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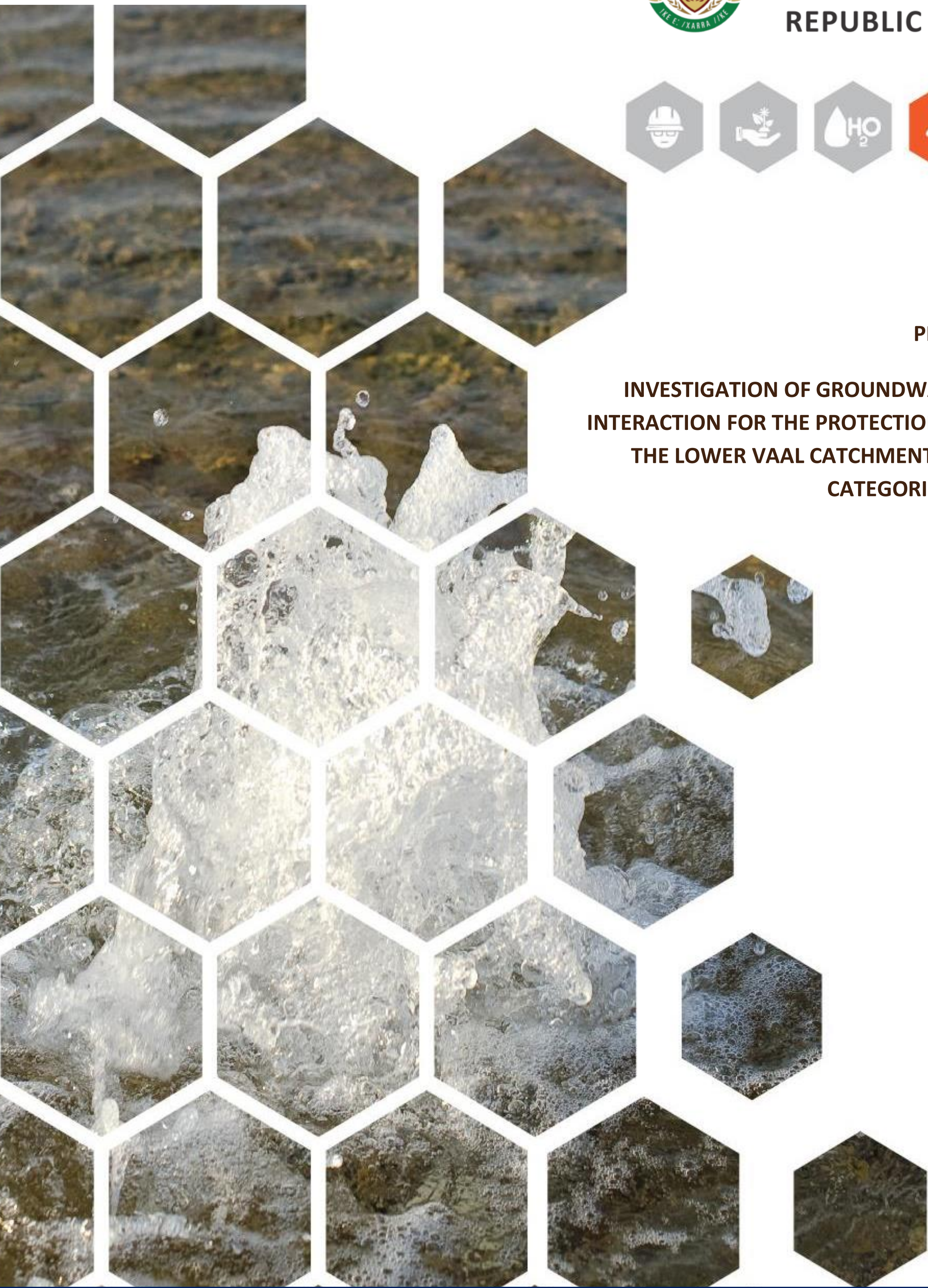

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INVESTIGATION OF GROUNDWATER AND SURFACE WATER INTERACTION FOR THE PROTECTION OF WATER RESOURCES IN THE LOWER VAAL CATCHMENT. GROUNDWATER QUALITY CATEGORISATION REPORT (WP11380)

DATE: November 2023

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INVESTIGATION OF GROUNDWATER AND SURFACE WATER INTERACTION FOR THE PROTECTION OF WATER RESOURCES IN THE LOWER VAAL CATCHMENT
WP11380

GROUNDWATER QUALITY CATEGORISATION REPORT

NOVEMBER 2023
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DOCUMENT INDEX

Report name	Report number
Inception Report	RDM/WMA05/00/GWSW/0122
Literature Review and Data Gathering Report	RDM/WMA05/00/GWSW/0222
Gap Analysis Report	RDM/WMA05/00/GWSW/0322
Hydrocensus Report	RDM/WMA05/00/GWSW/0422
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Quantified Recharge and Baseflow Report	RDM/WMA05/00/GWSW/0123
Groundwater Quality Categorisation Report	**RDM/WMA05/00/GWSW/0223**
Protection Zones Report	RDM/WMA05/00/GWSW/0323
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Main Report on Surface-Subsurface Interactions	RDM/WMA05/00/GWSW/0723
Close-out Report	RDM/WMA05/00/GWSW/0823

Bold indicates this report

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First draft	March 2023
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Final V2	October 2023

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1 INTRODUCTION

1.1 Study Context

The purpose of the NWA (1998) is to ensure that the nation's water resources are protected, used, developed, conserved, managed and controlled in ways which take into account amongst other factors: promoting equitable access to water; redressing the results of past racial and gender discrimination; promoting the efficient, sustainable and beneficial use of water in the public interest; facilitating social and economic development; protecting aquatic and associated ecosystems and their biological diversity and; meeting international obligations (NWA, 1998). Chapter 3 introduces a series of measures which together are intended to protect all water resources.

The Chief Directorate: Water Ecosystems Management (CD: WEM) is tasked with the responsibility to coordinate all Reserve determination studies which have priority over other uses in terms of the NWA.

This study intends to determine and quantify groundwater and surface water interactions and identify protection zoning to prevent the disturbance of the ecological integrity of ecosystems where such interactions occur. A feasibility study undertaken by the Department of Water and Sanitation (DWS) in 2007 and the National Water Resource Strategy II identified the need for surface-subsurface interaction studies in the lower Vaal. The purpose of such studies would be understanding subsurface processes when determining the Reserve.

1.2 Aims and Objectives of the Project

The need to undertake significant groundwater-surface water interaction studies became apparent to the DWS due to the need to understand the groundwater balance when determining the Reserve. Groundwater not only provides for dispersed water supply needs, but also make significant contributions to the ecological reserve, as well as to Basic Human Needs for future water supply. The main objectives of the study are:

- Review existing water resource information;
- Conduct a hydrocensus on an institutional level;
- Conduct a water resource assessment of surface water, groundwater, baseflow, abstraction, surface and groundwater balance, present status category;
- Quantify aquifer parameters and describe aquifer types;
- Determine groundwater-surface water interactions both in terms of quality and quantity to determine protection zones;
- Capacity building and skills transfer to DWS staff.

The project timeframe is 24 months, starting from November 2021-November 2023.

1.3 Purpose of Report

This report is submitted to Department of Water and Sanitation (DWS) by WSM Leshika Consulting to categorise groundwater quality for macro and microconstituents in terms of:

- Quaternary catchment
- Processes and Catchment characteristics that impact on groundwater quality

Chapter 2 describes the study area. **Chapter 3** describes the methodology utilised and **Chapter 4** categorises groundwater quality.

2 STUDY AREA

The study area has been described in the Water Resources Assessment Report and is only summarized here.

2.1 Location and Drainage

The Lower Vaal catchment (former WMA 10) lies in the north-eastern part of the Northern Cape Province, the western part of Northwest Province, and a part of the northern Free State Province (**Figure 2-1)**. It contains the Molopo and Kuruman (D4), Harts (C3), and the Vaal (C9) (below Bloemhof dam and above Douglas Weir) catchments. These catchments include Tertiary catchments C31-C33, C91-92, D41, and Quaternary catchments D73A, D42C-D, D73B-E. They contain dolomite aquifers, where interaction with surface water can be significant. The water in the Lower Vaal region drains to the Lower Orange drainage region before reaching the Atlantic Ocean near the town of Alexander Bay in the western corner of the country.

The basins are located in a semi-arid to arid region of South Africa. Most of the surface water resources originate upstream of Bloemhof dam. Groundwater is an important water resource, especially in areas located away from surface water bodies. Groundwater use depletes the already meagre surface water resources by inducing losses from river channels or depleting flow from dolomitic eyes and as baseflow.

The Lower Vaal is located between the Middle Vaal drainage region and the Lower Orange drainage region, with the Upper Orange basin to the southeast, and Botswana to the north. The Lower Vaal has an area of approximately 136 146 km^2. It excludes the Riet-Modder River catchment) (C5), the Molopo River system above its confluence with the Nossob (parts of D42) and portions of the Vaal River catchment below the confluence with the Harts and Douglas weir (parts of C92B and C, and D71B). It is important to note that although the Riet-Modder Catchment forms part of the Vaal River Basin, it is included as part of the Upper Orange River sub-system, mainly due to the fact that there are several transfers from the Orange River to support water requirements in the Riet-Modder catchment. The only connection between the Vaal and Riet-Modder rivers is the spills from the Riet-Modder catchment into the Vaal River just upstream of Douglas Weir.

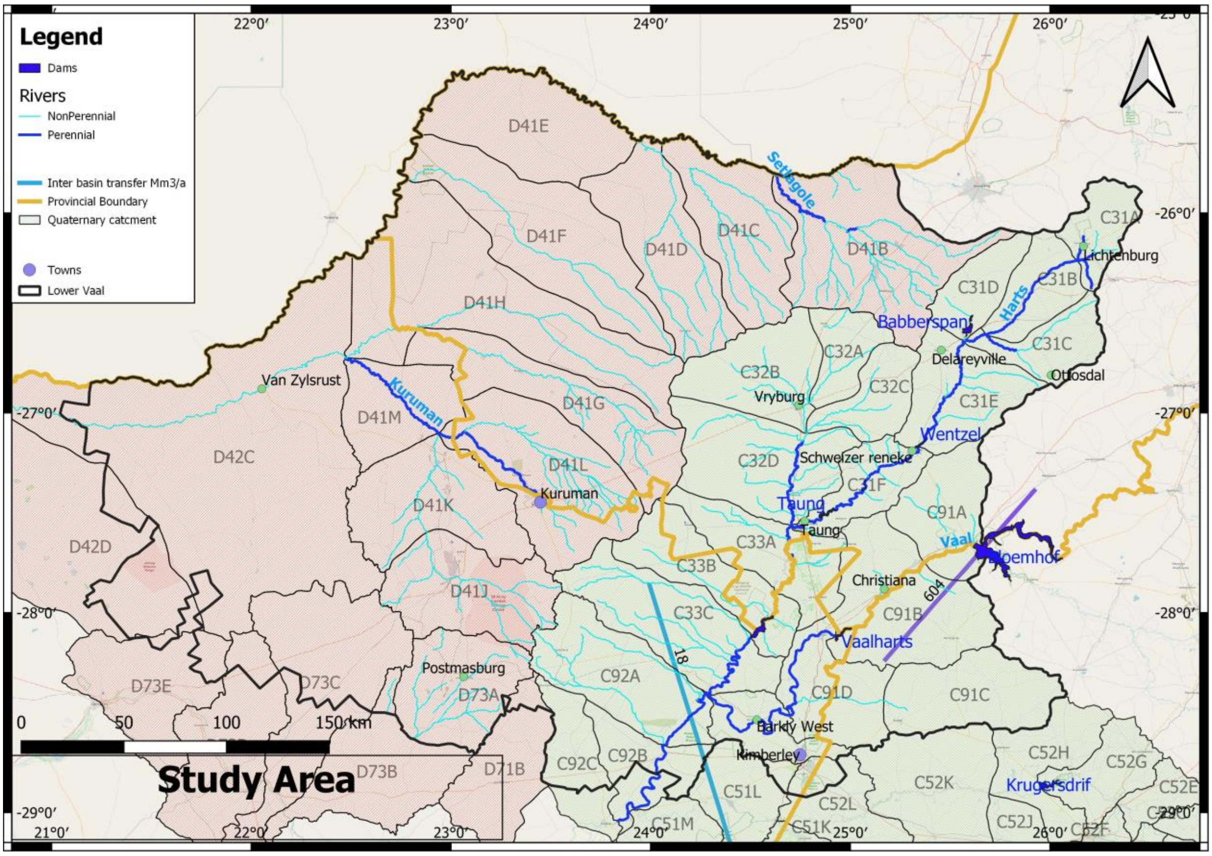


Figure 2-1 Lower Vaal drainage Region

The main rivers of the Lower Vaal catchment, the Vaal and Harts Rivers, are perennial and most of their tributaries are ephemeral. The main source of surface water is the Vaal River, which flows into the study area below Bloemhof Dam, before its confluence with the Orange River. The main dams are Wentzel, Taung, Spitskop, Vaalharts Weir, Douglas weir and Bloemhof. The largest pan is Babberspan, located in the Harts sub-catchment.

The Kuruman and Molopo Rivers, which drain the Kalahari and northern Lower Orange regions, do not make a meaningful contribution to the surface water resources of the Orange River, and interact with groundwater via evapotranspiration and losses of flow generated by upstream springs into dry river channels.

The dolomitic springs in the Harts and Molopo catchments form distinct groundwater ecosystems and are themselves a form of surface-groundwater interaction.

2.2 Climate

Climate plays a significant role in groundwater quality in terms of the aridity concentrating the load of salts, and evaporation concentrating salt loads.

Minute by minute gridded rainfall shows that the MAP ranges from 150 to over 600 mm/a, with the highest rainfall in the northeast, declining to the west. (**Figure 2-2**).

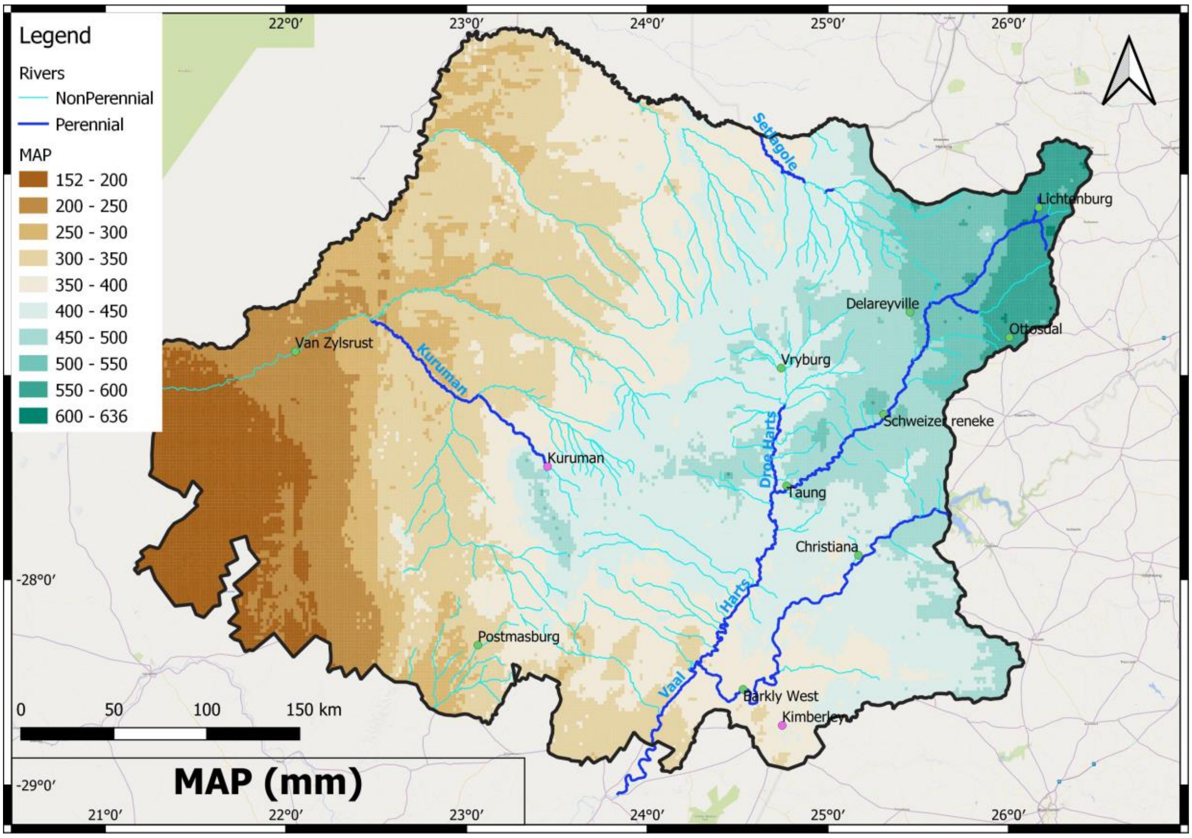


Figure 2-2 MAP in the lower Vaal

S-pan evaporation increases from 1800 mm/a in the east to 2690 mm/a in the west (**Figure 2-3).** Net evaporation losses from open water surfaces can be significant.

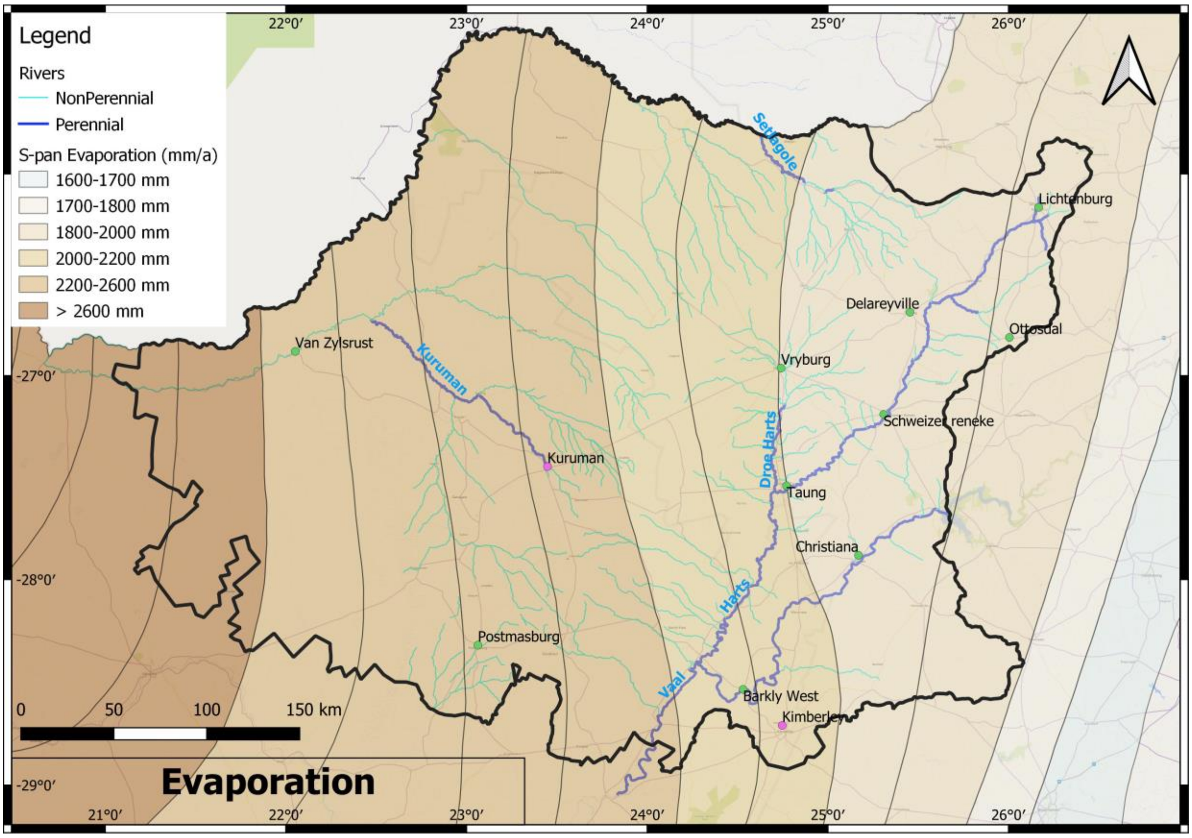


Figure 2-3 Mean annual S-pan evaporation

2.3 Geology

The Lower Vaal catchment area is underlain by diverse lithologies. Several broad lithostratigraphic units fall within the boundaries. A simplified geological map of the study area is presented in **Figure 2-4** and the legend is shown in **Table 2-1,** from oldest to youngest lithologies.

A large portion of the central and north-east corner of Lower Vaal is underlain by the Transvaal Supergroup (ANbr-Rvw), with much of it consisting of dolomite, chert, and subordinate limestone. The dolomitic area is characterised by a high potential for groundwater development, with relatively high recharge, storage and borehole yields. The groundwater level is between 8 to 20 metres below ground level on average. Water is found mainly in fractures; dissolution features are not prominent. Interactions occur where these compartments drain via dolomitic eyes.

Unlike the central dolomitic area, the geology of the western part of the catchment does not lend itself to significant groundwater resources. Boreholes tend to be less successful and much deeper, up to 125 metres below ground level. Water is also often saline. It is this very limited and unreliable groundwater resource that necessitated the implementation of the Kalahari East and West rural water supply schemes. There is no connection between surface and groundwater.

The Olifantshoek Supergroup (Orlm-Ecz) lies to the west of the study area in the vicinity of Van Zylsrust, Hotazel, Sishen and Postmasburg. Here the geology consists of very low-to-low grade metamorphic rocks of schist, quartzite, lava, sub greywacke and conglomerates. Dwyka Tillite with Ecca sandstone, mudstone, and shale (C-pd-Pt) is also found in the area (DWAF,2004).

The Ventersdorp Supergroup (ANkb-ANbo) lies to the east and north of the Transvaal Supergroup and is composed mainly of volcanic rocks, andesite, quartz porphyry, sedimentary rocks, conglomerate, and sandstone. This area also represents a low-grade metamorphism and water is found in weathered fractures. The probability of a successful borehole yielding >2l/s is 10-20% with the average groundwater level being between 8 to 20 metres below ground level.

Table 2-1 Stratigraphy of the study area

Age	Map label (Figure 2-7)	Group	Lithostratigraphy	Lithology
	N-Qg		ALLUVIUM, COLLUVIUM, ELUVIUM, GRAVEL, SCREE, SAND, SOIL, DEBRIS	Alluvium, colluvium, eluvium, boulder gravel, gravel, scree, sand, soil, debris
Neocene	N-Ql		CALCRETE, SURFACE LIMESTONE, HARDPAN	Calcrete, surface limestone, hardpan
Cretaceous	K-Qk	Kalahari	KALAHARI GROUP	Pebbly and calc-conglomerate, mudstone, gritstone, siliceous/calcareous sandstone, silcrete, diatomaceous limestone, calcrete
Jurassic	Jd		KAROO DOLERITE SUITE	Dolerite, minor ultrabasic rocks
	Pbf	Adelaide	BALFOUR FORMATION	Greenish- to bluish-grey and greyish-red mudstone, siltstone, subordinate sandstone
	Pt		TIERBERG FORMATION	Grey shale with interbedded siltstones in the upper part
	Pw		COLLINGHAM AND WHITEHILL FORMATIONS	Grey shale, tuff, minor sandstone, chert, black (white-weathering) carbonaceous shale
	Ppw		PRINCE ALBERT, WHITEHILL AND COLLINGHAM FORMATIONS	Green to grey shale, rapidly alternating grey shale (and subordinate sandstone/siltstone), thin yellow-weathering tuff (K-bentonite) layers
Permian	Pe	Ecca	ECCA GROUP	Shale, carbonaceous shale, siltstone, tuff, chert, phosphatic nodules, sandstone
Carboniferous	C-Pd	Dwyka	DWYKA GROUP	Diamictite, varved shale, siltstone, mudstone with dropstones, fluvioglacial gravel and sandstone
	ECz		ZONDERHUIS FORMATION	Reddish/purplish quartzite, phyllite, schist, dolomite, conglomerate
	ORpy		PRYNNSBERG FORMATION	Muscovite quartzite, schist
	ORbs		BRULSAND SUBGROUP	Fine- to medium-grained, white, and grey quartzite
	ORma	Volop	MATSAP SUBGROUP	Coarse-grained, reddish-brown to grey and purple quartzite/subgreywacke, minor conglomerate
	ORha		HARTLEY FORMATION	Basalt, basaltic andesite, tuff, quartzite, minor conglomerate

Age	Map label (Figure 2-7)	Group	Lithostratigraphy	Lithology
	ORlm	Olifantshoek	LUCKNOW AND MAPEDI FORMATIONS	Quartzite, flagstone, shale, dolomitic limestone, andesite
Mokolian	Rvw		VOELWATER SUBGROUP	Dolomite, jasper, iron-formation, chert, minor volcanic rocks
	Rd		DIABASE	Magnesium-rich tholeiite, melanorite
	Rog	Cox	ONGELUK FORMATION	Biotite-muscovite metapelite
	Rmg		MAKGANYENE FORMATION	Diamictite, subordinate sandstone, carbonate rock, jaspilite, mudrock, chert and conglomerate
	ORgm		GAMAGARA FORMATION	Conglomerate and shale
	SDko		KOEGAS SUBGROUP	Jaspilite, banded iron-formation (minnesotaite lutite, minor riebeckite lutite), jaspilite, mudrock, claystone, siltstone, quartzite, quartz wacke, stromatolitic dolomite, chert
	SDda		DANIELLSKUIL FORMATION	Iron-formation ("jaspilite"), mudrock (towards top), minor crocidolite, riebeckite and minnesotaite
	ANrv		REIVILO FORMATION	Chert-poor dolomite characterized by giant stromatolite domes, laminated, iron-rich dolomite, ferruginous chert
	ANpa		PAPKUIL FORMATION	Dolomite, limestone, banded iron-formation, quartzite, shale, jaspilite, chert
	SDku	Griquatown	KURUMAN FORMATION	Banded iron-formation, riebeckite-amphibolite, chert, minor minnesotaite and crocidolite, finely laminated brown to red-brown shale
	SDwo		WOLHAARKOP FORMATION	Ferruginised brecciated banded ironstone
	ANkf		KLIPFONTEINHEUWEL FORMATION	Dolomite, prominent chert at base
	ANko		KOGELBEEN FORMATION	Dolomite/limestone, banded iron-formation, quartzite, shale, jaspilite, chert
	ANkl		KLIPPAN FORMATION	Conglomerate, talus breccia, quartz arenite, shale, andesite, limestone
	ANga		GAMOHAAN FORMATION	Dolomite, limestone, banded iron-formation, quartzite, shale, jaspilite, chert
	ANff		FAIRFIELD FORMATION	Stromatolitic dolomite
	ANmo		MONTEVILLE FORMATION	Dolomite and subordinate shale, siltstone, and quartzite
	ANcw		CLEARWATER FORMATION	Shale, minor dolomite
	ANbp	Campbell	BOOMPLAAS FORMATION	Dolomite/limestone, mudrock
Vaalian	ANvb		VRYBURG FORMATION	Quartzitic sandstone, mudrock, andesite, basalt, siltstone, dolomite, limestone, minor conglomerate, tuff, and chert

Age	Map label (Figure 2-7)	Group	Lithostratigraphy	Lithology
	Rtr	Pretoria	TIMEBALL HILL AND ROOIHOOGTE FORMATIONS	Mudrock, quartzite (ferruginous in places), wacke, chert breccia, minor diamictite, conglomerate, shale, magnetic ironstone
	ANml	Chuniespoort	MALMANI SUBGROUP	Dolomite, stromatolitic, interbedded chert, minor carbonaceous shale, limestone, and quartzite
	ANbr		BLACK REEF FORMATION	Quartzite, subordinate conglomerate, and shale
	ANmt	Intrusive	MOSITA GRANITE	Pinkish, coarse-grained, porphyritic granite
	ANbo		BOTHAVILLE FORMATION	Conglomerate, gritstone, quartzite, subgreywacke, shale lenses
	ANal		ALLANRIDGE FORMATION	Andesite, tuff
	ANrg		RIETGAT FORMATION	Andesite to dacitic volcanic rocks, minor conglomerate, greywacke, and shale
	ANmk		MAKWASSIE FORMATION	Acid volcanic rocks (mainly quartz porphyry), ash flows, subordinate sedimentary rocks
	ANgg		GOEDGENOEG FORMATION	Greenish grey porphyritic and subordinate non-porphyritic mafic volcanic rocks
	ANka	Platberg	KAMEELDOORNS FORMATION	Shale, conglomerate, greywacke
	ANkb	Klipriviersberg	KLIPRIVIERSBERG GROUP	Tholeiitic basalt, andesite, basalt, tuff, and agglomerate
	AMhh	West Rand	HOSPITAL HILL SUBGROUP	Fine- to medium-grained quartzite, shale, magnetic shale
Randian	AMdo	Dominion	DOMINION GROUP	Basaltic andesite, quartz-feldspar porphyry, amygdaloidal andesite, tuff, conglomerate, quartzite
	AMlv		LINDEN GNEISS, MIDRAND GNEISS, VICTORY PARK GRANODIORITE, HONEYDEW GRANODIORITE	Ultramafic rocks, granitic rocks, dioritic gneiss, hornblende gneiss, biotite gneiss, hybrid mafic rocks, migmatite, porphyritic granodiorite
	AM-APg	Intrusive	UNDIFFERENTIATED TONALITE, GRANITE AND GNEISS	Potassic gneiss and migmatite, strongly porphyroblastic
	APzu	Intrusive	MULDERSDRIF, ROODEKRANS, CRESTA-ROBINDALE, EDENVALE-MODDERFONTEIN, ZANDSPRUIT COMPLEXES, UNDIFFERENTIATED MAFICS AND ULTRAMAFICS	Serpentinised dunite, harzburgite, lherzolite, pyroxenite and gabbro
	AMkh		KHUNWANA FORMATION	Banded chert/jaspilite, minor metavolcanic rocks, and amphibolite
	AMfr		FERNDALE FORMATION	Variegated, banded jaspilite
Swazian	AMgg	Kraaipan	GOLD RIDGE FORMATION	Mica, pyrophyllitic and quartz-chlorite schists, magnetite quartzite, dolomite, banded iron-formation and amphibole-rich zones

Age	Map label (Figure 2-7)	Group	Lithostratigraphy	Lithology
	AMkr		KRAAIPAN GROUP	Banded iron-formation, jaspilite, metavolcanic rocks (amphibolite)

2.4 Hydrogeology

The region is divided into several groundwater regions **(Figure 2-5)**:

- The Eastern and Western Kalahari are covered by extensive Cretaceous to Quaternary sand overlying a host of lithologies
- The Zeerust-Delmas Karst Belt consists of Malmani dolomites;
- The Ghaap Plateau is underlain by Campbell and Griquatown Group dolomites and banded ironstones;
- West Griqualand consists of the Olifantshoek Group, Volop Group, Griquatown and Cox Groups banded ironstone, mudstone, shale, tillite and quartzite;
- The Taung-Prieska Belt consists of Vrgburg Group quartzite, Ventersdorp volcanics, and some Ecca Group shale;
- The Western Highveld contains banded ironstone of the Kraaipan Group, intrusive granite and gneiss, Witwatersrand Supergroup rocks of the Dominion and West Rand Group, Ventersdorp Supergroup volcanics and Ecca group shales;
- The Northeast and Central Pan contains Ecca Group, and Balfour Formation shales, mudstones, and sandstones, and extensive dolerite intrusions.

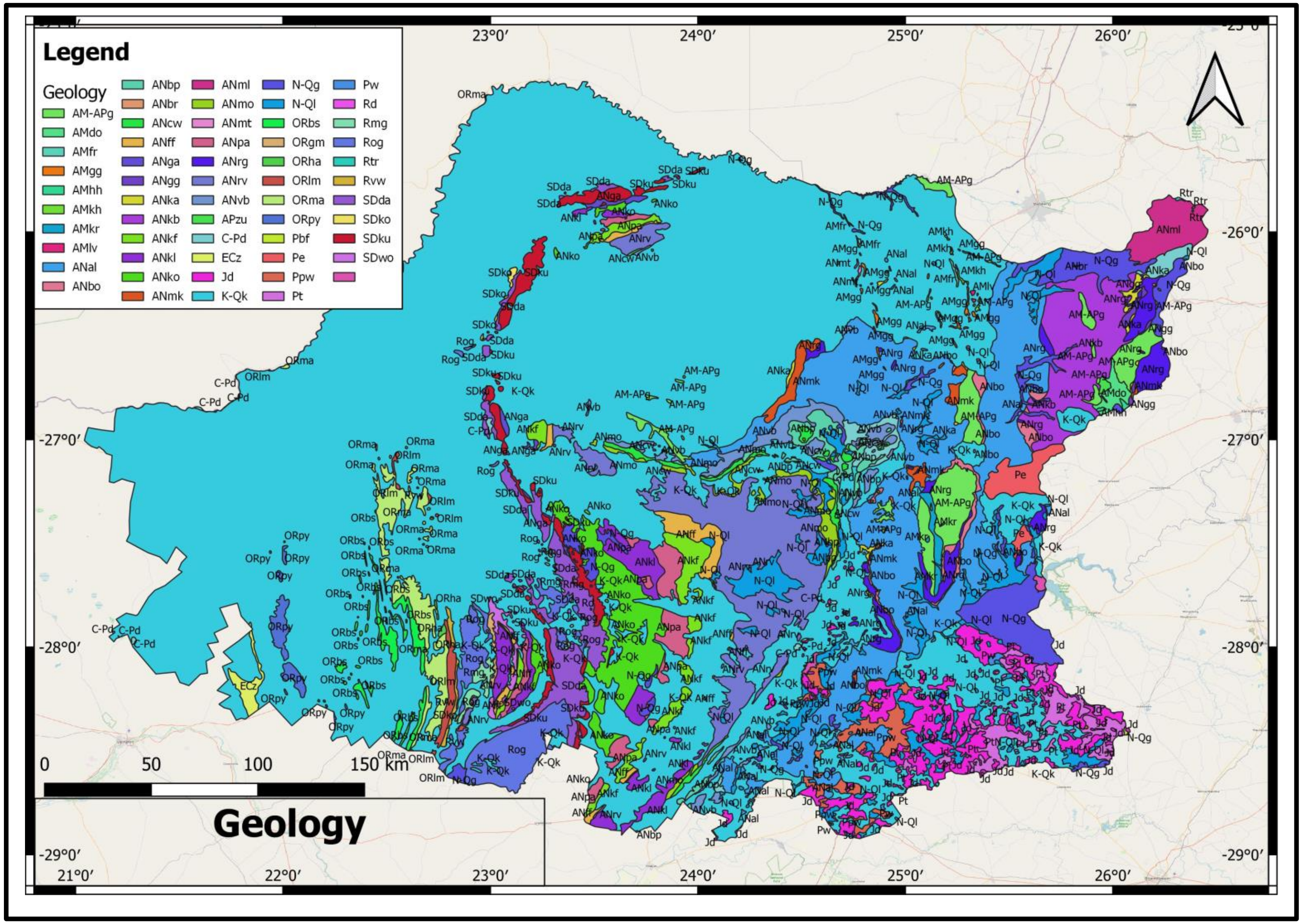


Figure 2-4 Geology. See Table 2-1 for the lithology of Geology codes

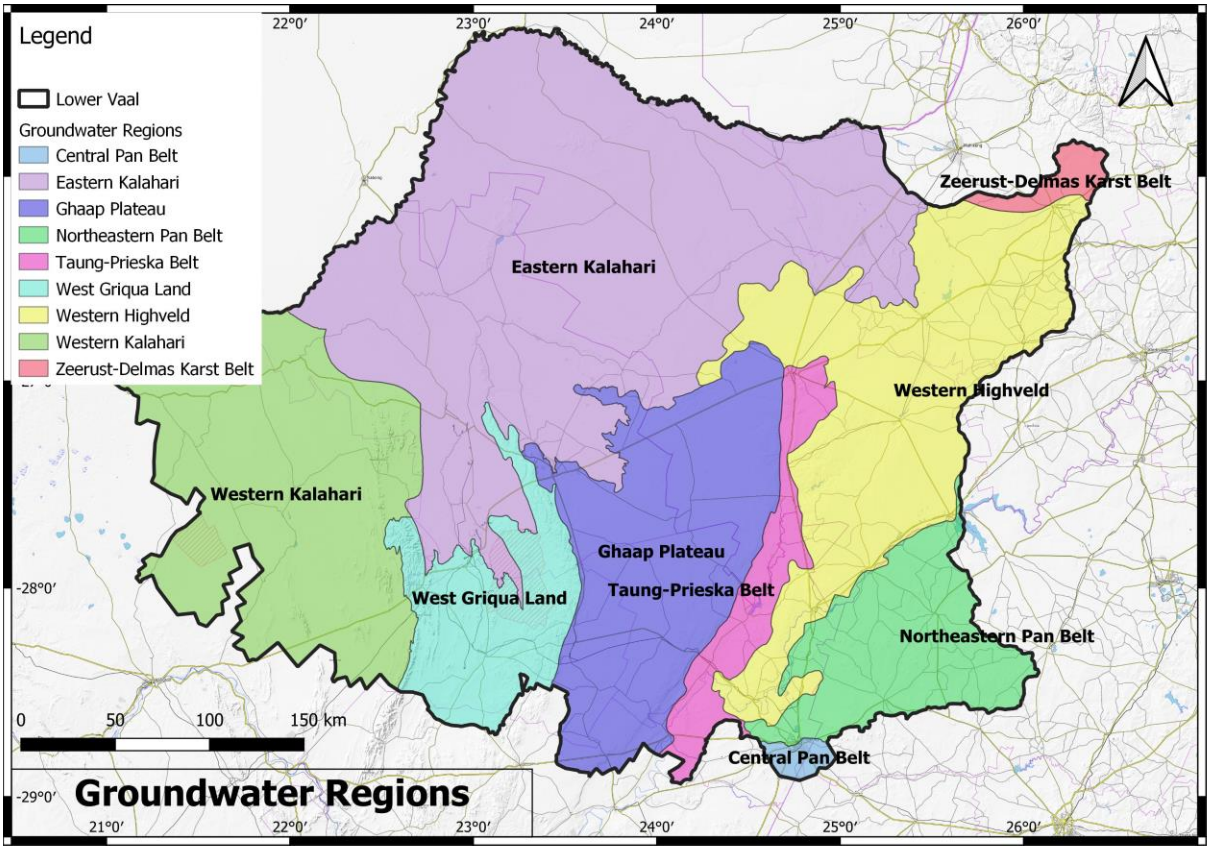


Figure 2-5 Groundwater regions

3 METHODOLOGY

All hydrochemical data were collated from the DWS Resources Quality Information Services. Data was assessed for potable use by using the Guidelines for Domestic Water Quality (DWS, 1998) (**Table 3-1**). Potable groundwater is defined as water of Class 0 and 1.

Table 3-1 DWS Guidelines for Domestic Water Quality (DWAF, 1998)

Analyses	Unit	Classification				
		Class 0 IDEAL	Class I GOOD	Class II MARGINAL	Class III POOR	Class IV UNACCEPTABLE
pH		5.5 - 9.5	4.5-5.5 and 9.5-10	4-4.5 and 10-10.5	3-4 and 10.5-11	< 3 or > 11
Conductivity	mS/m	< 70	70 - 150	150 - 270	270 - 450	> 450
TDS	mg/l	< 450	450 - 1000	1000 - 2400	2400 - 3400	> 3400
Total Hardness	CaCO 3	< 200	200 - 300	300 - 600	> 600	
Calcium	mg/l	< 80	80 - 150	150 - 300	> 300	
Copper	mg/l	< 1	1 - 1.3	1.3 - 2	2 - 15	> 15
Iron	mg/l	< 0.5	0.5 - 1	1 - 5	5 - 10	> 10

Analyses	Unit	Classification				
		Class 0 IDEAL	Class I GOOD	Class II MARGINAL	Class III POOR	Class IV UNACCEPTABLE
Magnesium	mg/l	< 70	70 - 100	100 - 200	200 - 400	> 400
Manganese	mg/l	< 0.1	0.1 - 0.4	0.4 - 4	4 - 10	> 10
Potassium	mg/l	< 25	25 - 50	50 - 100	100 - 500	> 500
Sodium	mg/l	< 100	100 - 200	200 - 400	400 - 1000	> 1000
Chloride	mg/l	< 100	100 - 200	200 - 600	600 - 1200	> 1200
Fluoride	mg/l	< 0.7	0.7 - 1	1 - 1.5	1.5 - 3.5	> 3.5
Nitrate NO3 - N	mg/l	< 6	6 - 10	10 - 20	20 - 40	> 40
Nitrite NO2 - N	mg/l	< 6	6 - 10	10 - 20	20 - 40	> 40
Orthophosphate (PO4 as P)	mg/l	< 0.1	0.1 - 0.25	0.25 - 1	> 1	
Sulphate (SO4)	mg/l	< 200	200 - 400	400 - 600	600 - 1000	> 1000
MPN E. coli	/100 ml	0	0 - 1	1 - 10	10 - 100	> 100

Water quality classification is based on the number of samples falling within each class of the South African Water Quality Guidelines for Domestic use (**Table 3-1**) for the Present Status Category (PSC) assessment of a water resource (**Table 3-2).**

Table 3-2 Classification by water quality

Management Class	Description
I	>95% Class 0 or 1
II	>95% Class 0-2
III	Class 3 or 4 or <75% Class 0-2

For trace metals, all analyses with results below detection limits were removed to remove spurious results. Constituents with maximum results above SANS-241 limits were evaluated.

4 GROUNDWATER QUALITY

4.1 Electrical Conductivity

The distribution of EC is shown in **Figure 4-1, Tables 4-1 and 4-2.** Groundwater quality is of Class 0 to 1, with an EC of less than 150 mS/m, in the dolomitic aquifers of C31A around Lichtenburg and Kuruman in D41G and D41J-L. Only a few boreholes are of Class 2, indicative of very localised contamination. These boreholes are found at small communities like Tsineng, Ga Mopedi and Mothibistad or at farms.

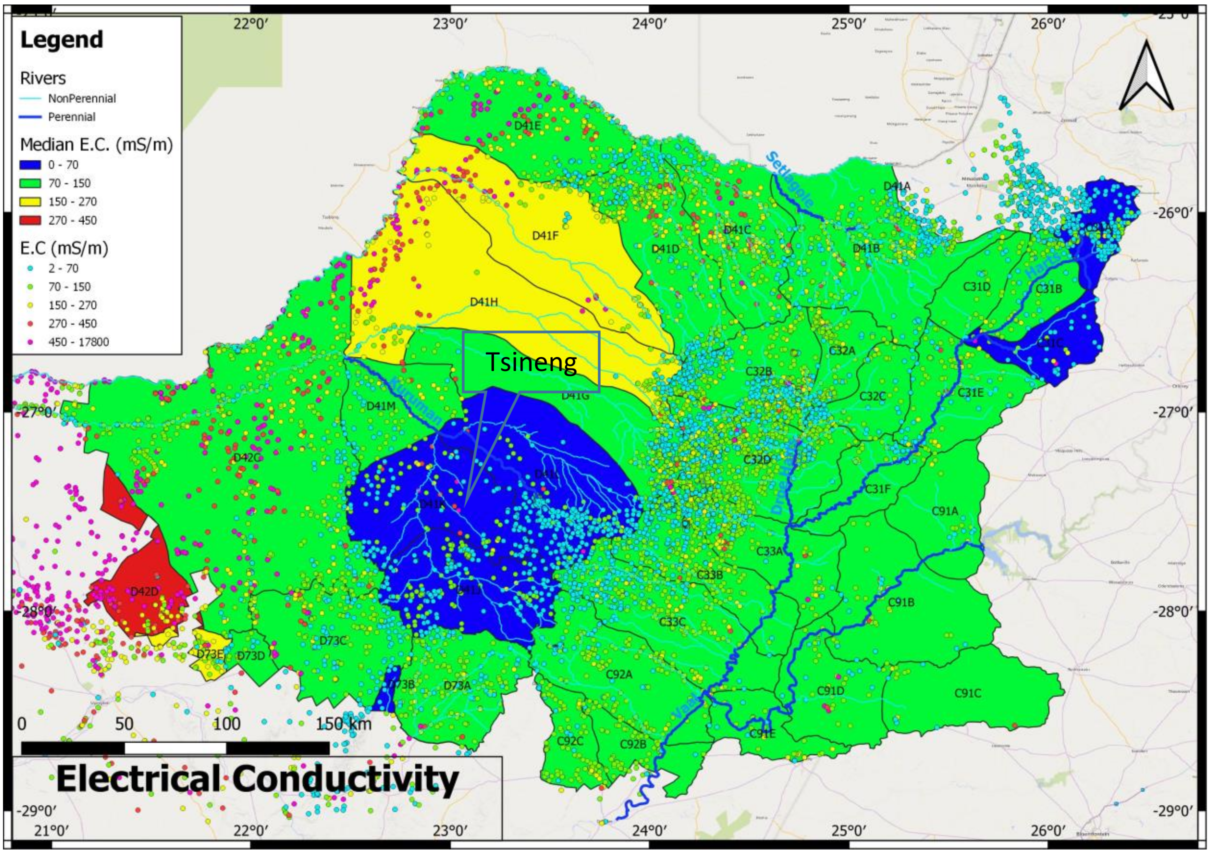


Figure 4-1 Groundwater EC by Quaternary catchment

Over most of the eastern portion of the study area groundwater is of Class 1-2, with a median of Class 1. Groundwater of Class 2 and 3 is found at Hartswater where irrigation from the Vaalharts occurs in C33A-C, however, the median remains Class 1. Groundwater of Class 3-4 occurs from Vryburg to Reivilo in C32B, D41G and C33B. These areas are associated with communities, irrigated lands, and extensive dryland farming.

The western region has highly variable water quality, with medians of 1-3 in non-dolomitic areas. The presence of large endoreic areas (**Figure 4-2)** in the drier western regions results in worsening groundwater quality to Class 3 and 4 since salts are not exported and accumulate in pans, creating variability in water quality.

Linear trends of Class 0-1 groundwater occur along the Kuruman and Molopo rivers, indicative of flood waters and discharge from dolomite springs recharging the aquifer along the rivers. This can be noted along the Kuruman River to the confluence with the Molopo River as far as D41E.

The presence of endoreic salt pans northeast of Kimberley in C91D also results in elevated salinity.

Table 4-1 Distribution of EC in mS/m by Percentile

Quat	Average	Median	20th percentile	40th percentile	60th percentile	80th percentile	100th percentile	Potable fraction
C31A	60.96	60.15	35.86	57.1	62.9	75.1	291.2	98.72
C31B	79.77	74.4	60.7	68.28	78.38	96.24	206	97.65
C31C	98.64	51.7	28.1	43.2	60.2	142	658	82.05
C31D	85.30	79.3	64.7	72.6	89.3	110.2	149	100.00
C31E	88.94	76.75	57.34	70.52	83.12	104.52	433	90.43
C31F	78.68	75.7	46.8	69.2	83.8	102.9	164	92.68
C32A	136.81	90.5	71.94	84.2	96.22	109.86	2330	90.48
C32B	155.01	81.3	54.9	73.7	90	124.9	15600	85.92
C32C	79.89	72	57	66.02	76.66	97.24	283	93.94
C32D	91.07	79.15	63.9	73.98	85.44	104.48	780	92.20
C33A	99.00	84.2	67	78.7	88.8	107.2	1180	89.75
C33B	90.46	79.45	60.9	72.7	86.8	107.5	451.1	92.23
C33C	81.88	72.1	55.3	65.66	78.32	100.44	514	93.15
C91A	100.39	73.7	59.92	65.1	85.56	125.06	243.5	86.67
C91B	116.49	95	70	79	113.6	142.6	359	82.61
C91C	102.88	79.1	55.7	68.44	86.74	116.6	354	84.62
C91D	177.58	80.9	60.2	72.42	88.72	116.36	1888.9	84.62
C91E	122.23	106.45	64.32	89.18	118.92	186.4	339.2	66.67
C92A	75.63	73.8	40.2	62.7	81.8	104.2	199	95.52
C92B	100.17	99.65	79.44	91.94	102.8	119.66	160	98.44
C92C	100.13	90.2	73.04	84.06	98.68	120.12	352	86.41
D22A	308.00	308	308	308	308	308	308	0.00
D41A	64.05	58.2	46.7	54.7	61.52	77.18	225	97.88
D41B	100.07	79.2	53.7	71.86	94.38	122.02	664	84.37
D41C	143.01	109.95	76.76	96.54	126.72	202	752	64.78
D41D	115.85	90.7	66.6	83	99.54	160	550	77.35
D41E	249.24	114.9	68.8	90.9	191	317	1570	55.38
D41F	314.85	206	89.6	163	246	393.4	4270	37.72
D41G	101.81	78	56.7	67.96	84.46	125.7	724.6	85.20
D41H	252.43	164.3	78.32	123.88	271	407.68	1219	47.21
D41J	74.91	69.45	45.4	62.8	75.46	89.14	521.8	94.84
D41K	95.67	68	26.48	50.12	72.44	106.16	1370	86.47
D41L	59.43	55	41.62	51.8	57.96	67.28	483.5	98.88
D41M	107.01	88.2	64.96	75.98	99.7	144.6	402	82.35
D42A	1 000.53	606.3	273.12	461.88	857.92	1675.2	5620.3	5.49
D42B	666.50	448	253.08	383.62	570.72	884.32	6643.1	6.23
D42C	358.37	140	78	106	182.4	440.3	9800	53.17
D42D	817.87	384	146.6	277.38	517.3	1012.82	17800	20.67

D42E	412.68	315	128.88	260.74	402.4	600.5	3904	23.62
D73A	96.90	81.2	66.7	76.26	84.64	107.58	849	91.28
D73B	107.64	51.5	15.86	35.86	67.88	128.56	1264	81.65
D73C	118.72	82	35.5	64.34	100.48	156.98	772	77.69
D73D	191.17	123.8	66.7	99.4	161.3	264	1187	54.35
D73E	205.61	158.2	95.9	139.6	180.64	273.22	950	45.45
D73F	204.49	175.5	112	143.98	214.54	283.32	517	45.45

Table 4-2 Number of boreholes with EC in quality class

Quaternary	Class 0	Class 1	Class 2	Class 3	Class 4	Classification
C31A	172	59	2	1	0	I
C31B	37	46	2	0	0	I
C31C	26	6	5	0	2	III
C31D	8	18	0	0	0	I
C31E	35	50	6	3	0	II
C31F	17	21	3	0	0	II
C32A	28	124	9	2	5	II
C32B	246	395	73	21	11	II
C32C	46	47	5	1	0	II
C32D	291	537	57	8	5	II
C33A	85	239	29	6	2	II
C33B	143	213	25	4	1	II
C33C	131	141	18	1	1	II
C91A	7	6	2	0	0	II
C91B	9	29	5	3	0	III
C91C	5	6	1	1	0	III
C91D	11	22	2	1	3	III
C91E	11	17	13	1	0	II
C92A	93	99	9	0	0	I
C92B	4	59	1	0	0	I
C92C	17	72	13	1	0	II
D22A	0	0	0	1	0	III
D41A	278	92	8	0	0	I
D41B	127	159	42	9	2	II
D41C	43	163	85	23	4	III
D41D	105	216	71	22	1	III
D41E	53	86	48	28	36	III
D41F	12	31	29	22	20	III
D41G	108	105	24	10	3	III
D41H	31	62	24	51	29	III
D41J	128	111	10	2	1	II

D41K	73	42	8	7	3	III
D41L	299	54	1	2	1	I
D41M	27	43	11	4	0	II
D42A	4	5	24	31	100	III
D42B	2	21	60	103	182	III
D42C	104	324	116	103	157	III
D42D	25	165	170	150	409	III
D42E	4	26	24	29	44	III
D73A	43	114	12	2	1	II
D73B	66	23	12	2	6	III
D73C	106	82	34	10	9	III
D73D	11	14	12	6	3	III
D73E	15	50	49	17	12	III
D73F	1	19	12	10	2	III

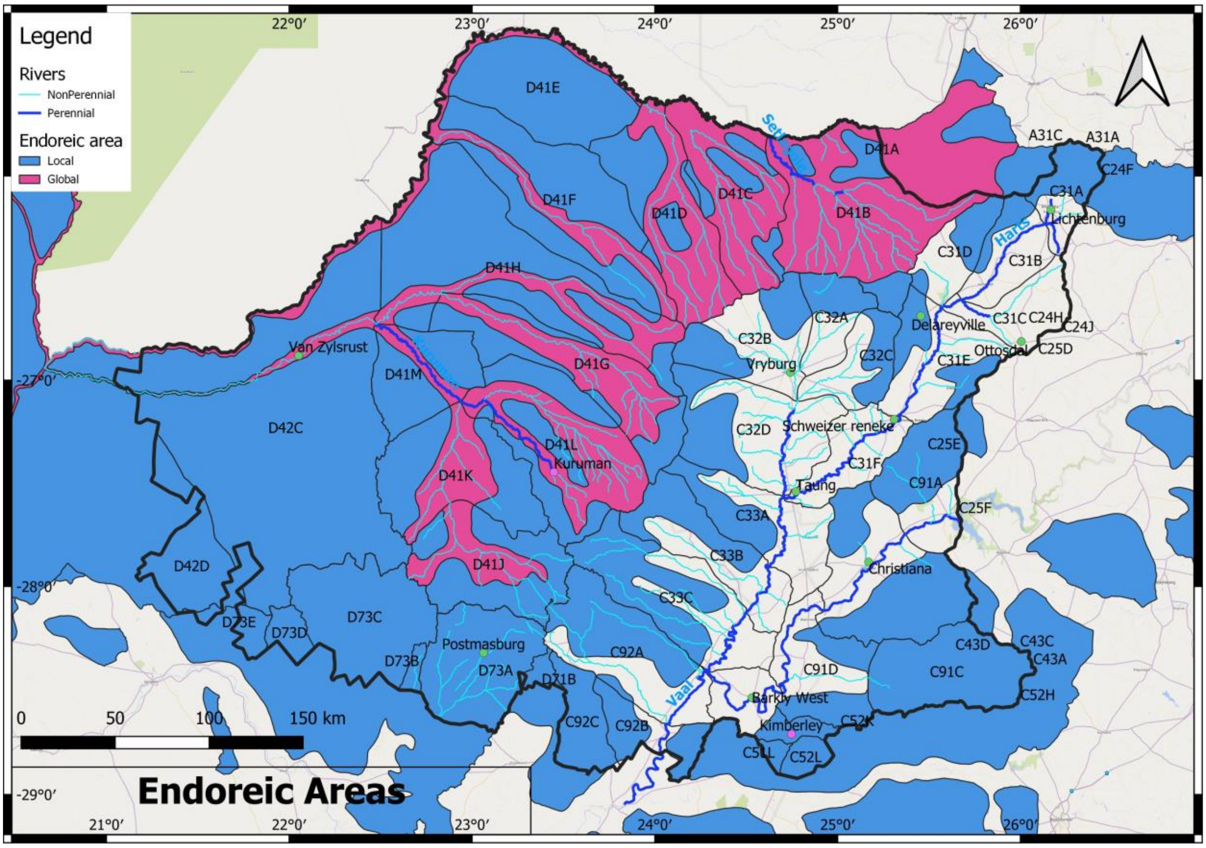


Figure 4-2 Endoreic areas

Boreholes with a high electrical conductivity of Class 3 and 4 are largely restricted to areas covered by Kalahari sands, which are dry, endoreic, and where the sand cover serves to reduce recharge (**Figure 4-3).**

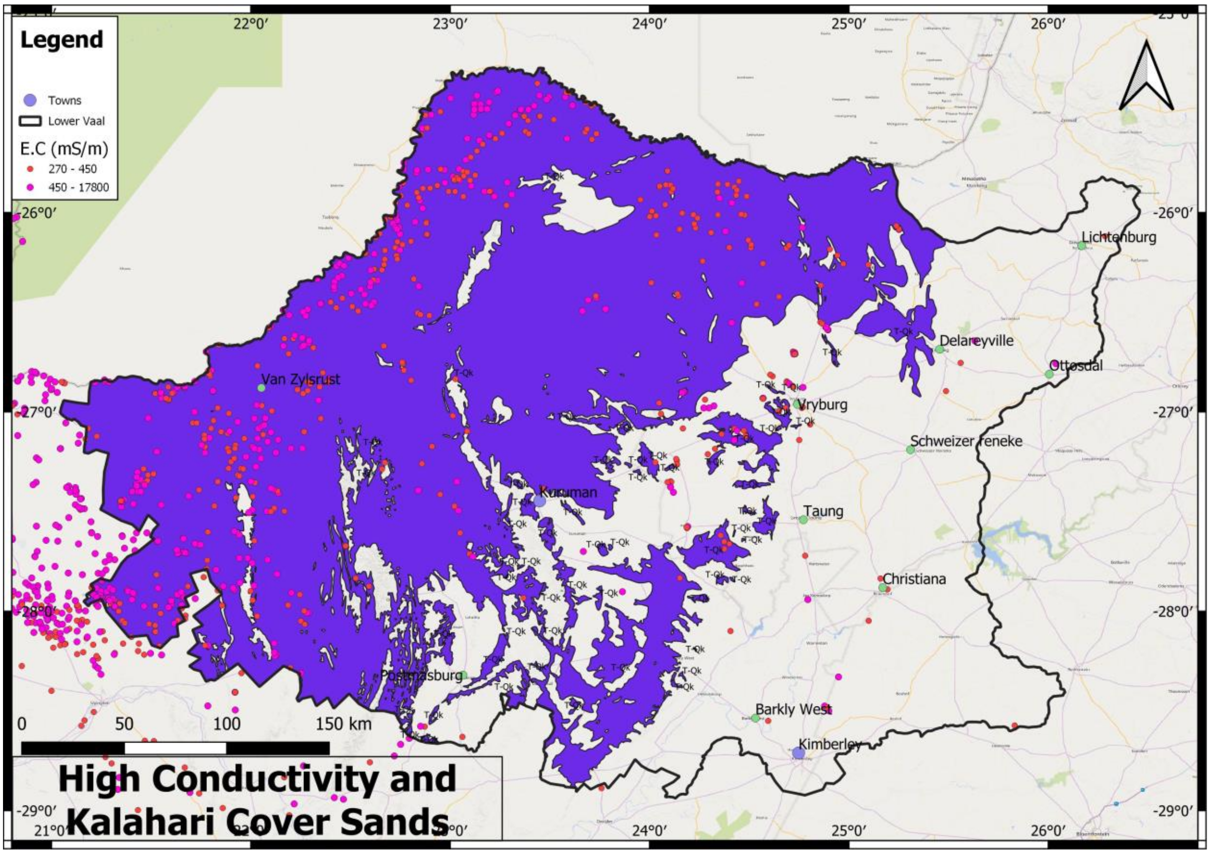


Figure 4-3 Boreholes with high EC and Kalahari sand cover

4.2 Nitrates

Groundwater quality in terms of nitrates is shown in **Figure 4-4, Tables 4-3 and 4-4.** No significant nitrification is evident in the lower Vaalharts area of C33, although elevated nitrates occur in a band of dryland agriculture between Vryburg and Lichtenburg in C31and C32, and east of Kimberley and Christiana in C91C. In the west, natural dryland nitrate conditions occur due to the absence of vegetation and organic material to uptake nitrates, resulting in the median nitrate concentration to decrease to Class 2 in D42, and in increasing number of boreholes of class 3 and 4 in the western Quaternaries of D41.

In C31 and C91C, less than 50% of boreholes are potable due to nitrates (**Figure 4-5).** Potability also decreases westwards to under 50% in D42 and D73.

Many catchments are borderline but classified as Present Status Category (PSC III), with 80-95% of boreholes in Class 0-2.

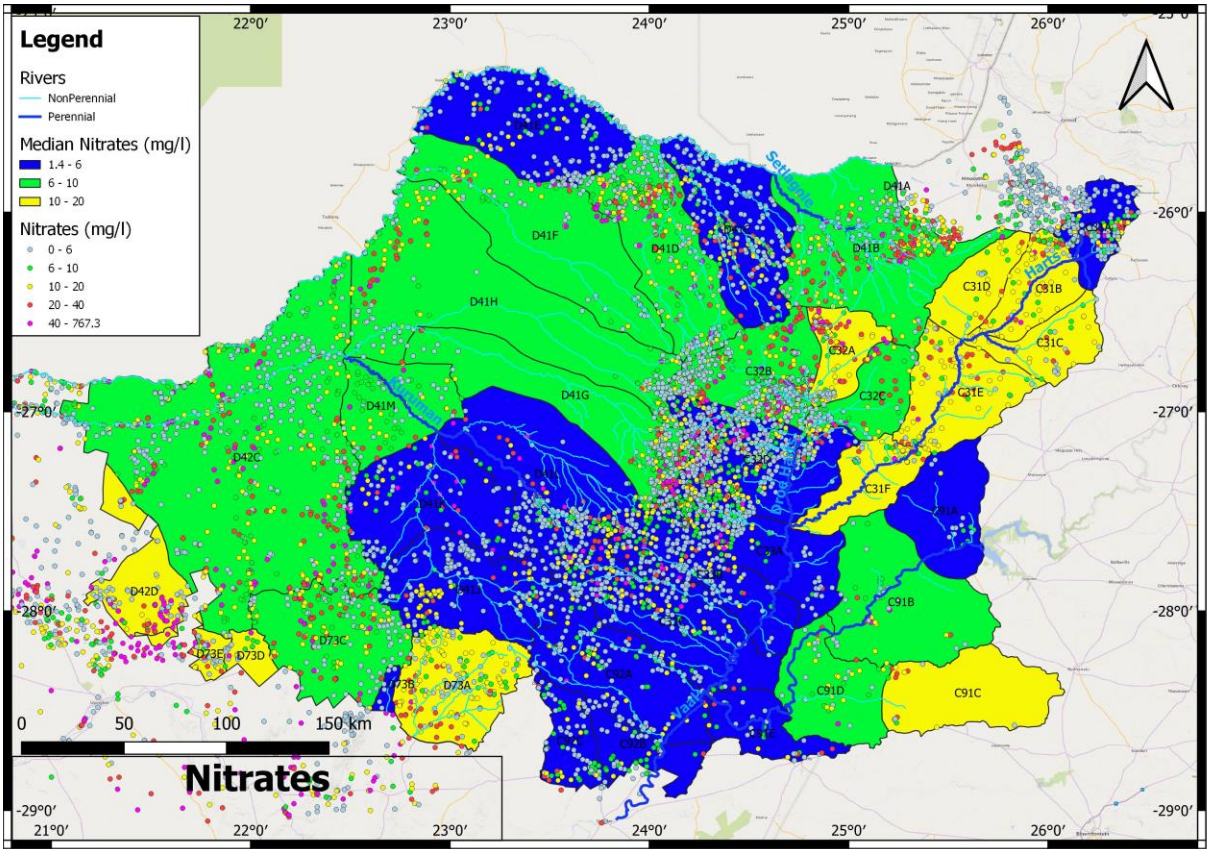


Figure 4-4 Nitrates in Groundwater by Quaternary catchment

Table 4-3 Distribution of Nitrates in mg/l by Percentile

Quat	Average	Median	20th percentile	40th percentile	60th percentile	80th percentile	100th percentile	Potable fraction
C31A	7.69	4.60	1.65	3.71	5.93	11.83	42.82	74.79
C31B	14.91	13.98	6.31	11.61	15.68	19.91	69.08	31.76
C31C	11.07	10.53	2.04	8.73	11.46	18.73	36.51	46.15
C31D	11.37	10.47	6.79	9.17	12.02	17.45	22.89	46.15
C31E	14.55	14.10	4.79	11.32	15.49	20.99	97.66	32.98
C31F	14.05	11.86	7.08	9.36	13.34	21.04	45.55	46.34
C32A	17.50	15.38	4.28	11.67	17.26	24.59	107.46	35.71
C32B	15.85	7.01	2.31	5.09	9.37	20.32	373.45	62.87
C32C	12.85	6.04	1.73	4.73	10.60	23.16	70.82	58.59
C32D	10.16	4.28	0.58	2.89	6.41	12.72	376.87	72.49
C33A	8.97	5.76	1.63	4.01	7.37	11.84	131.13	74.79
C33B	8.76	5.40	1.74	3.38	7.56	11.66	74.89	73.58
C33C	7.45	3.71	1.28	2.75	5.12	9.87	99.38	80.41
C91A	4.51	3.13	1.22	2.89	5.13	7.08	12.49	93.33
C91B	11.32	6.80	2.23	5.45	7.72	22.46	46.90	65.22
C91C	12.72	16.43	2.77	7.91	17.60	21.66	24.51	46.15

C91D	11.29	9.71	1.91	7.68	11.72	18.30	62.38	53.85
C91E	8.48	5.85	0.50	3.58	7.65	15.53	38.80	71.43
C92A	5.40	3.07	0.99	2.52	3.85	8.06	97.36	86.07
C92B	6.09	5.08	1.83	3.24	6.22	8.12	34.92	87.50
C92C	8.00	4.52	1.86	3.64	6.18	10.16	58.92	79.61
D22A	1.47	1.47	1.47	1.47	1.47	1.47	1.47	100.00
D41A	7.02	3.25	0.79	2.03	4.62	11.77	70.30	78.04
D41B	13.98	9.92	1.75	6.54	14.14	25.13	110.12	50.00
D41C	7.88	3.97	1.23	3.15	5.71	13.26	64.65	73.27
D41D	12.55	6.89	1.46	4.84	10.71	18.40	161.21	59.28
D41E	3.48	1.41	0.12	0.88	2.34	6.49	39.48	90.84
D41F	16.35	6.25	0.38	2.78	9.22	17.92	145.25	62.28
D41G	17.49	6.55	0.97	4.51	9.13	21.98	234.94	61.60
D41H	10.82	7.32	1.44	4.22	10.02	19.03	47.35	59.90
D41J	5.13	2.20	1.08	1.70	3.44	10.10	28.04	79.37
D41K	14.98	4.46	0.99	3.45	5.94	13.02	242.16	75.19
D41L	8.87	3.89	1.41	3.03	5.06	9.55	278.41	80.95
D41M	11.23	7.68	2.92	6.47	8.33	14.91	103.91	71.76
D42A	30.25	18.01	5.12	12.59	26.18	53.41	220.67	32.93
D42B	35.58	27.24	11.40	22.12	32.56	58.01	275.69	17.07
D42C	13.63	6.11	1.14	3.97	8.63	18.89	275.37	65.16
D42D	30.93	14.25	2.06	8.87	21.06	42.61	767.30	43.63
D42E	14.42	9.47	3.43	7.73	11.72	18.11	171.79	54.33
D73A	11.96	10.29	3.31	7.85	12.18	18.78	66.57	47.67
D73B	15.46	5.87	0.67	3.74	11.57	25.14	91.96	57.80
D73C	18.78	8.35	1.68	5.17	11.83	21.39	410.12	53.72
D73D	28.86	11.26	4.12	7.26	14.13	35.90	278.98	44.44
D73E	28.22	11.84	3.06	8.20	20.30	45.49	318.28	44.76
D73F	17.19	5.90	2.74	4.97	11.55	26.09	119.71	56.82

Table 4-4 Number of boreholes with Nitrates in quality class

Quaternary	Class 0	Class 1	Class 2	Class 3	Class 4	Classification	% Class 0-2
C31A	142	33	34	22	3	III	89.32
C31B	16	11	41	15	2	III	80.00
C31C	13	5	17	4	0	III	89.74
C31D	5	7	10	4	0	III	84.62
C31E	22	9	42	20	1	III	77.66
C31F	8	11	13	7	2	III	78.05
C32A	41	19	52	44	12	III	66.67
C32B	336	133	126	90	61	III	79.76

C32C	49	9	17	17	7	III	75.76
C32D	526	125	155	51	41	III	89.76
C33A	187	83	59	19	13	III	91.14
C33B	205	79	62	27	13	III	89.64
C33C	194	40	34	14	9	III	92.10
C91A	9	5	1	0	0	II	100.00
C91B	22	8	6	8	2	III	78.26
C91C	4	2	3	4	0	III	69.23
C91D	14	7	14	3	1	III	89.74
C91E	21	9	7	5	0	III	88.10
C92A	148	25	23	4	1	II	97.51
C92B	36	20	5	3	0	II	95.31
C92C	59	23	11	8	2	III	90.29
D22A	1	0	0	0	0	I	100.00
D41A	250	45	41	39	3	III	88.89
D41B	127	42	82	72	15	III	74.26
D41C	197	36	51	32	2	III	89.31
D41D	191	55	99	46	24	III	83.13
D41E	194	34	20	3	0	II	98.80
D41F	57	14	22	9	12	III	81.58
D41G	119	35	40	30	26	III	77.60
D41H	86	32	43	29	7	III	81.73
D41J	185	15	45	7	0	II	97.22
D41K	80	20	13	7	13	III	84.96
D41L	246	43	35	22	11	III	90.76
D41M	29	32	14	7	3	III	88.24
D42A	38	16	34	32	44	III	53.66
D42B	40	23	75	118	113	III	37.40
D42C	395	125	133	88	57	III	81.83
D42D	282	119	138	183	197	III	58.65
D42E	38	31	35	15	8	III	81.89
D73A	55	27	64	25	1	III	84.88
D73B	55	8	18	14	14	III	74.31
D73C	103	27	57	35	20	III	77.27
D73D	14	6	10	6	9	III	66.67
D73E	46	18	21	25	33	III	59.44
D73F	22	3	8	5	6	III	75.00

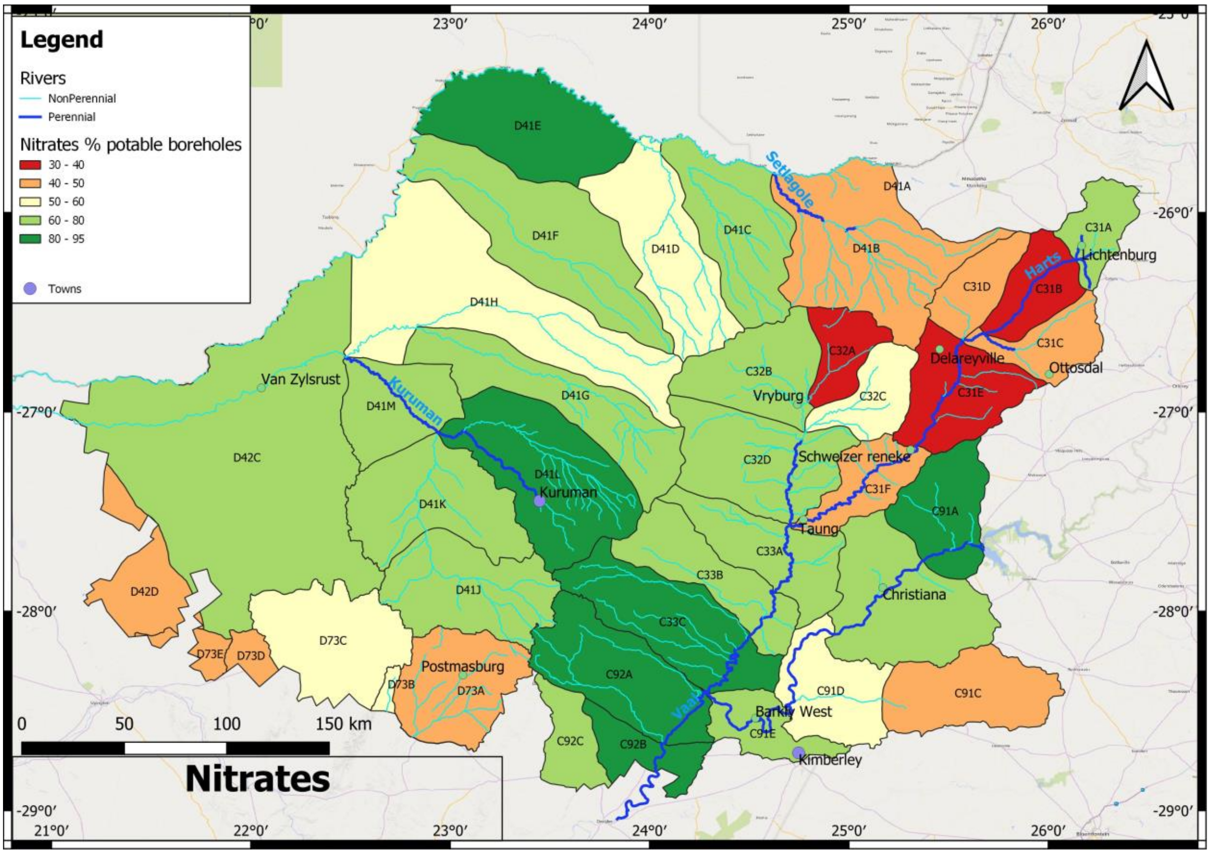


Figure 4-5 Percent of boreholes with potable groundwater in terms of nitrates

4.3 Fluoride

Groundwater quality in terms of fluoride is shown in **Figure 4-6, Tables 4-5 and 4-6.**

Water quality is generally of Class 0. Only in the western half of D41C and in D42D are areas of high fluoride found. Isolated areas of high Fluoride are found in Randian age volcanics (such as the Rietgat Formation (ANrg), and in some intrusive and extrusive granitoids, volcanics and metamorphics.

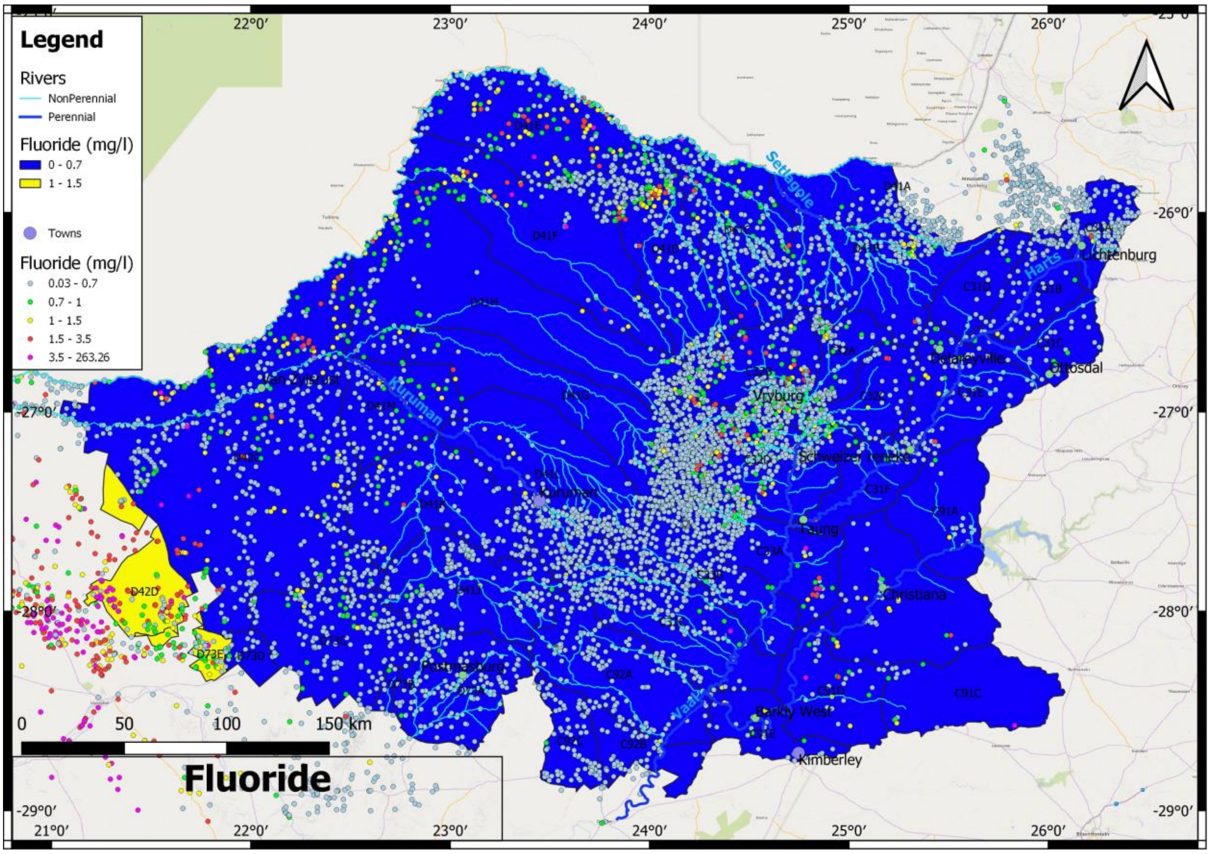


Figure 4-6 Fluoride in Groundwater by Quaternary catchment

Table 4-5 Distribution of Fluoride in mg/l by Percentile

Quat	Average	Median	20th percentile	40th percentile	60th percentile	80th percentile	100th percentile	Potable fraction
C31A	0.15	0.1	0.05	0.1	0.12	0.2	2.15	99.10
C31B	0.25	0.23	0.1	0.2	0.26	0.37	1.057	98.73
C31C	0.31	0.25	0.192	0.24	0.27	0.378	0.94	100.00
C31D	0.42	0.42	0.27	0.41	0.45	0.47	0.725	100.00
C31E	0.43	0.33	0.23	0.3	0.398	0.55	1.81	93.62
C31F	0.48	0.432	0.25	0.36	0.47	0.56	1.9	95.12
C32A	0.63	0.565	0.34	0.5	0.6364	0.78	2.17	86.59
C32B	0.53	0.41	0.22	0.35	0.47	0.68	4.68	90.03
C32C	0.49	0.4	0.27	0.35	0.42	0.604	2.55	92.93
C32D	0.43	0.33	0.22	0.29	0.38	0.56	3.31	95.10
C33A	0.39	0.3	0.21	0.27	0.33	0.47	3.7	96.68
C33B	0.25	0.24	0.13	0.2	0.28	0.36	1	99.74
C33C	0.28	0.21	0.1	0.168	0.24	0.36	12	98.61
C91A	0.39	0.27	0.206	0.258	0.316	0.59	1.04	93.33
C91B	0.69	0.5	0.23	0.38	0.61	1.13	2.04	73.91
C91C	0.94	0.6	0.3074	0.3682	0.6752	0.86	5.72	84.62

C91D	0.69	0.45	0.266	0.402	0.508	0.782	3.89	88.24
C91E	0.47	0.47	0.233	0.392	0.57	0.643	1.1	95.12
C92A	0.26	0.25	0.1292	0.2	0.284	0.372	1.46	99.50
C92B	0.33	0.3	0.24	0.292	0.33	0.4064	0.87	100.00
C92C	0.36	0.33	0.274	0.31	0.35	0.446	0.9	100.00
D41A	0.20	0.16	0.05	0.13	0.2	0.27	2.97	98.59
D41B	0.35	0.287	0.18	0.25	0.32	0.43	4.3	96.76
D41C	0.49	0.39	0.23	0.35	0.432	0.64	4.36	93.71
D41D	0.53	0.37	0.23	0.3088	0.45	0.76	5.21	90.12
D41E	0.74	0.49	0.27	0.41	0.64	1.21	7.14	73.71
D41F	0.76	0.52	0.226	0.412	0.684	1.088	6.98	75.44
D41G	0.28	0.22	0.128	0.19	0.25	0.37	3.37	98.00
D41H	0.61	0.54	0.23	0.4	0.65	0.928	3.34	85.28
D41J	0.27	0.24	0.13	0.2	0.27	0.36	1.23	99.20
D41K	0.33	0.25	0.11	0.17	0.332	0.49	2.93	96.99
D41L	0.16	0.13	0.05	0.11	0.14	0.1994	1.85	98.88
D41M	0.49	0.45	0.306	0.374	0.48	0.664	1.44	95.24
D42A	6.28	2.84	0.986	2.25	4.266	8.108	52.64	20.25
D42B	6.20	3.61	1.848	2.93	4.756	8.87	40.79	3.82
D42C	0.67	0.44	0.22	0.35	0.51	0.8	12.69	85.73
D42D	2.62	1.26	0.81	1.07	1.53	2.68	263.26	35.87
D42E	3.38	3.42	1.35	2.942	3.748	4.582	10.92	14.52
D73A	0.33	0.313	0.24	0.2804	0.34	0.4216	0.86	100.00
D73B	0.29	0.2485	0.15	0.22	0.282	0.438	1.14	99.07
D73C	0.45	0.305	0.16	0.24	0.38	0.6	4.65	93.33
D73D	0.78	0.59	0.404	0.54	0.654	1.0912	2.602	76.74
D73E	1.48	1.03	0.584	0.848	1.24	1.99	10.46	47.55
D73F	4.39	4.31	2.832	3.7834	4.582	5.592	12.04	2.33

Table 4-6 Number of boreholes with Fluoride in quality class

Quaternary	Class 0	Class 1	Class 2	Class 3	Class 4	Classification
C31A	218	1	1	1	0	I
C31B	77	1	1	0	0	I
C31C	35	4	0	0	0	I
C31D	24	2	0	0	0	I
C31E	81	7	5	1	0	II
C31F	38	1	0	2	0	I
C32A	110	32	18	4	0	II
C32B	595	73	37	35	2	II
C32C	84	8	5	2	0	II

C32D	802	52	23	21	0	I
C33A	339	10	4	6	2	I
C33B	382	3	1	0	0	I
C33C	278	6	3	0	1	I
C91A	13	1	1	0	0	II
C91B	30	4	7	5	0	III
C91C	8	3	1	0	1	III
C91D	26	4	2	1	1	III
C91E	35	4	2	0	0	I
C92A	198	1	1	0	0	I
C92B	63	1	0	0	0	I
C92C	100	3	0	0	0	I
D22A	1	0	0	0	0	I
D41A	346	4	4	1	0	I
D41B	317	11	9	1	1	I
D41C	265	33	11	8	1	II
D41D	315	59	26	14	1	II
D41E	155	30	37	27	2	III
D41F	69	17	20	6	2	III
D41G	240	5	3	2	0	I
D41H	127	41	22	7	0	II
D41J	241	8	2	0	0	I
D41K	123	6	3	1	0	I
D41L	351	2	3	1	0	I
D41M	68	12	4	0	0	I
D42A	21	12	11	46	73	III
D42B	7	6	30	120	177	III
D42C	604	81	57	40	17	III
D42D	138	187	206	259	116	III
D42E	9	9	11	34	60	III
D73A	169	3	0	0	0	I
D73B	104	3	1	0	0	I
D73C	203	21	5	10	1	II
D73D	28	5	6	4	0	III
D73E	37	31	29	34	12	III
D73F	1	0	1	10	31	III

4.4 Metals

The maximum concentration of metals identified as exceeding SANS-241 limits in the Lower Vaal are shown in **Table 4-7.** The most widespread problem constituent is arsenic.

Table 4-7 Maximum concentration of metals in mg/l

Quat	As	B	Ba	Cd	Cr	Fe	Hg	Mn	Mo	Ni	Pb	Zn
C31A		0.049	0.054		0.009	0.159		0.066				0.946
C31B	0.023	0.107	0.266		0.009	0.022		0.01	0.007			1.082
C31C		0.015	0.081					0.108	0.004	0.008		
C31D		0.06	0.194		0.007	0.027		0.002	0.013			0.04
C31E		0.189	0.574		0.007				0.006	0.009		0.019
C31F	0.013	0.25	0.176	0.002	0.003	0.021		0.008	0.007			0.016
C32A	0.041	0.948	0.103		0.003	0.014			0.021			0.359
C32B	0.078	0.165	0.147			0.067			0.014			0.228
C32C		0.108	0.005	0.002	0.01	0.023		0.008	0.014			0.16
C32D		1.296	0.009	0.007	0.004	1.17		0.051	0.007			1.193
C33A	0.087	0.213	0.046	0.004	0.006	0.993		0.396	0.011			0.12
C33B		0.139	0.231	0.002	0.005	0.075		0.095	0.01			0.541
C33C		0.182				0.807						1.049
C91A	0.029	0.133	0.115	0.006	0.006	0.029			0.007			0.008
C91B	0.093	1.151	0.611		0.016	0.027		0.025	0.007	0.056		0.722
C91C	0.009	0.121	0.023		0.004			0.002	0.01			0.03
C91D												
C91E		0.068	0.034		0.006				0.009			
C92A	0.042		0.046			0.695		0.002	0.008			0.011
C92B												
C92C						0.366						
D22A												
D41A	0.094	1.716	0.219	0.007	0.02	1.238		42.449	0.019	0.662	0.006	1.848
D41B	0.011	0.211	0.56		0.018	2.235		0.191	0.018		0.048	1.535
D41C		0.172	0.285	0.002	0.005	0.031		0.091				0.004
D41D		0.636	1.095		0.01	0.09			0.029			0.083
D41E		0.943	0.051		0.021	0.017		0.002	0.026			0.01
D41F		1.035	0.025		0.013	0.026		0.003				0.012
D41G		0.131	0.43	0.002	0.008	1.166		0.002	0.012			0.013
D41H		1.052	0.504		0.009	0.057		0.005	0.012			0.237
D41J		0.32	0.4	0.011	0.111	0.32	0.001	0.055	0.07	0.06	0.103	5.813
D41K	0.52	0.299	0.916	0.017	0.107	2.117		0.159	0.097	0.042	0.133	5.913
D41L	0.081	0.493	0.061		0.007	1.579		0.025	0.019			0.031
D41M												
D42A	0.063	5.25	0.17		0.277	0.019			0.036			0.234
D42B		4.244	0.634	0.003	0.211	0.042			0.027			0.199
D42C	0.017	0.425	0.428	0.005	0.019	0.032		0.018				0.245
D42D		0.185	0.018		0.006	0.788		0.257	0.009		1.528	0.577
D42E	0.032	1.176	0.071	0.007	0.009	0.1		0.155	0.041			0.113

D73A												
D73B	0.023	0.036	0.04	0.004	0.004	0.02		0.004	0.029		0.013	0.009
D73C	0.047	1.142	0.081	0.012	0.01	0.018			0.007			0.274
D73D												
D73E												
D73F		0.398		0.023					0.075			

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

The Target Water Quality Guideline Range is 0 - 10 ug/l and should never exceed 200 ug/l, which would result in serious health risk (DWAF, 2006b). The distribution of As occurrence over 10 ug/l is shown in **Figure 4-7**.

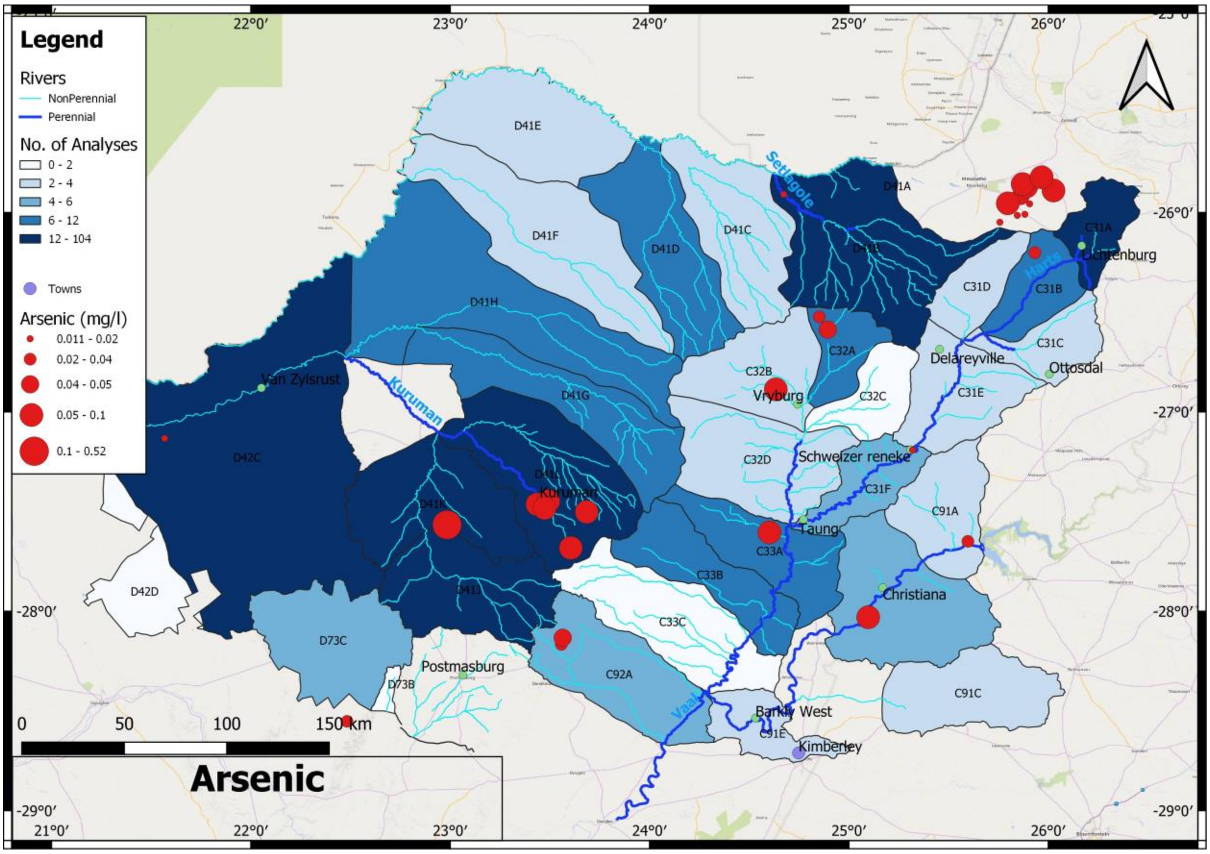


Figure 4-7 Distribution of arsenic in groundwater

The following lithologies are associated with arsenic:

- Kraaipan Group: pyrite associated with pyritic gold bearing quartz veins in banded iron formations in the Vryburg-Mafikeng area.
- Campbell Rand and Asbestos Hills Subgroups of the Ghaap Plateau dolomites: Sporadic mineralisation occurs in the vicinity of Griquatown, where the dolomite is intruded by thin basic dykes. Between Griquatown and Prieska sulphides occur in banded iron of the Asbestos Hill Subgroup in quartz-carbonate veins. At Reivelo, breccia bodies in the dolomites also contain sulphides assocaiated with lead-zinc deposits. Southwest of Vryburg spalerite and galena are concentrated in massive sulphide bodies in carbonates of the Campbell Rand, with minor traces of pyrite.
- South of Zeerust, arsenic is associated with lead-zinc in the Malmani Formation near the contact with the Pretoria Subgroup.
- Dominion Group, Platberg Group, Olifantshoek Supergroup, Cox Group andesites: These volcanics can potentially host arsenic without mineralisation.

The lithologies predicted to host arsenic (Sami & Druzynski, 2003) relative to high arsenic concentrations are shown in **Figure 4-8.** Much of the northwest is covered with Kalahari sand, hence the underlying lithology cannot be shown.

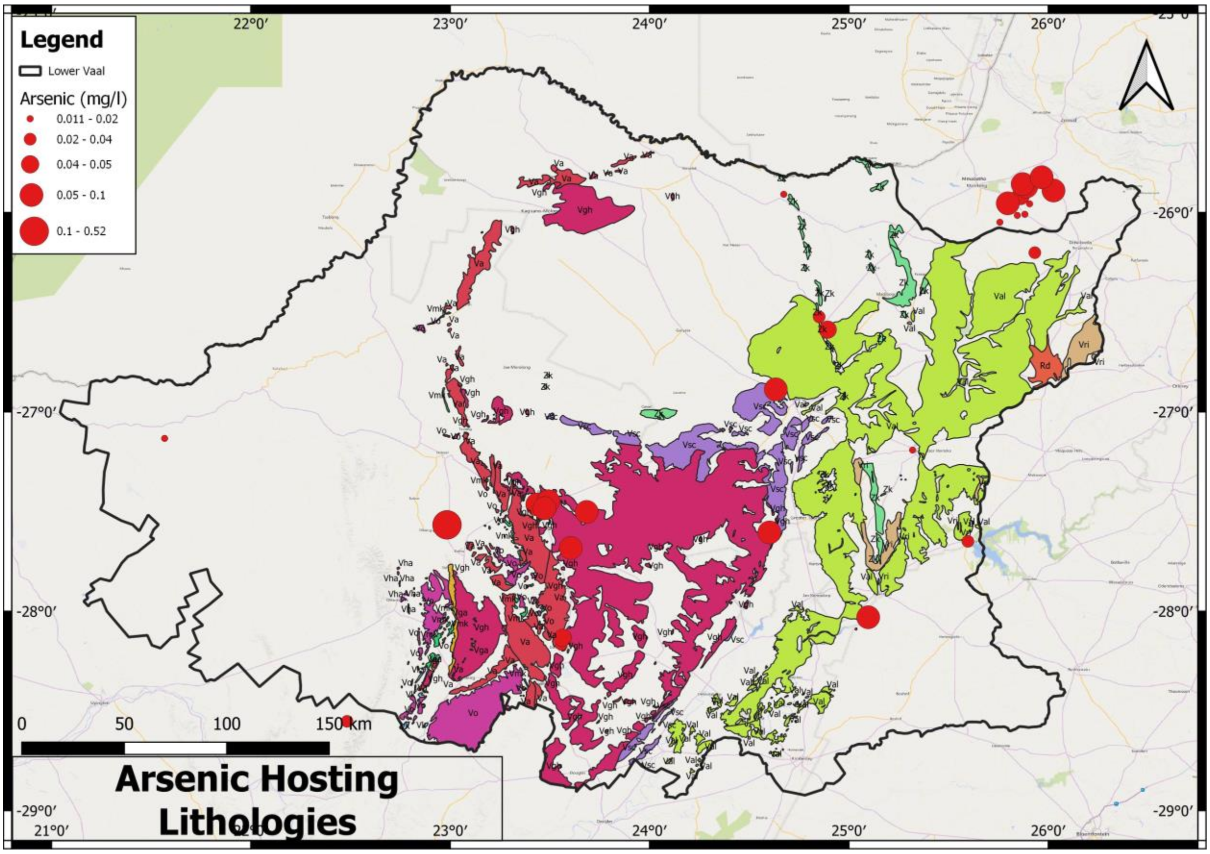
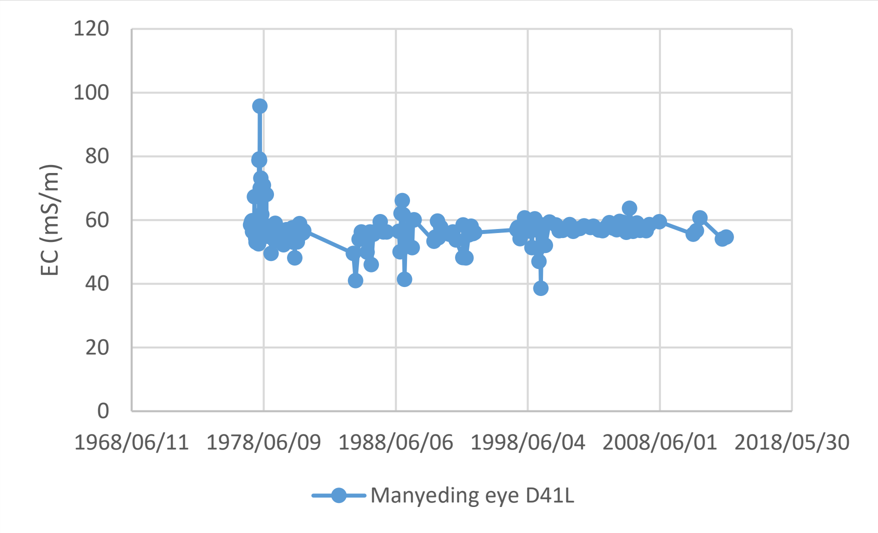


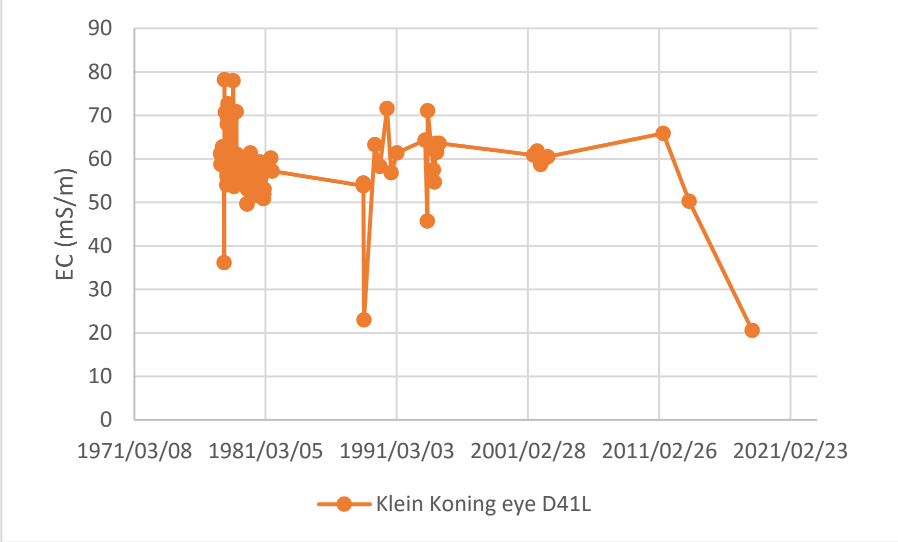
Figure 4-8 High arsenic concentrations and arsenic hosting lithologies

4.5 Temporal Trends

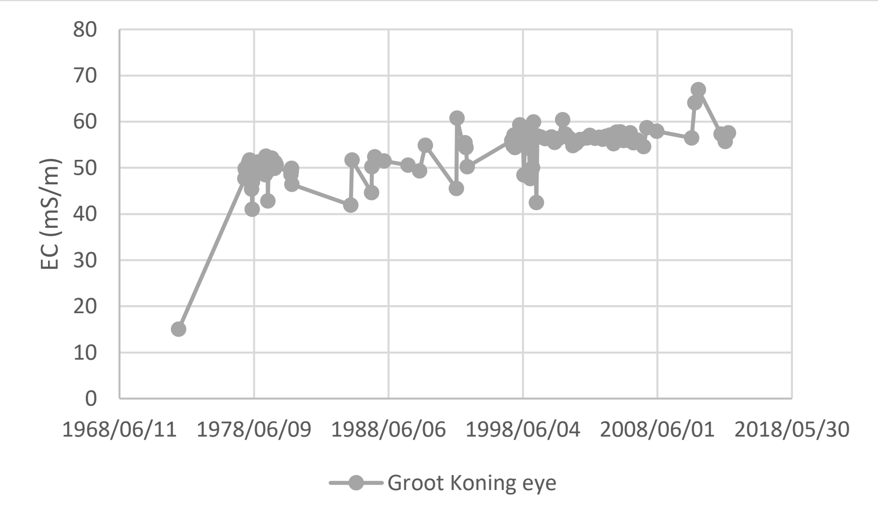
To investigate temporal trends in groundwater quality, open active water quality stations with more than 50 analyses were plotted for electrical conductivity. Data from 7 stations are available. No trend in deteriorating quality can be observed (**Figure 4-9**). Other water quality analyses with between 40 and 50 records are shown in **Appendix 1.** None exhibit long term temporal trends.



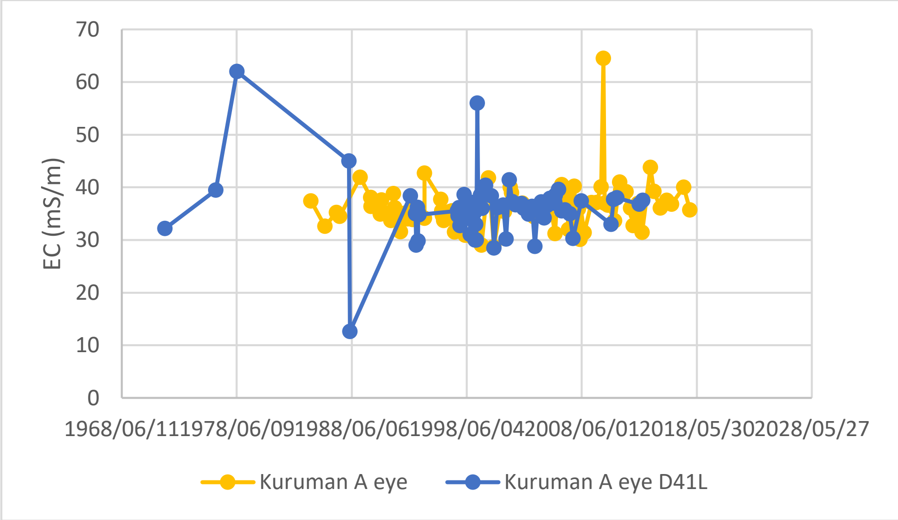
EC (mS/m)
120
100
80
60
40
20
0
1968/06/11
1978/06/09
1988/06/06
1998/06/04
2008/06/01
2018/05/30
Manyeding eye D41L



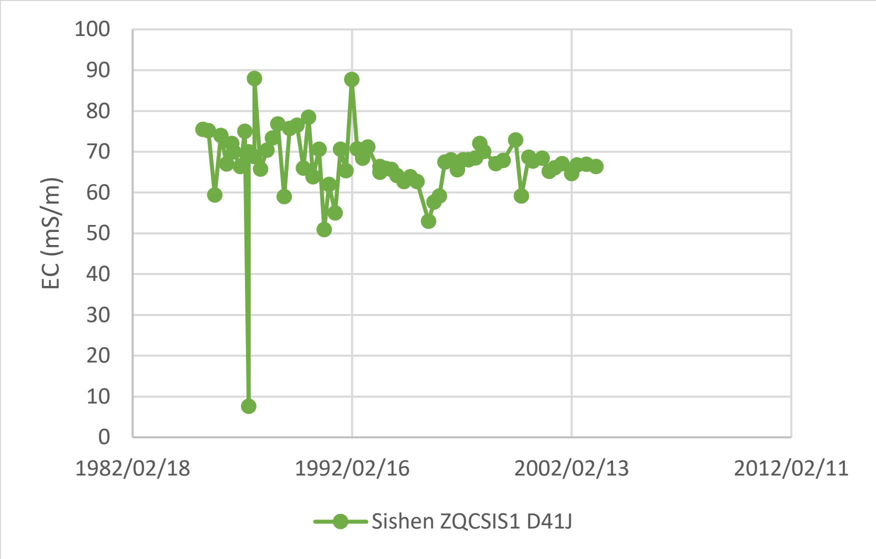
EC (mS/m)
90
80
70
60
50
40
30
20
10
0
1971/03/08
1981/03/05
1991/03/03
2001/02/28
2011/02/26
2021/02/23
Klein Koning eye D41L



EC (mS/m)
80
70
60
50
40
30
20
10
0
1968/06/11
1978/06/09
1988/06/06
1998/06/04
2008/06/01
2018/05/30
Groot Koning eye



EC (mS/m)
70
60
50
40
30
20
10
0
1968/06/11
1978/06/09
1988/06/06
1998/06/04
2008/06/01
2018/05/30
2028/05/27
Kuruman A eye
Kuruman A eye D41L



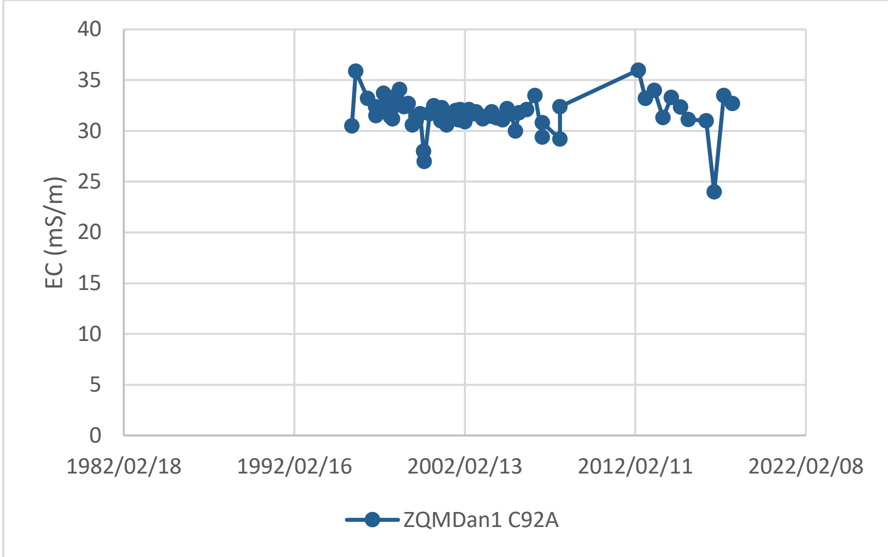


Figure 4-9 Electrical conductivity over time

4.6 Groundwater Types

Groundwater was classified according to dominated ions (**Figure 4-10)**. The dominant type (3223 samples) is Ca-Na-HCO_3-Cl-SO_4. It is widespread throughout the Lower Vaal. Ca-Mg-HCO_3-Cl-SO_4 (1468 samples) and Ca-Mg-HCO_3 (562 samples) is found only in the dolomites. Na-Cl groundwater is found only in the far west. Going eastward, the groundwater is of increasingly mixed Na-Ca-Cl mixed types. Along the Kuruman River, a linear trend of Ca Ca-Na-HCO_3-Cl-SO_4 groundwater is present amidst prevalent NaCl groundwater due to channel losses from water originating from the dolomites. This is not noted along the Molopo because channel losses in the Molopo are largely from storm runoff rather than dolomite discharge.

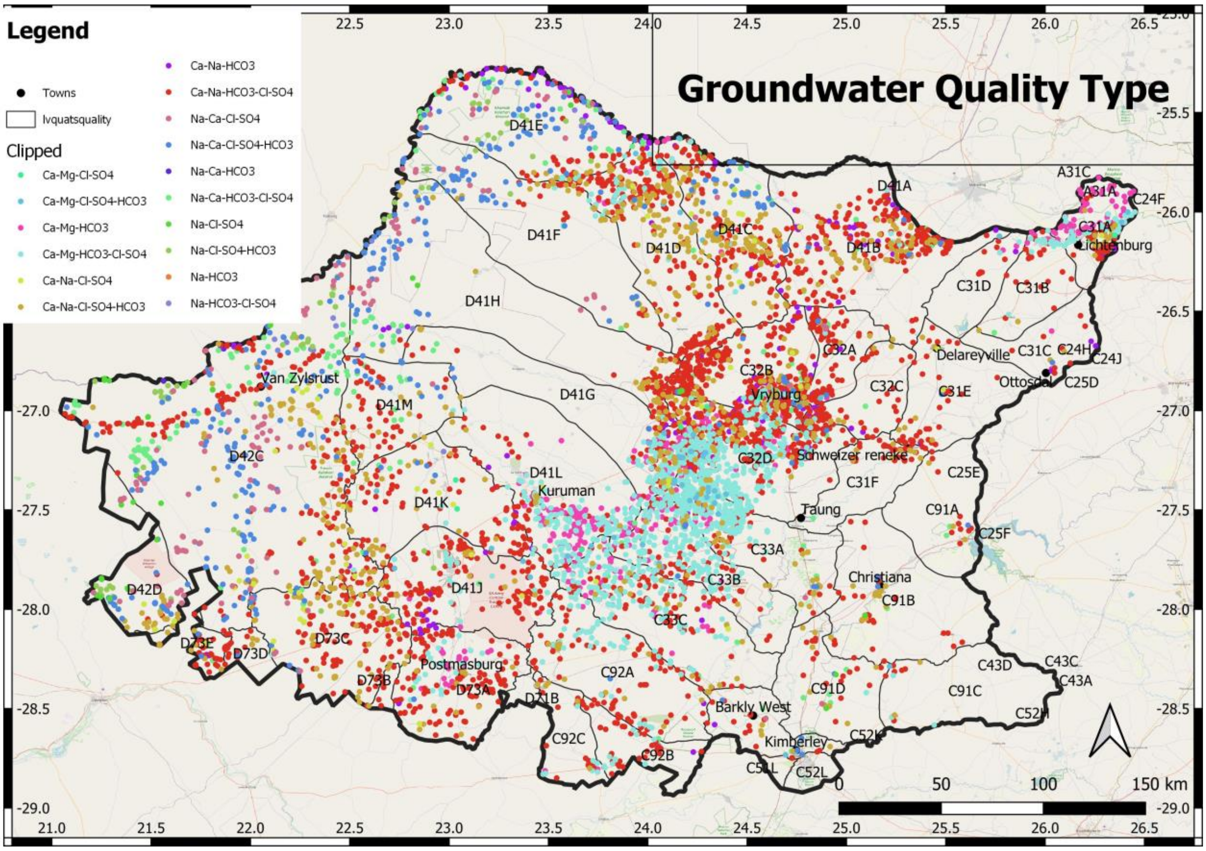


Figure 4-10 Groundwater type

4.7 Surface Groundwater Interaction Processes and Groundwater Quality

The main mechanisms affecting groundwater quality can be summarised as:

- High recharge resulting in the Ideal to Good water quality in the dolomites
- Losses of streamflow to the aquifer ameliorating water quality by dilution in a linear pattern along the Kuruman and Molopo Rivers
- Endoreic areas exhibiting poorer water quality due to the lack of surface runoff to export salts and their accumulation in pans, resulting in highly variable water quality

- Localised contamination from irrigation, vegetation removal for dryland agriculture and possibly sanitation practices, resulting in nitrate enrichment
- Isolated zones of mineralisation results in pockets of elevated metal concentrations, especially arsenic.

Groundwater can be categorised according to Present Status Category (**Table 3-2**) based on the worst PSC category in terms of EC, Nitrates and Fluoride (**Figure 4-11**). Groundwater is generally of Category III in the Lower Vaal. Many catchments are borderline classified as PSC III, with 80-95% of boreholes in Class 0-2 in terms of nitrates.

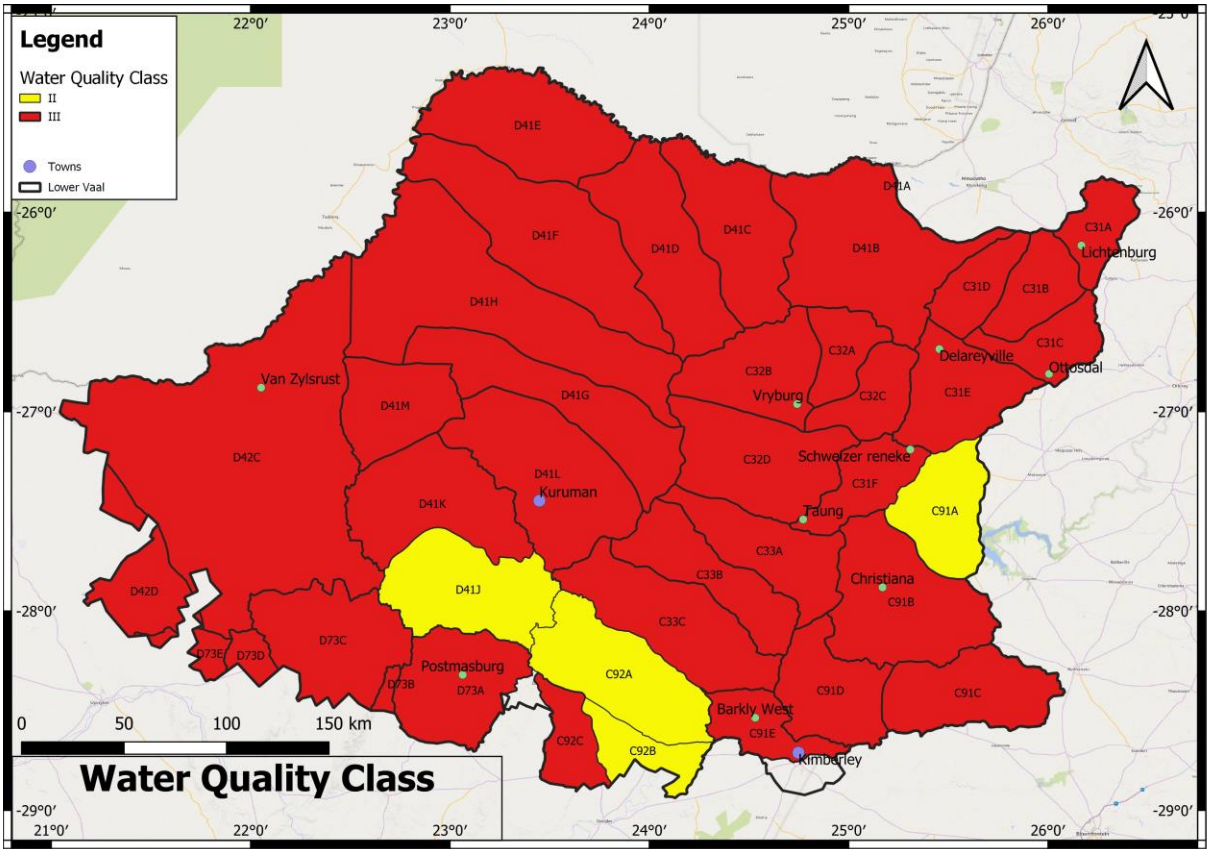


Figure 4-11 Groundwater Present Status Category

5 CONCLUSIONS

The following conclusions can be drawn regarding the categorization of groundwater:

- In terms of EC as a measure of total dissolves salts, the median groundwater quality is of Class 0 to 1, with an EC of less than 150 mS/m, in the dolomitic aquifers of C31A around Lichtenburg and Kuruman in D41L. Over most of the eastern portion of the study area groundwater is of Class 1-2, with a median of Class 1. Groundwater of Class 2 and 3 is found at Hartswater where irrigation from the Vaalharts occurs in C33A-C. Groundwater of Class 3-4 occurs from Vryburg to Reivilo in C32B, D41G and C33B. These areas are associated with communities, irrigated lands, and extensive dryland farming. The western region has highly variable water quality, with medians of 1-3 in non-dolomitic areas. The presence of large endoreic areas in the drier western regions results in worsening groundwater quality to Class 3 and 4 since salts are not exported and accumulate in pans, creating variability in water quality.

- Linear trends of Class 0-1 groundwater occur along the Kuruman and Molopo rivers, indicative of flood waters and discharge from dolomite springs recharging the aquifer along the rivers. This can be noted along the Kuruman River to the confluence with the Molopo River as far as D41E.
- Boreholes with a high electrical conductivity of Class 3 and 4 are largely restricted to areas covered by Kalahari sands, which are dry, endoreic, and the sand cover serves to reduce recharge.
- In terms of nitrates, no significant nitrification is evident in the lower Vaalharts area of C33, although elevated nitrates occur in a band are of dryland agriculture between Vryburg and Lichtenburg in C31and C32, and east of Kimberley and Christiana in C91C. West of Kuruman natural dryland nitrate conditions occur due to the absence of vegetation and organic material to uptake nitrates, resulting in the median nitrate concentration to decrease to Class 2 in D42, and in increasing number of boreholes of class 3 and 4 in D41. In C31 and C91C, less than 50% of boreholes are potable due to nitrates**.** Potability also decreases westwards to under 50% in D42 and D73.
- In terms of Fluoride, water quality is generally of Class 0. Only in the western half of D41C and in D42D are areas of high fluoride found. Isolated areas of high Fluoride are found in in Randian age volcanics and in some the some intrusive and extrusive granitoids, volcanics and metamorphics.
- Several lithologies are associated with high levels of arsenic, these being the Kraaipan Group, the Campbell Rand and Asbestos Hills Subgroups of the Ghaap Plateau dolomites, the Malmani Formation south of Zeerust, andesitic Formations of the Dominion Group, Platberg Group, Olifantshoek Supergroup and Cox Group.
- No trend in deteriorating quality can be observed from the available long term monitoring data.
- The dominant groundwater type is Ca-Na-HCO_3-Cl-SO_4. It is widespread throughout the Lower Vaal. Ca-Mg-HCO_3-Cl-SO_4 and Ca-Mg-HCO_3 is found only in the dolomites. Na-Cl groundwater is found only in the far west. Going eastward, the groundwater is of increasingly mixed Na-Ca-Cl mixed types. Along the Kuruman River, a linear trend of Ca Ca-Na-HCO_3-Cl-SO_4 groundwater is present amidst prevalent NaCl groundwater due to channel losses from water originating

from the dolomites. This is not noted along the Molopo because channel losses in the Molopo are largely from storm runoff rather than dolomite discharge.

- The main mechanisms affecting groundwater quality can be summarised as: High recharge resulting in Ideal to Good water quality in the dolomites, losses of streamflow to the aquifer ameliorating water quality by dilution in a linear pattern along the Kuruman and Molopo Rivers, endoreic areas exhibiting poorer water quality due to the lack of surface runoff to export salts and their accumulation in pans, resulting in highly variable water quality, localised contamination from irrigation, vegetation removal for dryland agriculture and possibly sanitation practices, resulting in nitrate enrichment, isolated zones of mineralisation results in pockets of elevated metal concentrations, especially arsenic.
- Groundwater is generally of PSC Category III in the Lower Vaal, however, this is the result of nitrates being on the border line of PSC category II and III in terms of nitrates, with many quaternaries having just under the threshold of 95% of boreholes of Class 0-2.

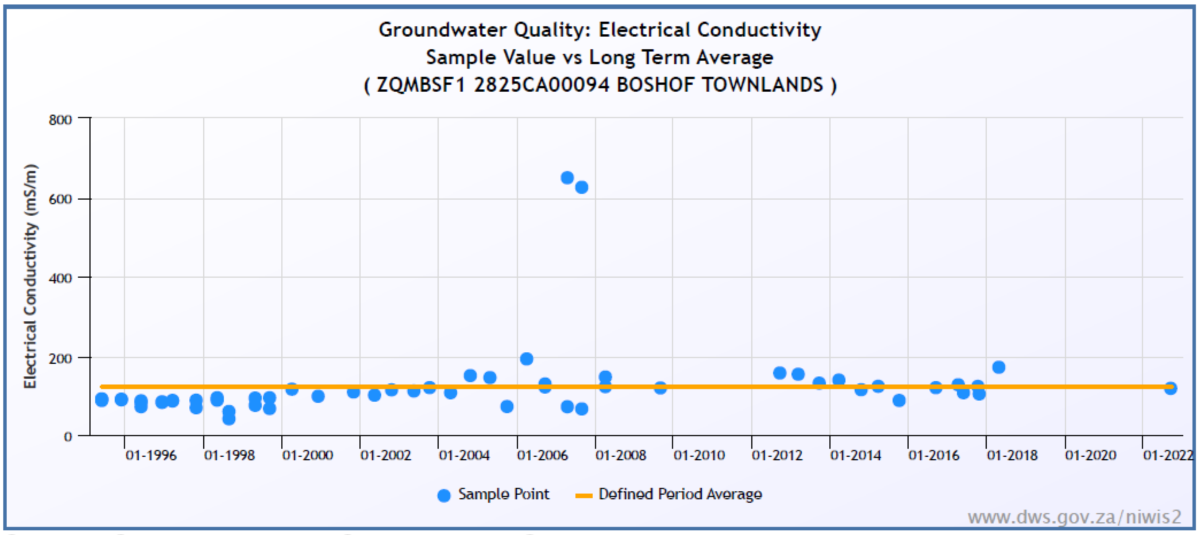
6 REFERENCES

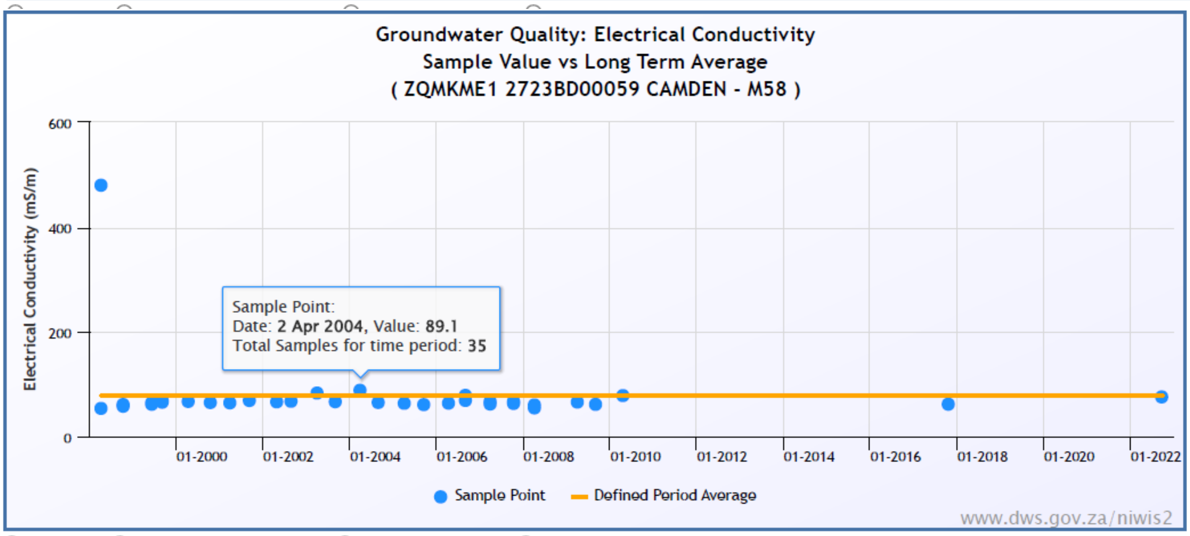
Department of Water Affairs. (1998). WRC Report Nr. TT 101/98: Quality of Domestic Water Supplies. Volume 1: Assessment Guide. The Department of Water Affairs and Forestry, Pretoria.

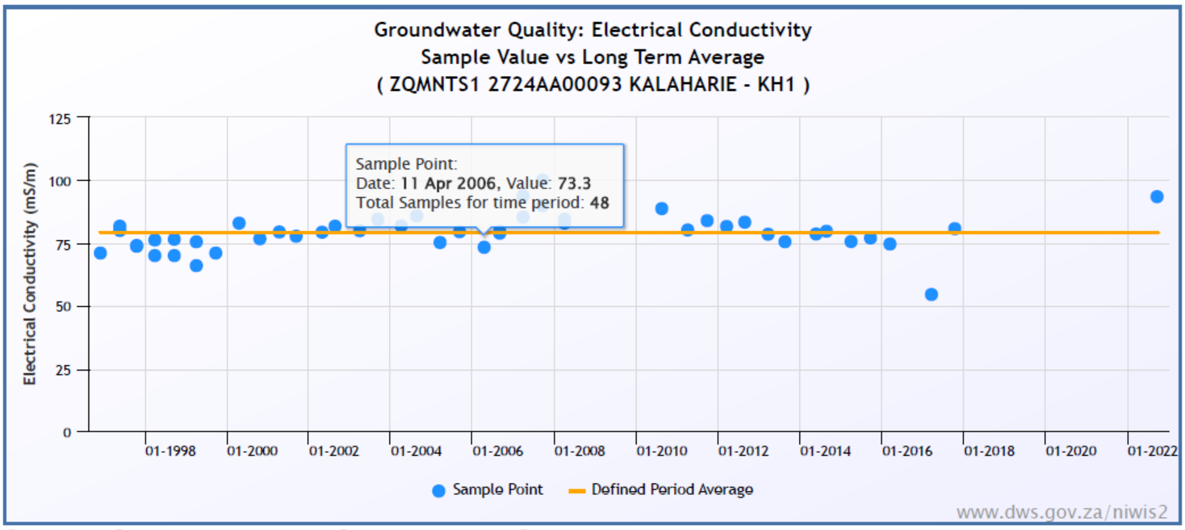
Department of Water Affairs and Forestry, South Africa. 2004. Internal Strategic Perspective: Vaal River System Overarching. Report No P RSA C000/00/0103. Prepared by: PDNA, WRP Consulting Engineers (Pty) Ltd, WMB and Kwezi-V3.

Sami, K & Druzynski, AL (2003). Predicted Spatial Distribution of naturally Occurring Arsenic, Selenium and Uranium in groundwater in South Africa-Reconnaissance Survey. WRC Report 1236/1/03.

7 APPENDIX 1 GROUNDWATER EC OVER TIME






Groundwater Quality: Electrical Conductivity
Sample Value vs Long Term Average
(ZQMNTS1 2724AA00093 KALAHARIE - KH1)
Electrical Conductivity (mS/m)
0
25
50
75
100
125
01-1998
01-2000
01-2002
01-2004
01-2006
01-2008
01-2010
01-2012
01-2014
01-2016
01-2018
01-2020
01-2022
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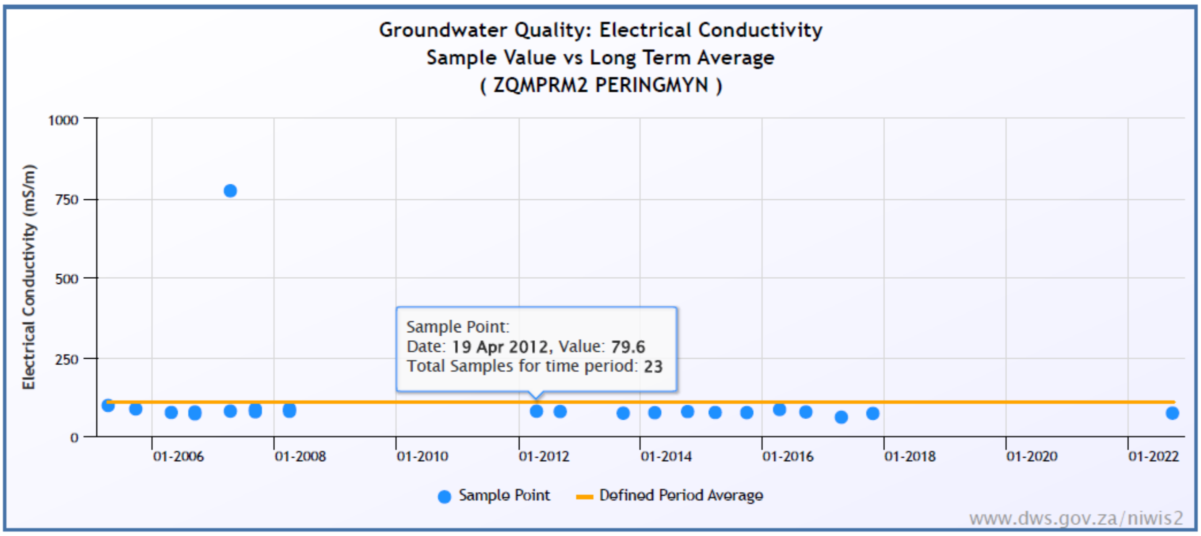
Date: 11 Apr 2006, Value: 73.3
Total Samples for time period: 48
Sample Point
Defined Period Average
www.dws.gov.za/niwis2


Groundwater Quality: Electrical Conductivity
Sample Value vs Long Term Average
(ZQMPRM2 PERINGMYN)
Electrical Conductivity (mS/m)
0
250
500
750
1000
01-2006
01-2008
01-2010
01-2012
01-2014
01-2016
01-2018
01-2020
01-2022
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Total Samples for time period: 23
Sample Point
Defined Period Average
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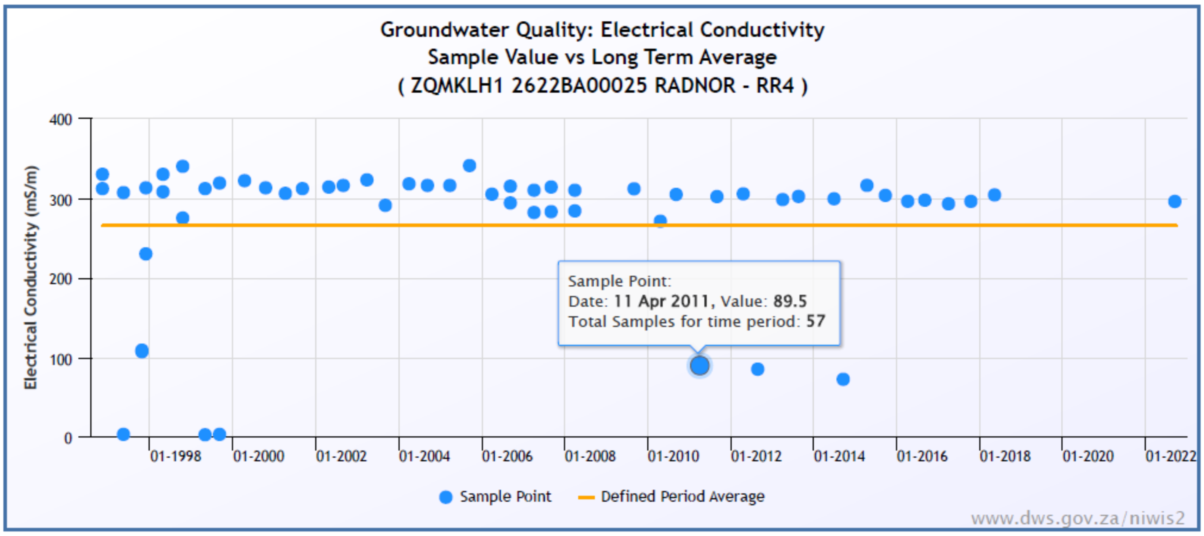
Groundwater Quality: Electrical Conductivity
Sample Value vs Long Term Average
(ZQMKLH1 2622BA00025 RADNOR - RR4)
Electrical Conductivity (mS/m)
0
100
200
300
400
01-1998
01-2000
01-2002
01-2004
01-2006
01-2008
01-2010
01-2012
01-2014
01-2016
01-2018
01-2020
01-2022
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Date: 11 Apr 2011, Value: 89.5
Total Samples for time period: 57
Sample Point
Defined Period Average
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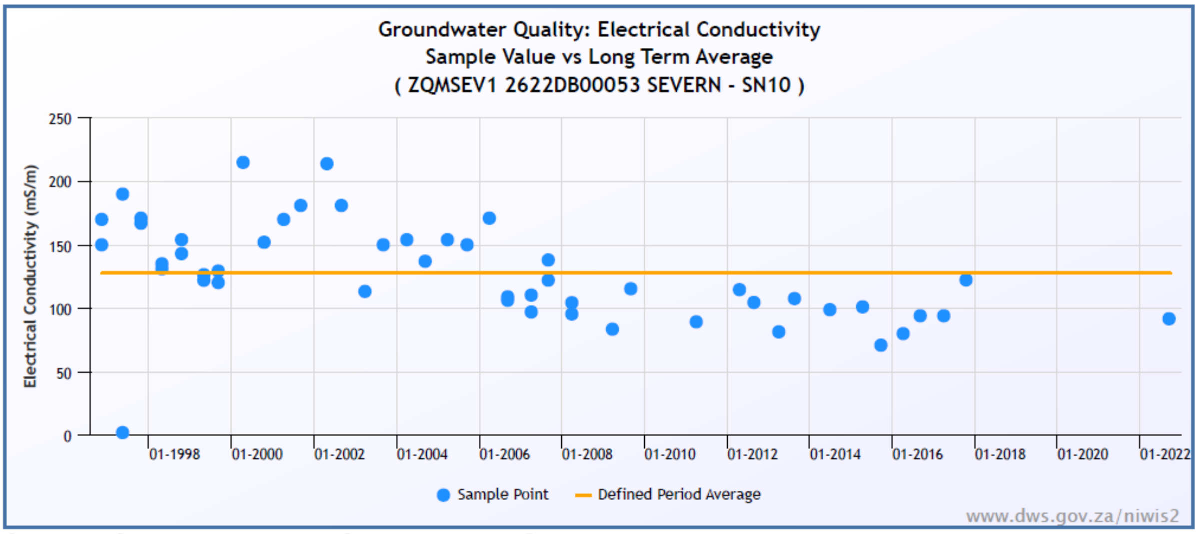
Groundwater Quality: Electrical Conductivity
Sample Value vs Long Term Average
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Electrical Conductivity (mS/m)
0
50
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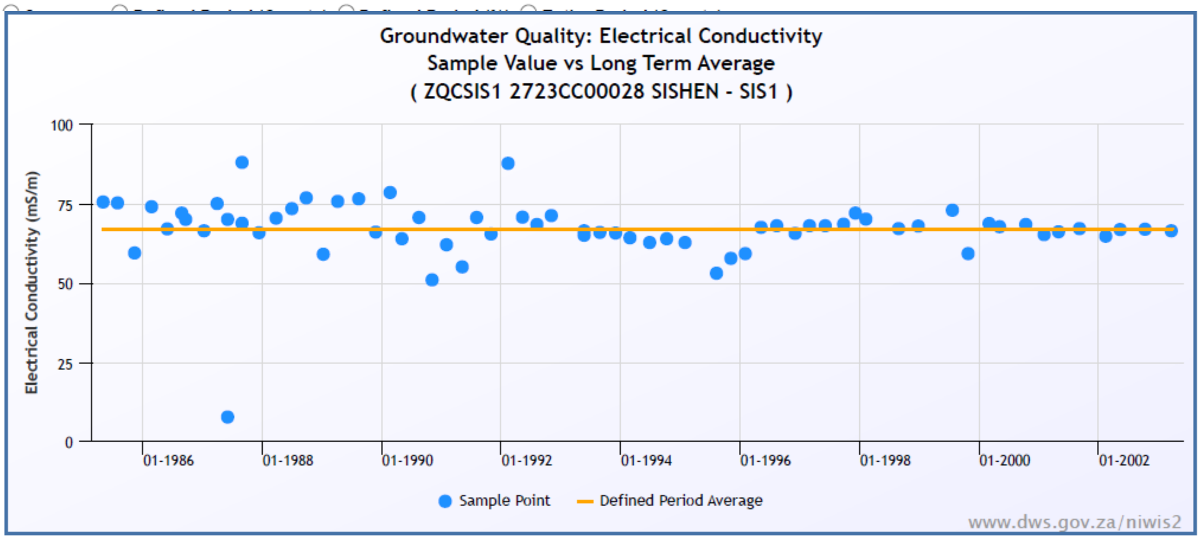
01-2000
01-2002
01-2004
01-2006
01-2008
01-2010
01-2012
01-2014
01-2016
01-2018
01-2020
01-2022
Sample Point
Defined Period Average
www.dws.gov.za/niwis2


Groundwater Quality: Electrical Conductivity
Sample Value vs Long Term Average
(ZQCSIS1 2723CC00028 SISHEN - SIS1)
Electrical Conductivity (mS/m)
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25
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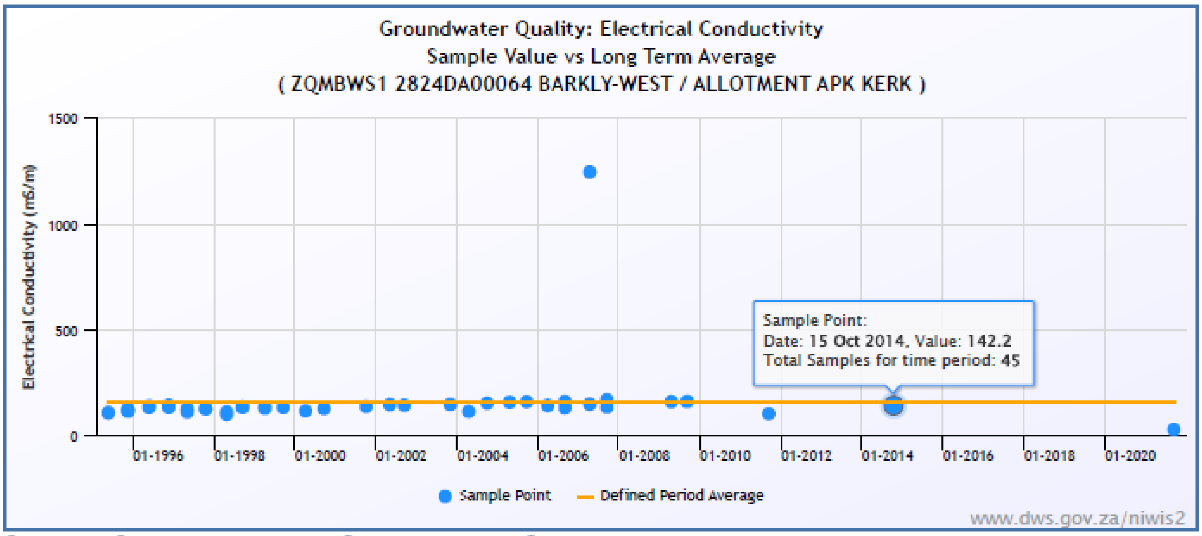
75
100
01-1986
01-1988
01-1990
01-1992
01-1994
01-1996
01-1998
01-2000
01-2002
Sample Point
Defined Period Average
www.dws.gov.za/niwis2


Groundwater Quality: Electrical Conductivity
Sample Value vs Long Term Average
(ZQMBWS1 2824DA00064 BARKLY-WEST / ALLOTMENT APK KERK)
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1000
1500
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Total Samples for time period: 45
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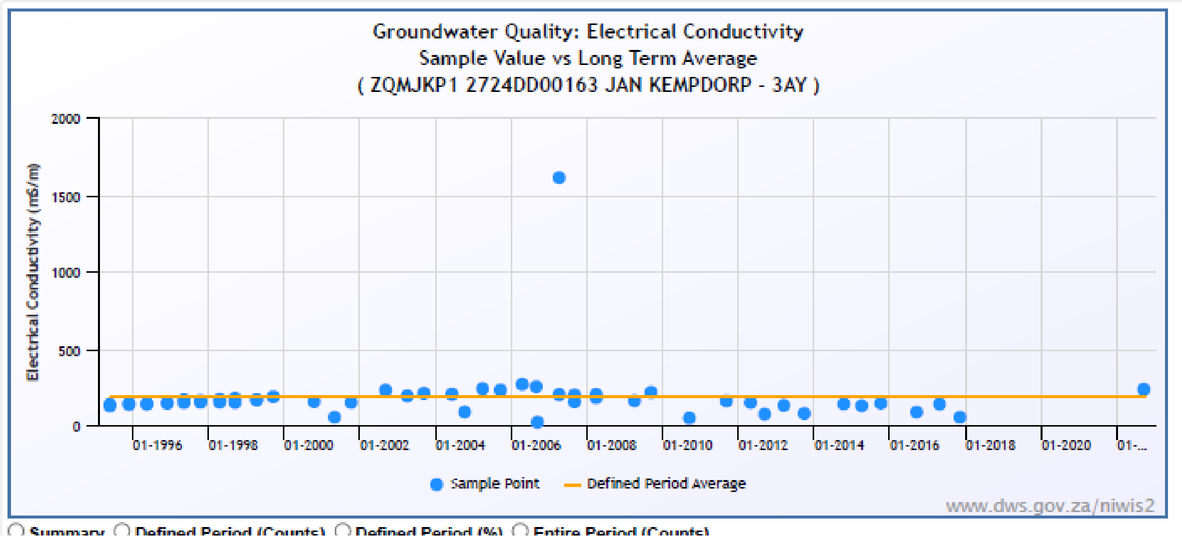
01-1998
01-2000
01-2002
01-2004
01-2006
01-2008
01-2010
01-2012
01-2014
01-2016
01-2018
01-2020
Sample Point
Defined Period Average
www.dws.gov.za/niwis2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Sample Value vs Long Term Average
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Electrical Conductivity (mS/m)
2000
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01-1998
01-2000
01-2002
01-2004
01-2006
01-2008
01-2010
01-2012
01-2014
01-2016
01-2018
01-2020
01-...
Sample Point
Defined Period Average
www.dws.gov.za/niwis2