CHAPTER 4: WATER RESOURCES AND AQUATIC ECOLOGY

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APPENDIX A: DATA ACCESSED IN DEVELOPMENT OF THE WATER RESOURCES CHAPTER

A1 Surface water assessment

The surface water assessment drew on the following datasets:

- Catchment runoff, dry periods and meteorological data (Current and Near Future) extracted and interpreted from databases of Schütte *et al*.(2023)
- Mean Annual Runoff, Rainfall and Evaporation from WR2012 (Herold and Bailey, 2016) used for comparative purposes.
- Daily runoff record for the Buffels river derived from published figure in Benito *et al.* (2011)
- Orange River abstractions, current and future water demands lifted from DWS (2012), DWS (2023), BVI (2023a) and BVI (2023b)
- Farm dam density distribution lifted from Mantel and Hughes (2023)
- Aridity definition and limits lifted from Gunkel and Lange (2017).

A2 Groundwater assessment

The following datasets were accessed as part of the groundwater assessment:

- WARMS 2025 Database
- NGA Database
- 1:250 000 and 500 000 Geological Maps (CGS)
- 1: 500 000 Hydrogeological Maps (DWS)
- Soil Classification Maps from the Water Resources of South Africa (WRC 2012).
- Overlays of National Strategic Groundwater Resources data

A3 Aquatic ecosystems

The aquatic ecosystems assessment has drawn on the following datasets:

- Data from the National Freshwater Ecosystems Priority Area (NFEPA) project (Driver *et al.* 2011);
- National data from the most recent National Wetland Map (NWM Ver 5)
- National Biodiversity Assessment (NBA) for aquatic ecosystem data including estuaries (Van Deventer *et al.* 2018);
- Overlays of the national 1:50 000 rivers and topographical GIS layers;
- Overlays of national Strategic Surface and Groundwater Resources data;
- Ecoregion data (Kleynhans *et al.* 2005)

- Bioregion data (from the NWM dataset)
- The 2018 Northern Cape biodiversity spatial plan, including aquatic ecosystems (Northern Cape Department of Environment and Nature Conservation 2018)
- Outputs from available water resource classification studies in the study area (e.g. Lower Orange River Classification study, currently under way)
- Reporting and datasets (DWAF 2017a and b)
- DWS Water quality data – DWS (2024a) https://www.dws.gov.za/iwqs/wms/data/WMS_WMA_txt.asp
- The findings of the groundwater and surface hydrological studies for this project.

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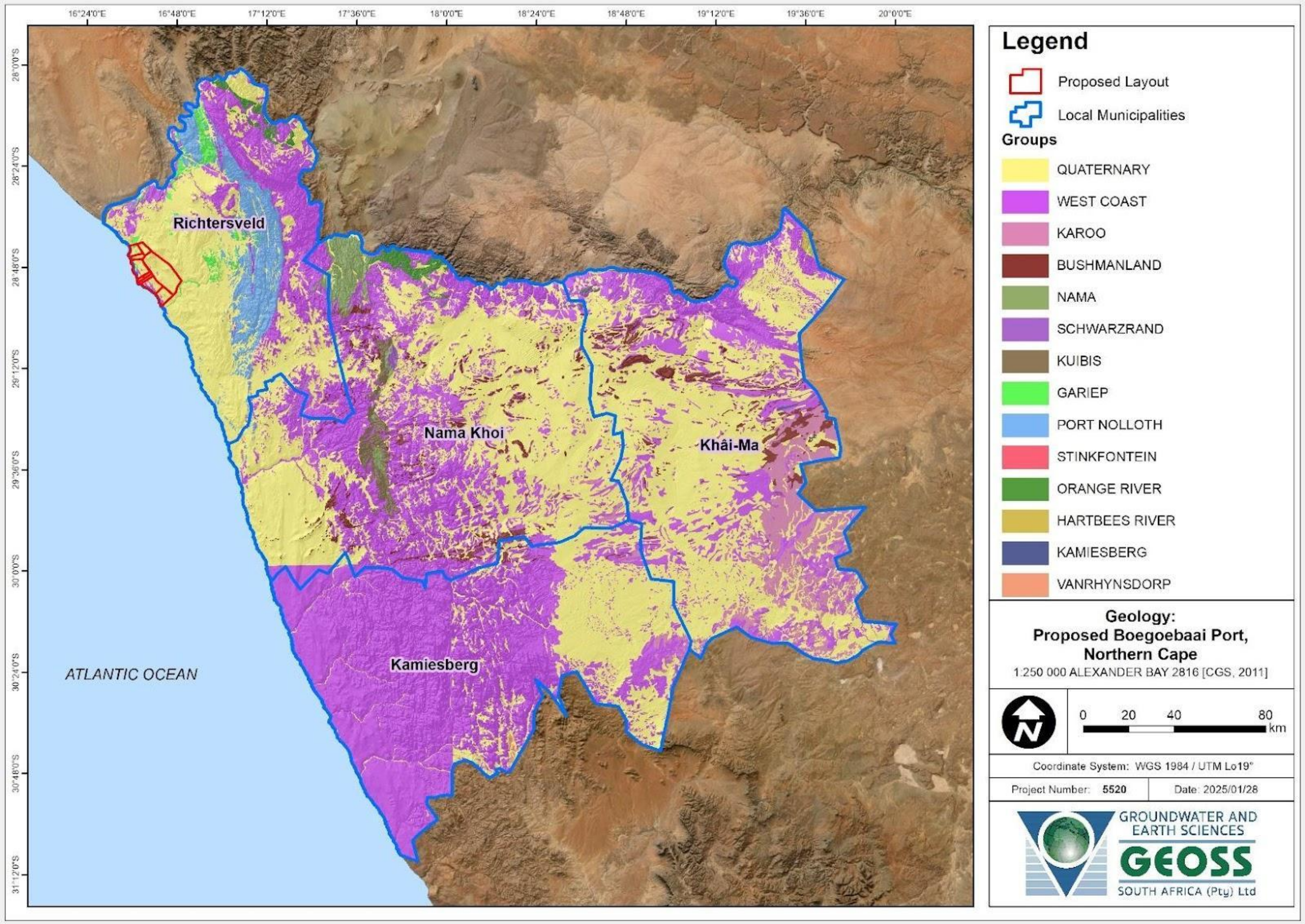
Figure B1: Location of the proposed Boegoebaai Port in comparison to the broader Namakwa Region, Northern Cape.



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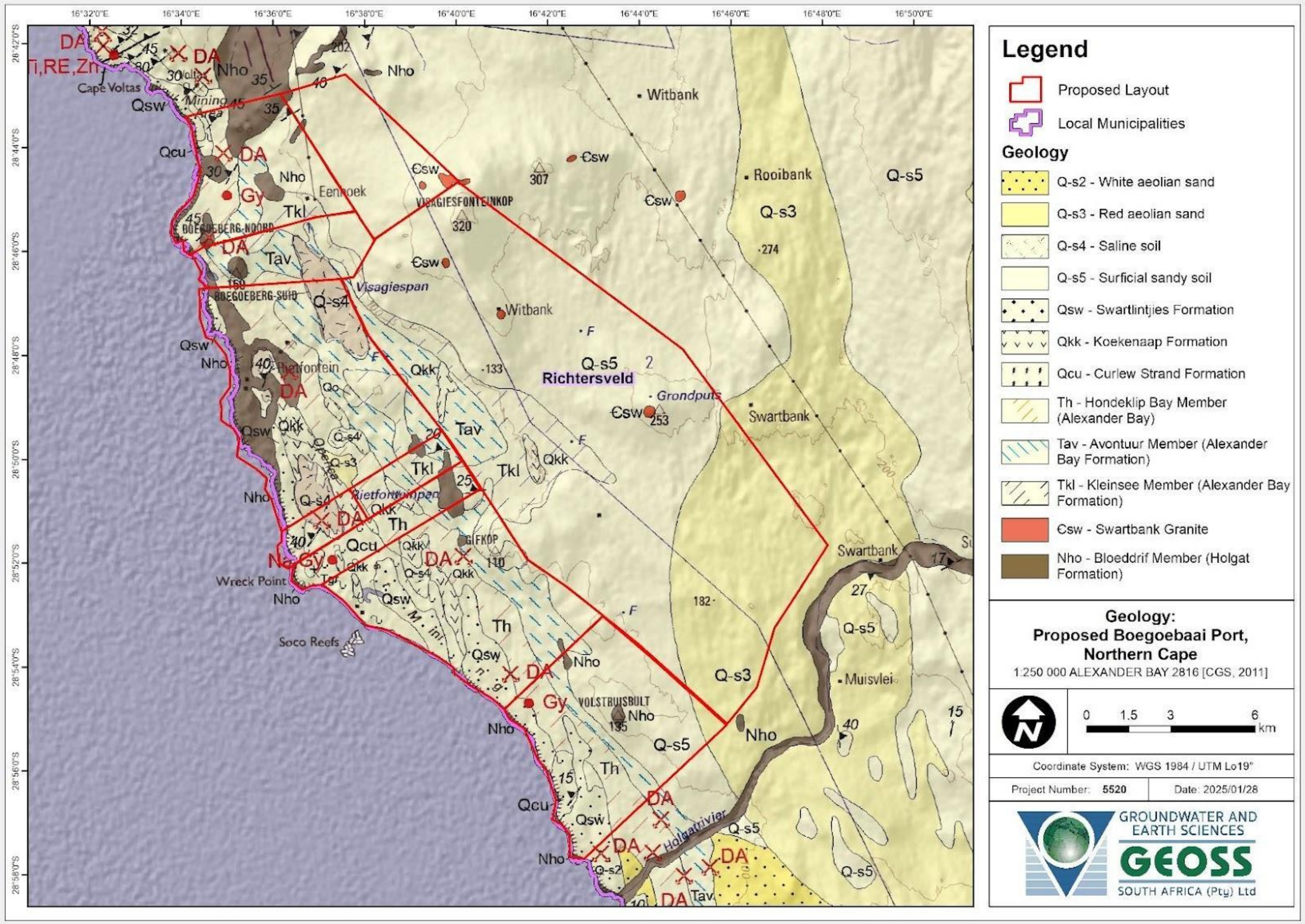

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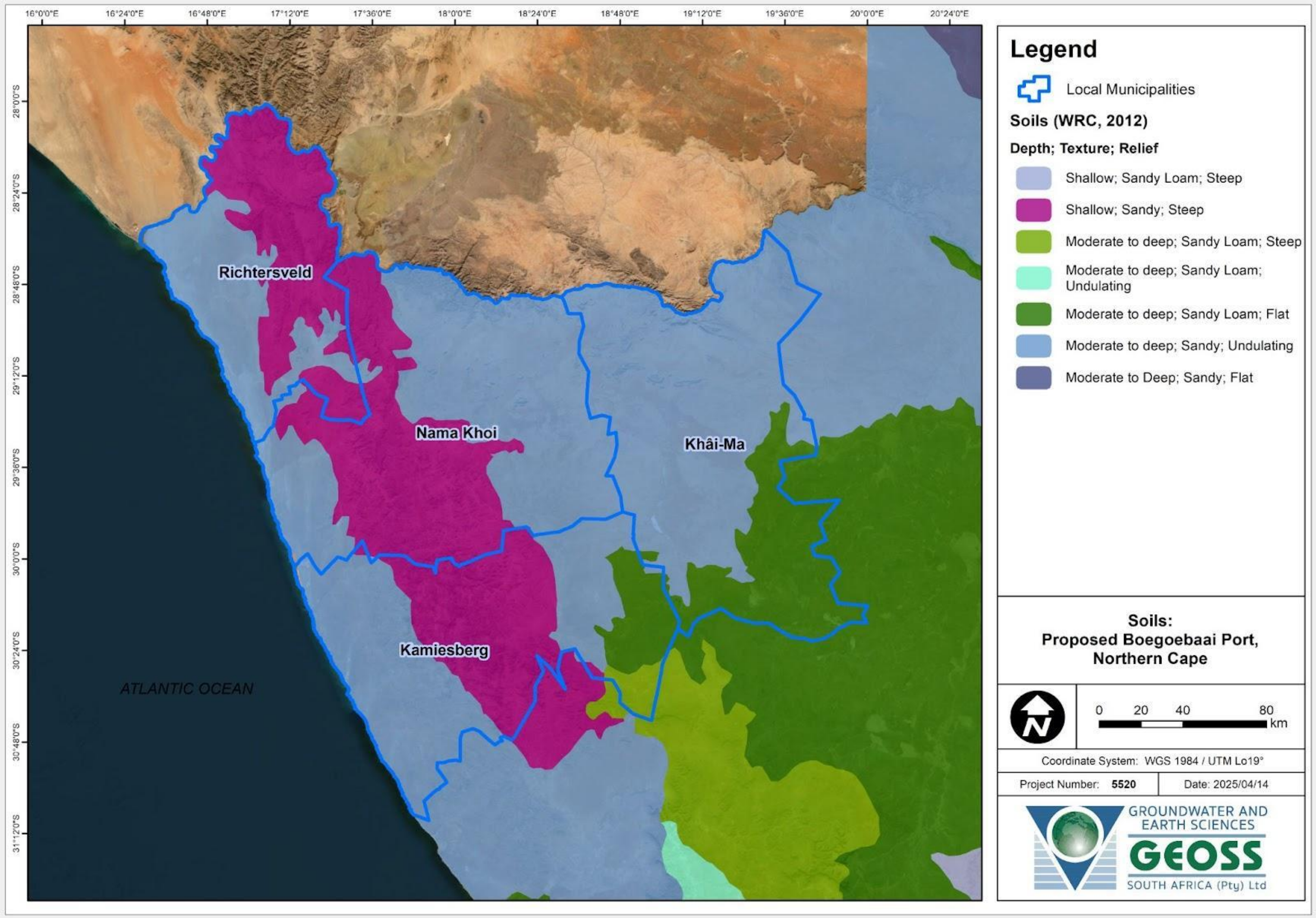

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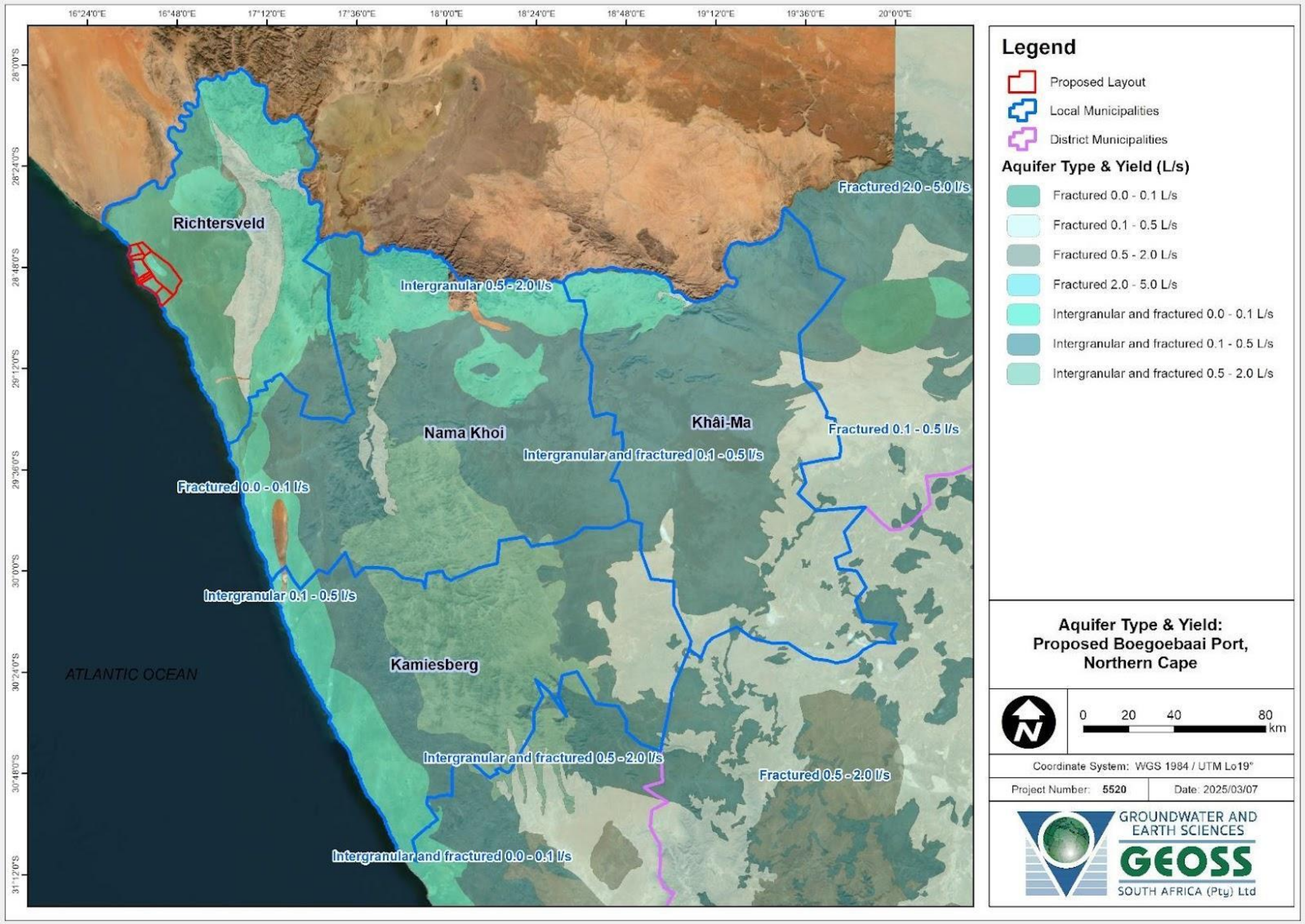

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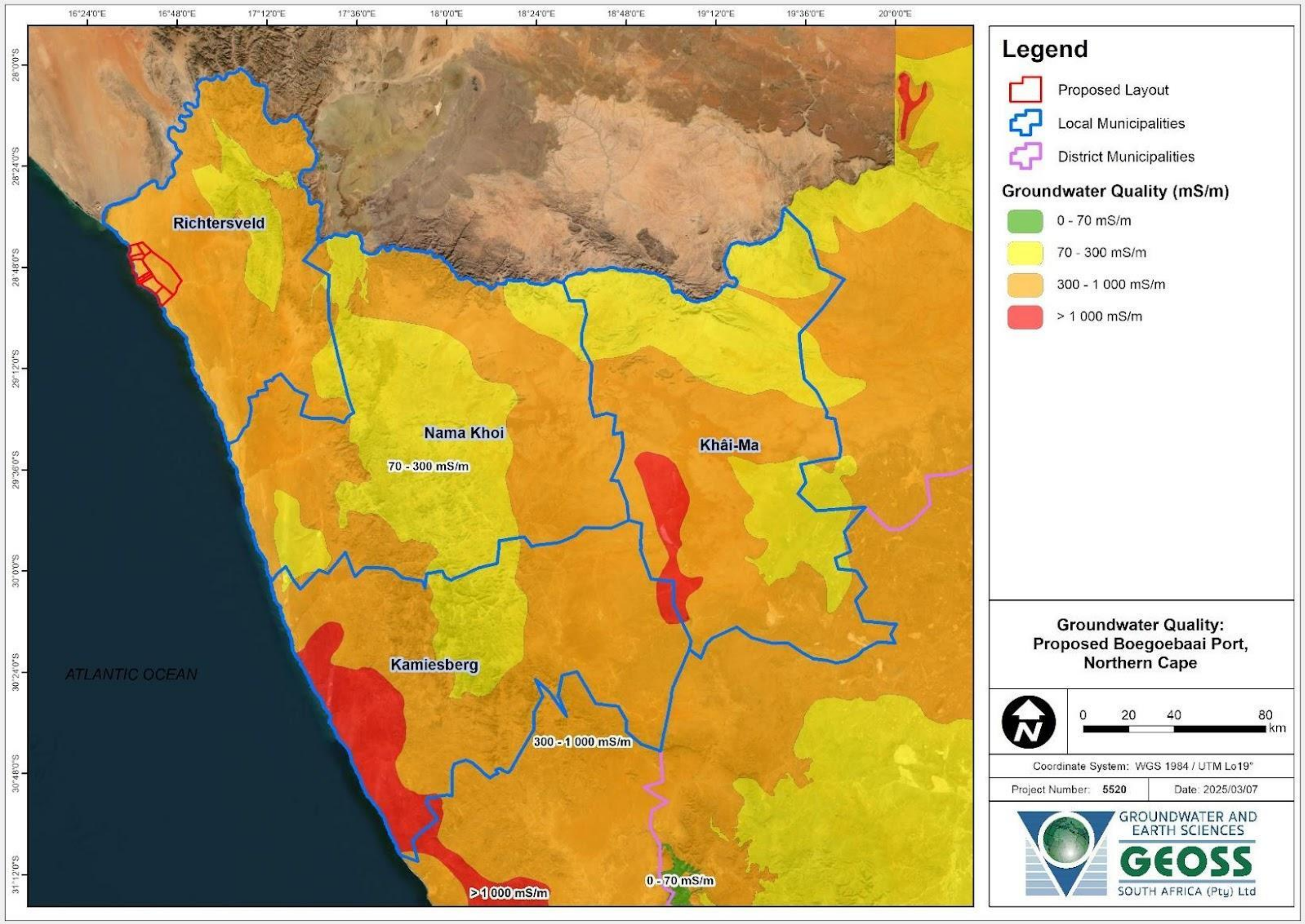

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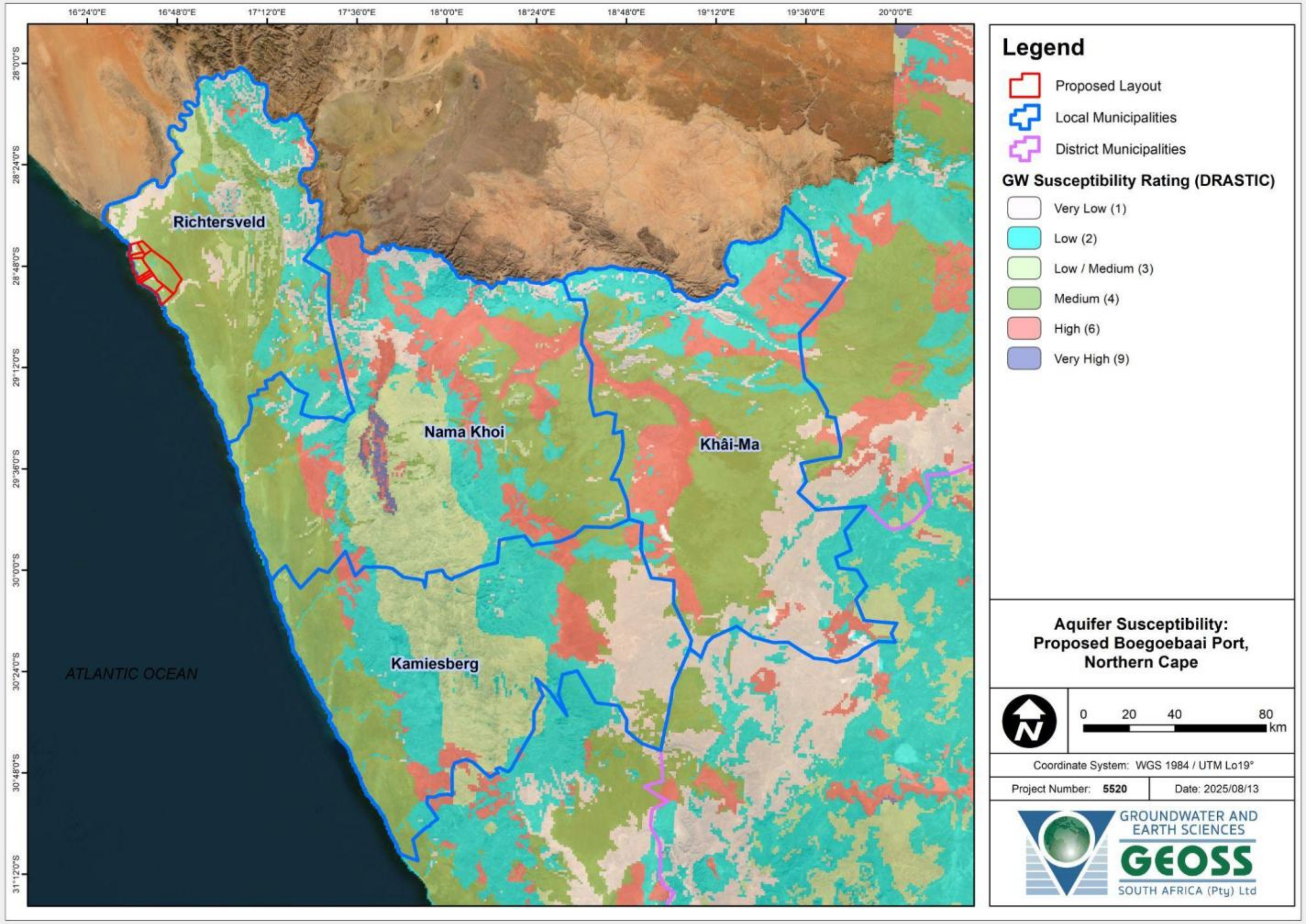


Figure B7: Susceptibility rating (DWAF 2005) and groundwater depths (mbgl).

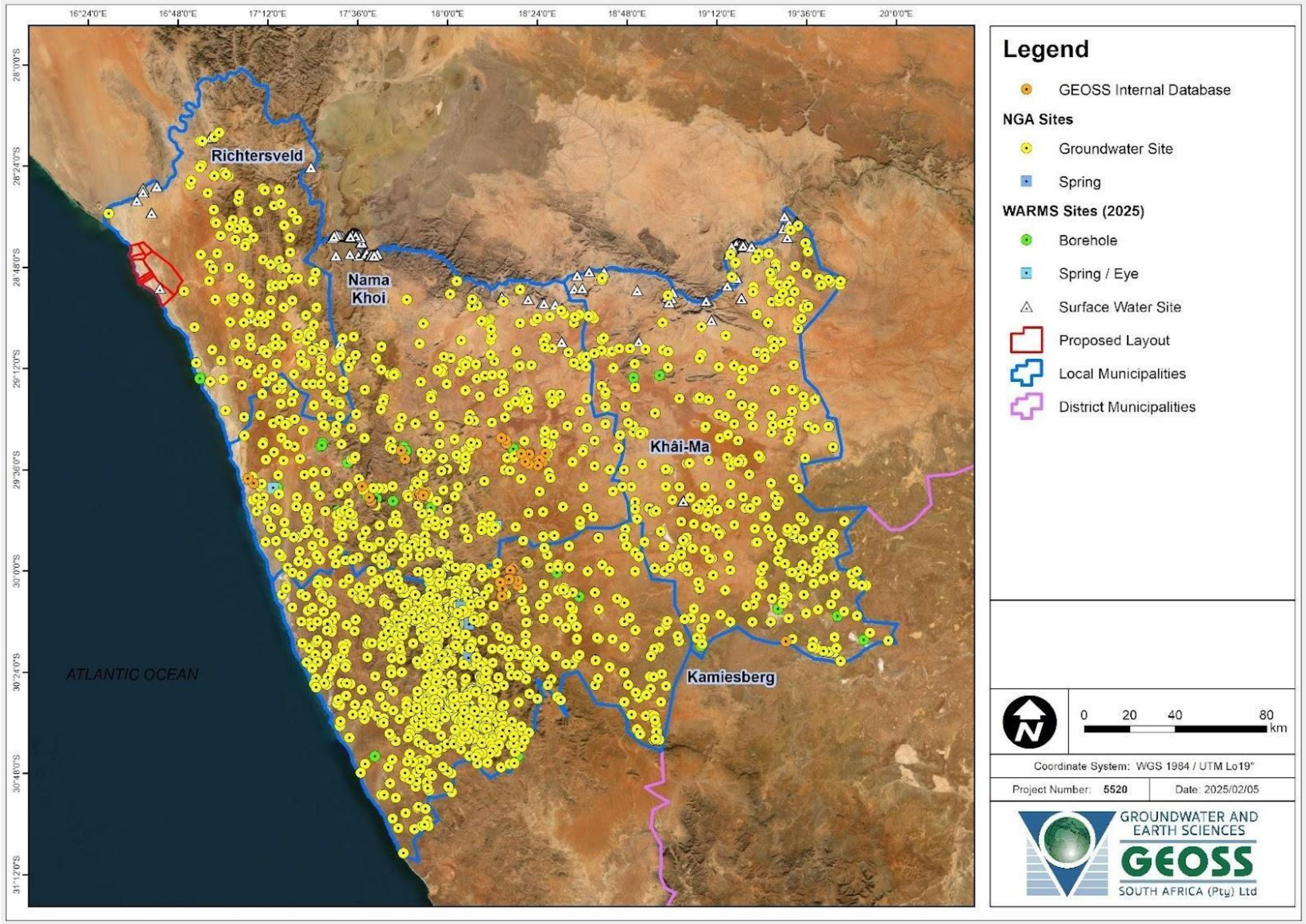
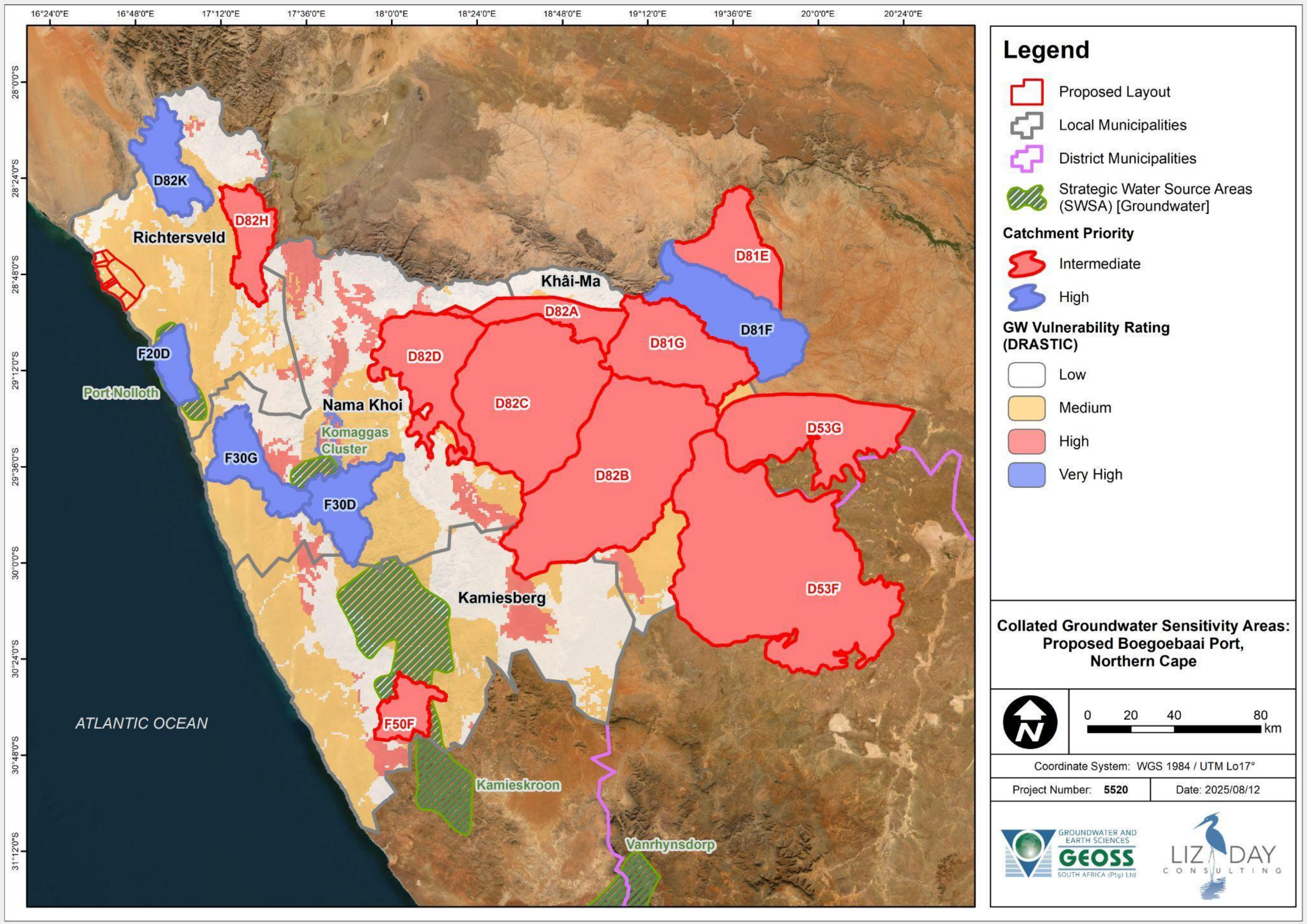


Figure B8: Registered groundwater users in the greater Namakwa Region, Northern Cape.



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Appendix C1: Meteorological Trends

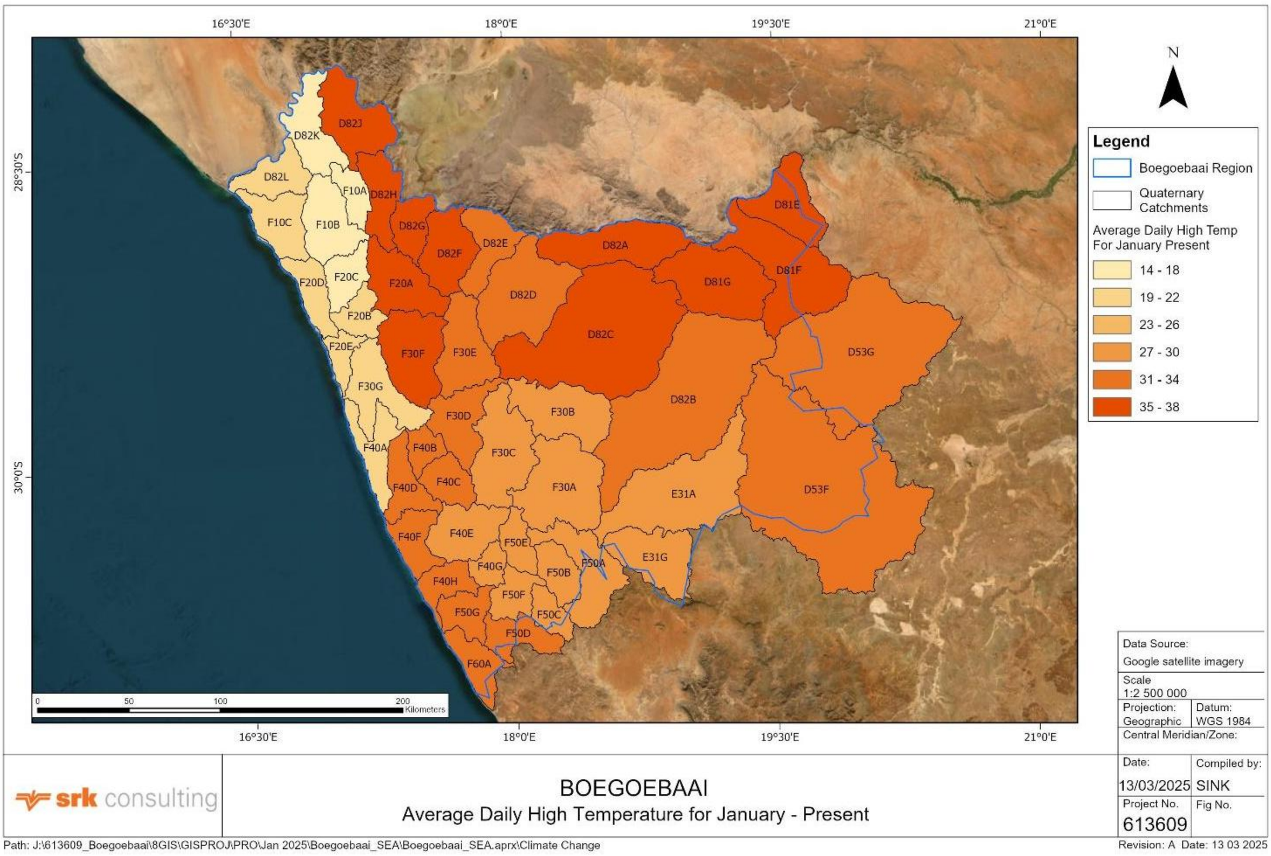

Figure C1.1: Average Daily High Temperature for January – Present (from Schütte *et al*. 2023)

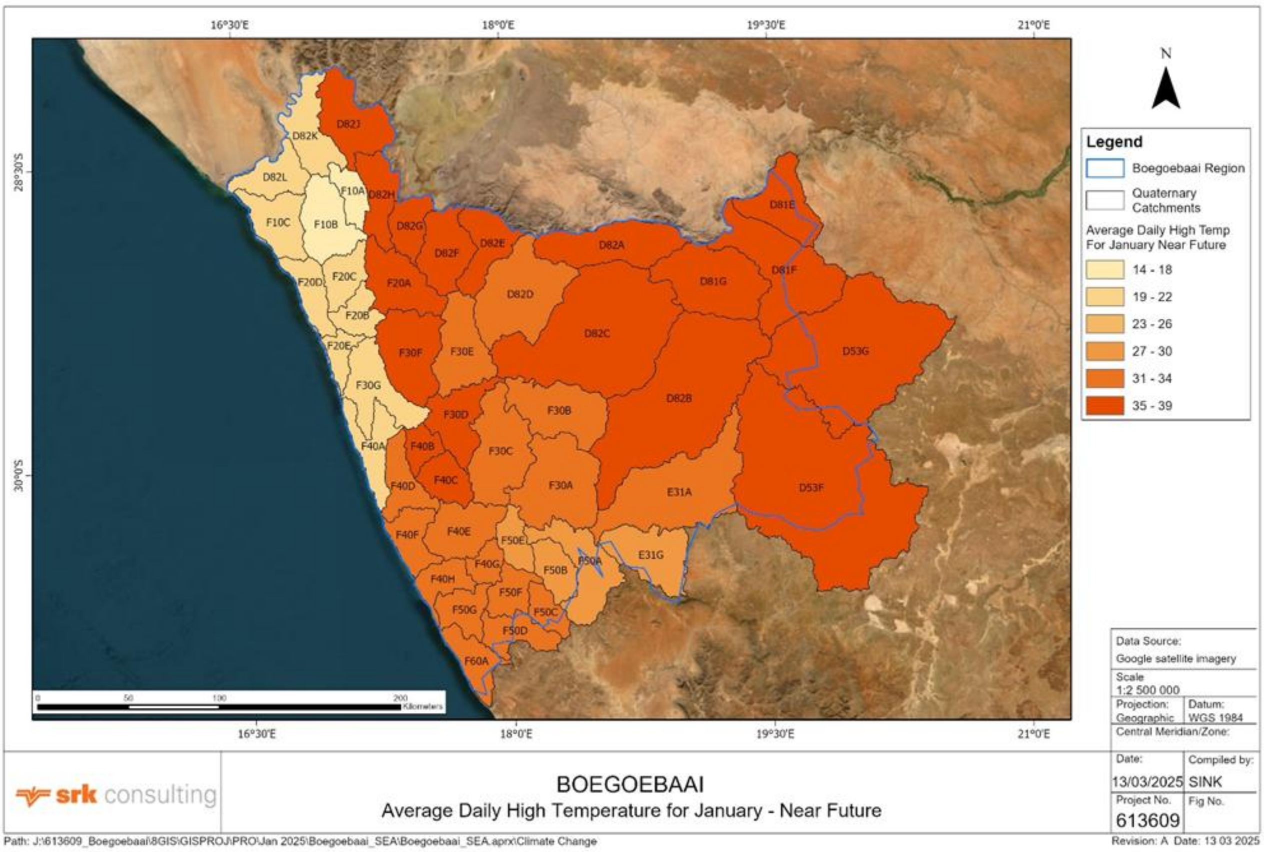

Figure C1.2 Average Daily High Temperature for January – Near-Future (from Schütte *et al*. 2023)

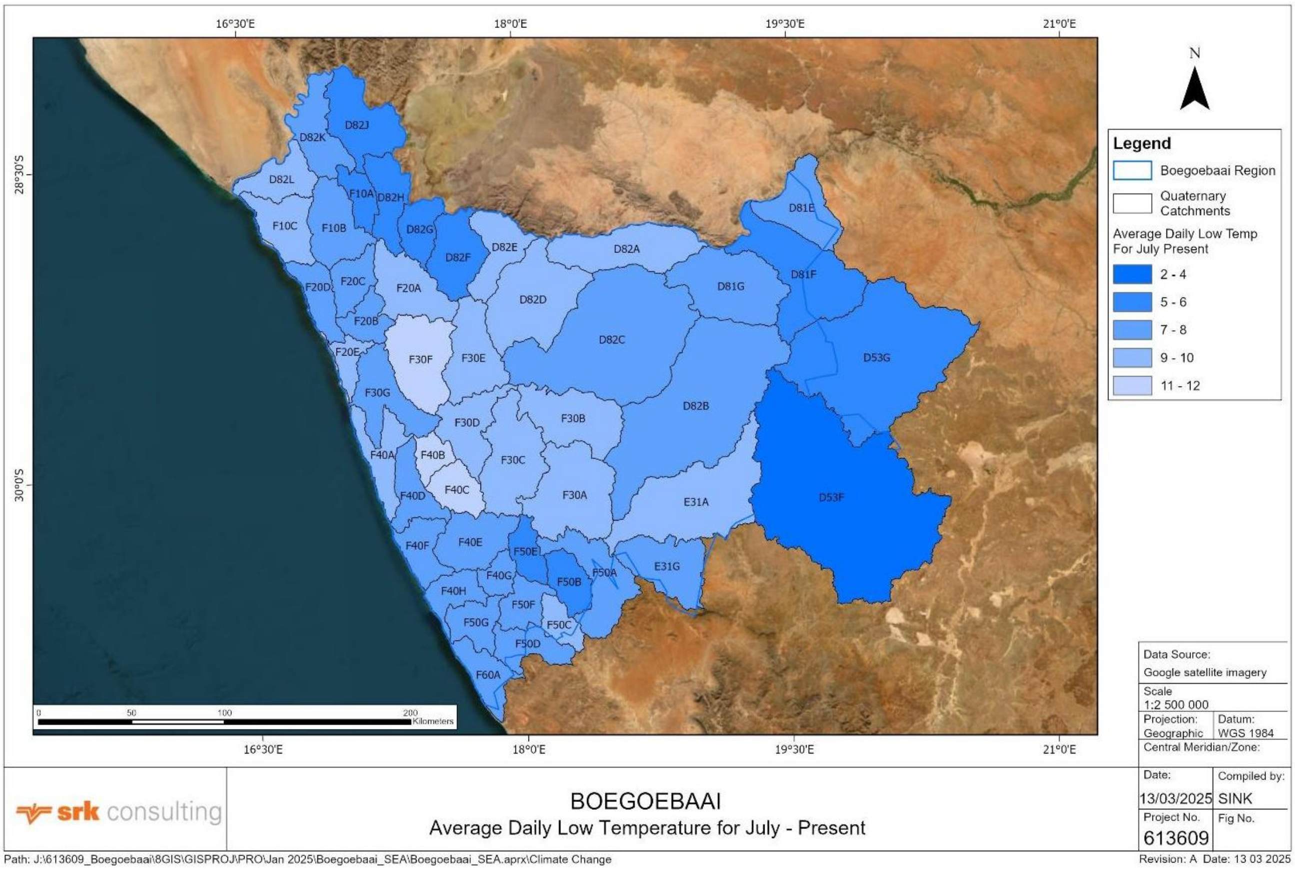

Figure C1.3 Average Daily Low Temperature for July – Present (from Schütte *et al*. 2023)

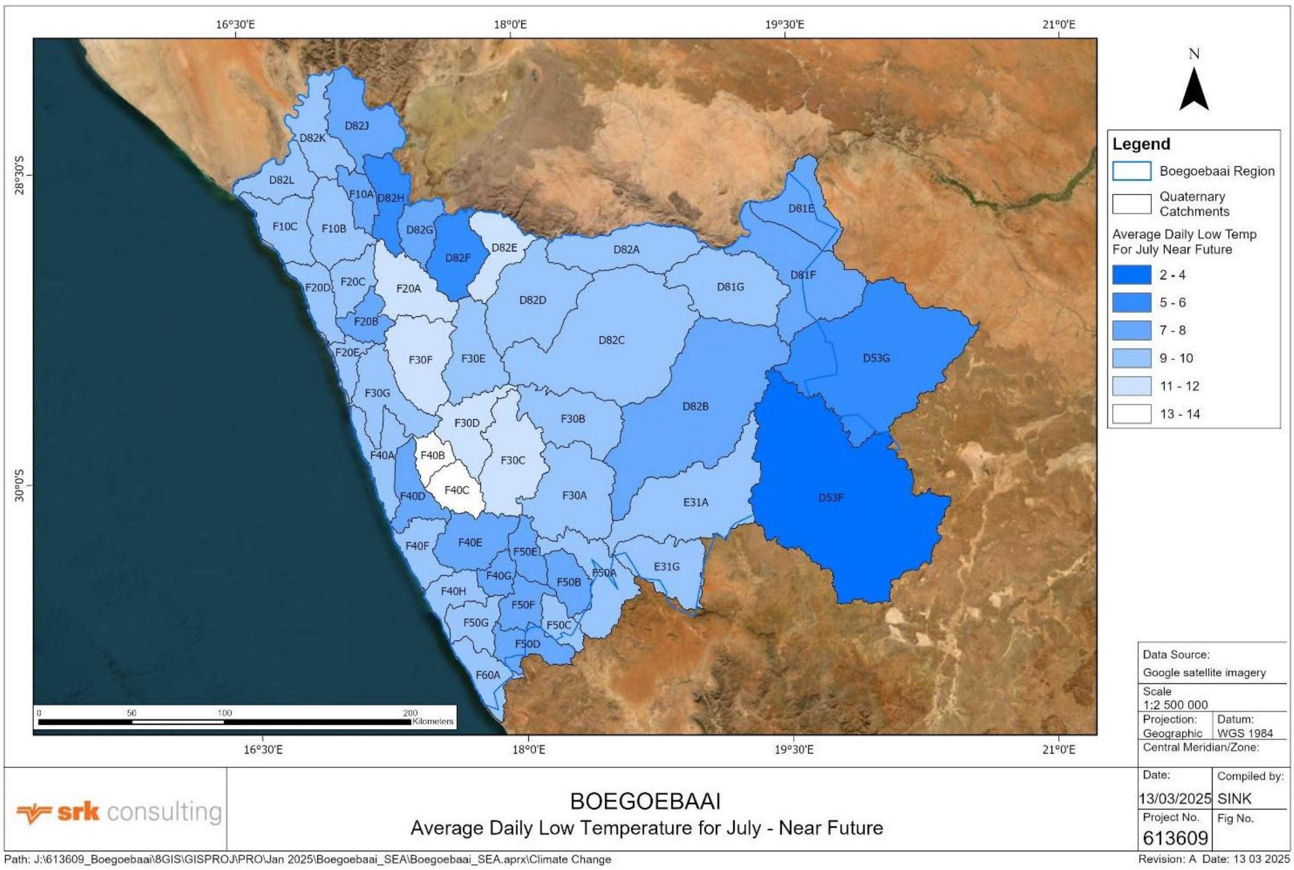

Figure C1.4: Average Daily Low Temperature for July – Near Future (from Schütte et al. 2023)

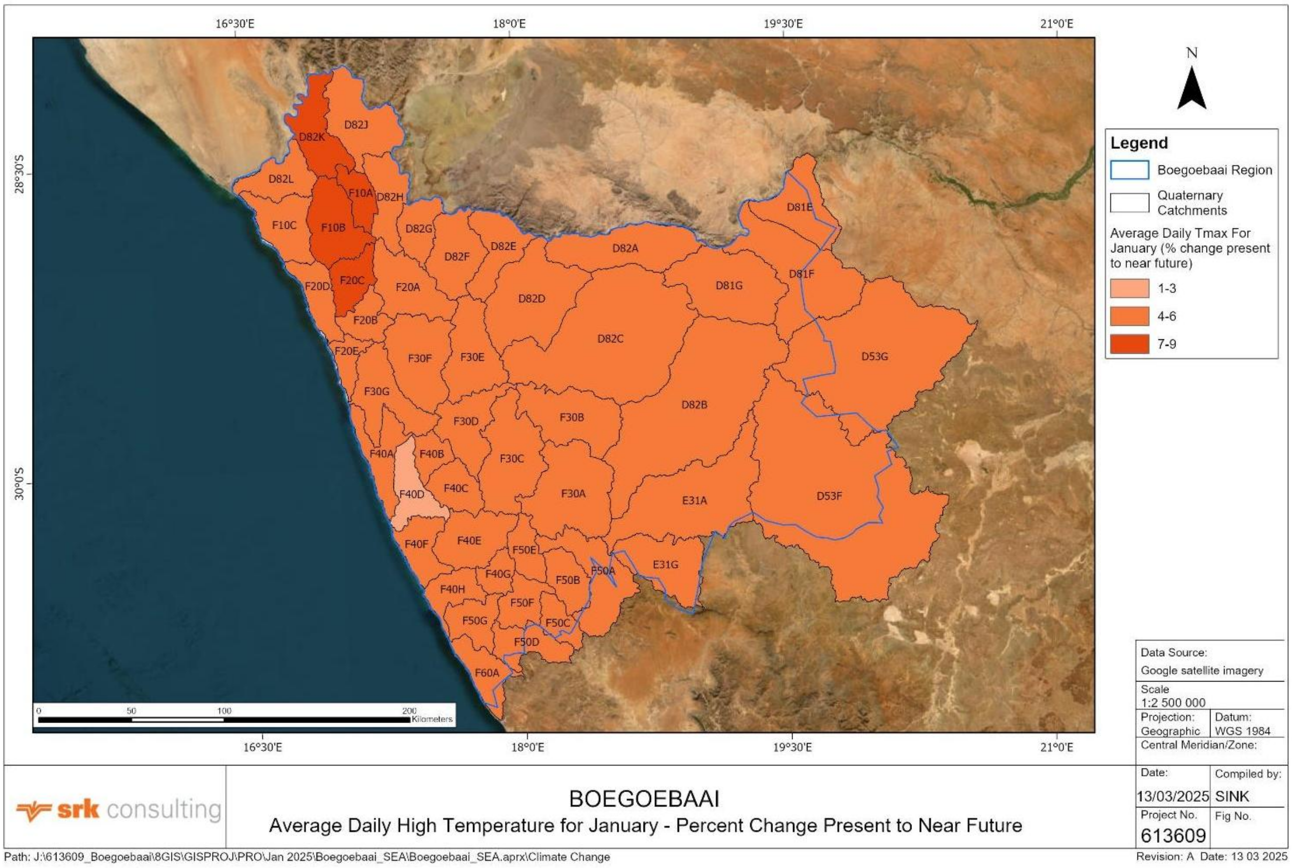

Figure C1.5: Average January Daily High Temperature – % Change from Present to Near Future

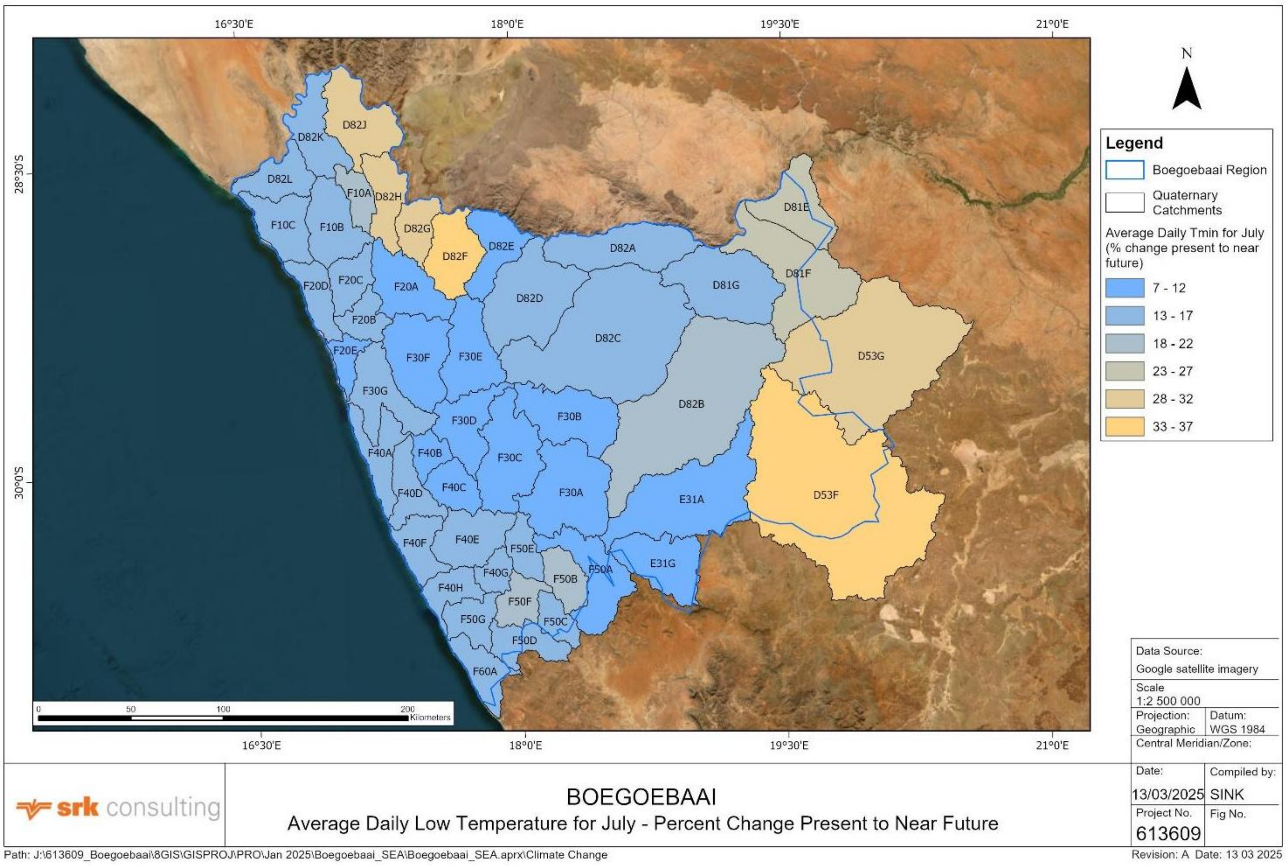

Figure C1.6: Average July Daily Low Temperature – % Change from Present to Near Future

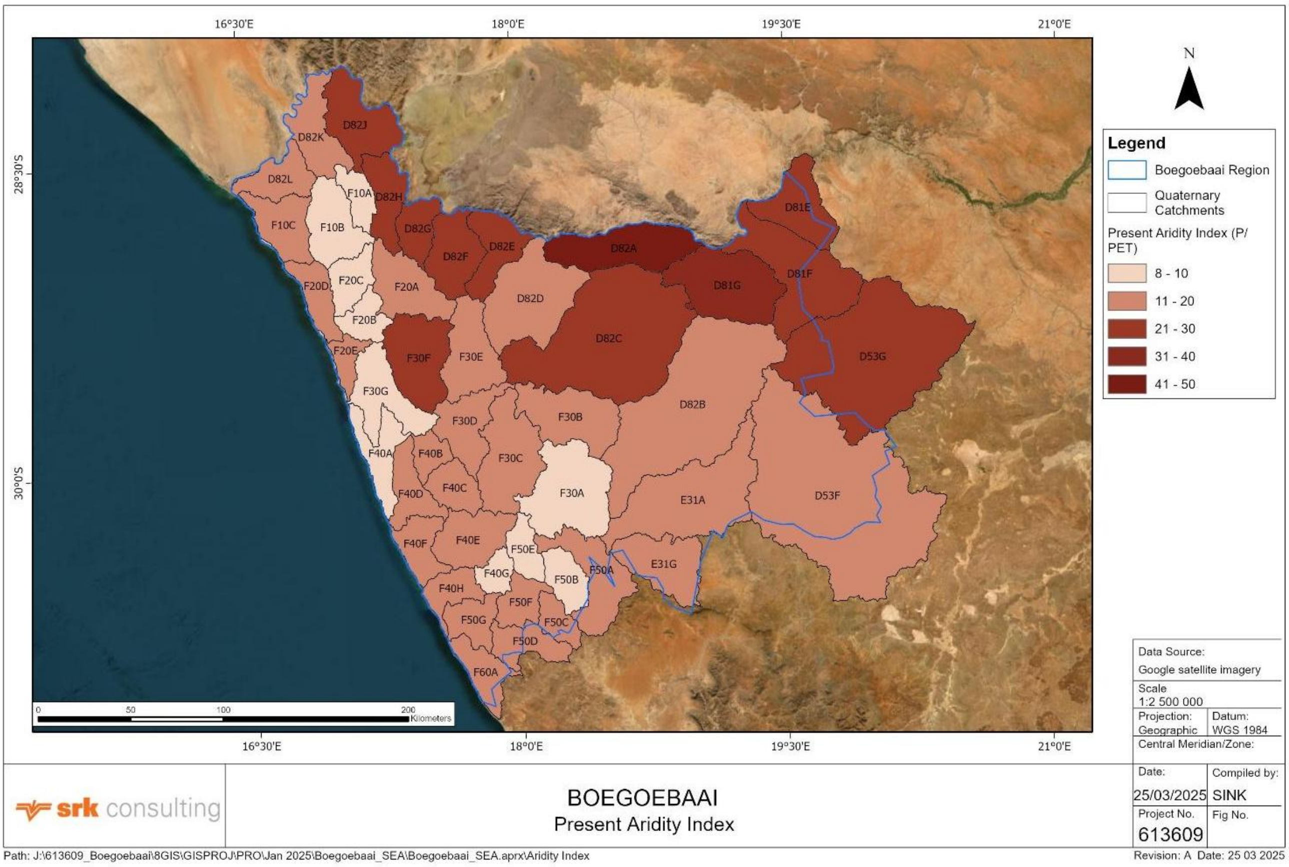

Figure C1.7: Distribution of Aridity Index: Present Climate (Average of 6 GCMs).

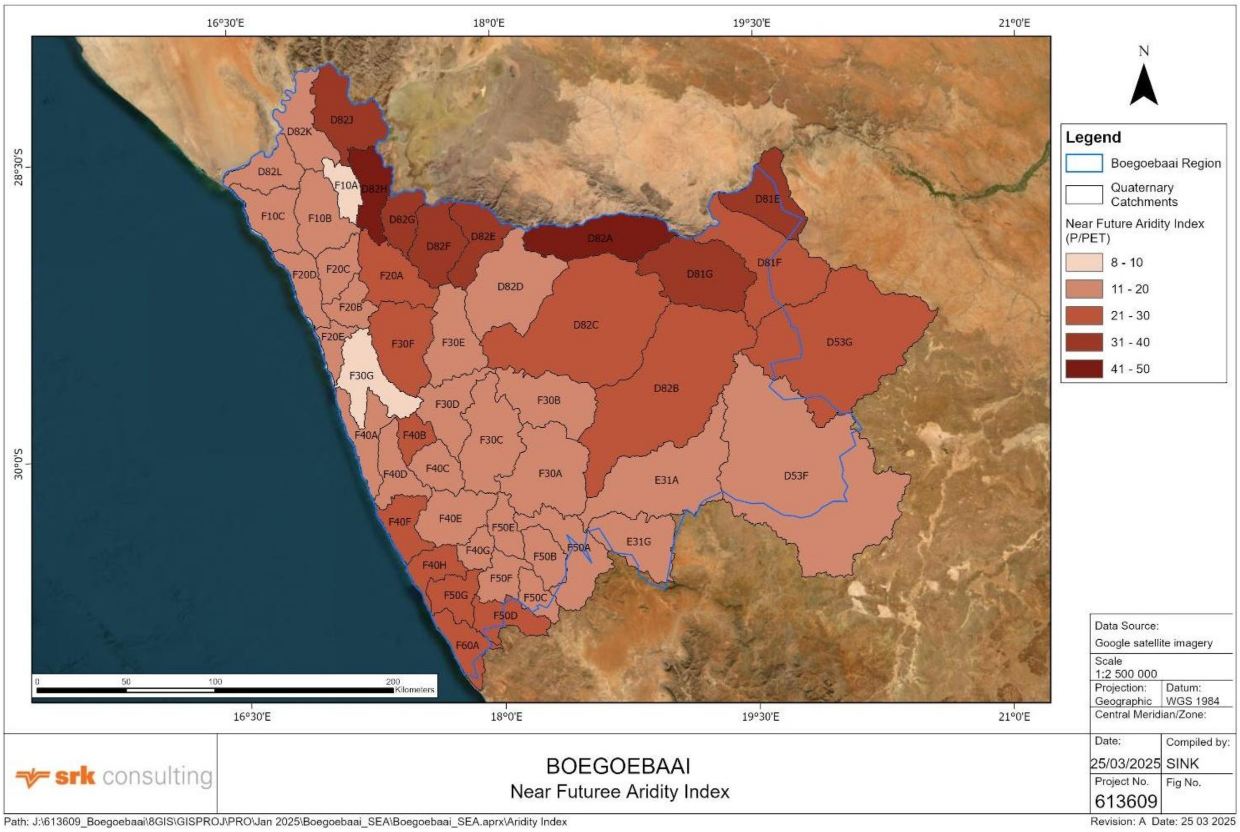

Figure C1.8: Distribution of Aridity Index: Near Future Climate (Average of 6 GCMs).

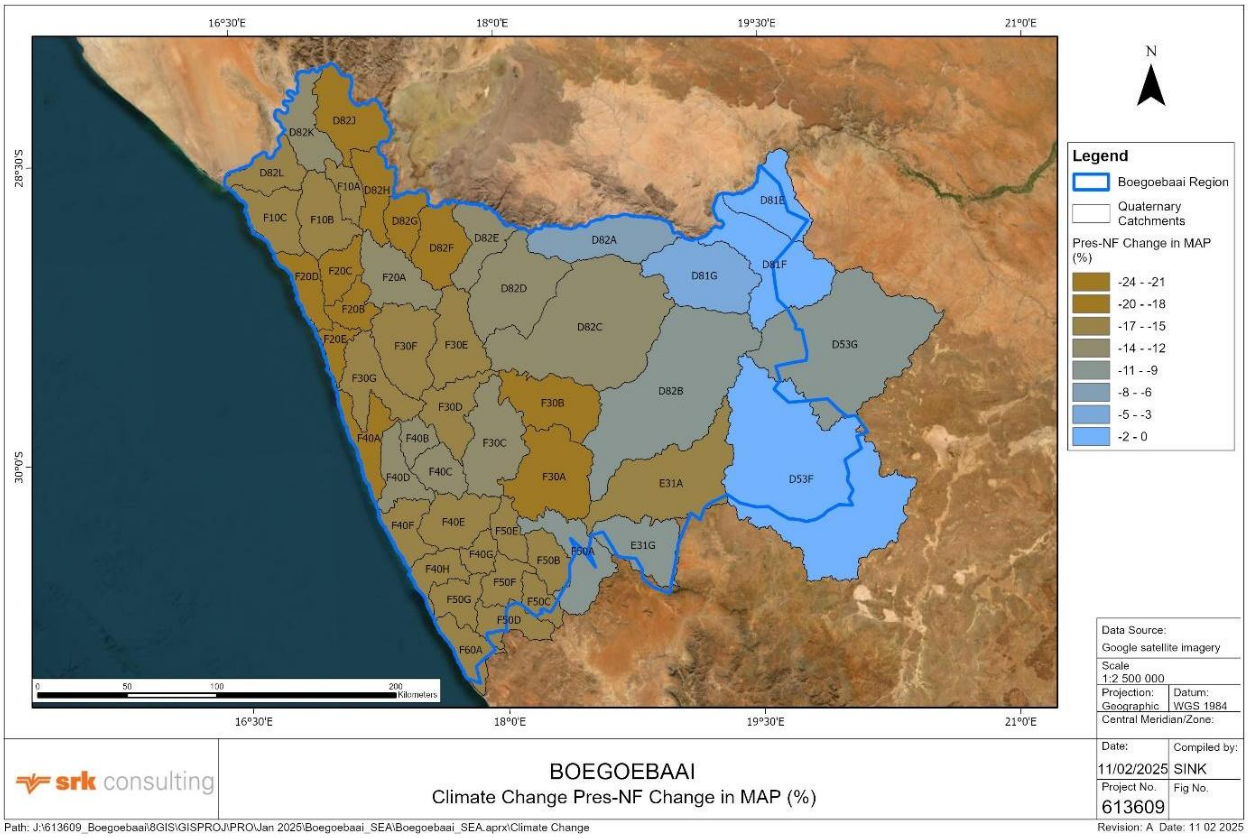

Figure C1.9: Estimated % Change in MAP for Near Future (Average of 6 GCMs, Extracted from Schütte, et al. 2023)

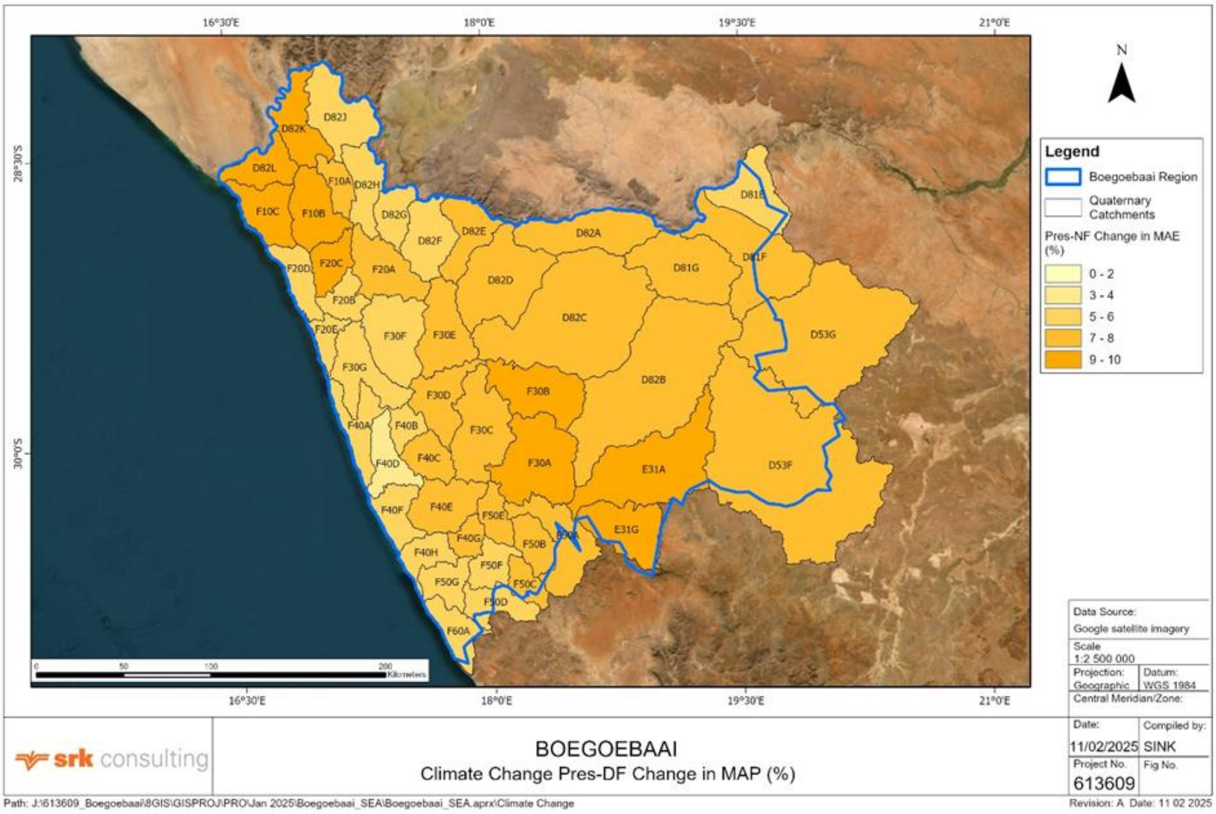

Figure C1.10: Estimated % Change in MAPE for Near-Future (average of 6 GCMs, Extracted from Schütte, et al. 2023)

Appendix C2: Quaternary Catchment Runoff

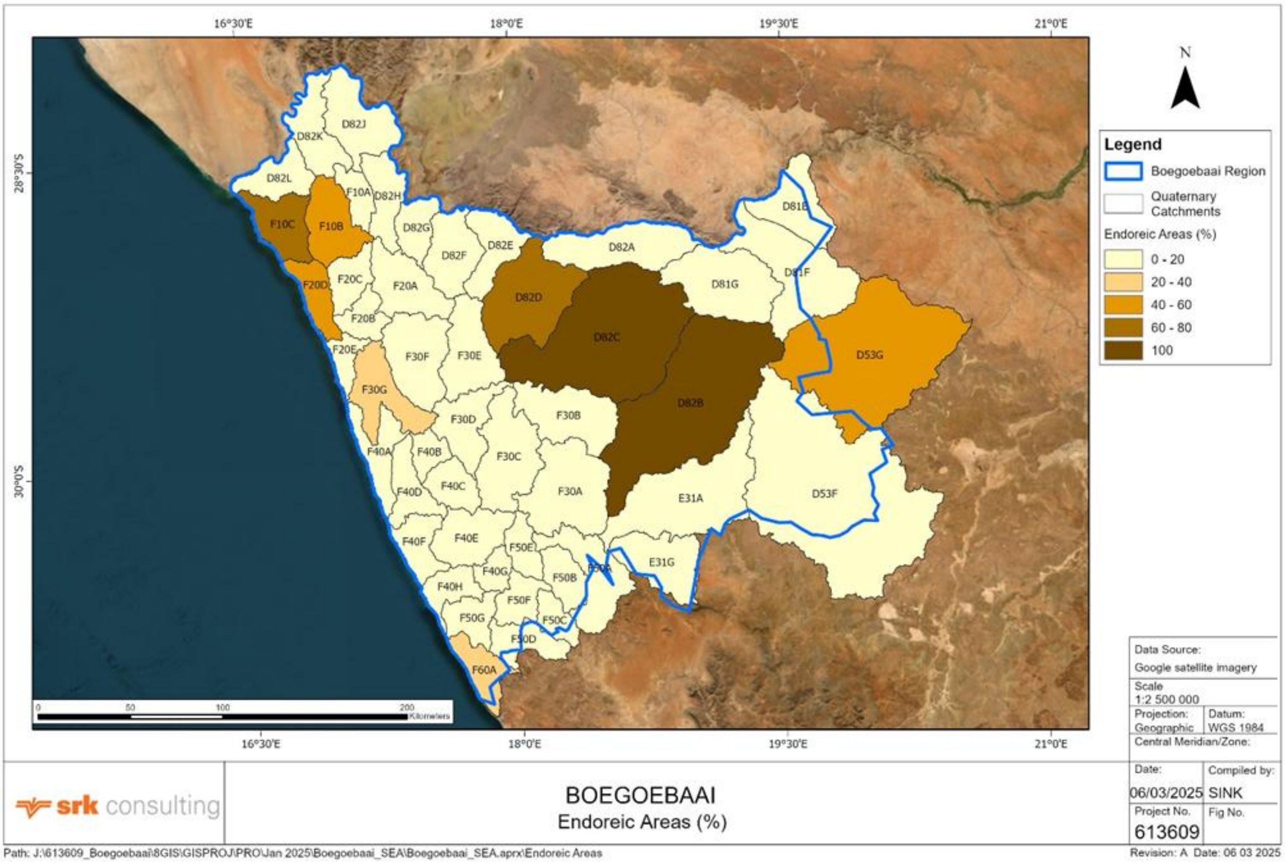

Figure C2.1: Distribution of endoreic areas (WR2012, Herold and Bailey, 2016)

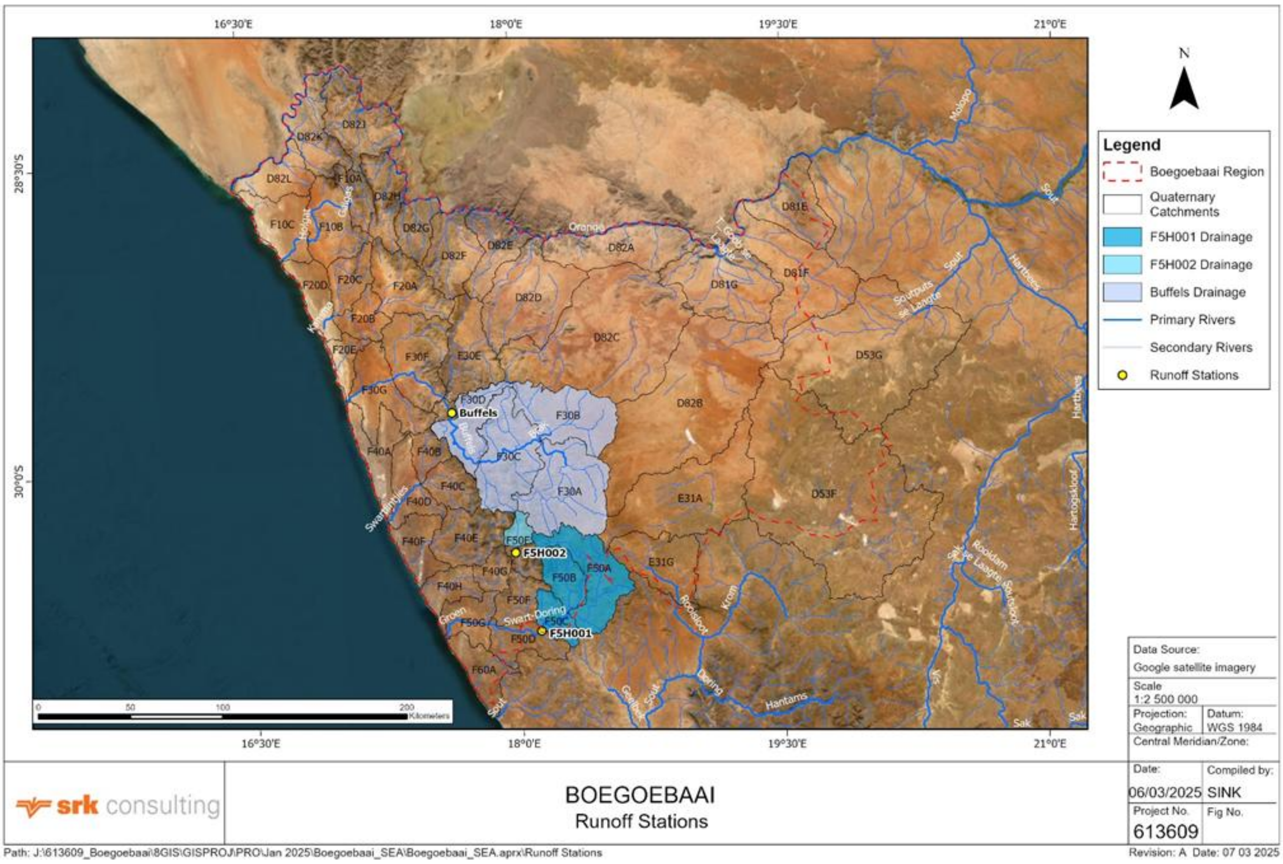

Figure C2.2: Location of River Monitoring Stations (DWS and Benito et al. 2011)

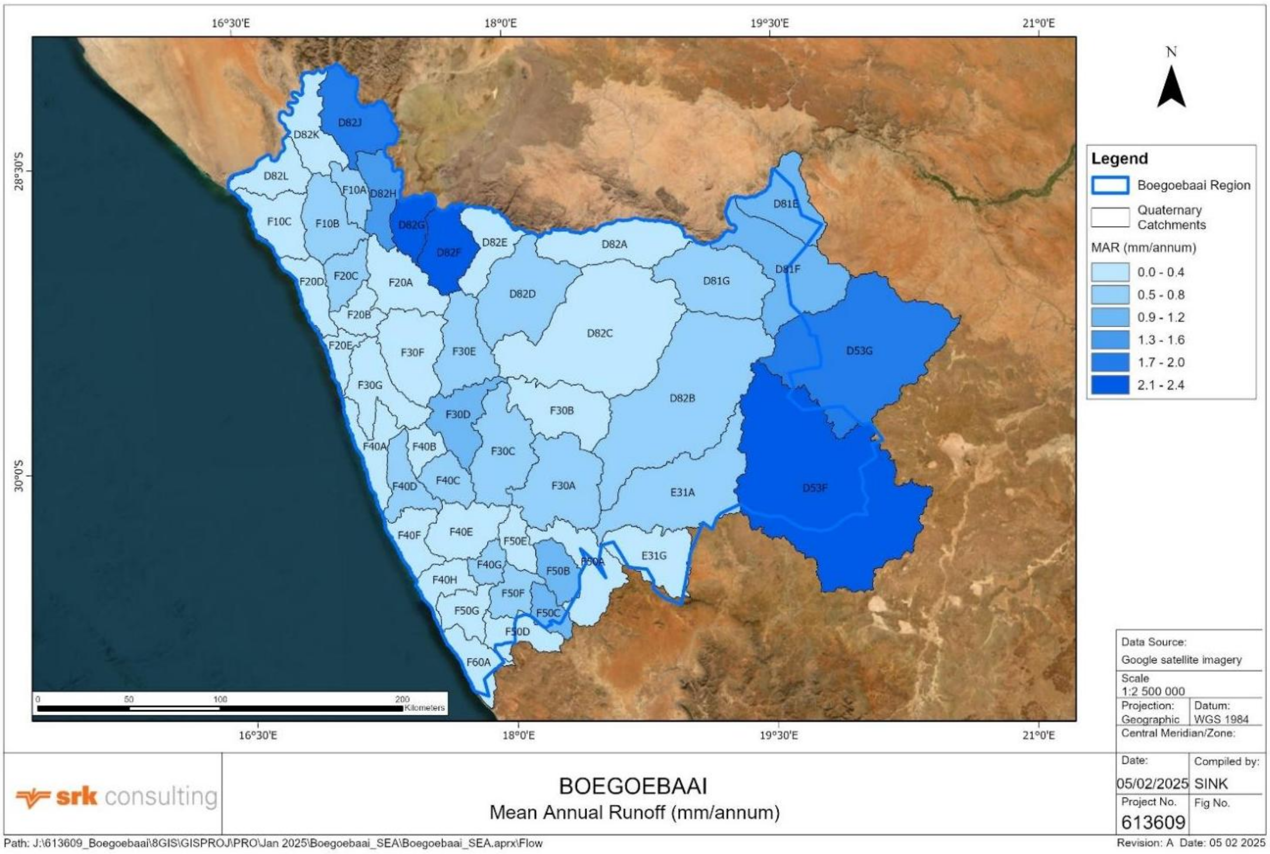

Figure C2.3: Distribution of Mean Annual Runoff, MAR (mm/annum), in the study area.

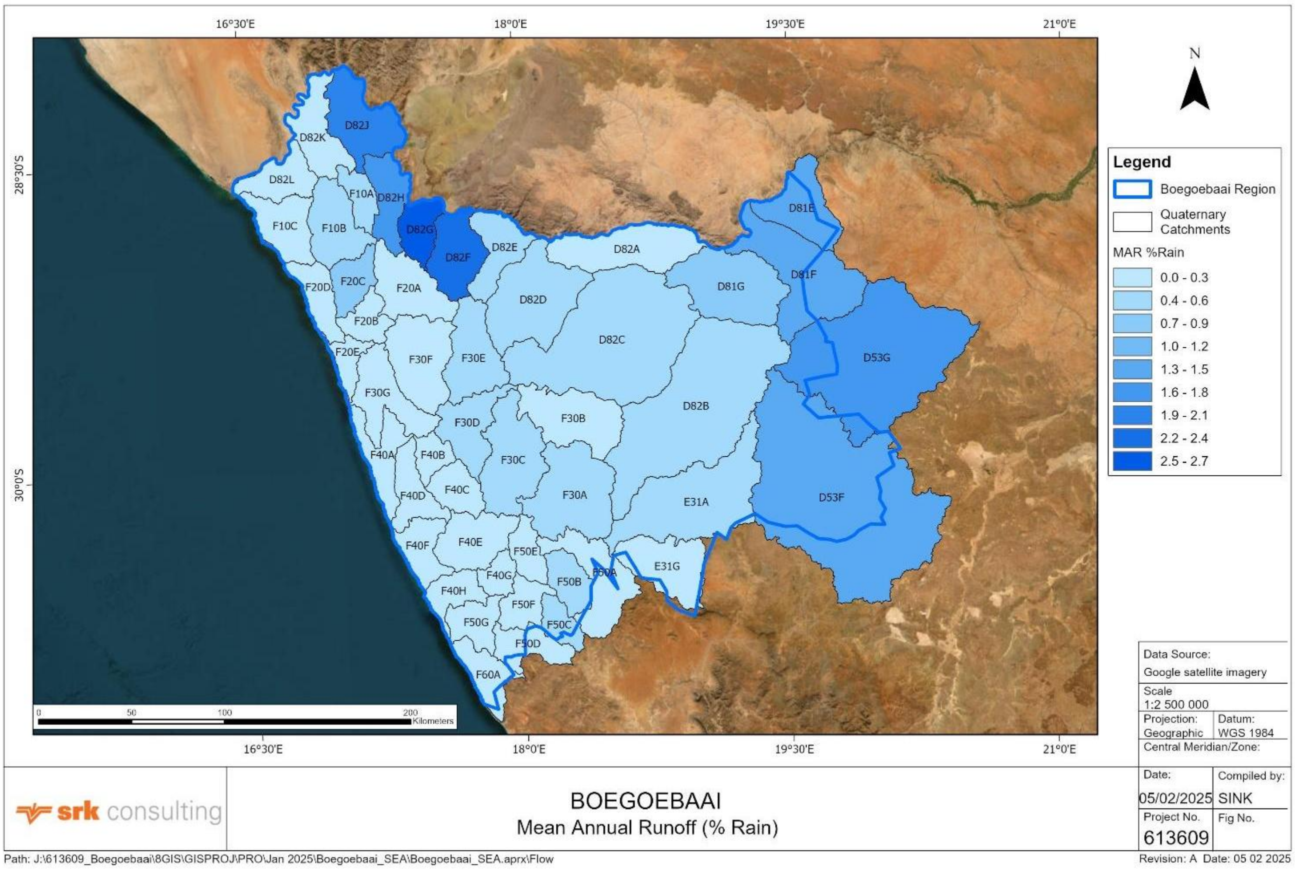

Figure C2.4: Distribution of the Quaternary MARs as a percent of rainfall.

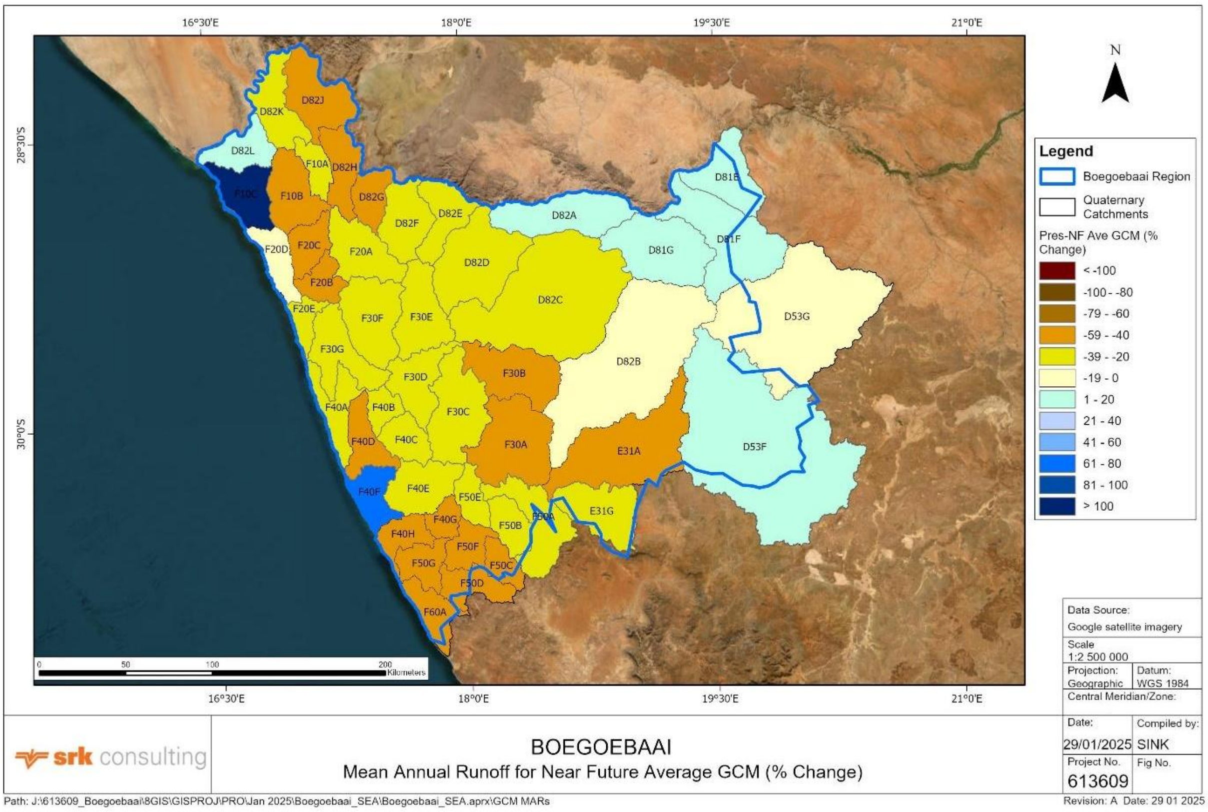

Figure C2.5: Percent Change in Near Future Mean Annual Runoff (average of 6 GCMs)

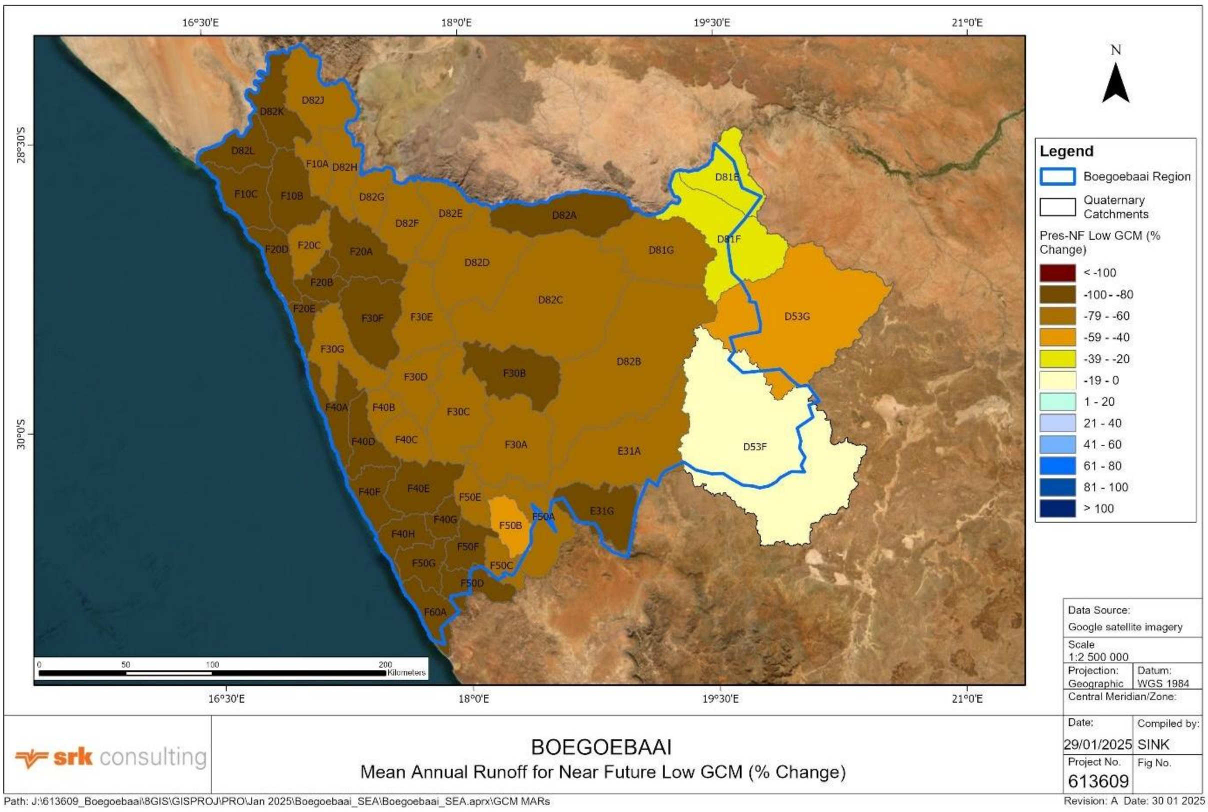

Figure C2.6: Percent Change in Near Future Mean Annual Runoff (lowest of 6 GCMs)

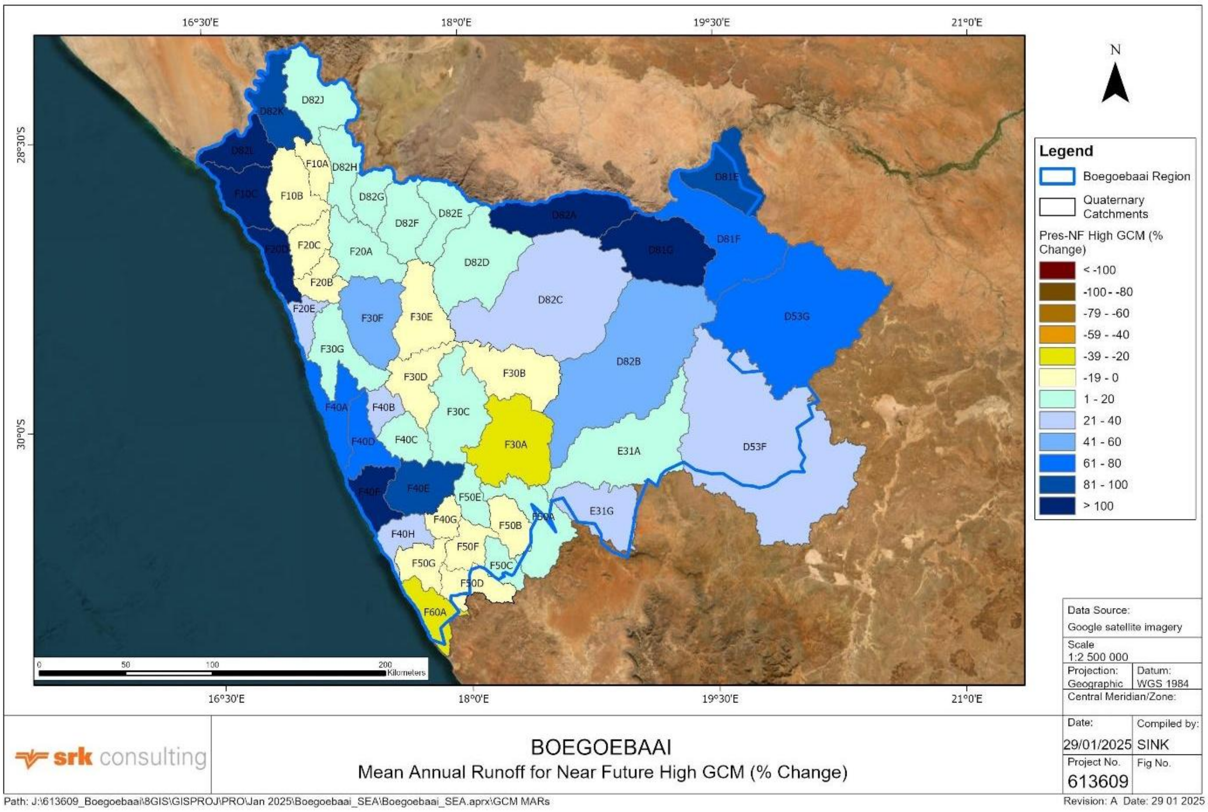

Figure C2.7: Percent Change in Near Future Mean Annual Runoff (highest of 6 GCMs)

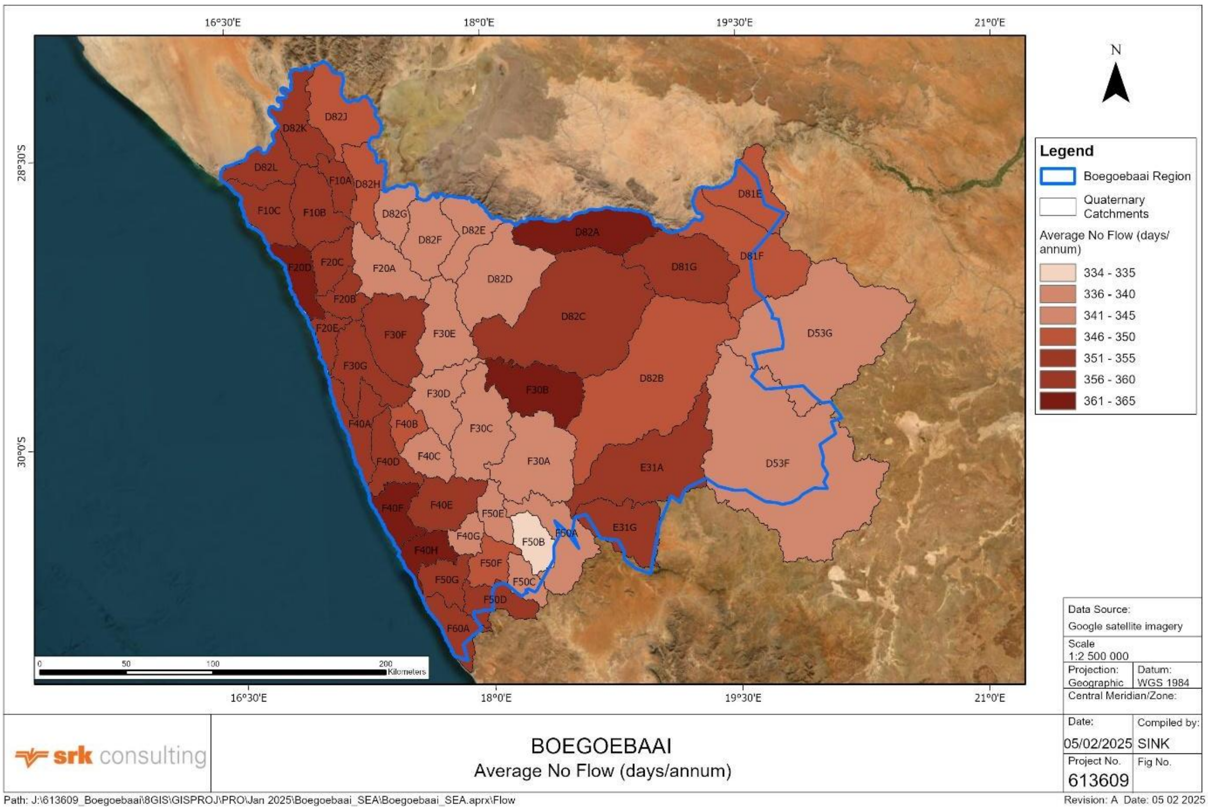

Figure C2.8: Distribution of Average Days of No-Flow (extracted from Schütte, et al. 2023)

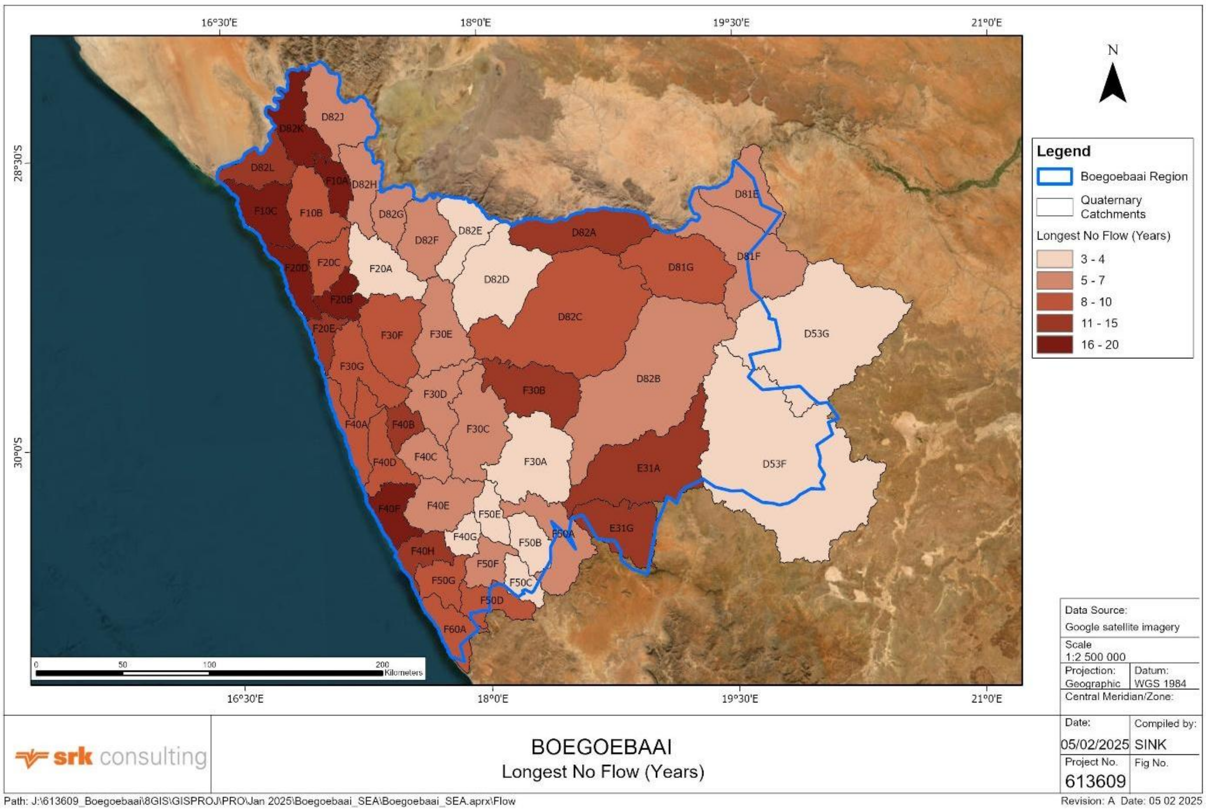

Figure C2.9: Distribution of Maximum Period of No-Flow (from Schütte, et al. 2023)

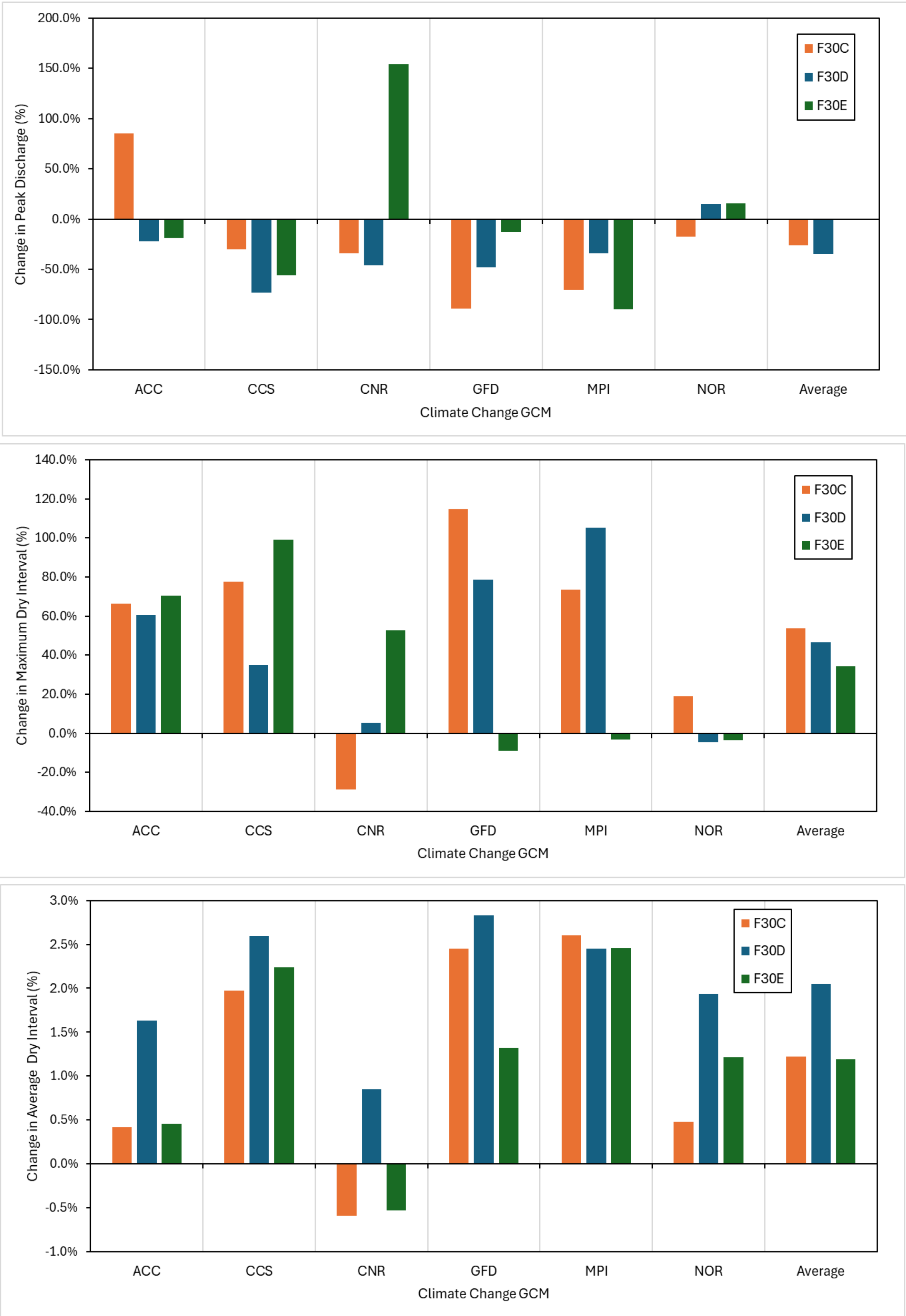

Figure C2.10: Percent Change in Peak Discharge and Dry Periods for Quaternaries F30C, F30D and F30E (6 GCMs, Schutte et al. 2023)

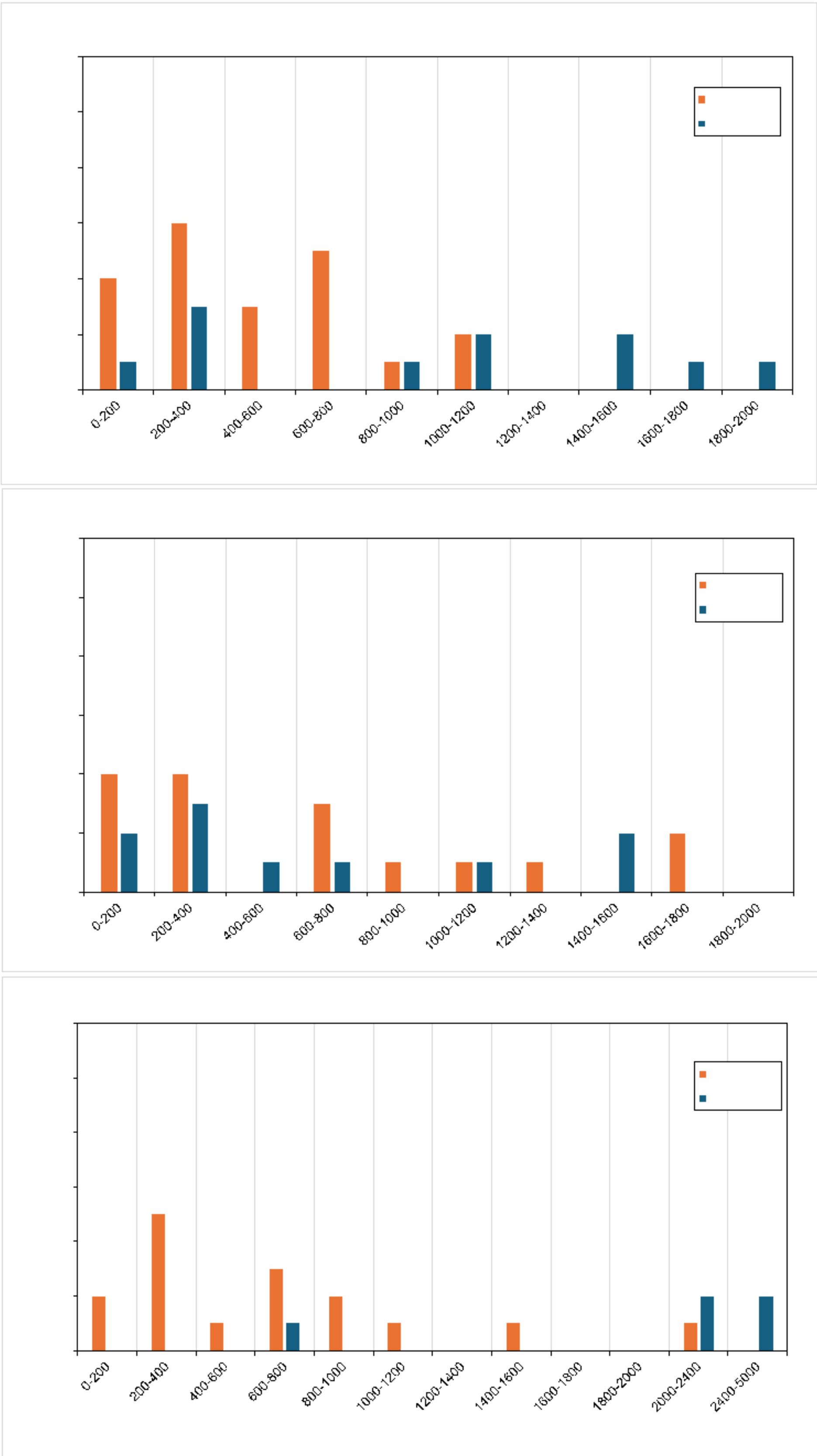

Figure C2.11: Dry period changes from Present to Near Future Climate F30C (3 GCMs)

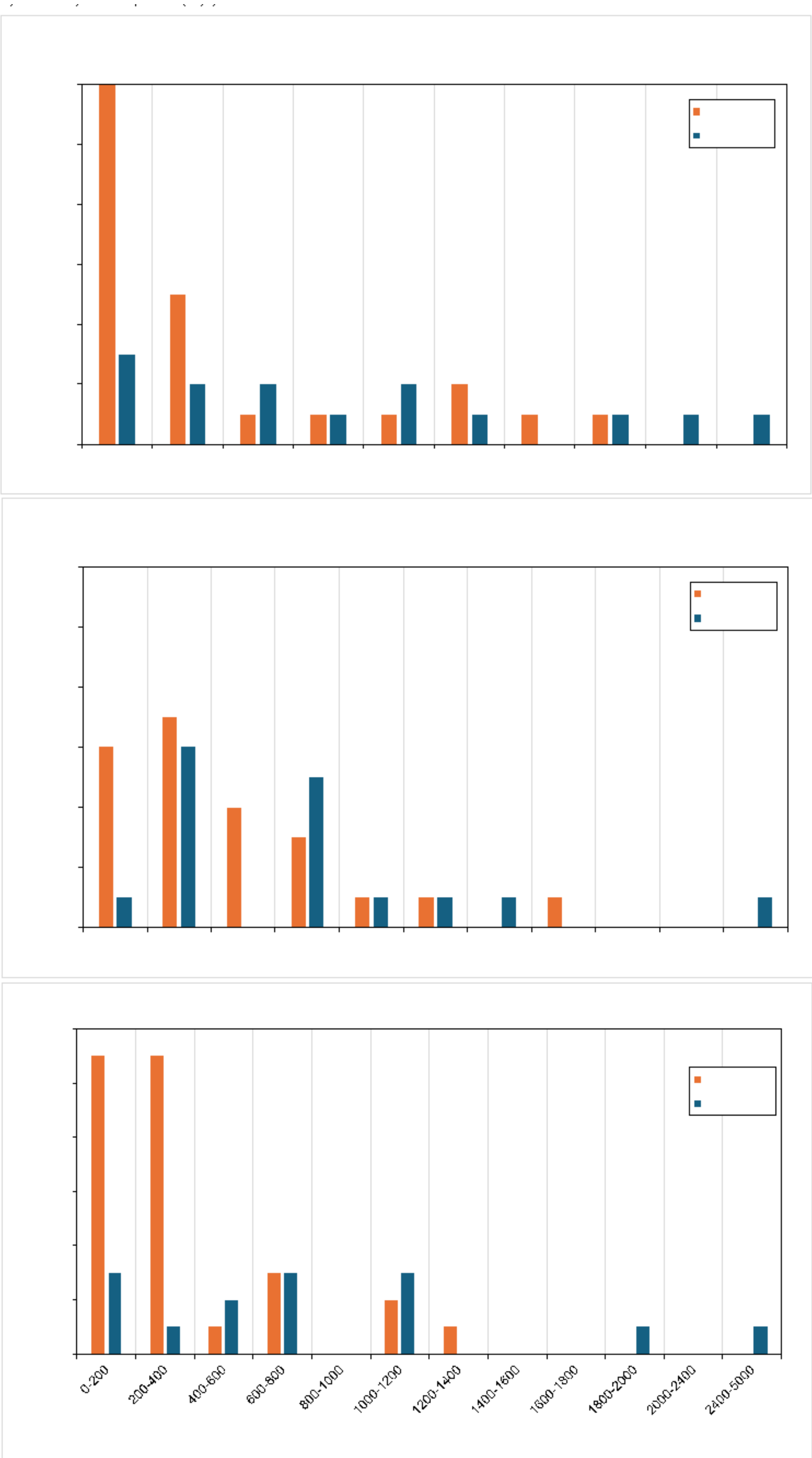

Figure C2.12: Dry period changes from Present to Near Future Climate F30D (3 GCMs)

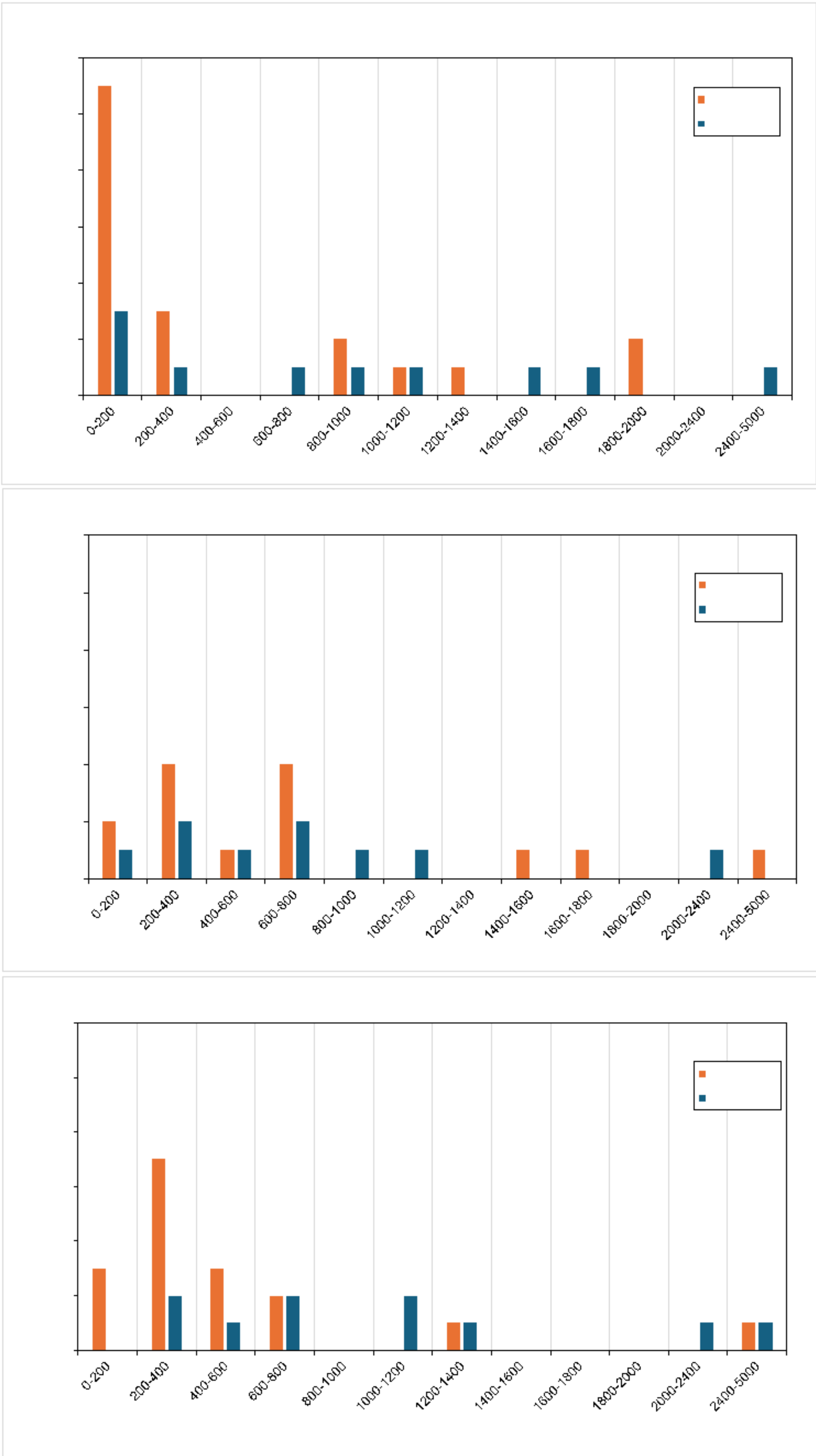

Figure C2.13: Dry period changes from Present to Near Future Climate F30E (3 GCMs)

Appendix C3: Orange River Yield

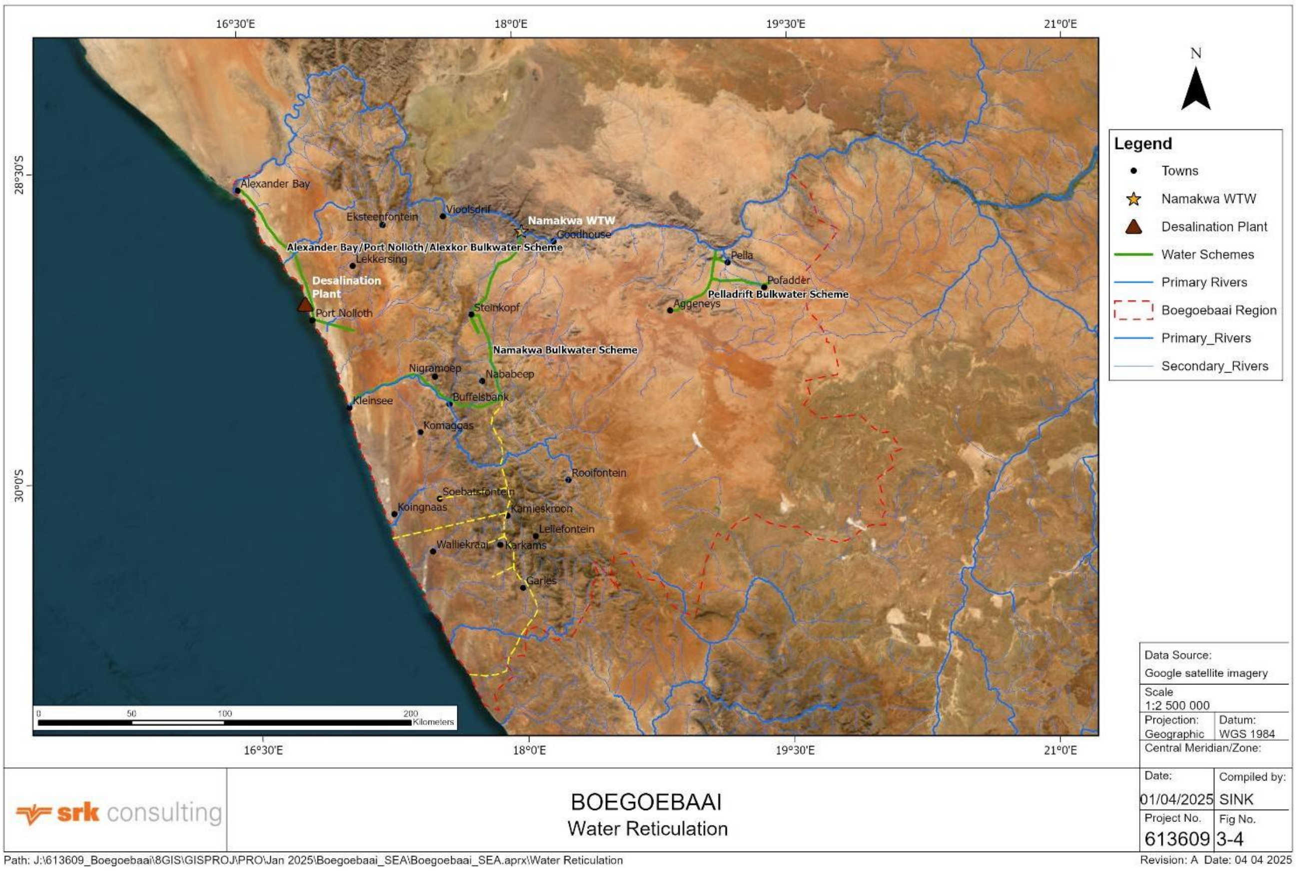

Figure C3.1: Orange River Water Supply Reticulation

APPENDIX D: WATER QUALITY

Table D1

Summary water quality data for DWS monitoring sites along the Orange River, between Onseepkans and Alexander Bay. Data extracted from DWS (2024a)

Site	Location and dataset	Electrical conductivity (mS/m)		Orthophosphate (PO_4-P) (mg P/L)		Total Oxidised Nitrogen (TON) (NO_2+NO_3)-N (mg N/L)		Total ammonia (NH_4-N) (mg N/L)	
		Median	Range	Median	Range	Median	Range	Median	Range
D8H4	Onseepkans 1971-2023	30.9	11.3-106	0.018	0.013-0.592	0.055	0.02-1.24	0.02	0.02-0.52
D8H8	Orange River at Pella Mission 1980-2023	39.7	18.5-75.2	0.02	0-0.62	0.047	0-3.17	0.02	0-1.5
D82 182752	Orange River at Henkries Namaqua Water Board Abstraction 2002-2003 & 2022	36.4	21.9-57.6	0.02	0.012-0.051	0.045	0.02-0.599	0.02	0.02-1.5
D8H3	At Vioolsdrift on Orange River 1965-2023	34.3	19.1-120	0.019	0.003-0.5	0.04	0.005-3.09	0.02	0.015-1.96
D8H7	Orange River at Korridor Brand Kaross 1971-2023	33.4	18.1-88.0	0.013	0.003-0.097	0.04	0.005-2.41	0.025	0.02-0.13
D8H12	Orange River at Alexander Bay at Sir Ernest Oppenheimer Bridge 1995-2011	47.2	23.4-93.9	0.026	0.005-0.422	0.041	0.005-2.13	0.02	0.02-0.545

Table D2

Interpretation of CRR scores, with colour coding as per 2023 Green Drop Report (DWS 2023)

Low	Medium	High	Critical
<50%	50%<70%	70% - <90%	90% - 100%

Table D3

CRR scores for WWTWs in the present study area, colour coded as per Table D2.

Data taken from Green Drop Report (DWS 2023)

WWTW	Municipality	CRR(%)(2011)	(CRR) 2013	(CRR) 2022	(CRR) 2023
Alexander Bay	Richtersveld	47.1	94.1	82.4	100
Port Nolloth	Richtersveld	47.1	94.1	82.4	100
Nababeep	Nama Khoi	82.4	82.4	94.1	88.2
Carolusberg	Nama Khoi	64.7	94.1	88.2	93.3
Springbok	Nama Khoi	64.7	94.1	88.2	93.3
Concordia	Nama Khoi	70.6	82.4	94.1	100
Komaggas	Nama Khoi	82.4	82.4	94.1	93.3
Steinkopf	Nama Khoi	82.4	88.2	82.4	86.7
Bergsig	Nama Khoi	82.4	82.4	94.1	93.3
Okiep	Nama Khoi	92.4	88.2	88.2	93.3
Garies	Kamiesberg	100	100	100	100
Kamieskroon	Kamiesberg	88.2	100	100	100
Pofadder	Khai-Ma	35.3	88.2	88.2	100
Aggeneys	Khai-Ma	0	0	100	100
Onseepkans	Khai-Ma	0	0	100	100
Pella	Khai-Ma	0	0	100	100

APPENDIX E: AQUATIC ECOSYSTEMS

Figure E1: Ecoregional context of the study area, showing main (1:500 000) rivers, mapped estuaries and quaternary catchments within the study area. Ecoregion data from Kleynhans et al. (2005) 35

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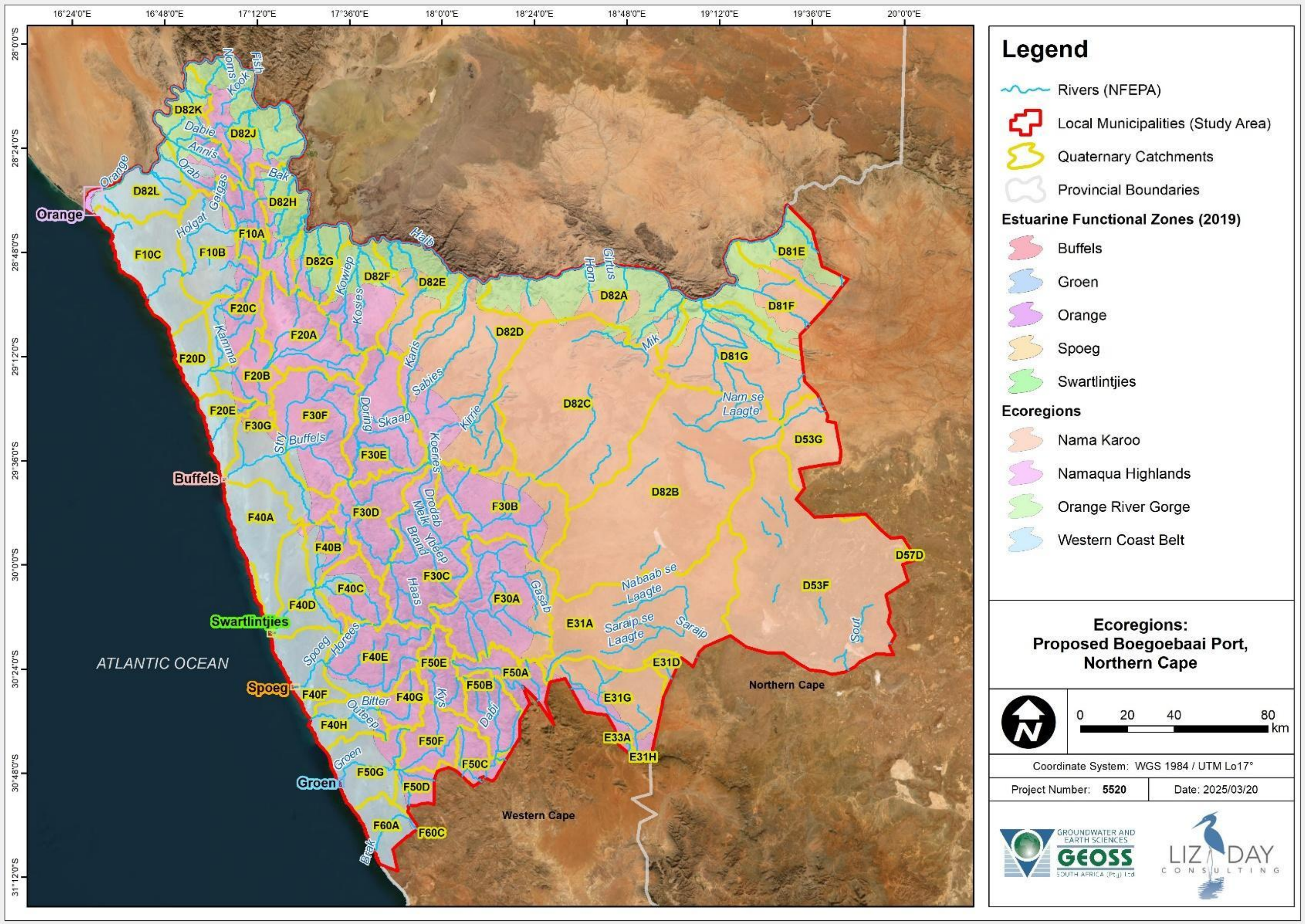

Figure E1: Ecoregional context of the study area, showing main (1:500 000) rivers, mapped estuaries and quaternary catchments within the study area. Ecoregion data from Kleynhans et al. (2005)

E1.1 National Freshwater Ecosystem (NFEPA) Programme Background

The National Freshwater Ecosystem (NFEPA) Programme (Driver *et al.,* 2011) includes rated Freshwater Ecosystem Priority Areas (FEPAs). These are strategic priority subcatchments that are needed for conserving freshwater ecosystems and supporting the sustainable use of water resources (Driver *et al.,* 2011). FEPAs have been determined for different river and wetland types throughout South Africa, on the basis of a number of criteria that included ensuring that there is an adequate extent of conservation of different river and wetland ecosystem types; that they represent sufficient habitats to support threatened fish species and their migration corridors; that free-flowing rivers (i.e. rivers without major dams) are prioritised as FEPAs; that water supply areas in high-water yielding sub-quaternary catchments are maintained; and that ecological connectivity between systems is maintained as far as possible.

FEPAs are often tributaries or rivers that support "hard working" rivers downstream (that is, rivers that are heavily utilised or impacted by agricultural, industrial or other human activities). They need to stay in (or get into) good condition to manage and conserve freshwater ecosystems and to protect downstream water resources for human use. Driver *et al.* (2011) stress however that FEPAs do not necessarily need to be protected from all human use. Rather, they should be supported by good planning, decision-making and management to ensure that human use does not impact on their condition or on the important resources they may protect downstream.

River FEPA ratings are important, because they assign different levels of conservation importance, associated with different requirements for the protection, rehabilitation and/or management of aquatic resources within these sub-catchments.

FEPA ratings include the following categories:

- River FEPA and associated sub-quaternary catchment (FEPA): River FEPAs achieve biodiversity targets for river ecosystems and threatened fish species, and were identified in rivers that are currently in a good condition (A or B ecological category). Their FEPA status indicates that they should remain in a good condition in order to contribute to national biodiversity goals and support sustainable use of water resources;
- Fish sanctuary and associated sub-quaternary catchment (FishFEPA): Fish sanctuaries are rivers that are essential for protecting threatened indigenous freshwater fish. They comprise rivers in a good condition (A or B ecological category) and their whole associated sub-quaternary catchment;
- Fish Support Area and associated sub-quaternary catchment (FishFSA): Fish sanctuaries in lower than an A or B ecological condition are rated as Fish Support Areas – they include sub-quaternary catchments that are important for the migration of threatened fish species;
- Upstream Management Areas: These are sub-quaternary catchments in which human activities need to be managed to prevent degradation of downstream river FEPAs and Fish Support Areas;
- Phase 2 FEPA: Phase 2 FEPAs are rivers that should not be degraded further, as they may in future be considered for rehabilitation once FEPAs in good condition (A or B ecological category) have been fully rehabilitated and are well managed;
- Free-flowing river: Free-flowing rivers are rivers without dams.

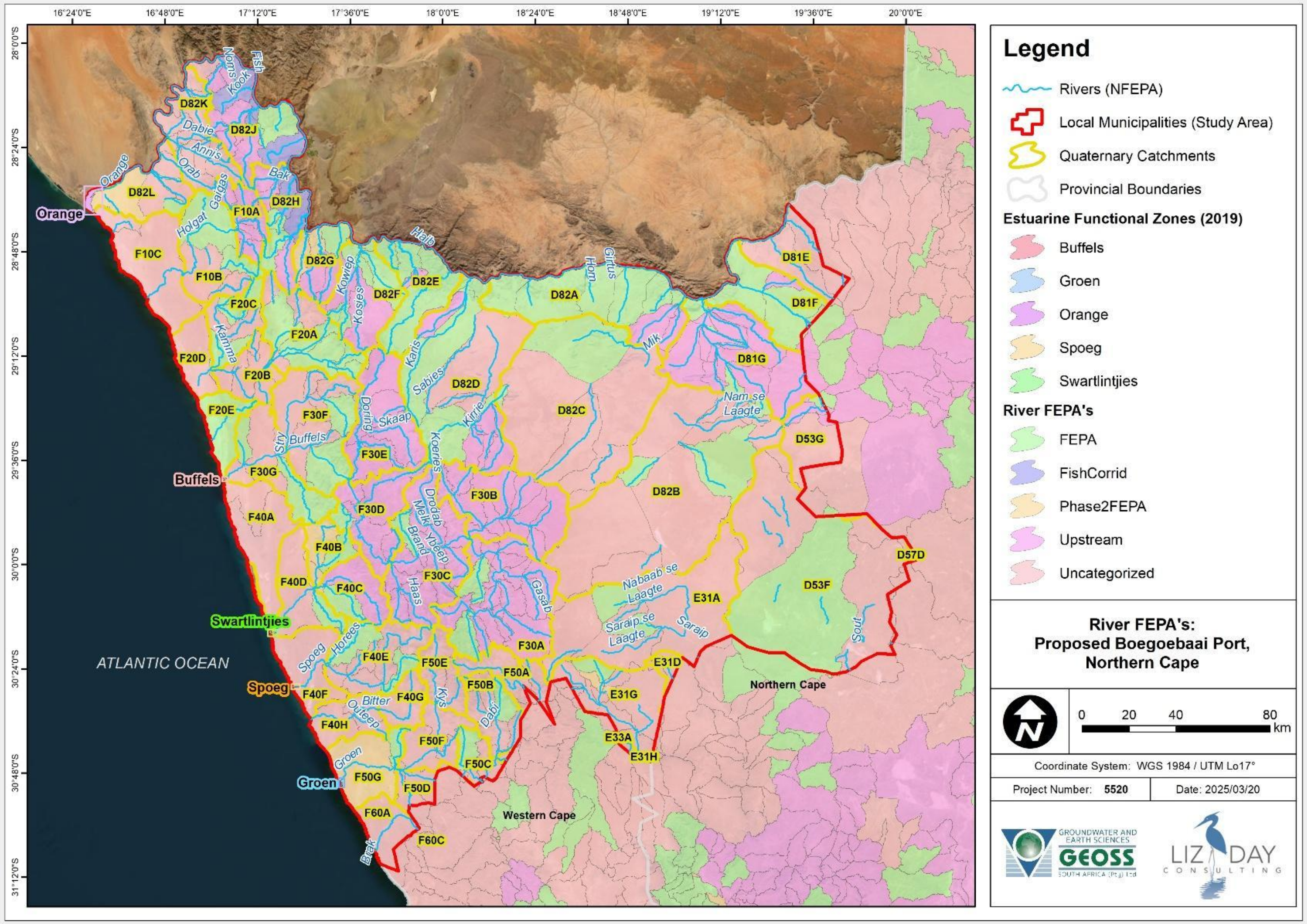

Figure E2: River FEPA context of the study area, showing main (1:500 000) rivers, mapped estuaries and quaternary catchments. FEPA data from Driver *et al.* (2011)

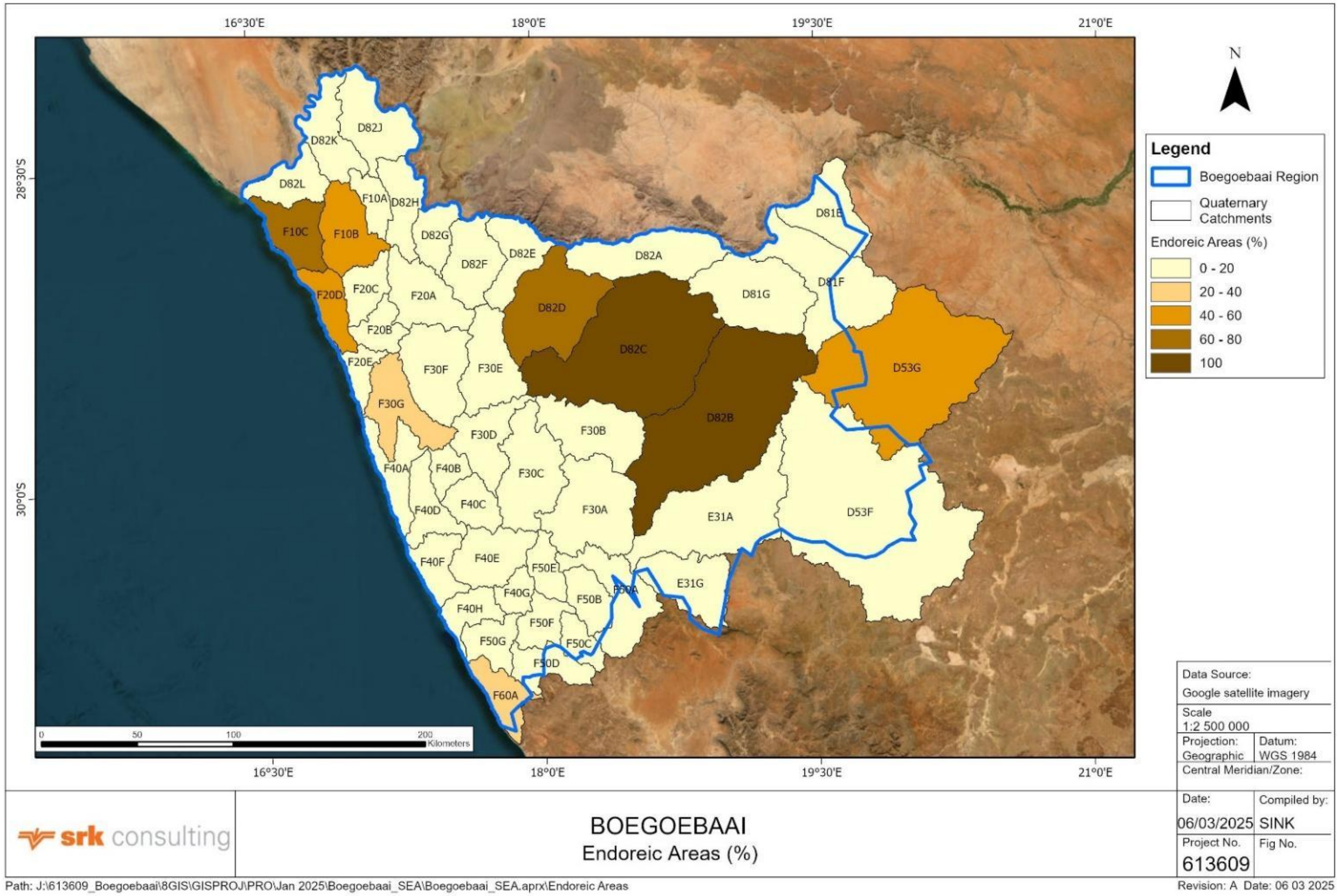

Figure E3: Endoreic Areas in the study area.
Data courtesy SRK Consulting, derived from Schutte et al 2023

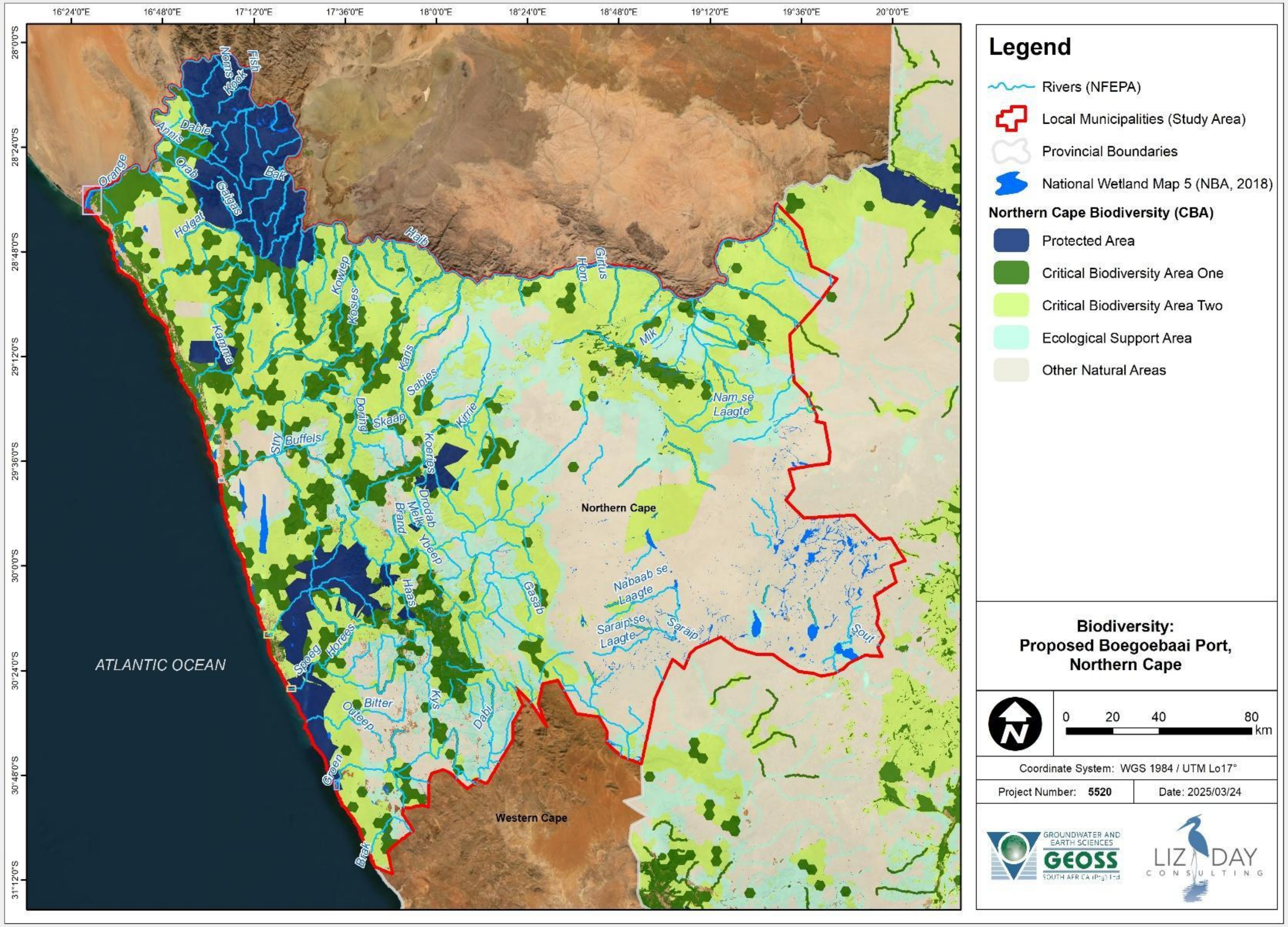

Figure E4: Study area in the context of the Northern Cape Biodiversity Planning dataset (Northern Cape Department of Environment and Nature Conservation 2018) for aquatic and terrestrial ecosystems

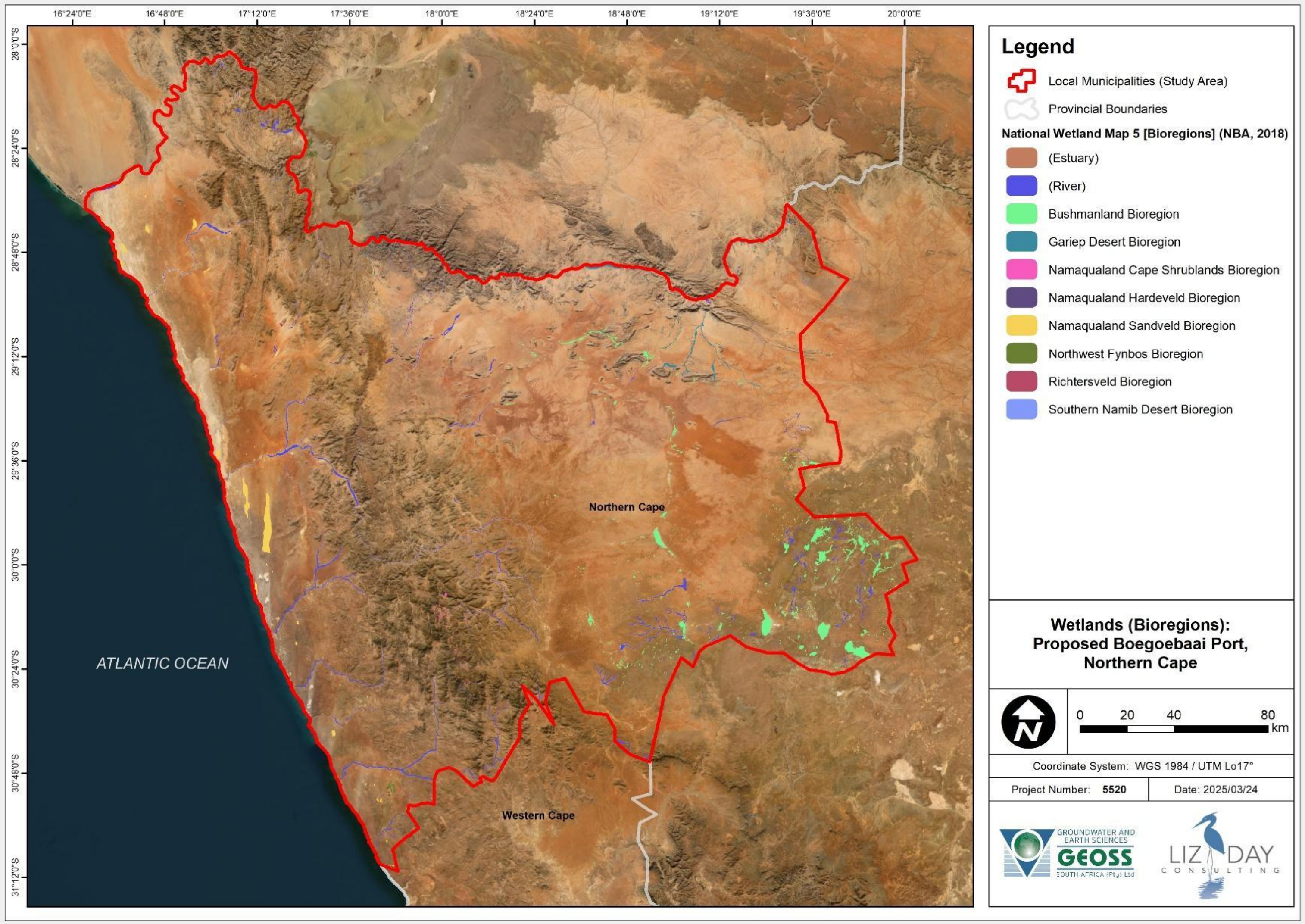

Figure E5: Bioregional context of the study area, showing wetlands from the NWM v5 (NBA 2018) coded in terms of wetland bioregions (zoom for detail).

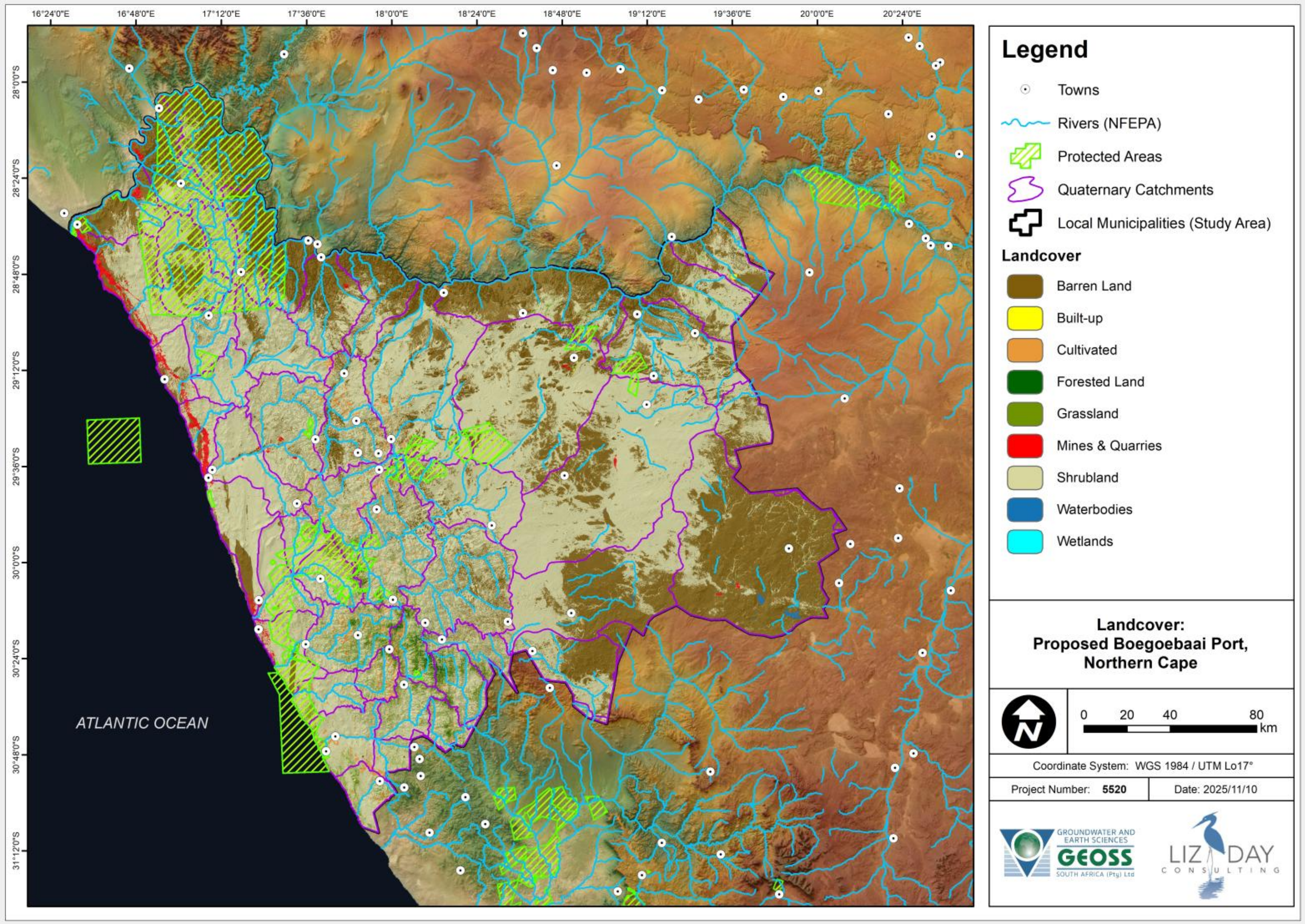

Figure E6: Study area showing protected areas (nature reserves and other conservation areas) and landcover (2022 South Africa Land Cover data)

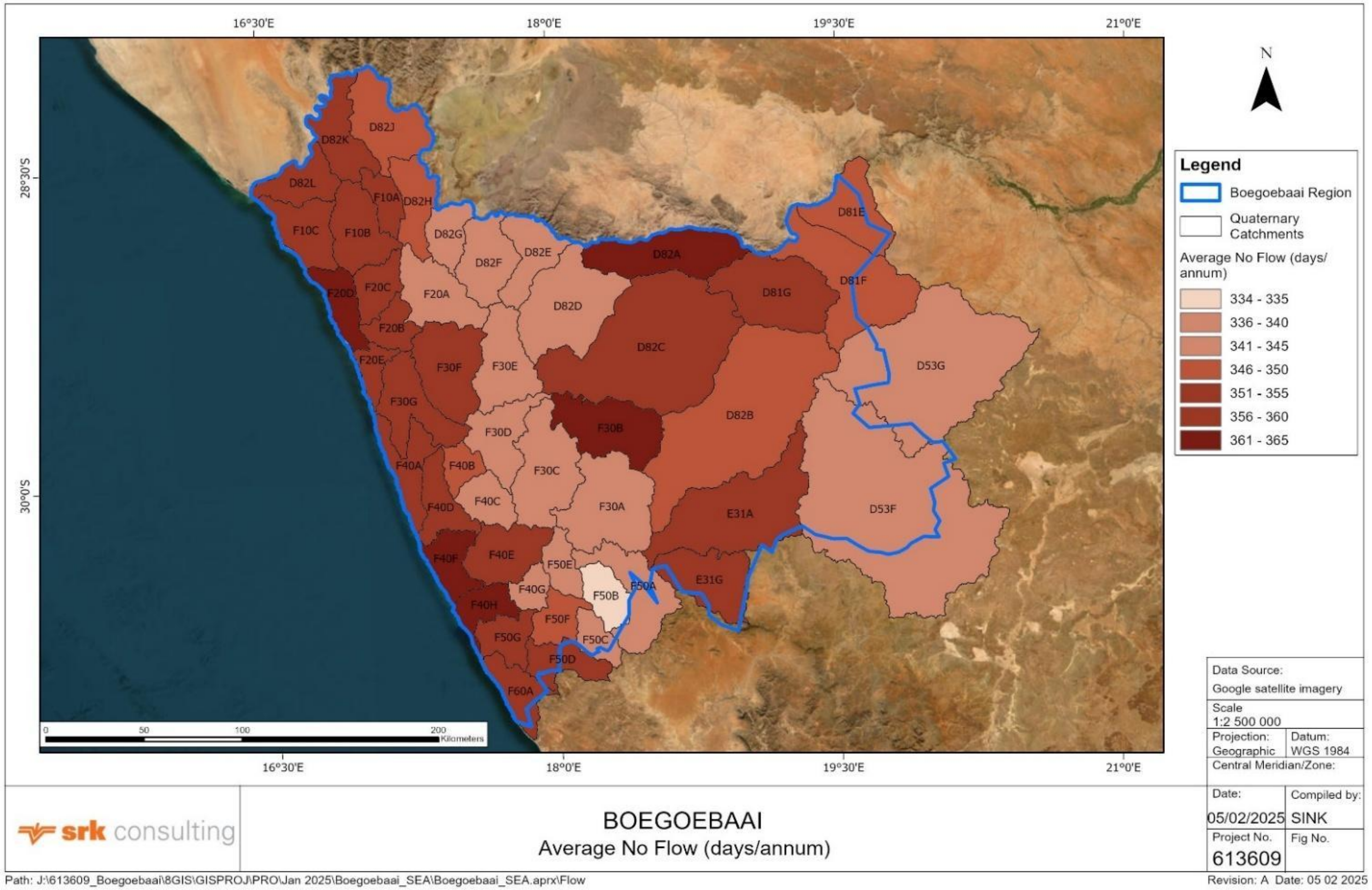

Figure E7: Study area showing modelled average no-flow days per quaternary catchment. Data courtesy SRK Consulting, derived from Schutte *et al.* 2023

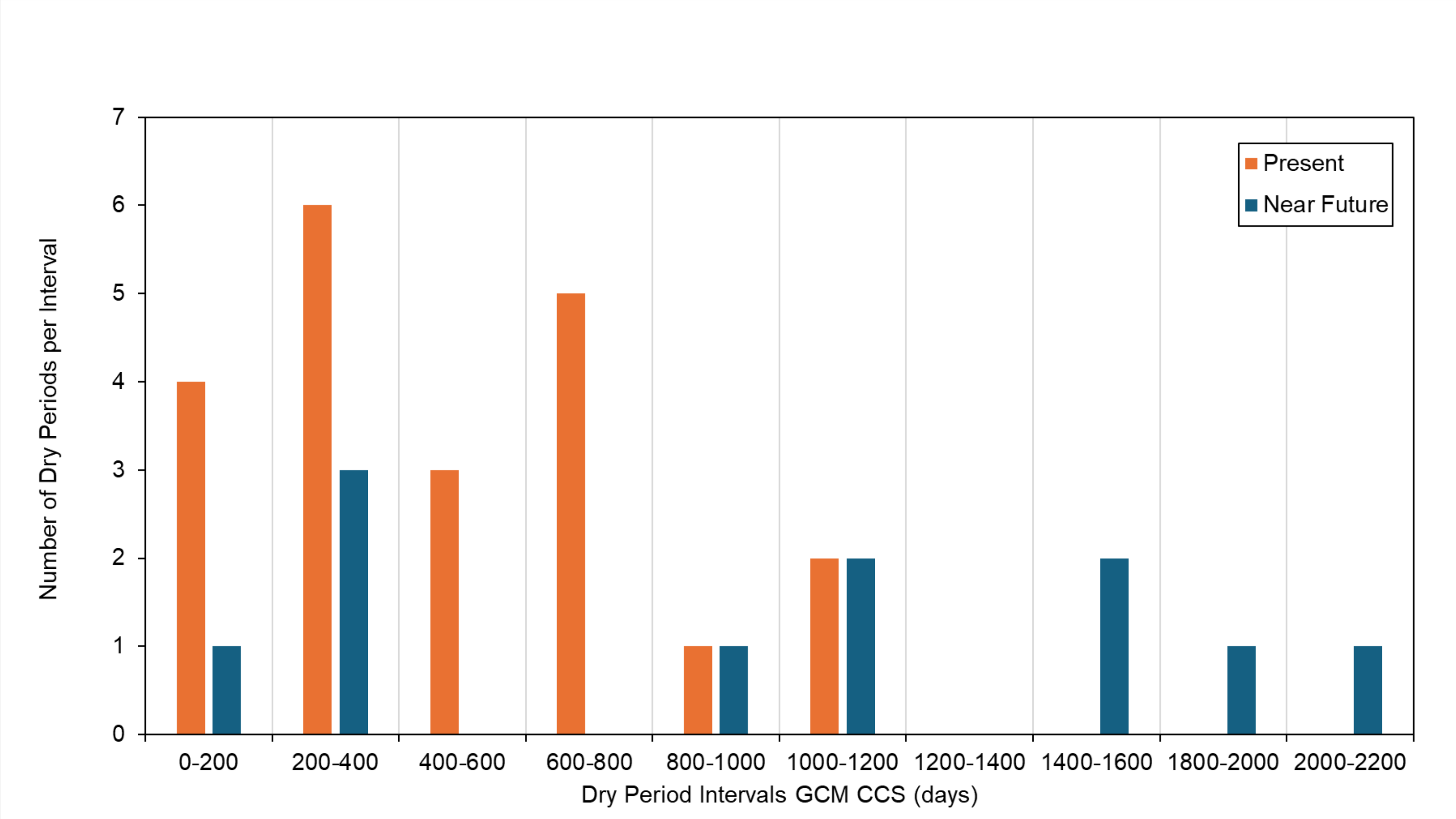

Figure E8: Distribution of dry day intervals for the 30-year Present record versus the 30-year Near-Future record for Quaternaries F30C, F30D and F30E. “Dry” meaning no runoff, and presumably also no significant rain. Data supplied by SRK Consulting

APPENDIX F: SPECIALIST HYDROLOGICAL REPORT

The findings of the attached report have been included in the main body of this chapter.

Boegoebaai Strategic Environmental Assessment WP2 – Surface Water

Report Prepared for

Liz Day Consulting

Report Number 613609

Report Prepared by

April 2025

Boegoebaai Strategic Environmental Assessment WP2 – Surface Water

Report to: Liz Day Consulting

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Executive Summary

Key Systems

The Boegeobaai area is classified mostly as Arid, with 24% of the area classified as Hyper-Arid, resulting in very limited surface water resources in the interior. Most drainage features drain westwards with a few eastward draining channels in the east of the area. However, large areas in the central region are endoreic. Runoff in the drainage network is very scarce, with discharge events only occurring during infrequent heavy rains, and lasting only a few days. Runoff is limited to less than 10% of the time with long dry periods between events. The Orange River bounds the region in the north, flowing westwards to discharge at Alexander Bay. Abstractions from the Orange River sustain much of the communities and industry in the north of the region.

Current Trajectory and Anticipated Scenario 1 and Impacts

The region is predicted to become warmer and drier in the near future, with some 18% of the area likely to change from Arid to Hyper-Arid, offering less opportunities outside the Orange River supply network. Planned augmentation of the Orange River abstraction infrastructure and reticulation is aimed at supplying anticipated needs for GH_2 Scenario 1. However, with the current system consistently yielding less than the design demand, future schemes will require improved operation and maintenance, requiring adequate funding and capacity to operate the scheme. It is also likely that continued and augmented groundwater supply to communities will require desalination planet, also requiring capacity for operating the sophisticated technology.

Main Sensitivities

The current abstractions from the Orange River and reticulation into the interior of the region are ageing and often do not yield their design demand, which continues to increase. Proposed new and augmented abstraction works and reticulated networks, are considered extremely sensitive to poor management and maintenance, since they have been assessed as being the only viable source for sustaining water supply to the region. These systems may be supplemented by coastal desalination works, but there is some concern over the local operators' capacity to cope with the more sophisticated technology.

With the very low occurrence of runoff events and long periods without runoff, all rivers and floodplains are considered fragile to disturbance, being dry most of the time and unable to resist disturbance. It is also considered that river networks would be unable to reconfigure from disturbance within periods of several decades

Key Recommendations

- Provide for Orange River abstractions and reticulation to the level of Scenario 1 demand, while providing for adequate operation and maintenance of the abstraction, treatment, reticulation and storage works.

- Provide for expertise to operate desalination plants at proposed coastal locations.

- Prevent all disturbances to river systems and floodplains, particularly at infrastructure crossings. Prevent any encroachment of structures or dwellings into the floodplain.

Disclaimer

The opinions expressed in this Report have been based on the information accessed by SRK Consulting (South Africa) (Pty) Ltd (SRK) by sources as specified. The opinions in this Report are provided in response to a specific request from Liz Day Consulting to do so. SRK has exercised all due care in reviewing the supplied information. Whilst SRK has compared key supplied data with expected values, the accuracy of the results and conclusions from the review are entirely reliant on the accuracy and completeness of the supplied data. SRK does not accept responsibility for any errors or omissions in the supplied information and does not accept any consequential liability arising from commercial decisions or actions resulting from them. Opinions presented in this report apply to the site conditions and features as they existed at the time of SRK's investigations, and those reasonably foreseeable. These opinions do not necessarily apply to conditions and features that may arise after the date of this Report, about which SRK had no prior knowledge nor had the opportunity to evaluate.

List of Abbreviations

DWAF	Department of Water Affairs and Forestry
DWS	Department of Water and Sanitation
EC	electrical conductivity
ha	hectares
L/p/day	litres per person per day
m	metres
m^3	cubic metres
Mm^3	million cubic metres
mamsl	metres above mean sea level
MAP	mean annual precipitation
MAPE	mean annual potential evapotranspiration
mm/a	millimetres per annum
WR2012	Water Resources of South Africa, 2012 edition

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1: Introduction and Scope of Report

Liz Day Consulting (Pty) Ltd ("LDC") has been appointed by the CSIR to oversee and integrate the Water Resources and Aquatic Ecology Study for Work Package 2 of the above SEA. The study is aimed at assessing the state of resources in the region affected by the development of Green Hydrogen production in the area. The study is carried out as a collaborative project, working with surface and groundwater specialists as well as other aquatic ecology specialists, as necessary.

SRK Consulting SA (Pty) Ltd (SRK) were awarded the Surface Water study and this report presents the outcomes of the analyses, sensitivity determinations, risks and remediations for three scenarios related to Green Hydrogen development in the study region.

The work was intended as a desktop study, using available publications and data.

2: Major Water Resources Drivers

2.1 Climate

2.1.1 Rainfall

The rainfall in the study area is the lowest in the country, with Mean Annual Precipitation (MAP) varying from 60mm to 215mm as illustrated in Figure 2-1. Lowest rainfall areas include the north-east coastal region and along the Orange River. Rainfall increases towards the southern interior of the region, with highest values in the Kamiesberg mountains. Along the coastline, frequent fog occurs during winter due to the cold Benguela current, contributing to moisture levels.

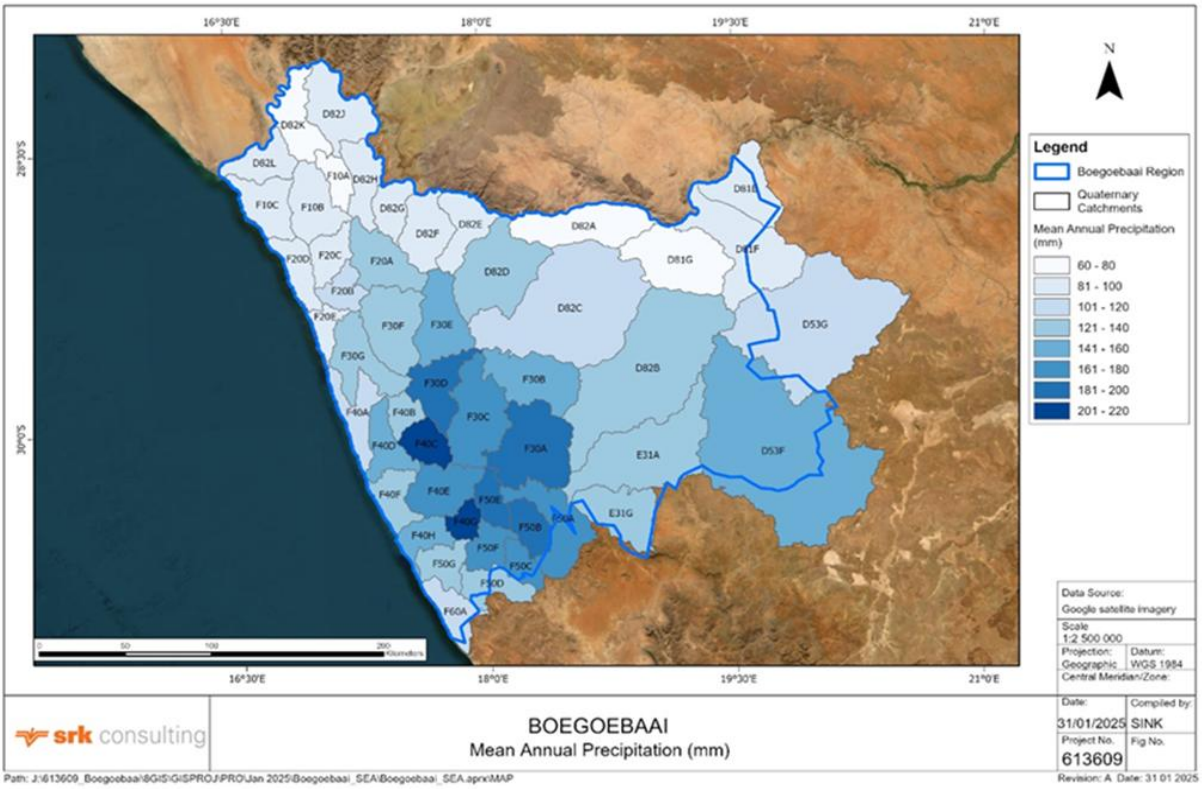

Figure 2-1: Distribution of the mean annual rainfall in the study area.

However, mean annual values are extremely deceptive, since the distribution of rainfall events is large, with some areas experiencing no rain for periods of years and rainfall often occurring in extreme events. This is reflected in the runoff analysis and particularly the number of dry days between runoff events.

> Mean Annual Precipitation is predicted to decrease by 12% in the Near Future (2050). This result is derived from the average of six GCMs applied to the study area. The maximum change GCM predicts a 24% decrease and the minimum a 5% increase.
>
> The distribution of estimated Near Future changes in MAP is illustrated for the Average of 6 GCMs in Appendix A

2.1.2 Temperature

The region has warm summers, with temperatures averaging around 30°C and occasionally peaking at 40°C, while winters are cooler, with daily averages ranging from 8 to 17°C. Observed average daily temperatures for Springbok are shown in Figure 2-2.

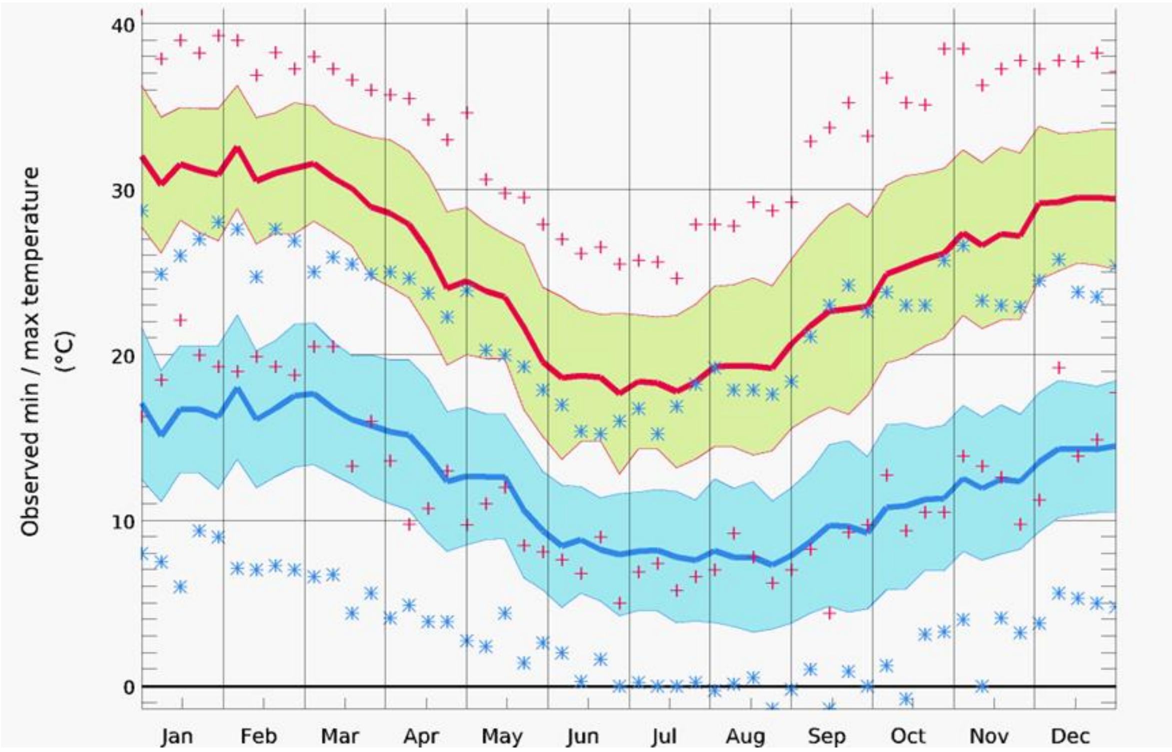

Figure 2-2: Mean daily maximum and minimum temperatures at Springbok.

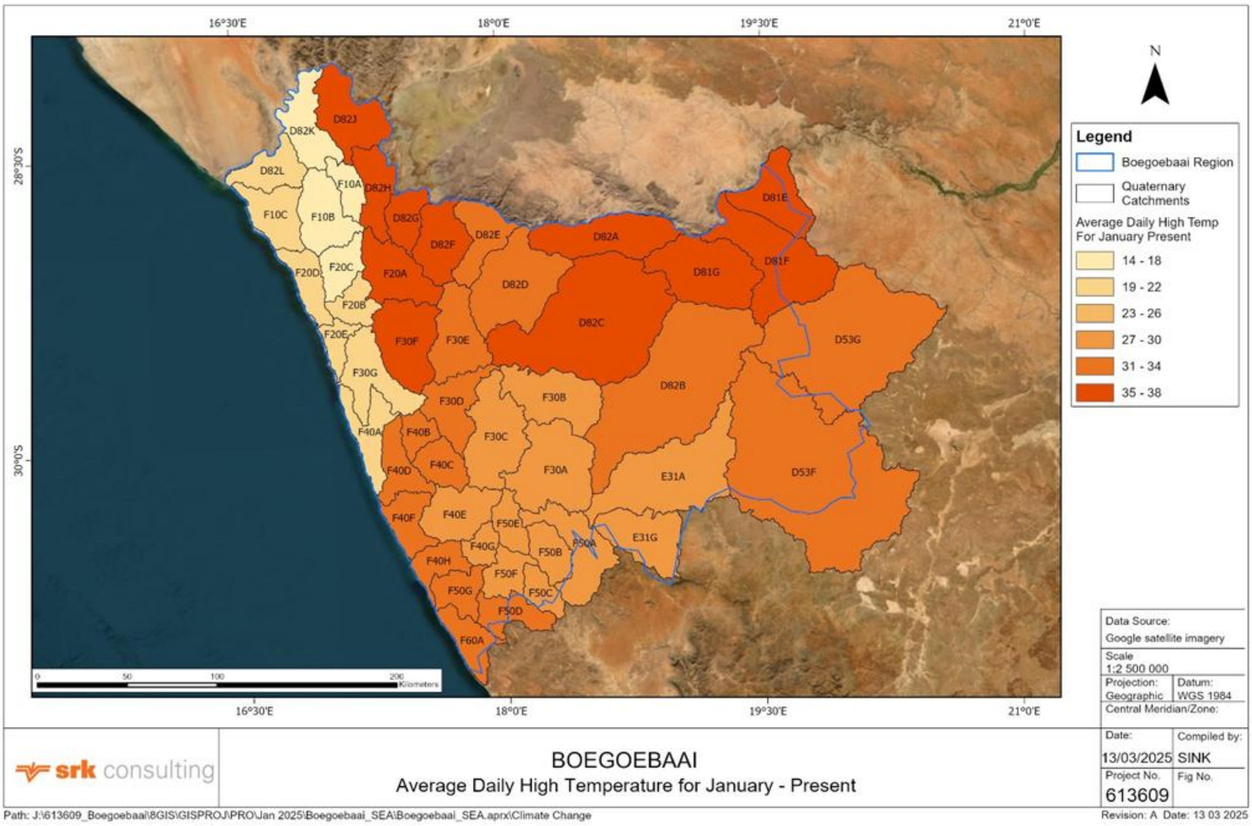

Figure 2-3: Distribution of average Temperatures for January.

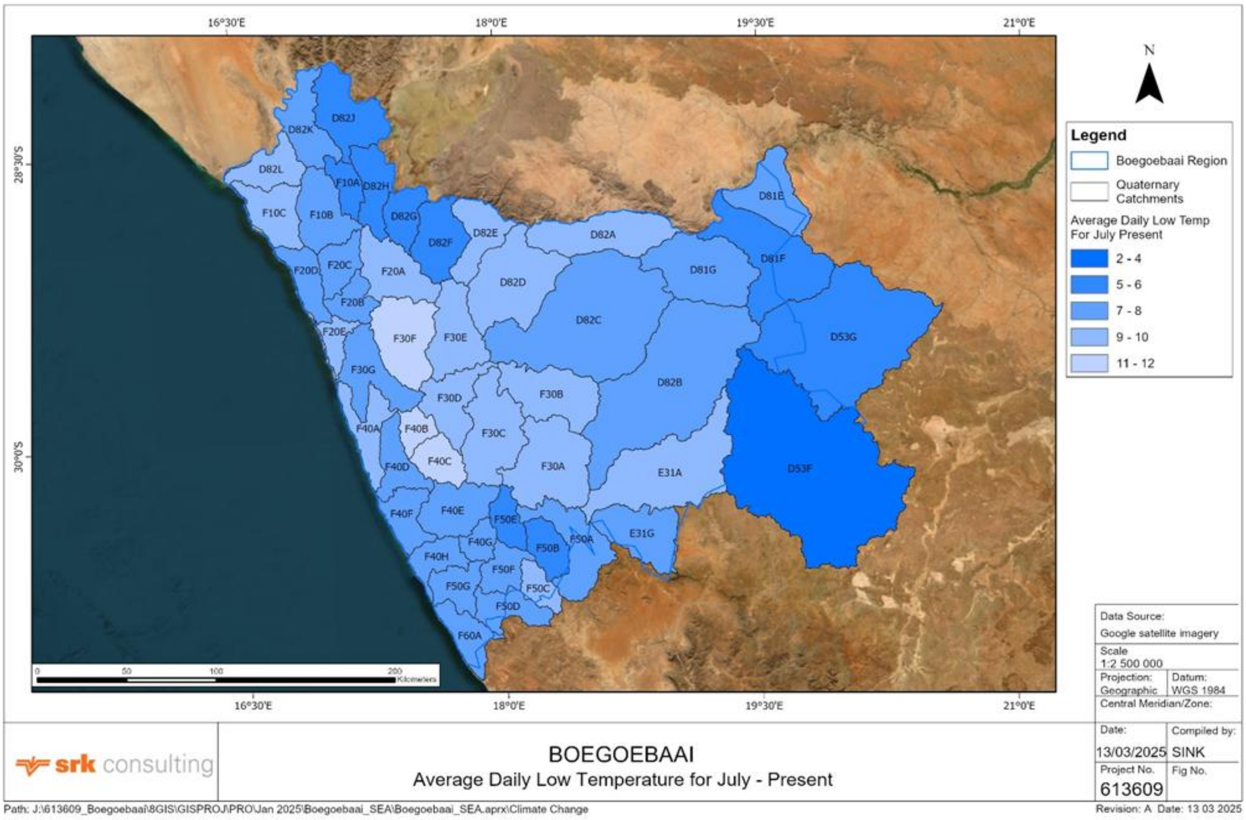

Figure 2-4: Distribution of Average Temperatures for July.

2.1.3 Mean Annual Potential Evaporation

The Mean Annual Potential Evaporation (MAPE) ranges between 611mm and 2 680 mm (Figure 2-2) and exceeds the MAP by between 8 to 44 times. Evaporation rates are lowest in the northwest coastal areas of the region and increase towards the east and south.

The Aridity Index, defined as the ratio MAPE/MAP, is greater than 20 over 24% of the quaternary catchments, classifying these as Hyper-Arid (Gunkel and Lange, 2017). The remainder are all classified as Arid, being less than 20, while 12% of the quaternaries have an Aridity Index less than 10. However, none of the quaternary catchments have an Aridity Index less than 5, which might classify these as Semi-Arid.

Mean Annual Potential Evaporation is predicted to increase by 7% in the Near Future (2050). This result is derived from the average of six GCMs applied to the study area. (WRC, 2023). With the predicted changes in MAP and MAPE, in the Near Future, some 18% of the quaternary catchments are likely to change from Arid to Hyper-Arid. (estimated from Schutte et al., 2024; Gunkel and Lange, 2017)

The distribution of estimated Near Future changes in MAE is illustrated for the Average of GCMs in Appendix A. The Present and Near-Future distributions of Aridity Index are also presented in Appendix A.

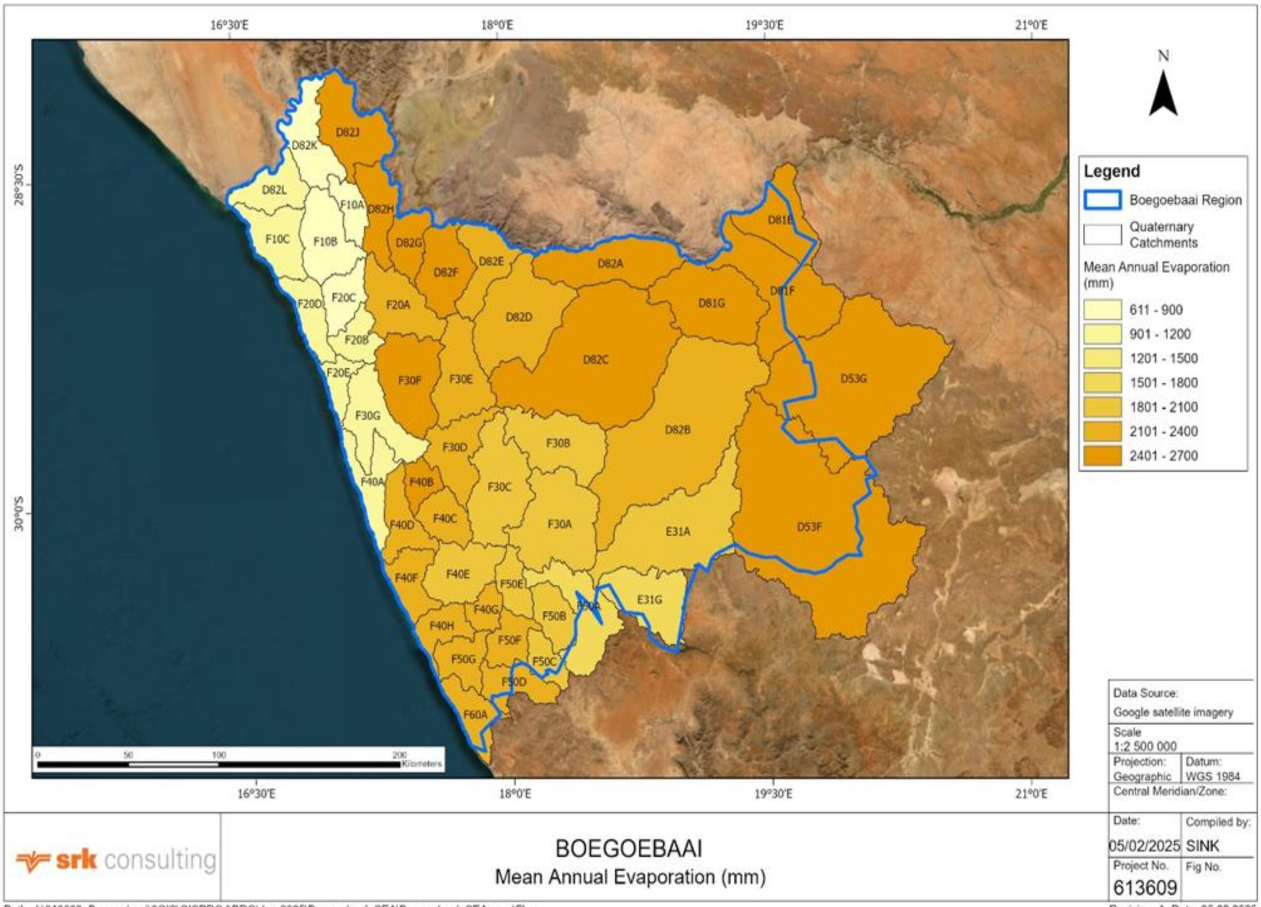

Figure 2-5: Distribution of Mean Annual Potential Evaporation.

2.1.4 Geology and Soils

Geology and Soils are described in the Groundwater section.

2.1.5 Land Use

The Land Cover 2022 is shown in Figure 2-6, while the number of small dams per quaternary are shown in in Figure 2-7.

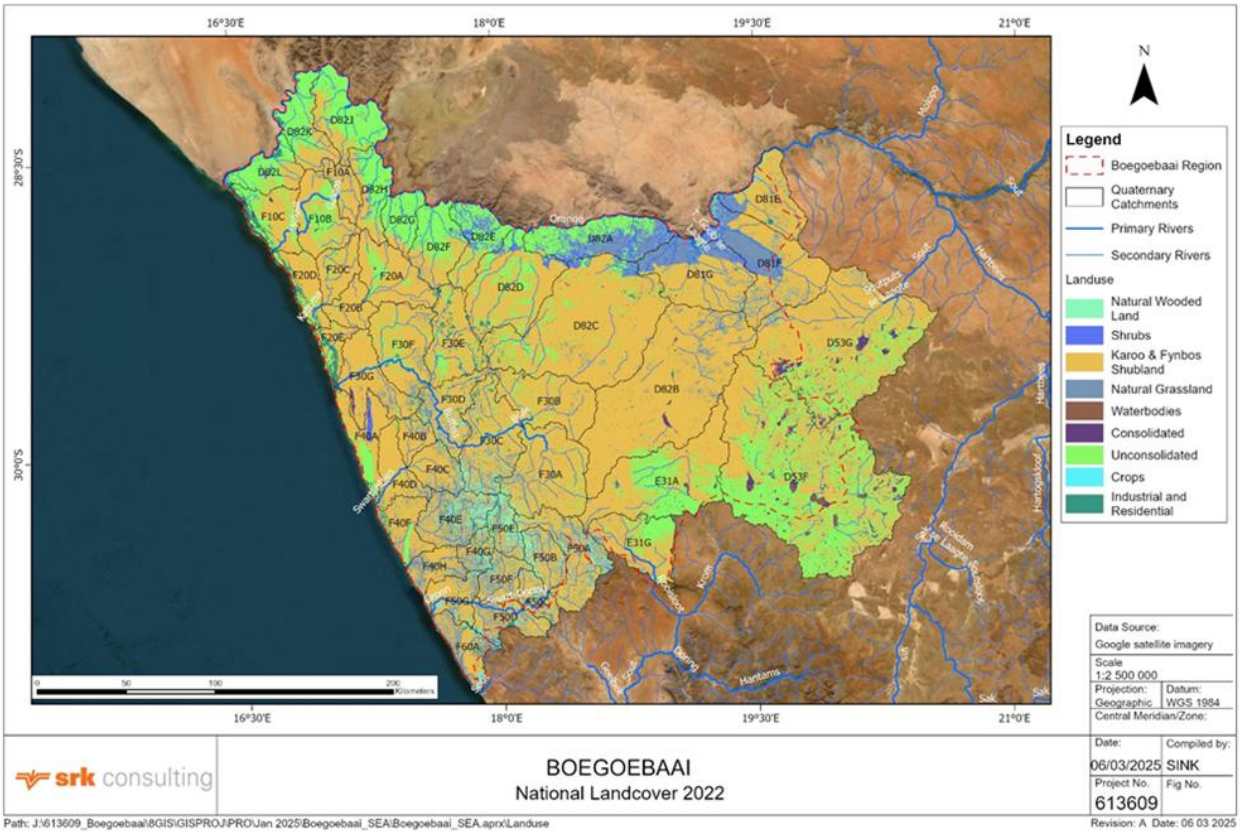

Figure 2-6: Distribution of Land-Use in the study area (SA Land-Use, 2022).

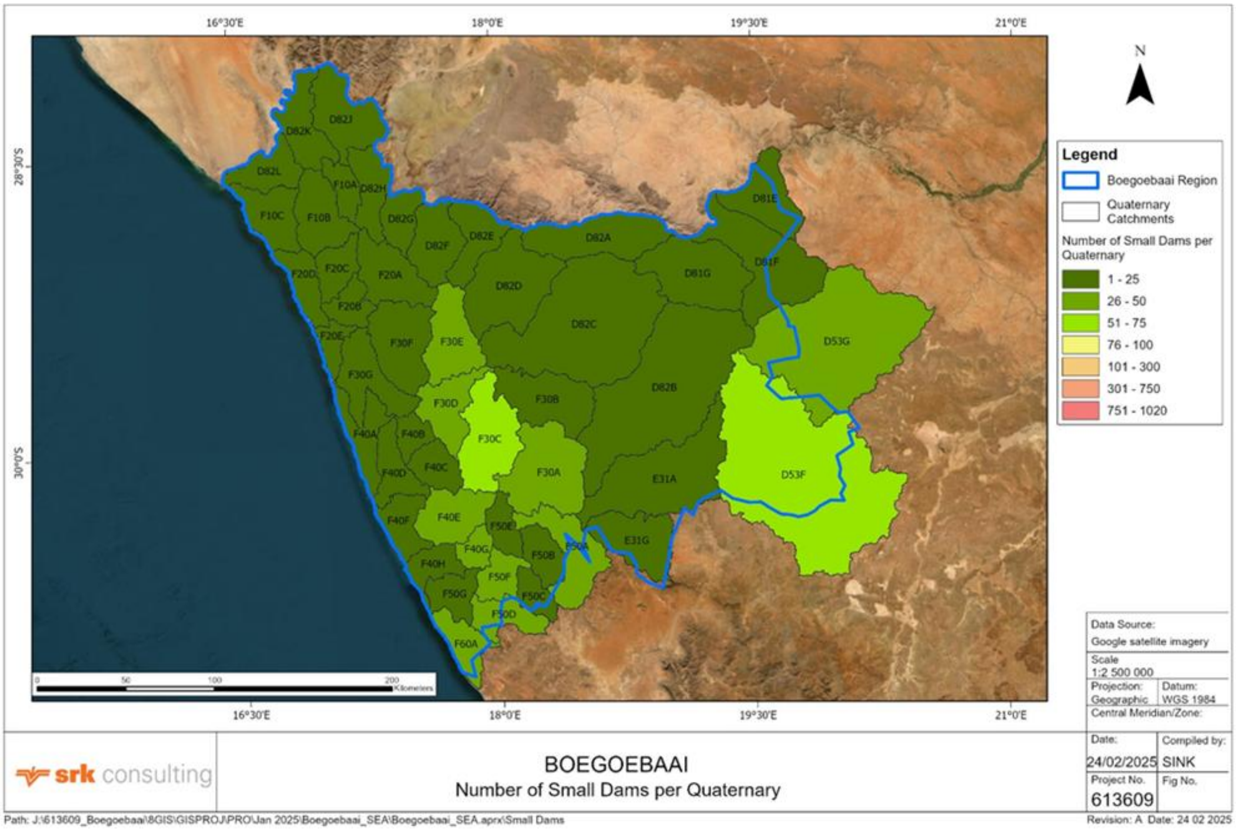

Figure 2-7: Distribution of the number of small dams per quaternary.

3: Surface Water Resources

3.1 Catchment Context – Major Rivers, Quaternaries

Major rivers and quaternary catchments are illustrated in Figure 3-1.

3.2 Surface Water Hydrology

The entire study area is classified as either Hyper-Arid or Arid, with no Semi-Arid catchments. The surface water resources are therefore very limited, with ephemeral streams and sporadic runoff events, mostly lasting for only a few days, with long dry periods in between events. The surface water runoff has been assessed on a Quaternary catchment basis.

3.3 Quaternary Runoff

Endoreic Areas

Two large Quaternary catchments (D82B and D82C) are completely endoreic as illustrated in Figure 3-2. This means that no surface runoff or stream discharge leaves these catchments, and all internal surface runoff terminates in internal pans or groundwater recharge zones. A few other Quaternaries have a portion of their area defined as endoreic, but otherwise most have drainage features that leave the Quaternary (Figure 3-2).

Figure 3-1: Quaternary catchments and river drainage in the study area.

The Mean Annual Runoff (MAR) for the Quaternary catchments in the study area have been estimated in WR2012, (Herold and Bailey, 2016). These estimates reveal mean annual quaternary runoff varying from a minimum of 0 (completely endoreic) to a maximum of 1.24% of the average annual rainfall, with the average of all Quaternaries without endoreic areas reporting MAR of 0.57% of MAP. However, average annual estimates of runoff are misleading in areas with such sporadic runoff regimes. An effort was therefore made to estimate the distribution and magnitude of runoff events and dry periods between these.

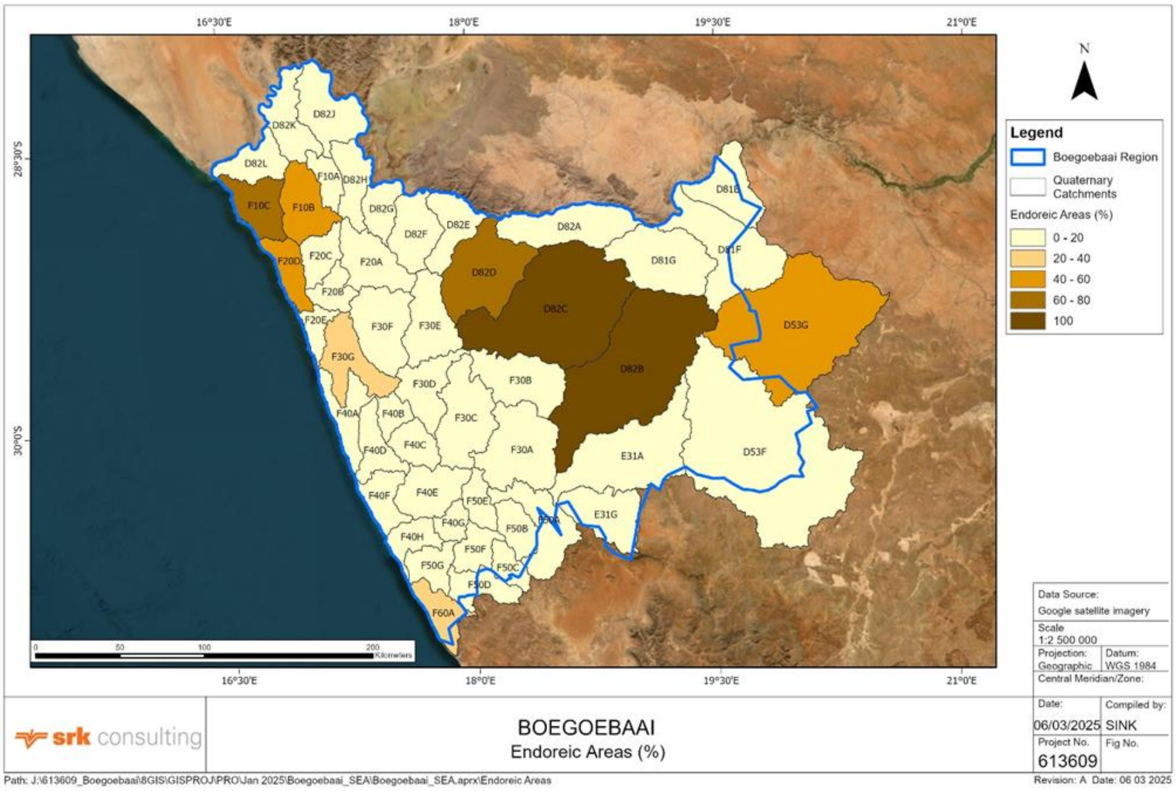

Figure 3-2: Distribution of endoreic areas (Mantel and Hughes, 2023).

Simulations of the quinary catchments making up the quaternaries in the study area had been modelled using the ACRU agro-hydrological model, with daily meteorological inputs (Schütte *et al.,* 2023). These simulations were calibrated using observed daily runoff data from two stations, F5H001 and F5H002 as well as a daily runoff record derived from a study on the Buffels river (Benito *et al*., 2011). The stations and contributing catchments are illustrated in Appendix B, Figure B-2.

The simulated and observed flow regimes for the Buffels river catchment indicate the sporadic nature of runoff, with all discharge events occurring over less than 10% of the time (Figure 3-3).

The simulated runoff for all quaternaries resulted in similar flow regimes and very low annual runoff. The MAR is predominantly less than 2 mm per annum, with lowest MAR along the coast, increasing towards the east, particularly in the high lying interior, decreasing again, eastwards on the leeward side of the mountains and finally increasing again in the far east of the region and far north along the Orange River (Figure B-3). The Quaternary MARs are generally less than 1% of the MAP, except in the far east and north, where the Quaternary MARs are some 2% of MAP (Figure B-4).

Mean Annual Runoff is predicted to decrease by 20-40% over most of the region in the Near Future (2050). A few Quaternaries in the coastal north and in the far east of the region are predicted to increase (up to 20%) in the Near Future. (Figure B-5). This result is derived from the average of six GCMs applied to the study area. (Schütte, *et al.*, 2023). The highest of the GCMs predicts mostly increasing MAR, while the lowest GCM predicts decreasing MAR everywhere (Figures B-6 and B-7).

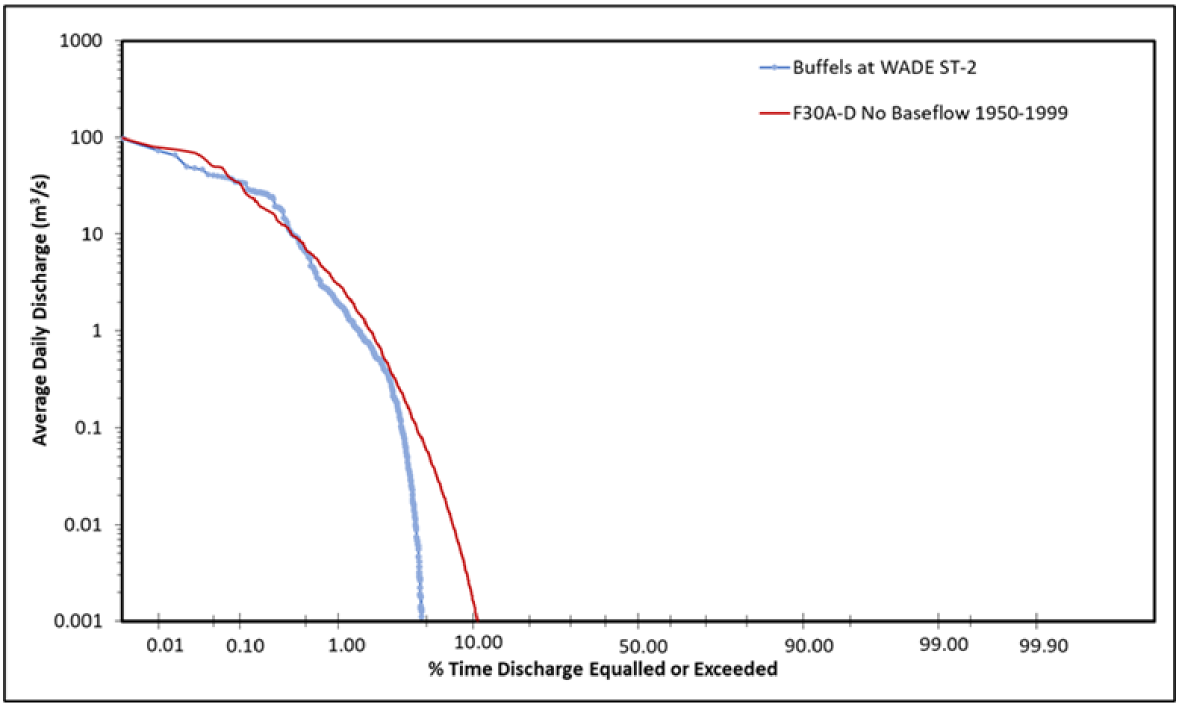

Figure 3-3: Comparison of simulated and observed flow regimes for the Buffels river WADE station 2 (Figure B-2).

Long periods without any flow occurring (No-Flow periods) are particularly prevalent throughout the region. The average duration of No-Flow periods ranges from 334 to 365 days, (Figure B-7), while the longest period of No-Flow in the 50-year simulated record, ranges from 3 to 7 years over most of the region, with maximum No-Flow durations reaching 16 years in the north coastal region (Figure B-8).

No-Flow periods are predicted to decrease in number but increase in duration in the Near Future (2050). (Figures B9 to Figure B-11).

3.4 Orange River Yield

The Mean Annual Runoff in the Orange River, without abstractions, has been simulated as 24 400 Mm³/annum (Schutte *et al.*, 2023). The current Urban, Industrial and Mining abstractions from the Orange River, overall are estimated to be 360 Mm³/annum, while future abstractions (2040) could reach 479 Mm³/annum (DWS 2012). Average annual river losses from the Vanderkloof dam to the mouth are estimated at 615 Mm³/annum.

3.5 Water Yield/Demand

The Water Yield is provided by abstraction schemes as illustrated in Figure 3-4.

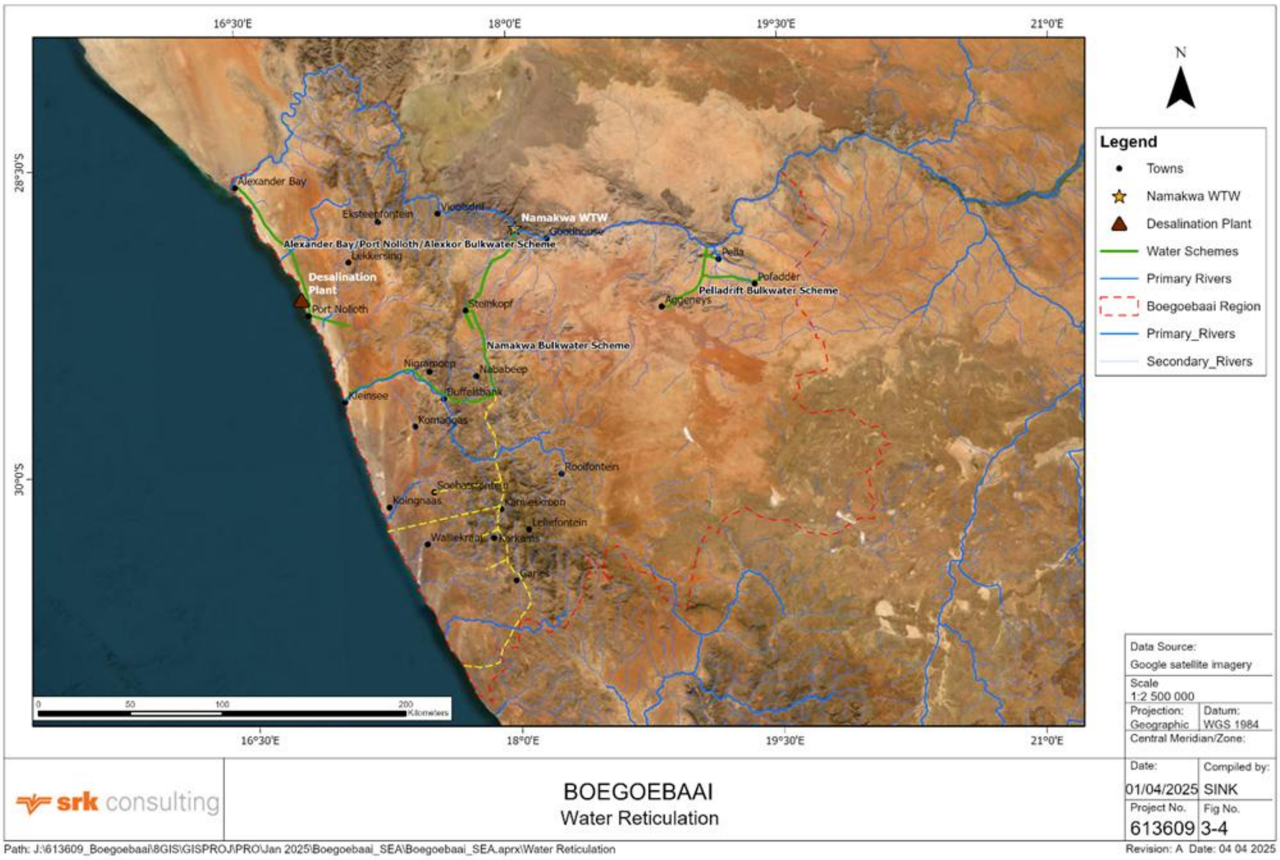

Figure 3-4: Water supply reticulation from the Orange River and desalination plants.

4: Surface Water Sensitivity Classification

Surface water sensitivity has been assessed for linear and distributed criteria. Linear features subject to impact are the drainage network (river system) and the Orange River abstraction and reticulation network. Distributed features include aridity levels and the density of farm dams.

4.1 Stream Networks

Although surface water discharge only occurs occasionally in the drainage network, the responses are generally brief and can be intense, when they do occur. The drainage networks are particularly sensitive to disturbance (road crossings, bridges, encroachment into the flood plain) and the alluvial flood plains are critical for groundwater recharge, which occurs mainly during flood events.

Disturbances and restrictions in the stream network could give rise to extensive upstream flooding and, if breaches occur, downstream damage. Restrictions in the streams could also give rise to increased velocities and scour damage to stream banks and bed. Where riverbeds comprise mostly sands and floodplains mostly silts, disturbances are likely to cause significant changes in sediment transport and scour.

With the very low occurrence of runoff events and long periods without runoff, all rivers and floodplains are considered fragile to disturbance, being dry most of the time and unable to resist disturbance. It is also considered that river networks would be unable to reconfigure from disturbance within periods of several decades (Fryirs, 2017).

4.2 Water Supply Reticulation

The extensive use of groundwater in the area has stretched the resource to a limit and further groundwater exploitation in the region is limited. The current abstractions from the Orange River and reticulation into the interior of the region are also ageing and often do not yield their design demand, which continues to increase (DWS 2012; BVI, 2023a). These abstraction works and reticulated networks, including planned extensions and improvements are considered extremely sensitive, since they have been assessed as being the only viable source for sustaining water supply to the region.

These systems may be supplemented by coastal desalination works, but there is some concern over the local operators' capacity to cope with the more sophisticated technology.

4.3 Aridity

All quaternary catchments in the study area are categorised as either arid or hyper-arid. It is considered that hyper-arid areas would be insensitive to water supply impacts as the yield is negligible. These areas are considered unsuitable for crops or grazing. In arid regions, some grazing systems may be supported, but co crops would be viable without irrigation. Aridity indices (defined as the ratio between average annual evapotranspiration to precipitation) above 20 are classed as hyper-arid and those between 5 and 20 as arid. It is deemed that the quaternaries with low aridity indices (5 to 10) would be highly sensitive to disturbance, since these would be the most suited to cattle farming. Quaternaries with aridity indices between 11 and 20 would be considered having medium sensitivity.

4.4 Farm Dams

In a similar way to the aridity indices, areas with small farm dams are also considered sensitive. Disturbances in these areas which might restrict replenishment of the dams would impact on the capacity to water cattle.

4.5 Sensitivity Classification

The linear and areal sensitivity criteria are summarised in Table 1.

Sensitivity	Sensitivity Feature	Motivation
Very High	• Orange River and buffer area. • Water supply reticulation pipeline from the Orange River and desalination plants, including towns they supply. • All river systems and buffers.	DWS current and future supply schemes (Figure 4-9). River systems (Figure 4.1)
High	• Areas with more than 50 farm dams per quaternary or • Areas classified as Arid, but with Aridity index less than 10.	Mantel and Hughes, 2023 Gunkel and Lange 2017.
Medium	• Areas with fewer than 50 farm dams per quaternary or • Aridity Index greater than 10, but in Arid classification (Aridity Index less than 20).	Mantel and Hughes, 2023 Gunkel and Lange 2017.
Low	• Areas classified as Hyper-Arid (Aridity Index greater than 20). • No surface water supply or storage	Schutte, *et al.*, 2024; Gunkel and Lange 2017. (While these areas may be sensitive to hyper-arid ecosystems, they are not considered sensitive to surface water supply).

5: Projected Impacts on Surface Water

5.1 Baseline Scenario: Scenario 0

Both groundwater withdrawals and the reticulated supply from the Orange River are severely stressed in the region. Assessment studies point to augmenting the abstractions and reticulation of supply from the Orange River (BVI, 2023a; DWS, 2012). Desalination of ocean water and borehole water has been assessed as a supplementary option, but studies warn of the lack of current capacity to operate this sophisticated technology.

With expected growth remaining at 1.68% per annum in the Port Nolloth Bulk Water supply scheme, the current system will require augmentation to supply some 917 000 kL/annum (based on consumption of 125L/person/day plus losses and municipal use, making 145 L/person/day). The Alexander Bay pipeline is designed to deliver approximately 504 000 kL/annum, and even this is not systematically delivered. Groundwater may yield some 345 000 kL/annum, but this is increasingly subject to desalination prior to household consumption.

5.2 Further Development (Boegoebaai Port): Scenario 1 and 2

The predicted increase in population to include Boegoebaai SEZ in the Port Nolloth supply area amounts to some 76% by 2040, being a population increase from 7 078 to 12 503. Other areas may also see significant increase in population.

Combinations of Orange River abstractions from the Port Nolloth Bulk Water Supply scheme, Namakwa Supply scheme as well as desalination of borehole and ocean water will be required to meet the expected increase in demand in the region.

6: Risk Assessment

6.1 Surface Water Resources Drivers

Table 1: Surface Water Resources Drivers

Theme/Driver Surface Water resources	Trend	Explanation
Evapotranspiration	↗	Projected increase in Mean Annual Potential Evapotranspiration (MAPE) of 6 to 10% (WRC 2023). Increased vegetation uptake will impact agriculture and ecosystems. Human comfort levels will deteriorate, and water demand will increase. Stored open water bodies will experience higher losses.
Rainfall	↘	Mean Annual Precipitation (MAP) has reduced from 100 years ago, but past 50 years has been stable (Benito 2011). MAP is projected to decrease between 10-20% in most places, but some locations between 0 -10% (WRC 2024). Less local water in quaternary catchments.
Mean Runoff	↓	Runoff has been dropping marginally over past 50 years in Namaqualand (Benito *et al*., 2011). Mean Annual Runoff (MAR) is projected to reduce by up to 50% in most quaternary catchments but may increase by up to 25% in a few places. The sporadic nature of runoff events offers very limited opportunity for useable storage. Some small farm dams are concentrated in the mountainous areas of the Buffels river and in the Salt pan areas of quaternaries D53F and D53G.
Runoff Extremes	→	Flood events are not likely to increase in intensity. (Present to Near-Future Climate change GCMs predict a 20% reduction in maximum discharge). Riparian areas will be subjected flood levels and crossings exposed to flood damage.
Dry Periods	↑	Current average duration of runoff-free periods is 350 days, with some places reporting dry periods of several years (SRK Quaternary Runoff Analysis). These dry intervals are likely to increase (Climate change GCMs predict slight increase in average duration – 1%, but large increases in the maximum dry periods up to 45%). 9 of the quaternary catchments are likely to change classification from Arid to Hyper-Arid in the near future. Extended runoff-free dry periods will impact ecosystems and agriculture.
Water Demand	↑	Increasing MAPE, reduction in average rainfall and decrease in rainfall frequency (WRC 2023) will intensify the pressure on existing and future water resources.
Water Scarcity	↑	Within quaternary catchments, higher MAPE and lower MAP will increase water scarcity. Higher extreme runoff events are not likely to improve or lessen recharge to riparian aquifers, although salinity may increase due to the higher MAPE (Benito 2011). However, predicted increase in flows in the Orange River due to future MAP increase in Lesotho and eastern RSA may allow for increased abstractions, depending on upstream water use in the Orange-Vaal system.
Bulk Water Supply	↗	Increase in demand will be met from Orange River abstractions due to projected increase in Orange River MAR at points of abstraction due to predicted Climate Change increases in runoff in Lesotho and eastern RSA (WRC, 2023). However, availability for abstraction will depend on upstream water use in the Orange-Vaal systems.

6.2 Consequence Definitions

Table 2: Negative and Positive Consequences related to Surface Water

	Consequence	Description
Negative	Slight	• Current flow regimes would largely remain constant. – Low rainfall-runoff intensity and duration of no-runoff increase at local extent and persist for medium term – Low rainfall-runoff intensity and duration of no-runoff increase at medium extent and persist for short term – Low to medium rainfall-runoff intensity and duration of no-runoff increase at local extent and persist for short term. • Slight change to discharge or access of Orange River abstractions.
	Moderate	• Moderate change to flow regimes. • Impacts to ecosystems, drainage crossings, access points manageable. • Moderate reduction in discharge or abstraction potential of Orange River flows.
	Substantial	• Substantial change to flow regimes. • Higher extreme events and longer dry periods result in substantial deterioration of ecosystems, drainage crossings and access points. • Substantial reduction in discharge or abstraction potential of Orange River flows.
	Severe	• Severe changes to flow regimes. • Increase in extreme events and longer dry periods between events lead to loss of income in agriculture and hardships in health, livelihoods and income. • Severe reduction in discharge or abstraction potential of Orange River flows.
	Extreme	• Extreme flow regime changes. • Increase in extreme events and extension of dry periods between events lead to irreversible, severe effects to income in agriculture and hardships in health, livelihoods and income for urban communities. • Extreme reduction in discharge or abstraction potential of Orange River flows.
Positive	Slight	• Perturbations to flow regimes would not impact ecosystem, agriculture and human demand. • No shortfall in Orange River discharge and access.
	Moderate	• Perturbations to flow regimes marginally improve supply to agriculture, ecosystems and human demand. Drainage systems remain intact and riparian system benefit. • Moderate improvement in discharge and abstraction potential of Orange River flows.
	Substantial	• Substantial improvement to flow regimes. • Lower extreme events and shorter dry periods result in substantial improvement to ecosystems, drainage crossings and access points. MAR increase. • Substantially improved discharge and abstraction potential in Orange River flows.
	Severe	• Severe improvements to flow regimes. • Decrease in extreme events and shorter dry periods between events lead to access of quaternary catchment water and improvement to agriculture productivity, health, livelihoods and income. • Severe increase in discharge and abstraction potential of Orange River flows.
	Extreme	• Extreme improvements in flow regimes. • Decrease in extreme events and reduction of dry periods between events lead to improvements to income in agriculture and, livelihoods and income for urban communities. Surface water storage become possible in quaternary catchments. • Extreme improvement in discharge and abstraction potential of Orange River flows satisfy all demands and provide excess for storage.

6.3 Potential Impacts

6.3.1 Impact identification

The Boegoebaai delimited area is classified as either arid or hyper-arid. Water scarcity for life and livelihoods is limited and is likely to become more so, without effective alternative water supplies. The potential impacts include:

- Limited water supply from the Orange River to increasing population due to inadequate system operation and maintenance, (current delivery is consistently below design yield), budget limits to expansion and lack of capacity to operate.
- Shortage of water to sustain life and livelihoods where areas change from arid to hyper-arid in future.

6.3.2 Mitigation Measures

Mitigation measures to water supply, particularly in the north-west of the delimited area will include:

- Appropriate estimation of future needs, design and implementation of new and augmented water supply schemes from the Orange River.
- Implementation of effective desalination plants for saline groundwater and seawater use.
- Effective capacity building and proper operation and maintenance of abstraction works reticulation and local water supply infrastructure.
- Prevention of pollution to the abstraction works, where Orange River water is drawn from riparian subsurface (to allow for abstraction of filtered Orange River yield).

6.3.3 Impact Assessment

Table 6.3 provides formal ratings of the above impacts, considering their application to areas of different surface water sensitivity (Very High to Low sensitivity, as defined in **Section 4-5**), for the Baseline Scenario (Sc0) and the two development scenarios (Sc1 and Sc2).

The ratings are carried out separately, with and without the recommended mitigation and management measures outlined above.

Table 3: Assessment of potential impacts on surface water resource availability, quality and security

Impact	Scenario	Spatial receiving environment or receptor	Without Management			With Management		
			Consequence (-)	Likelihood	Risk	Consequence (-)	Likelihood	Risk
Negative	S0: Baseline	Very High Sensitivity	Severe	More likely	Very High	Substantial	Less Likely	Moderate
	S1: Small GH2		Extreme	Likely	Very High	Substantial	Less Likely	Moderate
	S2: Big GH2		Extreme	Likely	Very High	Substantial	Less Likely	Moderate
	S0: Baseline	High Sensitivity	Substantial	More likely	High	Moderate	Unlikely	Low
	S1: Small GH2		Severe	Likely	High	Moderate	Unlikely	Low
	S2: Big GH2		Severe	Likely	High	Moderate	Unlikely	Low
	S0: Baseline	Medium Sensitivity	Moderate	More likely	Moderate	Moderate	Unlikely	Low
	S1: Small GH2		Substantial	Likely	Moderate	Moderate	Unlikely	Low
	S2: Big GH2		Substantial	Likely	Moderate	Moderate	Unlikely	Low
	S0: Baseline	Low Sensitivity	Slight	Likely	Low	Slight	Unlikely	Very Low
	S1: Small GH2		Moderate	Unlikely	Low	Slight	Unlikely	Very Low
	S2: Big GH2		Moderate	Unlikely	Low	Slight	Unlikely	Very Low

7: Recommended Strategic Management Actions

The following strategic management actions are recommended:

- Provide for Orange River abstractions and reticulation to the level of Scenario 1 demand. Provide for adequate maintenance of the abstraction, treatment, reticulation and storage works.
- Provide for protection of abstraction works and reticulation pipelines.
- Provide for expertise to operate desalination plants at proposed coastal locations.
- Prevent all disturbances to river systems and floodplains, particularly at infrastructure crossings. Prevent any encroachment of structures or dwellings into the floodplain.
- Assign protective measures to quaternary catchments with high sensitivity with regard to aridity and density of small farm dams.

8: Data accessed for the Water Resources Chapter

The surface water assessment drew on the following datasets:

- Catchment runoff, dry periods and meteorological data (Current and Near Future) extracted and interpreted from databases of Schütte et al., 2023, WRC Report 2833/1/22.
- Mean Annual Runoff, Precipitation and Evaporation from WR2012, (Herold and Bailey, 2016) used for comparative purposes.
- Daily runoff record for the Buffels river derived from published figure in Benito et al., 2011.
- Orange River abstractions, current and future water demands lifted from DWS 2012, DWS 2023, BVI 2023a and BVI 2023b.
- Farm dam density distribution lifted from Mantel and Hughes, 2023.
- Aridity definition and limits lifted from Gunkel and Lange, 2017.

9: References

Benito, G., Botero, GA., Thorndycraft, VR., Rico, M., Sanchez-Moya, Y., Sopena, A., Machado, MJ. and Dahan, O. 2011. Rainfall-runoff modelling and palaeoflood hydrology applied to reconstruct centennial scale records of flooding and aquifer recharge in ungauged ephemeral rivers. Hydr. Earth. Syst. Sci. 15:1185-1196.

BVI Consulting Engineers. 2023a. Feasibility Study – Port Nolloth Bulkwater Supply. Project Ref 34141.

BVI Consulting Engineers. 2023b. Feasibility Study – Port Nolloth Bulkwater Supply. Annexure H: Water demand till 2040 assuming Boegoebaai and Special Economic Zone. Project Ref 34141.

DWS. 2012. Namaqua Water Supply Scheme. Sedibeng Water and BVI Consulting Engineers DWS report to DWS regional Bulk Infrastructure Grant. Feasibility and Implementation Readiness Study: Phase 3, November 2012.

DWS. 2013. Development of Reconciliation Strategies for Large Bulk Water Supply Systems Orange River: Current and Future Urban/Industrial Water Requirements. Report prepared by: WRP Consulting Engineers, Aurecon, Golder Associates Africa, and Zitholele Consulting. Report No. P RSA D000/00/18312/4

Fryirs, KA. 2017. River sensitivity: a lost foundation concept in fluvial geomorphology. Earth Surf. Process. Landforms 42:550-70.

Gunkel, A. and Lange, J. 2017. Water scarcity, data scarcity and the Budyko curve – An application in the lower Jordan river basin. Journal of Hydrology: Regional Studies 12(2017):136-149.

Mantel, S. and Hughes, D. 2023. Farm Dams in Southern Africa: Balancing Environmental and Socio-Economic Sustainability (in): Dam Engineering – Design, Construction, and Sustainability, DOI: 10.5772/intechopen.113930

Schulze, RE. Hydrology and Agrohydrology. A Text to Accompany the *ACRU* 3.00 Agrohydrological Modelling System. WRC Report: TT 95/69, 43. Water Research Commission, Pretoria, South Africa.

Schütte, S., Schulze, RE. and Clark, DJ. 2023. A National Assessment of Potential Climate Change Impacts on the Hydrological Yield of Different Hydro-Climatic Zones of South Africa: Report 1 - Methodology and Results. WRC Report No. 2833/1/22. Water Research Commission, Pretoria, South Africa.

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All data used as source material plus the text, tables, figures, and attachments of this document have been reviewed and prepared in accordance with generally accepted professional engineering and environmental practices.

Appendices

Appendix A: Meteorological Trends

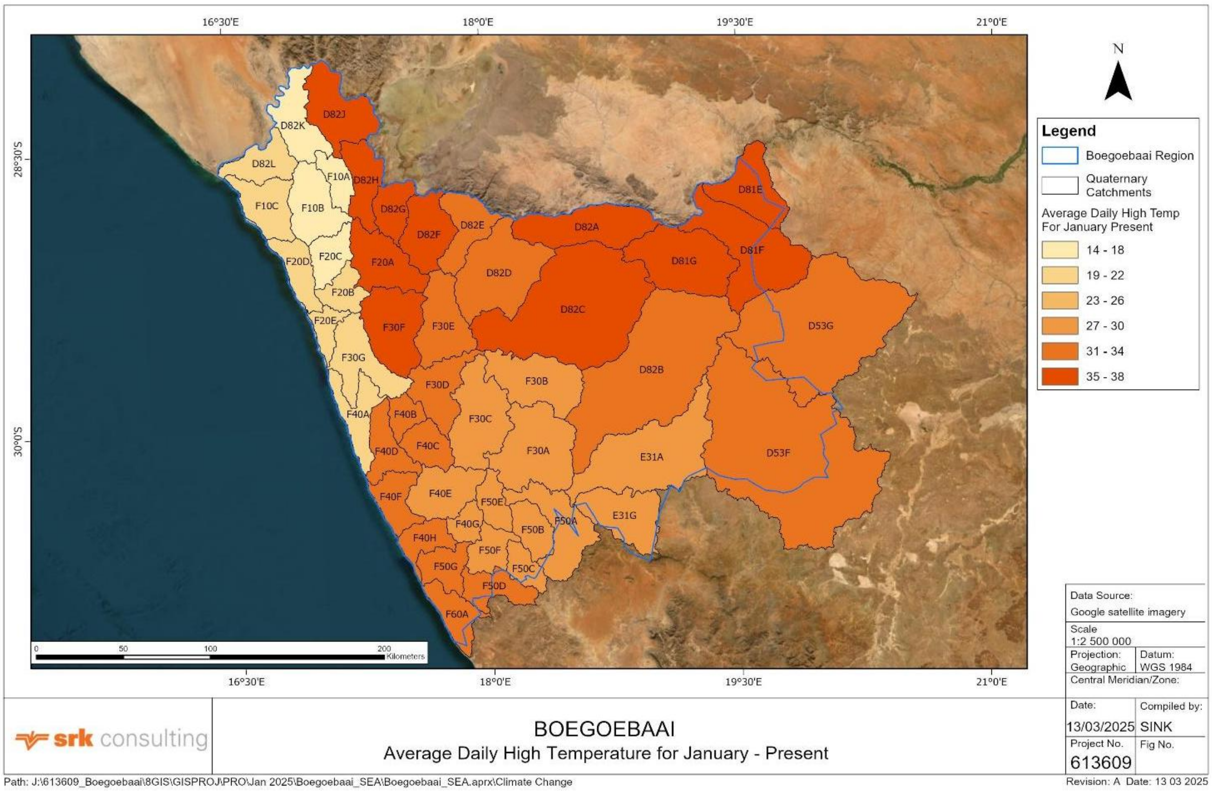

Figure A-1: Average Daily High Temperature for January – Present (from Schutte *et al.*, 2023)

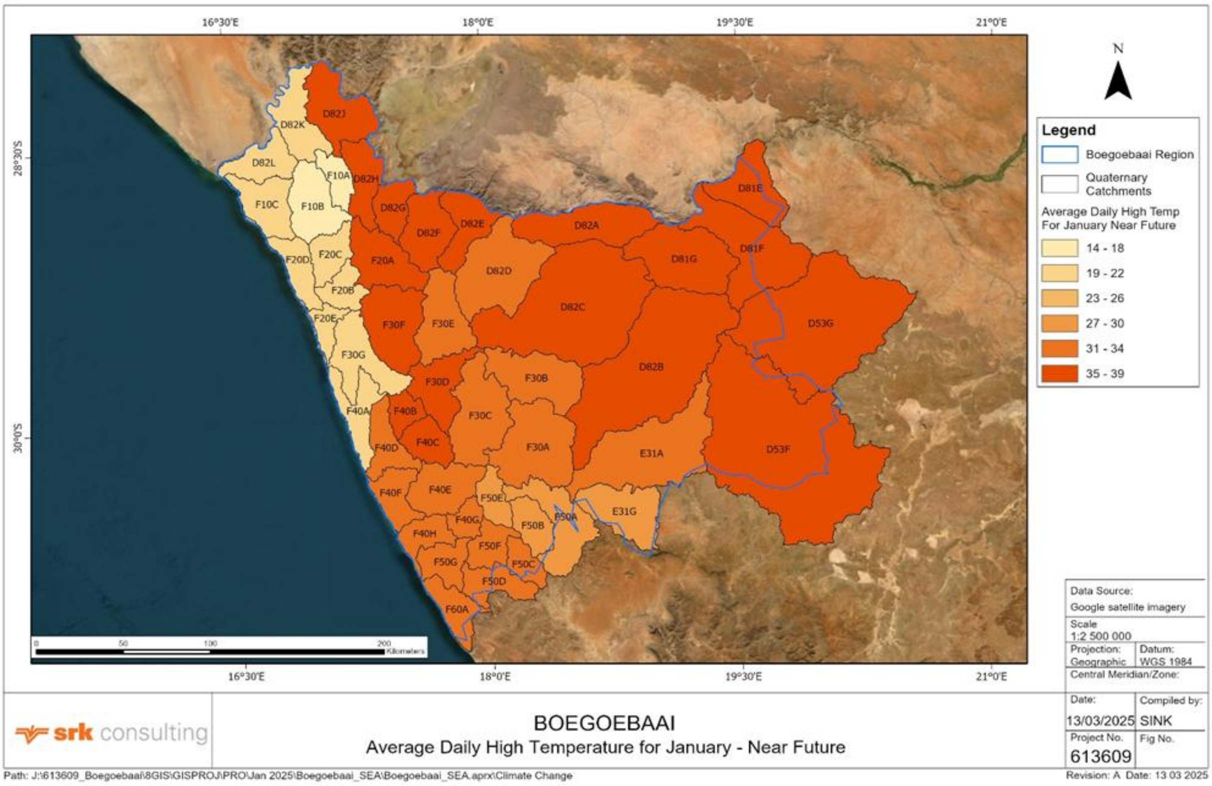

Figure A-2: Average Daily High Temperature for January – Near-Future (from Schutte *et al.*, 2023)

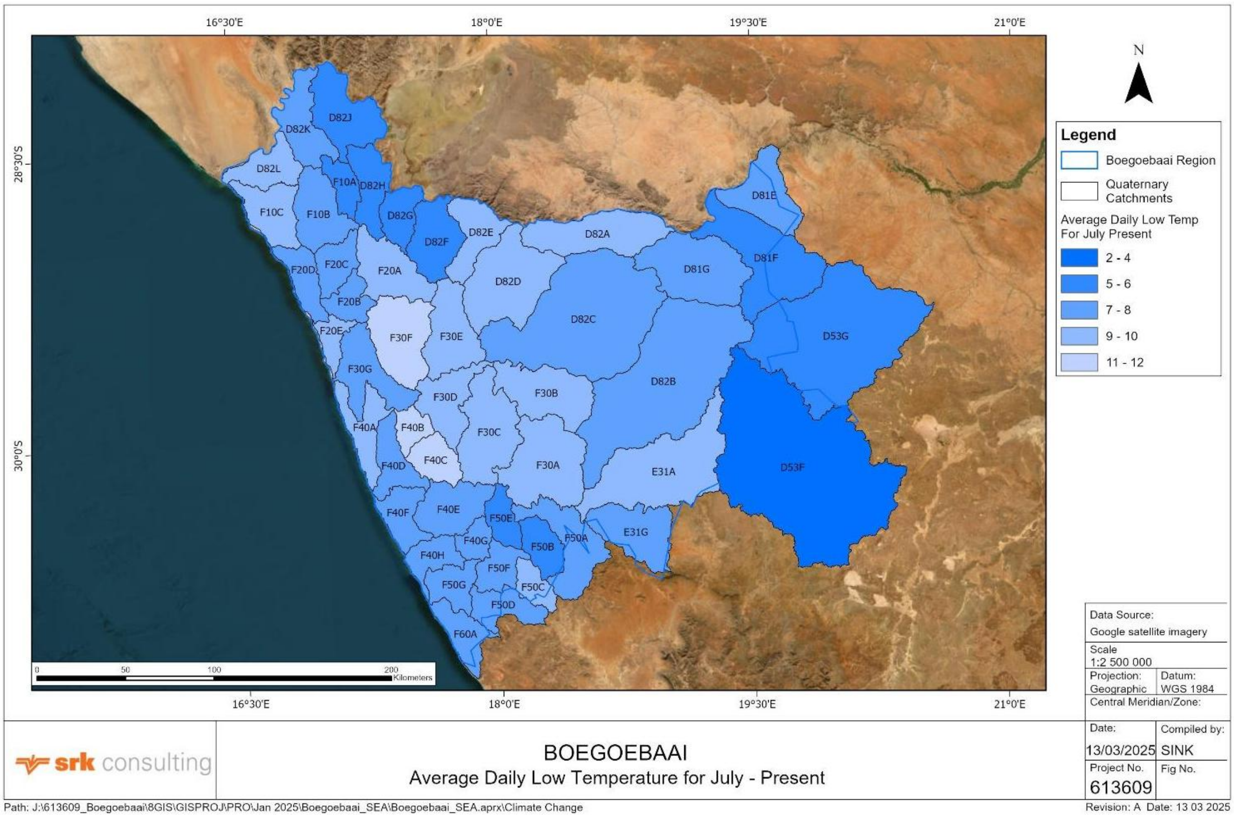

Figure A-3: Average Daily Low Temperature for July – Present (from Schutte *et al*., 2023)

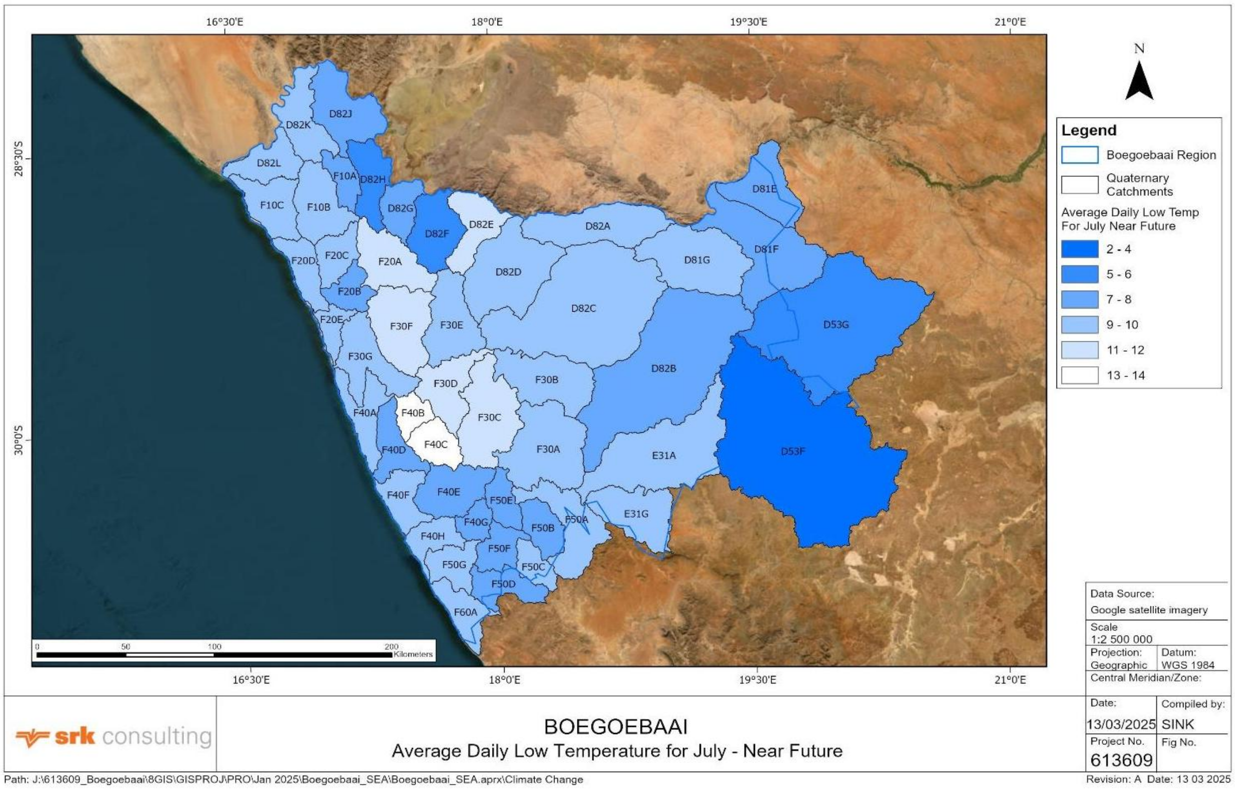

Figure A-4: Average Daily Low Temperature for July – Near Future (from Schutte et al., 2023)

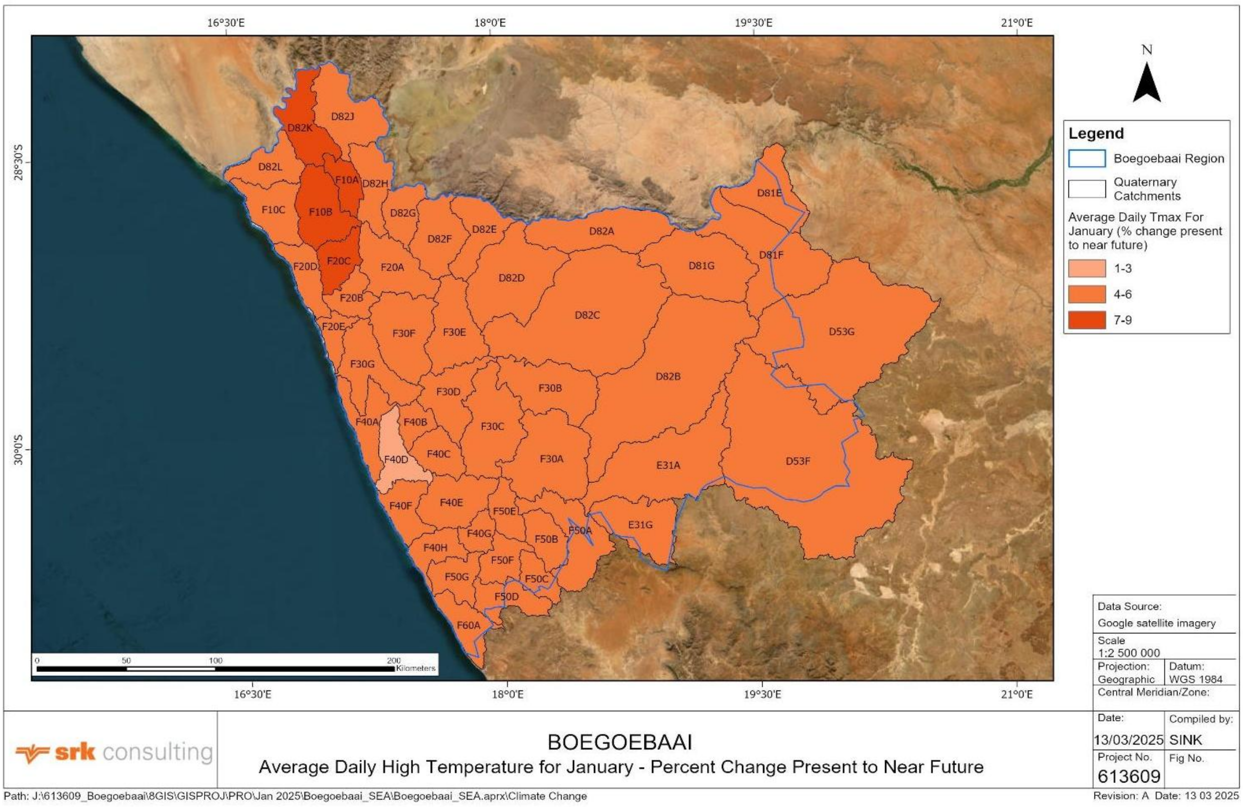

Figure A-5: Average January Daily High Temperature – % Change from Present to Near Future

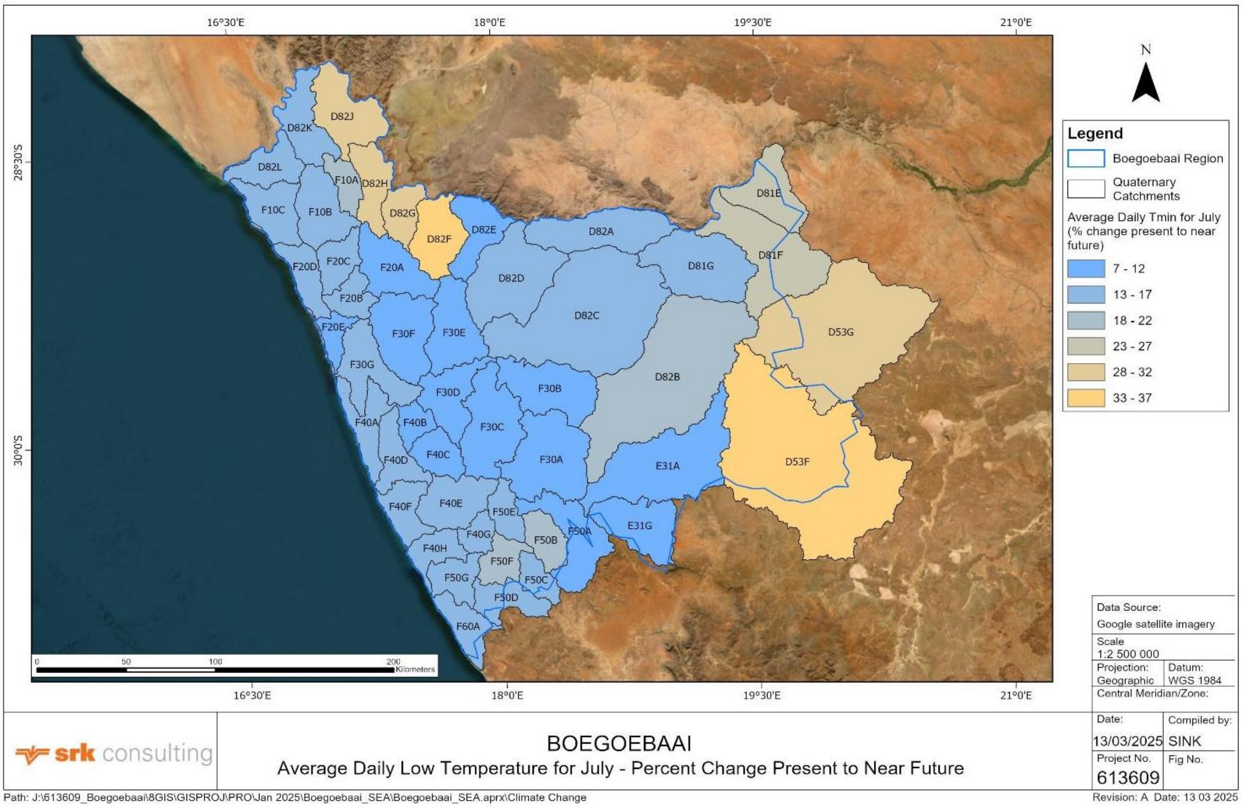

Figure A-6: Average July Daily Low Temperature – % Change from Present to Near Future

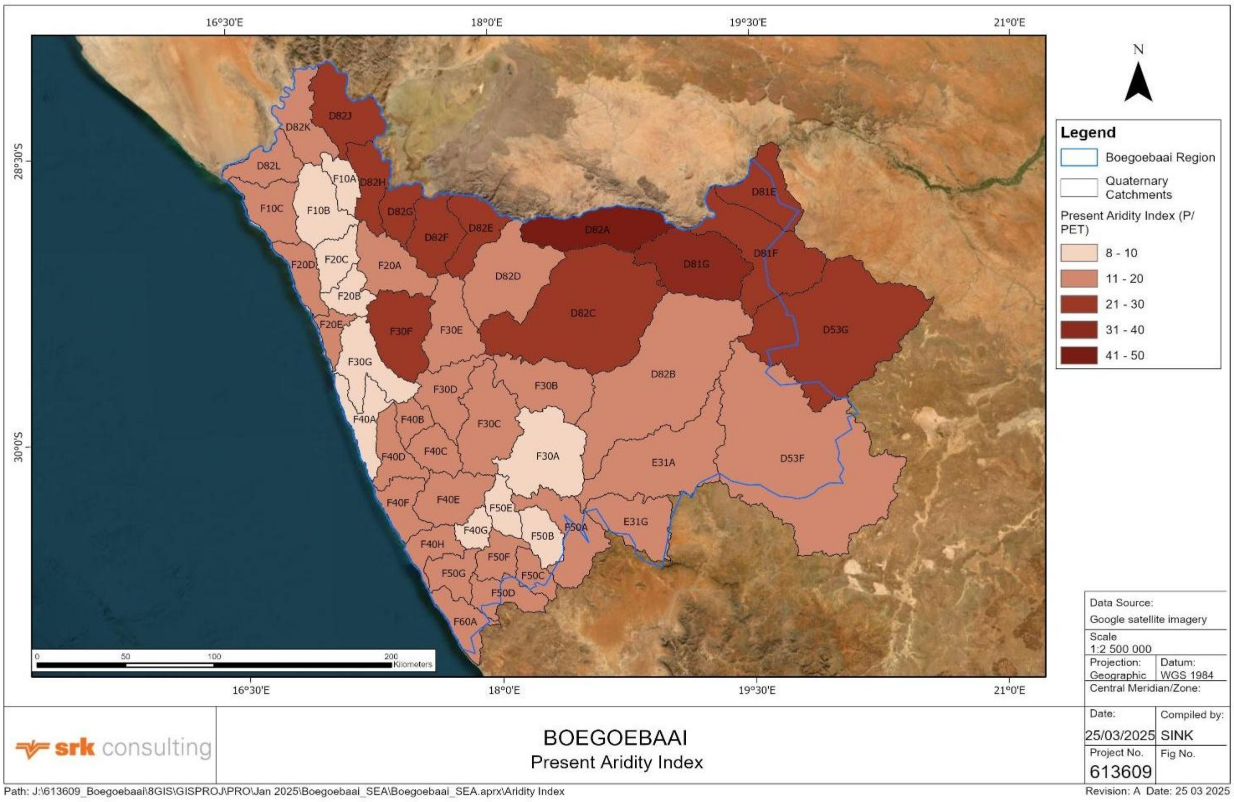

Figure A-7: Distribution of Aridity Index: Present Climate (Average of 6 GCMs).

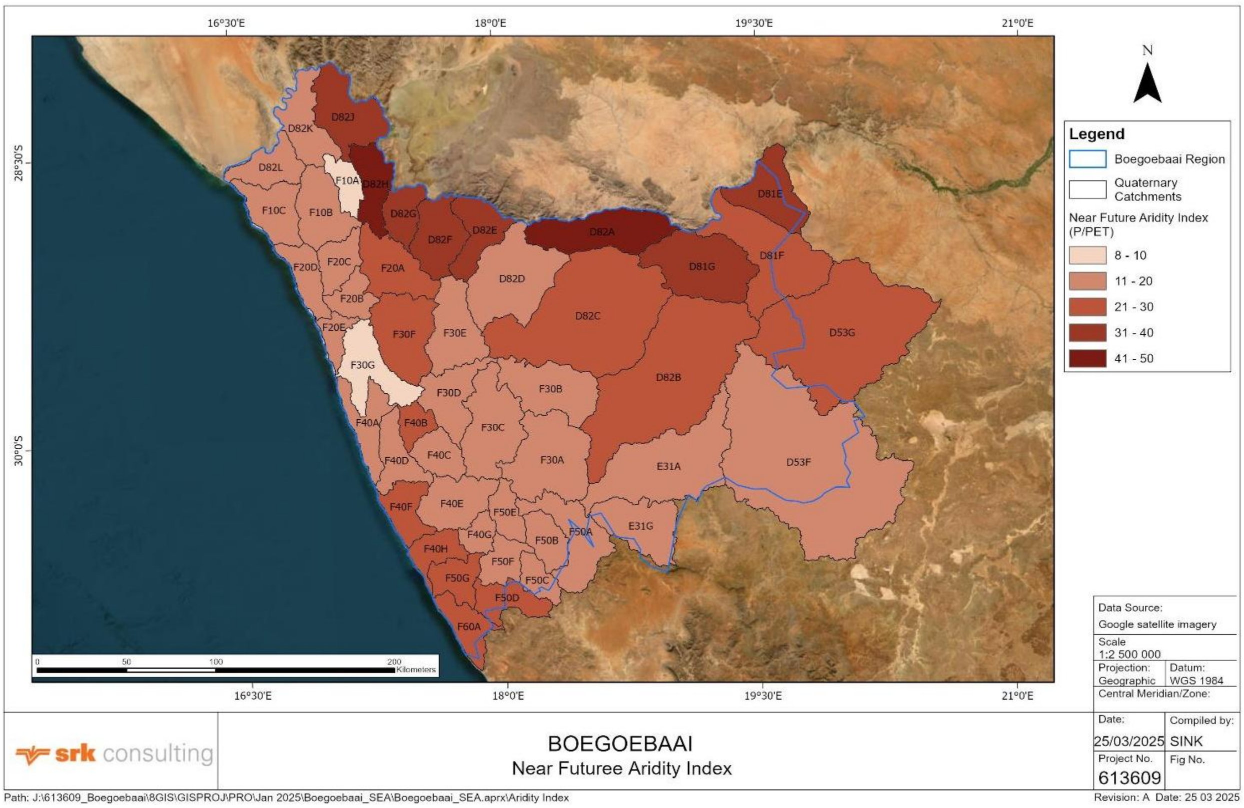

Figure A-8: Distribution of Aridity Index: Near Future Climate (Average of 6 GCMs).

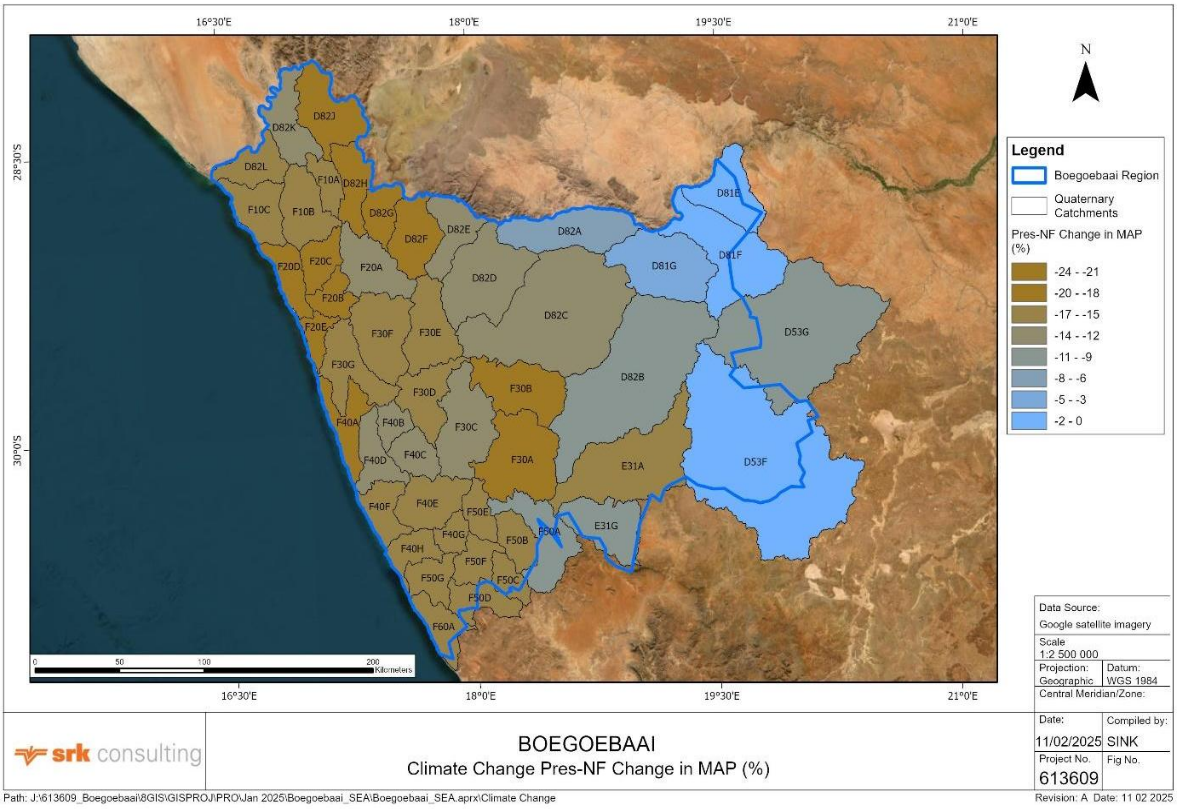

Figure A-9: Estimated % Change in MAP for Near Future (Average of 6 GCMs, Extracted from Schütte, et al., 2023)

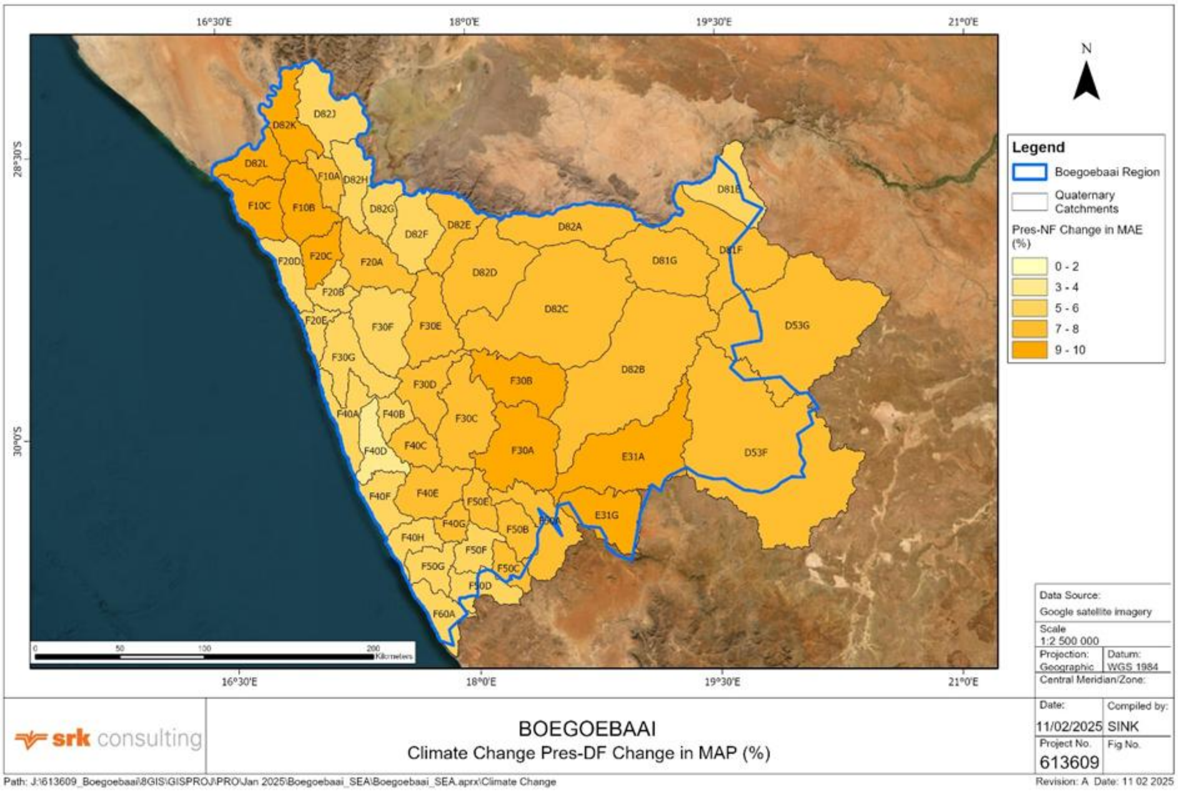

Figure A-10: Estimated % Change in MAPE for Near-Future (average of 6 GCMs, Extracted from Schütte, et al., 2023)

Appendix B: Quaternary Catchment Runoff

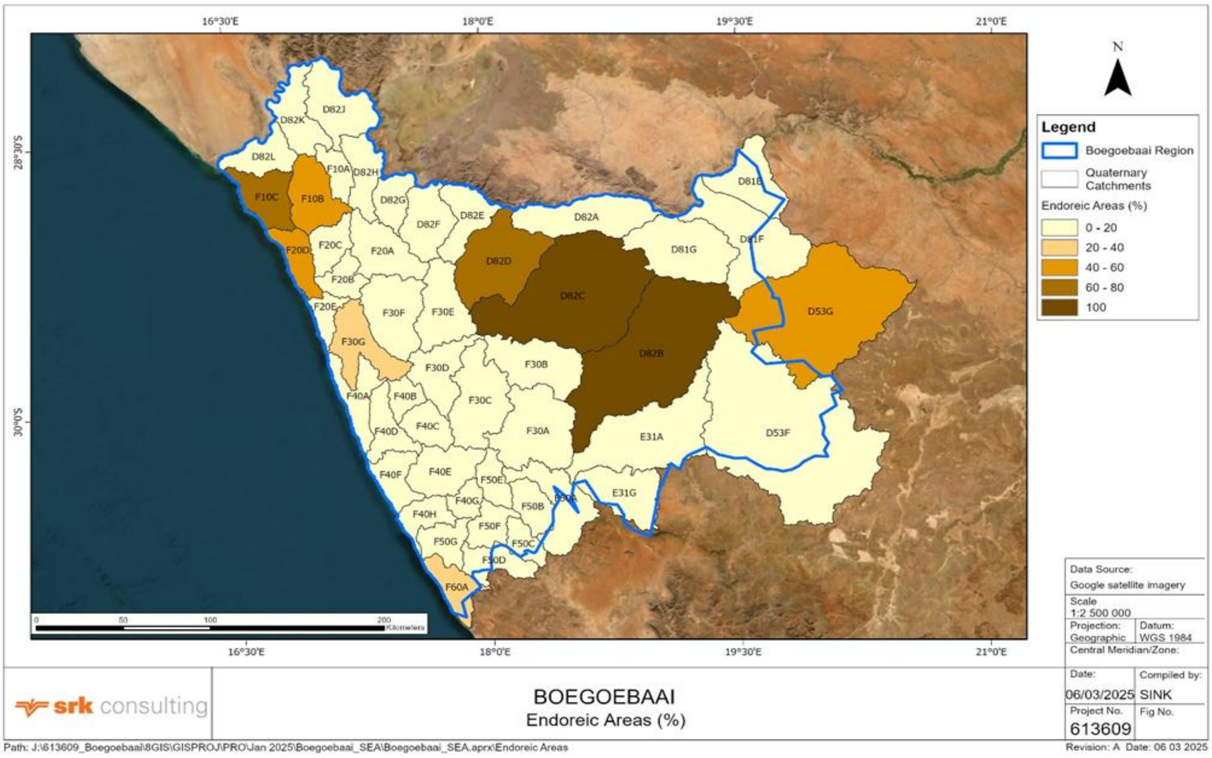

Figure B-1: Distribution of endoreic areas (WR2012)

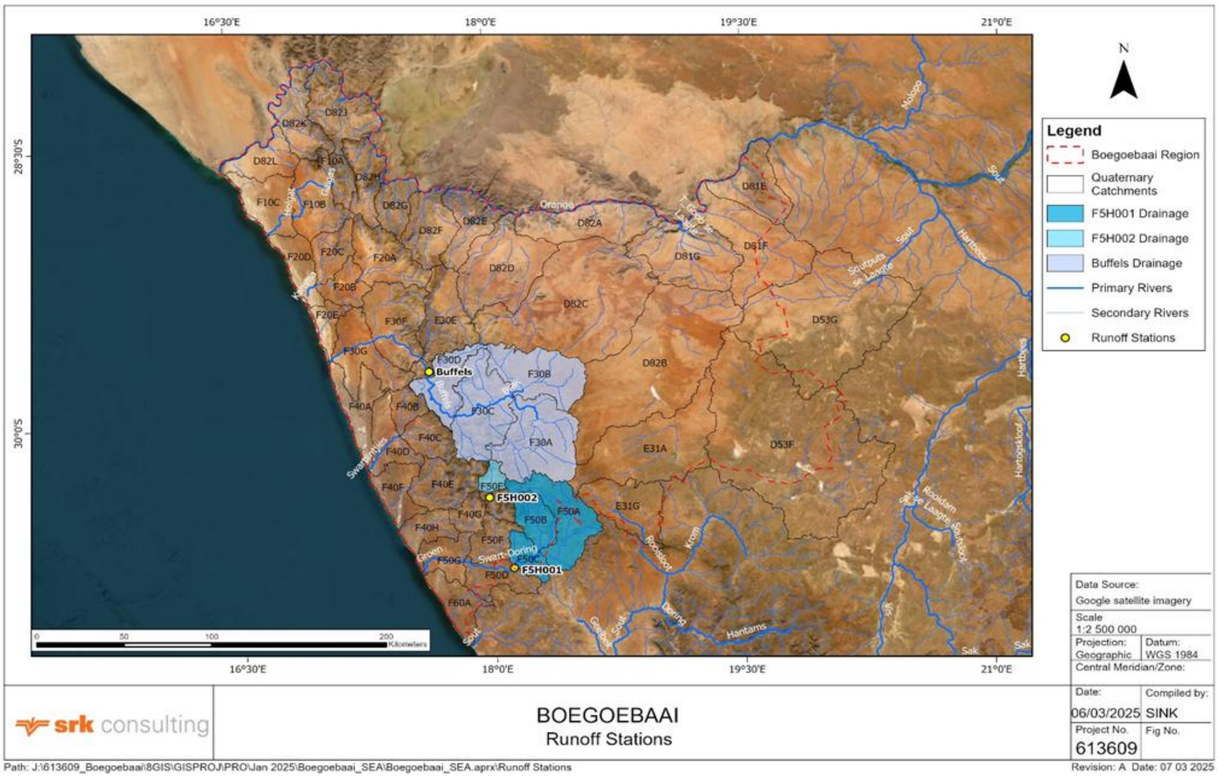

Figure B-2: Location of River Monitoring Stations (DWS and Benito et al., 2011)

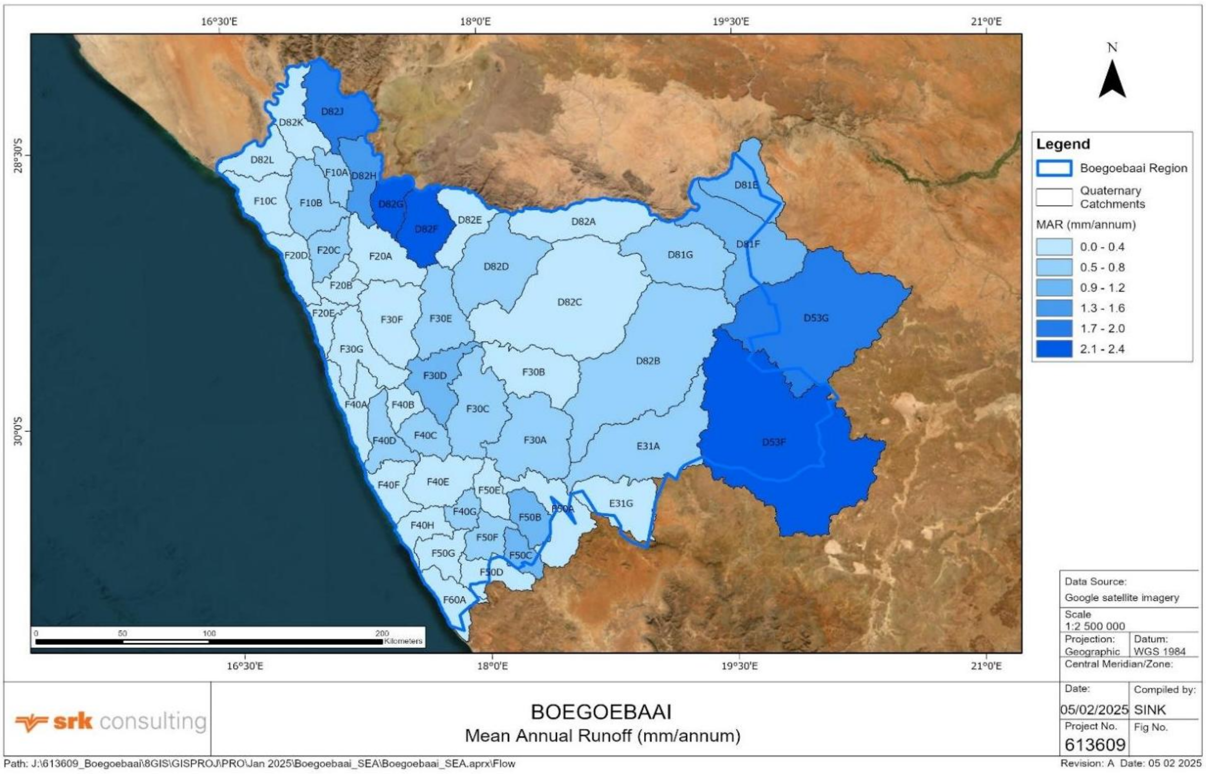

Figure B-3: Distribution of Mean Annual Runoff, MAR (mm/annum), in the study area.

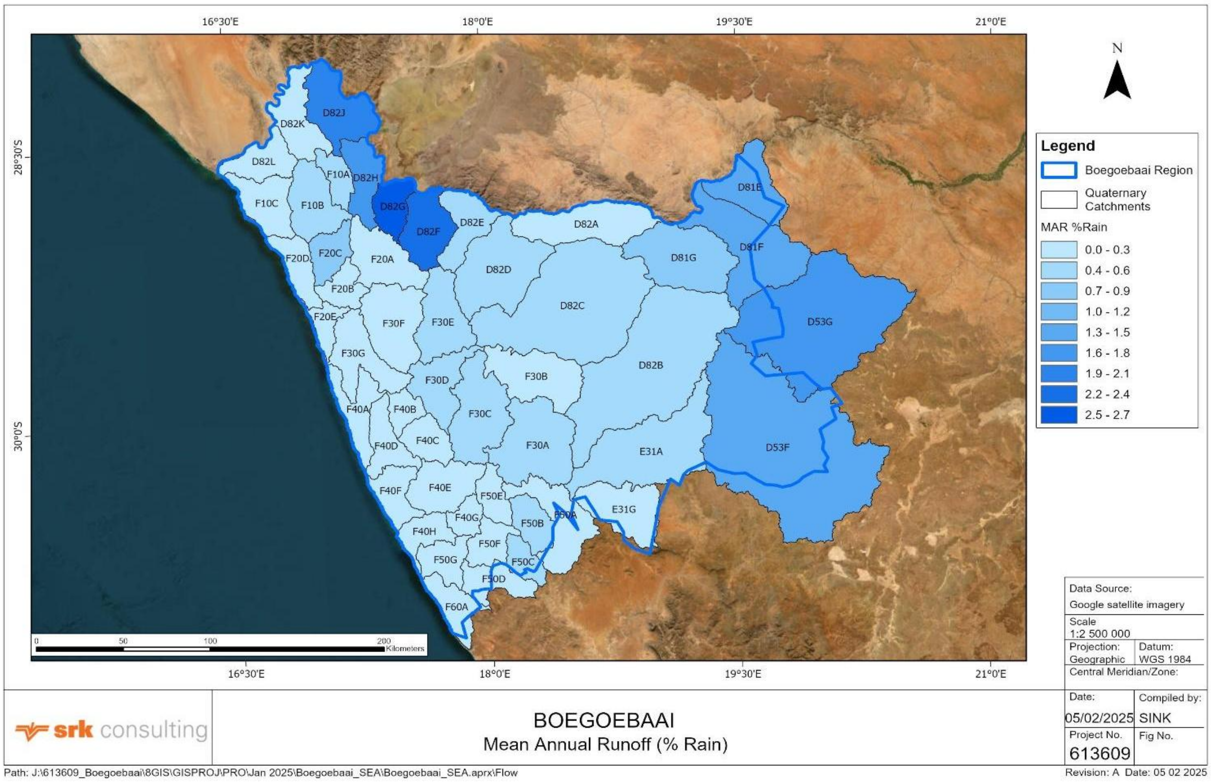

Figure B-4: Distribution of the Quaternary MARs as a percent of rainfall.

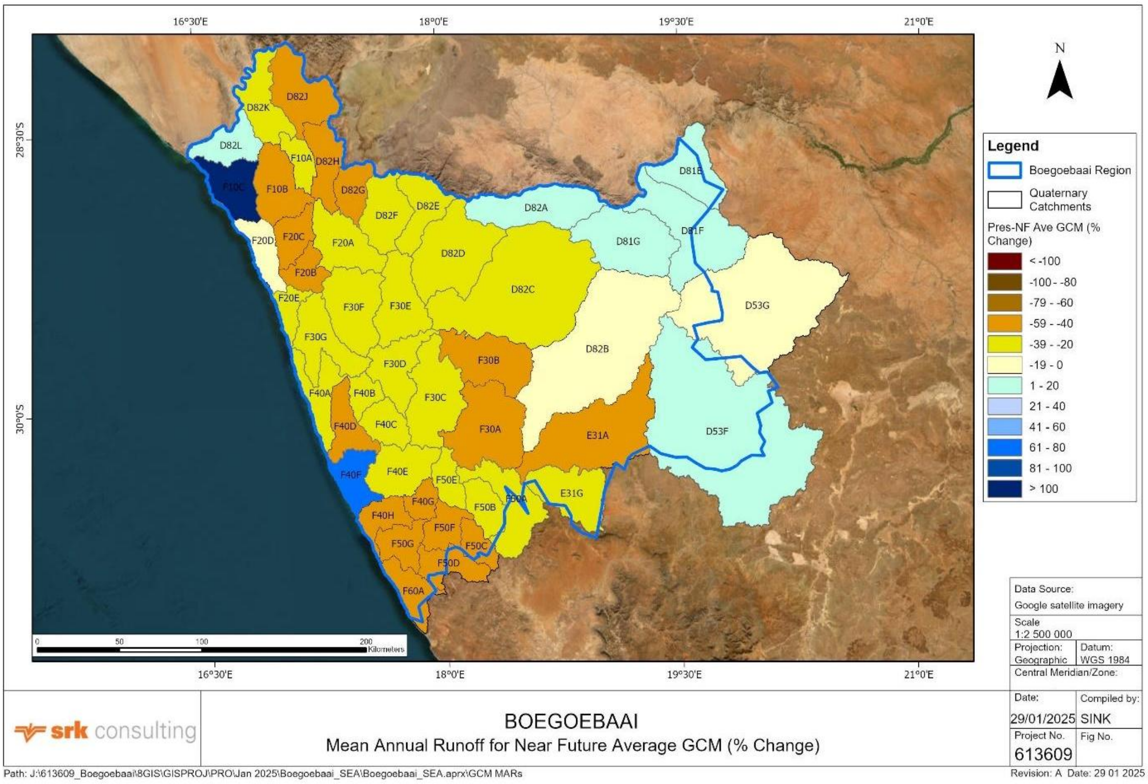

Figure B-5: Percent Change in Near Future Mean Annual Runoff (average of 6 GCMs)

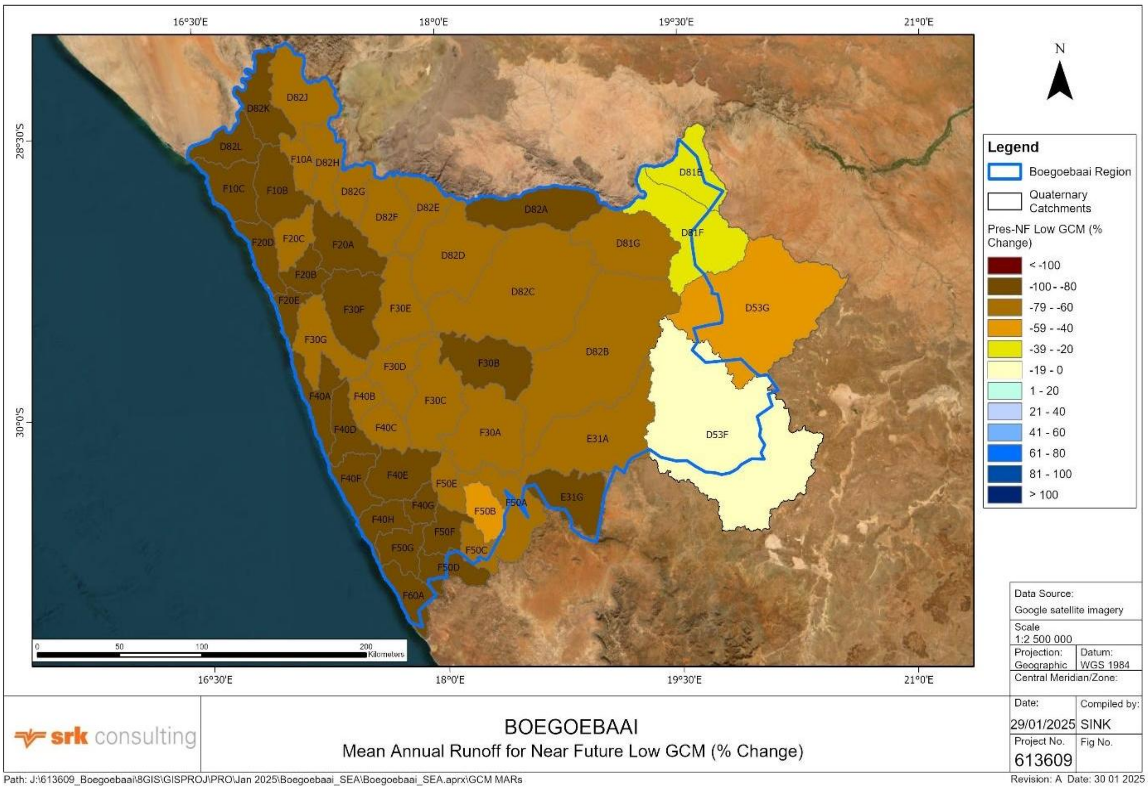

Figure B 6: Percent Change in Near Future Mean Annual Runoff (lowest of 6 GCMs)

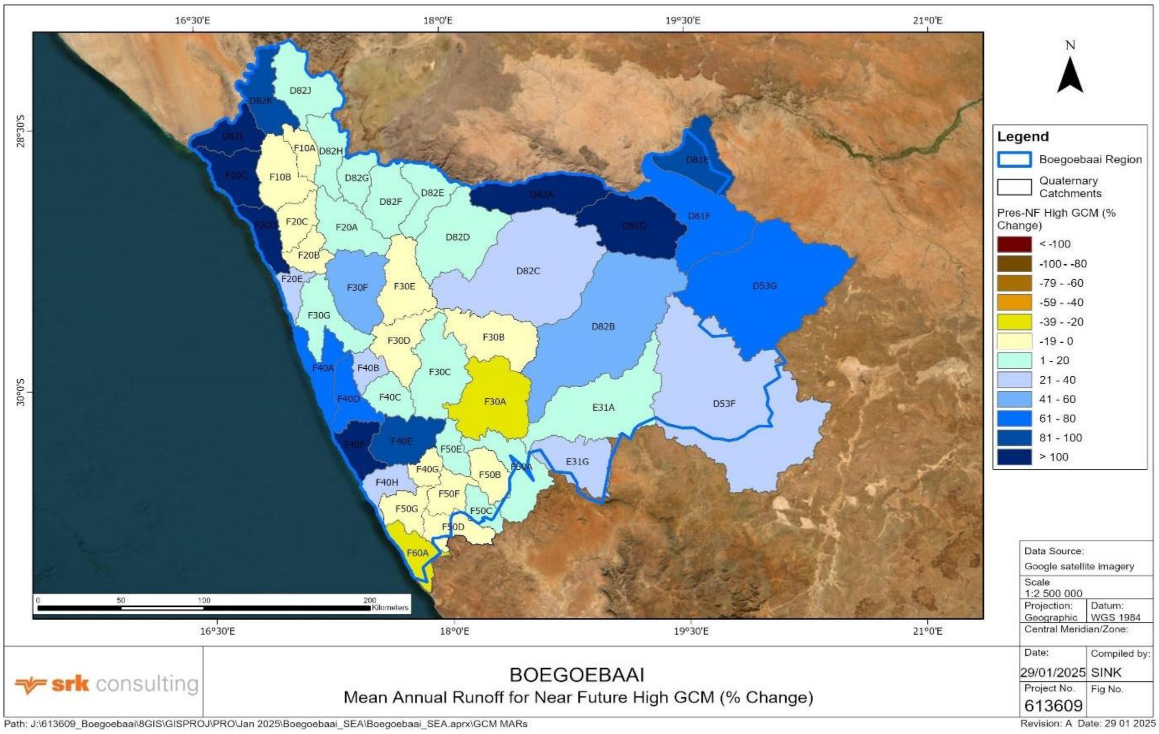

Figure B-7: Percent Change in Near Future Mean Annual Runoff (highest of 6 GCMs)

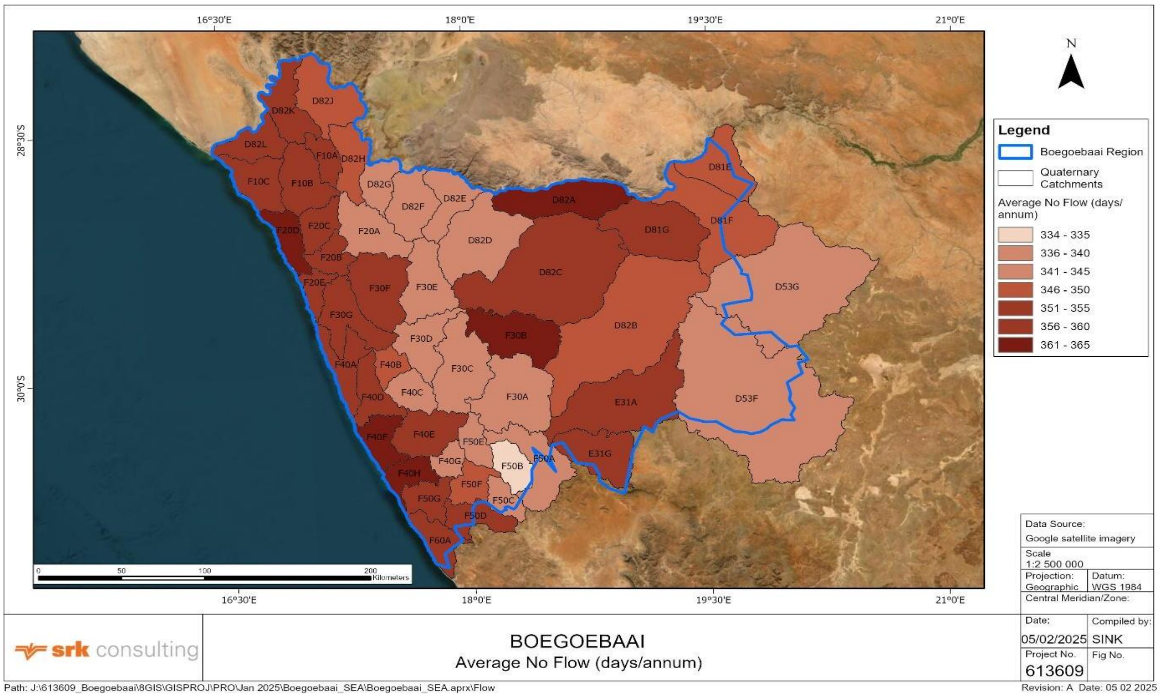

Figure B 8: Distribution of Average Days of No-Flow (extracted from Schütte, et al., 2023)

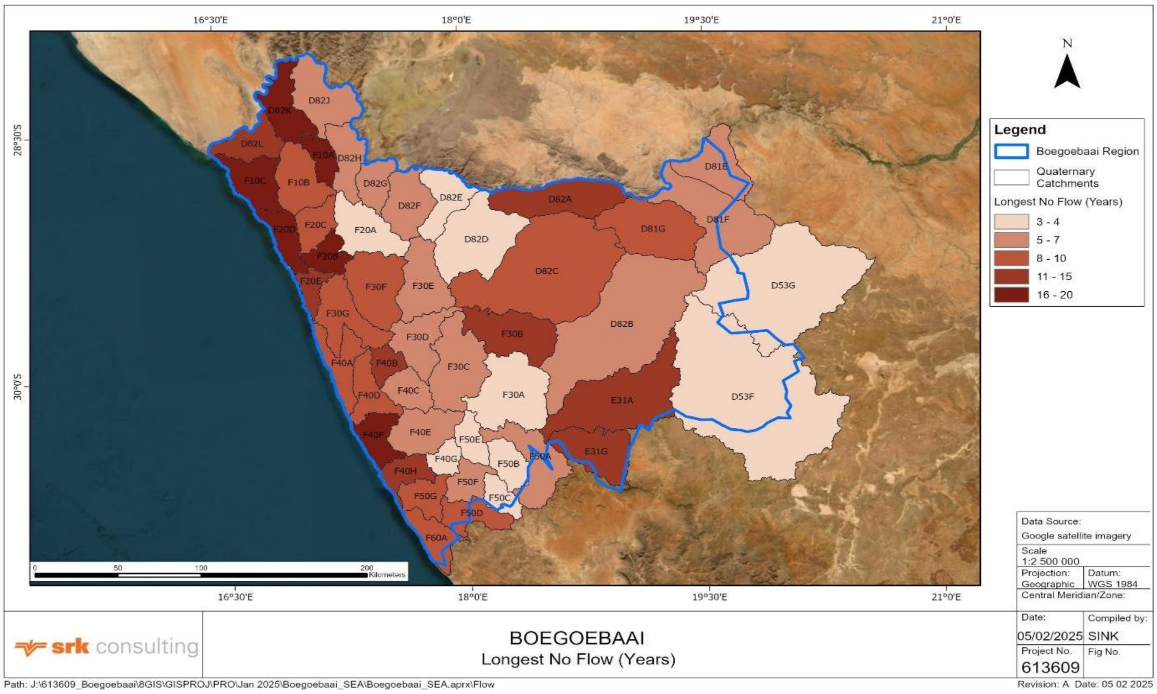

Figure B-9: Distribution of Maximum Period of No-Flow (from Schütte, et al., 2023)

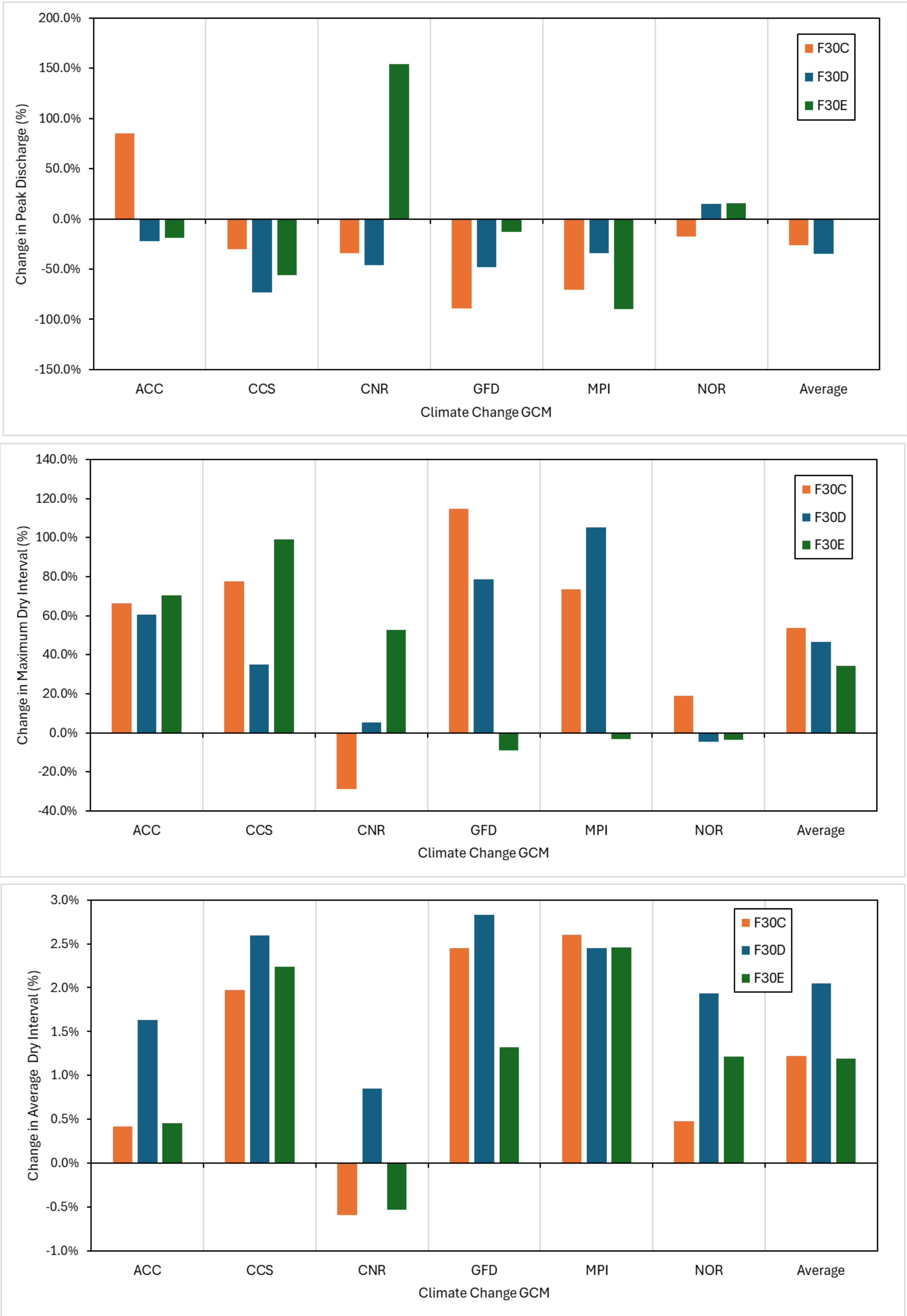

Figure B-10: Percent Change in Peak Discharge and Dry Periods for Quaternaries F30C, F30D and F30E (6 GCMs, Schutte et al., 2023)

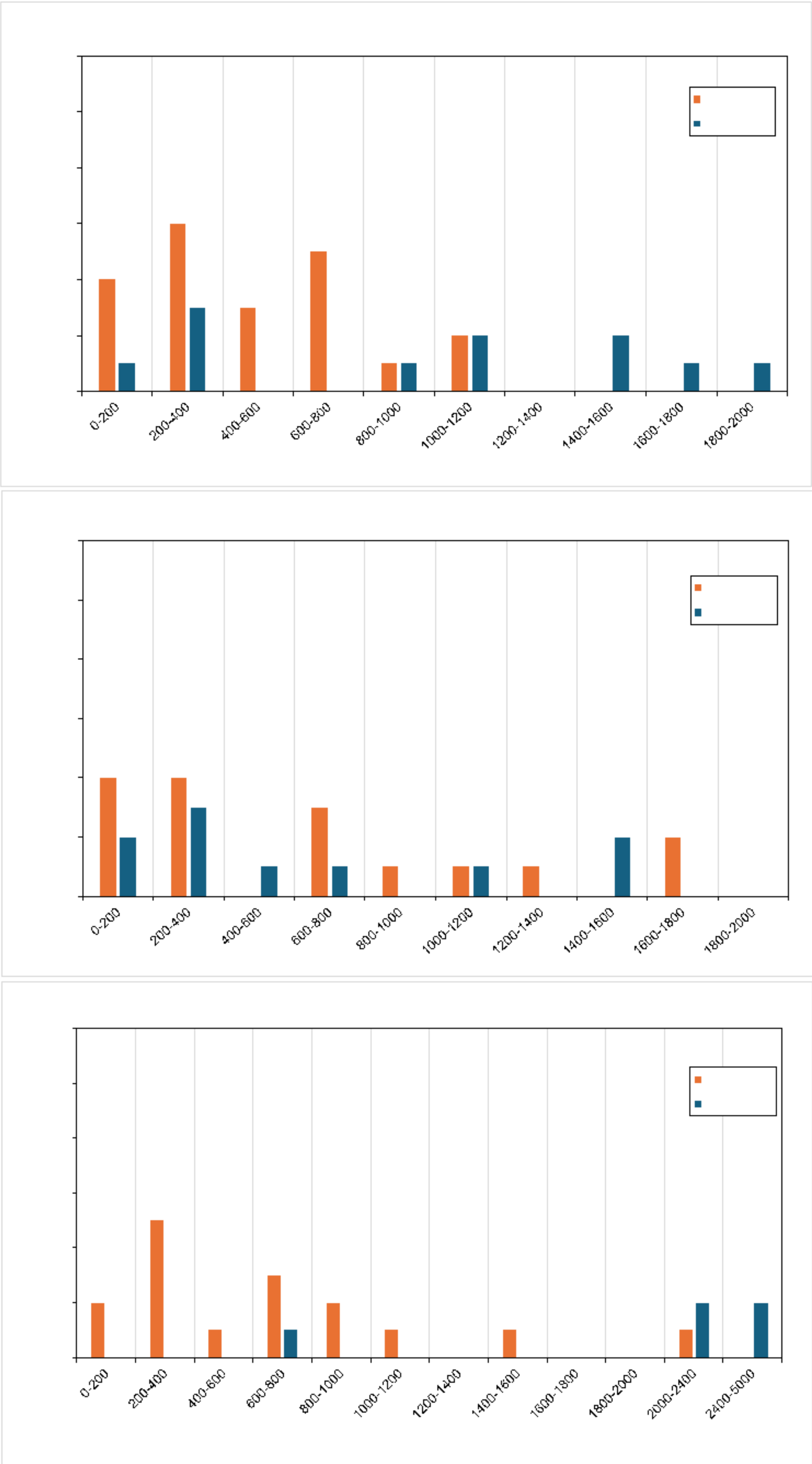

Figure B-11: Dry period changes from Present to Near Future Climate F30C (3 GCMs)

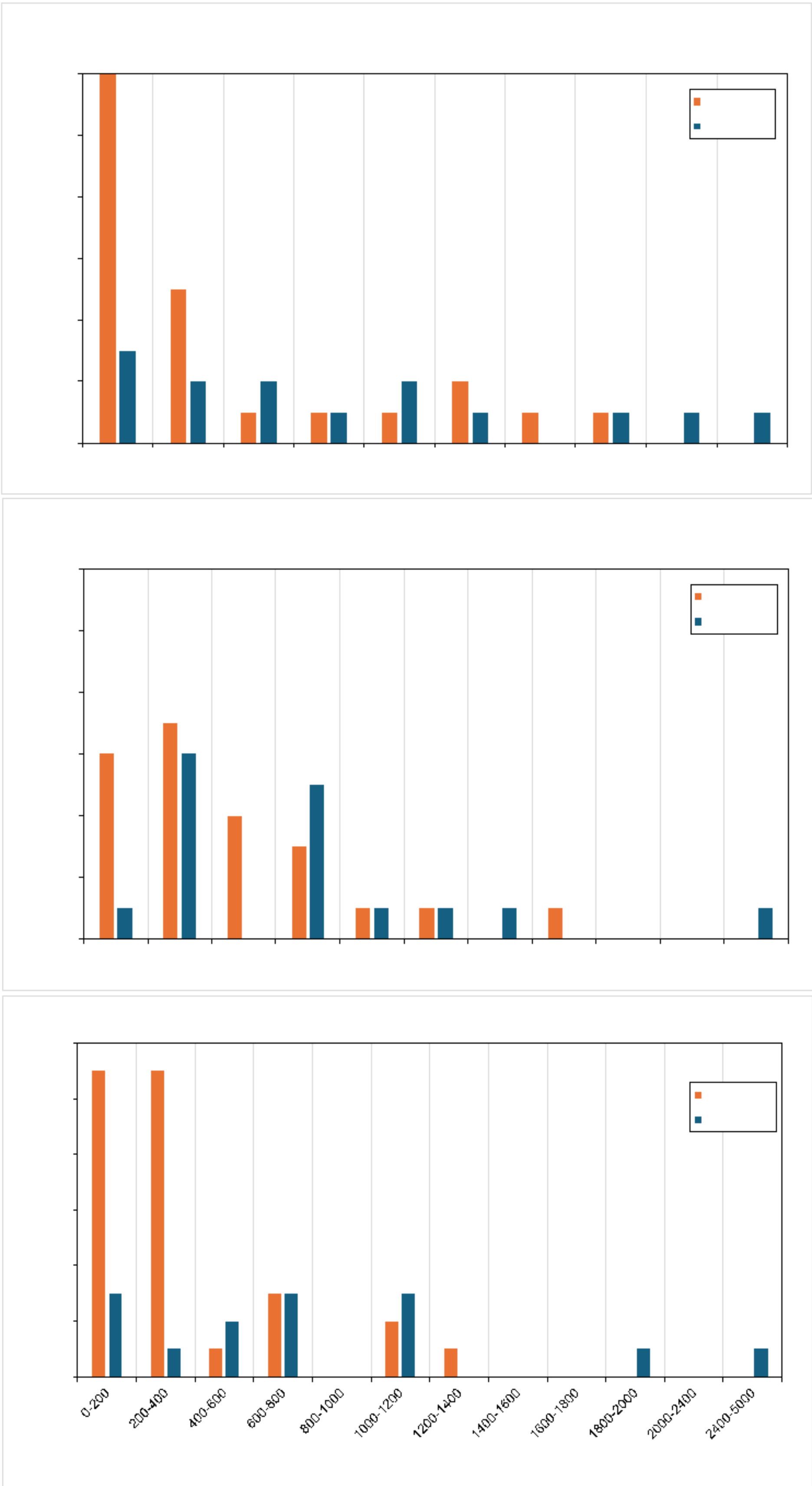

Figure B-12: Dry period changes from Present to Near Future Climate F30D (3 GCMs)

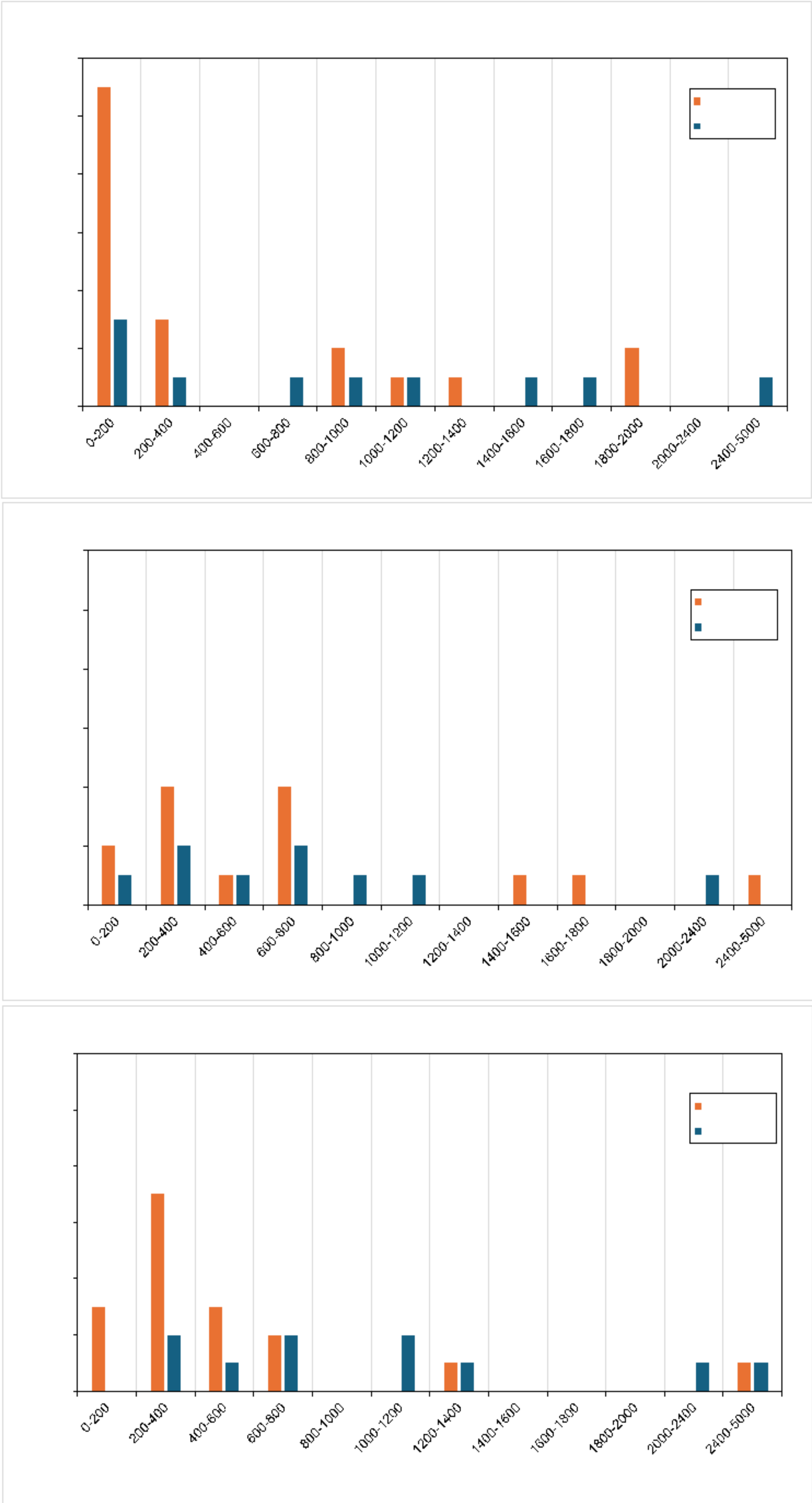

Figure B-13: Dry period changes from Present to Near Future Climate F30E (3 GCMs)

Appendix C: Orange River Yield

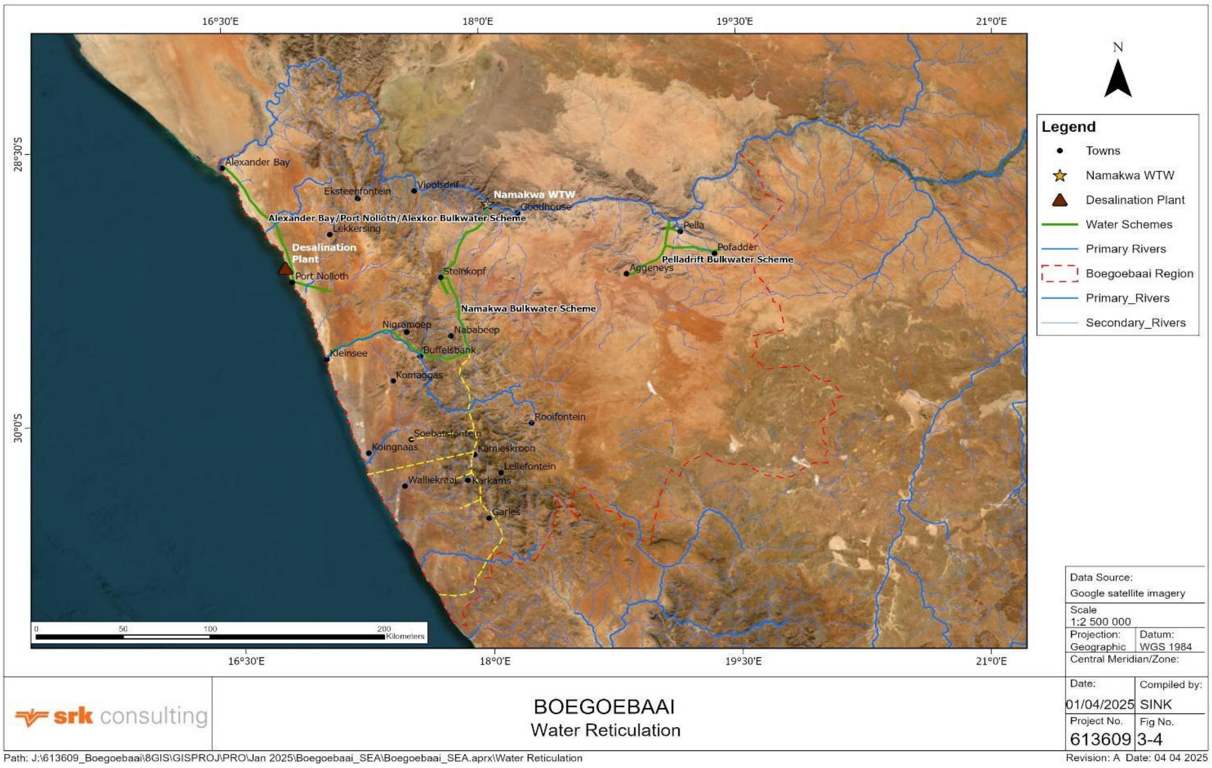

Figure C-1: Orange River Water Supply Reticulation