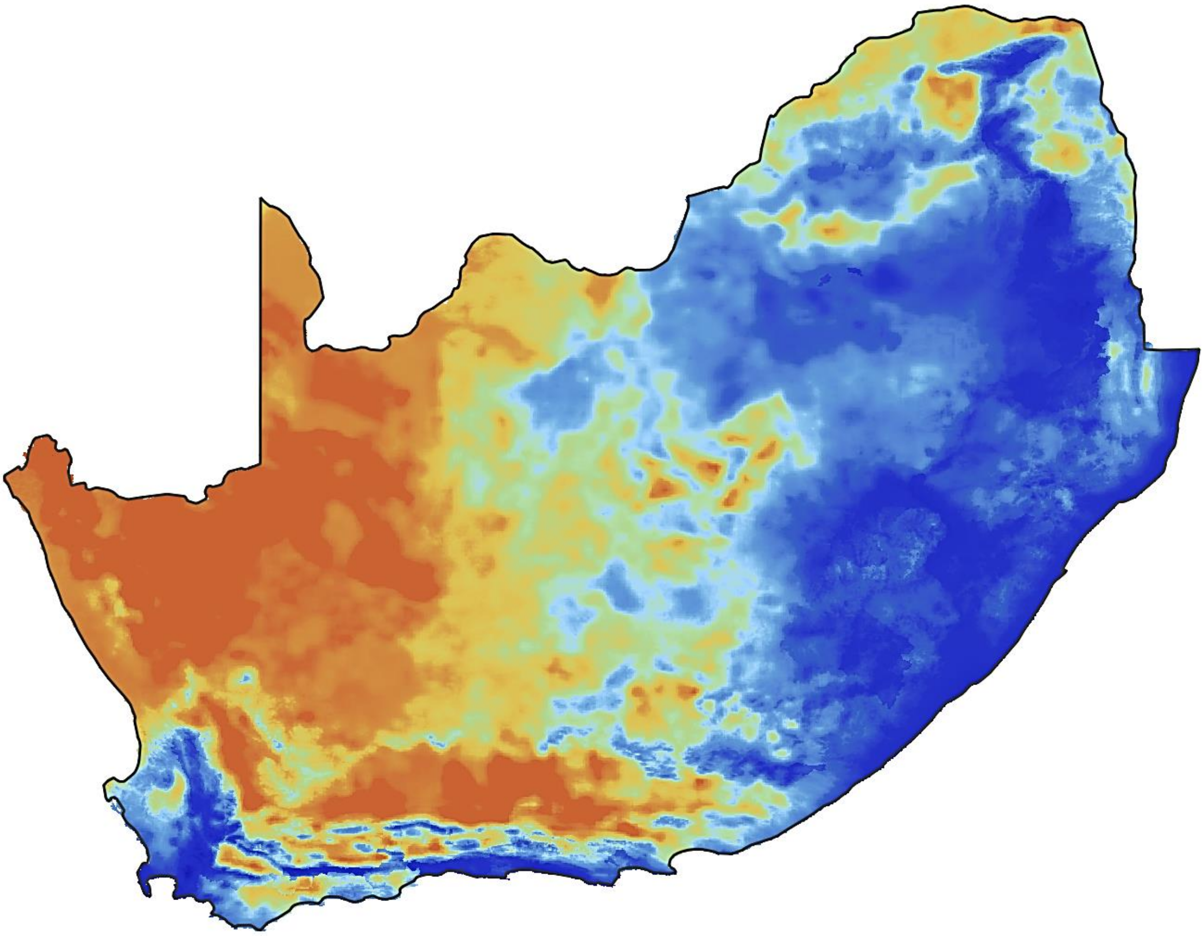
REFINEMENT OF STRATEGIC GROUNDWATER SOURCE AREAS OF SOUTH AFRICA



Gap Analysis Report
Final Draft

Prepared for:

Department of Water and Sanitation
Chief Directorate: Water Ecosystems Management

Executive Summary

BACKGROUND

Sustainability, efficiency, and equity are the guiding principles of South Africa's water resource management efforts. The National Water Resource Strategy (NWRS-3, 2023), developed by the Department of Water and Sanitation (DWS) in line with the National Water Act (Act No. 36 of 1998), outlines policies to safeguard and manage national water resources for sustainable and equitable use. The "Refinement of Strategic Groundwater Source Areas of South Africa" project, led by DWS and executed by Umvoto South Africa (Pty) Ltd, aims to refine the delineation of South Africa's Strategic Water Source Areas (SWSAs), focusing specifically on Strategic Groundwater Source Areas (SWSA-gw). Building on the existing 37 SWSA-gw (Le Maitre et al., 2018), this project seeks to update and enhance the methodology to delineate these areas at both national and transboundary scales. This refinement aims to incorporate the most up-to-date groundwater data, focusing on groundwater quality, contributions to baseflow, and protection measures, with the goal of producing aquifer-specific delineations to guide effective groundwater management.

AIMS AND OBJECTIVES

This Gap Analysis Report provides a comprehensive review of the existing groundwater data relevant to the project. The primary goals are to evaluate data availability, identify gaps, and determine whether these gaps could affect the project's objectives. It also offers recommendations for addressing these gaps through various data collation and supplementation techniques across different phases of the project.

The report reviews the data requirements for key hydrogeological areas, such as subsurface information, groundwater quantity and quality, transboundary aquifers, and rainfall-recharge-discharge dynamics. It highlights data gaps and assesses whether these gaps pose significant barriers or can be managed within the project's scope.

Key baseline studies relevant to the project include:

1. National Spatial Biodiversity Assessment (Driver et al., 2004)
2. National Freshwater Ecosystem Priority Areas Project (Nel et al., 2011)
3. South Africa's Strategic Water Source Areas Project (Nel et al., 2013)
4. SWSA Project (Le Maitre et al., 2018a)
5. Fine-scale Delineation for SWSA-sw (Lötter and Le Maitre, 2021)

In addition, various groundwater resource tools and datasets were evaluated, including WARMS, NGA, WMS, Hydstra, SADC-GIP, IGRAC, GRIP, NIWIS, RQIS, and others.

GAP ANALYSIS SUMMARY

This report evaluates the current groundwater data landscape for Phase 3, focusing on assessing the 37 existing SWSA-gw and establishing foundational data to refine methodologies for delineating SWSA-gw using groundwater quality, transboundary aquifers, baseflow contributions, and resource management. The baseline studies provide valuable insights but reveal gaps in spatial resolution, outdated datasets, and data inconsistencies. However, the existing data is adequate to proceed with the next phase of the project (i.e., Phase 3).

Key Findings:

- Groundwater Use: WARMS data is valuable but requires GIS-based coordinate verification and additional municipal hydro-census data incorporation to address inaccuracies.
- Groundwater Levels: Hydstra data gaps can be supplemented with NGA, IGRAC, and SADC data to improve geographic accuracy.
- Subsurface Information: NGA data on boreholes can be enhanced with municipal hydro-census and integrated with CGS and GRIP datasets (specifically for Limpopo, KwaZulu Natal and the Eastern Cape Province).
- Groundwater Quality: WMS dataset gaps can be supplemented with data from local monitoring programs, GRIP (specifically for Limpopo, KwaZulu Natal and the Eastern Cape Province), NCMP, and NGwQMP.
- Transboundary Aquifer Data: Coarse resolution and inconsistencies can be improved by aligning national datasets with finer-scale transboundary data from neighbouring countries via DWS collaboration.
- Rainfall-Recharge: Comparison of various MAP datasets are required to evaluate WR2012 recharge estimations and improve the groundwater-surface water interaction understanding.

Recommendations:

- Coordinate Verification: Use GIS techniques and coordinate verifications with DWS to correct dataset inaccuracies.
- Supplement Datasets: Leverage additional data sources, including municipal hydro-census data, IGRAC, SADC, and CGS, to improve groundwater levels and borehole information.
- Data Integration: Integrate finer scale national and transboundary datasets to create a holistic view of rainfall-recharge-discharge dynamics.
- Refinement of SWSA-gw: Use updated, fine-scale data to improve aquifer-specific delineations for enhanced groundwater management and protection.
- Enhance Groundwater Quality Monitoring: Supplement monitoring data using GRIP (specifically for Limpopo, KwaZulu Natal and the Eastern Cape Province), NCMP, and other datasets to address spatial and temporal inconsistencies.

CONCLUSION

Despite some limitations, the available data is sufficient for Phase 3. Identified gaps offer opportunities for improvement rather than presenting barriers. Addressing these gaps will enable more refined SWSA-gw delineations, support informed decision-making, and ensure sustainable groundwater management across South Africa.

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AFR CGMW	-	Africa Commission for the Geological Map of the World
ARTV	-	A Recharge Threshold Value
BHN	-	Basic Human Needs
BRGM	-	French Geological Survey
CD: WEM	-	Chief Directorate: Water Ecosystems Management
CMB	-	Chloride Mass Balance
CSIR	-	Council for Scientific and Industrial Research
DFFE	-	Department of Forestry, Fisheries and the Environment
DRASTIC	-	Depth to water, Recharge, Aquifer media, Soil media, Topography, Impact of the vadose zone, and Hydraulic Conductivity
DWA	-	Department of Water Affairs
DWAF	-	Department of Water Affairs and Forestry
DWS	-	Department of Water and Sanitation
EBK	-	Empirical Bayesian Kriging
EC	-	Electrical Conductivity
EWR	-	Ecological Water Requirement
FEPA	-	Freshwater Ecosystem Priority Area
GDE	-	Groundwater Dependent Ecosystem
GGIS	-	Global Groundwater Information System
GIS	-	Geographic Information System
GPS	-	Global Positioning System
GPZ	-	Groundwater Protection Zone
GRAII	-	Groundwater Resource Assessment II
GRIP	-	Groundwater Resource Information Project
IGRAC	-	International Groundwater Resources Assessment Centre
IWRM	-	Integrated Water Resource Management
JRC	-	Joint Research Centre
Km^2	-	Kilometre squared
Ltd	-	Limited Company
Mamsl	-	Metres above mean sea level
MAP	-	Mean Annual Precipitation
MAR	-	Mean Annual Runoff
Mg/l	-	Milligrams per litre
Ml/yr	-	Megalitres per year
Mm^3	-	Million cubic metres
MTPA	-	Mpumalanga Tourism and Parks Agency
NCMP	-	National Chemical Monitoring Programme
NDP	-	National Development Plan
NFEPA	-	National Freshwater Ecosystem Priority Areas
NGA	-	National Groundwater Archive
NGS	-	National Groundwater Strategy
NGwQMP	-	National Groundwater Quality Monitoring Programme
NIWIS	-	National Integrated Water Information System
NLC2000	-	National Land Cover (2000)
NMMP	-	National Microbial Monitoring Programme
NSBA	-	National Spatial Biodiversity Assessment
NWA	-	National Water Act
NWRS-1	-	National Water Resource Strategy Frist Edition
NWRS-2	-	National Water Resource Strategy Second Edition
NWRS-3	-	National Water Resource Strategy Third Edition
ORASECOM	-	Orange-Senqu River Commission

ORWSS	-	Orange River Water Supply Scheme
PCA	-	Potentially Contaminating Activity
PMC	-	Project Management Committee
PO	-	Purchase Order
PR	-	Progress Report
PS	-	Public Stakeholder
PSC	-	Project Steering Committee
PSP	-	Professional Service Provider
Pty	-	Proprietary Limited
RQIS	-	Resource Quality Information Services
RSIS	-	Ramsar Sites Information Service
SADC	-	Southern African Development Community
SADC-GIP	-	Southern African Development Community Groundwater Information Portal
SANBI	-	South African National Biodiversity Institute
SDGs	-	Sustainable Development Goals
StatsSA	-	Statistics South Africa
StepSA	-	Spatial and Temporal Evidence for Planning in South Africa
SWSA	-	Strategic Water Source Areas
SWSA-gw	-	Strategic Groundwater Source Areas
SWSA-sw	-	Strategic Surface Water Source Areas
ToR	-	Terms of Reference
TPI	-	Topographic Position Index
WAAS	-	Water Availability Assessment Study
WARMS	-	Water use Authorization & Registration Management System
WMA		Water Management Areas
WMS	-	Water Management System
WPDx	-	Water Point Data Exchange
WR2005	-	Water Resources Assessments (2005)
WR2012	-	Water Resources of South Africa (2012)
WRC	-	Water Research Commission
WRSM2000	-	Water Resources Simulation Model 2000
WSA	-	Water Source Areas
WSDP	-	Water Services Development Plan
WUL	-	Water Use Licence
WULA	-	Water Use License Application
WWF-SA	-	Worldwide Fund for Nature in South Africa

1. INTRODUCTION

1.1. Background and Motivation

The Department of Water and Sanitation (DWS) Chief Directorate: Water Ecosystems Management (CD: WEM) initiated the "Refinement of Strategic Groundwater Source Areas of South Africa" (WP114466) study, appointing Umvoto South Africa (Pty) Ltd as the Professional Service Provider (PSP). The primary objective of this project is to enhance the delineation of South Africa's Strategic Water Source Areas (SWSA), with a specific focus on Strategic Groundwater Source Areas (SWSA-gw). The goal is to identify and refine these areas with greater precision, to a spatial scale fine enough to be aquifer-specific (see DWS, 2024, and **Section 1.2. Terms of Reference**).

As part of this process, the study will update the methodology for identifying and delineating SWSA-gw on both a national and transboundary scale, building on previous studies, while also considering factors such as groundwater quality and the contribution of groundwater to baseflow. The updated delineation will support the DWS CD: WEM in managing SWSA-gw and guiding the implementation of various protective measures, aligning with the Integrated Water Resource Management (IWRM) initiative mandated by the National Water Act (NWA, Act No. 36 of 1998). This project builds on several foundational studies, including but not limited to:

1. **National Spatial Biodiversity Assessment (2004)**

   Driver, et al. (2004) produced a map of quaternary catchments in South Africa that yield approximately 50% of South Africa’s water supply and were identified as "high water yield areas" (see **Figure 1-1**).

2. **National Freshwater Ecosystem Priority Areas (NFEPA) Project (2011)**

   Nel, et al. (2011) refined the delineation of "high water yield areas" to a sub-quaternary scale (see **Figure 1-1**) where areas were identified based on their Mean Annual Runoff (MAR) contribution, which had to be more than three times the average for the related primary catchment.

3. **South Africa’s Strategic Water Source Areas (2013)**

   Nel, et al. (2013) introduced the term "Strategic Water Source Areas" (SWSA) and refined the concept further using a rainfall-runoff hydrological model, identifying the first set of 21 SWSAs across the country.

4. **Identification, Delineation, and Importance of the SWSA (2018)**

   Le Maitre, et al. (2018a) updated the definition of SWSAs for both surface and groundwater using a 1.7 by 1.7 km resolution MAR dataset. This study identified 22 SWSA-sw and 37 SWSA-gw (see **Figure 1-2**), with the SWSA-gw covering approximately 9% of South Africa's land surface and contributing approximately 42% to baseflow. The study also included a management & implementation framework (Le Maitre, et al., 2018b).

5. **Fine-scale Delineation for SWSA-sw in South Africa (2021)**

   Lötter and Le Maitre (2021) improved on the 2018 study and updated the SWSAs-sw at a finer resolution of 90 x 90 m. This refinement aimed to facilitate integration into various on-the-ground planning, management, and regulatory processes and replaced the broad-scale delineation of the 22 SWSA-sw developed in 2018 (see **Figure 1-2**).

Since a fine-scale refinement, i.e., Lötter, and Le Maitre (2021), has only been done for Surface Water SWSA, a similar refinement process is now required for Groundwater SWSA, one that integrates an updated identification and delineation process.

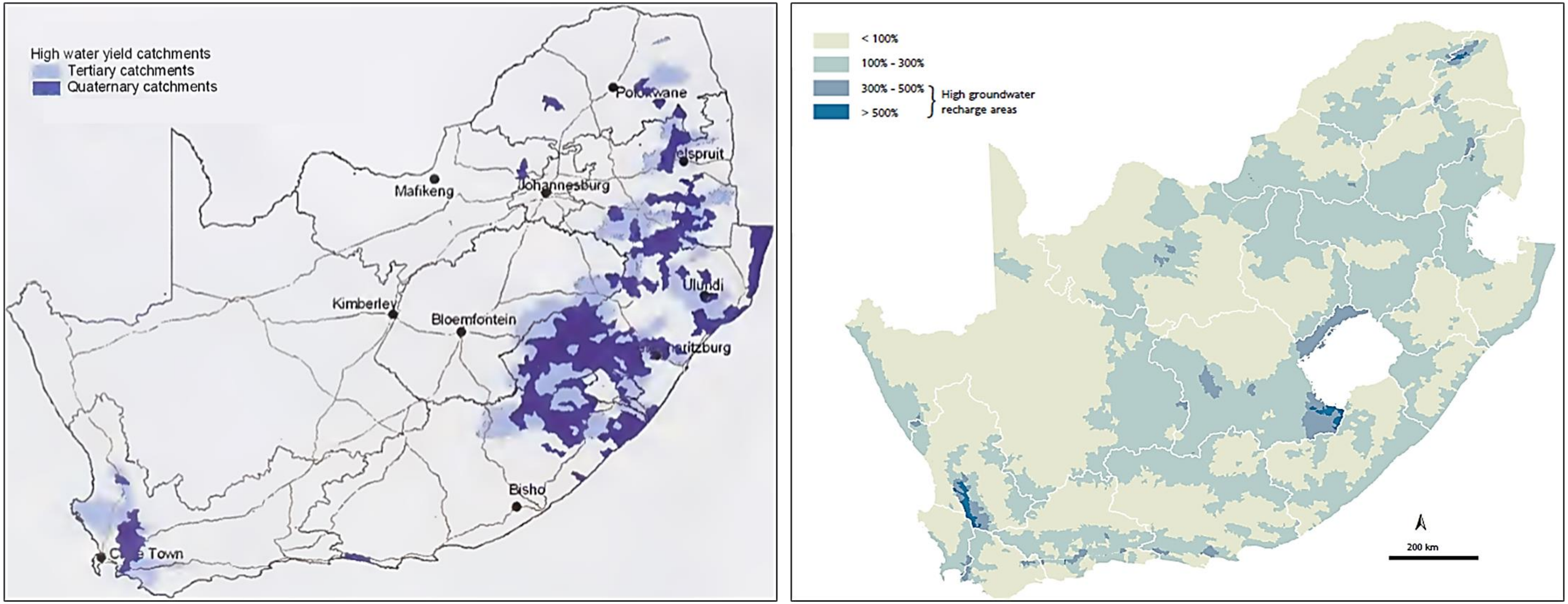


Figure 1-1 **Left: High water yield catchments based on tertiary and quaternary catchments (from Driver et al., 2004). Right: High groundwater recharge areas in South Africa, calculated as those sub-quaternary catchments where groundwater recharge is at least three times more than the average for the related primary catchment (Obtained from Nel et al., 2011).**

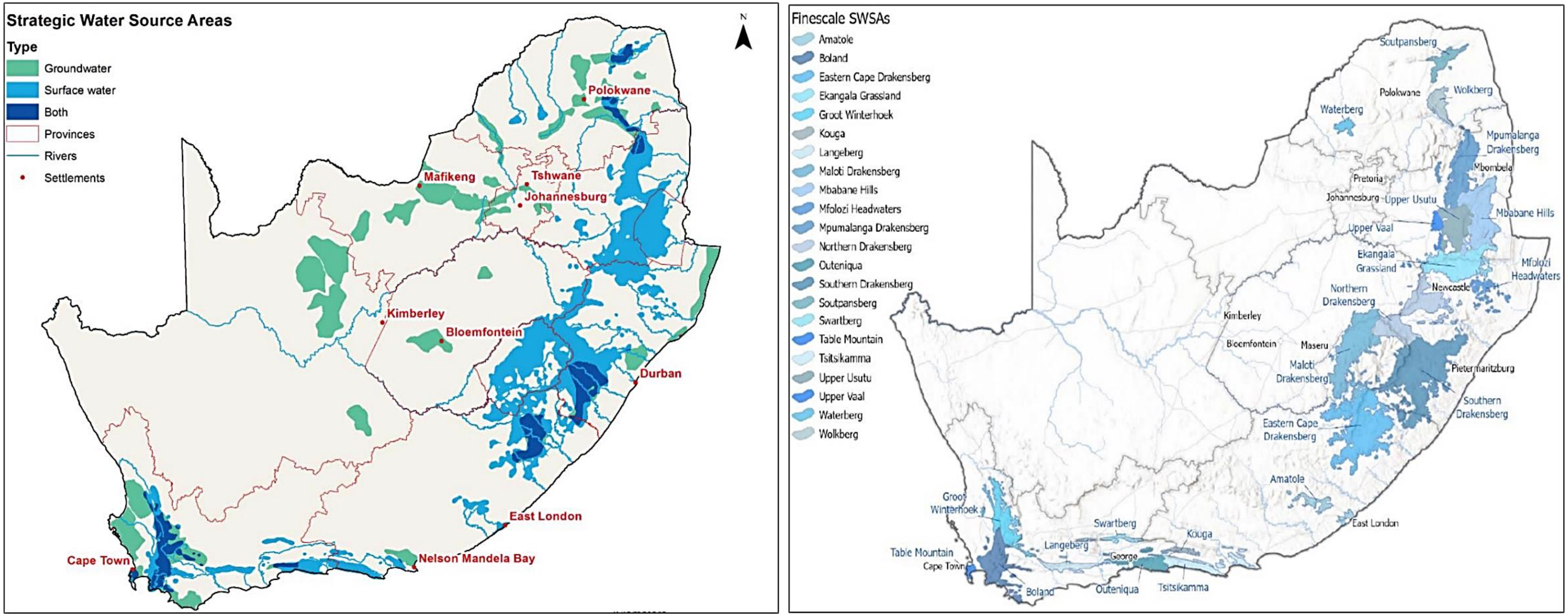


Figure 1-2 **Left: National and transboundary Strategic Water Source Areas (SWSA), including portions that fall within Lesotho and Swaziland (from Le Maitre et al., 2018). Right: Fine-scale Strategic Water Source Areas for surface water (SWSA-sw), based on the 22 SWSA-sw delineated in 2018 and a downscaled Mean Annual Precipitation (MAP) spatial layer for South Africa (Obtained from Lötter and Le Maitre, 2021).**

1.2. Terms of Reference

The ToR prepared by the DWS CD: WEM for this study outline the aims and objectives as follows:

"The primary aim of the project is to enhance the delineation of SWSA-gw to an aquifer-specific scale, building upon the baseline information provided by the 2018 study.

The objectives for the study include:

1. Developing a scientifically sound methodology for delineating SWSA-gw for both national and transboundary aquifers/aquifer systems, incorporating considerations for groundwater quality.
2. Reviewing and refining the scale of SWSA-gw to the aquifer level.
3. Developing an approach for the protection and management of the refined SWSA-gw.

Throughout these processes, it is imperative to ensure consultative engagement, keeping all interested and affected parties, stakeholders, water users, etc., informed about developments."

1.3. Aims and Objectives of this Report

The Gap Analysis Report, **Deliverable 2.1 of Phase 2** of this study (see **Table 1-1**), aims to systematically collect, organise, review, and analyse all relevant water resource data and information for the project to identify data gaps (refer to the projects Inception Report; DWS, 2024). This phase is divided into two main tasks, which together evaluate whether the available data for the project can be confidently used for decision-making during the SWSA-gw refinement process.

A summary of the tasks and report outcomes are listed below:

Task T2.1.1:

- List existing datasets to identify any data or information gaps and determine their implications on the project’s goals.
- Gather all known datasets from various sources, including all relevant literature (technical reports and publications), maps, models (where available), aerial imagery, remote sensing materials, and other potentially sensitive information that will benefit the project.
- Assess these datasets to evaluate their accessibility, usability, and applicability to the study.

Task T2.1.2:

- Compile an inventory of relevant groundwater resource tools and provide detailed explanations of their applicability to the study. Comment on how these tools can be used within the study's context and scope, and how they can enhance the refinement process for SWSA-gw.

Data gaps identified are assessed through a series of validation steps, including expert opinions. If gaps are found, recommendations are made for addressing them within the scope of this project or through future data collection and refinement strategies. Any resulting limitations are clearly communicated, with an action plan proposed for data supplementation or future collection as part of this phase’s findings.

Table 1-1: Deliverables and Associated Tasks by Project Phase.

Phase 0: Project Management, Administration, Communication and Capacity Building		
P0	**P0.1** General Project Management	
	P0.2 PMC Meetings	
	P0.3 PSC Meetings	
	P0.4 PS Meetings	
	P0.5 Ad Hoc Meetings	
	P0.6 Monthly Progress Reports	
	P0.7 Capacity Building	
Phase 1: Project Inception		
P1	**D1.1**: Inception Report	**T1.1.1**: Lit Review
Phase 2: Information and Data Gathering		
P2	**D2.1**: Gap Analysis Report	**T2.1.1**: Data and Information Assessment **T2.2.1**: Inventory of Water Resource Tools
Phase 3: Refinement of SWSA-gw		
P3	**D3.1:** Status Quo SWSA Report	**T3.1.1**: Status Quo SWSA Assessment
	D3.2: Refined Methodology Report	**T3.2.1**: Refined Methodology Assessment
	D3.3: Delineation of Refined SWSA-gw Report	**T3.3.1**: Delineation of Refined SWSA-gw **T3.3.2**: Groundwater Quality **T3.3.3**: Transboundary Aquifers **T3.3.4**: Updated Status Quo SWSA Assessment
	D3.4: SWSA-gw Protection and Management Report	**T3.4.1**: SWSA-gw Protection and Management
Phase 4: Project Closure		
P4	**D4.1**: Refined Strategic Groundwater Source Areas of South Africa Report	**T4.1.1**: Report Integration
	D4.2: External Review Summary Report	
	D4.3: Electronic Database	
	D4.4: Close Out Report	

1.4. Report Structure

The Approach and Methodology section describes the primary data sources used in the study and outlines the procedures and techniques employed for data collection, evaluation, and impact assessment. It also explains the methods for identifying data gaps and factors considered when evaluating how to address these gaps.

The Gap Analysis and Review section provides a detailed summary of the literature and technical reports, including the main background studies and additional reports. It lists and describes the databases and groundwater resource tools used, emphasising their relevance and utility to the study.

The Synthesis and Recommendations section outlines the findings and relates them to various overarching components such as groundwater use, levels, borehole information, quality, transboundary aquifers, and recharge. It presents the known limitations of each aspect and provides recommendations for improvement.

The Conclusion summarises the available data and the confidence it provides for the study. It also highlights any gaps and offers recommendations for addressing them to ensure the study's objectives are met.

2. APPROACH AND METHODOLOGY

Phase 2 of this project (Information and Data Gathering) focuses on collecting and evaluating a wide range of local-scale, national, and transboundary hydrogeological datasets. Due to the diverse formats, varying spatial scales, and complexity of the data, a standardised 'one-size-fits-all' approach to data quality evaluation is considered impractical for this project. As a result, the methodology integrates both quantitative and qualitative approaches to the gap analysis assessment.

While a quantitative evaluation assigns numerical values to describe data quality, the qualitative evaluation addresses more nuanced aspects, such as context-specific relevance, data integrity and consistency, and the suitability of the data for the intended hydrogeological analyses. The methodology is structured into three main steps: 1) Data Collection, 2) Data Evaluation, and 3) Impact Assessment.

2.1. Data Collection

The data collection process focuses on sourcing and acquiring datasets from various studies and repositories. This includes obtaining technical reports in formats such as PDFs or scans, as well as datasets in formats such as text/CSV files, excel spreadsheets, shapefiles, JPEGs, GeoTIFFs, KML/KMZ files, geo-databases, and others. The primary goal is to first gather all relevant data from the key SWSA-gw studies listed in **Section 1.1** to understand the general data requirements for the project, particularly those used in the 2018 delineation of SWSA-gw (Le Maitre et al., 2018a) and the datasets from the 2021 fine-scale delineation of SWSA-sw (Lötter & Le Maitre, 2021).

Although the 2021 study focused on surface water areas, the associated datasets were included as they contain input layers relevant to refining the SWSA-gw. The datasets from these two studies, as well as National Datasets provided by the DWS, form the foundation for this study.

After collecting the data, the datasets are organised based on their relevance to the project objectives. This categorisation (see **Table 2-1**) helps prioritise the most critical datasets for assessment during the data evaluation (see **Section 2.2**).

Table 2-1: Data Categories and Priority Levels

Priority Level	Category	Description
1	Data Required for both the Status Quo Assessment and the Refinement of SWSA-gw	Used in both determining the current status of SWSA-gw and in the refinement of SWSA-gw. This includes protection and management datasets, as well as hydrogeological studies, long-term monitoring data, and interdisciplinary research findings that provide both a snapshot of current conditions and a foundation for the refinement process.
2	Data Required for Refining SWSA-gw only	Specifically needed for the refinement of SWSA-gw. This includes data not necessarily included in the current status, such as finer scale data of geology, groundwater use and quality, and baseflow data, as well as data from new or previously under-represented areas.
3	Data Required for Determining the Status Quo only	Specific datasets used to accurately depict the existing groundwater situation in South Africa, specifically for the known SWSA-gw (i.e., those delineated in 2018). This involves identifying available data and assessing its quality, completeness, and relevance. Includes data on water quality, water levels, recharge rates, abstraction rates, and other key indicators.

2.2. Data Evaluation

The data evaluation process follows a structured approach to: 1) assess the suitability of the collected datasets in achieving the project's objectives (as outlined in **Section 1.2**); 2) determine whether the datasets have been updated since the 2018 delineation of SWSA-gw (Le Maitre et al., 2018a); 3) evaluate known data limitations; and 4) identify other data gaps specifically related to hydrogeological, socio-economic, and protection and management plans relevant to the SWSA-gw refinement process. The evaluation is conducted using two main approaches:

1. **Quantitative Evaluation:** This method assigns a value to describe data availability (see **Table 2-2**), calculated based on the percentage of complete data for selected parameters. This provides a snapshot overview of the raw data's consistency, reliability, and completeness of the datasets.
2. **Qualitative Evaluation:** Narrative descriptions and expert evaluations are used to assess data quality, capturing nuanced factors such as the context of the data and known limitations from previous studies (see **Table 2-3**). This qualitative analysis is essential for understanding the overall strengths and weaknesses of the datasets and identifying potential data gaps that might not be evident through a quantitative method alone.

Table 2-2: Overall data availability score.

Availability Score	Description
5	All Data Available (100%)
4	Most Data Available (75 – 99%)
3	Partial Data Available (50 - 74%)
2	Limited Data Available (25 - 49%)
1	No Data Available (< 25%)

Table 2-3: Overall data quality score.

Quality Score	Description
5	Excellent
4	Good
3	Average
2	Poor
1	Very Poor

In both evaluation approaches, several types of data gaps (see **Table 2-3**) are identified and formed important considerations for the data evaluation, particularly in the qualitative descriptions:

1. **Data Quality and Integrity:** Issues related to variations in reliability and accuracy, incomplete datasets, or insufficient metadata that hinder understanding of the data's origin, context, or limitations.
2. **Integration and Compatibility:** Challenges arising from varied data formats and processing methods, leading to difficulties in integrating and comparing datasets across projects.
3. **Coverage and Spatial Resolution:** Gaps related to insufficient geographic or temporal data coverage, leading to biases and potential misinterpretations due to discrepancies in spatial relationships or resolution.

Table 2-4: Types of Data and Information Gaps.

Gap Category	Gap Type	Description
Data Quality & Integrity	Quality	Variations in the reliability and accuracy
	Consistency	Inconsistencies within the data over time
	Incomplete	Gaps where expected data points are absent or incomplete
	Documentation	Insufficient metadata, making it challenging to understand the data's origin, context, or limitations
Integration & Compatibility	Methodological	Inconsistencies in the methods used to collect, process, or analyse data
	Interoperability	Issues with data being in incompatible formats or systems, hindering integration
Coverage & Spatial Resolution	Spatial / Coverage	Insufficient geographic coverage or missing spatial data in certain areas
	Temporal	Incomplete or missing data for specific periods
	Coverage Bias	Certain areas, groups, or variables are overrepresented or underrepresented
	Topological Inconsistencies	Errors or discrepancies in the spatial relationships and connectivity between geographic features
	Resolution & Scale	Differences in the granularity or detail of the data

2.3. Impact Assessment

The data collection and evaluation process (as described in **Sections 2.1** and **Section 2.2**) provides an initial understanding of overall data quality and identifies several data gaps. To further assess these gaps, internal reviews were conducted within the DWS and the PSP project teams to determine if additional data sources need to be considered. Additionally, consultations with stakeholders and subject matter experts during and after the Project Steering Committee (PSC) and Public Stakeholder (PS) meetings offered valuable insights and recommendations for data sources and supplementation (refer to the project's Inception Report for more information regarding the Project Team and Stakeholder Engagement strategy; DWS, 2024).

The overall process is intended to be iterative, allowing for adjustments to be made as new data gaps or limitations are discovered, or additional datasets become available. While several data gaps are identified, not all are considered significant at this stage of the project. However, as the project progresses into the next phase (i.e., Phase 3: Refinement of SWSA-gw: T3.1.1: Status Quo SWSA Assessment, see **Table 1-1**), areas lacking groundwater information will become more apparent, requiring further or intensive investigation on a more local scale. Below is a summary of the key components of the Impact Assessment, with **Table 2-5** describing some additional factors considered in the assessment.

- **Internal Reviews and Expert Consultations:** Significant data or information gaps identified during internal reviews were discussed with subject matter experts, who helped source the relevant datasets or suggested updates to refine and address them.
- **Iterative Feedback Loop:** A feedback loop, facilitated by the DWS project team through PS and PSC meetings, ensured efficient communication for data sourcing. This allowed the data assessment to remain ongoing as new or updated datasets became available.
- **Review of Gap Options and Strategies:** Various recommendations were developed to address the identified gaps. High-impact gaps were prioritised, with action steps including data supplementation, expert consultations, and the potential use of proxy indicators.

Table 2-5: Additional factors considered during the impact assessment.

Factor Category	Considerations
Resource and Technical Feasibility	1 Are the necessary resources (funding, time, personnel, technology) available to address the gap? 2 Can the required data be collected or improved to meet project standards? 3 Does the project team possess the necessary expertise, or will external expertise be required?
Project Constraints and Risks	4 Can the gap be addressed within the project timeframe? 5 What are the costs vs. benefits of addressing the gap? 6 Where in the project scope will these gaps be addressed?
Alignment and Sustainability	7 Does addressing the gap align with the project's overall goals? 8 Will the solutions be implementable on a national scale? 9 Can data quality improvements be maintained beyond the project's duration?

Once the potential impact assessment is complete, strategies are formulated to address them:

- **High-Impact Data Gaps:** These require immediate recommendations. Solutions are evaluated based on feasibility and effectiveness, with actionable steps put forward. Where addressing the gaps is not feasible (see **Table 2-5)**, alternative solutions or further assessments are proposed.
- **Low-Impact Data Gaps:** These gaps are considered manageable. In some cases, addressing them could be deferred to later phases of the project, or the datasets can be used as-is. Where necessary, recommendations for ongoing monitoring or future updates are made.

Table 2-6: Various options and strategies presented to address identified data gaps.

Strategy	Example
Data Supplementation	Sourcing additional datasets from government agencies, private providers, and academic institutions.
Interpolation	Using statistical or spatial interpolation techniques to estimate missing values.
Model-Based Estimations	Developing predictive models validated with existing data.
Leveraging Existing Data	Reusing data from previous studies, ensuring relevance and accuracy.
Expert Consultations	Engaging experts for insights and informed assumptions.
Data Integration	Combining data from multiple sources for consistency and accuracy.
Remote Sensing and Satellite Data	Using satellite imagery to fill data gaps in inaccessible areas.
Collaborative Data Sharing	Establishing data-sharing agreements to improve coverage.
Investment in New Data Collection	Conducting new surveys and studies to address gaps.
Use of Proxy Indicators	Identifying proxy indicators to estimate missing data.
Data Quality Improvement Programs	Improving data quality through cleaning and standardization efforts.

3. GAP ANALYSIS AND REVIEW

3.1. Literature Review

3.1.1. Main Background Studies

3.1.1.1. National Spatial Biodiversity Assessment 2004

South Africa's National Spatial Biodiversity Assessment (NSBA) conducted by Driver et al. (2004) was the first comprehensive spatial analysis of biodiversity across South Africa. The NSBA addressed four key environmental components: terrestrial, freshwater, estuarine, and marine ecosystems. The primary objective of the assessment was to evaluate the current status and protection levels of these ecosystems and to identify priority areas for conservation. Notably, the emphasis extended beyond the establishment of Protected Areas (Driver et al., 2004), focusing on the sustainable management of many natural resources across both landscapes and seascapes. This approach aimed to integrate biodiversity considerations into the activities of a range of public and private sector services, ensuring that biodiversity and its conservation play a central role in sustainable development planning.

Groundwater Aspects of the Project

While the NSBA primarily focuses on surface water systems, groundwater plays a crucial role in supporting freshwater ecosystems and maintaining baseflows in rivers, particularly within river catchments. The study identified “high water yield areas”, which were based on tertiary and quaternary catchments that contribute approximately 50% of South Africa's water supply (**Figure 1-1**; Driver et al., 2004). These catchments, mainly located in mountainous areas and along the escarpment (**Figure 1-1**), are essential for sustainable water management. However, the report does not delve deeply into the groundwater contribution to baseflow, leaving a critical gap in the understanding of the full hydrological cycle at the time of the study, and its implications for long-term water security.

Limitations of the Data

The NSBA acknowledges several data and information limitations that may affect the accuracy of its groundwater assessment. A key limitation is the reliance on the 1996 National Land Cover (NLC2000) dataset, which is now outdated and does not account for more recent land-use changes that could significantly impact groundwater resources.

Additionally, the low spatial resolution of the tertiary and quaternary catchment delineations used at the time of the assessment further constrained the analysis. Since then, catchment delineation in South Africa has been refined through several iterations, driven by advancements in hydrological understanding, the availability of higher-resolution spatial data, and improvements in Geographic Information Systems (GIS). Notably, the 2012-2013 revision that reduced the number of Water Management Areas (WMAs) from 19 to 9, along with the outputs of Water Resources of South Africa, 2012 Study (WR2012), which incorporated factors such as climate variability, land use changes, and enhanced hydrological models, have resulted in a more refined version of national catchment delineations. Although the report provides valuable spatial data on surface water systems, which are important data inputs for refining SWSA-gw, the integration of groundwater data was limited. This represents a gap in fully understanding groundwater resources. While the NSBA provides a solid foundation for identifying priority water catchments in South Africa from a surface water perspective, there is a clear need for more up-to-date and comprehensive groundwater data.

3.1.1.2. National Freshwater Ecosystem Priority Areas 2011

The National Freshwater Ecosystem Priority Areas (NFEPA) project conducted by (Nel, et al., 2011) was launched to identify and protect South Africa's most critical freshwater ecosystems and ensure the sustainable use of linked water resources. The main objective was to define priority areas for biodiversity conservation, known as Freshwater Ecosystem Priority Areas (FEPAs), which include rivers, wetlands, and estuaries crucial for the resilience of water systems. The project was a collaborative effort involving multiple stakeholders, including the Council for Scientific and Industrial Research (CSIR), the South African National Biodiversity Institute (SANBI), the Water Research Commission (WRC), the Department of Water Affairs (DWA), and the World Wide Fund for Nature South Africa (WWF-SA). Systematic biodiversity planning was employed to set conservation targets and integrate FEPAs into water resource management at both national and sub-national levels.

Groundwater Aspects of the Project

Although the NFEPA project primarily focused on surface water ecosystems, it also acknowledged the important role of groundwater discharge in sustaining freshwater systems (**Figure 1-1**). Groundwater discharge is essential for maintaining river baseflows and supporting Groundwater Dependent Ecosystems (GDEs), particularly in "high water yield catchments" identified in studies like Driver et al. (2004). The NFEPA project refined the delineation of these catchments to a sub-quaternary scale, identifying those contributing at least three times the MAR of the related primary catchment. These "high water yield areas" play a vital role in ensuring reliable water supply for downstream ecosystems and human uses, even in distant regions.

In parallel, high groundwater recharge areas were recognised as critical for long-term water security. These areas replenish aquifers, where their associated discharge sustains river baseflows, especially during dry seasons. The recharge zones were mapped based on factors such as rainfall and geological permeability, which influence their effectiveness. By protecting these recharge areas from over-abstraction and land degradation, the project aimed to maintain the integrity of these systems, which are vital for sustaining GDEs and Groundwater Reserves.

Limitations of the Data

Despite its comprehensive scope, the NFEPA project faced data limitations, particularly concerning spatial resolution and groundwater data. Like the NSBA (i.e., Driver et al., 2004), NFEPA encountered challenges with outdated datasets, such as the NLC2000, and inconsistent catchment delineation across different regions. These gaps made it difficult to fully incorporate groundwater recharge areas into the broader conservation framework. High groundwater recharge areas, while identified, were not fully integrated into the FEPA strategy due to the lack of high-resolution data on specific groundwater systems and their interactions with surface water ecosystems.

Furthermore, the limited availability of updated spatial data hindered the development of a more nuanced groundwater conservation strategy. The project recommended improving data quality through advancements in GIS and hydrological modelling, which would help refine the delineation of "high water yield areas". Such updates would enhance future conservation efforts and support more effective management of freshwater ecosystems.

Despite the challenges faced, the NFEPA project established a critical foundation for the integration of surface water and groundwater management in South Africa's national conservation strategies. By identifying "high water yield areas" and high groundwater recharge areas, the project significantly contributed to understanding the country's freshwater ecosystems and the interdependence of surface and groundwater systems. The NFEPA framework will be vital for guiding future conservation efforts, especially as water resources face increasing pressure from climate change and human activities.

3.1.1.3. South Africa's Strategic Water Source Areas 2013

The "Defining South Africa's Water Source Areas" project, initiated by WWF-SA (Nel, et al., 2013), aimed to safeguard areas critical to the country's water security. These regions, termed "Strategic Water Source Areas", were identified as areas that generate a disproportionately high amount of water relative to their size (Nel, et al., 2013), significantly supporting downstream ecosystems, economies, and urban centres. Through the use of a rainfall-runoff hydrological model, the study refined the understanding of these "high water source areas" and identified the first set of 21 SWSAs spread across South Africa, Lesotho, and Swaziland. These areas collectively contribute approximately 50% of the national water supply, despite covering only 8% of the land surface area (Nel, et al., 2013). This disproportionate contribution highlights their "strategic" importance for sustaining economic growth, agriculture, and biodiversity across the region which led to their inclusion in the 2013 National Water Resources Strategy (NWRS; see **Section 3.1.1.6**).

Groundwater Aspects of the Project

While the project's main focus was on SWSAs for surface water resources, it recognised the role of groundwater discharge in maintaining river baseflows. These discharge areas were considered in the identification of the 21 SWSAs, and with their inclusion in NWRS (2013), the project aimed to ensure the year-round availability of water for GDEs (Driver et al., 2004 and Nel, et al., 2011).

Using a rainfall-runoff relationship model refined at a 1x1 minute grid resolution, the study accounted for areas where the MAR was substantially higher than the surrounding primary catchments (after Nel, et al., 2011). These areas are vital not only for supporting freshwater ecosystems and maintaining Ecological Water Requirements (EWRs), especially in dry or drought-prone periods, but also for ensuring the sustainability of water supplies for Basic Human Needs (BHN).

Limitations of the Data

The study encountered several key limitations in its data and methodologies. The rainfall-runoff models used were based on Water Resources of South Africa, 2005 Study's (WR2005) data, which, while widely recognised, lacked comprehensive high-resolution groundwater recharge data integration. As a result, groundwater's role in supporting SWSAs was not fully captured, which represents a gap in understanding the interaction between surface and subsurface hydrological processes. Additionally, the report relied heavily on WR2005 MAR data, which averages water flows over time. This can mask the year-to-year variability in water availability, particularly in regions subject to inter-annual fluctuations in rainfall (Nel, et al., 2013). The report also acknowledged that the outdated NLC2000 dataset, particularly for the areas outside South Africa, may not have reflected current land-use practices at the time, such as urbanisation or deforestation, which could significantly impact water yield and groundwater recharge.

Despite these challenges, the project successfully established a critical baseline for understanding the "strategic" importance of water source areas, with a clear recommendation for future research to integrate more higher resolution groundwater data, updated land cover information, and refined models to better capture variability in MAR calculations.

3.1.1.4. Identification, Delineation, and Importance of the SWSA 2018

The Integrated Report on the "Identification, Delineation, and Importance of Strategic Water Source Areas (SWSAs) for both Surface Water and Groundwater" by Le Maitre, et al. (2018a) updated the definition for SWSAs to include "areas of land that either: (a) supply a disproportionate (i.e. relatively large) quantity of mean annual surface water runoff in relation to their size and so are considered nationally important, or (b) have high groundwater recharge and where the groundwater forms a nationally important resource; or (c) areas that meet both criteria (a) and (b). They include transboundary Water Source Areas that extend into Lesotho and Swaziland", Le Maitre, et al. (2018a). This study identified 22 SWSA-sw and 37 SWSA-gw, which are considered nationally significant for ensuring South Africa's water and economic security (see **Figure 1-2**). Some of these SWSAs extend into neighbouring countries, with some SWSA-sw particularly crucial for the Gauteng metropolitan area (see **Figure 1-2,** Le Maitre, et al., 2018a).

Groundwater Aspects of the Project

The project expands the concept of SWSAs to explicitly include SWSA-gw in the SWSA definition. These areas were identified based on high groundwater recharge (used as a proxy for high groundwater availability) and the significant reliance on groundwater for human and economic activities. 37 SWSA-gw areas were delineated, covering approximately 9% of South Africa's land area and contributing approximately 42% of baseflow (crucial in maintaining river flows during dry seasons). The analysis indicated that groundwater use in the SWSA-gw areas is predominantly for agricultural irrigation (46%) and various industry activities (47%)

- **Refinement Using a Rainfall-Runoff Model:** A rainfall-runoff relationships model (Hughes, 2004) was used to improve the understanding of surface-groundwater interaction, where recharge data from the Groundwater Resource Assessment II (GRAII) was used as a proxy for groundwater availability. The findings reveal that areas satisfying criterion (a) often correspond with SWSA-sw, which is understandable given that regions with high rainfall typically experience greater recharge, leading to increased discharge, and by extension, increased baseflow.

  Additionally, these regions see higher runoff, with SWSA-sw further bolstered by the elevated baseflow (Vegter, 1995). Due to this overlap, areas with significant groundwater recharge already received a degree of protection as part of the SWSA-sw. Therefore, delineating regions based solely on criteria (a) and (b) was viewed to have limited value. As a result, the mapping of SWSA-gw includes areas where groundwater plays a vital role, covering both key 'resource' and 'source' zones. SWSA-gw are thus areas where groundwater availability and utilization are essential.

- **Groundwater Contribution to Baseflow:** A simplified analysis showed that 16 out of the 22 SWSA-sw areas receive more than 10% of their total water from groundwater baseflow (Le Maitre, et al., 2018a), with areas such as Mpumalanga Drakensberg and Upper Usutu receiving more than 20%.

  This underscores the interconnectedness between groundwater and surface water, stressing the need to protect these groundwater recharge areas (to ensure continuous groundwater discharge) to ensure the sustainability of both systems.

Limitations of the Data

The report highlights several data limitations:

- **Recharge Data:** It was noted that all SWSA-sw regions overlap with SWSA-gw or areas of high recharge, indicating a correlation between abundant surface water and groundwater availability. However, the GRAII recharge dataset used for groundwater availability calculations is now outdated, lacking the resolution needed to accurately capture the spatial variability of recharge in arid and semi-arid regions. As a result, the current SWSA-gw delineation may not fully reflect the complexities of groundwater in these areas. See GRA II Recharge (mm/a) in **Figure 3-1**.
- **Groundwater Use Data:** The Water Use Authorization & Registration Management System (WARMS) presents challenges due to inaccuracies in user-reported data, particularly regarding location and licensed use vs actual usage. This complicated assessing groundwater use. See groundwater use from WARMS (2016) expressed as l/s per 1 km^2 in **Figure 3-2**.
- **Baseflow Data:** The groundwater contribution to baseflow was estimated but this analysis is considered simplified, as it does not account for complexities such as upstream contributions/releases or interflow. This resulted in an underestimation of the true contribution of groundwater to overall water flow (see **Figure 3-3**).

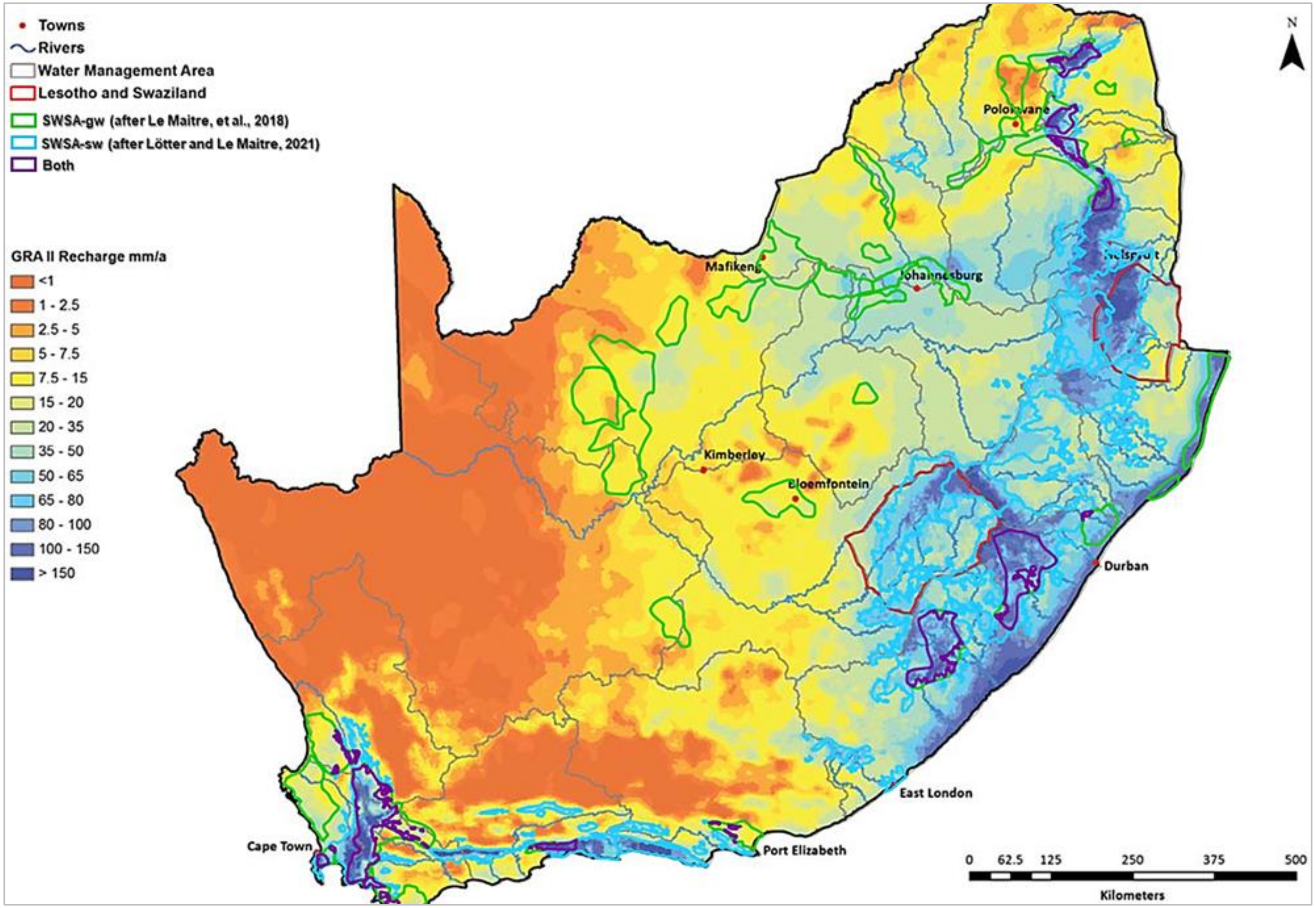


Figure 3-1 **Map of the aquifer recharge dataset from GRAII with the set of 37 SWSA-gw (Le Maitre, et al., 2018a) and the 22 fine-scale SWSA-sw (Lötter and Le Maitre, 2021).**

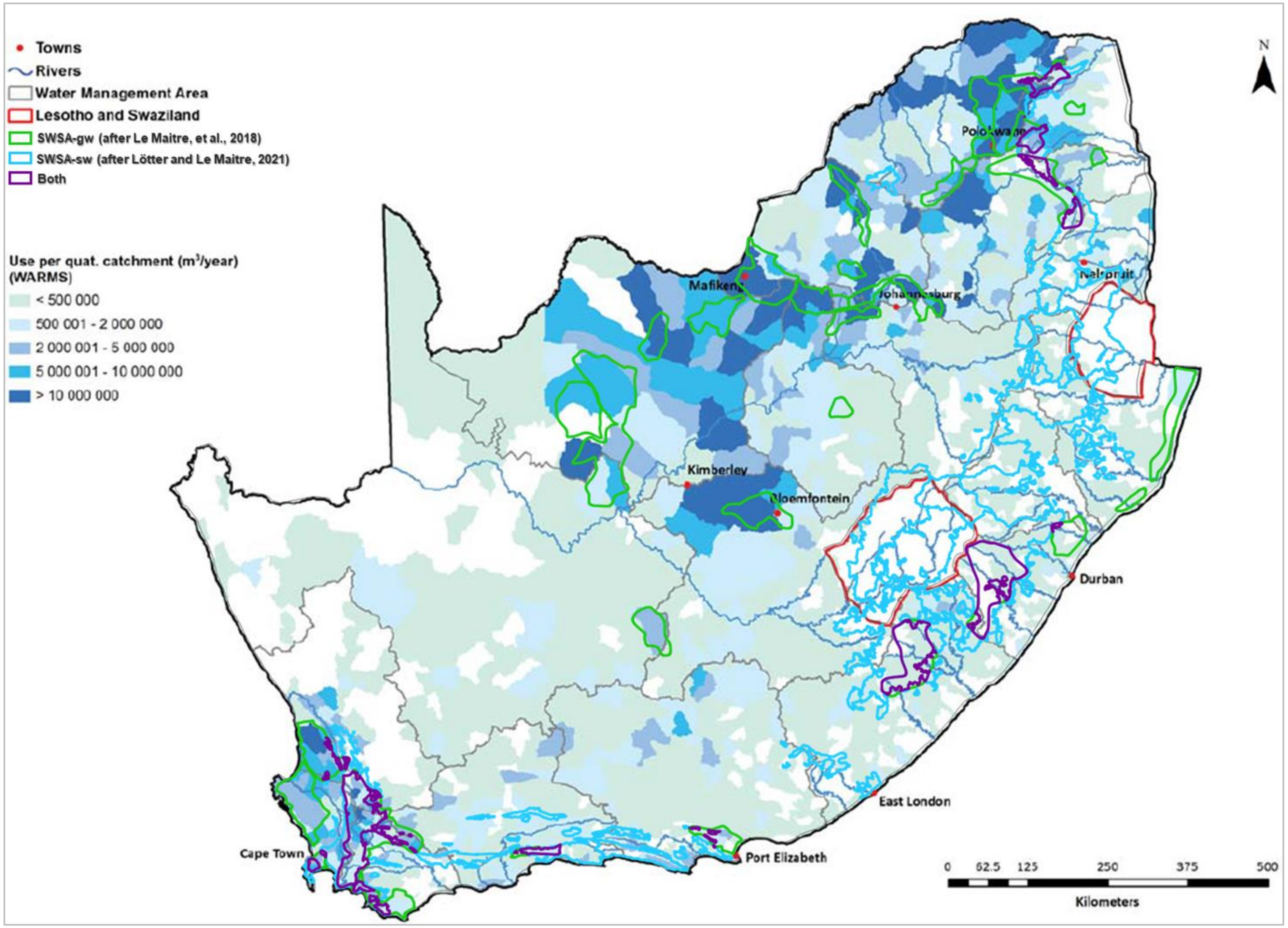


Figure 3-2 Map of groundwater use in WARMS – expressed as sum per quaternary catchment (WARMS data extracted in January 2016, with the set of 37 SWSA-gw (Le Maitre, et al., 2018a) and the 22 fine-scale SWSA-sw (Lötter and Le Maitre, 2021).

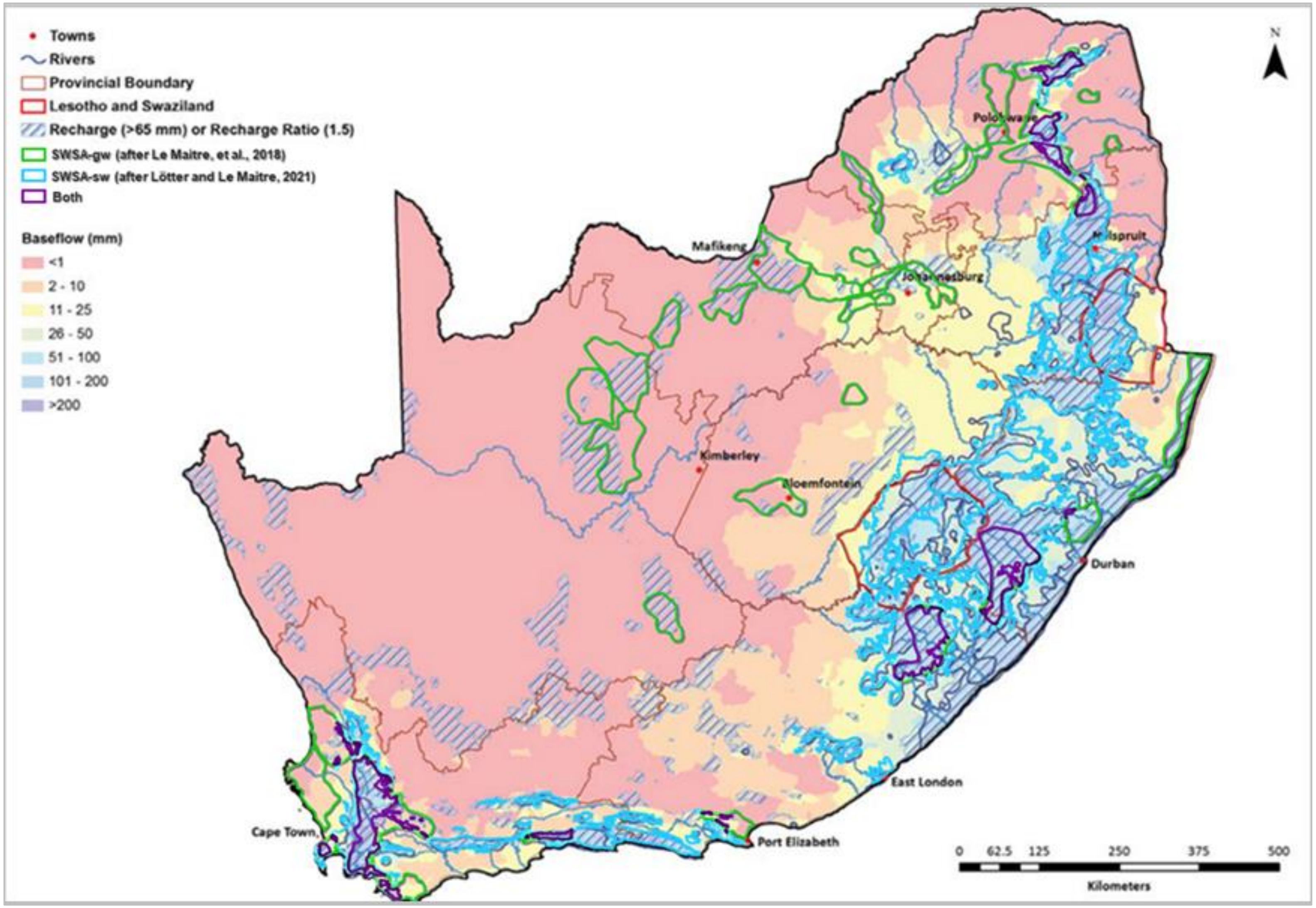


Figure 3-3 **The relationship between SWSA for groundwater and river baseflow from Vegter (1995) with the set of 37 SWSA-gw (Le Maitre, et al., 2018a) and the 22 fine-scale SWSA-sw (Lötter and Le Maitre, 2021).**

3.1.1.5. Fine-scale Delineation for SWSA-sw in South Africa 2021

The "Fine-Scale Delineation of SWSA for Surface Water in South Africa using Empirical Bayesian Kriging Regression Prediction" report by Lötter and Le Maitre (2021) focused on refining the boundaries of SWSA-sw to a finer resolution using the 2018 set of 22 SWSA-sw (**Figure 1-2**). The SWSA Spatial Task Team that collaborated on this project included representatives from CapeNature, CSIR, DWS, Department of Forestry, Fisheries and the Environment (DFFE), Ezemvelo KwaZulu-Natal Wildlife, Mpumalanga Tourism and Parks Agency (MTPA), SANBI, and WRC.

As defined by Le Maitre et al. (2018a), SWSAs cover approximately 10% of South Africa's land area but generate 50% of the country's water runoff. These areas were identified as "strategic" as they supply water to 60% of the population, supporting 90% of urban water users, and contributing to 70% of irrigated agriculture. The refinement to a "fine-scale", achieved through Empirical Bayesian Kriging (EBK) Regression Prediction, significantly improved the accuracy of precipitation and runoff predictions (see **Figure 3-4** and **Figure 3-5**), allowing for more effective integration of SWSA-sw into local-level water resource management and regulatory processes.

Groundwater Aspects of the Project

Although the focus of the report was on SWSA-sw, important groundwater interactions were noted, particularly in regions where groundwater discharge contributes to baseflows and where GDEs rely on groundwater to maintain water levels during dry seasons. The EBK prediction method used Mean Annual Precipitation (MAP) values from over 12,000 rain gauges across the country to map precipitation. This approach captured the variability in MAP and MAR, providing an indication of areas where groundwater recharge is likely higher. This represented an improvement from the WR2005 MAR data used in Nel et al. (2013), which averages MAR over time and often masks year-to-year variability in water availability (i.e., in regions subject to inter-annual rainfall fluctuations).

Additionally, the use of local topographical factors such as altitude, topographic position index (TPI), and continentality (distance from the coast) helped refine the identification of regions where groundwater recharge was more significant, particularly in mountainous and escarpment areas.

MAR was also used as an explanatory variable to model relationships between precipitation and runoff, indirectly aiding in a better understanding of groundwater recharge patterns across the study area (Lötter and Le Maitre, 2021). The inclusion of runoff data strengthened the connection between surface water and groundwater, recognising that wetland and riparian zones in both SWSA-sw and SWSA-gw contributed to both surface flow and groundwater recharge.

Limitations of the Data

The report identified a limitation in the availability of high-resolution groundwater data. While the fine-scale delineation improved surface water predictions, the integration of groundwater recharge data remained somewhat limited (Lötter and Le Maitre, 2021). The MAR data used was largely based on surface water dynamics, and finer-scale delineation of groundwater-dependent systems would require more specific groundwater datasets. The report acknowledged that further studies would be necessary to improve the integration of groundwater recharge and groundwater-surface water interactions in future SWSA delineations.

It is important to note that the fine-scale delineation of SWSA-sw was not intended as a revision of the 2018 SWSA-sw study. Instead, its primary purpose was to refine the spatial resolution of SWSA-sw so that it could be more reliably integrated into catchment- and local-level planning, management, and regulatory processes (see **Figure 3-6**). The report recommended that the next step in refining the SWSA delineations should involve creating a revised MAR surface that incorporated better groundwater recharge data. This is considered a critical step toward improving water resource management in South Africa.

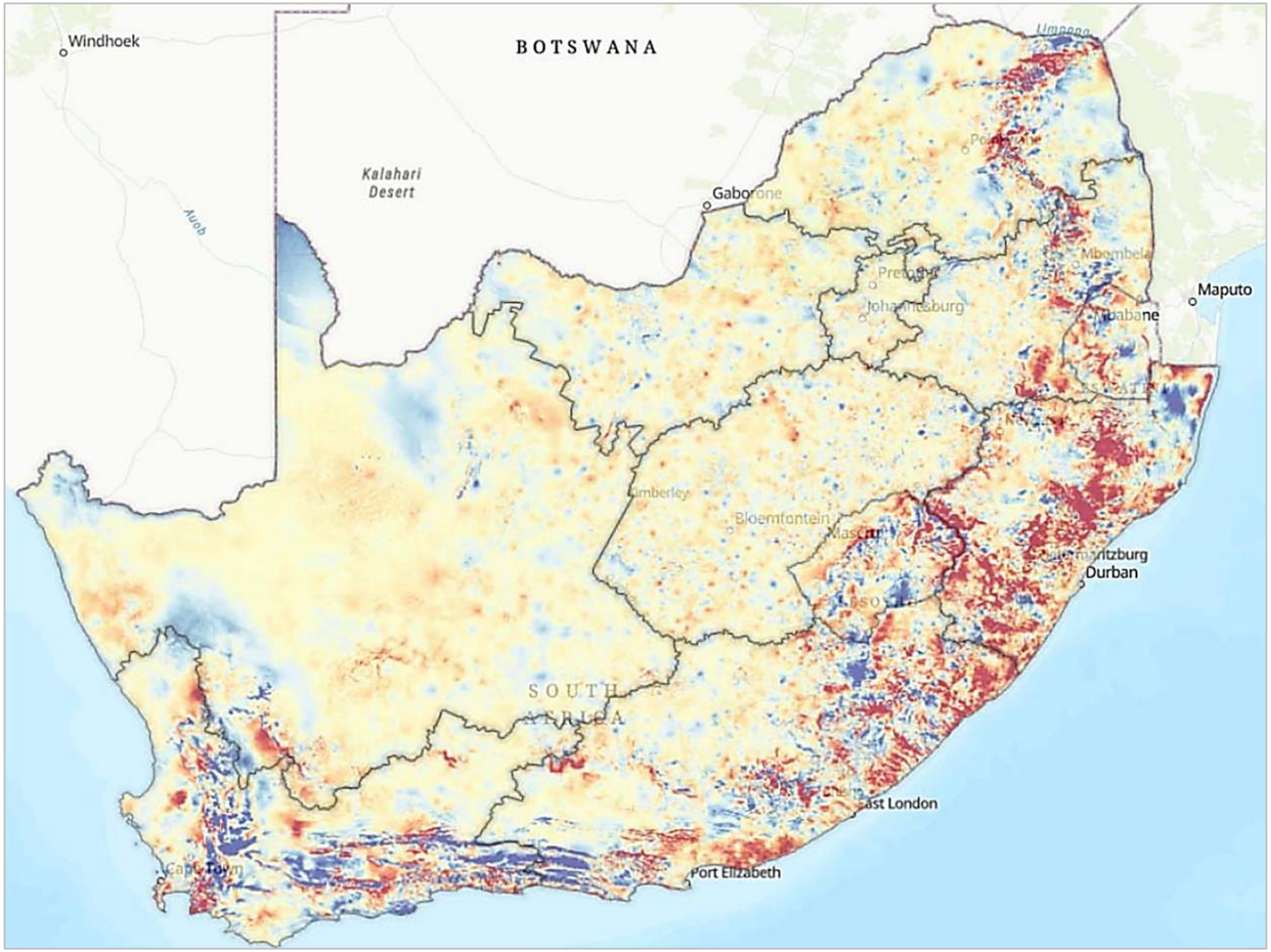


Figure 3-4 **Comparison between the downscaled precipitation surface and MAP surface from Schulze et al. (2008). Blue areas are those that the model predicts to be wetter, and red areas are those that the model predicts to be drier (from Lötter and Le Maitre, 2021).**

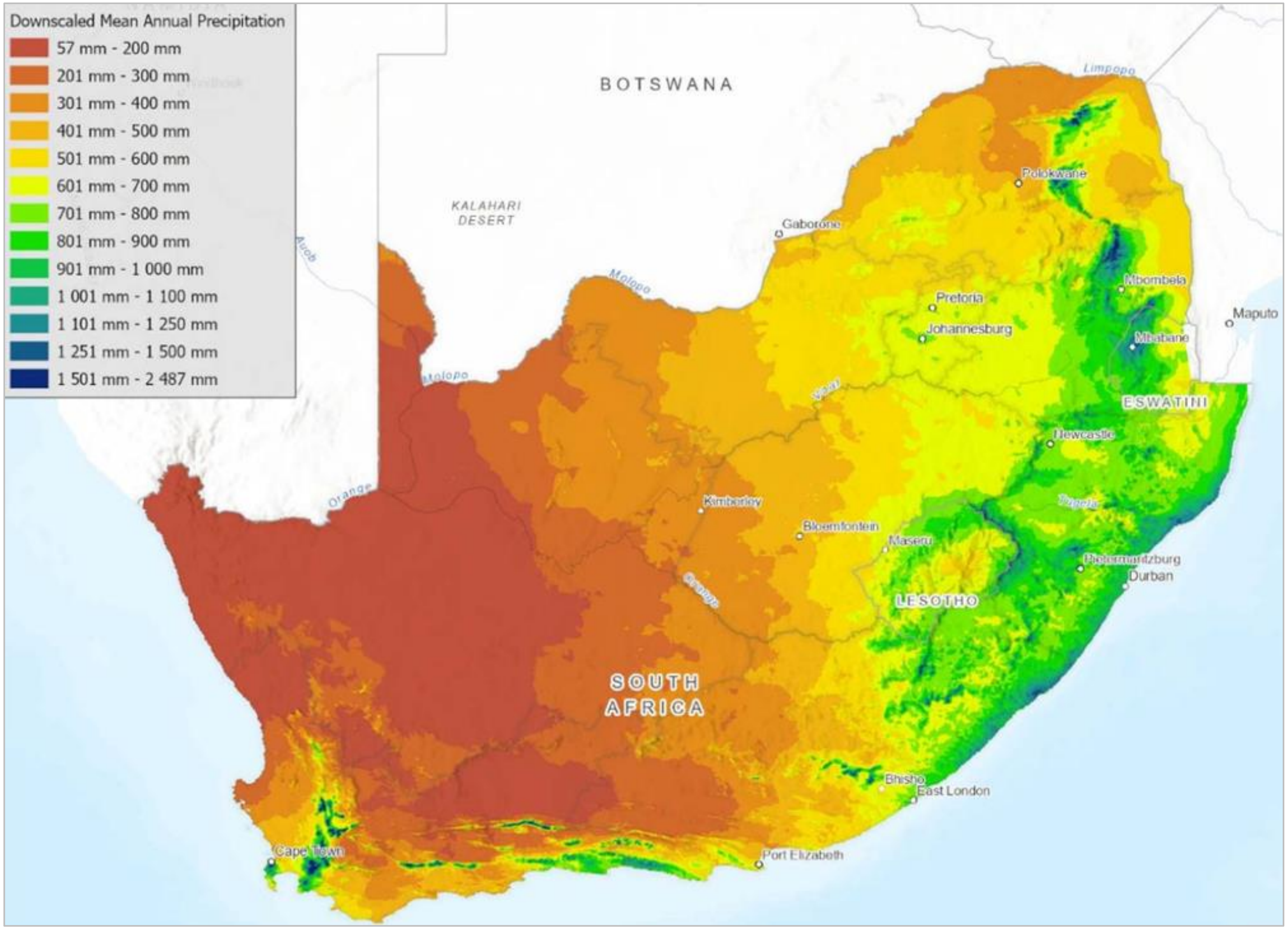


Figure 3-5 **Downscaled precipitation surface used to inform the fine-scale delineation of SWSA-sw (from Lötter and Le Maitre, 2021)**

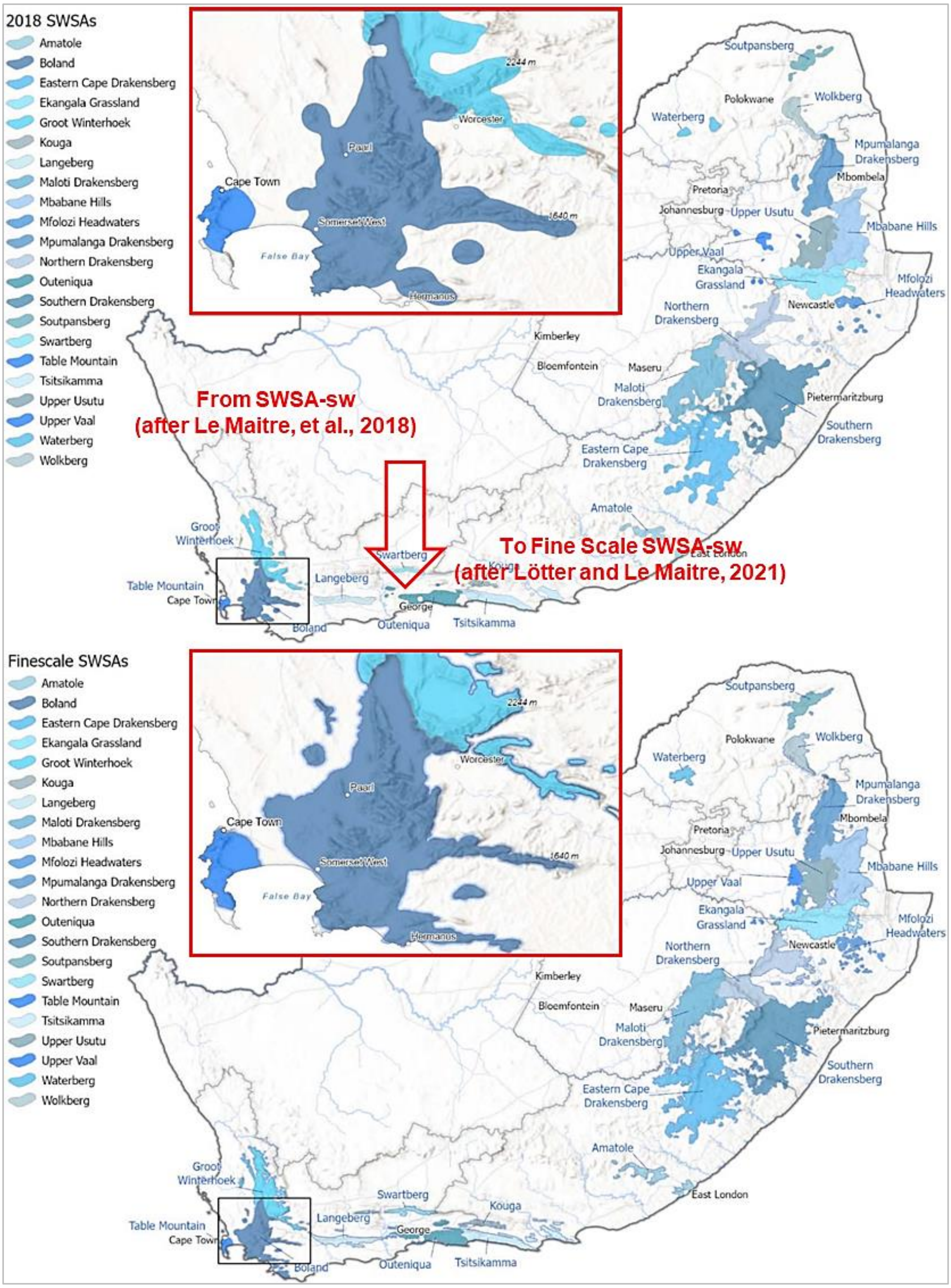


Figure 3-6 **The 22 SWSA-sw delineated at a broad scale in 2018 (upper, Le Maitre et al. 2018) which have now been refined to a finer scale (lower). The inset map illustrates the improved resolution for the Boland area (from Lötter and Le Maitre, 2021).**

The Department of Forestry, Fisheries, and the Environment's 2019/20 - 2023/24 Strategic Plan, under Programme 5: Biodiversity and Conservation, aims to regulate and manage biodiversity, heritage, and conservation to support sustainable economic growth and development. Interventions have been implemented to conserve SWSAs and wetlands, including five Ramsar-designated wetlands of international significance. Additionally, 11 of 22 SWSA-sw are in the process of being secured (see **Figure 3-8**), with the following targets: 2022/23 - Secured 5 SWSA-sw: 1) Boland, 2) Ekangala Grassland, 3) Mpumalanga Drakensberg, 4) Northern Drakensberg, 5) Southern Drakensberg. 2023/24 - Secured 6 SWSA-sw: 6) Maloti Drakensberg, 7) Eastern Cape Drakensberg, 8) Outeniqua, 9) Amatole, 10) Waterberg, 11) Wolkberg.

PROGRAMME 5: BIODIVERSITY AND CONSERVATION

Purpose: Ensure the regulation and management of all biodiversity, heritage and conservation matters in a manner that facilitates sustainable economic growth and development.

Outcome	Outcome indicators	Baseline (2017/18)	Five Year Target 2023/24
Ecosystems conserved, managed and sustainably used	Percentage of land under conservation	12.96% (15,797,120.74 / 121,909,000.00)	15.7% (19 175 164 / 121,909,000 ha) in total under conservation for 2023/2024. 0.5% of land under conservation added
	Number of new national parks established	N/A	2 national parks declared
	Percentage of area of state managed protected areas assessed with a METT score above 67%	75% of area of state managed protected areas assessed with a METT score above 67%	90% (6 566 977 / 7 296 641ha of area of state managed protected areas assessed with a METT score above 67%
	Number of interventions to ensure conservation of strategic water sources and wetlands developed and implemented	N/A	3 Interventions: National Joint Wetlands Management Policy developed
			5 wetlands of international significance (Ramsar sites) designated
			11 of 22 strategic water source areas secured

Figure 3-7 Programme 5: Biodiversity and Conservation (from DFFE 2019/20 - 2023/24 Strategic Plan).

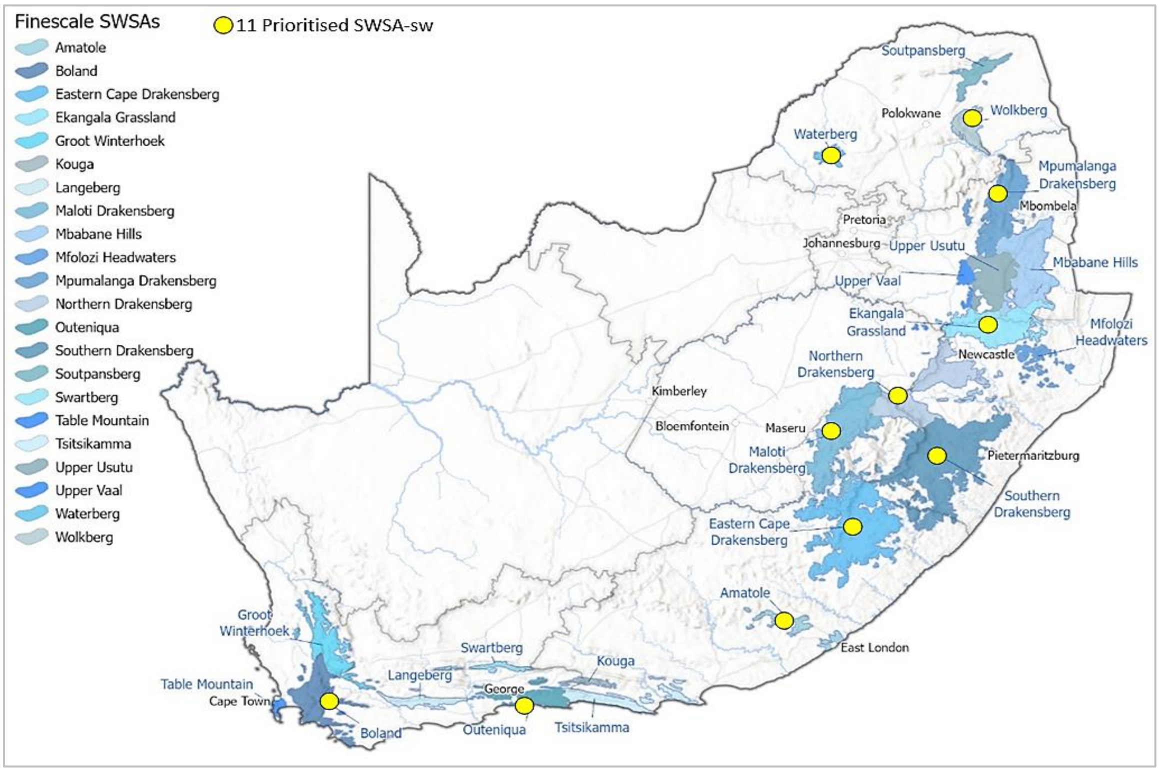


Figure 3-8 11 of the 22 SWSA-sw in the process of being secured by The DFFE 2019/20 - 2023/24 Strategic Plan, under Programme 5: Biodiversity and Conservation (from Lötter and Le Maitre, 2021).

3.1.1.6. National Water Resource Strategy

National Water Resource Strategy 2 (2013)

The National Water Resource Strategy Second Edition (NWRS-2), published in 2013, provides a comprehensive framework to ensure the efficient and sustainable management of South Africa’s water resources. It is aligned with the country's economic, social, and environmental priorities, focusing on equitable water access for all citizens, while supporting economic growth and protecting ecosystems.

The NWRS-2 emphasises water conservation, climate change adaptation, and sustainable development. Building on the initial NWRS-1 (2004), it incorporates lessons learned to secure a reliable water supply for future generations, prioritising water allocation reform, infrastructure investment, and the protection of vital water resources.

One of the key focus areas outlined in NWRS-2 is the protection of SWSAs which are critical for South Africa's water security. The NFEPA study in 2011 (**Section 3.1.1.2**) revealed concerning trends, with 48% of wetland types, 39% of estuary types, and 25% of river types classified as critically endangered. Wetland loss and degradation within major catchments are estimated to be between 35% and 60%.

The set of 21 SWSAs (see **Section 3.1.1.3**), which primarily focus on surface water, serve as essential ecological infrastructure, supporting water services and securing both water quality and quantity. Recognising their immense value, NWRS-2 designates the protection and management of SWSAs as a national priority. Therefore, SWSAs need to be acknowledged at the highest governmental levels and across all sectors to ensure their long-term sustainability.

National Water Resource Strategy 3 (2023)

The National Water Resource Strategy Third Edition (NWRS-3), published in March 2023, is South Africa’s current blueprint for water resource management. It aims to ensure equitable and sustainable access to water and sanitation services, building on the foundations laid by NWRS-1 (2004) and NWRS-2 (2013). The NWRS-3 aligns with national policies such as the National Development Plan (NDP) 2030 and international frameworks like the Sustainable Development Goals (SDGs), addressing challenges such as water scarcity, climate change, and the need for Integrated Water Resource Management (IWRM) strategies.

NWRS-3 also highlights that SWSAs (incorporated after Le Maitre, et al., 2018a; see **Section 3.1.1.4**) face significant threats from activities such as mining, urban development, and environmental degradation. Protecting these areas is critical, as they serve as foundational ecological infrastructure, ensuring water quality and quantity. The strategy calls for the exclusion of watercourses in SWSAs from mining activities and advocates for integrated catchment management to maintain the ecological health of these areas. Legal mechanisms are necessary to protect these assets and ensure that land use within SWSAs does not compromise their essential role in water provision.

The vision outlined in NWRS-3 for 2030 sets clear targets in relation to SWSAs, including reducing urban water demand by 15%, expanding water infrastructure, and restricting harmful activities within SWSAs. Additionally, the strategy underscores the importance of rehabilitating degraded water ecosystems and protecting critical groundwater recharge areas and riparian buffers. These areas are key to sustaining water supply and require proactive management, including the control of invasive species, continuous ecological health monitoring, and the integration of climate change adaptation measures into water resource planning.

3.1.2. Additional Studies and Technical Reports

Table 3-1 presents a summary of the other known studies and technical reports relevant to this project. These studies and reports, while important, do not fall under the main background studies (see **Section 3.1.1**). Instead, they provide supplementary insights and technical information that inform the overall understanding of specific groundwater resources, protection and management strategies, and various development protocols. These studies cover various years and focus on topics such as groundwater quantification, contamination management, and strategic groundwater use in South Africa.

Table 3-1: Additional Studies and Technical Reports.

Project Title	Year	Summary of Studies and Key Aspects/Outcomes	Reference
Groundwater Resource Assessment II	2004	The GRA II project introduced a framework to estimate groundwater availability, factoring in aquifer storage, recharge, and groundwater abstraction. • **Groundwater Quantification:** The Aquifer Assurance Method was developed to assess groundwater volumes under both normal and drought conditions. It provides a reliable estimate of groundwater storage that can be safely abstracted. • **Recharge Threshold:** A recharge threshold value (ARTV) was developed, indicating the minimum rainfall required to sustain groundwater recharge in different regions. The study showed that the recharge process is highly variable across catchments, especially in arid regions. The ARTV helps guide decisions on groundwater sustainability under varying climatic conditions. • **Groundwater-Surface Water Interactions:** A national algorithm was created to assess interactions between groundwater and surface water systems. This interaction was found to significantly impact river baseflows, particularly in areas with high groundwater abstraction. The study emphasised the need to manage groundwater use to avoid adverse effects on surface water systems and GDEs. • **Groundwater Use:** The study revealed gaps in groundwater use data, particularly in rural and agricultural sectors. The estimated total groundwater use in South Africa was found to be around 6% of the available groundwater resources (approximately 19.073 billion cubic meters per year). The project recommended improving data collection and monitoring to support sustainable water resource management.	Department of Water Affairs and Forestry (DWAF). (2004) Groundwater Resource Assessment II – Final Report 1A. Project No. 2003-150

Project Title	Year	Summary of Studies and Key Aspects/Outcomes	Reference
National Groundwater Strategy 2016	2016	The National Groundwater Strategy (NGS) 2016 aims to position groundwater as a key component of South Africa's overall water resource management. It seeks to ensure sustainable use, protect aquifers, and improve governance, particularly in response to growing water scarcity and the importance of groundwater for rural and drought-prone areas. • **Integration and Sustainable Management:** The NGS emphasizes the full integration of groundwater with surface water as part of national water resource management. It promotes sustainable use by protecting aquifers and recharge zones while ensuring groundwater complements surface water to enhance water security. • **Governance and Collaboration:** The strategy outlines a governance framework that supports local-level management while being driven by national leadership. It encourages collaboration between government, academic institutions, and stakeholders to build capacity and ensure effective management of groundwater resources. • **Groundwater-Surface Water Interactions and Ecosystem Protection:** The NGS highlights the importance of understanding the interaction between groundwater and surface water, especially in supporting baseflows and aquifer-dependent ecosystems. It also stresses the need to protect vulnerable aquifers from overuse and pollution, particularly in recharge zones. • **Aquifer Mapping, Research, and Data Management:** Groundwater mapping, research, and a comprehensive information management system are vital for sustainable groundwater management. These tools will improve decision-making, monitor aquifer conditions, and inform policy and governance. • **Strategic Resource and Transboundary Aquifers:** The strategy recognizes groundwater as a critical resource for water security, particularly in rural and drought-prone areas. It also promotes joint management of shared aquifers with neighboring countries to ensure sustainable and equitable use.	Department of Water and Sanitation (DWS). (2017) National Groundwater Strategy 2016

Project Title	Year	Summary of Studies and Key Aspects/Outcomes	Reference
Guidelines for Groundwater Development in the SADC Region	2001	The project goal was to develop minimum common standards for groundwater development in the SADC Member States, which would serve as regional standards and guidelines. • **Groundwater Resource Protection:** The guidelines emphasise the need to protect groundwater from contamination and over-abstraction, with a focus on safeguarding aquifers from pollution by industries and agricultural activities. • **Sustainable Groundwater Yield:** Strategies for determining and monitoring sustainable groundwater yields to avoid overuse are discussed, using hydrogeological models and aquifer testing. • **Transboundary Aquifer Management:** Cooperation between SADC countries is highlighted to manage shared aquifers sustainably. • **Artificial Recharge Potential:** The guidelines recommend potentially using artificial recharge in regions prone to seasonal droughts, storing surplus water during wet periods to maintain groundwater levels within aquifers. • **Groundwater Development Techniques:** Various borehole drilling and well siting techniques are recommended to ensure efficient groundwater abstraction and minimal environmental impact. • **Groundwater Monitoring and Data Collection:** Establishing comprehensive groundwater monitoring systems is critical to collect data on water levels, quality, and abstraction rates for sustainable groundwater management.	Southern African Development Community (SADC). (2001) Guidelines for the Groundwater Development in the SADC Region – Report No 2 (Final).

Project Title	Year	Summary of Studies and Key Aspects/Outcomes	Reference
A Protocol to Manage the Potential of Groundwater Contamination from On Site Sanitation - Edition 2	2003	A review of the GW Protocol found that while Edition 1 improved the environmental focus on sanitation projects, its inconsistent application raised concerns about its effectiveness in protecting groundwater and community health, leading to a revised Edition that addresses these issues through a two-part approach involving aerial surveys and simplified project-based procedures. • **Groundwater Contamination from Sanitation Systems:** On-site sanitation systems, such as pit latrines and septic tanks, pose contamination risks. Design modifications like raised pit latrines and filtration systems for septic tanks reduce groundwater contamination risks. • **Risk Assessment:** The report emphasises the need for a risk-based approach to assess the potential impact of sanitation systems on groundwater, factoring in aquifer vulnerability, sanitation system design, and proximity to contamination sources. The framework for assessing aquifer vulnerability is based on soil permeability, aquifer type, and depth to groundwater. • **Precautionary Measures:** Recommendations include installing lined and sealed pits, relocating water abstraction points, adopting updated sanitation technologies that minimize groundwater contamination, sanitary protection zones, and regular groundwater quality testing, especially for nitrates and pathogens.	Department of Water Affairs and Forestry (DWAF). (2003) A Protocol to Manage the Potential of Groundwater Contamination from On-Site Sanitation Practices, Edition 2
Policy and Strategy for Groundwater Quality Management in South Africa	2000	First Edition of the DWAF Policy and Strategy for the Groundwater Quality Management in South Africa. • **South Africa's water resources under stress:** The report highlights the importance of groundwater as a critical resource for more than two-thirds of South Africa's population, especially in rural and water-scarce areas. • **Policy and Strategy:** The strategy emphasises protecting groundwater from pollution and over-abstraction, with a focus on prevention, regulation, and remediation. It introduces a precautionary approach to managing groundwater resources, recognising its vulnerability and the difficulty of reversing contamination. The policy promotes public participation, IWRM, and the "polluter-pays" principle while calling for enhanced monitoring, better coordination between stakeholders, and the development of best practice standards to ensure sustainable groundwater use. • **Pollution Prevention and Control:** A Source-Directed approach to controlling pollutants, preventing contamination at the source, and remediation of polluted sites are emphasised. Resource-directed measures focus on the ecological and BHN Reserve and quality objectives for groundwater resources.	Department of Water Affairs and Forestry, Republic of South Africa. (2000). Policy and Strategy for Groundwater Quality Management in South Africa, First Edition.

Project Title	Year	Summary of Studies and Key Aspects/Outcomes	Reference
A Framework for a National Groundwater Strategy (NGS)	2007	The NGS framework was developed to provide a comprehensive approach to groundwater management in South Africa. • **Groundwater as a Strategic Resource:** Groundwater is positioned as a vital source for rural communities and agriculture, particularly in areas with limited surface water. The report emphasises integrating groundwater into South Africa's water management framework and integrating conjunctive use as an option to optimise water supply. • **Sustainable Abstraction and Aquifer Management:** Importance of regulating abstraction to prevent aquifer depletion, with a focus on irrigation-dependent regions. Emphasis was placed on sustainable abstraction and protection from pollutants, like mining runoff and agricultural waste, with recommendations for proper monitoring and management practices as well as protection zones. • **Groundwater Use Efficiency and Artificial Recharge:** Advocates artificial recharge in areas with drawdown and promotes efficiency through monitoring and incentives.	Department of Water Affairs and Forestry (DWAF). (2007) A Framework for a National Groundwater Strategy (NGS). First Edition. Prepared by Makgaleng Projects, Dirk Versfeld CC, and Water Geoscience Consulting. DWAF Report No. PRSA C000/00/4607.
Review, Evaluation, and Optimisation of South African Water Resources Monitoring Network	2017	The report aims to evaluate and optimise the South African National Water Resources Monitoring Network, focusing on both surface and groundwater systems. • **Groundwater Monitoring Sites:** The report assessed existing groundwater monitoring sites and compared them to theoretical models to identify areas that lack sufficient monitoring coverage. A priority scoring system was used to assess the importance of monitoring sites, particularly in regions with high groundwater abstraction, pollution threats, and important aquifers. • **Gaps in Monitoring Coverage:** It was noted that some areas have inadequate groundwater monitoring, particularly in regions where high-yield aquifers exist. The report suggests adding new baseline and trend monitoring sites to cover these gaps. • **Transboundary Monitoring:** Recommends collaborative monitoring programs for shared aquifers across national borders.	Department of Water and Sanitation (DWS). (2016) Review, Evaluation, and Optimisation of South African Water Resources Monitoring Network, Prepared by AECOM SA (Pty) Ltd

Project Title	Year	Summary of Studies and Key Aspects/Outcomes	Reference
Geohydrological Reports System	2024	The report highlights the distribution and availability of groundwater resources across different regions. It notes significant regional variations in groundwater availability, with some areas having abundant resources, while others are more constrained. • **Groundwater Quality Monitoring:** The report identifies gaps in specific groundwater monitoring data, which hinders effective management and decision-making. It recommends expanding the national monitoring network and improving data collection processes. The use of geohydrological models is encouraged to better understand the dynamics of groundwater systems and predict future changes in groundwater levels and quality. • **Aquifer Vulnerability and Recharge:** Data and maps assessing aquifer vulnerability to contamination and over-abstraction, with recharge estimates for sustainable management. The report discusses the natural recharge rates of aquifers and the impact of human activities on these rates. There are recommendations for controlled usage and the implementation of artificial recharge methods in areas with low natural recharge rates to maintain groundwater levels.	Geohydrological Reports System, Department of Water and Sanitation, 2024.
Guidance document on Protection Zones (Delineation and Protection): Development of methodological approach and implementation plan	2023	The report outlines a detailed methodology for assessing aquifer vulnerability using the DRASTIC system, which includes parameters such as Depth to Water, Recharge, Aquifer Media, Soil Media, Topography, Impact of the Vadose Zone, and Hydraulic Conductivity. This methodology is applied to delineate Groundwater Protection Zones (GPZs), identify Potentially Contaminating Activities (PCAs), and formulate responses to pollution. These parameters help identify areas at risk of contamination and prioritise them for protection. • **Delimiting Protection Zones:** GPZs are divided into inner, intermediate, and outer zones, each with specific protection criteria. The inner zone focuses on immediate protection near the borehole or wellhead, typically within a 10-meter radius. The intermediate zone is designed to cover areas with a two-year travel time for contaminants, and the outer zone encompasses a five- to ten-year travel time to the groundwater source. • **Management of Protection Zones:** The report recommends restricting or regulating industrial, agricultural, and wastewater activities that could introduce pollutants into the groundwater resource, ensuring that land use activities are compatible with maintaining aquifer integrity. • **Groundwater Monitoring:** The report advocates for regular monitoring within GPZs to detect contamination early and maintain aquifer health.	Gibson, K., Mc Gibbon, D. (2023) Guidance document on Protection Zones (Delineation and Protection): Development of methodological approach and implementation plan. Water Research Commission: Pretoria, WRC Report no. TT 902/22.

Project Title	Year	Summary of Studies and Key Aspects/Outcomes	Reference
Guidance Document on Groundwater Scheme Development	2023	The report outlines the six-stage lifecycle of groundwater schemes, which includes a "needs" assessment, legislative compliance, groundwater exploration, borehole drilling and testing, implementation, and operation and maintenance. • **Groundwater Exploration and Borehole Development:** The report provides technical guidance for locating groundwater using methods such as geophysical surveys, which help identify optimal drilling sites based on subsurface characteristics. Borehole development involves advanced drilling techniques tailored to specific geological conditions, ensuring that aquifers are tapped efficiently while minimising environmental impact. • **Sustainable Use of Groundwater:** A key focus is on ensuring that groundwater abstraction is balanced with natural recharge rates and storage to prevent long-term depletion, particularly in drought-prone areas. The report emphasises the need for municipalities to adopt sustainable water use practices, considering aquifer capacity, community demand, and climate variability. • **Operation and Maintenance:** Recommendations for maintaining boreholes, and pumps, and monitoring water quality to ensure continuous water supply.	Pietersen, K., Titus, R. (2023) Guidance document on groundwater scheme development. Water Research Commission: Pretoria, WRC Report no. TT 903/22.
Conjunctive Water Use Guideline	2023	The report provides guidelines for integrating the use of surface and groundwater to optimise water availability, particularly in drought-prone regions. • **Aquifer Recharge and Conjunctive Use:** Promotes Managed Aquifer Recharge as a strategy to maintain groundwater levels during periods of surplus surface water. This involves intentionally directing surface water into aquifers to replenish groundwater reserves, ensuring a balanced water supply during drier periods. By recharging aquifers when surface water is abundant, municipalities can safeguard against the long-term depletion of groundwater resources and ensure sustainable water management. • **Management of Aquifer:** Recommends monitoring groundwater levels alongside surface water availability to prevent aquifer depletion.	Masemola, M. and Pietersen, K. (2023) Conjunctive Water Use Guideline. Water Research Commission: Pretoria, WRC Report no. TT 904/22.
Guidance Document on Groundwater Data Collection	2023	Emphasises the importance of robust groundwater monitoring systems, collecting data on water levels, quality, and abstraction rates. • **Hydrogeological Data:** The report provides detailed protocols for data collection from boreholes and aquifers. It highlights methods for measuring water levels, such as using dip meters and data loggers, and provides guidelines for collecting water quality samples, including chemical analysis to detect contaminants. This systematic approach ensures accurate, reliable data for effective groundwater management. • **Data Standardisation:** Advocates for standardizing groundwater data collection methods across regions to ensure consistency and comparability.	Woolf, K., McGibbon, D., Misrole, M., Mkali, A., Flügel, T. (2023) Guidance Document on Groundwater Data Collection. Water Research Commission: Pretoria, WRC Report no. TT 905/22.

Project Title	Year	Summary of Studies and Key Aspects/Outcomes	Reference
Guidance Document for Management of a Groundwater Scheme	2023	Focuses on the long-term management of groundwater schemes, including operation, maintenance, and optimisation. • **Preventing Groundwater Over-Abstraction:** The guidance stresses the need to set abstraction limits that align with aquifer recharge rates, especially in areas at risk of over-abstraction. It advocates for sustainable water use through continuous monitoring and adaptive management practices, ensuring that groundwater abstraction does not exceed natural replenishment rates. This practice helps protect aquifers from long-term depletion and maintains their viability for future use. • **Groundwater Infrastructure Maintenance:** Stresses the importance of maintaining boreholes, pumps, and treatment systems to ensure a continuous water supply.	De Bruin, K., Rademan, Z., Towers, T. (2023) Guidance Document for Management of a Groundwater Scheme. Water Research Commission: Pretoria, WRC Report no. TT 906/22.
Stats SA: Census Data	2011 to 2022	Stats SA's Census Database provides socio-economic statistics, including population distribution and household data (i.e., those supplied by formal water schemes or their reliance/degree of dependence on other water resources for BHN). This information is vital for groundwater demand assessments and groundwater Reserve calculations, helping evaluate water resource dependency and access to basic services.	Stats SA: Census (2011), Community Survey (2016), Pilot Census (2018), Census (2022)
Water Availability Assessment Study (WAAS)	2005 to 2017	WAAS integrates groundwater and surface water data to quantify allocable water and assess water availability in South Africa. It is crucial for water resource management and licensing and provides integrated data on groundwater and surface water availability. • **Have**: The Assessment of Water Availability in the Berg Catchment • **Need**: Upper Orange WAAS, Vaal WASS, Limpopo Basin WASS, Olifants WASS, Breede-Gouritz WASS, Mzimvubu to Tsitsikamma WASS, KwaZulu-Natal WASS and Western Cape System WAAS	Department of Water Affairs and Forestry, South Africa. 2008. The Assessment of Water Availability in the Berg Catchment (WMA 19) by Means of Water Resource Related Models: Groundwater Model Report Volume 5 – Cape Flats Aquifer Model. Prepared by Umvoto Africa (Pty) Ltd in association with Ninham Shand (Pty) Ltd on behalf of the Directorate: National Water Resource Planning. DWAF Report No. P WMA 19/000/00/0408
Water Resources of South Africa Study (WR2012)	2012	WR2012 offers integrated data on rainfall, runoff, and groundwater, providing valuable insights into recharge rates and baseflow It builds on WR2005 and includes additional datasets for South Africa, Lesotho, and Swaziland, using the WRSM2000/Pitman model for hydrological studies. The study contains rainfall data, network diagrams, streamflow data, and water quality information, making it a key resource for water resource assessments. Data on rainfall, runoff, groundwater recharge, GIS maps, streamflow data, water quality, land/water use, and reservoir records are included.	Sami, K., 2015. Water Resources Of South Africa, 2012 Study (WR2012). Water Research Commission.

Project Title	Year	Summary of Studies and Key Aspects/Outcomes	Reference
Some Legal Options to Ensure the Protection of South Africa's Utilisable Groundwater Resources	2002	The report emphasises that groundwater is susceptible to over-abstraction and pollution, especially from land-based activities such as mining, industrial waste disposal, and improper use of septic tanks. Unregulated land use is a significant threat to groundwater sustainability. • **Legislative Framework:** South Africa's National Water Act of 1998 integrates groundwater and surface water under a single legal framework. However, the document notes that existing legislation leans heavily toward surface water, with insufficient focus on groundwater management and protection. • **Groundwater Protection Zones:** The authors suggest implementing Groundwater Protection Zones (GPZs) as a key legal mechanism to safeguard vulnerable groundwater areas. These zones would restrict harmful land-use activities and ensure that land development does not threaten groundwater quality. International examples from the UK and Germany are mentioned as models for such an approach. • **Recommendations:** The document recommends integrating groundwater management into land-use planning and proposes legislative amendments to enforce the creation of GPZs. Stronger regulatory enforcement is required to manage and protect South Africa's aquifers.	Viljoen, G. and Bosman, C. (2002) Some Legal Options to Ensure the Protection of South Africa's Utilisable Groundwater Resources, Department of Water Affairs and Forestry

Project Title	Year	Summary of Studies and Key Aspects/Outcomes	Reference
The National Water Monitoring Plan (NWMP)	2022	The National Water Monitoring Plan (NWMP) provides a strategic framework to improve water resource monitoring across South Africa. Groundwater monitoring is critical for ensuring sustainable water management, and this plan seeks to address data gaps, optimize monitoring networks, and integrate groundwater monitoring into national water governance. • **Groundwater Integration and Monitoring:** Groundwater is recognized as a critical component of the country's water resources. The NWMP calls for a more comprehensive groundwater monitoring network to support sustainable management and to provide accurate data for decision-making. Special emphasis is placed on enhancing existing groundwater monitoring programmes. • **Data Management and Infrastructure:** The plan identifies key challenges such as data gaps, lack of standardization, and poor maintenance of monitoring infrastructure. It proposes improving data acquisition, enhancing the monitoring network, and upgrading monitoring stations. This will ensure reliable groundwater data is available for policy-making and resource management. • **Collaboration and Capacity Building:** The NWMP emphasizes the need for greater collaboration between government entities, academic institutions, and local stakeholders to improve groundwater data collection and analysis. It also highlights the importance of capacity-building to address skills shortages in groundwater monitoring. • **Governance and Standardization:** Improved governance is a central focus, with the aim to streamline monitoring operations and standardize protocols for data collection, management, and dissemination. Partnerships between stakeholders are encouraged to integrate groundwater data with other water resource management systems.	Department of Water and Sanitation. (2022). National water monitoring plan (Final version, 2021/22). Department of Water and Sanitation, South Africa.
Aquifers of South Africa	Various	• **Table A-3, Table A-4, Table A-5, Table A-6, and Table A-7** provide a list and summary description of groundwater-related studies across several regions of South Africa. Each table contains information on key aquifers, study areas, and summaries of significant research findings, along with identified limitations and gaps in data (see **APPENDIX A**). • The focus is on groundwater recharge potential, aquifer characteristics, and the challenges related to managing water resources in arid and semi-arid regions. Common challenges highlighted include data scarcity, high variability in recharge rates, and the complexity of aquifer systems, which complicates predictive modelling and sustainable management efforts. These insights are critical for improving groundwater governance and addressing water scarcity challenges in South Africa.	Various

3.2. Groundwater Resource Tools and Databases

As outlined in **Section 1.3** and **Table 1-1**, Task T2.1.2 of Phase 2 of the project involves compiling an inventory of relevant groundwater resource tools and providing some explanation of their applicability to the study. The focus is on assessing how these tools can be effectively used within the study's scope and objectives, and how they can contribute to the refinement process for SWSA-gw. The task includes providing detailed explanations of each tool's relevance and commenting on how they can enhance groundwater resource management in the context of the study.

Table 3-2 below presents an overview of key tools and data sources related to groundwater and water resource management in South Africa. These tools, databases, and programs are instrumental for monitoring, regulation, and analysis, supporting the sustainable management of both surface and groundwater resources. Each entry outlines the type of tool/database, its role in resource assessment, and the latest available updates. Together, these tools play a crucial role in enhancing water conservation, ensuring regulatory compliance, and informing resource allocation decisions.

Table 3-2: Key Groundwater and Water Resource Management Tools in South Africa

Data Source	Overview	Available data	Website	Dataset downloaded
Africa Groundwater Atlas	A comprehensive online resource designed to improve access to groundwater information across Africa. It provides key data on groundwater resources for 51 African countries, including hydrogeological summaries, maps, and references for further research. The platform aims to support the sustainable use and management of groundwater resources, which is crucial for water security, economic growth, and food security on the continent.	Aquifer types, groundwater productivity, hydrogeological maps (GIS shapefiles available), and supporting information on groundwater status, usage, and management.	https://africangroundwateratlas.org	Available for download if required
Aquaknow	An advanced knowledge-sharing platform, developed by the European Commission's Joint Research Centre (JRC), focused on the water sector. It provides access to a variety of datasets, documents, and tools related to water resource management, particularly aimed at supporting decision-making in developing countries. AquaKnow offers geo-referenced datasets that cover multiple fields such as hydrology, soil, climate, land use, and topography.	Water resources, soil properties, hydrological, and climate data.	https://aquaknow.jrc.ec.europa.eu	Available for download if required

Data Source	Overview	Available data	Website	Dataset downloaded
CSIR: Spatial and Temporal Evidence for Planning in South Africa (StepSA)	Socio-economic data for assessing groundwater demand and usage patterns. The platform integrates spatial socio-economic data to support water resource management, urban planning, and investment decisions. This helps in evaluating the socio-economic impact of groundwater resources.	Provides tools for simulating land use, population trends, and economic factors to assess water demand and groundwater's socio-economic impact.	https://stepsa.co.za	The most recent data was downloaded on 27/06/2024.
Global Groundwater Information System (GGIS)	An interactive, web-based portal to access information on groundwater resources across the world, for supporting groundwater resource assessments and management.	Provides access to groundwater data globally, including map layers, well and monitoring data, thematic map viewers, and documents.	https://ggis.un-igrac.org	Available for download if required
Groundwater Resource Information Project (GRIP)	Unpublished groundwater data by verifying boreholes in the field, focusing on rural areas in South Africa. It has significantly enhanced groundwater data resources, particularly in Limpopo, KwaZulu Natal and the Eastern Cape Province, improving borehole drilling success rates and groundwater management. The initiative improves groundwater management by providing unpublished data.	Borehole data, groundwater levels, and field assessments, primarily focused on rural areas.	https://www.dws.gov.za	The most recent data was downloaded on 27/06/2024.
Hydstra	A national groundwater database was established by the DWS in 2004 to address limitations in the National Groundwater Archive (NGA), especially for storing large datasets. It holds continuous groundwater level measurements recorded at daily, hourly, or even second intervals, making it a critical resource for long-term groundwater monitoring, modelling, and recharge estimation. NGA data collected after 2004 was migrated to Hydstra. If sites were inactive at the time of migration, they are kept in the NGA database (only active sites were migrated).	Groundwater level measurements (hourly, daily), test pumping data, abstraction rates, and historical data for long-term monitoring.	https://www.dws.gov.za	The most recent data was downloaded on 11/09/2024.
International Groundwater Resources Assessment Centre (IGRAC)	IGRAC is a global centre for groundwater information, providing datasets on transboundary aquifers, groundwater monitoring, and international water resource management. It supports both global and regional groundwater assessments.	Global groundwater data including transboundary aquifers, groundwater monitoring, and international cooperation in groundwater assessments.	https://www.un-igrac.org	The most recent data was downloaded on 27/06/2024.

Data Source	Overview	Available data	Website	Dataset downloaded
Mine Water Atlas	The Mine Water Atlas contains data on groundwater contamination risks associated with mining activities in South Africa. It provides solutions to mitigate these risks and manage groundwater resources affected by mining.	Groundwater contamination data in mining areas, risk assessments, and mitigation strategies for managing water resources impacted by mining.	https://www.wrc.org.za	The most recent data was downloaded on 27/06/2024.
National Chemical Monitoring Programme (NCMP)	Monitors the chemical quality of South Africa's water resources, including major ions and trace elements, to assess the suitability of groundwater for drinking and agricultural use.	Data on water quality, including chemical parameters such as major ions and trace elements.	https://www.dws.gov.za	The most recent data was downloaded on 27/06/2024.
National Groundwater Archive (NGA)	A repository for various borehole datasets, including borehole information, lithology, groundwater levels (inactive sites pre-2004), and abstraction rates. It is essential for capturing, storing, and accessing national groundwater information. Established in the 1960s, it serves hydrogeological assessments, desktop studies, and groundwater modelling. Test pumping data is also available, offering which can be used to calculate recommended abstraction rates based on aquifer tests.	Borehole data (location, lithology, water strikes, water level), abstraction rates, water quality (EC, pH, temperature), and historical groundwater data.	https://www.dws.gov.za	The most recent data was downloaded on 24/04/2024.
National Groundwater Quality Monitoring Programme (NGwQMP)	Integrates long-term groundwater quality data, monitoring trends in pollutants and contamination risks, helping assess changes in groundwater chemistry over time and potential risks to human health.	Long-term groundwater quality data, including major elements.	https://www.dws.gov.za	The most recent data was downloaded on 27/06/2024.
National Integrated Water Information System (NIWIS)	Provides dashboard-based information on water resource management, covering climate change, water quality, disaster management, and water services. It facilitates high-level analysis and decision-making across South Africa's water value chain, offering data on drought conditions, groundwater status, and water quality compliance.	Dashboard-based data on climate, water quality, water resource management, and disaster monitoring.	https://niwis.dws.gov.za	The most recent data was downloaded on 24/04/2024.
National Microbial Monitoring Programme (NMMP)	Tracks microbial contaminants in groundwater across South Africa (focusing on pathogens) to ensure the safety of groundwater sources for public and environmental health.	Monitors microbial contaminants in groundwater, including data on microbial pathogens.	https://www.dws.gov.za	The most recent data was downloaded on 27/06/2024.

Data Source	Overview	Available data	Website	Dataset downloaded
OneGeology	An international initiative aimed at making global geoscience data more accessible through the use of web services. It is coordinated by a consortium of geological surveys and geoscience organizations worldwide. The initiative focuses on promoting the exchange of geological knowledge, skills, and data using standardised geodata formats.	Geological map data from participating countries and organisations.	https://www.onegeology.org	Available for download if required
ORASECOM GIS Server	Focuses on providing spatial data and maps related to the Orange-Senqu River Basin, which spans across Botswana, Lesotho, Namibia, and South Africa. It supports regional water resource management under the custodianship of the Orange-Senqu River Commission (ORASECOM).	Boundaries for tertiary and quaternary surface water catchments, information on transboundary aquifers, spatial data on water quality, temperature data, rainfall, and other climatological variables for the basin.	http://gis.orasecom.org	Available for download if required
Ramsar Sites Information Service (RSIS)	An online platform that provides access to data about wetlands of international importance, known as Ramsar Sites. These sites are designated under the Ramsar Convention, an international treaty for the conservation and sustainable use of wetlands. The service enables users to search for sites by region, country, designation date, wetland type, ecosystem services, and more.	Boundary data of designated Ramsar Sites, descriptions of the wetland’s biodiversity, ecological character, water flow systems, and threats. Site management plans and information on why the site was designated, such as its importance for waterfowl, rare species, or unique ecosystems.	https://rsis.ramsar.org	Available for download if required
Resource Quality Information Services (RQIS)	Stores data on surface water quality, often combined with groundwater data for integrated water resource management.	Summaries of water quality data for rivers, dams, and lakes.	https://www.dws.gov.za	The most recent data was downloaded on 27/06/2024.
SADC Groundwater Information Portal (SADC-GIP)	A regional database that consolidates groundwater data from Southern African countries, supporting transboundary water management and aquifer assessments. It provides access to datasets on boreholes, groundwater quality, and geological maps, along with data on waste management and water supply systems across the region. This portal facilitates cross-border cooperation for shared groundwater resources and addresses regional water challenges.	Hydrogeological maps, borehole locations, groundwater quality, and aquifer data for cross-border management in Southern Africa.	https://sadc-gip.org	The most recent data was downloaded on 26/06/2024.

Data Source	Overview	Available data	Website	Dataset downloaded
SADC Groundwater Literature Archive (SADC-GLA)	An online platform that provides access to published and unpublished literature relevant to groundwater management within the SADC. The archive contains over 4,000 references, including journal articles, books, reports, theses, conference papers, policy documents, and maps.	Published and unpublished literature	https://sadc-gla.org	Available for download if required
South African GeoPortal	Provides geographic and hydrological data essential for environmental conservation and regional water resource planning. It includes datasets like Water Management Areas (WMA) from 2004 and 2023, as well as primary, secondary, tertiary, and quaternary catchment data, which are important for managing hydrological flows and water resource planning.	Geographic and hydrological data, including WMAs, quaternary catchment data, and land use information for hydrological modelling.	https://za.africageoportal.com	The most recent data was downloaded on 27/06/2024.
South African National Biodiversity Institute (SANBI)	SANBI provides biodiversity data used in groundwater studies to assess the ecological impacts of groundwater use. This information supports conservation efforts and ensures the sustainability of groundwater resources.	Biodiversity data (i.e., protected areas) supporting conservation and ecological impact studies related to groundwater. The National Spatial Biodiversity (2018), hosted on the SANBI website was used.	https://www.sanbi.org	The most recent data was downloaded on 27/06/2024.
Water Management System (WMS)	WMS is a database for storing groundwater quality data from multiple monitoring programs, essential for tracking groundwater quality over time. It includes data from the National Groundwater Quality Monitoring Programme (NGwQMP), offering over 38,460 macro-element samples and 661,360 individual laboratory analyses (according to the website). The system aids in ensuring compliance with water quality standards.	Groundwater quality data (pH, EC, temperature), major ions, trace elements, and microbiological data.	https://www.dws.gov.za	The most recent data was downloaded on 24/04/2024.
Water Point Data Exchange (WPDx)	A global platform dedicated to sharing and managing water point data. WPdx aggregates data from over 435,000 water points, contributed by governments, NGOs, and other organisations. The platform focuses on enhancing water service management, particularly in rural and underserved areas.	A dataset containing all water point data shared on the platform can be filtered, visualized, and downloaded. Includes basic information about the water points, such as location, status, and technology used.	https://www.waterpointdata.org	Available for download if required

Data Source	Overview	Available data	Website	Dataset downloaded
Water Research Commission Knowledge Hub	A “Knowledge Hub” dedicated to advancing water-related research, innovation, and policy development. Through its platform, the WRC provides access to a vast repository of research reports, tools, and GIS resources on topics such as water management, sanitation, groundwater governance, and ecosystem monitoring.	Research reports related to water resource management, sanitation technologies, and water use in agriculture. This includes access to studies and tools for groundwater management, water use, and policy implementation.	https://search.wrc.org.za	Available for download if required
Water Services Development Plan (WSDP)	Offers a comprehensive framework for water services planning at the municipal level, integrating surface and groundwater resources to promote sustainable water use. It provides access to demographic and service level data to assist local governments in making informed water resource management decisions.	Demographic data, water quality compliance, groundwater use (abstraction data per scheme) and groundwater-surface water integration.	https://www.dws.gov.za	The most recent data was downloaded on 27/06/2024.
Water Use Authorization & Registration Management System (WARMS)	A national database that tracks registered water use volumes for both surface and groundwater in South Africa. It plays a crucial role in managing water allocations, monitoring usage, and ensuring compliance with water use regulations. This data supports groundwater resource assessments by providing insights into water use volumes and locations, aiding in the implementation of Section 137(2)(c) of the National Water Act (NWA) of 1998.	The system provides detailed data on registered water use including resource types (boreholes, dams), sectors (irrigation, industry), registered water volumes, date of registration, and associated property information.	https://www.dws.gov.za	The most recent dataset was downloaded on 17/04/2024.
World-wide Hydrogeological Mapping and Assessment Programme (WHYMAP)	An initiative designed to compile and visualise global groundwater data to support the sustainable management of groundwater resources.	A variety of detailed maps and datasets on groundwater resources, aquifer systems, and their vulnerability to environmental threats such as floods and droughts.	https://www.whymap.org	Available for download if required

4. SYNTHESIS AND RECOMMENDATIONS

4.1. Groundwater Use

As summarised in **Section 3.2** (see **Table 3-2**), the WARMS database is a national database that tracks registered water use volumes for both surface and groundwater in South Africa. It plays a critical role in managing water allocations, monitoring usage, and ensuring compliance with national water use regulations. The database contains detailed information on current and intended water use, registration dates, and associated property data. This information supports various groundwater resource assessments by providing insights into water use volumes and allocations, thereby aiding in the implementation of Section 137(2)(c) of the National Water Act (NWA) of 1998.

Key data parameters were identified to assess data quality and integrity of the WARMS database, focusing on Geographic and Property Identifiers (e.g., register number, borehole location, latitude and longitude, WMA registration, property ID, and Surveyor-General Cadastral Code) and Monitoring and Water Use Data (e.g., registration status, water use number, resource type, water use sector, and registered volume). After evaluating the completeness of these datasets, the overall data availability and completeness scores were calculated as 4.4 for Geographic and Property Identifiers and 4.6 for Monitoring and Water Use Data (see **Section 2.2**). This data provides crucial insights and will be used to assess the status quo for the total water distribution across various water resources and water use sectors, particularly in SWSA-gw.

As of 17 April 2024 (WARMS data download date), there are 159,030 active registered water users nationwide, collectively using a total of 35,699.76 Mm^3 of water. Of this volume, 5,589.79 Mm^3 are from boreholes and 308.67 Mm^3 from springs/eyes. The majority of active registered water users come from boreholes and river/stream sources, accounting for 120,842 registrations combined (see **Table 4-1** and **Figure 4-1**).

Regionally, the Vaal-Orange WMA holds the highest registered water volume at 10,628.09 Mm^3, of which 6,407.30 Mm^3 is used for agriculture, particularly crop irrigation, and 2,173.25 Mm^3 is used for urbanized industry. There are a total of 21,070 scheme registrations, the majority of which are surface water schemes, using a total volume of 17,635.51 Mm^3 (see **Table 4-2, Table 4-3, Table 4-4** and **Figure 4-2, Figure 4-3, Figure 4-4**).

Table 4-1: Total number of registrations and corresponding registered volumes (Mm^3) by water resource type in South Africa (source: WARMS downloaded 17 April 2024).

Water Resource Type	Total No. of Registrations	Total Registered Volume (Mm^3)
Borehole[1]	59,028	5,589.79
Dam[2]	12,172	2,582.49
Estuary[2]	32	7.60
Lake[2]	134	66.51
River/Stream[2]	61,814	9,485.01
Scheme[3]	21,070	17,635.51
Spring/Eye[1]	4,658	308.67
Wetland[2]	122	24.17
Grand Total	**159,030**	**35,699.76**

[1] Considered Groundwater
[2] Considered Surface Water
[3] In the WARMS database, there is no clear or consistent data field that distinguishes groundwater schemes from surface water schemes, although the majority are surface water linked to dams.

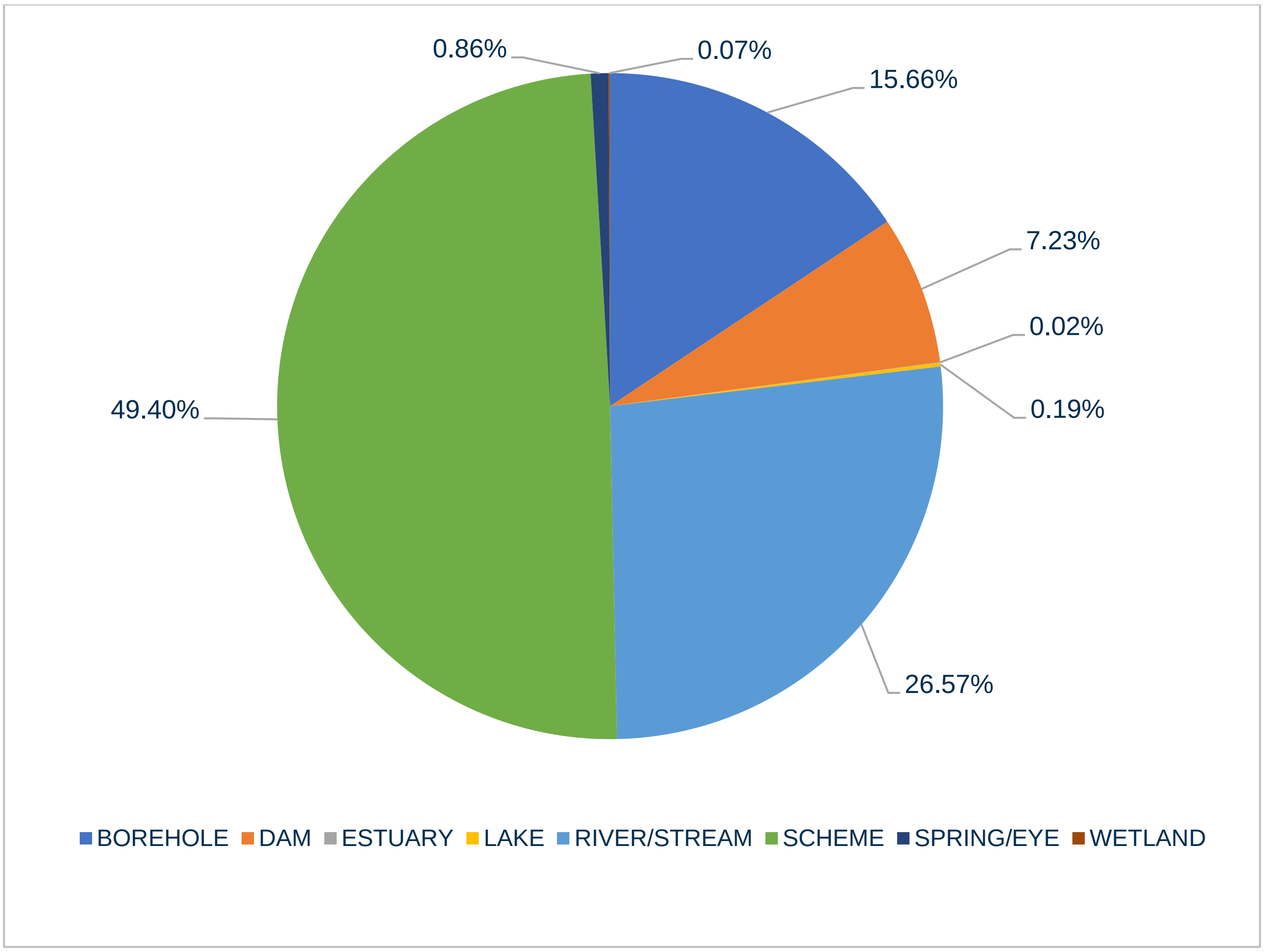


Figure 4-1 **Percentage of total registered volume by water resource type in South Africa (source: WARMS downloaded 17 April 2024).**

Table 4-2: **Total number of registrations and corresponding registered volumes (Mm^3) by water use sector in South Africa (source: WARMS downloaded 17 April 2024).**

Water Use Sector	Total Registrations	Total Volume (Mm^3)
Agriculture: Aquaculture	334	89.69
Agriculture: Irrigation	111,380	22,415.31
Agriculture: Watering Livestock	6,694	128.18
Industry (Non-Urban)	4,386	505.29
Industry (Urban)	5,192	3,948.54
Mining	5,098	1,846.20
Power Generation	536	67.24
Recreation	318	12.70
Schedule 1	16,192	141.97
Urban (Excluding Industrial &/Or Domestic)	326	6.40
Water Supply Service	8,574	6,538.24
Grand Total	**159,030**	**35,699.76**

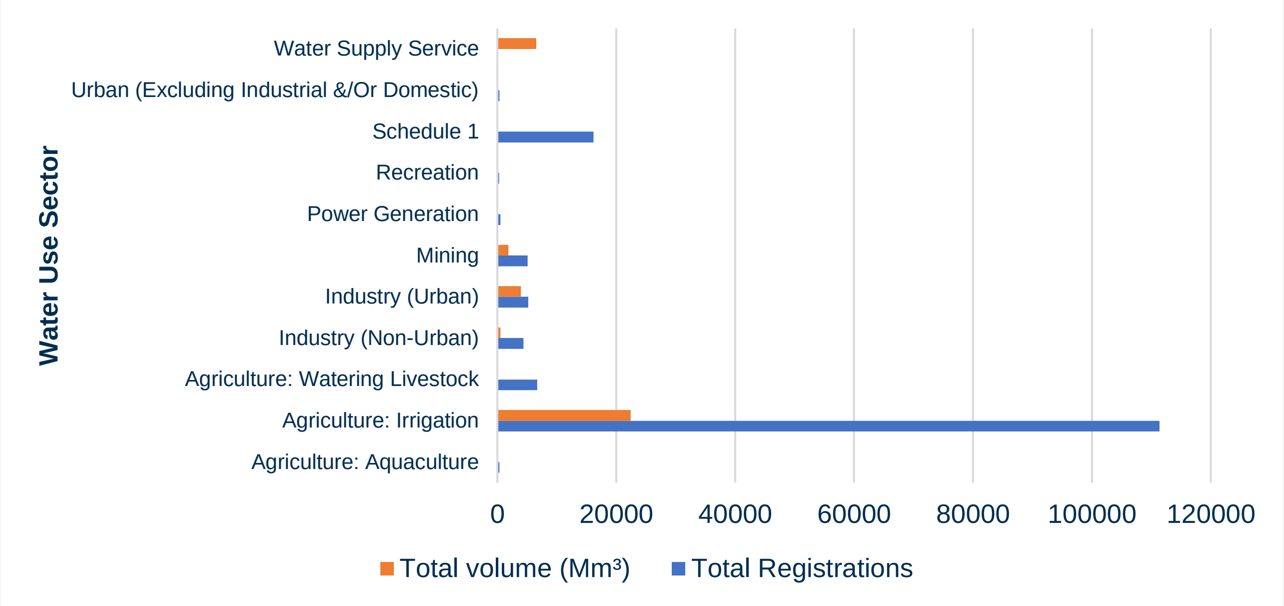


Figure 4-2: **Distribution of the total number of registrations and corresponding registered volumes (Mm^3) by water use sector in South Africa (source: WARMS downloaded 17 April 2024).**

Table 4-3: **Total number of registrations and total registered volume (Mm^3) per Water Management Area (WMA) as defined in NWRS-3, 2023 (source: WARMS downloaded 17 April 2024).**

Water Management Area	Total No of Registrations	Total Registered Volume (Mm³)
Breede-Olifants	33,834	2,916.17
Inkomati-Usuthu	5,096	1,504.87
Limpopo-Olifants	35,720	3,737.68
Mzimvubu-Tsitsikamma	20,946	1,859.81
Pongola-Mtamvuna	23,782	2,517.31
Vaal-Orange	39,652	5,314.04
Grand Total	**159,030**	**35,699.76**

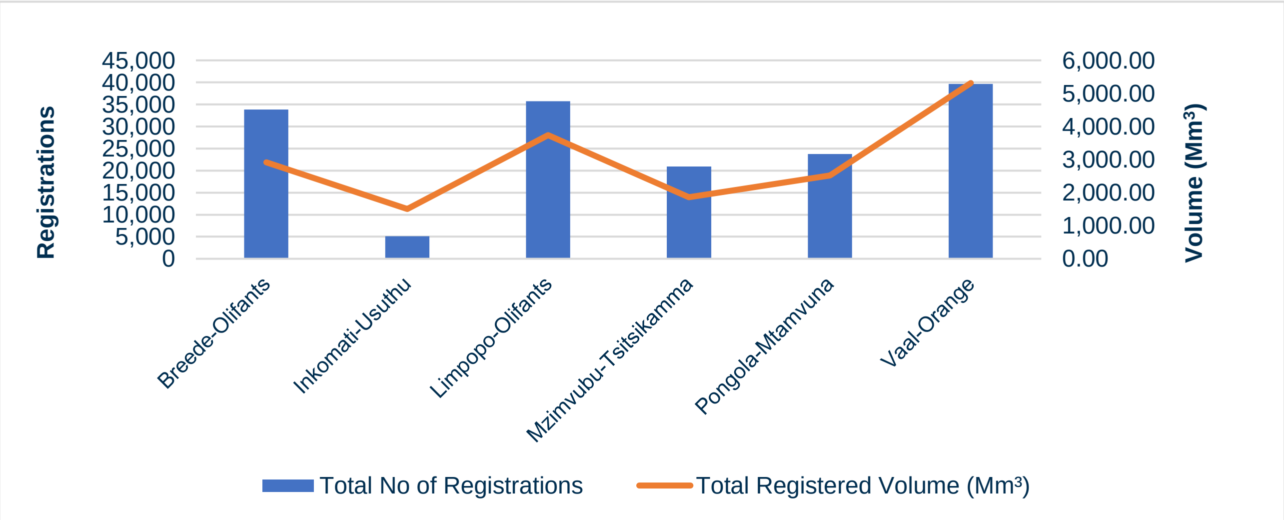


Figure 4-3 **Total number of registrations and total registered volume (Mm^3) per Water Management Area (WMA) as defined in NWRS-3, 2023 (source: WARMS downloaded 17 April 2024).**

Table 4-4: Total number of registrations and corresponding registered volumes (Mm³) per WMA by water use sector in South Africa (source: WARMS downloaded 17 April 2024).

WMA	Water Use Sector	Total No of Registrations	Total Volume (Mm³)
Breede-Olifants	Agriculture: Aquaculture	72	9.20
	Agriculture: Irrigation	27,974	4,380.32
	Agriculture: Watering Livestock	1,594	28.32
	Industry (Non-Urban)	1,006	22.74
	Industry (Urban)	1,406	832.57
	Mining	62	8.10
	Power Generation	118	3.35
	Recreation	44	2.89
	Schedule 1	432	2.43
	Urban (Excluding Industrial &/Or Domestic)	46	2.27
	Water Supply Service	1,080	540.14
Subtotal		**33,834**	**5,832.33**
Inkomati-Usuthu	Agriculture: Aquaculture	46	3.02
	Agriculture: Irrigation	2,686	2,097.38
	Agriculture: Watering Livestock	174	2.64
	Industry (Non-Urban)	358	40.28
	Industry (Urban)	464	390.30
	Mining	306	41.84
	Power Generation	8	0.19
	Recreation	28	0.13
	Schedule 1	364	0.14
	Urban (Excluding Industrial &/Or Domestic)	2	0.00
	Water Supply Service	660	433.82
Subtotal		**5,096**	**3,009.75**
Limpopo-Olifants	Agriculture: Aquaculture	158	68.92
	Agriculture: Irrigation	27,162	4,717.01
	Agriculture: Watering Livestock	1,682	30.76
	Industry (Non-Urban)	668	160.21
	Industry (Urban)	1,236	467.33
	Mining	2,744	1,059.52
	Power Generation	24	29.14
	Recreation	124	5.98
	Schedule 1	620	115.02
	Urban (Excluding Industrial &/Or Domestic)	84	2.54
	Water Supply Service	1,218	818.93
Subtotal		**35,720**	**7,475.36**
Mzimvubu-Tsitsikamma	Agriculture: Aquaculture	20	0.25
	Agriculture: Irrigation	11,262	2,456.89
	Agriculture: Watering Livestock	1,560	20.58
	Industry (Non-Urban)	320	4.95
	Industry (Urban)	396	6.55
	Mining	56	1.48
	Power Generation	106	2.26
	Recreation	62	2.73
	Schedule 1	4,002	21.20
	Urban (Excluding Industrial &/Or Domestic)	44	0.74
	Water Supply Service	3,118	1,201.98
Subtotal		**20,946**	**3,719.62**
Pongola-Mtamvuna	Agriculture: Aquaculture	22	4.57
	Agriculture: Irrigation	10,016	2,356.39
	Agriculture: Watering Livestock	862	14.30
	Industry (Non-Urban)	428	199.84
	Industry (Urban)	354	78.54

WMA	Water Use Sector	Total No of Registrations	Total Volume (Mm^3)
	Mining	140	75.94
	Power Generation	6	24.00
	Recreation	42	0.43
	Schedule 1	10,732	3.04
	Urban (Excluding Industrial &/Or Domestic)	146	0.76
	Water Supply Service	1,034	2,276.79
Subtotal		**23,782**	**5,034.61**
Vaal-Orange	Agriculture: Aquaculture	16	6,407.30
	Agriculture: Irrigation	32,280	31.57
	Agriculture: Watering Livestock	822	77.27
	Industry (Non-Urban)	1,606	2,173.25
	Industry (Urban)	1,336	659.32
	Mining	1,790	8.28
	Power Generation	274	0.54
	Recreation	18	0.14
	Schedule 1	42	0.10
	Urban (Excluding Industrial &/Or Domestic)	4	1,266.58
	Water Supply Service	1,464	3.74
Subtotal		**39,652**	**10,628.09**
Grand Total		**159,030**	**35,699.76**

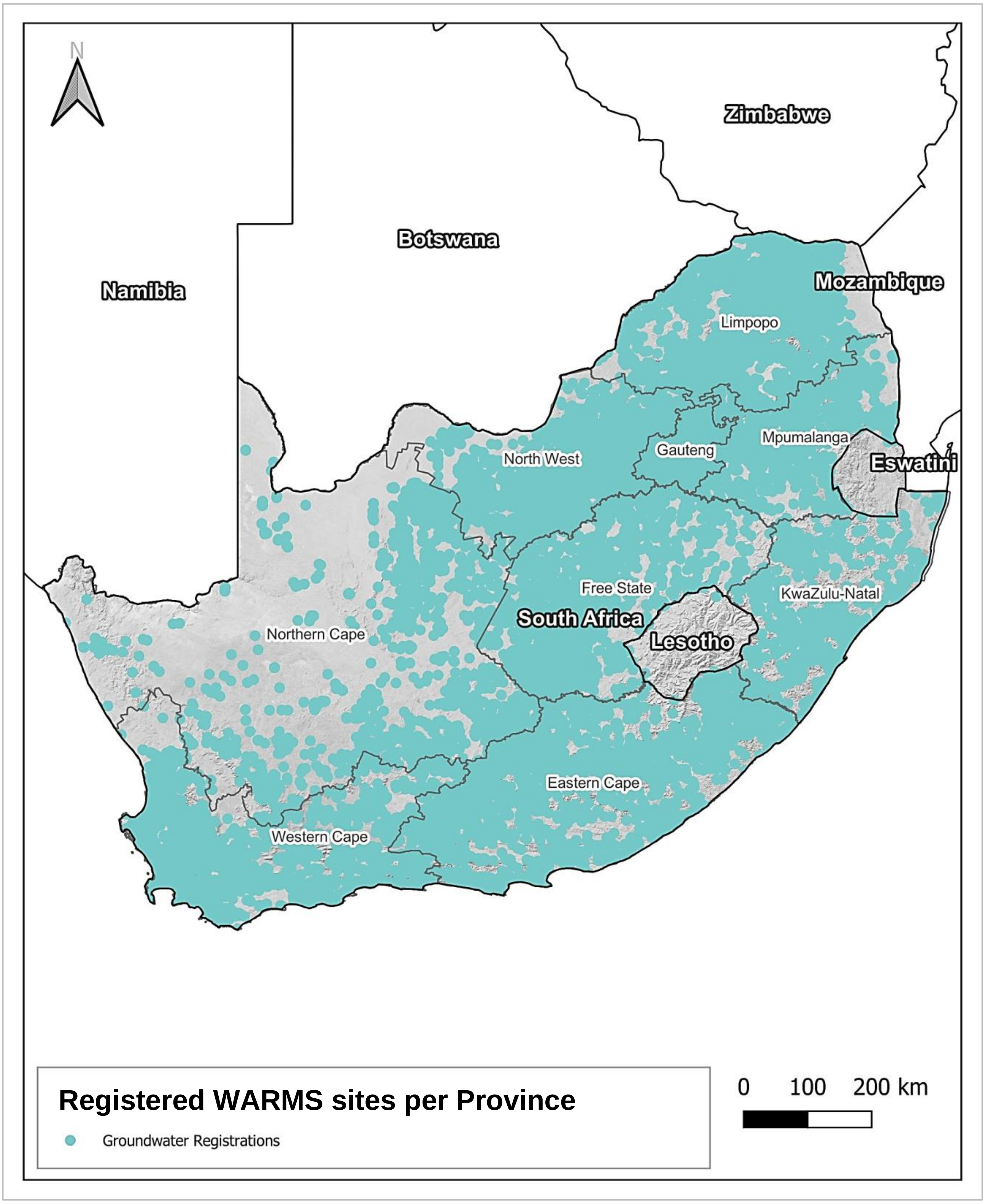


Figure 4-4 Map showing the distribution of registered groundwater use (WARMS).

4.1.1. Summary of Known Limitations

The WARMS database, while essential for managing water allocations and tracking water usage in South Africa, faces several limitations that impact its overall effectiveness for this study (see **Section 1.2**). A key issue is the inaccuracy of site coordinates, as many historical records were captured using the outdated Cape (Modified Clarke) datum, which has not been consistently transformed to the current Hartebeesthoek (WGS84) system, or spatial errors where locations were incorrectly captured, sometimes placing the registration in a different quaternary catchment altogether. However, it is important to consider if water use is being assessed on a more local level for the refinement of SWSA-gw.

Additionally, the WARMS database does not comprehensively capture all the data for small-scale water users, particularly those under "Schedule 1" usage. For these users, only the maximum “allocated volume” is recorded, which may not reflect actual current water usage. Inconsistent data completeness is another challenge, particularly for older water use activities that were not fully captured during the systems transitions or updates. This results in incomplete historical records, further affecting data quality.

Moreover, the accuracy of registered water volumes is often questionable due to potential under-reporting or data entry errors. This results in discrepancies between allocated volumes and actual current usage, where actual water use may exceed the registered volume. Kapangaziwiri et al. (2016) estimates that, in the KwaZulu-Natal province, up to 27% of water users remain unregistered, even though they are legally required to register under the NWA.

There are also geographical gaps, particularly in remote or less regulated regions (see **Figure 4-4**), where water use may be underreported or entirely unregistered, leaving parts of the country inadequately represented in the database.

4.1.2. Recommendations

To address these limitations, the following recommendations are proposed:

- Site coordinate verification should be prioritized for the current 37 SWSA-gw (2018) by defining transformation parameters using common reference points between the outdated and current coordinate system (i.e., confirming site vs quaternary/sub-quaternary catchments). Additionally, missing information for small-scale water users (i.e., Schedule 1) should be supplemented using census data or and additional municipal records.
- It is recommended that projects for capturing or estimating actual water use be initiated, potentially integrating telemetry from digital water monitoring devices or smart meters. Additionally, historical data recovery could be systematically included in those projects to fill gaps in older records. Cross-verification audits should also be conducted to ensure that reported water volumes reflect actual use. This recommendation will be included as part of the implementation and management plan (see **Table 1-1**).

To supplement and bridge the gaps in groundwater use data, the following sources and insights from related projects can be integrated:

- Coordinate Verification and Geographic Accuracy
    - The Hydstra database (see **Section 3.2**), which holds continuous groundwater level measurements, can potentially be used to verify geographic coordinates, especially in areas where WARMS data is outdated.
    - The NGA database (see **Section 3.2**) includes borehole information, historical water levels (pre-2004), and abstraction rates which be used to cross-check WARMS volumes for improved accuracy.

- Supplementing Information on Schedule 1 and Other Water Users
    - Water use data in the WARMS database will be reviewed, cross-referenced, and supplemented with various municipal and water scheme records (see **Sections 3.1.2** and **3.2**).
    - The WSDP Geodatabase will be used to update abstraction rates related to supply schemes.
    - StatsSA census data (see **Section 3.1.2**), can be used to estimate groundwater demand in regions where actual water use data for Schedule 1 Users is limited.
    - The GRIP project (see **Section 3.2**) provides supplementary data for specific rural areas (specifically for Limpopo, KwaZulu Natal and the Eastern Cape Province) where small-scale water users may not be fully registered in WARMS.
    - StepSA's (see **Section 3.2**) socio-economic data can help assess groundwater demand for Schedule 1 users, particularly in rural areas.
- Historical Data Recovery and Completeness
    - The GRA II project (see **Section 3.2**) introduced methodologies for estimating groundwater availability and abstraction. Its historical data can serve as a baseline to cross-check older WARMS records.
- Cross-Verifying Registered Water Volumes
    - The GGIS and SADC-GIP platforms (see **Section 3.2**) can be used to cross-reference international groundwater data for transboundary aquifers, potentially transforming the datasets to match the format of the WARMS database, and helping to verify and correlate transboundary groundwater abstraction volumes.

In conclusion, these recommendations aim to improve data quality of Groudnwater Use datasets specifically for use in the refinement of SWSA-gw project. WARMS data will serve as the baseline dataset, and the additional datasets from the aforementioned sources will be used to bolster and supplement it. By integrating these data sources, a comprehensive assessment of all boreholes and licensed water volumes can be achieved to a reasonably reliable state and format for the purposes of refining SWSA-gw. This consolidated data will then be spatially reviewed and applied in Phase 3 of this project (see **Table 1-1**).

4.2. Groundwater Levels

As summarised in **Section 3.2**, the Hydstra database, established in 2004, was designed to address the limitations of the NGA, particularly in storing long-term, continuous groundwater levels. It stores water level data from both sensor readings and manual measurements.

The dataset includes parameters such as site locations, groundwater levels, and date-time references. Before the initial data availability and quality assessment, the dataset was checked for duplicate records, and sites with missing values were removed. The temporal range, spanning the earliest to the latest measurements, was also verified. To further understand the data distribution, the information was categorised by geosite and province.

The completeness of essential parameters was evaluated across all provinces, resulting in an overall data availability score of 5 and a data quality score of 3.7, which indicates that all sites have an associated water level record of most of the data being of a usable quality (see **Section 2.2** and **Table 4-5**). The dataset covers the period from 1936 to 2024 and includes data originally collected by the NGA, which was migrated to Hydstra after 2004.

When comparing the number of groundwater monitoring points across the provinces, the Western Cape had the highest number, with 1,567 sites (26.36%), followed by the Northern Cape with 1,255 sites (21.11%), and the North West with 963 sites (16.20%). The provinces with the lowest number of monitoring points were Mpumalanga (193, 3.25%), KwaZulu-Natal (181, 3.04%), and the Free State (151, 2.54%). Other provinces, such as Gauteng (759, 12.77%), Limpopo (550, 9.25%), and the Eastern Cape (326, 5.48%), also contributed to the network, which includes various types of monitoring points such as springs, dug wells, and well points (see and **Table 4-5**, **Figure 4-5** and **Figure 4-6**).

As of July 2024, the total number of active groundwater monitoring sites stands at 1,739, indicating a widespread and extensive network across South Africa. Provinces such as the Western Cape, Limpopo, Northern Cape, and parts of Gauteng show a high concentration of boreholes. **Figure 4-6** illustrates the distribution and density of groundwater monitoring stations, with sites colour-coded by the responsible provincial offices. Detailed maps for each province are available in **APPENDIX A.**

Table 4-5 Groundwater level data completeness and groundwater points across South African provinces.

Province	Date from	Date to	% Completeness	Boreholes	Spring	Dug Wells	Well Points	Mines	Total
Eastern Cape	01/01/1956	19/07/2024	100	324	1	0	0	1	**326**
Free State	20/09/1954	16/05/2024	100	151	0	0	0	0	**151**
Gauteng	22/07/1953	18/07/2024	100	758	1	0	0	0	**759**
KwaZulu-Natal	12/12/1956	12/06/2024	100	181	0	0	0	0	**181**
Limpopo	29/05/1953	26/06/2024	100	549	0	1	0	0	**550**
Mpumalanga	29/12/1951	13/06/2024	100	193	0	0	0	0	**193**
North West	19/02/1936	20/06/2024	100	962	1	0	0	0	**963**
Northern Cape	18/09/1948	18/10/2023	100	1248	5	2	0	0	**1255**
Western Cape	15/07/1954	28/08/2024	100	1513	6	27	21	0	**1567**
Total				**5879**	**14**	**30**	**21**	**1**	**5945**

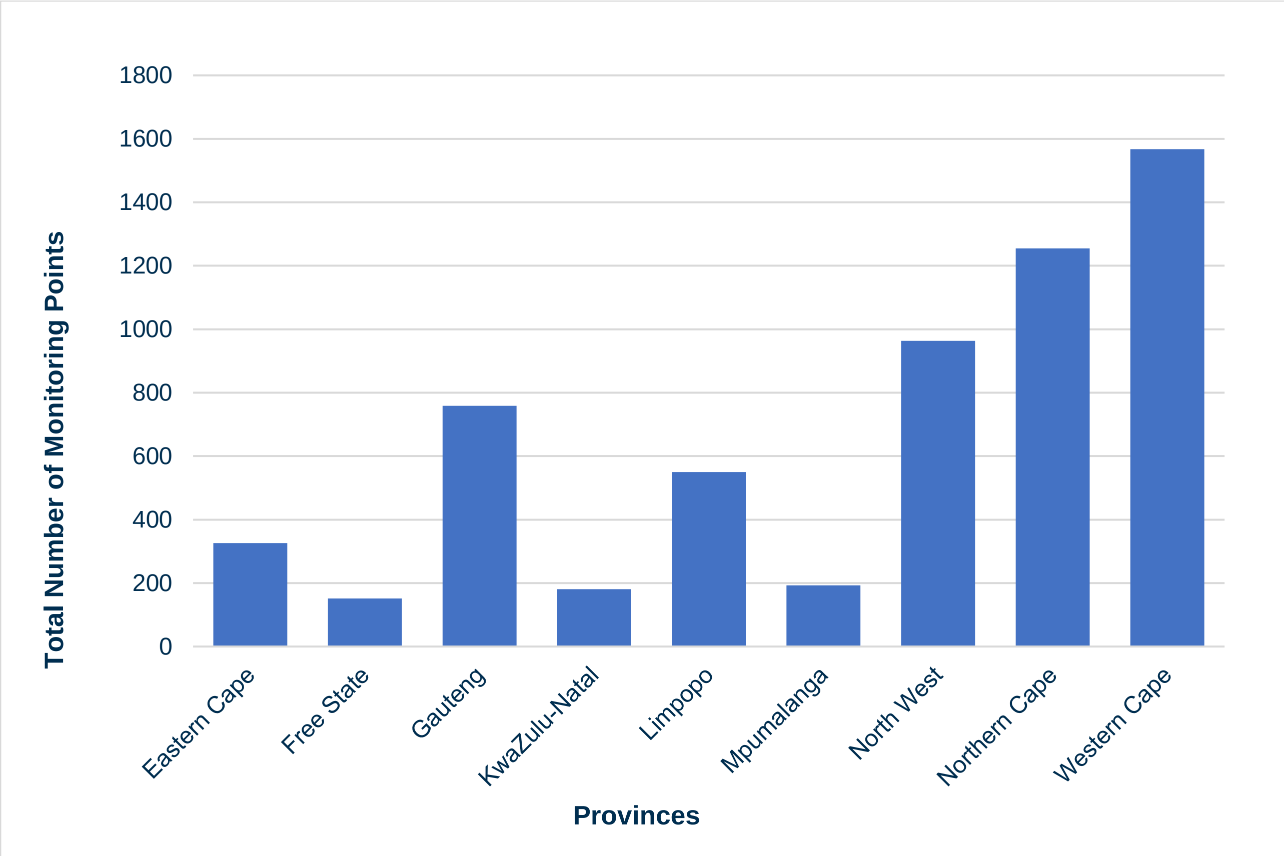


Figure 4-5 Total number of active Hydstra monitoring points per province.

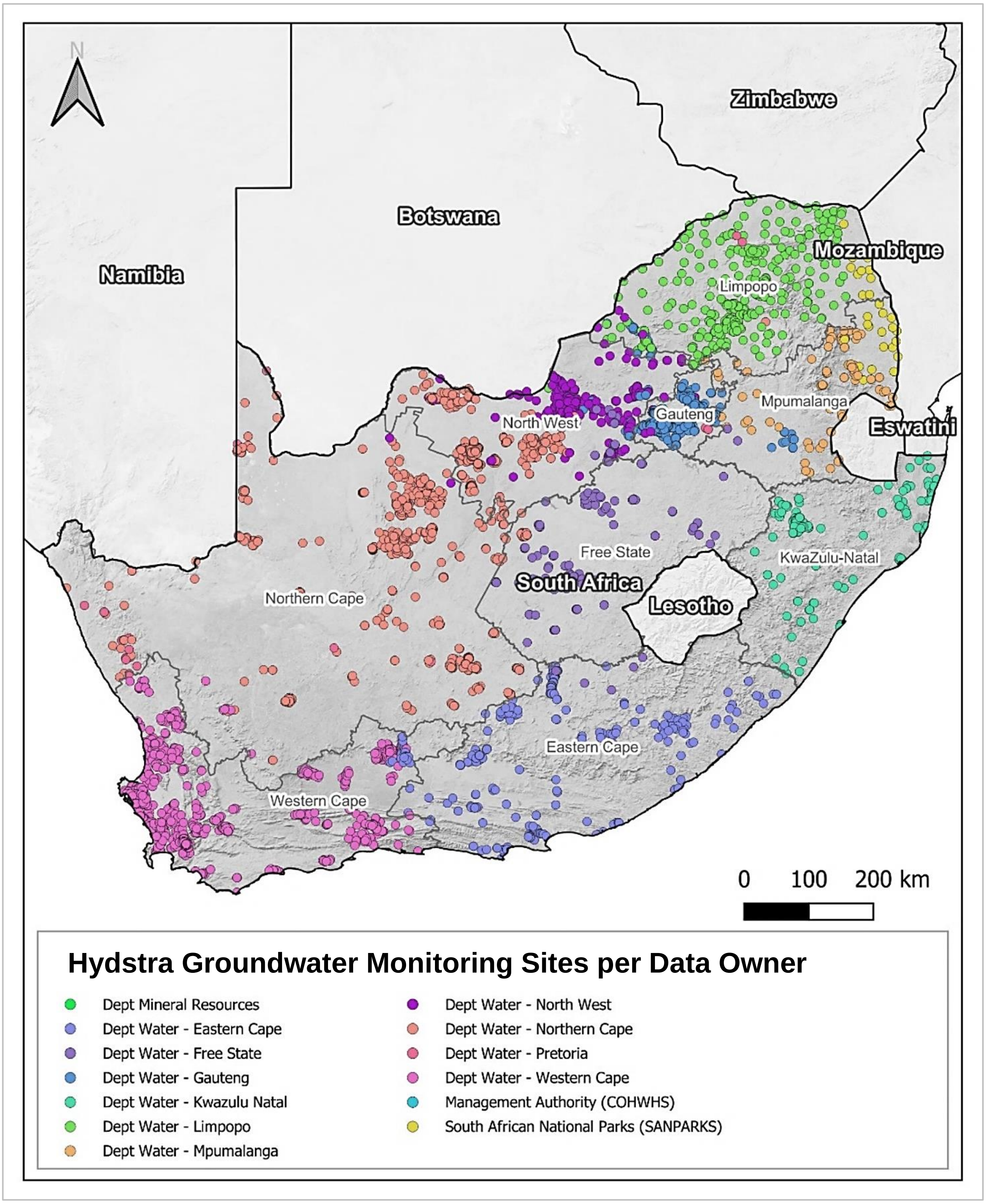


Figure 4-6 **Map showing the distribution of Hydstra groundwater level monitoring sites per data owner.**

4.2.1. Summary of Known Limitations

The Hydstra database faces several limitations, particularly with coordinate accuracy. As shown in **Figure 4-6**, many groundwater monitoring points are incorrectly plotted or labelled in the wrong provinces. When multiple departments use different mapping systems, discrepancies arise, complicating efforts to integrate data accurately on a single map, especially regarding consistency between coordinates and site identifiers from NGA and Hydstra. Additionally, the dataset continues to have historical gaps and missing values. Since the data originally came from NGA, potential inconsistencies from the earlier system have been carried over. Mismatches in geosite information, including changes in site names and locations during the migration process, further complicate the correlation and integration of datasets between Hydstra, NGA, and other platforms, making it challenging to maintain accurate and consistent groundwater monitoring data.

4.2.2. Recommendations

To address the limitations of the Hydstra database, the following actions are recommended:

- Coordinate accuracy verification should be prioritised for active sites within the SWSA-gw. Misplaced sites due to incorrect coordinates should be checked and corrected. For areas near provincial borders, proximity analysis should ensure correct attribution of sites.
- Standardise coordinate systems across departments and agencies by implementing a unified coordinate reference system, such as WGS 84, for all data contributors. Historical datasets should also be transformed to this standard. This standardisation should be integrated into the Hydstra data management plan (see **Table 4-5**).

To further supplement and improve the Hydstra dataset, additional data sources and processes can be integrated:

- Coordinate verification: Cross-check borehole information and water level data from NGA with Hydstra to verify geographic coordinates. Other datasets, including WARMS, WMS, and the National Monitoring Network, can provide additional geographic verification.
- Supplement historical data: Use historical water levels and borehole data from GRIP (specifically for Limpopo, KwaZulu Natal and the Eastern Cape Province) to supplement the dataset where groundwater monitoring has been sparse or inconsistent.

4.3. Subsurface Information

As summarised in **Section 3.2** (see **Table 3-2**), the NGA serves as a repository of various groundwater datasets. It plays an important role in hydrogeological assessments, desktop studies, and groundwater modelling by capturing, storing, and facilitating access to various datasets. The NGA contains geosite information and locations, borehole construction details (such as drilling screen, casing, and annular fill), lithology, groundwater levels (pre-2004), blow yields, discharge rates, water strikes, and water quality field measurements such as electrical conductivity (EC), HCO_3, pH, and temperature.

These NGA parameters provide critical insights into the geology, aquifer depth, and groundwater yield in the areas where the boreholes are located. It also contributes to a better understanding of the overall groundwater quantity, quality, hydrogeological makeup, and aquifer conditions in these regions, supporting the overarching objective of the study (see **Section 1.2**). The evaluation of this data involved analysing the overall completeness of the dataset across various parameters. The overall percentage of non-null values for each parameter was calculated, and each borehole was assigned a score from 1 to 5 based on data availability (see **Section 2.2**).

For the 269 030 boreholes selected from the NGA database (see **Figure 4-7**), the average parameter completeness was approximately 30.47% across all sites. Key parameter groups and their associated completeness scores are reported as follows: 1) Geosite Information, which includes data such as identifier, latitude, longitude, and elevation, had a completeness score of 4.7. 2) Drilling Depth and Diameters, with a focus on depth to bottom, recorded a completeness of 3.3, while 3) Discharge Rate had 1.8. 4) Field Observations, including parameters such as measurement date and time, measurement depth, EC, pH value, temperature, and HCO_3, had a score of 1.2. 6) Lithology, capturing information such as lithology name and formation type had a completeness score of 2.16. Lastly, 7) Screen Information, which covers depth to top, depth to bottom had a completeness of 1.0 (see **Figure 4-8**).

After evaluating the completeness of the NGA dataset, significant variability in data quality and availability was observed across parameters, resulting in an overall parameter completeness score[4] of 2 and a data quality score of 3 (see **Section 2.2**). Many boreholes lack essential data, impacting the dataset's reliability. Although only 0.06% of the boreholes lack coordinates, the uneven borehole distribution across provinces could indicate either missing data or a scarcity of groundwater resources in these areas (see **Figure 4-9**).

Limpopo has the highest number of boreholes (54,128, or 20.12% of the total), followed by the Northern Cape with 44,694 boreholes (16.61%) and North West with 40,128 boreholes (14.92%). Despite the Northern Cape ranking second in total boreholes, it has the highest proportion of boreholes with low data completeness, with 71.5% scoring a 1, indicating very incomplete data.

In contrast, the Eastern Cape has the highest proportion of boreholes with a completeness score of 4, representing the province with the most complete dataset, although only 0.22% of all the boreholes in the province achieve this score. This suggests that while the Eastern Cape excels in data quality compared to other provinces, the actual number of fully complete boreholes is very small. While the NGA provides access to all borehole data, much of the necessary information is either missing or incomplete. This limitation reduces the dataset's utility for detailed hydrogeological assessments, as much of the data is either entered incorrectly or not collected by qualified professionals.

[4] *Only parameters deemed important for evaluating data quality were included and contributed to the overall data quality score.*

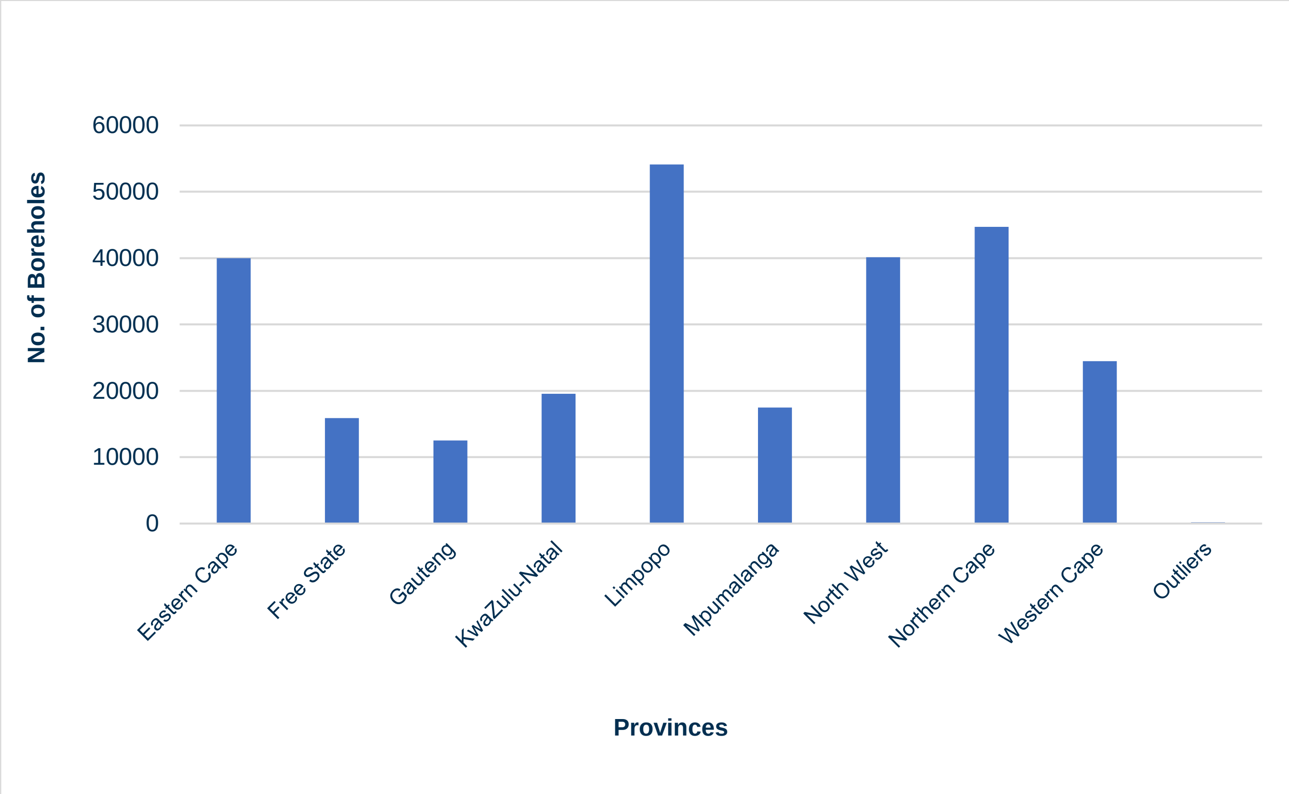


Figure 4-7 **Total number and distribution of NGA boreholes per province.**

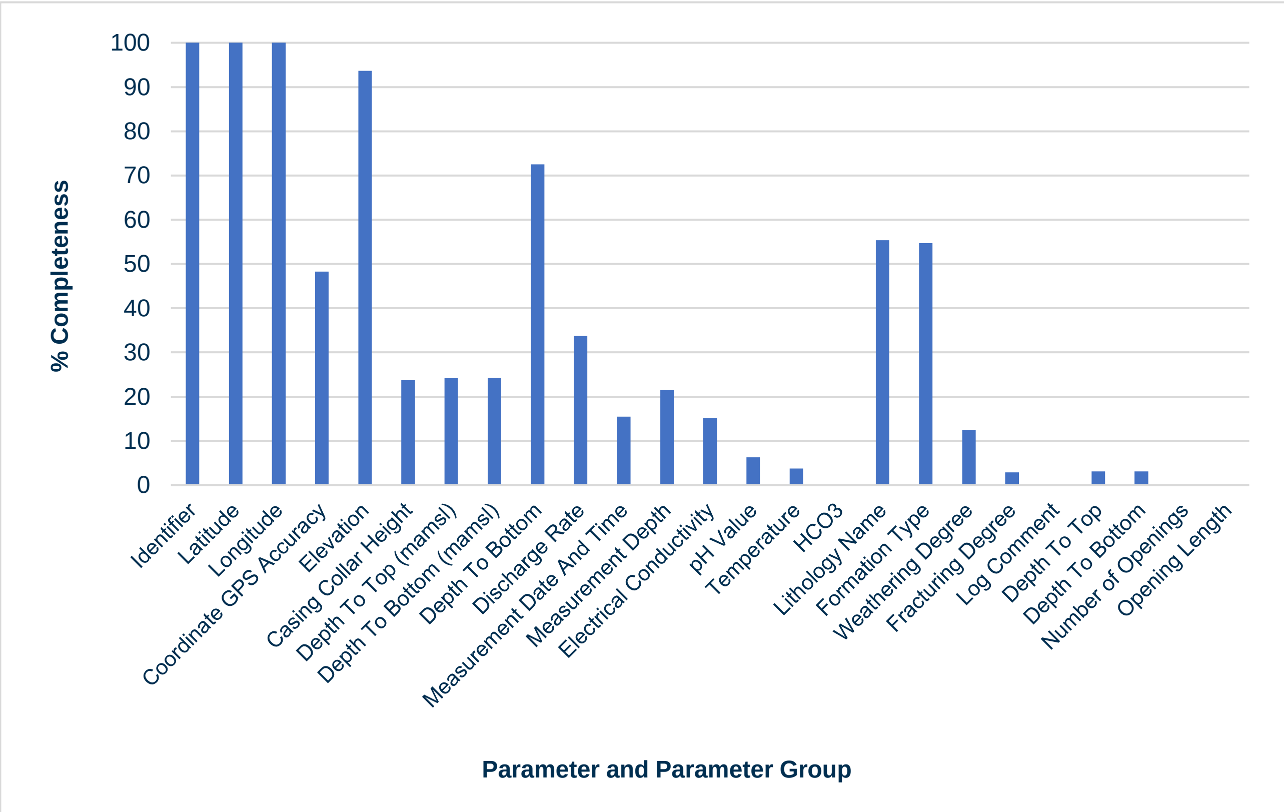


Figure 4-8 **Percentage completeness[4] of specific parameters for all NGA geosites.**

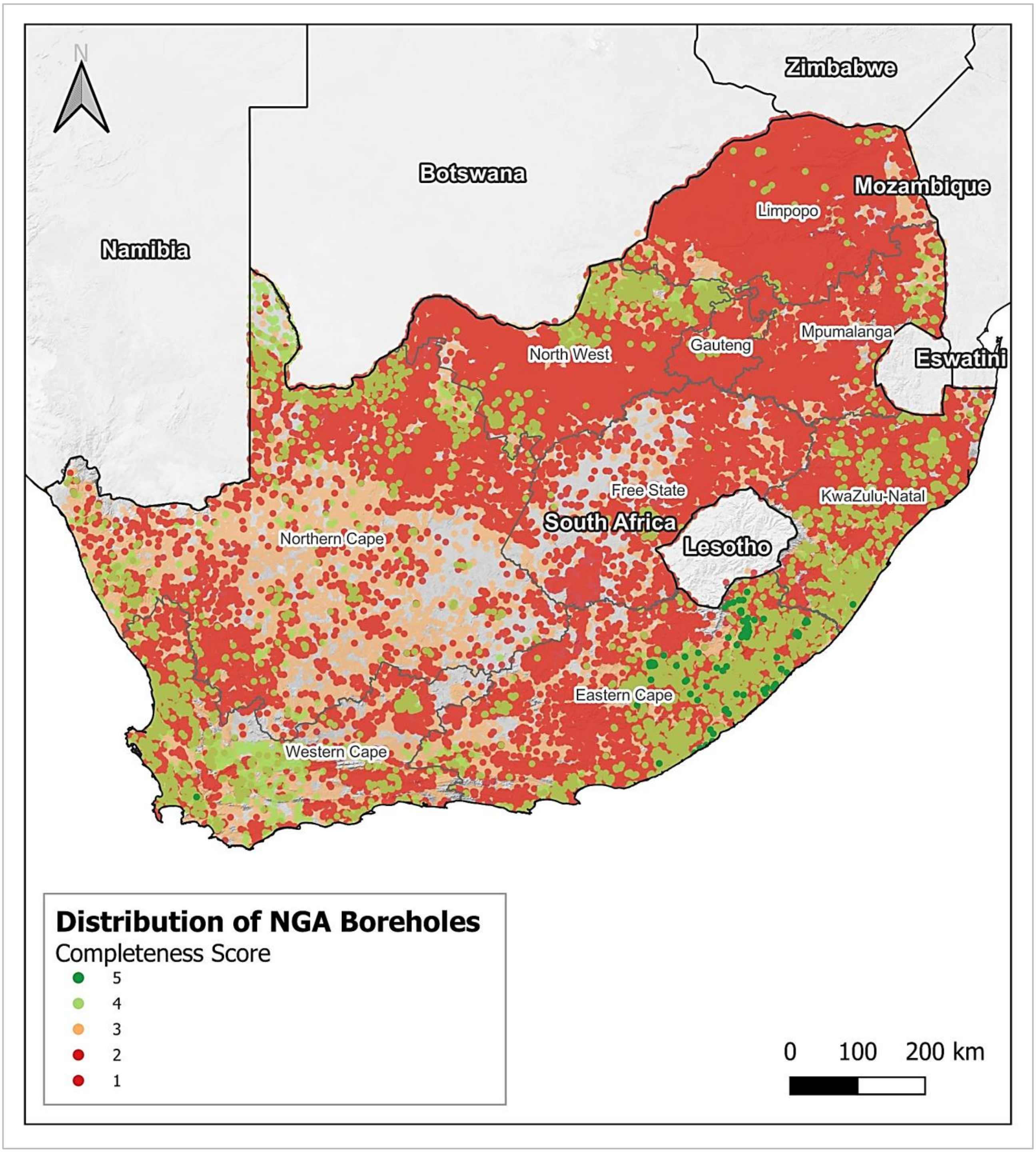


Figure 4-9 **Spatial distribution of NGA boreholes across South Africa showing the data completeness.**

4.3.1. Summary of Known Limitations

The NGA is an essential resource for groundwater evaluations however, it has several significant limitations that can impact the accuracy of this study. A major issue is the limited borehole information, particularly for older, privately drilled boreholes, which results in an incomplete representation of the national groundwater landscape (see **Figure 4-8**). Additionally, there are inconsistencies in data quality and completeness, with frequent occurrences of missing or inaccurate information.

According to the "Registration of Water Drilling Contractors of South Africa," an estimated 80,000 to 100,000 boreholes are drilled annually. This underscores a significant challenge with the time lag in updating data, as new borehole information is often delayed before being added to the system. This delay limits the NGA ability to accurately reflect the current situation on the ground. Additionally, many records lack essential metadata such as the borehole's purposes, which diminishes the dataset's utility for detailed hydrogeological assessments.

4.3.2. Recommendations

To address these limitations, the following recommendations are proposed:

- Gather additional data on privately drilled boreholes, specifically those in the current 37 SWSA-gw (2018) areas, with a focus on drilling data. This should include integrating borehole depth and lithology information from these supplementary sources with the existing NGA data to better understand the subsurface geology. During this process, spatial discrepancies in borehole coordinates should also be corrected.
- The DWS and NGA operators should collaborate to ensure stricter data entry standards for the drilling contractors. This can be achieved by establishing mandatory metadata requirements for all new data entries. Additionally, the DWS could initiate projects to retroactively update incomplete well construction records (where possible) as the consistency in capturing this borehole data is critical for accurately modelling groundwater resources in three dimensions.

To supplement and bridge the gaps in the borehole information data, the following sources can be integrated:

- Coordinate Verification and Geographic Accuracy
  - Hydstra (see **Section 3.2**) holds continuous groundwater level monitoring data. While primarily focused on groundwater levels, the geographical locations from Hydstra monitoring sites can help verify the spatial accuracy of boreholes in the NGA as it can be used in conjunction with borehole data to enhance spatial and temporal correlations for borehole construction records.
- Supplementing Borehole Construction Data
  - GRIP (see **Section 3.2**) provides unpublished borehole information, particularly in rural areas where NGA records may be incomplete. This data is particularly useful for filling gaps related to borehole depths and lithologies in areas such asLimpopo, KwaZulu Natal and the Eastern Cape Province, where well construction data may be lacking.

The recommendations focus on enhancing the NGA's value for the SWSA-gw project by ensuring that borehole data can be confidently used to understand the depth and geology of water-bearing formations in the targeted areas. By integrating additional data sources, especially for borehole drilling and lithology information, gaps in the NGA data will be addressed, ultimately improving its utility for refining SWSA-gw models and supporting broader groundwater management efforts in the country.

4.4. Groundwater Quality

As summarised in **Section 3.2** (see **Table 3-2**), the WMS database stores groundwater quality data from various monitoring programs, tracking changes over time to ensure compliance with national water quality standards. The database contains geosite information, including site IDs, sample locations, as well as the type of monitoring points. It also includes some less important information such as preservation substance information and depth of sampling events. In addition, water quality data, analysed by various laboratories, provides insight into the chemical composition and physical properties of groundwater, with parameters covering cations, anions, metals, nutrients, and macrochemistry.

Following a general data quality assessment, the WMS dataset was evaluated for data availability by calculating the percentage of non-null values for each parameter and assigning overall completeness scores accordingly (see **Section 2.2** and **Table 4-6**). This was calculated to a data availability score of 3.8 and a data quality score of 2.7. The dataset was filtered to account for unique monitoring points and to avoid double-counting.

A total of 55,391 sites with a total of 120,149 samples were included in the evaluation (data downloaded on 24/04/2024, see **Figure 4-10**). However only 1600 sites were considered "active" only 1,439 sites having water quality results.

Water quality parameters for cations, anions, nutrients, and macrochemistry show high completeness percentages, exceeding 70% (scoring 3 and 4). However, the completeness for metals and heavy metals is considerably lower, at 11.08% (scoring 2 and 1) (see **Figure 4-12**).

Table 4-6 Groundwater quality data completeness across South African provinces

Provinces	Total Sites	Inactive Sites	Active Sites	Date from	Date to	% Completeness across all parameters
Eastern Cape	3830	3316	514	24/08/1966	27/09/2023	28.4
Free State	2079	2050	29	24/02/1970	27/10/2023	30.8
Gauteng	2137	2090	47	18/02/1972	09/02/2024	31.6
KwaZulu-Natal	2345	2264	81	30/07/1970	01/06/2023	28.3
Mpumalanga	1216	1176	40	08/01/1970	24/10/2023	28.3
North West	8886	8742	144	06/06/1969	24/11/2023	28.6
Northern Cape	11948	11821	127	10/12/1969	19/10/2023	31.8
Limpopo	15196	15021	175	26/06/1968	26/11/2023	31.1
Western Cape	7754	7311	443	09/08/1967	23/11/2023	31.7
Grand Total	**55391**	**53791**	**1600**	**-**	**-**	**-**

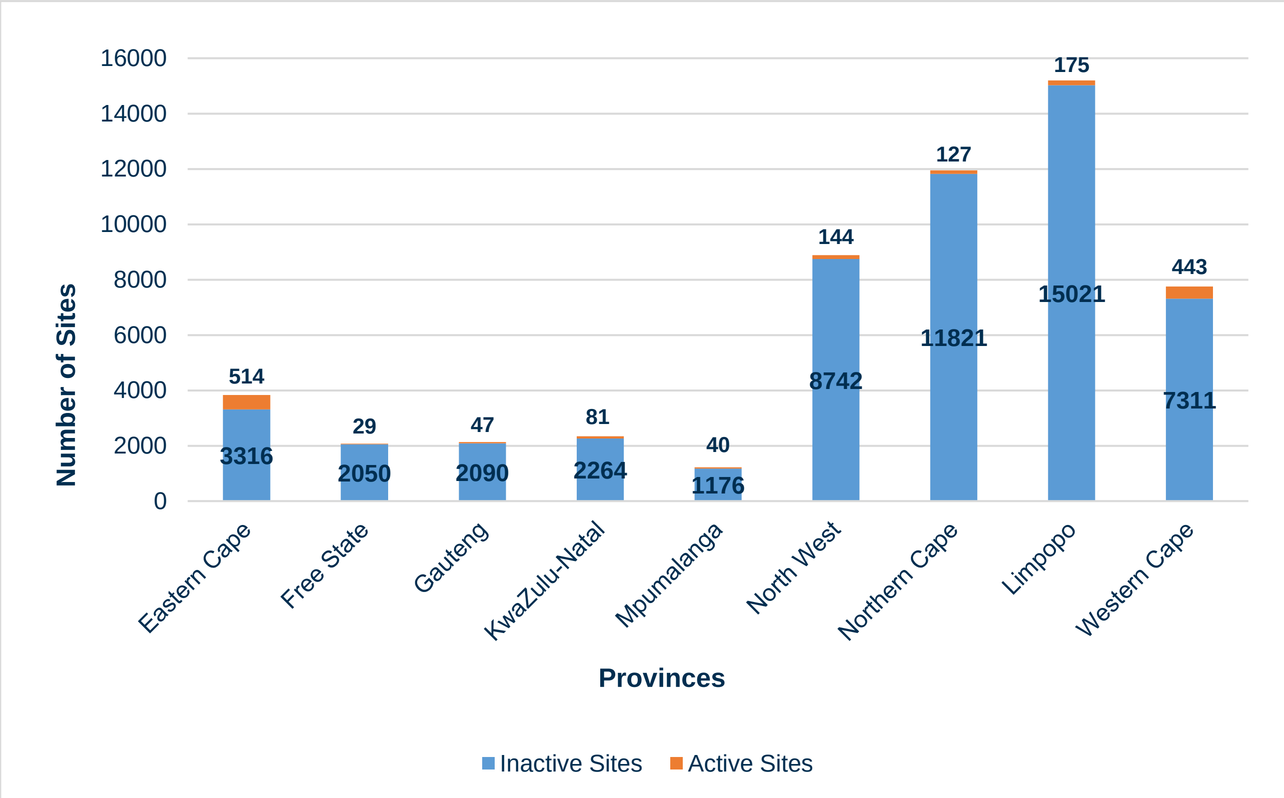


Figure 4-10 **Total number of active and inactive WMS sites per province.**

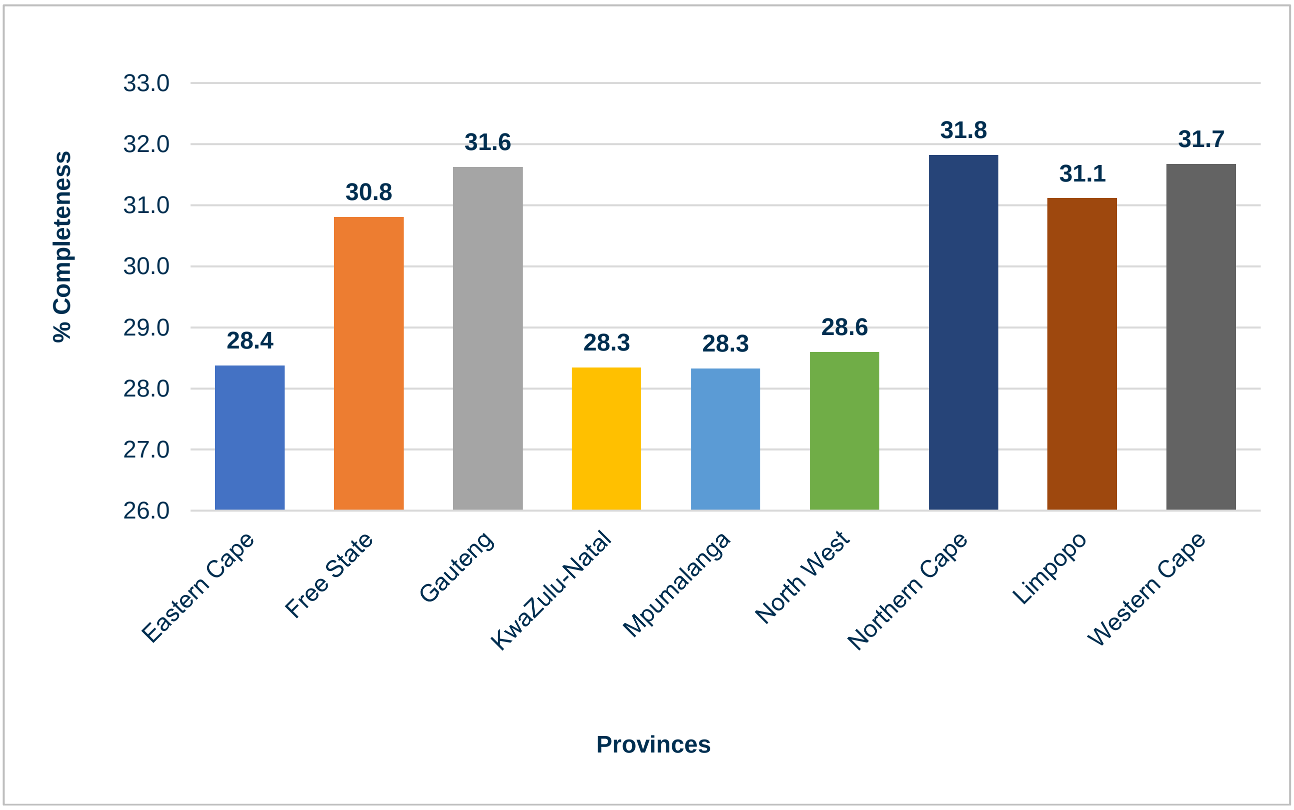


Figure 4-11 **Percentage completeness of the selected data parameters for active and inactive sites per province which can all be correlated to an overall data availability score of 2.**

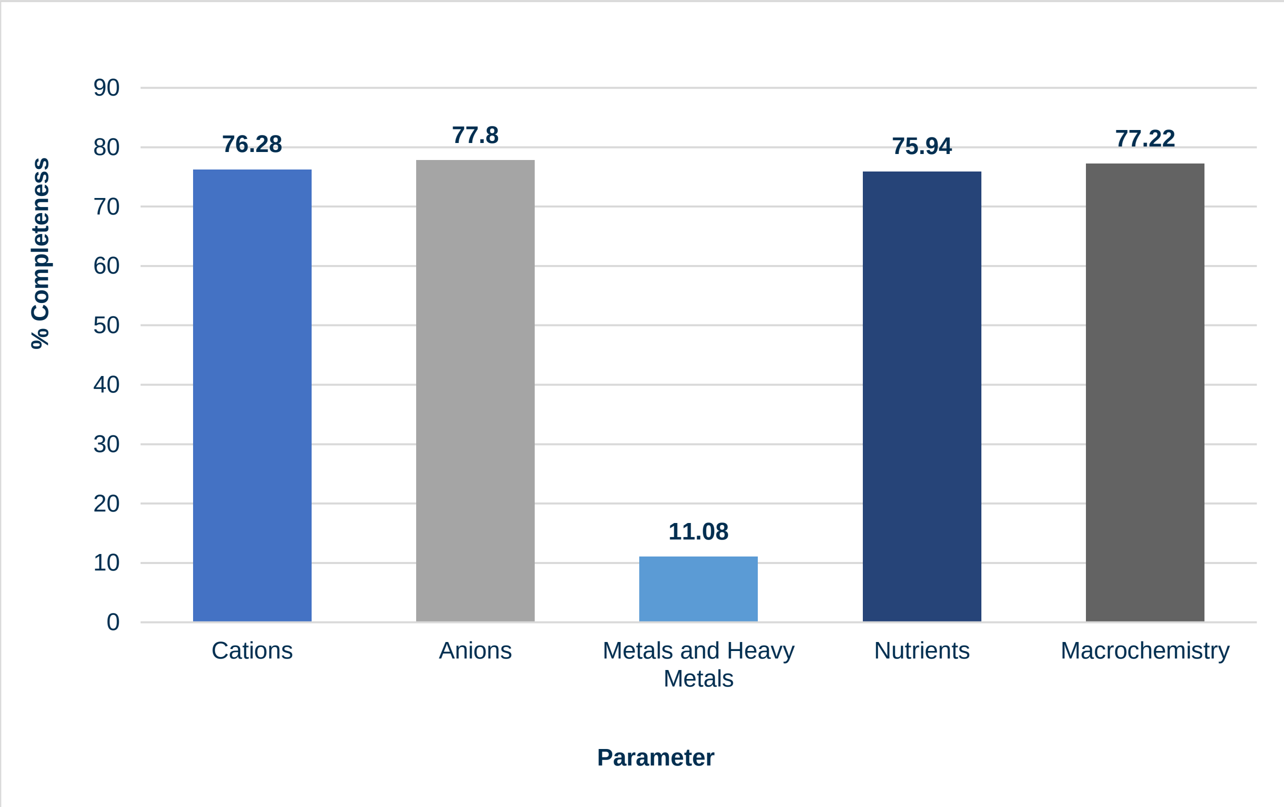


Figure 4-12 Percentage completeness of all sites per water quality parameter category with cations, anions, nutrients and microchemistry all having an overall data availability score of 4, while metals and heavy metals scoring a 1 for data availability.

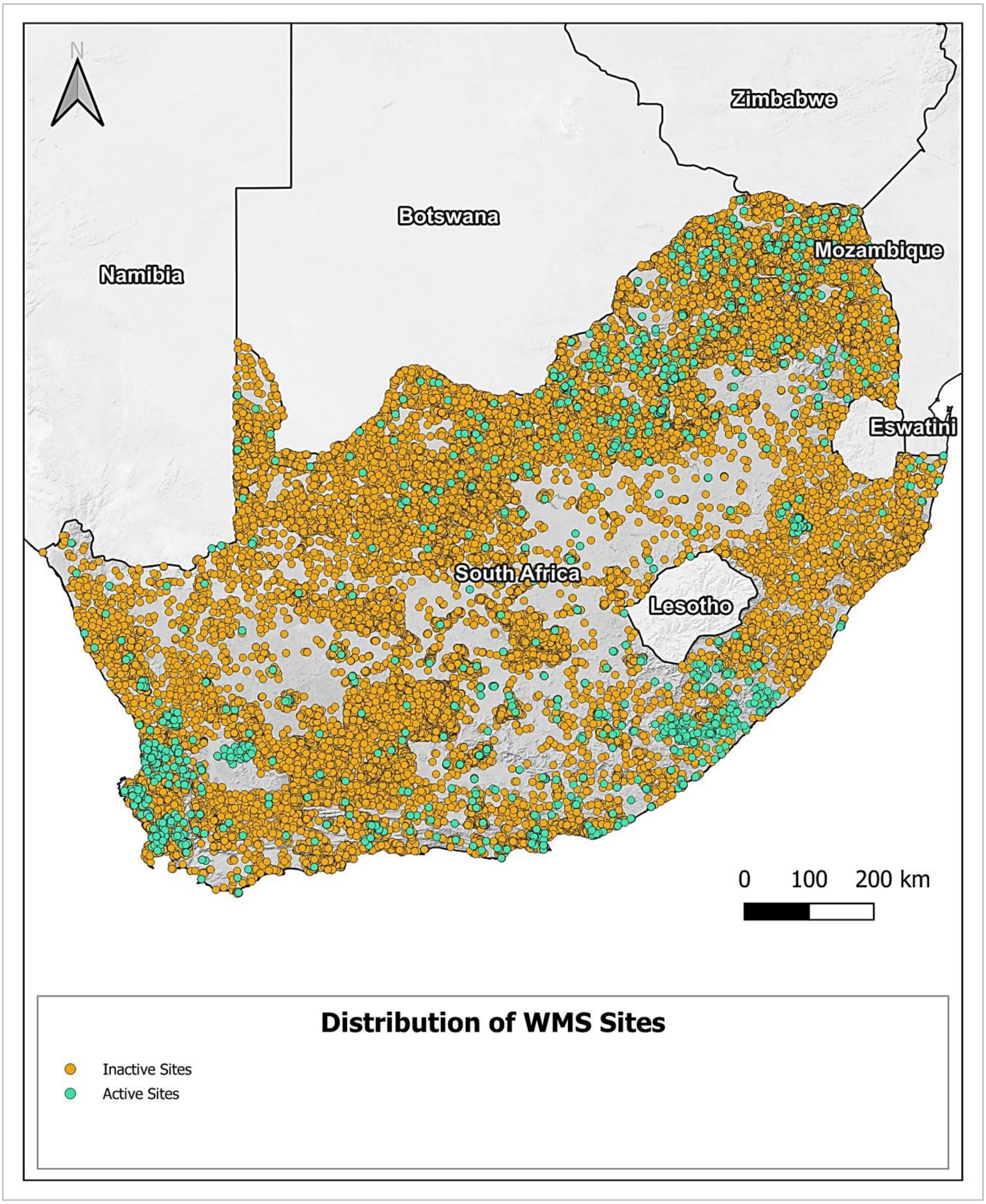


Figure 4-13 Spatial distribution of WMS monitoring locations across South Africa.

4.4.1. Summary of Known Limitations

The WMS dataset, while critical for groundwater monitoring, has several limitations that affect its effectiveness. One major issue is the spatial gaps, particularly in certain regions like the Eastern Cape, Mpumalanga, Free State, and KwaZulu Natal, where data was either not captured or is sparse (see **Figure 4-10** and **Figure 4-13**). Additionally, there are inconsistencies in the frequency of updates, meaning that some areas may not reflect the current groundwater quality conditions. Another challenge is the incomplete water quality records, particularly for trace elements, which may hinder comprehensive assessments for SWSA-gw that require particular attention. Furthermore, discrepancies in site naming between WMS and other databases, such as NGA and WARMS, introduce further complications, limiting data accuracy and consistency across platforms.

4.4.2. Recommendations

To address these limitations, the following recommendations are proposed:

- The WMS dataset will be supplemented with data from other active groundwater schemes, particularly where groundwater quality monitoring is mandated as part of the Water Use Licence (WUL) conditions. This data, which should be retrievable via DWS (feedback to the DWS via municipalities) and can enhance both spatial and temporal coverage of groundwater quality data (refer to **Section 3.1** for further details).
- Ensure better representation of groundwater quality in specific rural areas by incorporating data from GRIP (specifically for Limpopo, KwaZulu Natal and the Eastern Cape Province). This data can be used to fill some of the gaps in the WMS dataset, especially in regions/area with incomplete or underrepresented coverage.
- Improve data integration between WMS and NGA to resolve site renaming discrepancies. This is a consistent theme that links the four big National Groundwater datasets (including NGA, WMS, WARMS, and Hydstra).

To supplement and bridge the gaps in the groundwater quality data, the following sources can be integrated:

- Enhancing National Groundwater Quality Monitoring Data
  - NCMP (see **Section 3.2**) monitors water quality with a focus on major ions, trace elements, and nutrients. This data can bridge gaps in WMS's chemical monitoring, particularly for parameters such as trace metals and microbiological content.
  - NGwQMP (see **Section 3.2**) provides long-term groundwater quality data, tracking trends in pollutants and contamination risks. By integrating this program's data, WMS can improve its coverage of groundwater chemistry over time.
  - NIWIS (see **Section 3.2**) provides information on national water quality and facilitates high-level data analysis across South Africa's water value chain, offering data on drought conditions and groundwater status linked to water quality compliance.

These recommendations aim to enhance the WMS dataset for groundwater monitoring within the context of the SWSA-gw project (which will include transboundary water quality data, see **Section 4.5**). By integrating these additional data sources, the WMS data will be improved in terms of spatial coverage, data accuracy, and data completeness. This will lead to more robust groundwater monitoring and management efforts, ultimately ensuring better refinement of SWSA-gw across South Africa.

4.5. Rainfall and Groundwater Recharge

Rainfall plays a critical role in groundwater recharge, particularly in high-rainfall regions. These areas have been the primary focus for identifying SWSA-gw in South Africa based on the assumption that high rainfall leads to high recharge (**Sections 1.1 and 3.1.1**). This premise has underpinned the delineation of SWSA-gw over time, providing a reliable foundation for assessing groundwater resources. In unconfined aquifers that rely directly on precipitation, recharge can be calculated relatively easily, as rainfall infiltrates directly into the aquifer system, a method effective in regions where recharge zones are well-defined.

However, calculating groundwater recharge becomes more challenging in complex aquifer systems where the relationship between rainfall and recharge is not as straightforward. Recharge areas may be located far from the aquifer itself, and geological structures such as faults, folds, fractures, hydrotects, or confined layers can influence the recharge process. These complexities require a detailed understanding of aquifer boundary conditions, which determine where water enters, flows through, and exits the system. For instance, water may enter through distant recharge zones and exit via springs, rivers, or even ocean discharge points.

Aquifers with dual systems may rely on adjacent aquifers for recharge, adding another layer of complexity to conceptualizing how these groundwater systems function. Such intricacies highlight the need for a deeper understanding of boundary conditions, aquifer geometry, and interactions between multiple water sources. Accurate recharge assessments may need to be tailored to the specific characteristics of each aquifer to account for these complexities.

Several datasets can be employed to estimate groundwater recharge for this project, each bringing unique strengths and challenges:

- Lötter and Le Maitre (2021) MAP Layer: Developed using the EBK method (see **Section 3.1.1**) offers improved spatial accuracy by leveraging data from over 12,000 rain gauges across South Africa. It provides a detailed precipitation surface (**Figure 3-4** to **Figure 3-8**), but its ability to capture inter-annual variability remains limited, which can complicate recharge assessments in regions with significant year-to-year rainfall fluctuations.
- Schulze et al. (2008) MAP Layer: Published in the South African Atlas of Climatology and Agrohydrology, provides a broader historical perspective. While coarser in resolution than Lötter and Le Maitre (2021), it offers valuable long-term climate data that complements more recent datasets, particularly when cross-checking recharge estimates over extended periods.
- WR2012/WRSM2000 Dataset: The WR2012 dataset offers insights into MAR and groundwater recharge, particularly at the quaternary catchment level. This dataset is crucial for understanding the rainfall-runoff relationship and its role in groundwater recharge, especially in areas where ecosystems rely on sustained baseflows (**Figure 4-14** to **Figure 4-19**).

Runoff and Discharge in Ecosystems

MAR and discharge are essential processes that maintain ecosystem health, particularly in regions where ecosystems depend on consistent baseflows during dry seasons. The WR2012 MAR dataset helps in understanding these dynamics, which are critical for assessing groundwater-surface water interactions and their role in sustaining biodiversity.

Discharge zones, such as springs and rivers, act as critical outflow points for groundwater, helping maintain baseflows that support GDEs and maintain EWRs. Accurately identifying these areas is vital for effective groundwater management, especially in areas where ecosystems rely heavily on groundwater during periods of low rainfall.

4.5.1. Summary of Known Limitations

Despite improvements in data accuracy and modelling, there are still limitations that need to be considered. Although the WRSM2000 model (and iteration of the WR2012) represents an advancement over its predecessor, the Pitman model (Pitman, 1973), it remains a "lumped parameter" model in certain areas. This means that it averages hydrological variables over large regions, limiting its ability to account for spatial variability in rainfall, land use, and topography. These limitations affect its precision, particularly when simulating groundwater recharge and discharge in regions with complex geological or climatic conditions.

The accuracy of the WRSM2000 model also depends on high-quality streamflow data for calibration, which can be scarce or inconsistent in certain areas. This lack of data impacts the model's ability to accurately simulate groundwater-surface water interactions, a critical factor in understanding baseflow requirements for ecosystems during dry seasons.

4.5.2. Recommendations

To enhance the accuracy of groundwater recharge assessments, several actions are recommended:

- Although a downscaled MAP layer is available from Lötter and Le Maitre (2021), accurately estimating groundwater recharge remains challenging. Since the latest groundwater recharge data comes from the WR2012 assessment, comparing the Lötter and Le Maitre (2021) MAP data with the MAP data used in WR2012 is necessary. If the rainfall patterns are similar, the recharge values from WR2012 can serve as a basis to further refine the SWSA-gw. If they differ, adjustments to the WR2012 recharge estimates may be necessary. Integrating additional datasets, such as the Schulze et al. (2008) MAP layer, can aid in this process. Despite the challenges of merging datasets with different resolutions, doing so will enhance the understanding of groundwater recharge zones and improve the identification of GDEs.
- Better integration of groundwater and surface water datasets will be key to achieving a more complete understanding of rainfall-recharge-discharge dynamics. This integration is particularly important in regions reliant on baseflows to sustain ecosystem health during dry seasons.

Understanding the relationship between rainfall, groundwater recharge, runoff, and discharge is vital for managing South Africa’s critical groundwater resources. By refining datasets, improving the integration of groundwater and surface water models, a more accurate and detailed understanding of recharge-discharge dynamics can be achieved. These improvements are essential for the sustainable management of groundwater resources and ecosystems that depend on them.

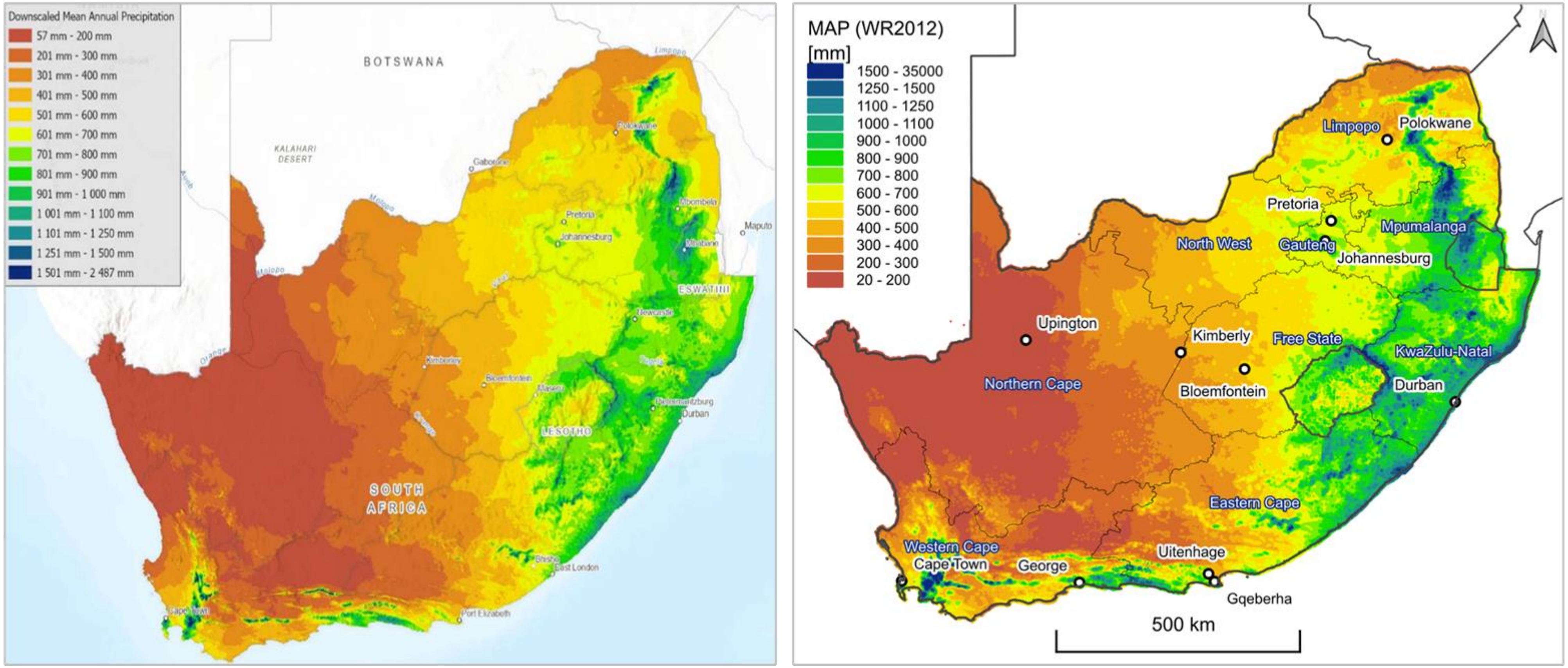


Figure 4-14 Left: Map of MAP layer by Lötter and Le Maitre (2021) , Right: MAP from WR2012 (from WR2012 Book of Maps).

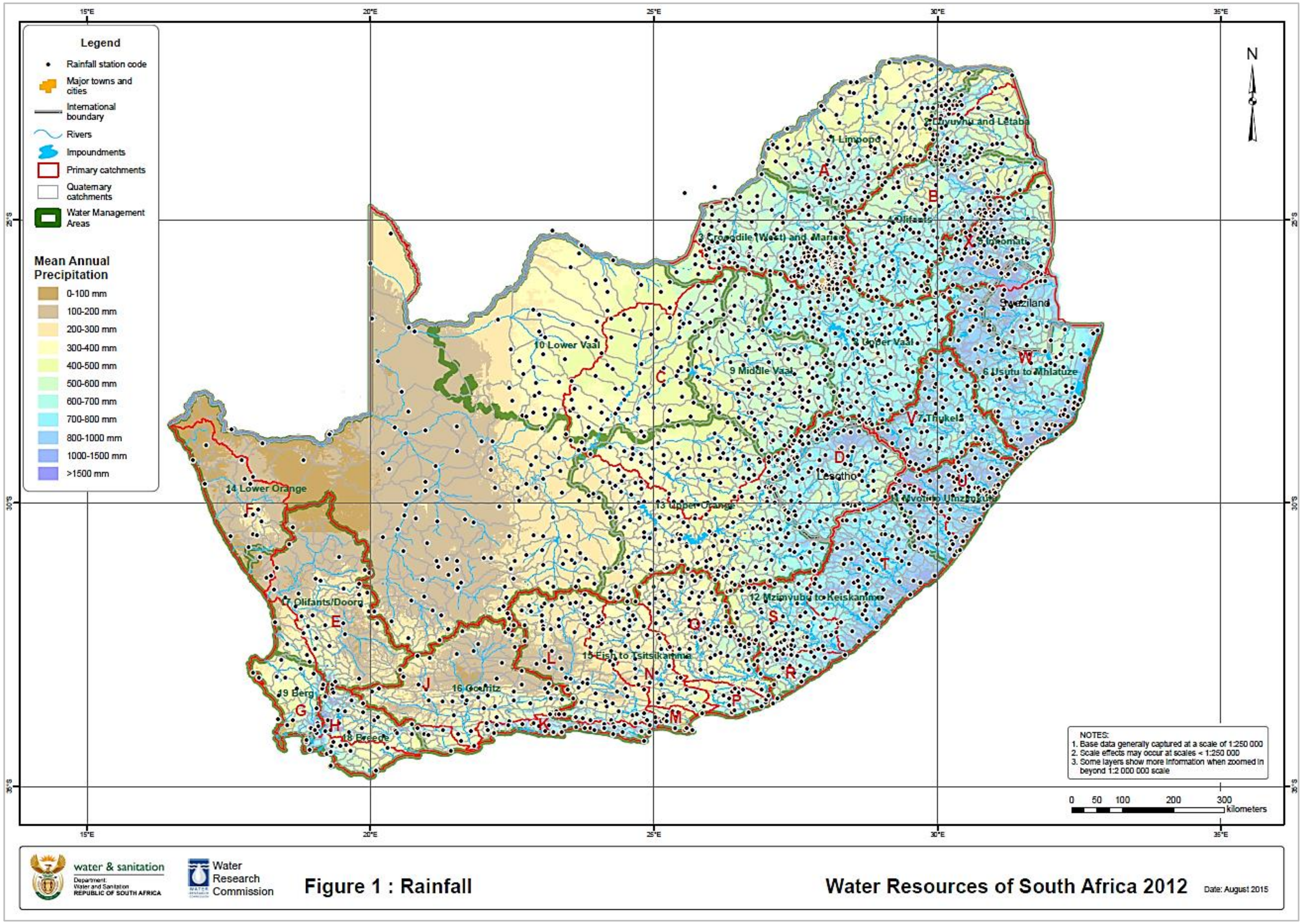


Figure 4-15 National Mean Annual Precipitation (MAP) with the base data generally captured at a scale of 1:250 000 (from WR2012 Book of Maps).

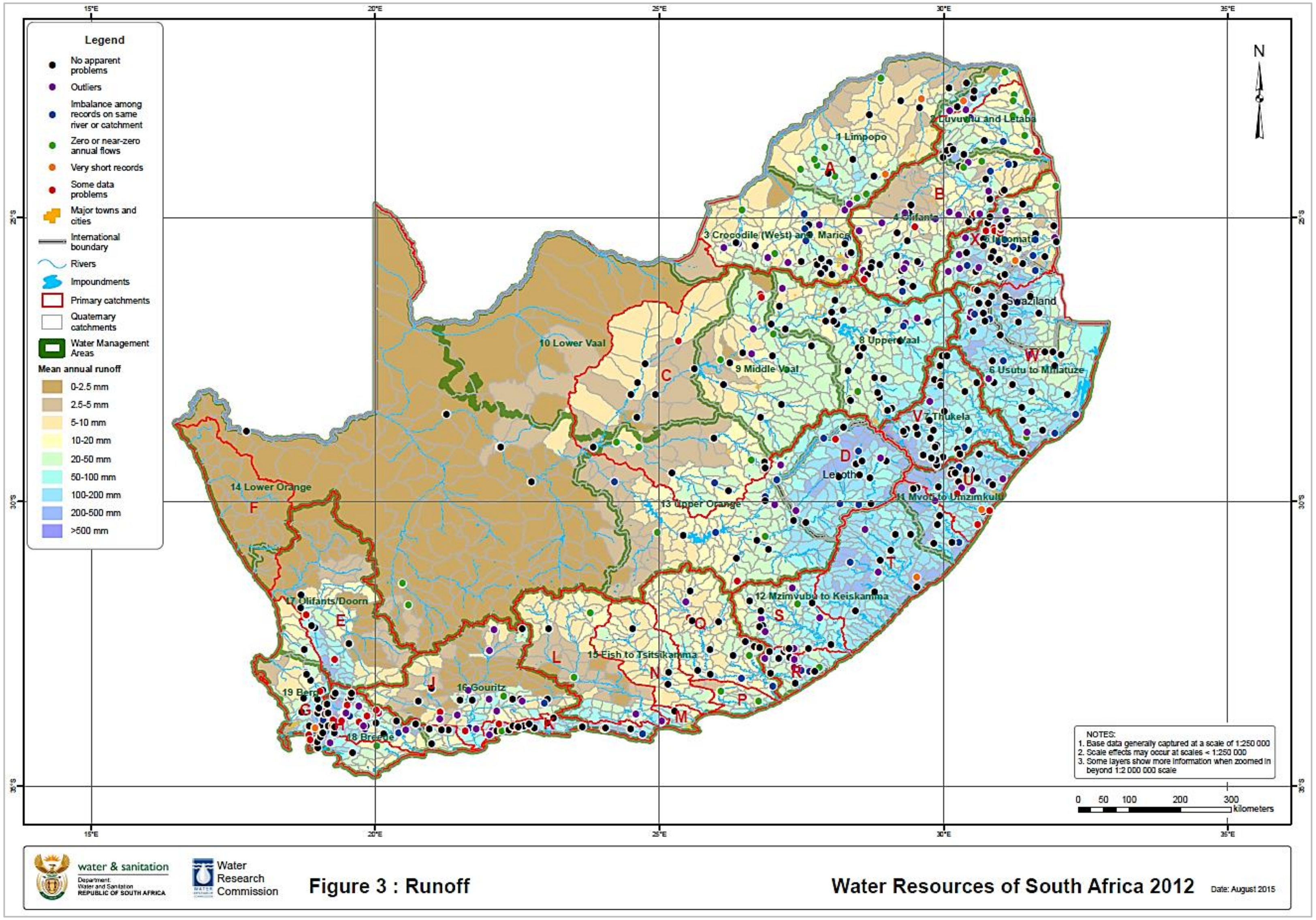


Figure 4-16 National Man Annual Runoff (MAR) with the base data generally captured at a scale of 1:250 000 (from WR2012 Book of Maps).

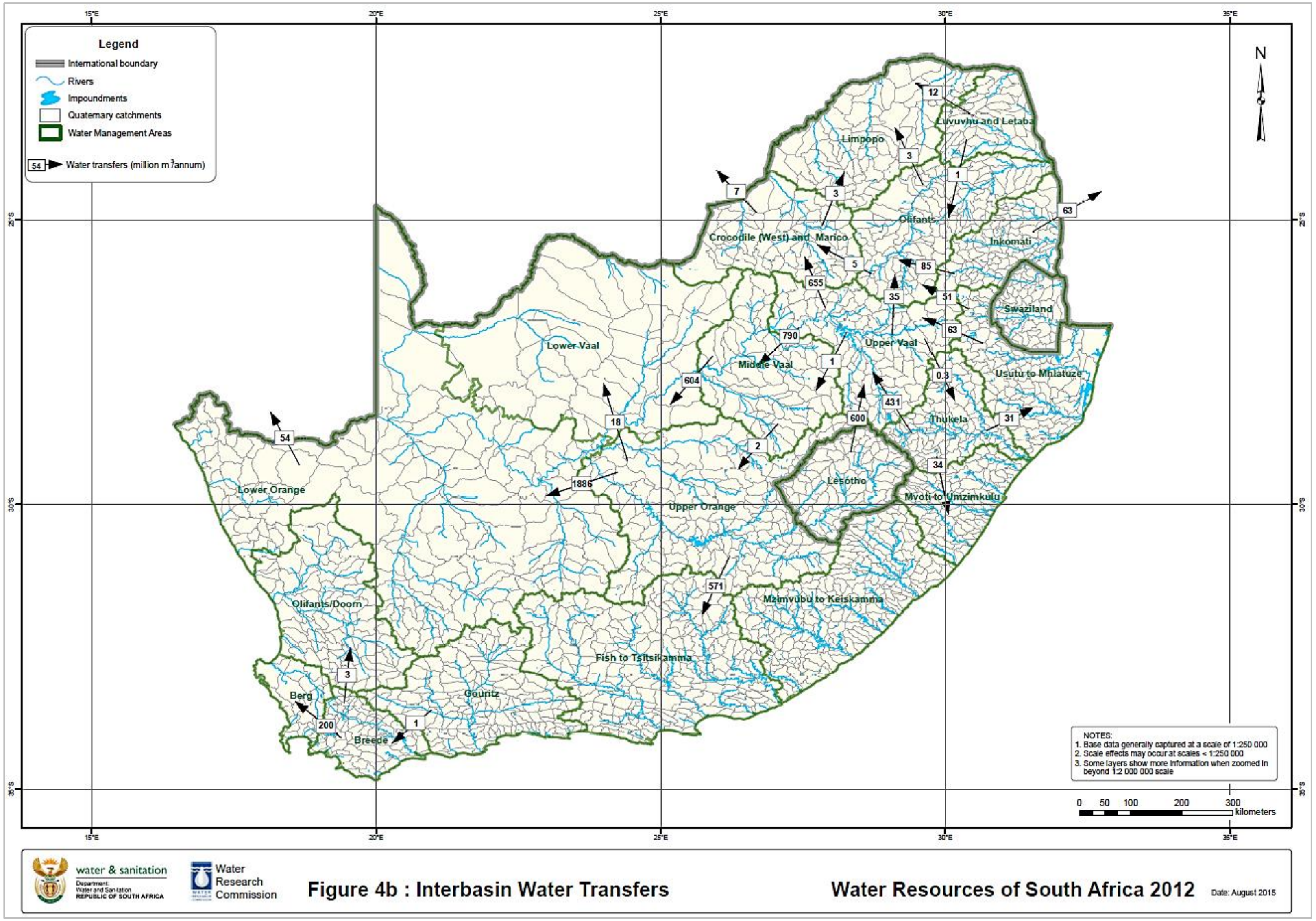


Figure 4-17 National Inter-basin Water Transfers with the base data generally captured at a scale of 1:250 000 (from WR2012 Book of Maps).

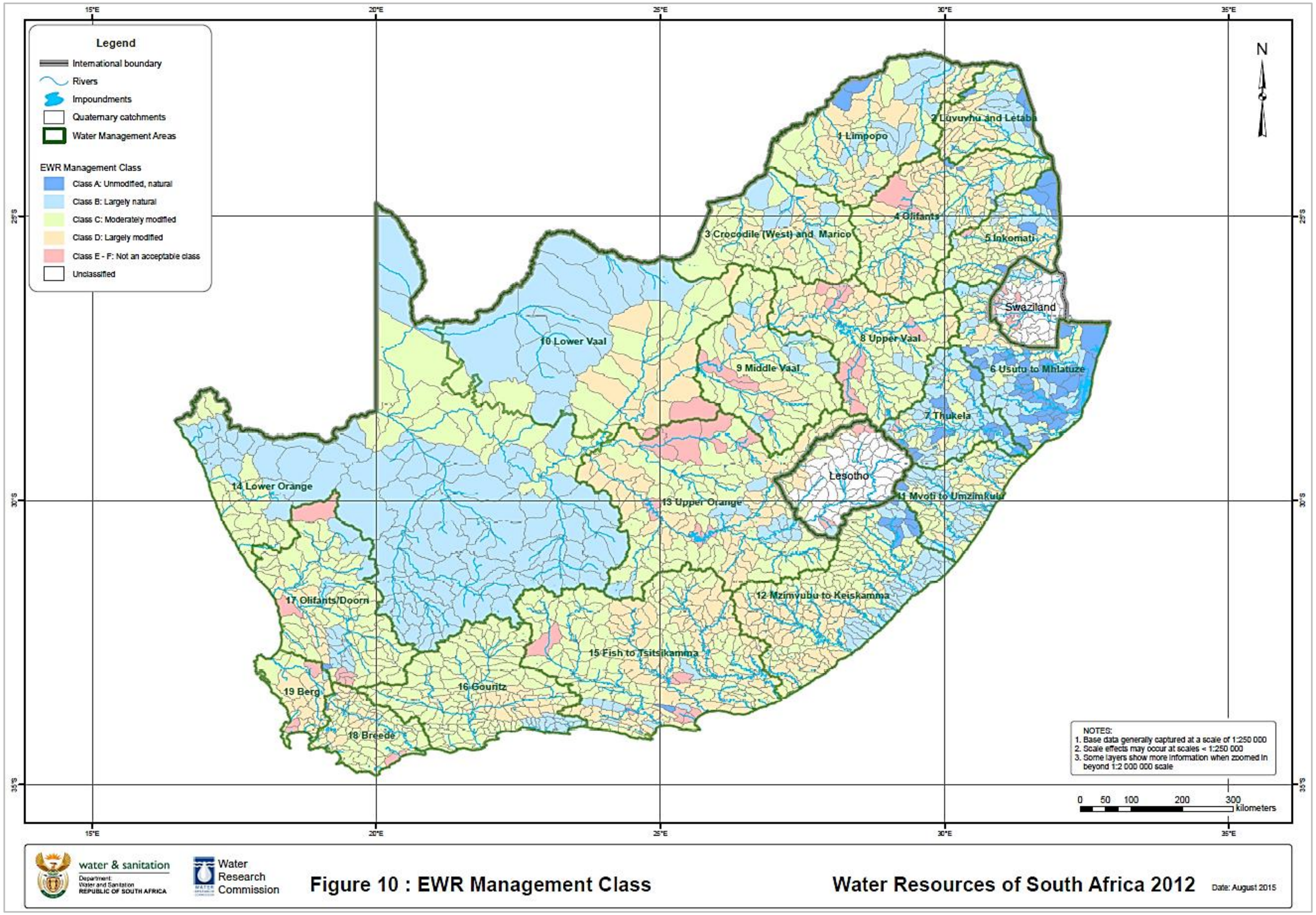


Figure 4-18 **Ecological Water Requirement (EWR) Management Class with the base data generally captured at a scale of 1:250 000 (from WR2012 Book of Maps).**

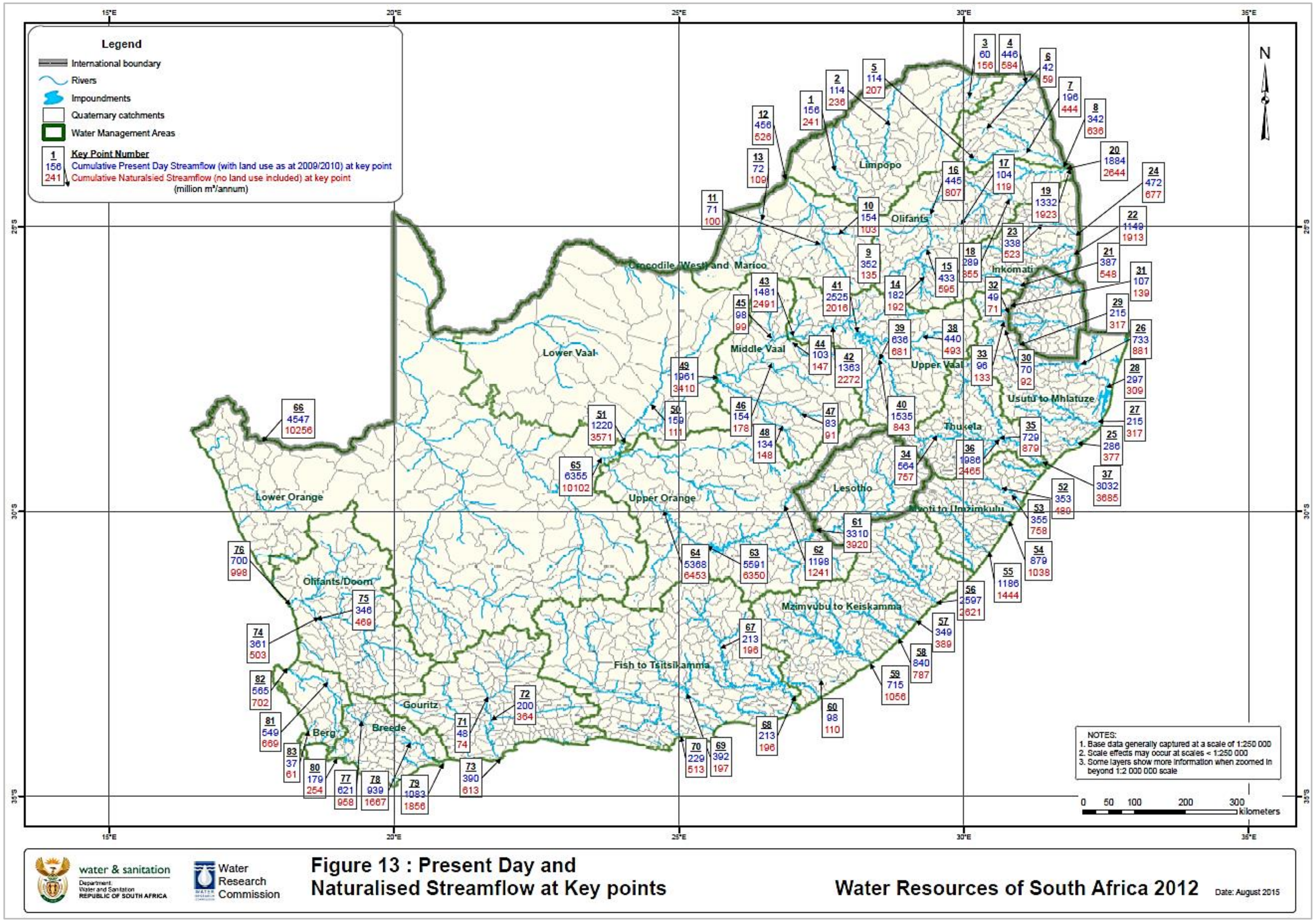


Figure 4-19 Present Day and Naturalised Streamflow at Key points with the base data generally captured at a scale of 1:250 000 (from WR2012 Book of Maps).

4.6. Transboundary Aquifers

As outlined in **Section 2**, the approach and methodology for evaluating the availability and quality of various transboundary datasets from multiple countries is extremely challenging. This is particularly true when accessing, sorting, downloading, synthesizing, and assessing transboundary groundwater datasets from numerous platforms and repositories (see **Section 3.1.2** and **3.2**). Certain datasets, such as geology, hydrogeology, and groundwater recharge are essential for mapping and delineating the boundaries of transboundary aquifers, and are crucial in the process of refining and protecting SWSA-gw in South Africa. These shared groundwater resources play a pivotal role in regional water security (see **Section 1.2**).

The GIS datasets (i.e., the project shapefiles and associated metadata) from these platforms are critical for visualising the spatial relationships between South Africa and its neighbouring countries. This enables a more comprehensive understanding of groundwater distribution and helps in identifying critical recharge areas and usage hotspots. Additionally, the groundwater monitoring datasets provide detailed information on monitoring points, such as the locations of boreholes and abstraction data for associated aquifers. **Table 4-7** and **Table 4-8** provide a summary of known transboundary aquifers shared with South Africa, offering an overview of their geological, hydrogeological, and groundwater resource characteristics.

The tables below summarise the availability of data from SADC and IGRAC sources, including details on the countries they span, the aquifer geometry, and the associated hydrogeological, environmental, and socio-economic aspects (see data examples in **Table 4-9** to **Table 4-13**).

This data will be important for linking and evaluating South Africa's current groundwater monitoring network (i.e., how it relates to the overall understanding of these shared systems) and will guide decision-making by identifying areas most vulnerable to groundwater depletion and contamination.

Key Dataset Information

- **Aquifer Characteristics:** Data on aquifer types (e.g., karst, sedimentary, etc), aquifer size, storage capacity, recharge rates, and water quality. This information is essential for assessing the groundwater availability and quality of shared groundwater resources.
- **Geographic Coverage:** Coordinates, maps and GIS datasets that outline aquifer boundaries, particularly where they cross national boarders, will enable better delineation of shared aquifer systems and their associated recharge areas.
- **Water Usage and Abstraction:** Data on water borehole locations and associated abstraction rates, which could highlight areas with high groundwater use or areas facing over abstraction, may indicate imbalances between groundwater recharge and usage in transboundary aquifer systems.
- **Management Agreements:** Information on existing international agreements governing the use and protection of transboundary aquifers, including legal frameworks, shared responsibilities, and collaborative efforts between countries.

By utilising geographic and aquifer-specific data, this project can accurately delineate and refine the boundaries of SWSA-gw that cross national boarders, highlighting areas that require enhanced protection or sustainable management. Moreover, geology and hydrogeology datasets will help assess the vulnerability of aquifers to pollution and overuse, providing a scientific foundation for shared management strategies with neighbouring countries. Identifying specific regions with high groundwater recharge potential will support sustainable water resource management and foster long-term resilience in the region.

Table 4-7: Overview of Transboundary Aquifers shared with South Africa, summarising geological, hydrogeological, and groundwater resource characteristics.

Aquifer Name	Countries	Geology	Hydrogeology	Groundwater Resources
Tuli Karoo Sub-Basin	Botswana, South Africa, Zimbabwe	Part of the Karoo Supergroup, which consists of sedimentary rocks including shales, sandstones, and minor coal deposits. The basin lies along the borders of Botswana, South Africa, and Zimbabwe and is part of the larger Kalahari-Karoo Basin.	Groundwater occurs within the porous sandstone layers and fractured shale. Water-bearing strata are often found at varying depths due to the geological heterogeneity. The permeability is generally moderate.	The aquifer supports small-scale irrigation and rural water supply, with moderate yields. However, the resources are vulnerable to over-abstraction, especially in areas with limited recharge.
Ramotswa /Zeerust / Lobatse Dolomite Basin Aquifer	Botswana, South Africa	This aquifer is composed of carbonate rocks, forming a karst system with caves and fissures that store and transmit water. Dolomite formations dominate the geology in this area, and it extends across the boarders of Botswana and South Africa.	The karstic nature of the aquifer results in high permeability and significant water storage capacity. The aquifer is recharged primarily by rainfall (recharge areas to be confirmed), and water moves quickly through the system due to the high transmissivity.	The aquifer provides a vital source of water for domestic use, agriculture, and industry. It is highly vulnerable to pollution from surface activities due to the rapid movement of water through the karst system.
Rhyolite-Breccia Aquifer	South Africa, Swaziland, Mozambique	The aquifer is formed from volcanic rocks, primarily rhyolite, and breccia. The rhyolite is a type of igneous rock, while breccia consists of angular rock fragments cemented together, often formed from volcanic activity.	Groundwater is stored and moves through fractures in the rock. These aquifers have low primary porosity but moderate secondary porosity due to fracturing, making groundwater flow through these systems localised and dependent on fracture networks.	The groundwater yield in this aquifer are generally low to moderate, and water yields are variable depending on the extent of fracturing. This type of aquifer is important for localised water supply and often limited in large-scale usage.
Coastal Sedimentary Basin V	South Africa, Namibia	Composed of sedimentary deposits of sands, gravels, and silts, deposited by marine and terrestrial processes. The sediments are often highly permeable, making them good aquifers.	Water flows through the porous layers of sand and gravel, with the aquifer primarily recharged by precipitation and rivers. The permeability of the sediments allows for relatively high groundwater flow rates, but the aquifer can be vulnerable to seawater intrusion if over-abstracted.	Provides significant groundwater for irrigation and drinking water in coastal regions. The risk of contamination from seawater or surface pollutants is high, so careful management is required.

Aquifer Name	Countries	Geology	Hydrogeology	Groundwater Resources
Stampriet Aquifer System	Botswana, Namibia, South Africa	Consists of sedimentary formations from the Kalahari, Karoo, and Kalkrand Groups, including various sandstones and conglomerates. It is located in Namibia and Botswana, with an arid climate making the aquifer crucial for water supply.	The aquifer is multi-layered with varying permeability. The main water-bearing units are in the sandstone layers, which store and transmit groundwater through both primary porosity and secondary fracturing.	The Stampriet system is used for agriculture, domestic use, and livestock. Low recharge rates in this arid environment pose challenges for sustainable use.
Khakhea/Bray Dolomite	Botswana, South Africa	Composed of dolomitic limestone with karst features.	The karstic structure of the dolomite provides storage in the form of cavities and channels. Water moves rapidly through the system, with high transmissivity and potential for large yields. Recharge comes from rainfall and surface water.	Used for agriculture and rural water supply. It is susceptible to contamination from agricultural runoff and industrial activities due to the rapid water movement through the system.
Coastal Sedimentary Basin VI / Coastal Plain Sedimentary Basin Aquifer	Mozambique, South Africa	Composed of sand, gravel, and silt layers that were deposited in coastal environments. These sediments can be well-sorted, making the aquifer highly permeable and capable of storing groundwater.	Water moves through the porous sands and gravels, and the aquifer is recharged by precipitation and nearby surface water bodies. The aquifer is highly transmissive but at risk of seawater intrusion if over-abstracted, especially in low-lying coastal areas.	The aquifer is a critical source of freshwater for coastal communities, irrigation, and industry.
Karoo Sedimentary Aquifer	Lesotho, South Africa	The aquifer forms part of the Karoo Supergroup, comprising layers of sandstone, shale, and coal. These rocks are sedimentary in origin and occur throughout southern Africa.	Groundwater is stored in the sandstone layers, with shales acting as aquitards (confining layers). Fracturing and faulting can enhance groundwater movement, although yields are often moderate and highly variable across the basin.	The Karoo aquifers are an essential water resource for rural communities and agriculture in semi-arid regions. Groundwater yields can be unpredictable, and recharge is often limited
Limpopo Basin	Mozambique, South Africa, Zimbabwe	The Limpopo Basin is underlain by a variety of rock types, including alluvial sediments, granites, and gneisses. The alluvial aquifers along the Limpopo River consist of sands and gravel, which are highly permeable and store water.	Alluvial aquifers are recharged by river flow and rainfall, with high transmissivity and storage capacity. However, the aquifers are also prone to rapid depletion during drought periods. Groundwater movement is generally controlled by river systems and the extent of alluvial deposits.	Water availability is highly variable, with frequent periods of water stress during droughts, requiring careful water resource planning. The aquifer supplies water for irrigation, domestic use and livestock.

Table 4-8: Summary of data availability for transboundary aquifers specifically from SADC and IGRAC sources, including an overview of the overlapping countries, aquifer geometry, and associated hydrogeological, environmental, and socio-economic aspects.

Aquifer Name	Countries	Basic Information [5]	Data Availability	Aquifer Characteristics					Hydrogeology Aspects	Environmental Aspects	Socio-economic Aspects	Legal and Institutional Aspects	Boundaries	Other Maps[6]
				Aquifer Type and Associated Geology	Depth to Water Table	Depth to Aquifer	Vertical Thickness	Aquifer Type and Degree of Connectivity [7]						
Tuli Karoo Sub-Basin	Botswana, South Africa, Zimbabwe	Yes	0% in Botswana and Zimbabwe 25-50% in South Africa	Limited data in Botswana and Zimbabwe. Multiple layer aquifer system (hydraulic connection) in South Africa	Data available for South Africa Limited data in Botswana and Zimbabwe	Data available for South Africa Limited data in Botswana and Zimbabwe	Data available for South Africa Limited data in Botswana and Zimbabwe	Limited data in Botswana and Zimbabwe Data available for South Africa	Limited data in Botswana and Zimbabwe Data available for South Africa	Limited data in Botswana and Zimbabwe Data available for South Africa	Limited data in Botswana and Zimbabwe Data available for South Africa	Limited data in Botswana and Zimbabwe Data available for South Africa	Yes for South Africa Limited information available for Botswana and Zimbabwe	Data available
Ramotswa / Zeerust / Lobatse Dolomite Basin Aquifer	Botswana, South Africa	Yes	0% in Botswana and 25-50% in South Africa	Multiple layer aquifer system (hydraulic connection) in South Africa and Limited data in Botswana	Data available for both South Africa and Botswana	Data available for both South Africa and Botswana	Data available for both South Africa and Botswana	Data available for South Africa and Limited data in Botswana	Data available for both South Africa and Botswana	Limited data available for Botswana	Limited data available for Botswana	Limited data available for Botswana	Data available for both South Africa and Botswana	Data available for both South Africa and Botswan a
Rhyolite-Breccia Aquifer	South Africa, Swaziland and Mozambiq ue	Yes	>75% in Swaziland and 0% in Mozambique . Limited information available for South Africa (This could be due to delineation)	Multiple layer aquifer system (hydraulic connection) in Swaziland and Limited data in Mozambique	Data available for Swaziland Limited data in Mozambique	Data available for Swaziland Limited data in Mozambique	Data available for Swaziland Limited data in Mozambique	Data available for Swaziland and Limited data in Mozambique	Data available for Swaziland and Limited data in Mozambique	Data available for Swaziland and Limited data in Mozambique	Data available for Swaziland and Limited data in Mozambique	Data available for Swaziland and Limited data in Mozambique	Yes, for Swaziland and Limited information available for Mozambique	Data available

[5] *Transboundary aquifer boundaries and associated GIS and metadata available (Yes/No).*
[6] *Including Climate zones, Rainfall, Climate zone per transboundary aquifer.*
[7] *Degree of connectivity referrers to whether or not the aquifer is unconfined, confined, semi-confined, etc.*

Aquifer Name	Countries	Basic Information [5]	Data Availability	Aquifer Characteristics					Hydrogeology Aspects	Environmental Aspects	Socio-economic Aspects	Legal and Institutional Aspects	Boundaries	Other Maps[6]
				Aquifer Type and Associated Geology	Depth to Water Table	Depth to Aquifer	Vertical Thickness	Aquifer Type and Degree of Connectivity [7]						
Coastal Sedimentary Basin V	South Africa, Namibia	Yes	Limited data available	Limited data available	Limited data available	Limited data available	Limited data available	Limited data available	Limited data available	Limited data available	Limited data available	Limited data available	Yes, only boundary GIS layer available	Limited data available
Stampriet Aquifer System	Botswana, Namibia, South Africa	Yes	>75% in Namibia and 0% in South Africa and Botswana	Multiple layer aquifer system (hydraulic connection) in Namibia and Limited data in South Africa and Botswana	Data available for Namibia Limited data for South Africa and Botswana	Data available for Namibia Limited data for South Africa and Botswana	Data available for Namibia Limited data for South Africa and Botswana	Data available for Namibia and Limited data in South Africa and Botswana	Data available for Namibia and Limited data in South Africa and Botswana	Data available for Namibia and Limited data in South Africa and Botswana	Data available for Namibia and Limited data in South Africa and Botswana	Data available for Namibia and Limited data in South Africa Partial data available for Botswana	Yes, for Namibia Limited information available for Botswana and South Africa	Data available
Khakhea / Bray Dolomite	Botswana, South Africa	Yes	0% in Botswana and 25-50% in South Africa	Multiple layer aquifer system (hydraulic connection) in South Africa and Limited data in Botswana	Data available for South Africa Limited data in Botswana	Data available for South Africa Limited data in Botswana	Data available for South Africa Limited data in Botswana	Data available for and Limited data in Botswana	Data available for South Africa and Limited data in Botswana	Data available for South Africa and Limited data in Botswana	Data available for South Africa and Limited data in Botswana	Data available for South Africa and Limited data in Botswana	Yes for South Africa and Limited information available for Botswana	Data available
Coastal Sedimentary Basin VI / Coastal Plain Sedimentary Basin Aquifer	Mozambique, South Africa	Yes	>0-25% in South Africa and 0% in Mozambique	Multiple layer aquifer system (hydraulic connection) in South Africa and Limited data in Mozambique	Data available for South Africa	Data available for South Africa	Data available for South Africa	Data available for South Africa and Limited data in Mozambique	Data available for South Africa and Limited data in Mozambique	Limited data available	Limited data available	Limited data available	Yes for South Africa and Limited information available for Mozambique	Data available
Karoo Sedimentary	Lesotho, South	Yes	>75% in Lesotho and	Multiple layer aquifer	Data available in	Data available in	Data available in	Data available for	Data available for Lesotho and	Data available for	Data available for Lesotho	Data available for	Yes, for Lesotho	Data available

Aquifer Name	Countries	Basic Information [5]	Data Availability	Aquifer Characteristics					Hydrogeology Aspects	Environmental Aspects	Socio-economic Aspects	Legal and Institutional Aspects	Boundaries	Other Maps[6]
				Aquifer Type and Associated Geology	Depth to Water Table	Depth to Aquifer	Vertical Thickness	Aquifer Type and Degree of Connectivity [7]						
Aquifer	Africa		50-75% in South Africa	system (hydraulic connection) in South Africa and Lesotho	both countries	both countries	both countries	Lesotho and South Africa	South Africa	Lesotho and South Africa	and South Africa	Lesotho and South Africa	Limited information for South Africa	
Limpopo Basin	Mozambique, South Africa, Zimbabwe	Yes	0% data in Zimbabwe, 25-50% in South Africa Limited shown on the map for Mozambique	Limited data in Zimbabwe, multiple layers in South Africa	Limited data available	Limited data available	Limited data available	Limited data in Zimbabwe, Data available for South Africa	Limited data in Zimbabwe, Data available for South Africa	Limited data available	Limited data available	Limited data available for Zimbabwe and data available for South Africa	Limited information available	Data available

Table 4-9: Spatial layer and summary of Global Groundwater Monitoring Network (GGMN) sites in South Africa, as provided by IGRAC.

Global Groundwater Monitoring Network (GGMN)	Summary	URL
	The Global Groundwater Monitoring Network (GGMN) is a compilation of groundwater level monitoring data collected under national and subnational monitoring programs. It provides information on borehole location, ground surface elevation, and groundwater level measurements (records). Only South Africa, Lesotho and Namibia is part of the GGMN highlighting missing information from Botswana, Zimbabwe, Mozambique, eSwatini.	https://ggis.un-igrac.org/catalogue/#/dataset/2472

Table 4-10: Spatial layer and summary of Global Groundwater Level Data and associated Aquifer System Boundaries (after Jasechko et al. 2024) from IGRAC.

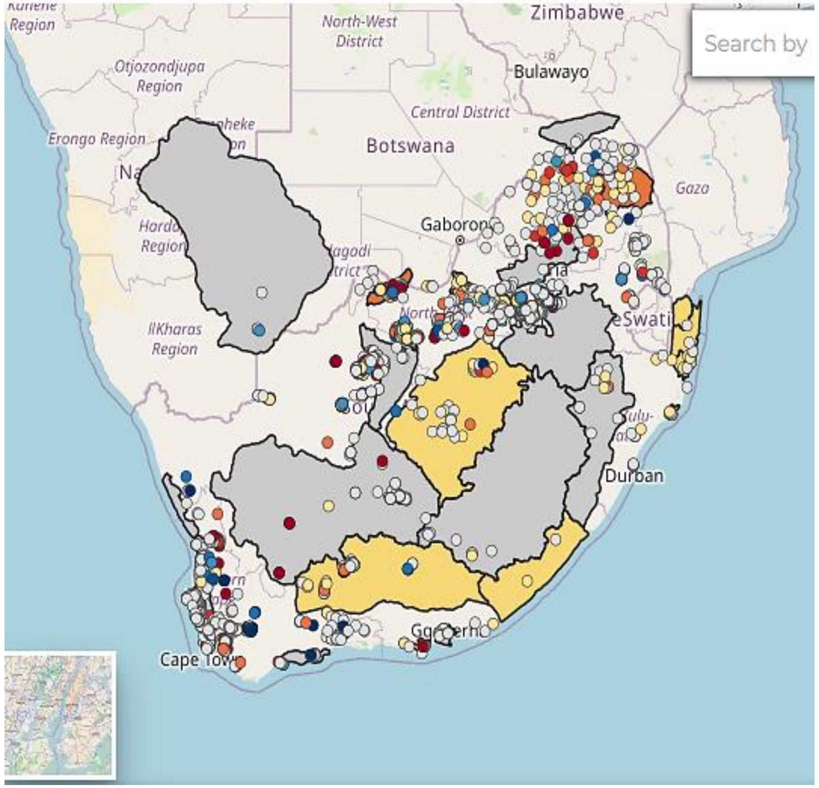
Global groundwater level data and aquifer system boundaries (Jasechko et al. 2024)	Summary	URL
	The global groundwater level data and aquifer system boundaries map provides valuable insights into both the rapid decline and occasional recovery of aquifers worldwide. It illustrates the spatial distribution of groundwater levels, helping to identify regions facing water scarcity, areas vulnerable to over-abstraction, and zones of hydrological connectivity. Additionally, this map highlights shared resource boundaries by displaying the Theil-Sen slope, a non-parametric statistical method used to estimate trends in groundwater data, such as changes in water levels over time.	https://ggis.un-igrac.org/catalogue/#/map/2504

Table 4-11: Spatial layer and summary of Groundwater Abstraction for Agricultural Use from IGRAC.

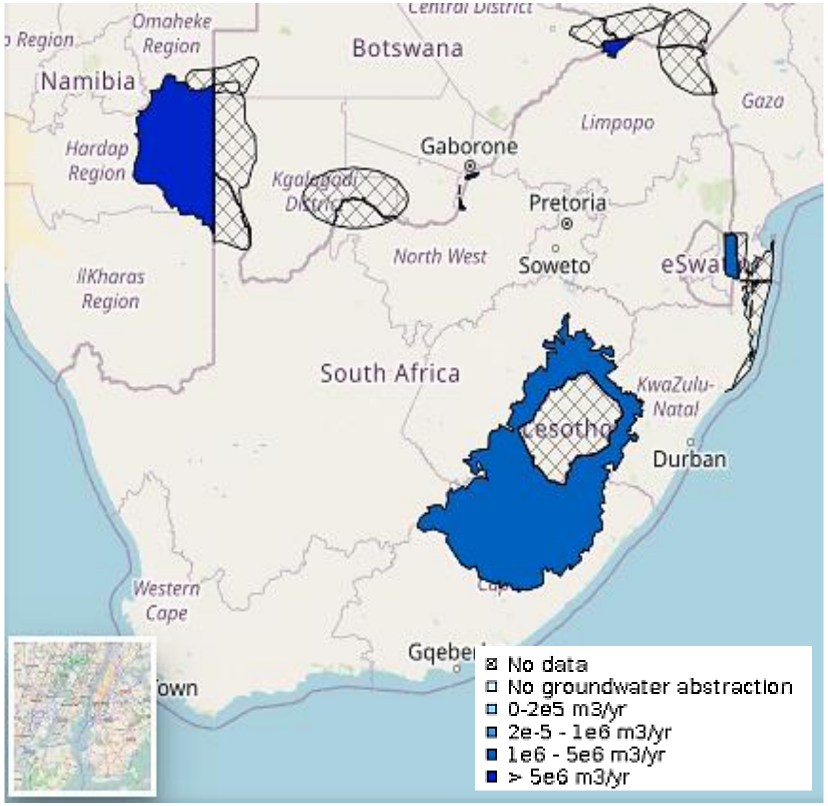
Groundwater Abstraction for Agricultural Use	Summary	URL
	This map layer, which includes data from WARMS, displays the total annual volume of groundwater abstraction from (measured in cubic meters, m³/yr) for agricultural purposes, such as irrigation and livestock watering, as well as groundwater use from wells and other devices. It also includes data on groundwater abstraction for industrial purposes. By analysing this data, insights can be gained into global groundwater usage patterns, its abstraction purposes, and sources, all of which are critical for effective water management and transboundary aquifer management. Areas with available data are highlighted in blue, while clear boxes indicate regions with no data available.	[Groundwater abstraction for agricultural use, including livestock [m3/yr] - IGRAC (un-igrac.org)]

Table 4-12: Spatial distribution of aquifer productivity (l/s) across Africa, showing categories from very high to very low productivity, based on IGRAC data.

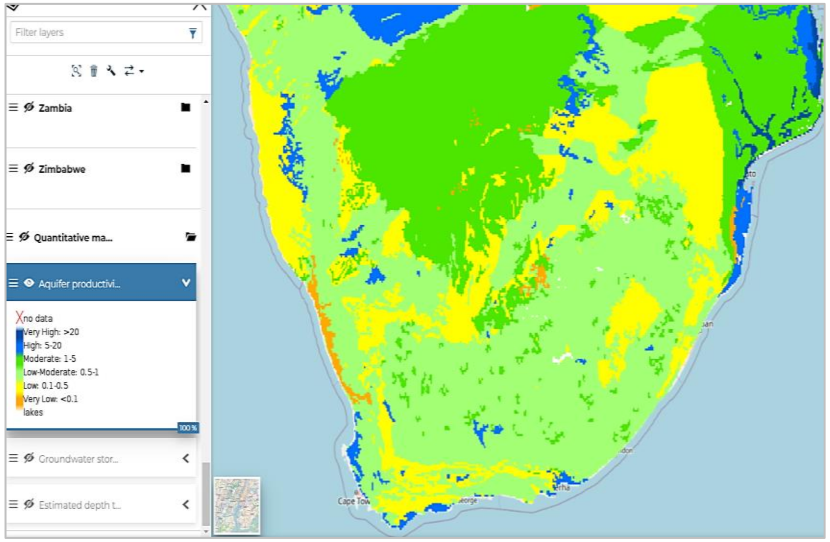
Aquifer Productivity	Summary	URL
	The groundwater productivity map indicates what borehole yields can reasonably be expected in different hydrogeological units. The ranges indicate the approximate interquartile range of the yield of boreholes that have been sited and drilled using appropriate techniques.	https://ggis.un-igrac.org/catalogue/#/dataset/1920

Table 4-13: Spatial layer and summary of the Global Managed Aquifer Recharge Inventory from IGRAC.

Global Managed Aquifer Recharge Inventory	Summary	URL
	The global Managed Aquifer Recharge Inventory contains data and parameters of Managed Aquifer Recharge case studies all over the world. Parameters include the site name, managed aquifer recharge type (such as infiltration ponds, recharge wells, or river banks filtration), year of scheme deployment, the source of infiltration water, the final use of abstracted water, as well as the main objectives of the project.	https://ggis.un-igrac.org/catalogue/#/dataset/1810

4.6.1. Summary of Known Limitations

While the SADC and IGRAC transboundary datasets are crucial for SWSA-gw delineations and transboundary groundwater management, several limitations reduce their overall effectiveness for the project. Factors such as coverage, scale (often larger than 1: 1000 000), and data quality across regions (see **Table 4-7** and **Table 4-8**) make it difficult to achieve a comprehensive understanding of all aquifer systems. Temporal gaps from outdated information limit effective trend analysis and decision-making. Furthermore, socio-economic and environmental data are often underreported (see **Table 4-7** and **Table 4-8**), restricting the ability to assess broader impacts on communities and ecosystems, especially when linking them to the portions of SWSA-gw that fall in South Africa. Finally, limited data accessibility due to restricted access or paywalls hinders full utilisation by stakeholders.

4.6.2. Recommendations

To address these limitations, the following recommendations are proposed:

- The project aims to merge transboundary groundwater datasets with national datasets such as WARMS, NGA, WMS, and Hydstra to standardize formats for spatial analysis, improving cross-border integration. To achieve this, priority will be given to acquiring up-to-date data by setting up meetings with the relevant DWS personnel responsible for transboundary coordination. These meetings will involve groundwater departments in neighbouring countries to discuss key parameters such as groundwater levels, usage, recharge, and quality, ensuring alignment and refining the delineations of SWSA-gw. Where data is unavailable, interpolation methods will be employed, with documented limitations or assumptions.
- The project recommends advocating for finer-scale, open-access data policies and enhanced sharing mechanisms between countries and institutions in the SADC region, ensuring access to high-resolution datasets. Data collection efforts should also expand to include detailed socio-economic and environmental information, supporting holistic groundwater management that considers community and ecosystem impacts.

To supplement and bridge the gaps in transboundary groundwater data, the following sources and insights from related projects can be integrated:

- Hydrogeological and Aquifer Characteristics:
  - Africa Groundwater Atlas (see **Section 3.2**) provides regional summaries and maps for groundwater systems extending across South Africa’s borders with SADC countries. This data can fill gaps in groundwater status and aquifer characteristics.
  - Aquaknow (see **Section 3.2**) offers geo-referenced datasets on hydrology, soil properties, and climate, which can help model recharge zones and estimate groundwater flow. While not specific to the required aquifer characteristics its environmental data can enhance hydrogeological assessments and supplement missing information on aquifer characteristics.
- Groundwater Monitoring and Quality Data:
  - GGIS (see **Section 3.2**) provides global groundwater data, including map layers, borehole data, and groundwater quality information. This system can help fill gaps in transboundary aquifer data and hydrogeological characteristics.

By integrating South African datasets with those from SADC and IGRAC, the project aims to improve the understanding of transboundary aquifers and their connection to South Africa's National Monitoring Network, enhancing data quality and consistency across borders. By focusing on acquiring up-to-date data this will help to fill temporal gaps and support more informed decision-making for sustainable transboundary aquifer management. Addressing current limitations and following the proposed recommendations will help refine SWSA-gw delineations and foster better collaboration between South Africa and its neighbouring countries in managing shared groundwater resources. The baseline data from SADC and IGRAC will form the foundation for this effort, promoting a more integrated and comprehensive approach to groundwater management.

4.7. Supplementary Data Categories

To support the main background studies (**Section 3.1.1**), other technical reports (**Section 3.1.2**), and the groundwater resources tools and datasets (**Section 3.2**), it is important to integrate supplementary data categories beyond core groundwater and hydrological data listed above. These categories contribute valuable context, particularly for socio-economic and land-use patterns, which influence groundwater resource use, protection status, and management decisions. The following categories have been identified as important for the Status Quo Assessment and will be explored further during Phase 3.

Socio-Economic

Socio-economic data play a critical role in understanding groundwater demand and pressures, as population growth and economic activities influence both water use and the potential for over-abstraction. Key sources include:

- Statistics South Africa (StatsSA): Published census data, including the Census 2022 and various Community Surveys, offer demographic and economic insights relevant to groundwater use patterns. These datasets, though valuable, have limitations in their granularity concerning groundwater-specific metrics. For example, they do not always capture informal water use practices such as unlicensed boreholes, which may be prevalent in certain regions. As a result, socio-economic data often require integration with tools like the WARMS to provide a more complete picture of groundwater stress in high-demand areas.

Land-Use

Land-use patterns, including urban expansion, agriculture, and conservation areas, directly affect groundwater recharge and quality. Relevant datasets include:

- National Land Cover (2020): This dataset offers high-resolution classification of land-use types across South Africa, essential for identifying areas where changes in land use (e.g., urbanization or deforestation) might alter groundwater recharge dynamics. For example, large-scale agricultural development can significantly impact aquifer recharge rates, particularly in vulnerable areas such as the Limpopo River Basin.

Protection Status and Conservation Areas

Conservation areas are vital for groundwater sustainability as they protect recharge zones from over-extraction and pollution. Key datasets include:

- South Africa's Protected Areas Database (SAPAD), Conservation Areas Database (SACAD), and the SANBI Database, all updated quarterly in collaboration with the DFFE, provide essential data on areas designated for biodiversity protection. These include national parks and nature reserves, which play a key role in preserving groundwater recharge zones. For example, Table Mountain National Park safeguards recharge areas crucial to the Table Mountain Group Aquifer.
- National Biodiversity Strategy and Action Plan (NBSAP): Focuses on expanding and managing protected areas, protecting threatened species, and restoring degraded ecosystems to enhance biodiversity and ecosystem services. It promotes sustainable resource use, integrates biodiversity into policies (e.g., land and water management), and engages communities in conservation efforts. Research, monitoring, and climate adaptation strategies are also prioritized to protect ecosystems against future threats.

Administrative Boundaries

Administrative boundaries, such as municipal and provincial lines, influence governance structures for groundwater management. Understanding these boundaries is critical for effective regulation and enforcement.

Active Organizations and Stakeholders

Several key organizations actively contribute to groundwater management and conservation across South Africa's SWSAs. Their work is essential for ensuring sustainable groundwater resource use.

- Table Mountain Partnership: Focused on sustainable land-use management in the Table Mountain area, this partnership plays a key role in protecting recharge areas of the Table Mountain Group Aquifer.
- Worldwide Fund for Nature (WWF-SA): WWF-SA leads initiatives in water stewardship, ensuring groundwater sustainability in key agricultural areas.
- StepSA (Spatial and Temporal Evidence for Planning in South Africa): Provides critical socio-economic and spatial planning data that influence groundwater use patterns, particularly in areas of rapid urban expansion.
- South African National Biodiversity Institute (SANBI): Plays a key role in biodiversity conservation, including efforts to protect ecosystems that are closely tied to groundwater recharge.
- Water Research Commission (WRC): Funds research projects focused on improving groundwater management practices and understanding groundwater-surface water interactions.

5. CONCLUSION

This Gap Analysis Report provides a comprehensive evaluation of the current data landscape for this project, with a focus on groundwater data availability and quality requirements for Phase 3 (see **Section 1 and Table 1-1**). This phase centres on determining the data requirements needed to achieve two key objectives: (1) assessing the current status of the 37 existing SWSA-gw (Le Maitre et al., 2018a) and (2) establishing the foundational data necessary to develop a refined methodology that incorporates groundwater quality, transboundary aquifers, significant groundwater contributions to baseflow, and aspects related to the protection and management of these resources.

The baseline studies referenced in this report provide valuable insights but also reveal areas where more detailed information is required. For instance, while the NSBA (2004) focused on surface water resources and identifying "high water yield areas", it emphasized the need for groundwater resources to be incorporated. Similarly, the NFEPA (2011) identified groundwater recharge areas as a significant factor but was limited by outdated and inconsistent datasets. The SWSA (2013) introduced the concept of "Strategic Water Source Areas" but required a more in-depth understanding of the complexities of groundwater systems and recharge dynamics. The SWSA (2018) expanded on the 2013 definition to include groundwater-specific SWSAs, but relied on older GRAII MAP data, which may not have had the spatial resolution required for a more refined, aquifer-specific SWSA-gw delineation. Moreover, while the Fine-Scale Delineation for surface water SWSAs (2021) improved the mapping for SWSA-sw, it lacked the high-resolution groundwater data necessary for a comparable refinement of SWSA-gw.

Despite the limitations of the baseline studies and national/transboundary hydrogeological datasets, there is sufficient data available to proceed with Phase 3 of the project. These limitations are not viewed as significant obstacles but rather as opportunities for **targeted** data improvements in specific categories. The key findings from each of the categories are summarised below (see **Table 5-1**):

- **Groundwater Use**

  The WARMS database faces challenges related to coordinate inaccuracies and incomplete records for small-scale users (Schedule 1 users). However, it remains a valuable resource for estimating groundwater use at a national level. Issues such as outdated coordinate systems and spatial errors can be mitigated by using GIS techniques, verifying site coordinates with DWS, supplementing missing information with municipal hydro-census data, and integrating datasets like Hydstra and NGA where necessary for specific details.

- **Groundwater Levels**

  While the Hydstra database has limitations like coordinate inaccuracies and difficulties in correlating site IDs with historical records, these issues can be resolved by prioritizing the verification of active sites in known national and transboundary aquifer systems. Supplementing Hydstra with data from NGA, IGRAC, and SADC will improve geographic accuracy and address historical data gaps.

- **Subsurface Information**

  The NGA faces challenges with incomplete borehole information and missing metadata. However, there is sufficient subsurface data for assessing and interpreting the hydrogeology setting on a national scale. Enhancing the NGA with municipal hydro-census data from privately drilled boreholes and integrating CGS and GRIP data (specifically for Limpopo, KwaZulu Natal and the Eastern Cape Province) will help fill gaps related to borehole depths and lithologies.

- **Groundwater Quality**

  While the WMS dataset has spatial and coverage inconsistencies, they can be supplemented with data from active groundwater schemes, local aquifer-specific monitoring programs, and the GRIP (specifically for Limpopo, KwaZulu Natal and the Eastern Cape Province) database. Additionally, other sources such as NCMP, NGwQMP, and NIWIS will support data needs for the updated SWSA-gw refinement criteria and methodology.

- **Rainfall-Recharge**

  Comparing MAP datasets from Lötter and Le Maitre (2021), WR2012, and Schulze et al. (2008) will determine whether recharge estimations from GRAII and WR2012 are adequate or need updating to support the understanding of groundwater-surface water interactions as well as the rainfall-recharge-discharge relationships across the county.

- **Transboundary Aquifer Data**

  Surface and sub-surface geology, groundwater quantity and quality, recharge and rainfall datasets are available but face various challenges, specifically coarse resolution and data quality inconsistencies. Aligning them with South African national datasets like WARMS, NGA, WMS, Hydstra, and our national MAP and Recharge (in terms of format and structure), as well as obtaining specific finer-scale data from neighbouring countries via DWS, will enhance the accuracy of SWSA-gw delineations.

Moving Forward

By addressing the identified gaps, the project will enhance the quality and accuracy of the primary datasets, leading to refined SWSA-gw delineations and improved decision-making concerning national and transboundary aquifer systems. The integration of national and transboundary datasets will provide a better understanding of rainfall-recharge-discharge dynamics, particularly in baseflow-dependent areas. Improving socio-economic and environmental data will also enable a more holistic assessment of groundwater impacts on communities and ecosystems.

In conclusion, despite the dataset limitations, they are sufficient for the project's current needs. The gaps identified represent opportunities for enhancement rather than significant barriers. By proceeding with the existing data and focusing on targeted improvements, Phase 3 is well-positioned to support the objectives of the project.

Table 5-1: Comprehensive Overview of Groundwater Data Gaps, Impact Scores, and Proposed Solutions, Action and Recommendations.

Gap Category	Description	Overall Availability	Overall Data Quality	High/Low Impact	Reasoning for Impact Score and a Summary of the Proposed Action/Recommendation
Groundwater Use	Inaccurate spatial coordinates in the WARMS database Incomplete records for small-scale water users (e.g., Schedule 1 users) Discrepancies in registered vs. actual water use volumes	4.4	4.6	Medium to Low	Accurate mapping of groundwater usage is critical for resource management. At the national scale, site verification is required only for specific locations, with priority given to the current 37 SWSA-gw (2018). Small-scale users contribute significantly to groundwater use, and any missing data could lead to underestimation. However, this can be supplemented with municipal records and other databases. Discrepancies between registered and actual water usage, often due to under-reporting or data entry errors, can affect long-term planning and compliance. To address these gaps, site verification should focus on the 37 SWSA-gw, utilizing municipal records to verify that sites are correctly located within quaternary/sub-quaternary catchments. Missing information for small-scale users (Schedule 1) will be supplemented with municipal records, census data, and data from various databases, including WARMS, Hydstra, NGA, WSDP Geodatabase, StatsSA Census Data, GRIP, StepSA, GRA II, GGIS, and SADC-GIP.
Groundwater Levels	Limited coverage and inconsistent data for borehole levels in Hydstra database Inaccurate borehole coordinates and site inconsistencies Gaps in long-term monitoring of water levels	3.8	4.2	Medium to Low	Groundwater level data is essential for long-term groundwater monitoring and resource management. However, inconsistencies in borehole data may result in planning issues and reduce the reliability of aquifer-specific spatial assessments. Gaps in long-term monitoring compromise trend analysis but can be supported with short-term data from other available sources. To resolve these issues, coordinate verification should be prioritized for active sites within the 37 SWSA-gw. Misplaced sites, especially those due to incorrect coordinates, should be identified and corrected. In areas near provincial borders, proximity analysis can ensure that sites are correctly attributed. To further enhance the Hydstra dataset, borehole information and water level data from NGA should be cross-checked to verify geographic accuracy. Additional data sources, such as WARMS, WMS, and the National Monitoring Network and the National Water Monitoring Plan (2022), can be used to further ensure coordinate and data accuracy. Historical water levels and borehole data from the GRIP project (particularly in Limpopo, KwaZulu-Natal, and Eastern Cape) will help fill gaps where groundwater monitoring has been inconsistent.

Gap Category	Description	Overall Availability	Overall Data Quality	High/Low Impact	Reasoning for Impact Score and a Summary of the Proposed Action/Recommendation
Groundwater Quality	Spatial gaps in groundwater quality monitoring, especially in rural areas Incomplete records for trace elements (metals and heavy metals) Inconsistent water quality data between WMS and NGA databases	3.2	3.6	Medium to Low	Gaps in groundwater quality data can lead to improper management and risks to public health, particularly in areas that rely heavily on groundwater. Trace elements, such as metals and other contaminants, are critical for both public health and environmental protection. Missing data increases the risk of underestimating contamination levels, while inconsistent data between sources reduces the ability to accurately assess overall water quality. However, these gaps are not immediately critical to the short-term objectives of the project and may present more of a concern during the aquifer-specific status quo assessment. To address these gaps, the WMS dataset will be supplemented with data from active groundwater schemes, particularly where groundwater quality monitoring is mandated by the WUL conditions. This additional data will enhance both the spatial and temporal coverage of groundwater quality monitoring. Missing information in rural areas will be supplemented using data from GRIP, particularly for Limpopo, KwaZulu-Natal, and the Eastern Cape Province, to fill gaps in the WMS dataset. Additionally, the integration of NGA, WMS, WARMS, and Hydstra will be pursued to ensure consistency across the board. The NCMP and NGwQMP will provide long-term groundwater quality data, tracking trends in pollutants and contamination risks, thereby improving the temporal coverage of WMS.
Recharge Data	Outdated MAP data used in GRAII recharge estimation. Discrepancies in national MAP datasets	3.5	3.8	Medium	Recharge data is important for understanding sustainable abstraction. However, discrepancies in recharge estimations (and the associated model inputs, such as MAP) can affect the accuracy of groundwater recharge assessments. To improve confidence in existing groundwater recharge estimations, the Lötter and Le Maitre (2021) downscaled MAP layer should be compared with the MAP data from WR2012, GRAII, Schulze et al. (2008), and other national-scale MAP layers. If the rainfall patterns are similar, the recharge estimations from GRAII and WR2012 can serve as a basis for validating recharge using other method. However, if significant differences in MAP are identified, adjustments to the recharge estimates may be required. Integrating additional datasets, although challenging due to differing resolutions, will improve the understanding of groundwater recharge zones and assist in identifying GDEs.

Gap Category	Description	Overall Availability	Overall Data Quality	High/Low Impact	Reasoning for Impact Score and a Summary of the Proposed Action/Recommendation
Transboundary Aquifers	Coarse resolution of data for aquifers shared between South Africa and neighbouring countries Gaps in cross-border data integration and shared groundwater monitoring	2.5	3.2	Medium	Coarser resolution transboundary data compared to national datasets can affect international water management, but improvements can be made through collaboration without significant delays. The lack of finer resolution shared data on cross-border aquifers could lead to resource mismanagement, making urgent data-sharing improvements necessary. To address these limitations, the project aims to merge transboundary groundwater datasets with national datasets such as WARMS, NGA, WMS, and Hydstra. This will standardize formats for spatial analysis, improving cross-border integration. Priority will be given to acquiring up-to-date data through coordination with relevant DWS personnel and neighbouring SADC countries to discuss key parameters such as groundwater levels, usage, recharge, and quality. Where data is unavailable, interpolation methods will be applied, with documented limitations and assumptions. To bridge gaps in transboundary groundwater data, the Africa Groundwater Atlas will provide regional summaries and maps for groundwater systems extending across South Africa's borders. The GGIS system offers global groundwater data, including map layers, borehole data, and groundwater quality information, which will help fill gaps in transboundary aquifer data. By integrating South African datasets with those from SADC and IGRAC, the project will improve the understanding of transboundary aquifers and their connection to South Africa's National Monitoring Network, enhancing data quality and consistency across borders.
Subsurface Information	Incomplete borehole depth and lithology data, particularly for older boreholes Limited integration of subsurface datasets across national platforms	3.7	4	Low to Medium	Borehole data is important for subsurface geological modelling but is not immediately critical for short-term project goals. The delays in data integration affect efficient data usage and resource planning, but this is not a critical issue for establishing rough aquifer extents. To address these limitations, additional data on privately drilled boreholes in the current 37 SWSA-gw (2018) areas should be gathered, with a focus on drilling data. This includes integrating borehole depth and lithology information from these sources with the existing NGA data to better understand subsurface geology. Additionally, GRIP provides unpublished borehole information, particularly in rural areas where NGA records may be incomplete. This data is especially valuable for filling gaps in borehole depths and lithologies in areas such as Limpopo, KwaZulu-Natal, and the Eastern Cape Province, where well construction data may be lacking.

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APPENDIX

Table A-1 Overview of hydrogeological maps and associated spatial data for South Africa and SADC countries from the SADC Groundwater Information Portal (SADC-GIP) and Groundwater Literature Archive (SADC-GLA) and the International Groundwater Resources Assessment Centre (IGRAC).

Country	Maps Available
Lesotho	• Hydrogeological map of Lesotho ○ Hydrological data (Rainfall, Precipitation, etc) ○ Hydrochemistry of Groundwater ○ Location of boreholes ○ Hydrometric stations (hydro-stations) with runoff ○ Hydrological basins and sub-basins ○ Elevation ○ Geology ○ Use of Groundwater Resources
Zimbabwe	• Hydrogeological map of Zimbabwe ○ Geological features (lines and polygons) ○ Hydrogeological units
Mozambique	• Hydrogeological map of Mozambique – South and North ○ Hydrogeological units ○ Water Quality features (lines, polygons, points) ○ Wells and boreholes ○ Geological Map ○ Geological Features (lines) ○ Groundwater Map ○ Groundwater Features (points and polygons)
Swaziland/ eSwatini	• Hydrogeological map of eSwatini ○ Hydrogeological units ○ Fault lines ○ Cross-sections (Hydrogeological map of Swaziland)
Botswana	• Botswana and South Africa geological maps (combined) ○ Geology ○ AFR CGMW-BRGM 1:10M Geological units ○ SADC Hydrogeological Map

Table A-2 Additional resource layers and associated metadata or descriptions for South Africa and associated SADC countries from SADC Groundwater Information Portal (SADC-GIP) and Groundwater Literature Archive (SADC-GLA) and the International Groundwater Resources Assessment Centre (IGRAC).

Resource Layers	Resource / Dataset Information
Agricultural Farming Activities	Metadata related to agricultural activities, possibly including water usage for farming, livestock, and irrigation, essential for understanding agricultural water demands.
Borehole Database (2010) - Mozambique	Similar to the South African borehole dataset, this file covers Mozambique, detailing borehole locations, water levels, and depths, can be used for groundwater resource monitoring.
Borehole Database (2010) - South Africa	Contains information on boreholes in South Africa, including geographical locations, water levels, and borehole depths, relevant for groundwater management.
Botswana And South Africa Geological Maps	Geological mapping data for Botswana and South Africa, useful for geological and hydrogeological studies, including information on rock formations, faults, and aquifers.
Deep Aquifers	Provides details on subsurface deep aquifers, including spatial data and boundaries, helpful in assessing groundwater storage and potential use of deep aquifers.
Dykes (Dinokana - Botswana, South Africa)	Metadata focused on dykes in the Dinokana area (Botswana and RSA), relevant for geological and structural studies.
Faults And Dykes	Information on geological faults and dykes, useful for understanding subsurface geological structures and their impact on groundwater flow and storage.
Formation Unspecified - Malmani Subgroup	Metadata related to the Malmani subgroup (Transvaal), potentially providing geological and hydrogeological information regarding formations and their water-bearing characteristics.
Frisco Formation (Transvaal) - South Africa	Geological metadata about the Frisco Formation in the Transvaal, including its composition, spatial distribution, and significance in regional hydrogeology.
Geological Features (Lines)	Contains information about geological line features such as faults and dykes, valuable for geological and hydrogeological mapping and analysis.
Geology - Simplified	Simplified geological mapping data for broader geospatial analysis of geological formations and groundwater resources.
Groundwater Level Points [Mamsl]	Contains elevation data for groundwater levels, useful for hydrological modeling and water resource assessment.
Groundwater Quality - All Hydrochemistry Data	Comprehensive dataset on groundwater chemistry, supporting analysis of water quality parameters like pH, metals, and major ions.
Groundwater Quality - Nitrate & Nitrite	Data on nitrate and nitrite levels in groundwater, critical for assessing water quality and environmental health impacts.
Groundwater Quality - Total Coliform	Provides data on total coliform contamination in groundwater, used for monitoring water quality and public health.
Groundwater Recharge	Provides information on groundwater recharge rates and areas to support resource sustainability and management.
Harmonized Borehole Database	A harmonized borehole dataset combining multiple sources for comprehensive groundwater resource monitoring.
Hydrogeological Map of Mozambique - South	Georeferenced hydrogeological map of southern Mozambique, relevant for water resource distribution and aquifers.
Hydrogeological Units	Contains data on hydrogeological units such as aquifers and groundwater occurrence areas.
Industry	Metadata on industrial activities related to water and land use, with data available in multiple formats.
Isotope Data	Contains isotope analysis data for groundwater samples from Botswana and South Africa, useful for environmental studies.
Lyttleton Formation (Transvaal) - South Africa	Geological data on the Lyttleton Formation in Transvaal, essential for regional hydrogeological studies.

Resource Layers	Resource / Dataset Information
Mining And Quarrying Activities	Provides data on mining and quarrying activities impacting water and land resources.
Monte Christo Formation (Transvaal) - South Africa	Geological data related to the Monte Christo Formation, essential for understanding hydrogeology in the region.
Oaktree Formation (Transvaal) - South Africa	Geological metadata on the Oaktree Formation in Transvaal, relevant for hydrogeological analysis and studies.
Regional Groundwater Drought Risk	Contains data on the potential risk of groundwater drought under different climate scenarios, essential for resource management.
Revised Groundwater Drought Risk for SADC (2020)	Revised dataset for assessing groundwater drought risk in the SADC region, focusing on updated climate impact scenarios.
Elevation	Provides elevation data in geospatial formats for analysis, important for hydrological and topographical studies.
Springs Or Waterholes	Provides geospatial information on natural springs and waterholes, valuable for water resource management and ecosystem conservation.
Surface Aquifers	Data on surface aquifers across the region, critical for evaluating water availability and hydrological connectivity.
Transboundary Aquifers (2010)	Information on aquifers shared across national boundaries, important for international water cooperation and policy development.
Piped Water - South Africa	Dataset related to water, sanitation, and hygiene (WASH) in South Africa, focusing on access to piped water.
Refuse or Rubbish Disposal - South Africa	Metadata on household waste management and refuse disposal facilities in South Africa, important for sanitation planning.
Toilet Facilities - South Africa	Data on the availability of toilet facilities in households across South Africa, useful for sanitation management.
Water Supply - South Africa	Contains data on water supply for household and housing units in South Africa, focusing on water infrastructure.
Waste Water Treatment Plants (South Africa)	Information on wastewater treatment plants across South Africa, sourced from the Department of Water and Sanitation.
Water Quality Features (Lines)	Provides data on water quality in different regions of South Africa, based on linear features such as rivers and canals.
Water Quality Features (Points)	Data on point-based water quality monitoring sites, essential for environmental assessments and public health.
Water Resources Management Activities	Metadata on activities related to the management of water resources in South Africa, assist in policy and planning.
Wells And Boreholes	Detailed information on wells and boreholes across South Africa, critical for groundwater resource management.

Table A-3 Literature and technical reports from various studies on aquifer systems in South Africa, focusing on aquifers in Gauteng, Limpopo, Mpumalanga, and Northwest. This table includes the aquifer name, general summary of the project/report, key findings, project limitations, and references.

Focus Area	Aquifers	Summary of the Report	Findings	Limitations and Gaps Identified/Challenges	Reference
Various South African catchments	Various South African Aquifers	Overview of water resources in South Africa, including hydrogeological characteristics of aquifers, water usage, and sustainable management.	The study highlights the diverse range of aquifers across the country, from fractured rock aquifers to dolomitic systems. Emphasis is placed on the need for sustainable management to prevent over-abstraction and contamination.	Water scarcity and pollution are significant risks, with many areas facing challenges in balancing groundwater abstraction and natural recharge	WaterSA (1978). Overview of South Africa's Water Resources. Water SA, 4(1), 88-95.
Karst areas of Southern Africa	Malmani Dolomite, Damara Marble	Systems model proposed to explain karst development in southern Africa, focusing on the interaction of solution processes with host rock.	Karst development is controlled by a combination of variables including climate, geology, and hydrology.	Karst systems are complex and unpredictable, making land use and water extraction challenging.	Marker, M. (1980). A Systems Model for Karst Development in Southern Africa. Earth Surface Processes, 5, 77-87.
Crystalline Basement Aquifers in Africa	Crystalline Basement Aquifers (Africa)	Overview of crystalline basement aquifers in Africa, focusing on water resources, geometry, and recharge.	Basement aquifers in tropical regions are essential for rural water supply, with the regolith and fractured bedrock acting as water storage zones.	High borehole failure rates and vulnerability to surface contamination are major challenges for basement aquifers.	Wright, E. P. (1992). The Hydrogeology of Crystalline Basement Aquifers in Africa. Geological Society Special Publication, 66, 1-27.
Limpopo Granulite-Gneiss Belt	Granulite-Gneiss Aquifer	Overview of the Limpopo Granulite-Gneiss aquifers, focusing on groundwater flow, storage, and potential for water supply.	The aquifers have moderate groundwater potential, especially in fractured zones.	Fracture variability complicates predicting borehole productivity, requiring detailed geological surveys.	Vegter, J. R. (2000). Hydrogeology of the Limpopo Granulite-Gneiss Belt (Region 3). South African Hydrogeological Review, 17, 32-45.
Nebo Granite, Limpopo	Nebo Granite Aquifer	Groundwater exploration in the Nebo Granite area, focusing on geological conditions and potential for water extraction.	Groundwater potential highly localised in fractured zones; successful boreholes are dependent on geological structures.	Limited hydrogeological data and variability in granite fracturing make borehole siting challenging.	Botha, F. S., de Jager, E., & Thamm, A. G. (2001). Groundwater Exploration in the Nebo Granite. Hydrogeological Review, 12, 23-45.
Makoppa Dome	Dome Aquifers (Makoppa)	Hydrogeological analysis of Makoppa Dome, focusing on groundwater recharge, aquifer characteristics, and potential for water extraction.	Groundwater availability is influenced by dome structures that promote the development of fracture systems with good borehole productivity.	The variability in fractures poses challenges in borehole siting.	Vegter, J. R. (2001). Hydrogeology of the Makoppa Dome (Region 1). South African Geological Journal, 54(1), 12-24.

Focus Area	Aquifers	Summary of the Report	Findings	Limitations and Gaps Identified/Challenges	Reference
Complex Terrain in SA	Fractured aquifers	Case studies on groundwater exploration in complex terrains, emphasising the importance of understanding geological structures for borehole siting.	Complex terrains present unique challenges, but a thorough geological understanding is critical for successful exploration.	The complexity of geological structures in these terrains makes borehole siting and drilling unpredictable.	Sami, K., & Marais, S. (2002). Groundwater Exploration in Complex Terrain: Case Studies. Groundwater Journal of Southern Africa, 47, 15-26.
Polokwane Plateau	Polokwane Plateau Aquifers	Hydrogeological study of the Polokwane Plateau, with a focus on groundwater flow, storage, and potential use for local communities.	The aquifers show good potential for sustainable water supply, especially in areas where fractures are well-developed.	Limited data on fracture networks and groundwater flow patterns makes sustainable extraction challenging.	Vegter, J. R. (2003). Hydrogeology of the Polokwane Plateau (Region 7). Hydrogeological Review, 22, 54-67.
Dolomitic Areas in SA	Malmani Subgroup Aquifer	Assessment of groundwater resources in dolomitic areas, focusing on sinkholes, subsidence, and risk management strategies for development in these areas.	Dolomitic aquifers have significant groundwater potential but are vulnerable to sinkhole formation, requiring careful groundwater management.	Difficulty in predicting sinkhole formation and subsurface subsidence, particularly due to dolomite dissolution.	Department of Water Affairs (2006). Vaal river system: large bulk water supply reconciliation strategy: groundwater assessment: dolomite aquifers. Pretoria: Department of Water Affairs.
Kruger National Park	Kruger National Park Aquifers	Groundwater chemistry study in Kruger National Park, focusing on how geology influences groundwater quality.	Groundwater chemistry varies significantly due to the region's diverse geological formations, impacting water quality.	Managing water quality across a geologically diverse park is difficult and requires tailored strategies.	Leyland, R., & Witthüser, K. T. (2008). Groundwater Chemistry of the Kruger National Park: Implications for Management. Water SA, 34(4), 491-498.
Dolomitic Land in Gauteng and NW	Malmani Dolomite Aquifer	Guidelines for managing groundwater in dolomitic areas, emphasising prevention of sinkholes and subsidence due to over-extraction.	Sustainable groundwater management is key to preventing collapses and sinkholes in dolomitic areas.	Balancing urban development with the risk of sinkholes.	DWA (2009). Guidelines for Managing Groundwater in Dolomitic Areas. Pretoria: Department of Water Affairs.
Basement aquifers in Southern Africa	Basement Aquifers	It analyses the hydrological characteristics of basement aquifers across Southern Africa, focusing on recharge rates, water storage, and groundwater availability for rural communities.	Basement aquifers are vital water sources for rural communities. These aquifers have low yields but can be sustainable when managed properly.	The low recharge rates and variability in water availability pose significant challenges, especially during droughts.	Titus, R., Adams, S., & Campbell, G. (2009). The basement aquifers of southern Africa. Water SA.
Groundwater resources in North West	Aquifers in NW Province	Overview of groundwater resources in North West Province, highlighting key aquifers, recharge mechanisms, and sustainable management practices.	Large groundwater potential exists in dolomitic aquifers, but the region faces risks of over-extraction and contamination, especially from agriculture.	The lack of strict monitoring and management poses long-term sustainability challenges for groundwater resources in the region.	Department of Water and Sanitation (2010). Northwest Groundwater Master Plan. DWS Report.

Focus Area	Aquifers	Summary of the Report	Findings	Limitations and Gaps Identified/Challenges	Reference
Cradle of Humankind	Cradle of Humankind Karst Aquifers	Description of karst systems in the Cradle of Humankind, focusing on groundwater movement and storage.	The karst aquifers are productive but vulnerable to contamination due to rapid groundwater flow through dissolution channels.	Managing groundwater in karst systems is complex due to the rapid movement of water and contamination risks.	South African Karst Group (2010). The Karst Systems of the Cradle of Humankind. Environmental Geology Report, 6(2), 123-145.
Basement aquifers in Limpopo	Basement Aquifers	Focuses on the hydrogeological properties of basement aquifers in Limpopo Province, evaluating groundwater storage and recharge in crystalline rock formations.	The study highlights that groundwater storage in basement aquifers is primarily confined to fractures and weathered zones, which can sustain small communities.	The highly variable nature of these aquifers makes water availability unpredictable, requiring careful borehole siting and monitoring.	Witthüser, K., Holland, M., & Titus, R. (2010). Hydrogeology of basement aquifers in Limpopo. Groundwater Journal.
Crystalline Basement Aquifers in Limpopo	Crystalline basement rock aquifers	This study focuses on the crystalline basement aquifers located in the Limpopo region of South Africa. It aims to understand the hydrogeological characteristics of these aquifers, including groundwater movement, recharge rates, and sustainable water use in rural areas.	Groundwater in crystalline basement aquifers is highly dependent on fracture networks and weathered zones for storage and transmission. Recharge to these aquifers is limited but can be significant in specific areas with higher rainfall or better fracture connectivity.	The spatial variability of fractures and weathering makes it difficult to predict groundwater availability across different areas. Due to the limited recharge rates, these aquifers are vulnerable to over-extraction during periods of drought.	Holland, M. (2011). Hydrogeological Characterisation of Crystalline Basement Aquifers in Limpopo. Journal of African Earth Sciences, 56(2-3), 147-158.
Limpopo Province	Fractured aquifers (Hout River Gneiss, Granite-Gneiss)	Analysis of groundwater as a bulk water resource for rural Limpopo using GRIP dataset.	Limpopo fractured aquifers hold significant potential for water supply; the GRIP dataset provides valuable insights for borehole siting.	Data quality and borehole equipment challenges limit groundwater potential realisation.	Du Toit, D. C., & Lubbe, L. J. (2012). Can Groundwater be a Bulk Water Resource for Limpopo? Department of Water and Sanitation (DWS) Report.
Limpopo Province	Fractured Rock Aquifers	Study on transmissivity and hydraulic parameters of fractured rock aquifers, focusing on groundwater movement and storage.	Transmissivity is influenced by fracturing, with high-yielding boreholes in contact zones between rock types.	Spatial variability in aquifer properties complicates well yield prediction.	Holland, M. (2012). Fractured Rock Aquifers in Limpopo: A Hydrological Assessment. Hydrological Processes, 26(22), 3367-3376.
Pretoria's Fountains	Pretoria's Fountain Aquifers	Historical and hydrogeological significance of Pretoria's fountains, focusing on groundwater recharge and supply.	The fountains play a vital role in recharging groundwater and have been a historical water source for Pretoria.	Urban development has affected recharge rates and groundwater quality.	Dippenaar, M. A. (2013). Pretoria's Fountains: Hydrogeological Significance and Historical Role. Water SA, 39(3), 371-376.

Focus Area	Aquifers	Summary of the Report	Findings	Limitations and Gaps Identified/Challenges	Reference
Maloney's Eye Catchment	Malmani Dolomite Aquifer	Groundwater resource-directed measures (GRDM) for the Maloney's Eye catchment, focused on understanding the hydrogeological setting, groundwater recharge, and flow dynamics.	Groundwater protection zones were developed, and a model was built to determine optimal abstraction rates while maintaining groundwater sustainability. The flow at Maloney's Eye is linked to rainfall, but groundwater abstraction has impacted spring discharge.	Groundwater management plans lack proper implementation, and there is inadequate technical capacity at DWA. Over-extraction for irrigation has caused declining groundwater levels and decreased spring discharge at Maloney's Eye.	Wiegmans, F. P., & Viljoen, G. (2013). GRDM for Maloney's Eye Catchment. Water Resources Journal, 21(4), 475-493.
Karst Belt (Region 10)	Karst Belt Aquifers	Hydrogeological overview of region 10's karstic formations, focusing on groundwater flow, storage, and vulnerability to contamination.	The Karst Belt aquifers are highly productive, but contamination risks and over-extraction pose significant challenges.	Managing karst aquifers is challenging due to the unpredictability of fracture networks and contamination risks.	Meyer, P. (2014). Hydrogeology of the Karst Belt (Region 10). South African Journal of Geology, 117(2), 123-136.
Groundwater potential in Limpopo	Karst, Fractured Rock Aquifers	This study examines the groundwater potential of Limpopo's karst and fractured rock aquifers, focusing on water availability and usage for agriculture and rural development.	The karst aquifers in Limpopo have high water storage potential, while the fractured aquifers provide smaller, localised sources of groundwater.	Groundwater contamination and over-extraction are critical concerns, particularly in agricultural areas.	Mndanwa, T. (2014). Groundwater potential of Limpopo's karst and fractured rock aquifers. Water Research Report.
Groundwater potential in Vryburg	Fractured Rock Aquifers, Dolomite Aquifers	This report investigates the groundwater potential in the Vryburg region of South Africa, focusing on the characteristics of fractured rock and dolomite aquifers.	The study found that Vryburg has considerable groundwater potential, specifically in dolomite aquifers, which have high transmissivity and can support large-scale abstraction.	Challenges include the variability of aquifer yields and the need for detailed hydrogeological surveys before borehole drilling.	Tessema, T., Ndlovu, M., & Kang, T. (2014). Groundwater potential of Vryburg. Journal of Hydrology.
Dolomite Aquifer in South Africa	Dolomite Aquifer	Uses hydrochemical and isotopic methods to study groundwater recharge and dynamics in the dolomite aquifer.	The study found that rainfall impacts recharge, with mean residence times ranging from 10 to 51 years.	Variability in recharge sources and MRTs indicates that more refined models are needed	Xiao, L., Xu, Y., & Talma, A.S. (2019). Hydrochemical and isotopic approach to dynamic recharge of a dolomite aquifer in South Africa. Hydrogeology Journal, 27(945-964).

Table A-4 **Literature and technical reports from various studies on aquifer systems in South Africa, specifically focusing on aquifers in the Karoo Supergroup. This table includes the aquifer name, general summary of the project/report, key findings, project limitations, and references.**

Focus Area	Aquifers	Summary of the Report	Findings	Limitations and Gaps Identified/Challenges	Reference
Geology of Karoo aquifers	Karoo Aquifers	Analyses the geological structure of Karoo aquifers, emphasising the influence of dolerite sills and ring complexes on groundwater flow and storage.	Dolerite intrusions play a significant role in controlling groundwater flow in Karoo aquifers, often improving connectivity and increasing water yields in fractured zones.	Fracture distribution is highly variable, making it difficult to predict aquifer productivity .	Botha, J. F., Verhagen, B. T., & Loots, F. (1998). Karoo aquifers - geology. Water Research Commission.
Influence of dolerite sills on Karoo aquifers	Karoo Aquifers	Investigates how dolerite sills and ring complexes affect groundwater movement in Karoo aquifers, with a focus on fractured rock aquifers.	Dolerite sills and ring complexes enhance groundwater storage and flow by creating fracture networks, particularly in areas with limited primary porosity.	Predicting groundwater flow in dolerite-intruded areas is challenging due to the complexity of fracture patterns.	Chevallier, L., Goedhart, M., & Woodford, A. (2001). Influence of dolerite sill and ring complexes on Karoo fractured aquifers. Journal of African Earth Sciences.
Hydrogeology of Main Karoo Basin	Main Karoo Basin Aquifers	A comprehensive overview of the hydrogeology of the Main Karoo Basin, highlighting the complexities of Karoo aquifers and the need for further research into groundwater reserves and the influence of dolerite intrusions.	Karoo aquifers are characterized by complex groundwater flow dynamics, with dolerite sills and dykes playing a critical role in enhancing groundwater storage and flow.	The variability in geological structures, particularly dolerite intrusions, complicates groundwater exploration and management	Woodford, A.C., & Chevallier, L. (2002). Hydrogeology of the Main Karoo Basin: Current Knowledge and Future Research Needs. Water Research Commission.
Hydraulic properties of Karoo aquifers	Karoo Aquifers	This study focuses on the hydraulic properties of Karoo aquifers, including permeability, transmissivity, and storativity, to assess groundwater movement and storage capacity.	The hydraulic properties of Karoo aquifers vary greatly, with lower permeability making them less productive, yet sufficient for local water supply.	Low permeability in Karoo aquifers limits their large-scale exploitation. Challenges include predicting water yields and ensuring sustainable use.	Botha, J. F., & Cloot, A. H. (2004). Karoo aquifers - hydraulic properties. Water Research Commission.
Hydrogeology of Qoqodala Complex	Qoqodala Aquifer Complex	Focuses on the hydrogeology of the Qoqodala Complex, a dolerite-intruded region, to understand its groundwater potential and flow dynamics.	The Qoqodala Complex shows significant groundwater potential due to the presence of dolerite sills, which improve fracture connectivity and water storage.	The variability in dolerite intrusion and fracture distribution makes it difficult to assess the overall aquifer productivity.	Chevallier, L., Goedhart, M., & Nel, H. (2004). Hydrogeology of the Qoqodala Complex, Great Kei. Water Research Commission.

Focus Area	Aquifers	Summary of the Report	Findings	Limitations and Gaps Identified/Challenges	Reference
Groundwater research needs in Eastern Karoo Basin	Karoo Aquifers	This report outlines the research needs for groundwater in the Eastern Karoo Basin, emphasising the need for improved data collection and understanding of groundwater systems in the region.	Key areas of research include geological controls on groundwater potential, borehole siting techniques, and improved management of groundwater recharge and sustainability.	Data gaps and lack of monitoring for deep-seated aquifers present significant challenges to understanding groundwater availability.	Murray, R., et al. (2006). Groundwater research needs in the eastern Karoo Basin of South Africa. Water Research Commission.
Karoo aquifers in EC and KZN	Karoo Aquifers (Eastern Cape, KZN)	Explores the groundwater resources of Karoo aquifers in the Eastern Cape and KwaZulu-Natal regions, focusing on water availability for local communities.	Karoo aquifers provide crucial water resources for small towns and rural areas, particularly in areas with dolerite sills. However, over-extraction poses a risk to long-term sustainability.	Over-extraction and limited recharge are significant challenges in managing Karoo aquifers.	Dondo, C., Dennis, I., & Tredoux, G. (2010). Karoo aquifers in the Eastern Cape and KwaZulu-Natal. Water Research Commission.
Groundwater planning toolkit for Karoo Basin	Karoo Aquifers	Focuses on developing a toolkit for groundwater planning and management in the Main Karoo Basin, aiming to provide better tools for water managers to sustainably develop and manage groundwater resources.	The toolkit includes methodologies for identifying high-yielding boreholes and assessing groundwater quality and quantity in Karoo aquifers, with a focus on dolerite-intruded areas.	Limited data on deep groundwater flow and recharge in dolerite intrusions hinder predictive models	Murray, R., et al. (2012). Groundwater planning toolkit for the Main Karoo Basin. Water Research Commission.
Climate change impacts on Karoo aquifers	Karoo Aquifers	This report assesses the potential impacts of climate change on Karoo aquifers, examining recharge rates, groundwater availability, and the effects of droughts and floods on aquifer sustainability.	Climate change is expected to increase the variability of recharge, with droughts reducing recharge rates and floods increasing the risk of groundwater contamination.	Lack of long-term climate data for groundwater systems makes it difficult to accurately predict the full impact of climate change on Karoo aquifers.	Dennis, I., Tredoux, G., & Nell, P. (2013). Potential climate change impacts on Karoo Aquifers. South African Journal of Geology.

Table A-5 Literature and technical reports from various studies on aquifer systems in South Africa, specifically focusing on aquifers in the Northern Cape. This table includes the aquifer name, general summary of the project/report, key findings, project limitations, and references.

Focus Area	Aquifers	Summary of the Report	Findings	Limitations and Gaps Identified/Challenges	Reference
Basement aquifers, Namaqualand	Basement Aquifers (Namaqualand)	This study assesses groundwater recharge of the basement aquifers in central Namaqualand, focusing on recharge estimation methods, particularly using rainfall and infiltration data.	The study found that recharge is highly variable depending on rainfall and local conditions, with some areas experiencing significant groundwater recharge.	The recharge estimation methods have uncertainties due to the variability of local climate and geology.	Adams, S., Titus, R., & Cobbing, J. (2004). Groundwater recharge assessment of basement aquifers of central Namaqualand. Water Research Commission.
Geomechanical modelling of fractured aquifers	Fractured Aquifers (Namaqualand)	The report discusses the development of a geomechanical model for fractured aquifers in Namaqualand, aiming to better predict groundwater flow and extraction potential in fractured rock environments.	The geomechanical model improved understanding of flow patterns in fractured rock, helping to enhance borehole siting and water extraction strategies.	Modelling limitations include insufficient data on fractures and fault systems, leading to uncertainties in predicting groundwater yields.	Friese, A., Witthüsser, K., & Nel, M. (2006). Geomechanical modeling of fractured aquifers in Namaqualand. Water Research Commission.
Hydrogeology of Bushmanland	Bushmanland Aquifers	Focuses on the hydrogeology of Bushmanland, with particular emphasis on groundwater occurrence in crystalline and fractured rock aquifers.	The fractured rock aquifers of Bushmanland have limited yields but can provide reliable water sources for small communities.	Groundwater availability is highly variable, with many boreholes producing low yields due to poor aquifer connectivity.	Vegter, J.R. (2006). Region 26 hydrogeology – Bushmanland. Water Research Commission.
Fluoride in drinking water, Northern Cape	Multiple aquifers (Northern Cape)	A detailed study of fluoride concentrations in groundwater sources across the Northern Cape and their effects on human health, focusing particularly on rural communities.	Identifies that fluoride concentrations vary widely across the region, with some communities at significant risk for dental and skeletal fluorosis.	Lack of access to fluoride treatment in rural areas poses significant health risks.	Moola, R. (2008). Fluoride in drinking water in the Northern Cape. Water Research Commission.
Groundwater resources in Northern Cape	Multiple aquifers in Northern Cape	Overview of groundwater resources in the Northern Cape, detailing aquifer types, recharge patterns, and groundwater management practices. Focuses on how water resources vary across the region.	Identifies large groundwater potential in karst and fractured rock aquifers but notes that many aquifers face depletion risks due to over-abstraction for agriculture and mining.	Significant risks from over-extraction and poor water quality, especially in drought-prone areas.	van Dyk, C., et al. (2008). Groundwater resources of the Northern Cape. Water Research Commission.

Focus Area	Aquifers	Summary of the Report	Findings	Limitations and Gaps Identified/Challenges	Reference
Groundwater management in Namaqualand	Namaqualand Aquifer Systems	This guide focuses on translating hydrogeological research into practical guidelines for groundwater management in Namaqualand, particularly in water-scarce areas where communities depend heavily on groundwater.	Emphasises the importance of sustainable groundwater management, with recommendations on borehole siting, drilling techniques, and resource monitoring to ensure long-term water supply.	Challenges include limited technical capacity in local governments and insufficient monitoring of groundwater levels.	Pietersen, K., Titus, R., & Cobbing, J. (2009). Effective groundwater management in Namaqualand. Water Research Commission.
Fluoride in drinking water, Northern Cape	Multiple aquifers (Northern Cape)	Examines the fluoride levels in groundwater supplies in the Northern Cape and their effects on human health. The study assessed water samples from various towns and investigated health issues such as dental fluorosis.	High fluoride levels in some areas (up to 8.2 mg/l) can lead to dental and skeletal fluorosis. Fluoride levels are generally lower in towns with central water supplies.	Fluoride removal technologies are underdeveloped in rural areas. Limited public awareness about the health risks of high fluoride levels in drinking water.	WRC. (2009). Fluoride in drinking water in the Northern Cape. Water Research Commission.

Table A-6 Literature and technical reports from various studies on aquifer systems in South Africa, specifically focusing on aquifers in the Table Mountain Group. This table includes the aquifer name, general summary of the project/report, key findings, project limitations, and references.

Focus Area	Aquifers	Summary of the Report	Findings	Limitations and Gaps Identified/Challenges	Reference
Nardouw and Peninsula Aquifer, Table Mountain Group (TMG)	Nardouw Aquifer (Steenbras-Nuweberg area)	A steady-state numerical model was developed to assess the potential for long-term groundwater abstraction from the Nardouw and Peninsula Aquifer to support the City's New Water Programme (NWP).	The model showed a highly parameterized system with a steady-state condition closely matching field data. The aquifer has potential for long-term sustainable abstraction.	Variability in recharge and aquifer properties across the region, as well as potential impacts on groundwater-dependent ecosystems	See Section 6 for full references Riemann, K. et al (2023). City of Cape Town New Water Programme: Table Mountain Group Aquifer. Steenbras Wellfield Integrated Water Use Licence Application: Section 21 Hydrogeological Report Rademan, Z. et al. (2021). City of Cape Town New Water Programme: Table Mountain Group Aquifer. Steenbras Wellfield Nardouw Aquifer Drilling and Testing Progress Report 2018-2021. City of Cape Town (2021). City of Cape Town New Water Programme: Table Mountain Group Aquifer, Steenbras-Nuweberg Nardouw Aquifer Steady-State Numerical Model Report. Report No. 899/07/02/2021, 54 pp. Blake, D., Hartnady, C. J. H., Hay, E. R. and Riemann, K. (2020). Geoethics of bulk groundwater abstraction in an ecologically sensitive area – Steenbras Wellfield (Cape Town). Geoethics & Groundwater Management International Congress, Porto (online), Portugal, May 2020.

Focus Area	Aquifers	Summary of the Report	Findings	Limitations and Gaps Identified/Challenges	Reference
Uitenhage Artesian Basin (Eastern Cape)	Uitenhage Artesian Basin (TMG Aquifers)	Discusses the hydrogeology of the Uitenhage Artesian Basin with reference to the Table Mountain Group aquifer, highlighting its importance for domestic and agricultural water supply.	The basin supplies approximately 1,400 Ml/yr of groundwater, mainly for irrigation. The aquifer is characterized by good water quality but requires water hardening due to its acidic nature. Recharge rates vary between 25-55% of annual rainfall.	Over-extraction and the need for a basin-scale management plan to ensure sustainable groundwater use.	Maclear, R.T. (2001). The hydrogeology of the Uitenhage Artesian Basin with reference to the TMG aquifer. South African Journal of Geology.
Hydrogeology of TMG	Table Mountain Group Aquifers	A synthesis of the hydrogeology of the TMG aquifers, providing an overview of recharge, storage, and water movement characteristics. The report aims to support water management practices in TMG-dominated regions.	TMG aquifers have significant groundwater potential, but their sustainability depends on effective management of recharge areas. The study highlights the importance of aquifer connectivity in maintaining water flow.	Limited data on deep groundwater storage and recharge rates, which are needed to improve groundwater management.	Pietersen, K., & Parsons, R. (2002). Synthesis of TMG hydrogeology. Water Research Commission.
Groundwater recharge in the TMG	Table Mountain Group Aquifers	Focuses on groundwater recharge estimation in the TMG aquifers using isotope and chloride mass balance (CMB) methods. The study aims to improve understanding of how these aquifers recharge and the factors influencing recharge.	Recharge is highly variable, with some areas showing strong potential for groundwater replenishment. Recharge rates are influenced by rainfall, geology, and vegetation cover.	Difficulties in measuring recharge accurately due to the complex geology of the TMG.	Xu, Y., Beekman, H., & Raitt, L. (2007). Groundwater recharge estimation of the Table Mountain Group (TMG) aquifers. Water Research Commission.
High-yielding groundwater areas in NMBM	Various aquifers around Nelson Mandela Bay	Identifies potential high-yielding groundwater areas around the Nelson Mandela Bay Municipality, using GIS-based methods to select target areas for drilling and exploration.	Multiple high-yielding aquifers were identified, with potential for municipal water supply. Artificial recharge options were also assessed to maximize conjunctive use of groundwater and surface water.	The high costs of deep drilling and infrastructure expansion are key challenges, especially in areas far from existing water supply infrastructure.	Murray, E.C., & Xu, Y. (2008). High-yielding groundwater areas around Port Elizabeth. Water Research Commission.
Water resources in the Klein Karoo	Klein Karoo Aquifers	Examines the availability and sustainability of groundwater resources in the Klein Karoo, focusing on agricultural and domestic water use.	Groundwater is a critical resource for the region, especially during dry seasons. Sustainable management practices are needed to avoid over-extraction.	Over-extraction for agricultural purposes is a significant concern, with limited data on long-term groundwater availability.	Le Maitre, D.C., Scott, D.F., & Colvin, C. (2009). Water resources in the Klein Karoo. Water Research Commission.

Focus Area	Aquifers	Summary of the Report	Findings	Limitations and Gaps Identified/Challenges	Reference
Groundwater flow and storage in the TMG	Table Mountain Group Aquifers	A conceptual study on groundwater flow and storage in the TMG aquifers. The report provides detailed models of water movement and storage in these aquifers, focusing on their role in regional water supply.	The TMG aquifers are characterized by large storage capacity and complex flow patterns. The study found that the connectivity between different aquifer units plays a significant role in water movement.	Lack of long-term monitoring data on groundwater levels and flow rate	Xu, Y., et al. (2009). Groundwater flow conceptualization and storage determination of the TMG aquifers. Water Research Commission.
Hydrostratigraphy and aquifer connectivity	Table Mountain Group (TMG) Aquifers	Uses stable isotope analysis to study hydrostratigraphy and aquifer connectivity in the Table Mountain Group (TMG). Focuses on improving the understanding of water movement and storage within these aquifers.	Identified varying levels of connectivity between aquifers. The study provided insights into recharge areas and pathways in the TMG.	The complexity of the TMG aquifers and the lack of comprehensive data pose challenges in fully understanding aquifer behaviour and predicting water yields.	Diamond, R.E., & Harris, C. (2019). Stable isotope constraints on hydrostratigraphy and aquifer connectivity in the Table Mountain Group (TMG). Journal of Hydrology.

Table A-7 Literature and technical report from various studies on aquifer systems in South Africa, specifically focusing on the Primary Aquifers in the Western Cape. This table includes the aquifer name, general summary of the project/report, key findings, project limitations, and references.

Focus Area	Aquifers	Summary of the Report	Findings	Limitations and Gaps Identified/Challenges	Reference
West Coast, South Africa	Langebaan Road, Elandsfontein, Grootwater, Adamboerskraal	Investigation of sustainable groundwater resources exploitation along the West Coast of South Africa. Focus on aquifer recharge and Managed Aquifer Recharge (MARS).	Groundwater recharge potential ranges from 3% (LRA) to 31% (TMG). A feasible MARS plan was developed.	Lack of data on groundwater-surface water interactions. Potential environmental impacts on Berg River.	Israel, S., Vermaak, N., Andries, C., van der Schyff, M., Tredoux, G., Jovanovic, N., Kanyerere, T., Zhang, H., Nel, J., Xu, Y., Fourie, F. & Pienaar, H., 2021. Towards sustainable exploitation of groundwater resources along the West Coast of South Africa. Water SA, 27(3), pp.349-356.
Groundwater management in semi-arid areas	Various aquifers (West Coast and Sandveld)	Discusses sustainable groundwater management practices in semi-arid regions, particularly focusing on the West Coast and Sandveld areas, where groundwater is critical for both urban supply and agriculture.	The study highlights the need for integrated groundwater management, with recommendations for improved recharge estimation and stricter regulation of borehole drilling and usage.	The lack of comprehensive groundwater data and challenges in estimating recharge make sustainable management difficult. Climate change is expected to intensify these issues further.	Watson, J., Le Maitre, D., & Chevallier, L. (2005). Groundwater management in semi-arid areas. Water Research Commission.
Groundwater recharge in Sandveld	Sandveld Aquifers	Focuses on the challenges of assessing groundwater recharge in the northern Sandveld region, addressing the spatial variability in recharge and the role of faults in groundwater movement.	Recharge in the region is estimated at only 0.2% to 3.4% of annual rainfall, significantly lower than earlier estimates. Groundwater is recharged both directly from rainfall and indirectly through faults from inland areas.	The high variability of recharge and the lack of long-term water level data complicates effective management of groundwater resources.	Conrad, J., Le Maitre, D., & Jewitt, G. (2007). The challenges and implications of assessing groundwater recharge in the northern Sandveld. Water Research Commission.
Climate change and farming in Sandveld	Sandveld Aquifers	This study investigates the impact of climate change on groundwater resources and intensive commercial farming in the semi-arid Sandveld region. Focus is on water supply challenges and management in an arid climate.	Climate change increase water scarcity in the Sandveld, leading to increased pressure on groundwater resources used for commercial farming.	Lack of robust long-term data on climate impacts and groundwater recharge rates. The dependence on groundwater for agriculture makes the region highly vulnerable to climate variability.	Archer, E., Conrad, J., Münch, Z., Opperman, D., Tadross, M., & Venter, J. (2009). Climate change, groundwater and intensive commercial farming in the semi-arid northern Sandveld, South Africa. Journal of Integrative Environmental Sciences, 6(2), 139-155.

Focus Area	Aquifers	Summary of the Report	Findings	Limitations and Gaps Identified/Challenges	Reference
Groundwater quality and quantity on West Coast	West Coast Aquifers	Examines groundwater quality and quantity on the West Coast, focusing on water supply for municipalities and agriculture, as well as estimating recharge rates for sustainable management of these aquifers.	Findings highlight declining groundwater quality, increased salinity in areas closer to the coast. Recharge estimates indicate that current extraction rates are unsustainable without interventions.	Increasing salinity and the lack of adequate recharge monitoring are major challenges in sustaining groundwater resources.	Miller, J., Chevallier, L., & Watson, J. (2018). Groundwater quality, quantity, and recharge estimation on the West Coast of South Africa. Water Research Commission.
Langebaan Road Aquifer Model	Langebaan and Elandsfontein Aquifer System	Focuses on the conceptual and numerical modeling of the Langebaan and Elandsfontein aquifer systems, aiming to assess groundwater availability and the potential for sustainable usage.	Both aquifers have significant recharge potential, but water use must be closely monitored to avoid over-extraction.	Potential over-abstraction in certain areas and vulnerability to saltwater intrusion.	Department of Water Affairs and Forestry, South Africa. 2008. The Assessment of Water Availability in the Berg Catchment (WMA 19) by Means of Water Resource Related Models: Groundwater Model Report Volume 6 – Langebaan Road and Elandsfontein Aquifer System Model. Prepared by Umvoto Africa (Pty) Ltd in association with Ninham Shand (Pty) Ltd on behalf of the Directorate: National Water Resource Planning. DWAF Report No. P WMA 19/000/00/0408
Groundwater Model in Cape Flats	Cape Flats Aquifer	The report presents the groundwater modeling results for the Cape Flats aquifer, emphasising water availability and sustainable water use in the region.	The study found that Cape Flats aquifer has moderate groundwater potential but is susceptible to pollution from urban and agricultural activities.	Contamination from surrounding land uses, limiting the aquifer's usability without substantial treatment.	Department of Water Affairs and Forestry, South Africa. 2008. The Assessment of Water Availability in the Berg Catchment (WMA 19) by Means of Water Resource Related Models: Groundwater Model Report Volume 5 – Cape Flats Aquifer Model. Prepared by Umvoto Africa (Pty) Ltd in association with Ninham Shand (Pty) Ltd on behalf of the Directorate: National Water Resource Planning. DWAF Report No. P WMA 19/000/00/0408

Focus Area	Aquifers	Summary of the Report	Findings	Limitations and Gaps Identified/Challenges	Reference
Atlantis Aquifer System	Atlantis Aquifer	This report provides a 3-D numerical model of the Atlantis Aquifer to assess the impact of groundwater abstraction for the Atlantis Water Resource Management Scheme (AWRMS).	The model estimated potential yields between 27-38 ML/d from wellfields under operating conditions, with minimal impact on surface water bodies like the Silwerstroom spring.	Challenges include uncertainty in recharge rates, reliance on historical data, and managing abstraction impacts on sensitive ecosystems.	City of Cape Town (2020a). Numerical Groundwater Model of the Atlantis Aquifer, CoCT New Water Programme: Atlantis Water Resource Management Scheme. Report No. 897/7.2b/12/2020, 103 pp.
Cape Flats Aquifer System	Cape Flats Aquifer	A numerical model was developed to aid the Cape Flats Aquifer Management Scheme (CFAMS), including managed aquifer recharge (MAR) using treated wastewater effluent to augment storage.	The model predicts the feasibility of MAR, and the scheme aims to increase groundwater abstraction while mitigating the risk of saline intrusion and managing groundwater levels.	The risks of saline intrusion and the dependence on treated wastewater are critical, especially with varying levels of effluent quality over time.	City of Cape Town (2020b). New Water Programme - Cape Flats Aquifer Management Scheme: Numerical Model of the Cape Flats Aquifer. Report No. 896/7.1/6/2020, 48 pp.

Table A-8 Literature and technical report from various studies on transboundary aquifer systems in South Africa, specifically focusing on aquifers associated with the Tuli Karoo Sub-Basin. This table includes the aquifer name, general summary of the project/report, key findings, project limitations, and references.

Focus Area	Summary of the Report	Findings	Limitations and Gaps Identified/Challenges	References
Sedimentology of Upper Karoo Fluvial Strata	The study analyses the sedimentology of the Upper Karoo fluvial deposits in the Tuli Basin, South Africa. It reconstructs the depositional environment, highlighting the paleo-environment of the basin.	Identified a semi-arid paleo-environment with episodic flash floods. Sandstone and conglomerates were common, reflecting fluvial sedimentation processes.	Difficulty in correlating these formations with the main Karoo Basin due to limited stratigraphic and paleontological data.	Bordy, E. M., & Catuneanu, O. (2001). Sedimentology of the Upper Karoo Fluvial Strata in the Tuli Basin, South Africa. Journal of African Earth Sciences, 33(3-4), 605-629.
Hydrogeological Mapping of Transboundary Aquifers	Focuses on mapping and assessing transboundary aquifers in Southern Africa, with a specific focus on the Tuli Karoo Sub-Basin and its importance for regional water supply.	Identified the Tuli Karoo Sub-Basin as a key transboundary aquifer with significant groundwater potential for shared water management between Botswana, Zimbabwe, and South Africa.	Limited availability of groundwater data, lack of cooperation in data sharing between countries, and the need for comprehensive scientific studies to guide sustainable management of the aquifer.	SADC-HGM (2010). Atlas of Transboundary Aquifers: SADC Hydrogeological Mapping Project. SADC.
Transboundary Aquifer Management	Discusses the challenges in managing transboundary aquifers, with a focus on cross-border collaboration, governance, and environmental challenges related to shared water resources.	Emphasises the need for regional governance, scientific integration, and improved stakeholder engagement for effective transboundary water resource management.	Governance issues, lack of data sharing, and environmental concerns such as over-extraction and pollution are key challenges identified for effective aquifer management.	ISARM (2010). Challenges and New Directions in Transboundary Aquifer Management. International Conference on Transboundary Aquifers.

Table A-9 **Literature and technical report from various studies on transboundary aquifer systems in South Africa, specifically focusing on aquifers associated with the Rhyolite-Breccia Aquifer. This table includes the aquifer name, general summary of the project/report, key findings, project limitations, and references.**

Focus Area	Summary of the Report	Findings	Limitations and Gaps Identified/Challenges	References
Hydrochemical and Geophysical Evaluation of Groundwater Pollution	The study uses geophysical and hydrochemical methods to assess groundwater contamination in the Rhyolite-Breccia Aquifer.	Found potential pollution sources near agricultural areas, with the aquifer vulnerable to surface contamination.	Limited long-term monitoring data. Future studies recommended on pollution sources and mitigation strategies.	Ranganai, R.T., Gotlop-Bogatsu, Y., Maphanyane, J., & Tladi, B. (2001). Hydrochemical and Geophysical Evaluation of Groundwater Pollution in the Rhyolite-Breccia Aquifer. BIE2001 Technical Papers.
Applied Hydrogeology of Fractured Rocks	This book provides an overview of the hydrogeological properties of fractured rocks, including the Rhyolite-Breccia aquifers, discussing flow characteristics and recharge mechanisms.	Discusses the fractured nature of the aquifer, leading to localised flow and varying recharge rates.	Data availability on recharge mechanisms and flow paths remains limited, necessitating further research in flow dynamics of fractured aquifers.	Singhal, B.B.S., & Gupta, R.P. (2010). Applied Hydrogeology of Fractured Rocks. Springer Science & Business Media.

Table A-10 Literature and technical report from various studies on transboundary aquifer systems in South Africa, specifically focusing on aquifers associated with the Ramotswa Aquifer. This table includes the aquifer name, general summary of the project/report, key findings, project limitations, and references.

Focus Area	Summary of the Report	Findings	Limitations and Gaps Identified/Challenges	References
Data and Information Management	Describes the development of the Ramotswa Information Management System (RIMS), an online portal for sharing groundwater data and maps for transboundary aquifer management.	RIMS allows stakeholders to visualise, share, and download spatial data for aquifer management, improving transparency and cooperation between Botswana and South Africa.	Challenges in ensuring the timely updating of data and ongoing maintenance of the platform. Integration of various datasets across national borders is still a work in progress.	IWMI (2018). Ramotswa Information Management System (RIMS): A Portal for Sharing Groundwater Data and Maps for the Ramotswa Aquifer. International Water Management Institute (IWMI).
Hydrogeological Modelling of Ramotswa Aquifer	This report describes the hydrogeological modelling conducted for the Ramotswa aquifer to improve understanding of water availability, flow, and sustainable management practices.	Provided detailed hydrogeological modelling outputs, highlighting potential recharge zones, groundwater-surface water interaction, and vulnerabilities to contamination.	Gaps in data integration between South Africa and Botswana, along with limited availability of long-term monitoring data for model calibration.	IWMI et al. (2018). Hydrogeological Modelling of the Ramotswa Aquifer: A Report for Improving Water Resource Management and Transboundary Cooperation. International Water Management Institute (IWMI).
Transboundary Water Management, Ramotswa Aquifer	The report focuses on the strategic action plan for joint management of the transboundary Ramotswa Aquifer, shared by South Africa and Botswana.	Emphasises transboundary cooperation, improving monitoring, data exchange, and capacity building for sustainable groundwater use.	Institutional harmonisation between Botswana and South Africa, and limited financial and human resources for implementing proposed actions.	IWMI et al. (2019). Joint Strategic Action Plan for the Ramotswa Transboundary Aquifer Area. International Water Management Institute (IWMI).
MAR Potential in the Ramotswa Aquifer	This report explores the potential for managed aquifer recharge (MAR) in the Ramotswa Aquifer to enhance groundwater storage and resilience to climate variability.	Identified several potential areas for MAR based on geological and hydrological conditions. Recommendations for further investigation into water quality for MAR projects.	Lack of infrastructure and funding for MAR projects, and the need for comprehensive environmental assessments before MAR implementation.	IWMI et al. (2018). Managed Aquifer Recharge (MAR) in the Ramotswa Aquifer: Exploring Potential for Climate Resilience. International Water Management Institute (IWMI).
Irrigation and Agriculture in Ramotswa Aquifer Area	This study evaluates water and nutrient-saving tools (chameleon sensors and wetting front detectors) in smallholder farms within the Ramotswa Transboundary Aquifer Area (RTBAA).	Water and nutrient-saving tools led to increased water productivity, reduced nutrient losses, and higher crop yields in the smallholder farms.	Limited research on the application of these tools in groundwater-based irrigation schemes and vegetable production. Need for further testing in different crops and climates.	Magombeyi, M., Altchenko, Y., Villholth, K.G., and Lefore, N. (2018). AgWater Solutions in the Ramotswa Aquifer Area: Evaluating Water and Nutrient-Saving Technologies for Smallholder Farms. International Water Management Institute (IWMI).

Focus Area	Summary of the Report	Findings	Limitations and Gaps Identified/Challenges	References
Groundwater Quality, Nitrate Contamination	This brief discusses the impact of climate change and nitrate contamination on the Ramotswa Aquifer, particularly due to the increased use of pit latrines during drought periods.	Identifies pit latrines and drought-related water supply issues as major contributors to nitrate contamination. Proposes bioremediation as a potential solution.	Limited feasibility data on bioremediation and the costs associated with upgrading sanitation infrastructure in rapidly urbanizing areas.	McGill, B., and Villholth, K.G. (2019). Enhancing Water Security by Tackling Nitrate Contamination in the Ramotswa Aquifer and Addressing Climate Change Impacts. International Water Management Institute (IWMI).
Development of Subsurface Mapping	The report details the completion of subsurface mapping of the Ramotswa aquifer using airborne geophysics for better understanding of the aquifer's extent and characteristics.	Successfully collected and interpreted AEM data for subsurface characteristics of Ramotswa aquifer, and identified several geological structures like dikes and faults.	Issues in obtaining uniform and updated borehole data. Difficulties in generating 3D grids for certain geological formations due to structural complexity.	XRI Holdings (2016b). Ramotswa Completion Report: Development of Subsurface Mapping for the Transboundary Ramotswa Aquifer using Airborne Geophysics. Prepared for Chemonics International Inc.
Geophysical Mapping, Subsurface Characteristics	The report covers the collection and processing of airborne electromagnetic (AEM) data for subsurface mapping of the Ramotswa aquifer to understand its geological structure and properties.	AEM data provided insights into subsurface resistivity and aquifer properties, allowing better understanding of geological features impacting groundwater flow and storage.	Data quality was affected by electromagnetic noise from infrastructure, as well as poor resolution in certain areas due to the geological complexity (e.g., thin dolomite outcrops). Ground-based investigations recommended for future studies.	XRI Holdings (2016a). Geophysical QA/QC Corrected and Final Inverted AEM Data Report for the Development of Subsurface Mapping for the Transboundary Ramotswa Aquifer using Airborne Geophysics. Prepared for Chemonics International Inc.

Table A-11 Literature and technical report from various studies on transboundary aquifer systems in South Africa, specifically focusing on aquifers associated with the Coastal Sedimentary Basin V. This table includes the aquifer name, general summary of the project/report, key findings, project limitations, and references.

Focus Area	Summary of the Report	Findings	Limitations and Gaps Identified/Challenges	References
Hydrogeological Mapping and Water Management in Southern Africa	This project focused on mapping the transboundary aquifers in the Southern African region, including the Coastal Sedimentary Basins. It provided an understanding of the hydrological structures.	Identified the Coastal Sedimentary Basin V as an important transboundary aquifer in the region, with the potential for large-scale water supply.	Limited data on recharge rates, groundwater flow, and sustainable water extraction limits. Regional cooperation between countries is essential for managing these aquifers.	SADC-HGM (2010). Atlas of Transboundary Aquifers: SADC Hydrogeological Mapping Project. SADC.
Groundwater Resources and Management in Africa	This study assessed the availability and management of groundwater in Southern Africa, focusing on recharge, extraction, and the sustainability of shared aquifers like Coastal Sedimentary Basin V.	Emphasised the importance of sustainable groundwater management practices and regular monitoring of water quality and quantity.	Lack of infrastructure for effective water resource management and monitoring. Need for enhanced cooperation between neighbouring countries to ensure the aquifer is not over abstracted	UNESCO (2016). Stampriet Transboundary Aquifer System Assessment: Technical Report. UNESCO.

Table A-12 Literature and technical report from various studies on transboundary aquifer systems in South Africa, specifically focusing on aquifers associated with the Stampriet Aquifer System. This table includes the aquifer name, general summary of the project/report, key findings, project limitations, and references.

Focus Area	Summary of the Report	Findings	Limitations and Gaps Identified/Challenges	References
Governance and Cooperation in Transboundary Aquifers	The report discusses the governance challenges in managing the STAS, focusing on transboundary cooperation mechanisms between Botswana, Namibia, and South Africa under the GGRETA project.	Effective cooperation mechanisms were developed between the three countries, but challenges remain in harmonizing water laws and ensuring consistent data sharing and use.	Need for improved cross-border legislative harmonization and enhanced local capacity for water management.	Kenabatho, P.K., et al. (2021). Towards Improved Governance of Transboundary Aquifers in Southern Africa: A Case Study of the Stampriet Transboundary Aquifer System. Global Water Security Issues Series No.3, UNESCO Publishing.
Hydrogeological Conceptual Model for the STAS	This paper discusses a revised hydrogeological model of the STAS, including groundwater flow dynamics, recharge patterns, and interactions between different aquifer units.	Groundwater flow is influenced by both surface topography and faulting, with mixing occurring between different aquifer units. Paleorecharge conditions were observed in some areas.	Data gaps in inter-aquifer mixing processes and the need for more accurate numerical models for long-term groundwater flow projections.	Kinoti, I., et al. (2024). Hydrogeological Conceptual Model of the Stampriet Transboundary Aquifer System. Journal of Hydrology.
Hydrostratigraphy and Aquifer Geometry in Southern Africa	This study provides an updated assessment of the Stampriet Transboundary Aquifer System (STAS), focusing on hydrostratigraphy, aquifer geometry, and environmental tracers in the aquifer.	The aquifer system consists of six hydrostratigraphic units, with significant fault influence on groundwater flow. Groundwater reserves are estimated between 3 to 5.1 x 1012 m³.	Limited data on faulting and groundwater interactions, as well as long-term impacts of climate variability on recharge and storage.	UNESCO (2016). Stampriet Transboundary Aquifer System Assessment: Technical Report. UNESCO.

Table A-13 Literature and technical report from various studies on transboundary aquifer systems in South Africa, specifically focusing on aquifers associated with the Khakhea Bray Dolomites. This table includes the aquifer name, general summary of the project/report, key findings, project limitations, and references.

Focus Area	Summary of the Report	Findings	Limitations and Gaps Identified/Challenges	References
Hydrogeological Modelling for Khakhea/Bray Dolomite	This report focuses on the modelling and assessment of the Khakhea/Bray Dolomite Aquifer as part of the Ramotswa Transboundary Aquifer System. It reviews hydraulic properties and permeability.	The study identified significant variability in permeability across the aquifer due to the presence of fractures and karst formations, leading to secondary porosity.	Limited borehole data and lack of extensive long-term monitoring across transboundary regions create gaps in understanding flow dynamics and recharge patterns.	Ramotswa Hydrogeological Modelling Report (2018). Hydrogeological Modelling for Khakhea/Bray Dolomite Aquifer.
Groundwater Resource Assessment	The study aims at assessing the availability and sustainable use of groundwater resources in dolomite aquifers, including Khakhea/Bray Dolomite. It includes a review of water abstraction impacts.	Water abstraction has impacted water levels, and increased vulnerability to contamination has been noted due to the presence of karst formations.	Over-abstraction and contamination risks are highlighted as significant issues, with limited data on the long-term impacts of groundwater extraction and recharge.	DWAF (2006). Groundwater Assessment of Dolomite Aquifers. Department of Water Affairs and Forestry, South Africa.
Groundwater Monitoring in Khakhea/Bray Dolomite	This study monitors the groundwater levels and quality in the Khakhea/Bray Dolomite region. It reviews water quality, emphasising the risks from agricultural and urban contamination.	Elevated nitrate levels and potential contamination from agricultural runoff and human settlements were identified as significant threats to groundwater quality.	Inadequate monitoring systems and lack of integrated transboundary management strategies were noted as challenges to achieving sustainable use of the aquifer's resources.	GCS (2000). Groundwater Monitoring Report for Khakhea/Bray Dolomite Aquifer. Geotechnical Consulting Services.

Table A-14 Literature and technical report from various studies on transboundary aquifer systems in South Africa, specifically focusing on aquifers associated with the Coastal Sedimentary Basin VI. This table includes the aquifer name, general summary of the project/report, key findings, project limitations, and references.

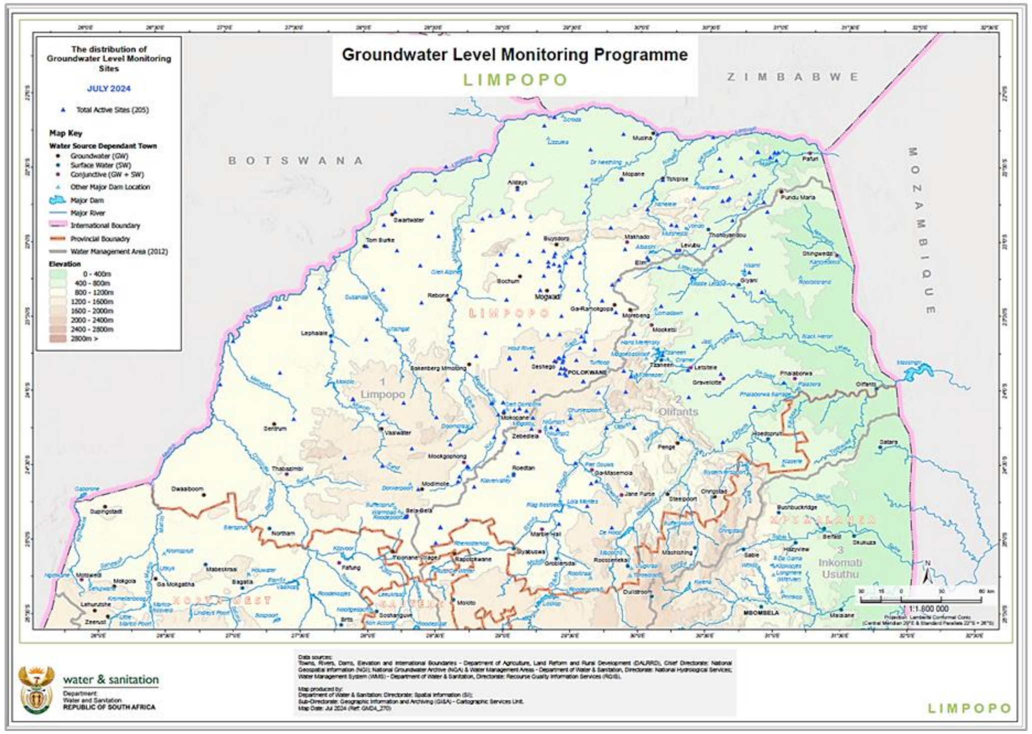
Focus Area	Aquifers	Summary of the Report	Findings	Limitations and Gaps Identified/Challenges	References
Hydrogeological Mapping of Southern African Aquifers	Coastal Sedimentary Basin VI	Focuses on mapping and studying the hydrogeology and groundwater resources of Southern African transboundary aquifers, including Coastal Sedimentary Basin VI.	Coastal Sedimentary Basin VI has been identified as a critical transboundary aquifer with significant water storage potential, requiring regional cooperation.	Limited data on long-term groundwater recharge rates, interactions with surface water, and impacts from human activities.	SADC-HGM (2010). Hydrogeological Mapping of Transboundary Aquifers in Southern Africa. SADC.
Transboundary Water Resources and Management	Coastal Plain Sedimentary Basin	Discusses the management of shared groundwater resources, highlighting the importance of cooperation between South Africa and Mozambique for sustainable water extraction.	There is potential for regional water supply development, but careful monitoring is required to avoid over-extraction and degradation of water quality.	Lack of shared infrastructure and effective transboundary agreements for groundwater extraction, with the need for better data-sharing mechanisms to address over-extraction and ensure sustainability.	Puri, S., & Aureli, A. (2016). Atlas of Transboundary Aquifers: Cooperation and Management of Shared Groundwater Resources. UNESCO.

Table A-15 Literature and technical report from various studies on transboundary aquifer systems in South Africa, specifically focusing on aquifers associated with the Karoo Sedimentary Aquifer. This table includes the aquifer name, general summary of the project/report, key findings, project limitations, and references.

Focus Area	Summary of the Report	Findings	Limitations and Gaps Identified/Challenges	References
Groundwater Management in Karoo Sedimentary Aquifers	A government report assessing water quality, groundwater extraction rates, and the sustainability of water resources in the Karoo Sedimentary Aquifers.	Highlighted the importance of monitoring, especially in areas with potential impacts from fracking and mining activities. Water contamination and aquifer depletion risks.	Gaps in long-term groundwater monitoring data and concerns over potential contamination from industrial activities such as mining and shale gas extraction (fracking).	Department of Water and Sanitation (DWS, 2016). Groundwater Management in Karoo Sedimentary Aquifers. South African Government Report.
Hydrogeology of the Main Karoo Basin	This study focuses on the geology and hydrogeology of the Karoo Basin, including groundwater flow, aquifer characteristics, and challenges in managing groundwater resources in the Karoo region.	The Karoo Basin has complex geology, with sedimentary layers that store groundwater in fractures and porous formations, making it an important but variable water resource.	Challenges include variable yields, deep drilling requirements, and limited recharge in arid areas, along with risks from groundwater contamination and over-extraction.	Woodford, A.C., & Chevallier, L. (2002). Hydrogeology of the Main Karoo Basin: Current Knowledge and Future Research Needs. Water Research Commission, South Africa.
Groundwater Management in Semi-Arid Regions	The report discusses the management of groundwater resources in semi-arid regions, specifically focusing on the Karoo Basin's potential for supporting rural water supply and agricultural use.	Highlights the potential for groundwater development in the Karoo Basin, but stresses the need for sustainable practices due to limited recharge and high demand.	Gaps in long-term monitoring and data availability for sustainable groundwater use, along with challenges in balancing agricultural needs with environmental conservation.	Hobbs, P., et al. (2011). Groundwater Management in Semi-Arid Regions: Challenges and Opportunities in the Karoo Basin. South African Water Research Commission Report.

Table A-16 Literature and technical report from various studies on transboundary aquifer systems in South Africa, specifically focusing on aquifers associated with the Limpopo Basin. This table includes the aquifer name, general summary of the project/report, key findings, project limitations, and references.

Focus Area	Summary of the Report	Findings	Limitations and Gaps Identified/Challenges	References
Water Management in the Limpopo Basin	Focuses on the shared water resources of the Limpopo Basin between Botswana, Zimbabwe, Mozambique, and South Africa, with a particular emphasis on groundwater management and challenges.	The study highlights the variability in groundwater resources, with highly permeable alluvial aquifers along the Limpopo River supporting agriculture and rural supply.	The basin is vulnerable to droughts, over-extraction, and political challenges between upstream and downstream users, leading to tensions in water allocation.	Ashton, P.J., et al. (2000). Water Management Challenges in the Limpopo River Basin. International Journal of Water Resources Development.
Transboundary Water Resource Management	Discusses the transboundary nature of the Limpopo River Basin, focusing on governance frameworks, cooperation between riparian states, and sustainable management of shared water resources.	Emphasises the need for integrated water management to address issues of over-extraction, pollution, and equitable distribution of water resources across the basin.	Lack of coordinated management strategies and inadequate infrastructure for monitoring groundwater levels and quality, particularly in remote areas.	UNESCO (2008). Managing Transboundary Water Resources in the Limpopo Basin: Cooperation and Governance. UNESCO Technical Report.



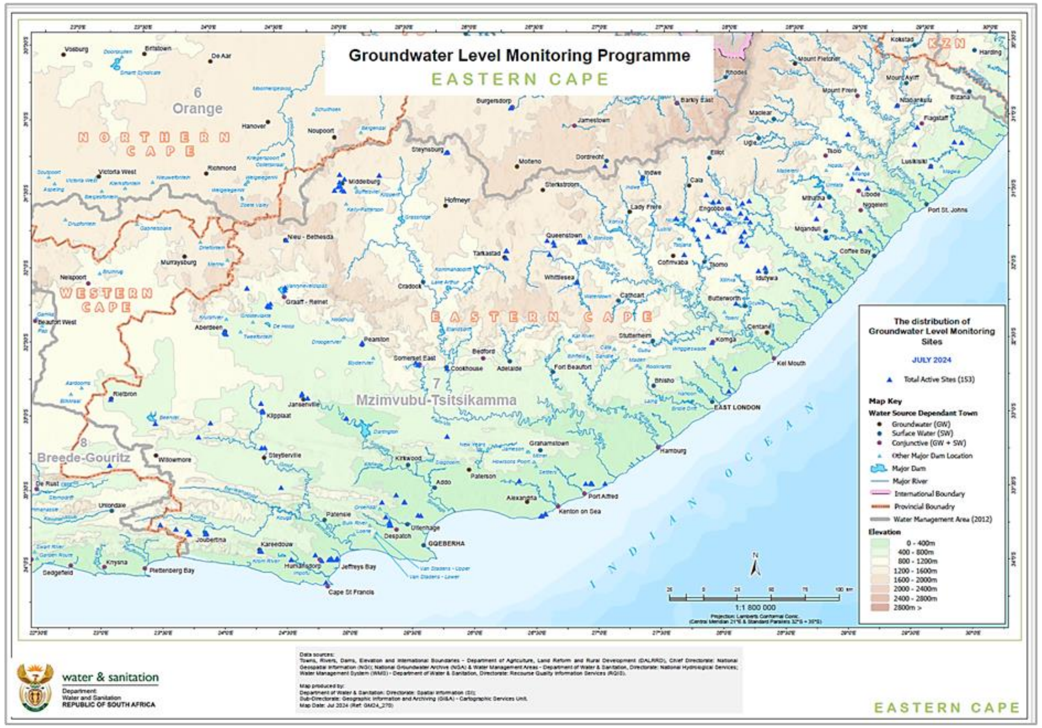
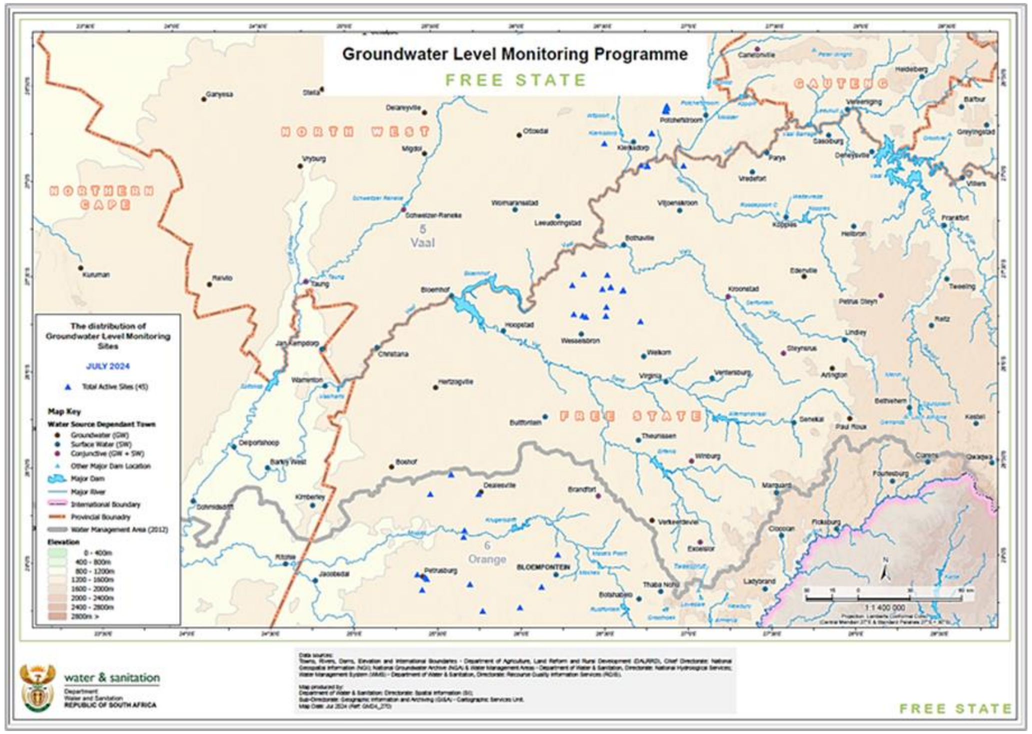


Figure A-1 Maps showing groundwater level monitoring for Eastern Cape, and Limpopo provinces.



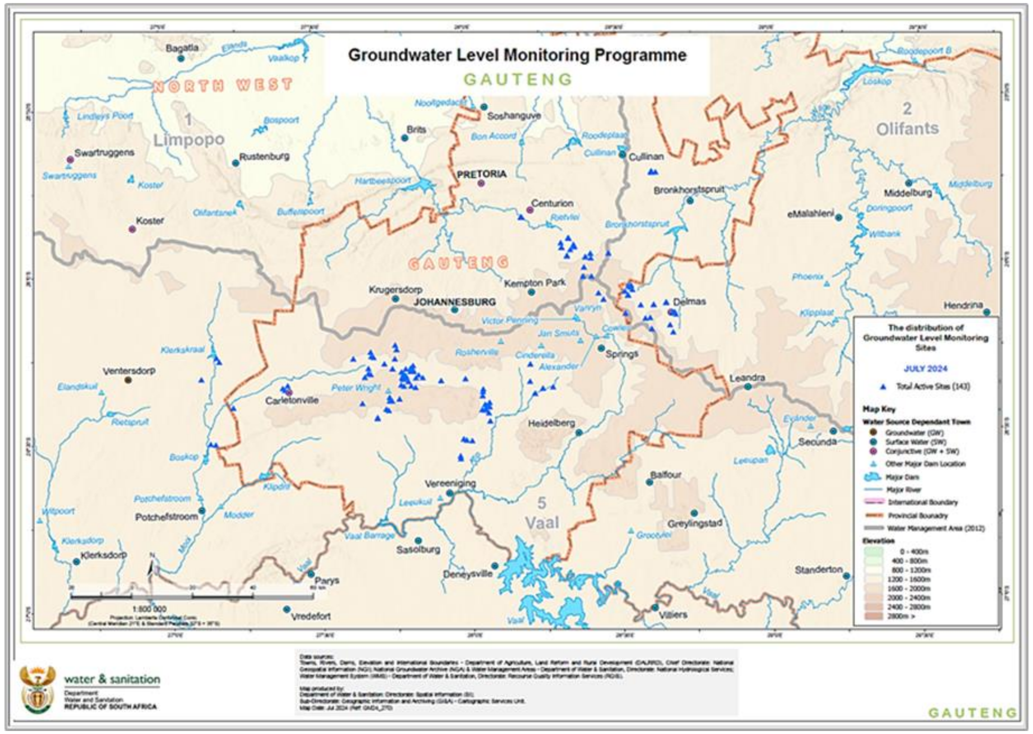


Figure A-2 Maps showing groundwater level monitoring for Free State and Gauteng provinces.

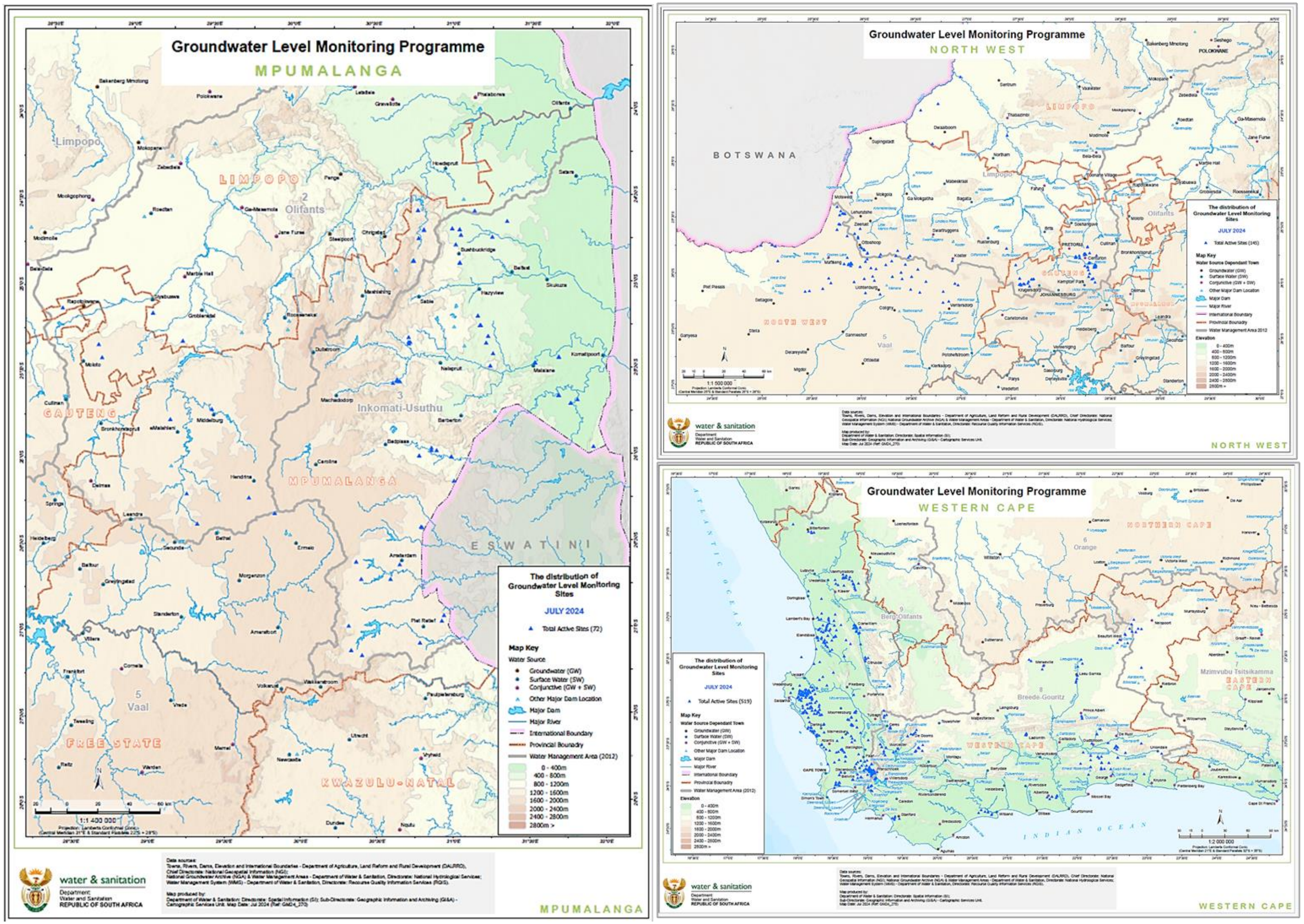
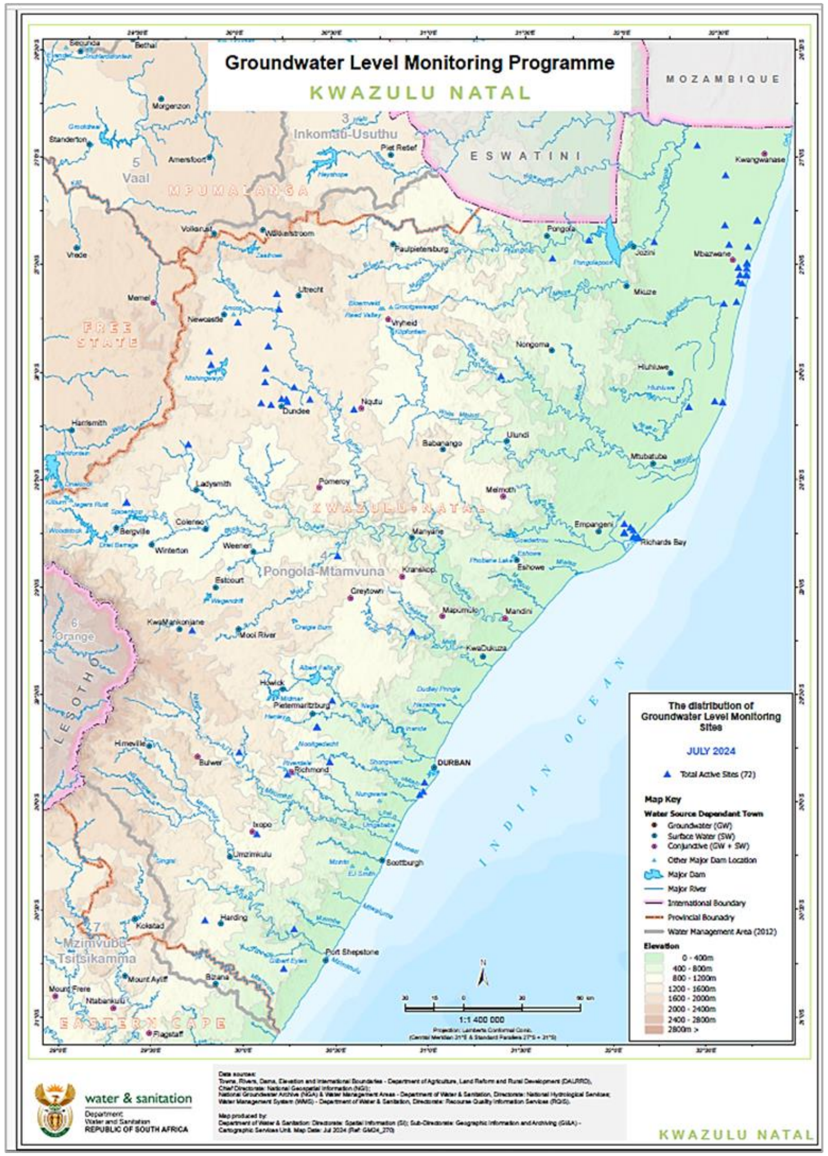


Figure A-3 Maps showing groundwater level monitoring for Mpumalanga, North West, and Western Cape provinces.



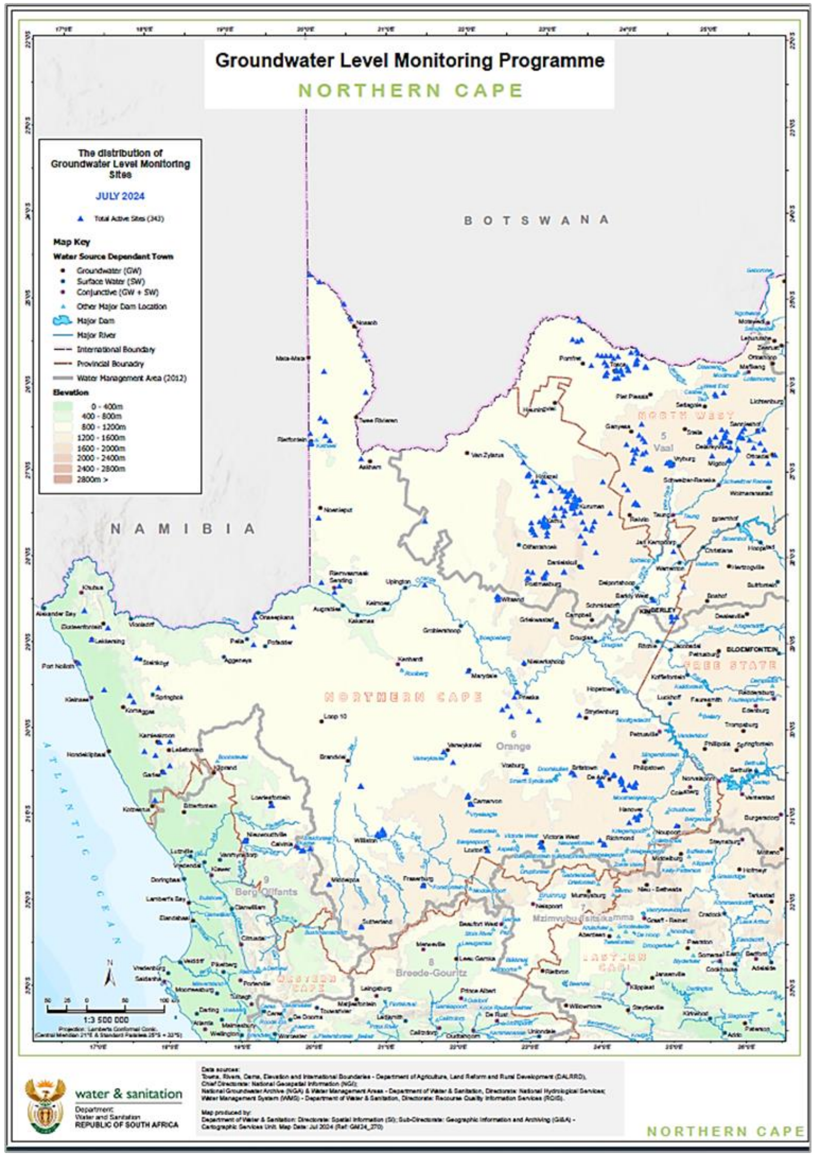


Figure A-4 Maps showing groundwater level monitoring KwaZulu-Natal, and Northern Cape provinces.