SPECIALIST HYDROGEOLOGICAL REPORT TO THE ENVIRONMENTAL IMPACT ASSESSMENT REPORT (EIA) AND ENVIRONMENTAL MANAGEMENT PLAN (EMP) REPORT/S

PROPOSED PETROLEUM (OIL AND GAS) EXPLORATION, DRILLING OF MULTIPLE STRATIGRAPHIC WELLS IN THE PETROLEUM EXPLORATION LICENSE (PEL) 73 COVERING BLOCKS 1819 AND 1820, KAVANGO BASIN, NORTH-EASTERN NAMIBIA

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SUBMITTED BY:

HM RW Cc
P.O. Box: 8574
Backbench, Windhoek
ERF 882, Cimbebasia
Email:mukendwah73@gmail.com
Cell: 081149281
Fax: 0886529523

SUBMITTED TO:

Risk Based Solutions (RBS) cc
P.O. Box 1839
Windhoek, Namibia
Email: smwiya@rbs.com.na

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1. Introduction

This report is a specialist surface water and groundwater Impact Assessment (IA) to describe the potential environmental impacts of the proposed petroleum (oil and gas) exploration (drilling of multiple stratigraphic wells) drilling in Kavango Basin which is part of the greater northern Namibia Etosha Basin and greater southern Africa Kalahari Basin. The also recommends mitigation measures that shall be implemented in order to manage any likely impacts on the receiving environment in relation to water issues. It describes, characterizes the sources and identifies potential environmental impacts of the proposed drilling, to ensure the development plan is environmentally responsive and presents management recommendations and strategies for key factors.

2. Scope

The scope of the study entails detailed characterization of existing status of the water environment around the proposed sites, in the Kavango East Region for various water environmental components viz. flow pattern disruptions, enhance or loss of runoff, flood risk, quality, quantity, releases, emissions, contamination, loss of catchment area, depth to groundwater under different seasonal conditions, geology and locations of aquifers, thicknesses, and their water supply potential, groundwater flow directions, locations/flows of springs and seeps, groundwater discharge locations in stream, groundwater uses.

3. Methodology

3.1. Method of Assessing Impacts

The impact assessment methodology is guided by the requirements of the NEMA EIA Regulations (2010) Republic of South Africa. The broad approach to the significance rating methodology is to determine the environmental risk (ER) by considering the consequence (C) of each impact (comprising Nature, Extent, Duration, Magnitude, and Reversibility) and relate this to the probability/likelihood (P) of the impact occurring. This determines the environmental risk. In addition, other factors, including cumulative impacts, public concern, and potential for irreplaceable loss of resources, are used to determine a prioritisation factor (PF) which is applied to the ER to determine the overall significance (S).

The significance (S) of an impact is determined by applying a prioritisation factor (PF) to the environmental risk (ER).

The environmental risk is dependent on the consequence (C) of the particular impact and the probability (P) of the impact occurring. Consequence is determined through the consideration of the Nature (N), Extent (E), Duration (D), Magnitude (M), and reversibility (R) applicable to the specific impact.

For the purpose of this methodology, the consequence of the impact is represented by: $C=E+D+M+R4\times N$

Each individual aspect in the determination of the consequence is represented by a rating scale.

4. Description of the natural environment

4.1. Locality

The study area is located in northern Namibia straddling portions of the East and Western Kavango Regions (**Figure 1**). By virtue of its location the study area forms part of a low lying peneplain of the Omatako, Cubango-Cuito and Okavango surface water Basins. The land surface gently slopes in the north easterly direction from an elevation of 1200 mamsl in the south western corner to about 1029 mamsl in the north eastern corner over a distance of about 230 km, which equates to a regional slope of 1 m for every 1400 m (**Figure 2**).

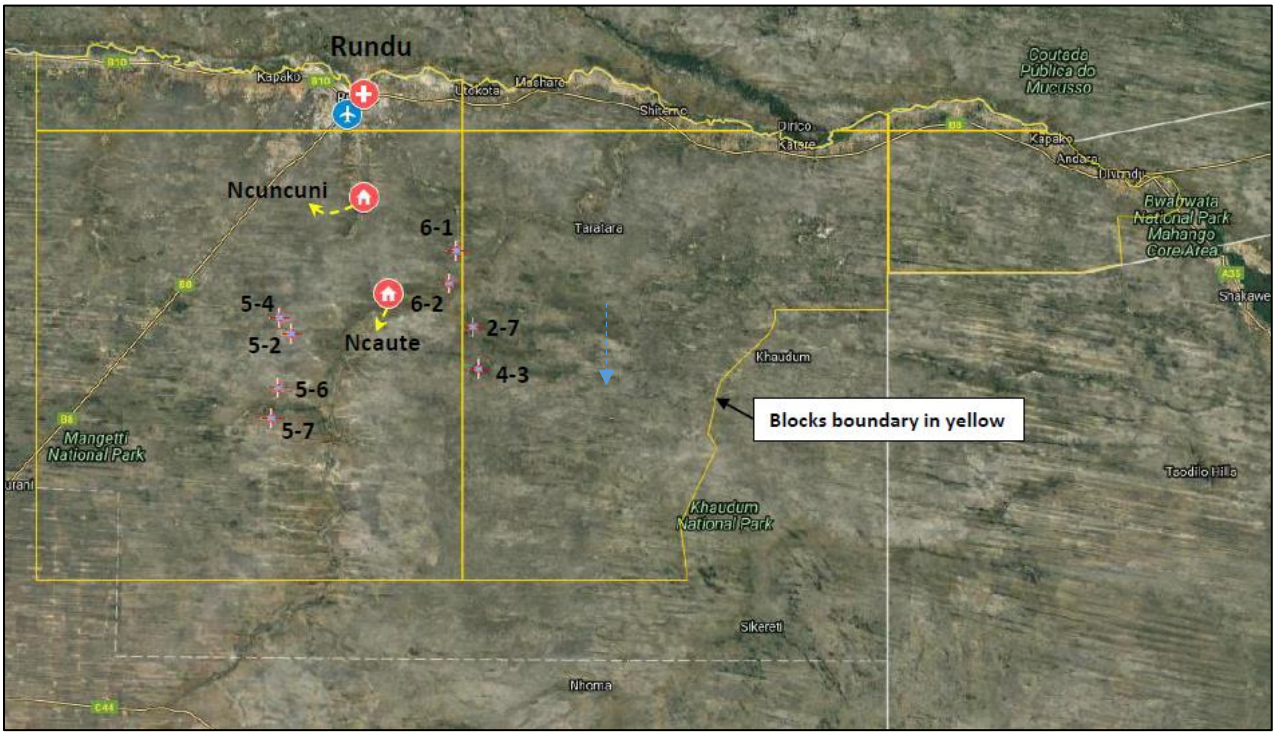


Figure 1: Proposed site locality

From the major towns, the study area is about 500 to 700 Km north east of central business district of Namibia-Windhoek, and encompasses the town of Rundu which is the main town around the administrative Kavango East and Kavango West Regions.

Geographically the study area lies between -18.970º; 18.989º south and -17.956º; 21.001º north and covers an area of approximately 22385 square kilometres.

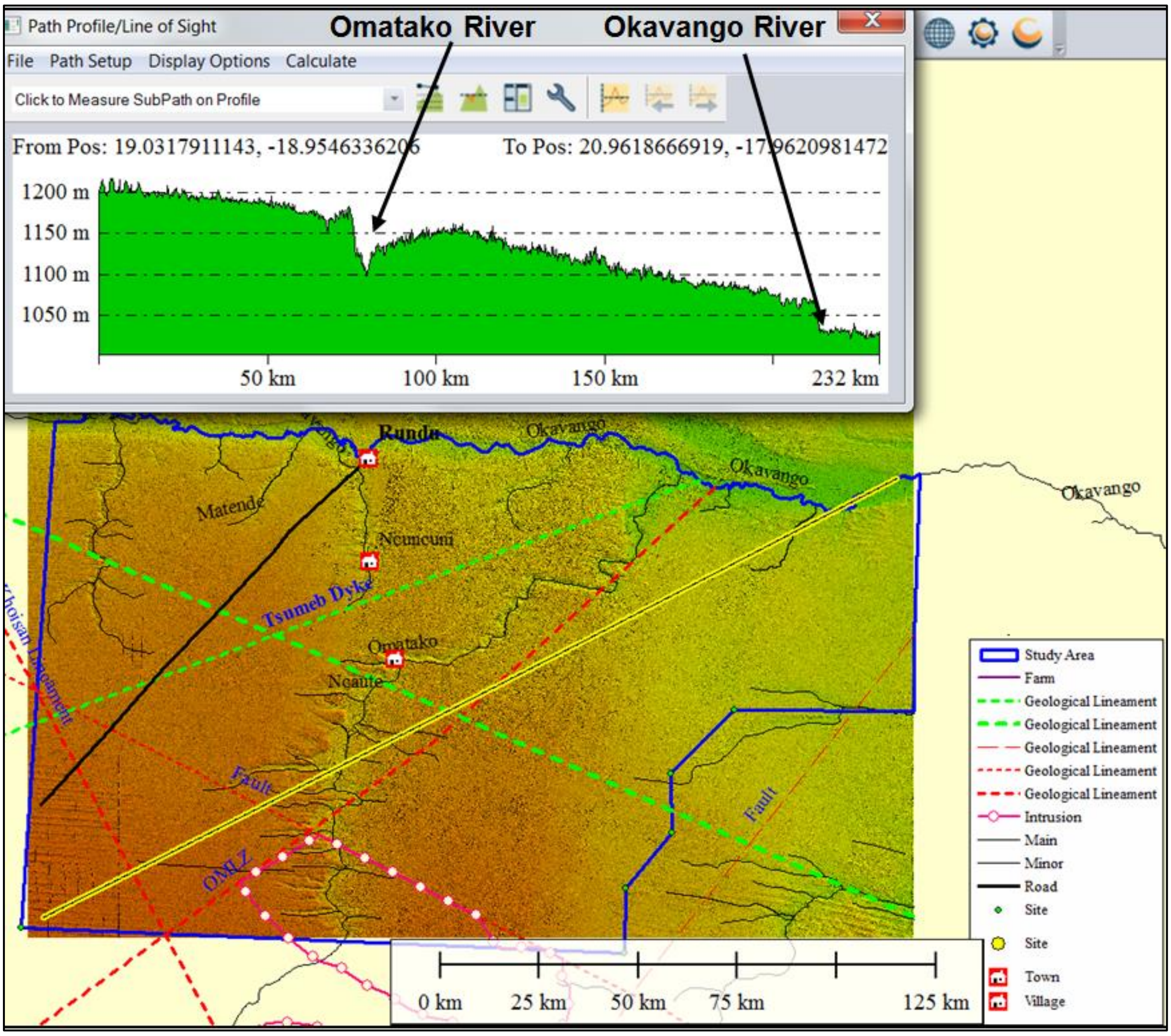


Figure 2: Regional topographic slope across the study area (along yellow line)

4.2. Climate

According to Koppen-Geiger Climate Classsification (Koppen, 1884), the climate in the study area is classified as hot semi-arid or steppe climate (BSh) and is characterized by the precipitation values below the potential evapotranspiration rates. In terms of ecological and agricultural potential, the area is intermediate between desert climate and humid climate; hot semi-arid area located in the tropics and subtropics.

4.2.1 Rainfall

The area is characterized by the absence of rain during winter and part of spring, usually, there is no rain between June and September. Annual average precipitation (AAP) is low such that in the last 20 years the AAP is 570 mm of which most (80 %) fall between November and March (**Figures 3 and 4, Weather.com, 2018**). What is of importance to the matter at hand is the annual average rainfall variations because they speak to extreme conditions, in Figure 4, it can be seen that annual average rainfall variations range is between 40 and 50 % meaning that during extremely wet rainfall seasons rainfall events in the range of 850 mm/a are possible, and that can induce infrastructure damaging overland flow or/and flash flooding of local ephemeral streams. Contamination risks elevate during months of peak rainfall (November to March), and therefore chemical stock piles and contaminated soil (from drilling) should be kept away from stream channels.

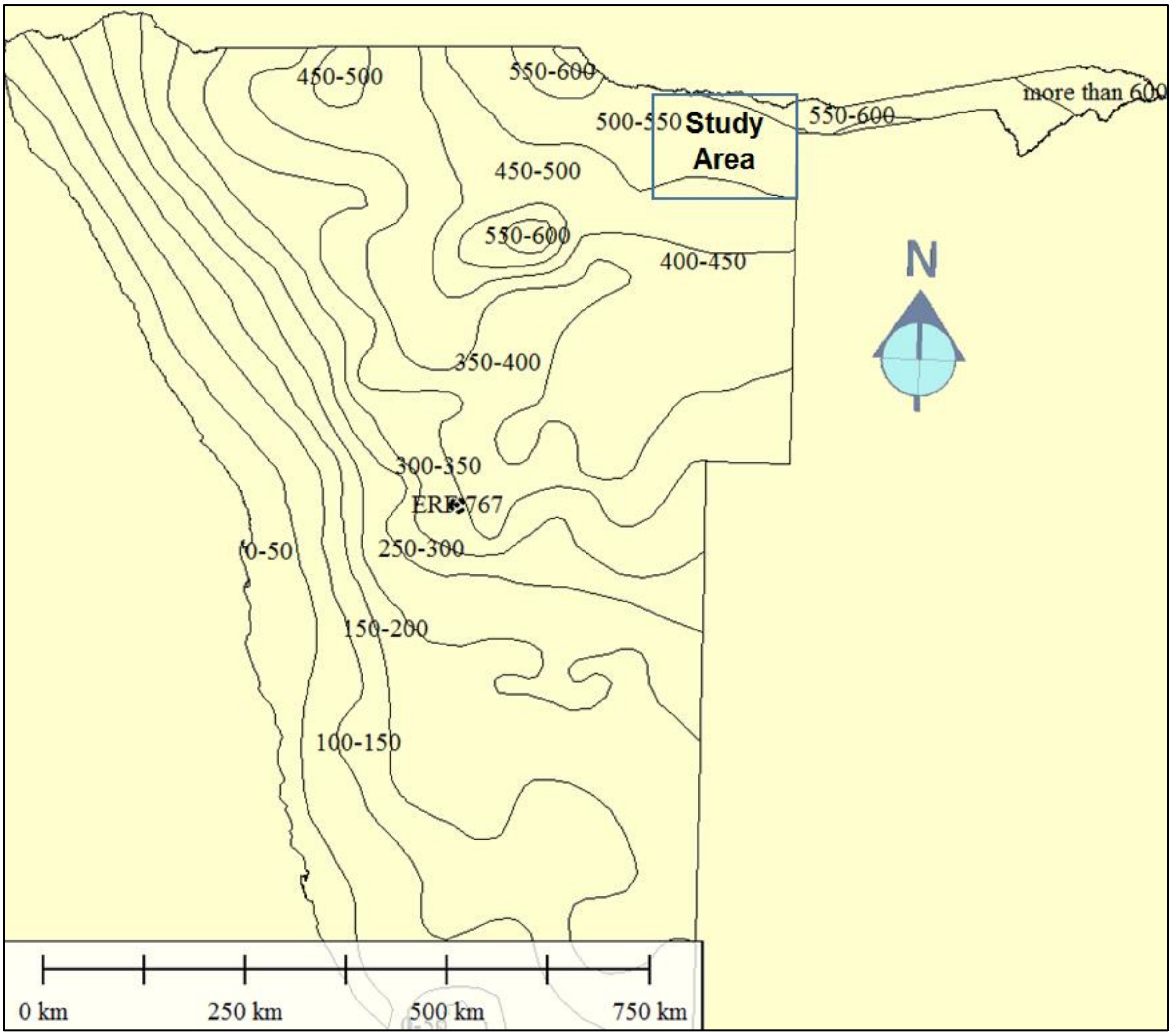


Figure 3: Annual average rainfall in the study area

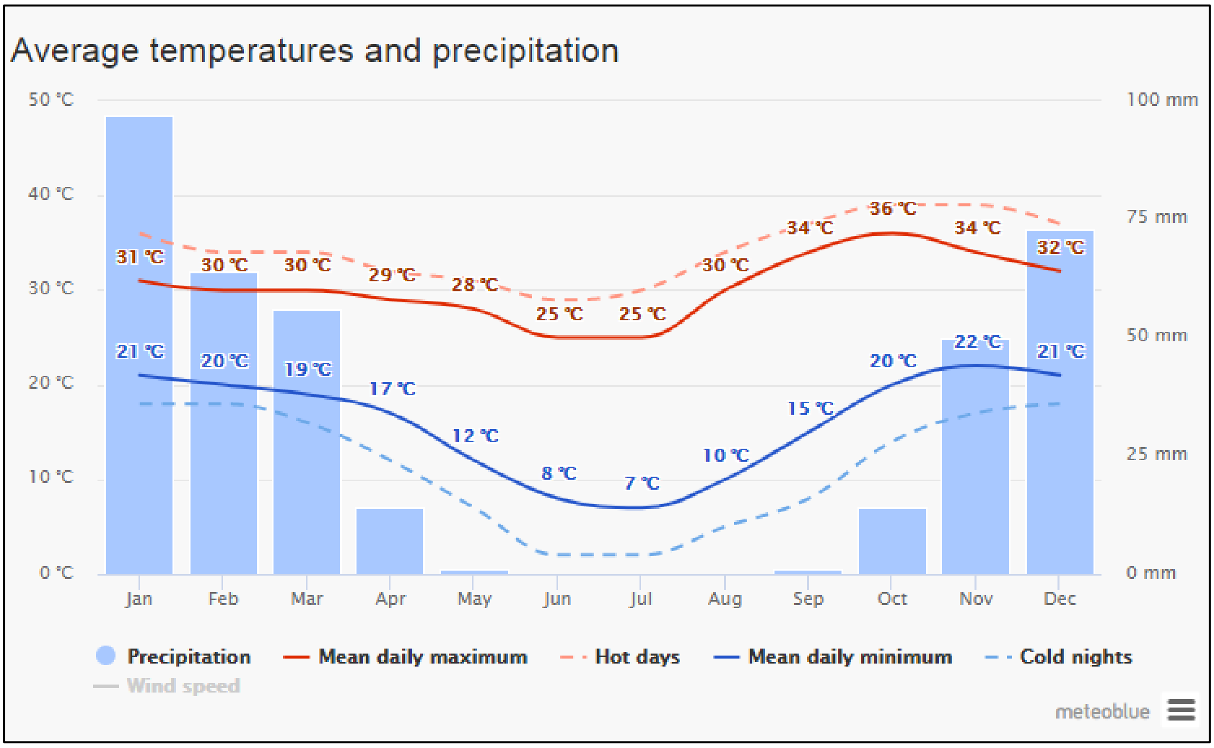
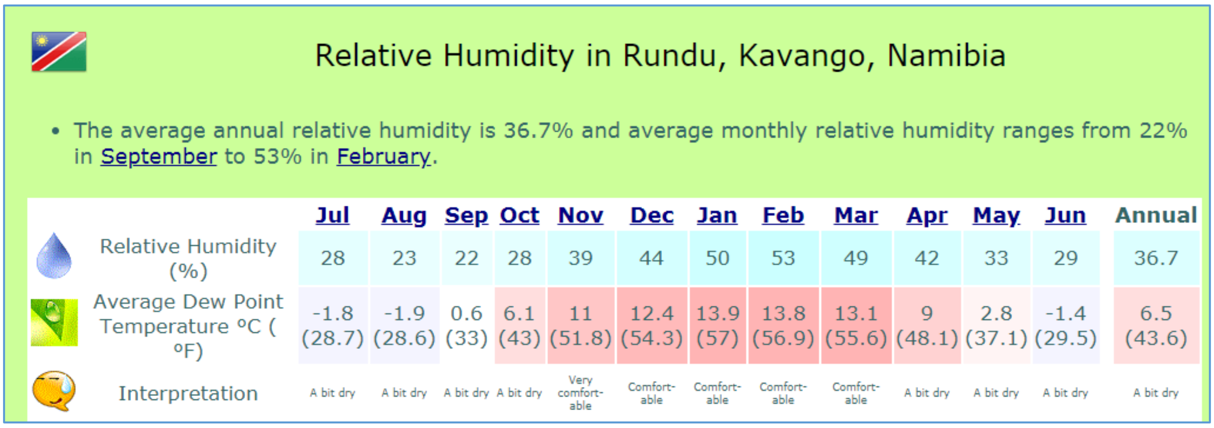


Figure 4: Precipitation trends at Rundu Airport

4.2.2 Humidity

The relative humidity range of the area is from 22 % to 53 %, with August and September recording the lowest while January and February record the highest levels of humidity (**Figure 5**).



Relative Humidity in Rundu, Kavango, Namibia

- The average annual relative humidity is 36.7% and average monthly relative humidity ranges from 22% in September to 53% in February.

	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Annual
Relative Humidity (%)	28	23	22	28	39	44	50	53	49	42	33	29	36.7
Average Dew Point Temperature °C (°F)	-1.8 (28.7)	-1.9 (28.6)	0.6 (33)	6.1 (43)	11 (51.8)	12.4 (54.3)	13.9 (57)	13.8 (56.9)	13.1 (55.6)	9 (48.1)	2.8 (37.1)	-1.4 (29.5)	6.5 (43.6)
Interpretation	A bit dry	A bit dry	A bit dry	A bit dry	Very comfort-able	Comfort-able	Comfort-able	Comfort-able	Comfort-able	A bit dry	A bit dry	A bit dry	A bit dry

Figure 5: Humidity trends at Rundu Airport

4.2.3 Temperature

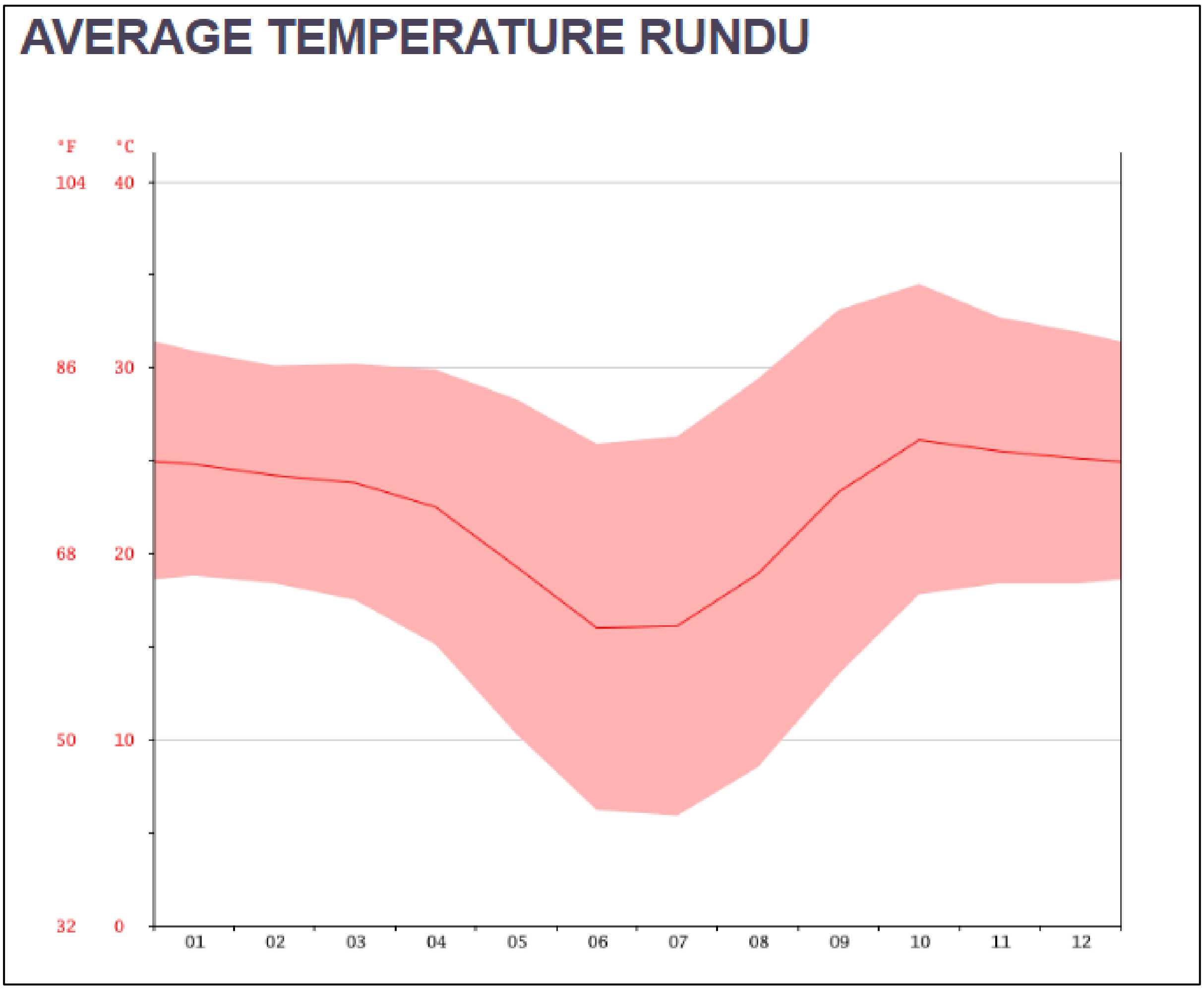


Figure 6: Temperature trends at Rundu Airport

Extreme heat is expected from September to February (**Figure 6**) each year, during that period caution should be exercised in view of declining water resource levels, especially in surface water impoundments and boreholes exploiting shallow groundwater resources.

4.2.4 Wind

From Figure 7 below, it appears that most winds are north east trending, this reality should be considered in the design of chemical and contaminated soil stock piles relative to localities of shallow groundwater resources as well as to surface water temporal impoundment areas.

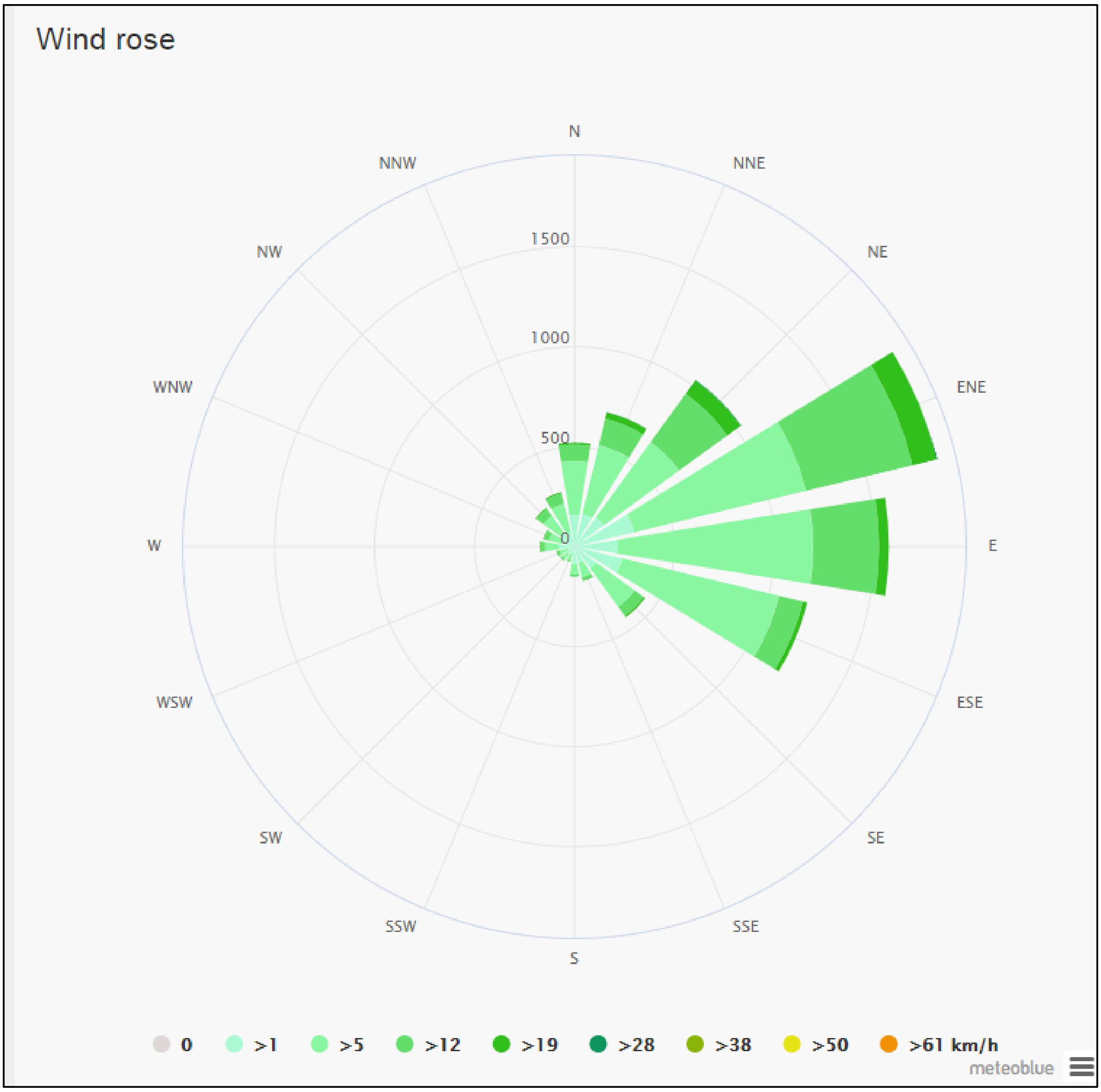


Figure 7: Wind direction trends at Rundu Airport

While most wind comes from the north eastern direction, strongest winds (**Figures 7 and 8**) are expected between July and October each year, during this period cautions related to wind related water resources risks of pollution should be maximized, particularly loose waste disposal and plastic bags.

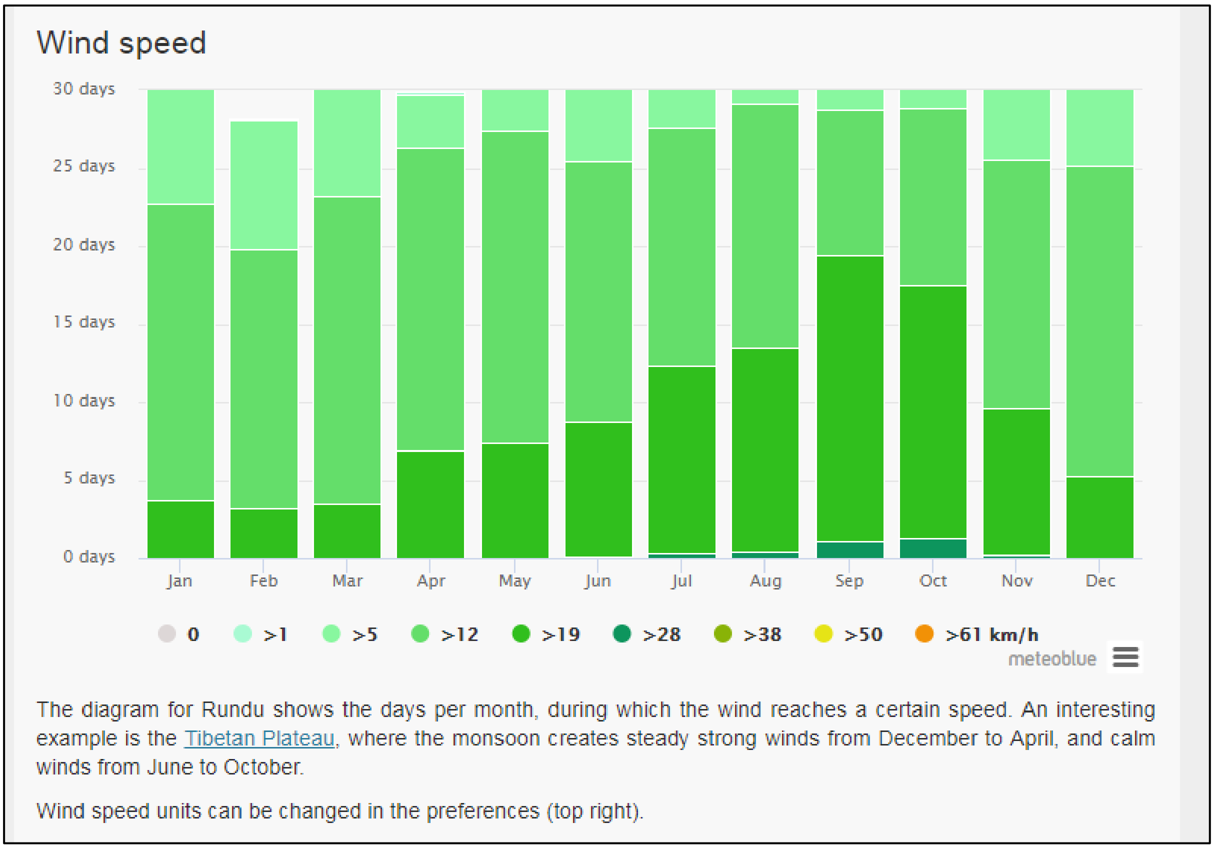


Figure 8: Wind speed trends at Rundu Airport

4.3. Topography and drainage

The study area straddles lower portions of five surface water basins (**Figure 9**), and from a geology (sedimentology) point of view the study area straddles three sedimentary basins, namely Cubango-Cuito, the Omatako and Eiseb Basins (**Figure 10**). The topography and drainage of the study area will therefore be abstracted within the above give context.

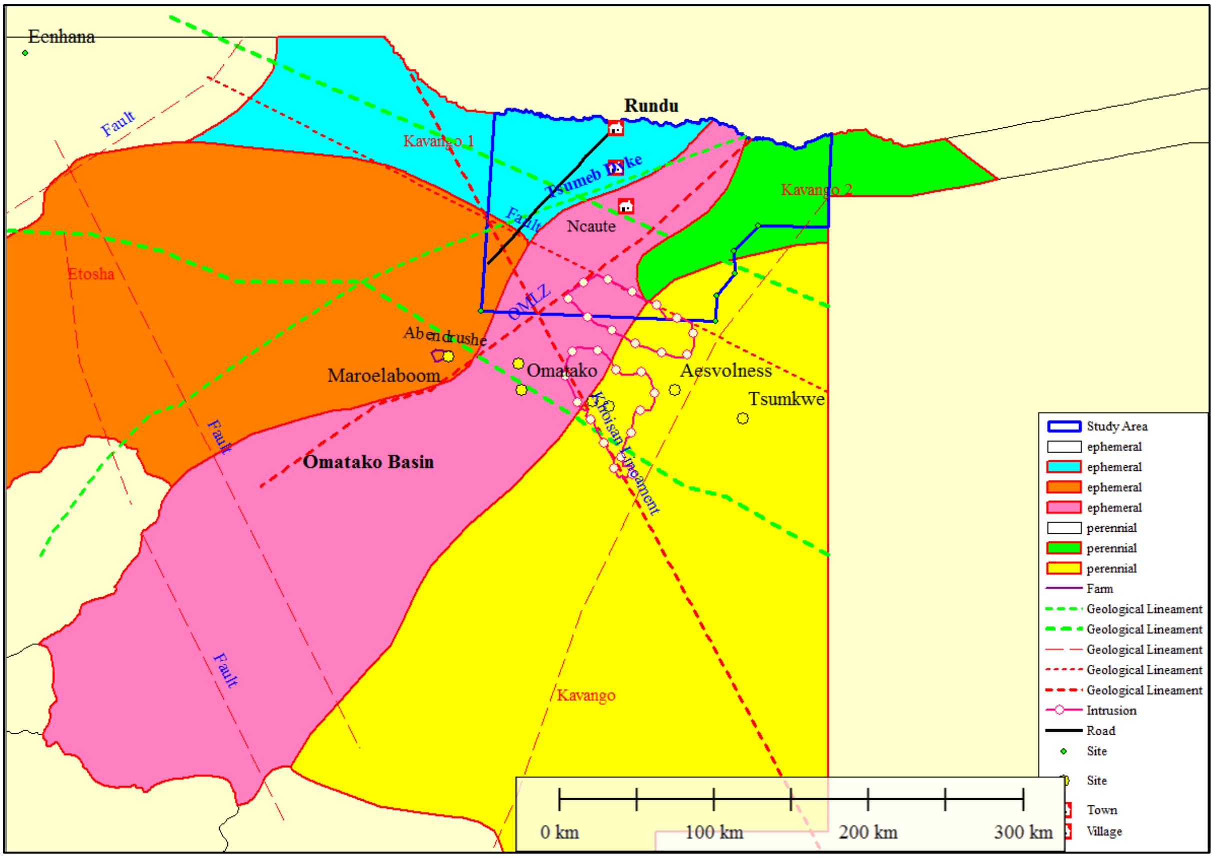


Figure 9: large scale surface water drainage of the study area

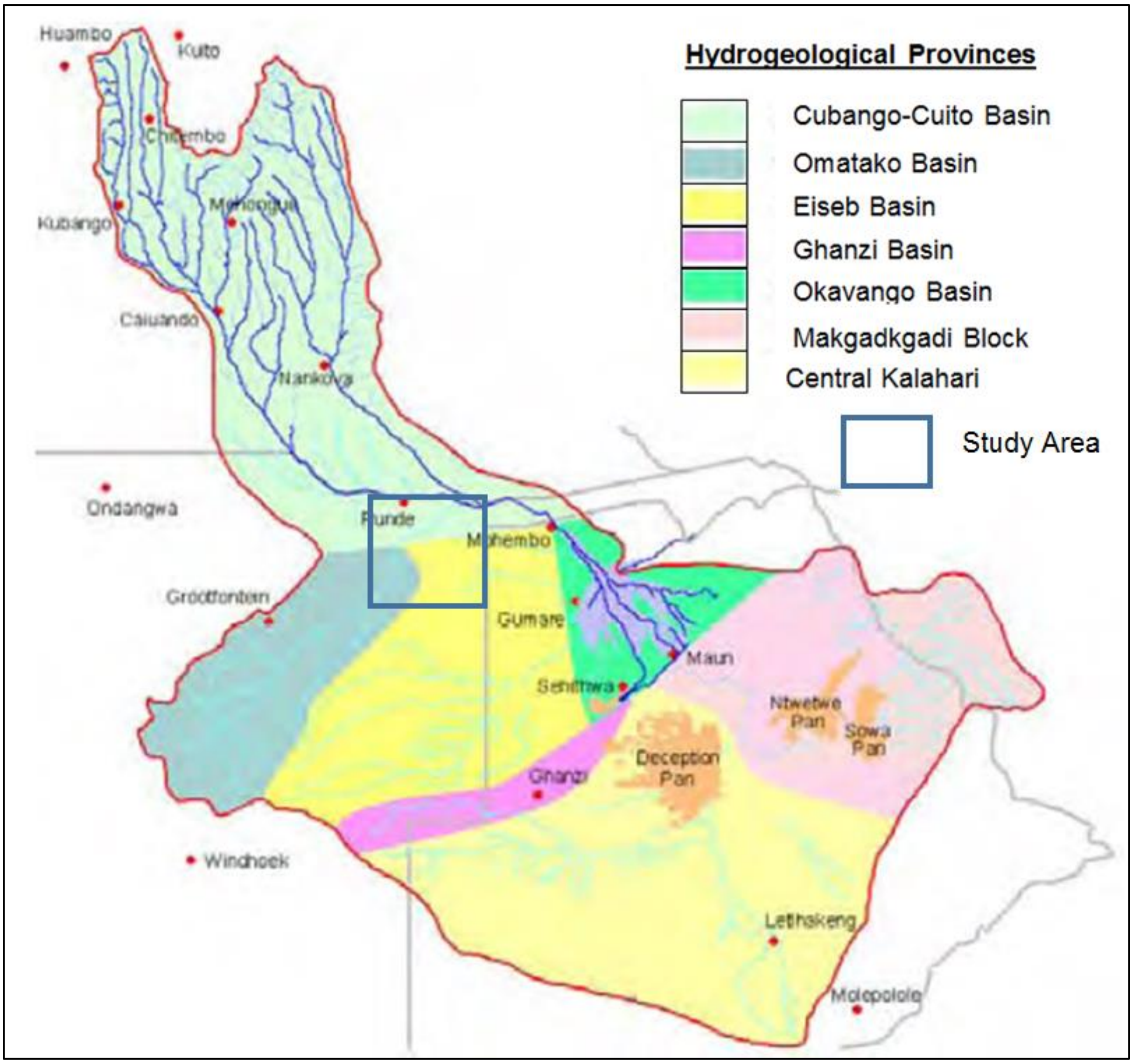


Figure 10: The Okavango hydrogeological provinces: Perennial rivers in mid blue and seasonal rivers in light blue (Jones, 2010)

From the geology point of view (**Figures 10 and 11**), there are four contributing factors to the regional slope (topography) of the greater Okavango Basin, namely; the central highlands in Angola, the Waterberg highlands and Otavi highlands in Namibia (*Source land*) as well as the Okavango Graben in Botswana (*deposition bound*). The influence of these four regional geological structures combined to give the driving force to the present day south east trending slope and drainage pattern observed in the study area.

4.3.1 Topography

Locally in the study area, elevation declines from 1200 mamsl in the south west corner to 1030 mamsl in the northeast corner of the study area over a distance of approximately 230 km, equating to a slope of 1m in 1400 m (**Figure 11**). However local slope variations can be observed with relatively steep slopes along river sections with high tributary network frequency i.e. along the Omatako and Mpuku ephemeral rivers. And lower than average slope (1: 1400) in lower sections of rivers/streams, also in sections with no or low tributary network frequency.

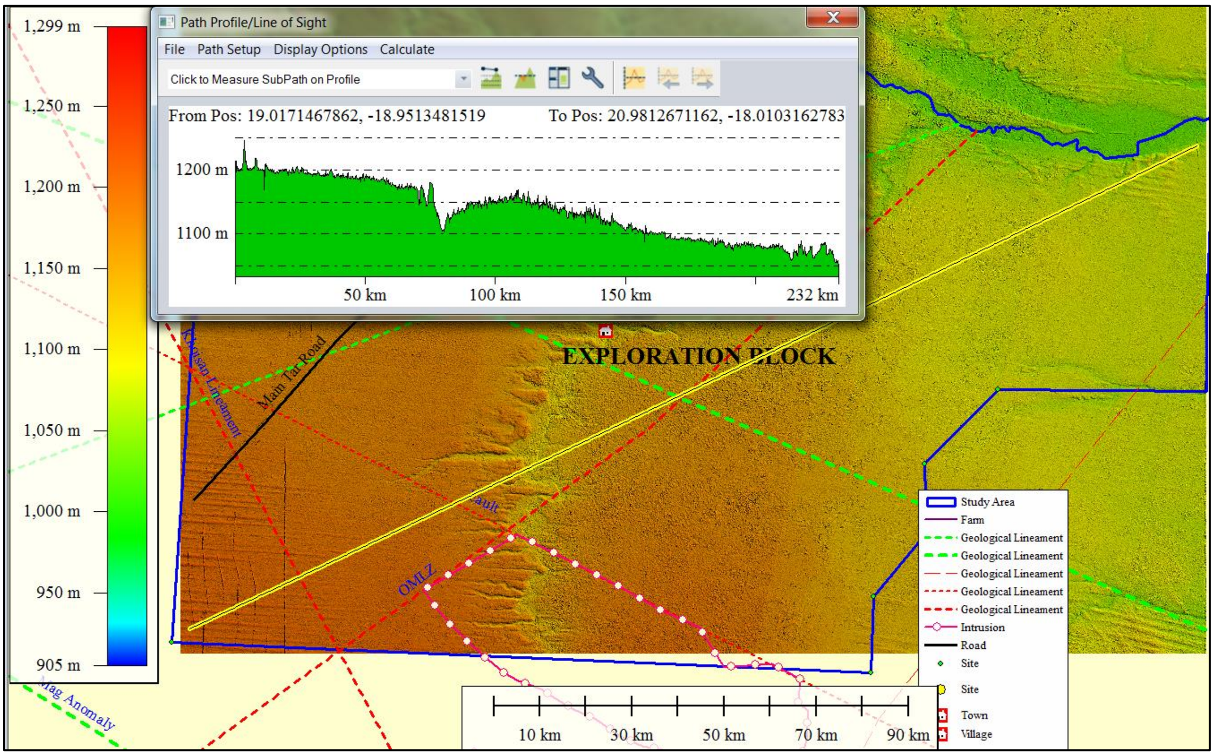


Figure 11: Elevation profile of the study area along the yellow line

4.3.2 Drainage

The present drainage in the study area, although largely ephemeral apart from the Okavango River are exorheic, meaning that it allows flow into other external bodies of water for example rivers, swamps and lakes. In this context they all drain into the greater Okavango River. This is true except for the Fumbe Stream (**Figure 12**) which is endorheic (*allows no flow into other external body of water*).

Of interest to hydrogeology with regard to drainage is stream network density (Dd), stream network frequency (Df), stream network texture, stream network topology and slope variations because these drainage aspects closely relate to dynamic nature of river sections or basin portions, dominant processes within basins/river sections, geology and geomorphology of basins/river sections and inform processes like run-off, inftiltration, overland flow, sediment response and through flow. For this reason more attention will be paid to these aspects and the findings thereafter will be used to infer hydrology and hydrogeological conceptual settings.

In Figure 12, the study area largely covers three basins, the Kavango 1 and the Kavango 2 dissected by the graben controlled Omatako Basin. In the Kavango 1 Basin streams essentially flow south-north into the Okavango River; deviating from the regional slope and probably emphasizing local structural control, whereas in the Omatako Basin the Omatako River flows north east into the Okavango River. Streams in the Kavango 2 Basin flow along the regional north east slope. It should be noted here that rivers initially follow slope and then adjust to local geologic structure as they incise their beds.

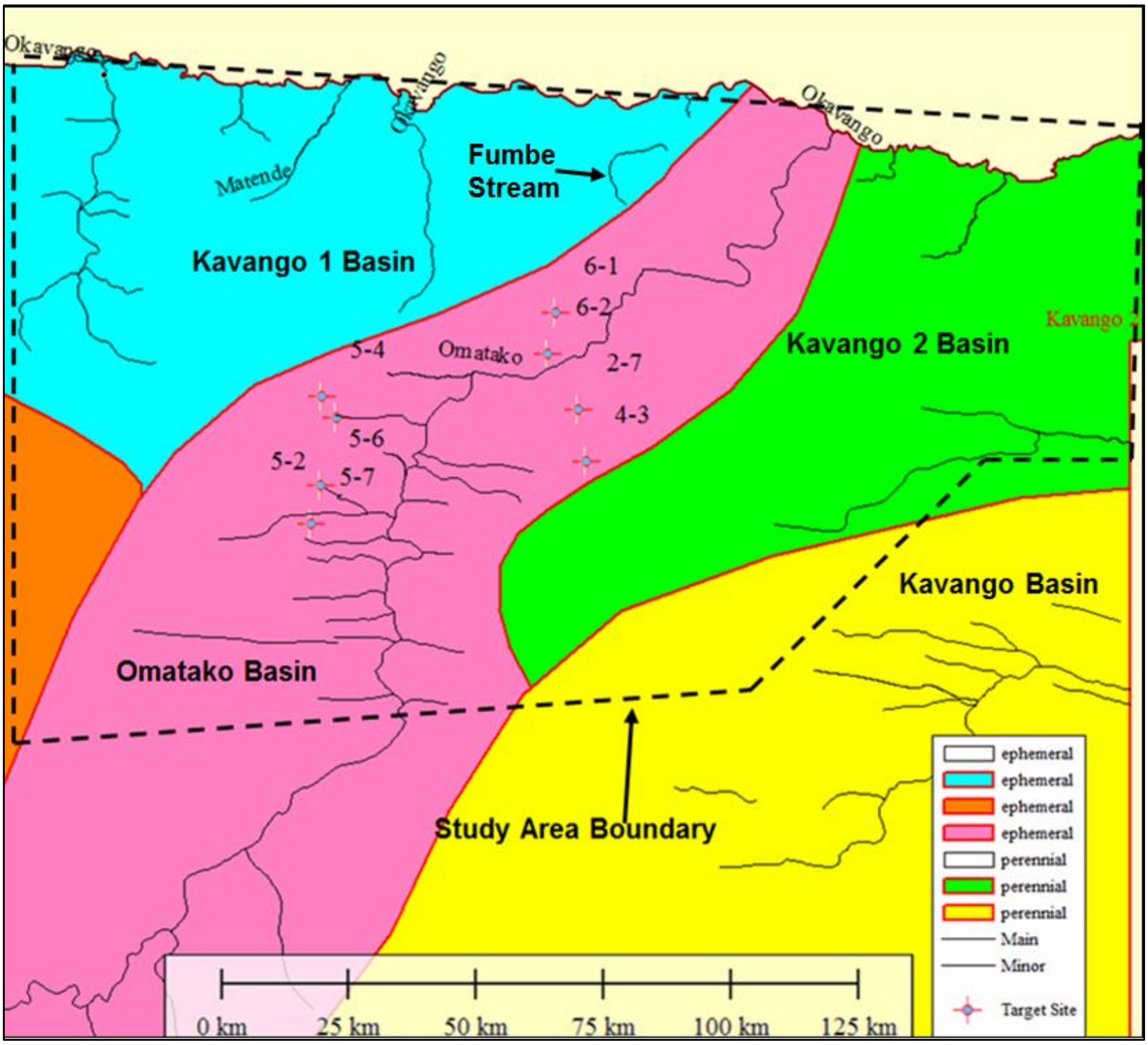


Figure 12: Local drainage system of the study area

In context of the above referenced value of stream/river aspects, in the far north west of the study area is Mpuku stream (Kavango 1Basin) which displays high tributary network frequency (*inter stream spacing along the trunk stream*) of approximately a stream tributary every 12 km compared to other streams of relatively same distance coverage like the Fontein stream draining Ncaute, Ncuncuni to Rundu. Another high tributary network frequency is observed along the first 67 km of the Omatako River from the southern border of the study area. In that section of the Omatako Basin the Omatako River has a tributary every 5.4 km; thereafter the Omatako River has no tributary for a distance of about 85 km.

With regard to stream network density (*sum of stream length per unit area of section of basin), km/km*^{2}) the dissected portion of the Omatako Basin's Dd is estimated at 0.033 whereas that of the Mpuku stream is approximately 0.072, meaning that the Mpuku Stream drainage area's runoff potential is relatively two fold more than that of the dissected portion of the Omatako River. However, it should be qualified here that stream density (Dd) values of less 5 (*0.033 for Omatako River, and 0.072 for the Mpuku stream*) imply coarse stream texture which is characteristic of dry regions with none perennial flow or flow only during rainy seasons.

These observations allow inference into the dynamic and active drainage portions of the study area. Portions outside the ones marked dynamic (**Figure 13**) are either quiet or relatively less dynamic, and play roles of sediment and run-off accommodation, through flow, and infiltration sites. The two areas marked dynamic portions (**Figure 13**) are the relatively dynamic drainage portions of the study area, and it is expected that these are sites of erosion, run-off and overland flow.

Drainage analysis efficiently links to surface-water Groundwater interaction, therefore the observations presented above offer an opportunity to infer the surface-water Groundwater interaction dynamics of the study area in view of preferential sites, losing or gaining, pathways, infiltration potential, and flow fields.

In the above given context and with regard to surface-water groundwater interaction, it is important to note that the rivers/streams in the study area are of coarse stream texture and only flow in exceptionally wet seasons and for short periods, this keeps their stream beds above the groundwater table for most of the time. Therefore when they flow after good rains they tend to lose the water to the sub-surface flow, with high evapotranspiration. This becomes even more-so considering that they are low gradient streams (*gradient of less than 2 %).*

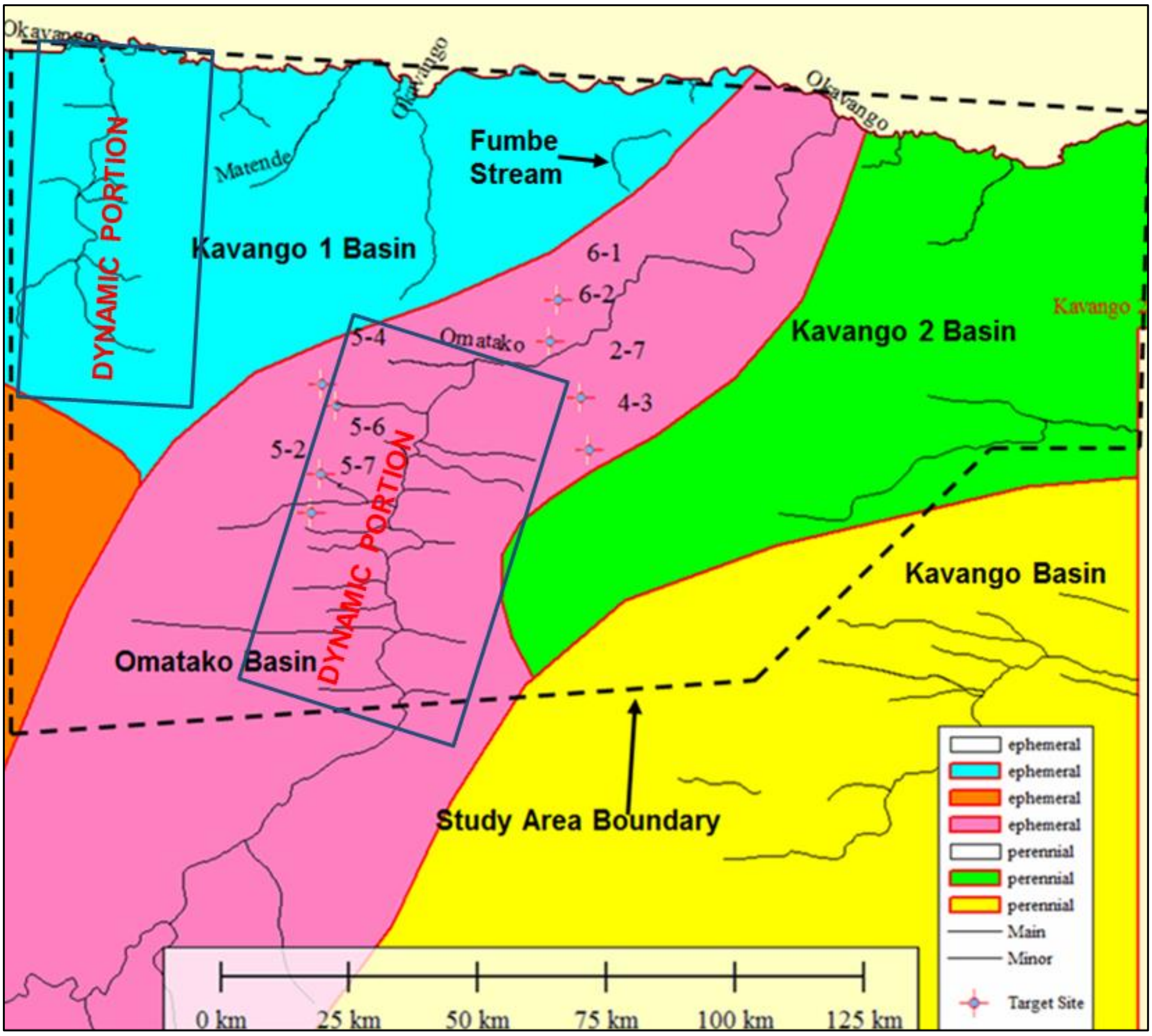


Figure 13: Active drainage portions of the study area

In view of the target exploration sites, it is important to note that sites 5-4, 5-6, 5-2 and 5-7 are situated on the western fringe of a drainage active zone; whereas sites 6-1, 6-2, 2-7 and 4-3 are slight out of the active zone of the Omatako River and are potentially areas of surface water ponding, infiltration and groundwater through flow. Productive boreholes will then be preferable located in the last quarter of the active zone to the second half of the inactive zone, this inference is based on the observed relative high mass transport capacity and the observation that this section of the Omatako River cuts from the western banks and buries on the eastern banks of the channel. Therefore productive boreholes in this section should be bias towards the eastern side of the river channel. These statements will be qualified in the hydrogeology part of the report when the mass transport and nature of the bedload sediment of that section of the Omatako River channel will be inferred.

4.4. General Geology and Hydrogeology

4.4.1 General Geology

The present day Kalahari Basin owes its origin to the uplift of the Southern Africa continental margin during the break-up of African proto-type continent known as Gondwanaland (Summerfield, 1985); this tectonic event created what is now known as the "The Great Escarpment" (**Figure 14)** by uplifting the Southern African continental margin followed by the down-warping of the continental interior – creating the Kalahari Basin (De Swardt & Bennet, 1974).

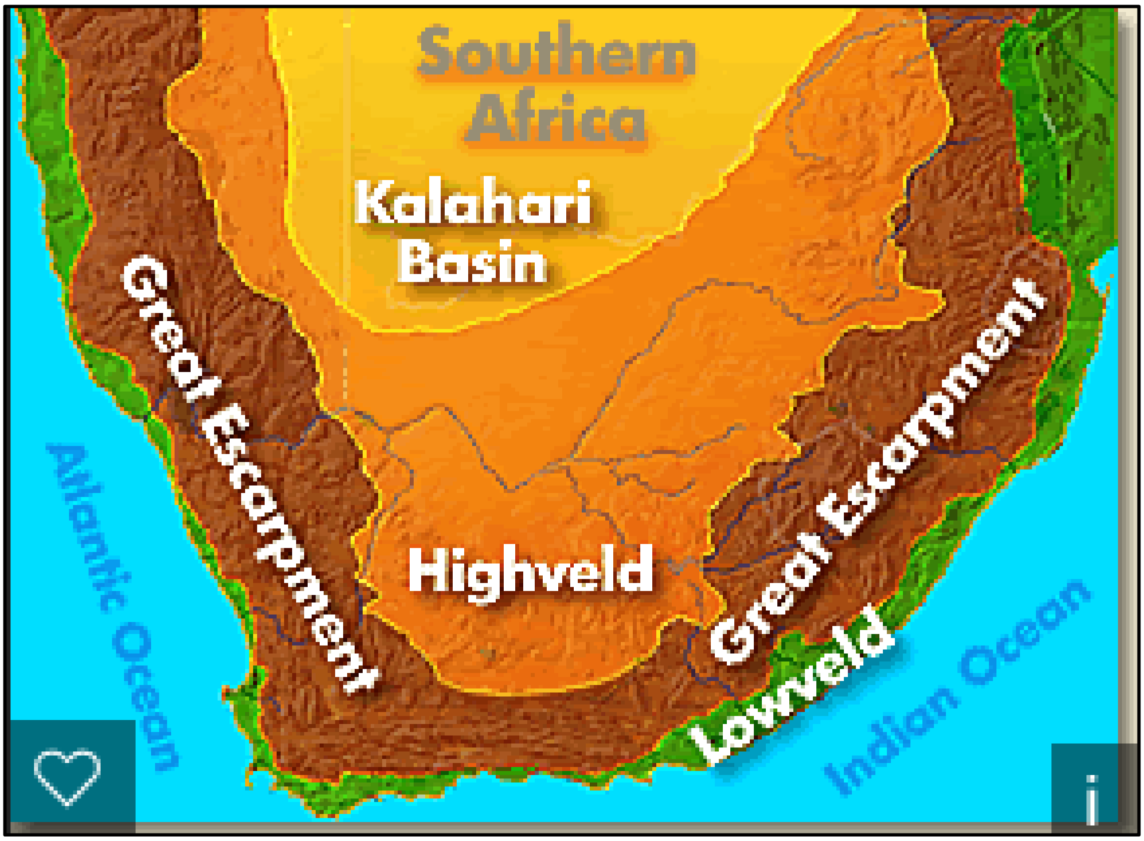


Figure 14: Tectonic and large scale geomorphic settings of the Kalahari Basin (Source, google images)

According to Summerfield (1985), further local tectonic activities associated with reactivation of D3 deformation events of the Damara Orogen and the Eastern African Rift System caused further subsidence along graben systems (**Figure 15**) of the central basin favouring thick sediment accumulations and creation of sub-basins.

The above given tectonic history contributed to the Kalahari Group in three ways:

(i) First by stablishing continental settings for deposition of sediments,

(ii) Second by contributing to the evolution of an endorheic drainage system, and

(iii) Thirdly by creating local conditions (local graben systems) favouring thick sedimentation (**Figure 15**).

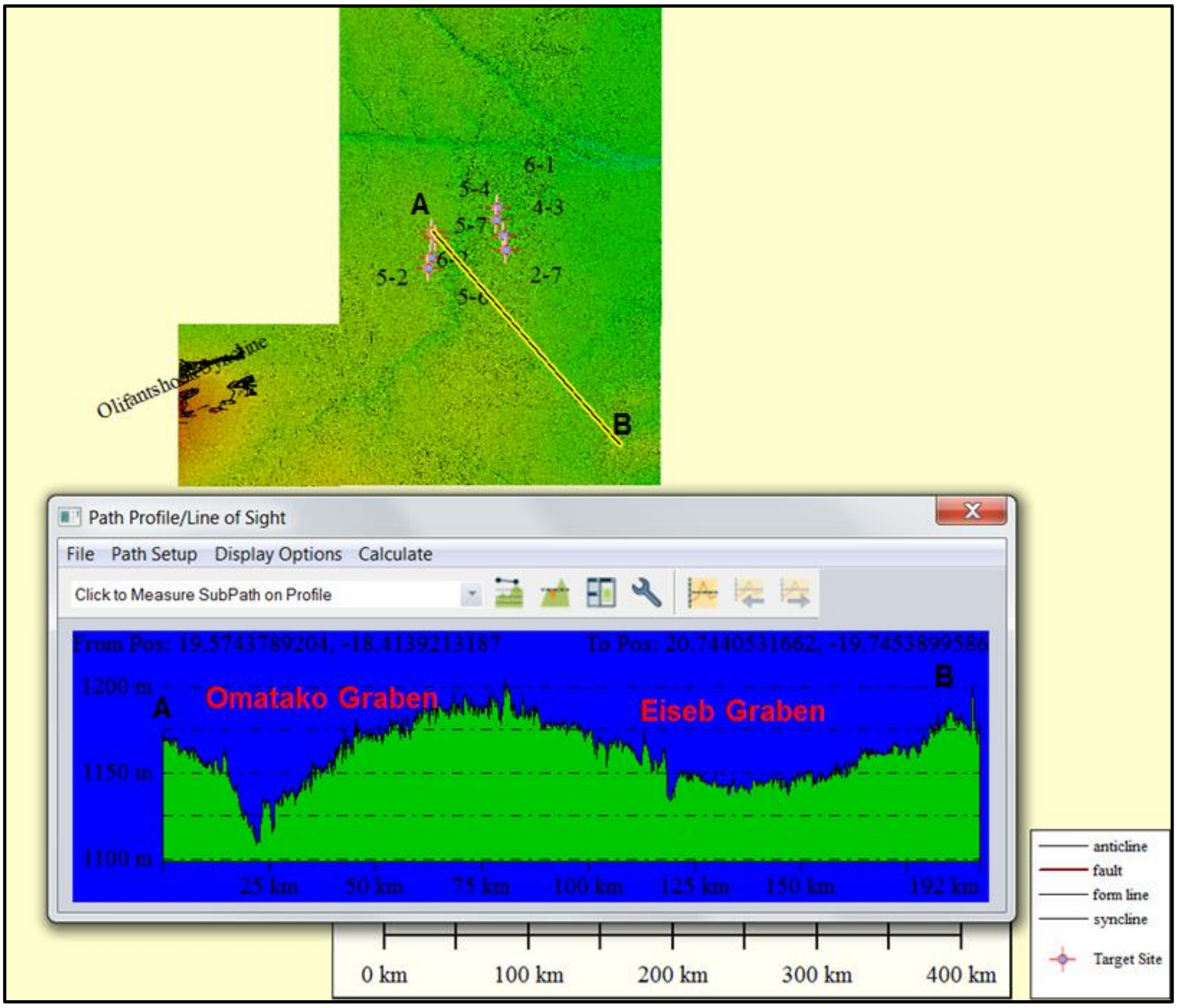


Figure 15: Typical grabens in the Kalahari Basin

The western sub-basins within which the study area is situated are locally dissected by numerous parallel faults which form graben; the most notable grabens to this study being the Omatako Graben (**Figure 15**). It therefore suffices to say that the Omatako River is largely structural-controlled.

It is on the basis of the above mentioned land mark structural and geomorphic units that the vertical and horizontal segregation, mineralogical content, texture and grain size of the sediments of the study area will be theoretically framed and evidently contextualized. This will be particularly so in the subsequent sections and in the discussion and conclusions of this study. And within that theoretical frame and contextual evidence, the hydrogeological settings (groundwater) investigations of the study area will be interrogated and framed into a concept, with acknowledgements of data and information limitations.

4.4.2 Hydrogeology

The geographic coverage and systematic hydrogeological investigations of the Kalahari Group in Namibia is limited to due to two cited factors; namely lack of mineral interests and that the area is sparsely inhabited (Wanke & Wanke, 2007; Jones, 2010).

The first concerted effort to study the hydrogeological potential of the Kalahari Group in general and in the Omatako Basin/graben in particular is that of the CSIR in 1982 when it was realized that Okarakara is becoming a population-growth point. Based on geophysical investigations (*vertical electrical sounding*) and core drilling of one exploration borehole, CSIR (1982) identified three hydrogeological units in the Kalahari Group; namely the upper, middle and lower Kalahari. Of the three units, the middle Kalahari sandstone was recognized as the most promising aquifer of the three units, whereas the lower Kalahari is reported to be argillaceous and of poor water quality.

Most of the findings of the CSIR (1982) were confirmed by a drilling campaign by the Department of Water Affairs in 1996/1997 (DWA, 1997). Furthermore, DWA (1997) contends that where the saturated thickness of the middle Kalahari is less than 100 m, borehole yields tend to decline with decreasing saturated thickness.

Without ruling out that one consecutive study might have been influenced by the findings of the previous one, Kuells (1998-2000) in his then unfinished PHD study assumed a general concept of the middle Kalahari sandstones as a well-developed aquifer system within the stratigraphy of the Kalahari Group, and goes further to characterize the sandstone as a semi-consolidated to consolidated homogeneous productive aquifer which depends on both defuse and direct recharge from sub-surface flows and from percolation following good rainfall events respectively. However, and probably influenced by the large geographic scale of his study, Simmonds (1999) contends that the aquifers of the Kalahari Group can be classified as either deltaic or Aeolian; characterizing them as low yielding, very fine sand, silty sand and sandstone aquifers with clayey horizons.

Jones (2010) adds a bit of substance to the nature of the lower Kalahari aquifer beyond what CSIR (1982) contends as argillaceous and describes it as fluvial and lacustrine. This position tallies with that of Thomas and Shaw (1991) in which the lower Kalahari is described as a conglomerate and gravel unit capped by pink to red marls in parts. Furthermore, Thomas and Shaw (1991) distinguish two other units of the Kalahari Group relating to varicoloured sandstone probably equivalent to the middle Kalahari and another unit starting with widespread calcrete, silcrete and other duricrust; probably signalling the onset of the upper Kalahari group. Jones (2010) relates the later (*widespread calcrete and silcrete unit*) to the onset of dry conditions and reduced denudation as the hydrological regime became seasonal following original perennial drainage becoming ephemeral and possible fragmentation of the drainage system into closed sub-basins.

Results from recent drilling of six boreholes all of them to a depth of 150 m at Katji na Katji (NamWAter, 2018) indicates a consistent stratification of fine sand with clayey horizons in the top 90 m followed either medium sand or sandstone from 90 to 150 m. Where there is fine to medium grained sand occurrence in the bottom 60 m, it would be calcareous on top and clayey at the bottom (**Figure 16**), Katji na Katji is situated within the study area about 40 km south west of the proposed drill sites.

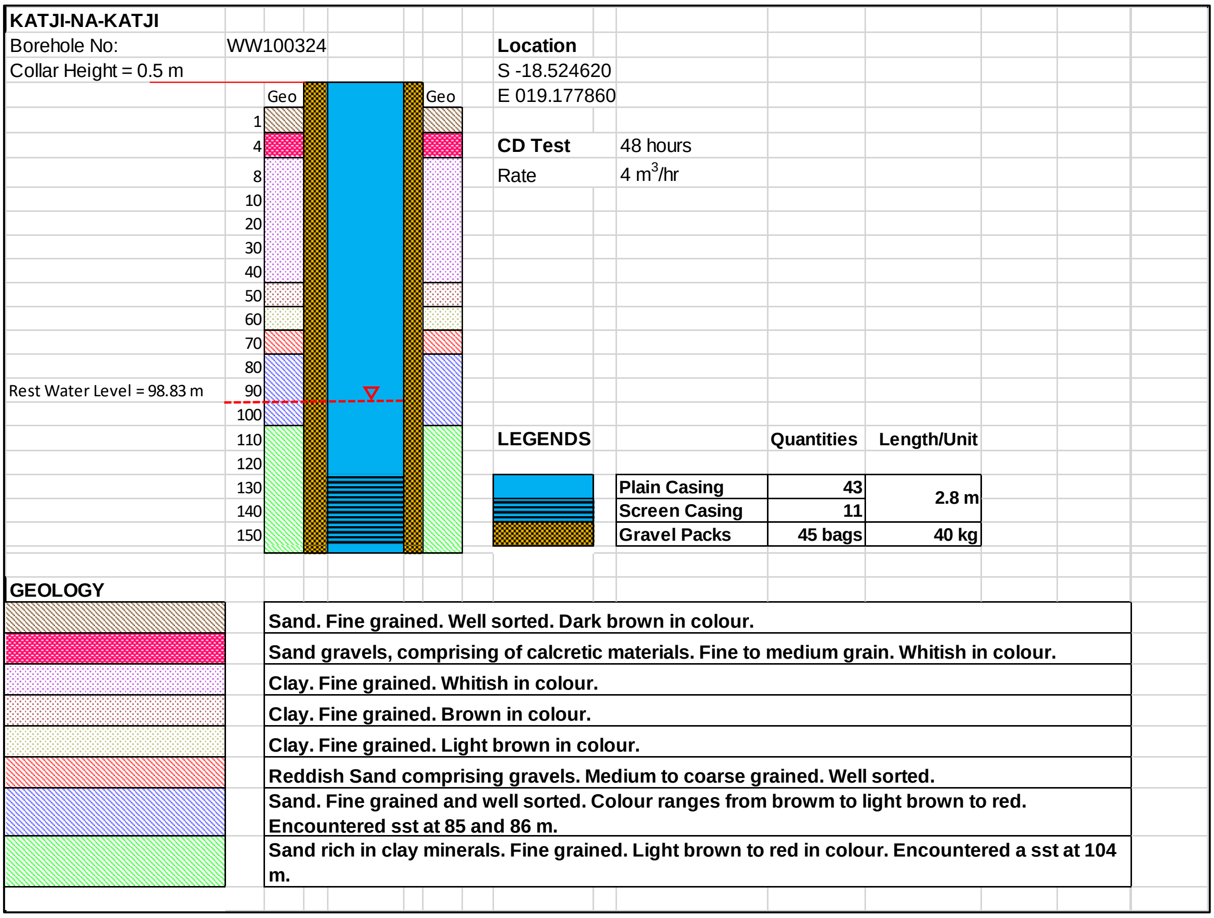


Figure 16: Typical layering at Katji na katji

It is from the above literature that this study will frame an integrated hydrogeological concept of the study area and localize it with some evidence observed within the study area, including inferences from the afore-given drainage analysis.

4.4.2.1 General Hydrogeological Concept of the Study Area

Integration of the above presented information and evidence postulates a general hydrogeological concept (**Figure 17 & Table 1**) with high transport capacity basal Kalahari unit consisting of conglomerate and gravels, this conceptual position is informed by several investigators (Boocock & Van Straten, 1962; Thomas & Shaw, 1991; Jones, 21010). Boocock & Van Straten (1962) contend that the basal gravels and conglomerate are extensive in the Kalahari Group and reflect the importance of the post Gondwanaland endorheic drainage system, whereas Thomas & Shaw (1991) state that marls are reportedly been found above the basal gravel but are confined to northern Namibia.

The second aquifer unit of the Kalahari in the study area is the medium sand and sandstone layer of the middle Kalahari, this aquifer (**Figure 17 & Table 1**) although reported be consistent by Kuells (2000) is expected to be discontinuous in this conceptual model given evidence of drying conditions which followed the basal Kalahari in which the hydrological regime is reported to have been ephemeral with wide spread deposition of laterite and duricrust (*alternate hot and wet conditions*) and discontinuous clay horizons. Drilling at both Goblenz and Katji na Katji confirm the presence of this red to pink sandstone at the depth of around 150 m depending on where you are in the basin.

This study does recognise the presence of the largely Aeolian upper Kalahari but does not appreciate it as an aquifer. This position is informed by the low energy drainage nature of the upper Kalahari presented in fine and silty sediment. However, where local streams have been uplifted by igneous impalements i.e. the first 68 km of the Omatako River within the study area up to the village of Ncaute the energy and mass transport capacity of the upper Kalahari can be considered as a local aquifer, particularly around stream banks where the stream channel has been burying and shifting away from. In this zone of the upper Kalahari water levels can be as shallow as 10 m and borehole depths of 70 m can yield up to 30 m^3/h with very high variability, therefore this is not a well-developed aquifer system.

Table 1: Conceptual hydrogeology of the study area

GROUP/SEQUENCE	STARTIGRAPIC NUIT	DESRIPTION	
		Nature Type	**Aquifer Potential**
Kalahari	Fine and Silt	Aquitard, leaky Aquifer	Low Yielding, locally high Yielding
	Sandstone, Sand & Clay	Aquifer	Low Yielding
	marl and clay	Confining Layer	none
	Conglomerate & Gravel	Aquifer	High Yielding
Karoo	Basalt/Sandstone	Aquitard/Weathered	Conditional
Damara	Schist/Quartzite/dolomite	Aquitard/Fractured	Conditional

Based on the above give hydrogeological concept, the deep and regional groundwater flow system (**Figure 17**) equivalent to the lower Kalahari aquifer unit benefits from direct recharge around the rim of the basin and from elevated outcrops, would characteristically artesian (*marl & clay confining layer*) with elevated total dissolved solids (TDS) due a long resident times, and therefore prone to poor water quality. This system is not expected to be shallower than 160 m except where elevated by igneous intrusions.

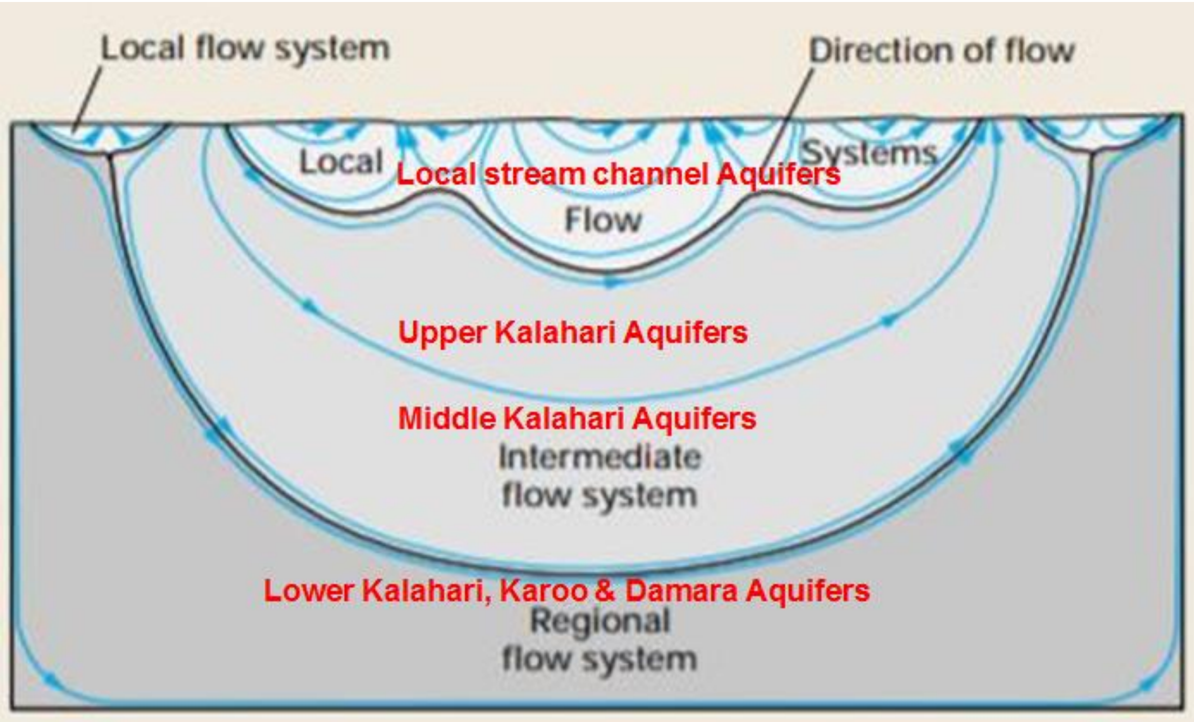


Figure 17: Conceptual flow components of the study area

The middle Kalahari aquifer (**Figure 17**), which is largely fine/medium grained sand and sandstone as stated earlier would benefit from leakage recharge from the upper Kalahari and is therefore expected to be semi-confined to confined in places, with limited storage capacity outside current or/and outside palaeo-stream channels. Water quality will be acceptable for human consumption along stream channels but may deteriorate away from existing or from palaeo-stream channels.

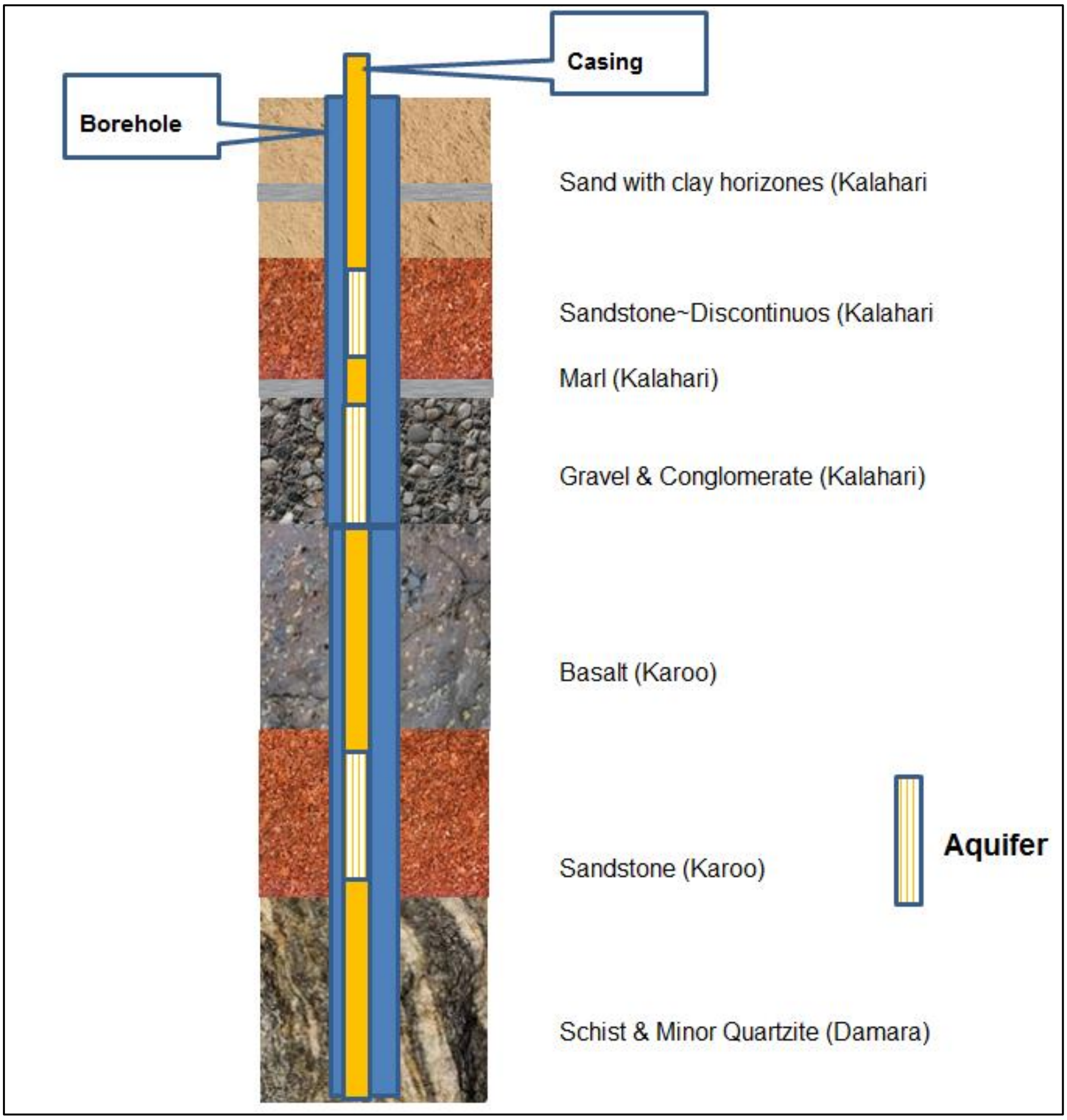


Figure 18: Vertical conceptual hydrogeology of the study area

On the basis of the developed conceptual hydrogeology model (**Figure 18**) of the study area, the Karoo sandstone/conglomerate and lower Kalahari aquifers are expected to be confined and therefore prone high hydraulic pressures during drilling, this applies to any significant water bearing layer in the Damara Aquifers, particularly fractured quartzite and dolomite/limestone formations. The depth of these aquifer units cannot be estimated but the onset of the Karoo is marked by gravity sediments – the Dwyka Formation which is a conglomerate or tillite, whereas the onset of the Kalahari is also marked by fluviatile gravels and conglomerates. These two stratigraphic markers should produce more water than others; that is besides fractured quartzite and dolomite/limestone of the Damara Sequence.

4.5. Water and environment

A generic water environment consists many measurable components and among others the important ones are rates of water flow, water flow direction, water stagnating/ponding, water flow pathways, replenishment of water sources, changes in storage, discharging of water from water bodies, physio-chemical, existing/expected organic load of the area and biological character of the water, flooding and depletion of water resources, water resources contamination as well as the terrestrial and aquatic life supported by water bodies.

In this section of the report, the study area is interrogated with regard to the current status, the implication and the vulnerability of the above listed aspects of the water environment in view of the envisioned drilling for gas and oil exploration holes, and possible drilling of one to two shallow water production boreholes.

4.5.1 Rates of Water Flow

Several factors impact rates at which both surface and groundwater flow, but generally the hydraulic gradient which is provided by both by elevation variations and confining pressure variations are groundwater is the main and principle driver of water flow rates. Other contenders would be flooding, recharge rates and depletion rates. With reference to the project area, the annual average rain is 577 mm. Generally, this amount of annual rainfall should not cause flooding especially in low topographic gradient areas (1:1400) like the study area. However flooding can be possible during wetly rain seasons, particularly along the Omatako River's first 67 km from the southern boundary of the study area to the village of Ncaute where the surface hydraulic gradient is 1:700 with relatively high tributary network frequency. Considering that drilling is earmarked in this area; caution should be exercised to avoid flood related risks as well as possible flood related water contamination events. Generation of flood risk coefficient s/figures on the basis of which earth-work designs should be based-on are beyond the scope of this study.

4.5.2 Water Flow Direction

Both surface and groundwater flow direction is south to the north, north easterly direction (**Figure 18**) towards the Okakavango River, however surface water has the potential of locally ponding during rain seasons from Ncaute down-stream due to relatively low topographic slope

(1:1640) as well as sharp stream channel directions (*potential riffles, pools in-channel landforms*). Therefore, any surface water contamination risks should be avoided in this area, nevertheless in case oil spills these areas could be potential capture and removal zones.

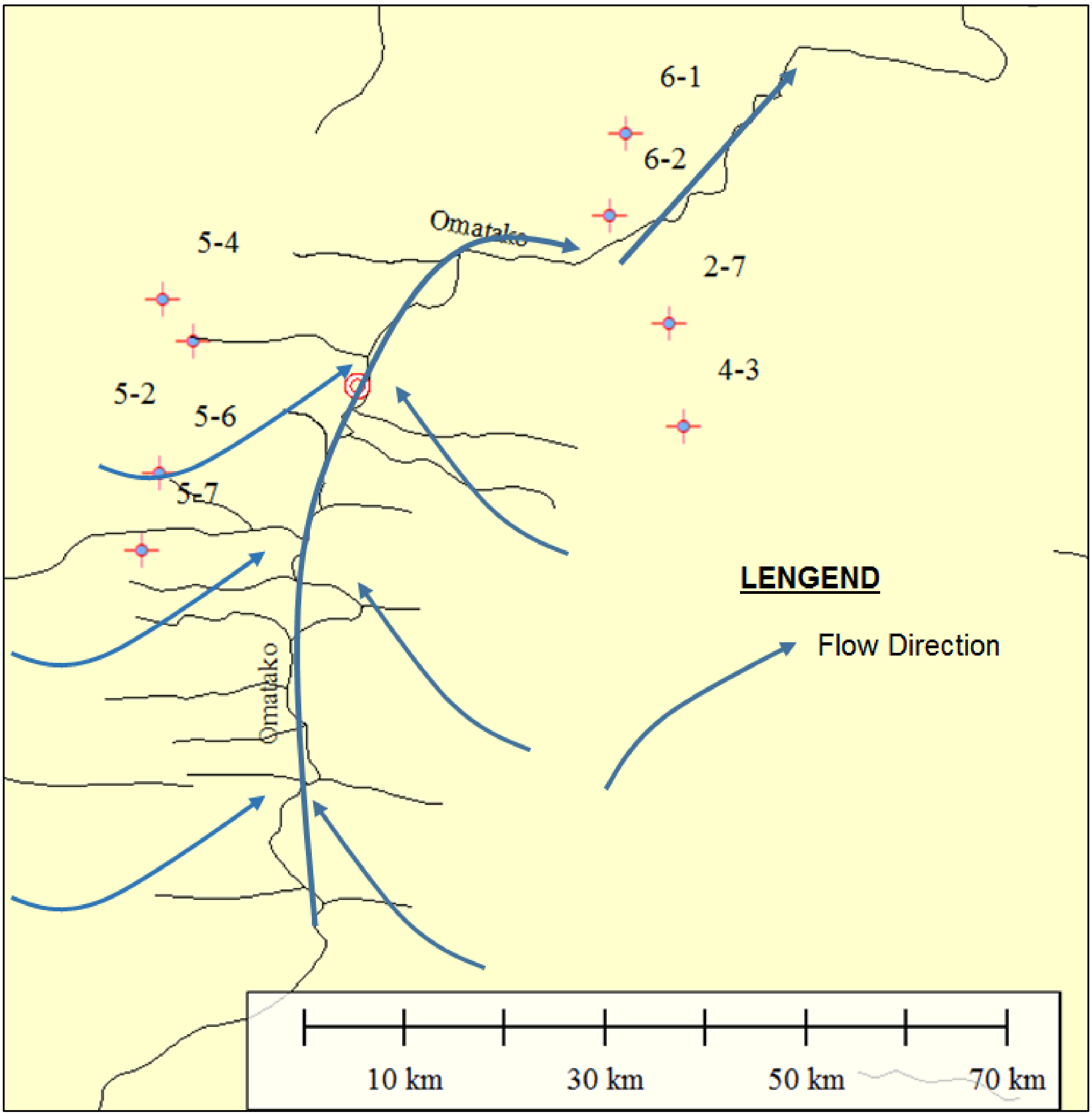


Figure 19: General groundwater and surface water flow direction

4.5.3 Contamination Pathways

Preferred contamination pathways in the context of this study area largely consist of steam channels, pools of surface water and boreholes, soil is also a pathway. Based on Figures 18 and 19, site 5-6 is situated at the up-stream onset of a stream

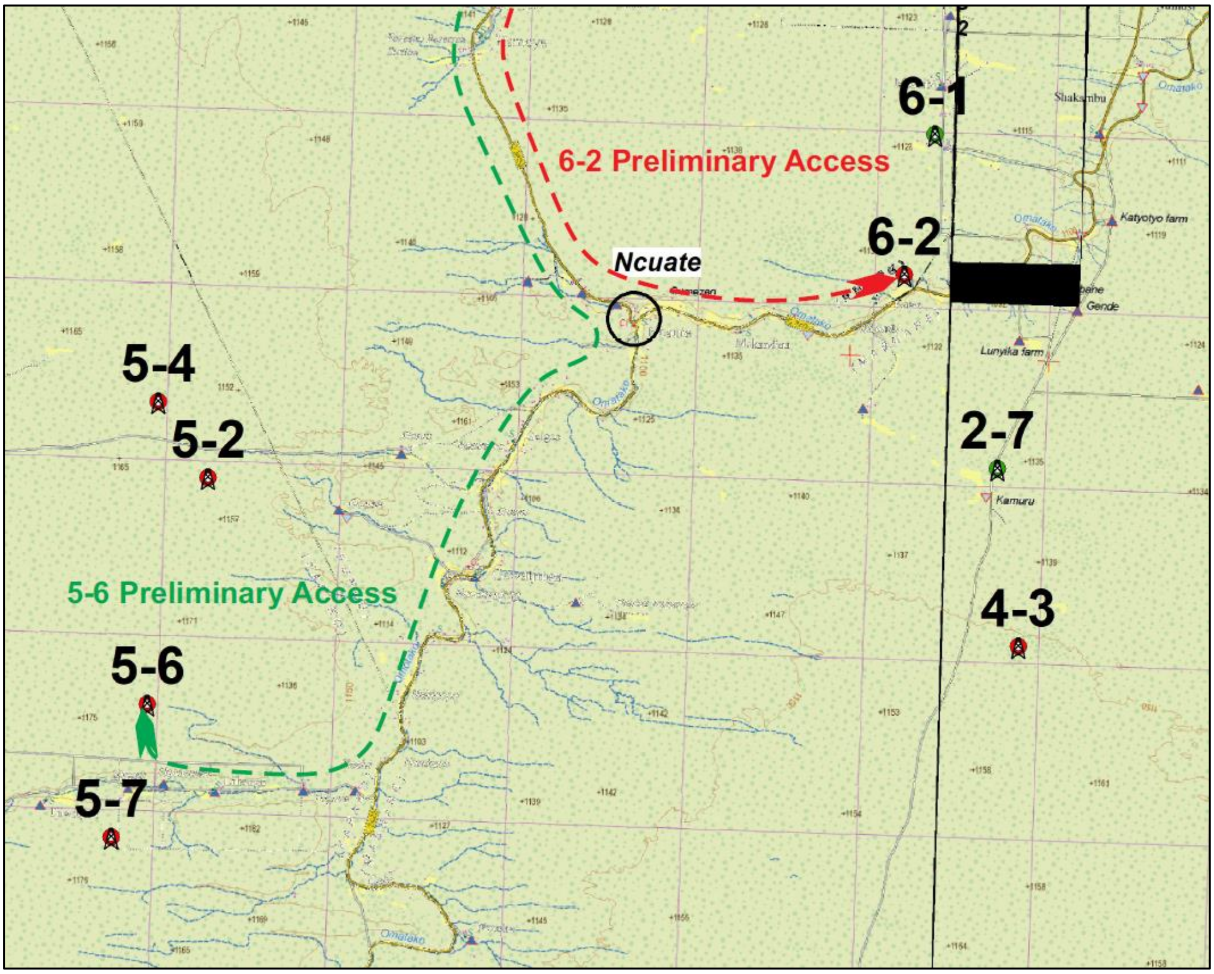


Figure 20: Proposed sites for exploration drilling

4.5.4 Changes in Water Storage

Generally it is theoretically expected that surface water ponding is very vulnerable to depletion by evaporation, then logically follows the shallow upper Kalahari aquifers, and this is more so for two reasons; first, the resource levels of these resources depend on seasonal direct recharge and would therefore mimic seasonal or/and short term rainfall departures from the regional annual rainfall. Second; the upper Kalahari has limited storage capacity due to the fine grain nature of their sediments. The second aspects also makes these resources highly localized and limited to small portions of good porosity, this makes them vulnerable to over-exploitation.

Groundwater storage stability is expected in the middle and lower Kalahari due to a more regional recharge regime which does not depend on seasonal rainfall. However, experience indicates that boreholes completed in the middle Kalahari have safe yields of about 5 m^3/h or less. This limitation of the safe yield of the middle Kalahari is closely related to the grain size of the red/pink sandstone aquifer.

Table 2 below indicates that boreholes completed in the conglomerate and gravels of the lower Kalahari (*250 to 462 m*) have safe yield in excess of 80 m^3/h, and even up to 100 m^3/h (DWA, 1997). However these results should not be directly correlated with what could be found in the study area because they come from relatively high energy and high sediment transport capacity area of the Omatako River channel with general slope of 1 in 300, compared to that of 1 in 700 at site 5-6 along the Omatako River channel.

Table 2: Details of exploration boreholes in the Goblenz Area (DWA, 1997)

WW No	Depth (m)	4.5 mm Casing Installed (m)		6 mm Casing Installed (m)		Rest Water Level	Test Yield
		Plain	Perforated	Plain	Perforated	(m)	(m^3/h)
36812	191	131.5	60.0	-	-	58.95	27.68
36813	120	6	-	-	-	-	-
36814	100	76.7	24.0	-	-	38.32	35.08
36815	252	168.4	84.0	-	-	38.37	88.63
36816	100	70.6	30.0	-	-	37.30	35.00
36817	100	70.5	30.0	-	-	39.20	40.00
36818	100	70.5	30.0	-	-	38.85	-
36819	100	70.5	30.0	-	-	34.50	25.00
36820	258	192.5	66.0-	-	-	39.38	56.60
36821	411	-	-	285.5	126.0	37.45	100.00
37740	427	-	-	278.2	150.0	34.63	101.00
37741	462	-	-	292.5	168.0	33.93	100.00
Totals	2 621	851.2	354.0	856.2	444.0		

4.6. **Potential Impacts**

Potential impacts and their associated significance were assessed using the methodology and formula given under the section: Methodology. Measures E, D, M, R and N can score to a maximum of 10 points, while likelihood has a minimum of 0 and maximum of 1, the Consequence (C) is calculated using the formula in the methodology section. The priority factor (PF) which is a measure of significance is a product of likelihood and consequence. On that basis PFs above 100 are considered high priority, above 50 but below 100 are moderate priorities while below 50 are lower priorities (**Table 3**). The numbers relating to 4.6 in Table below relate to impacts relating to items 4.6.1 to 4.6.14 respectively.

Table 3: Impact identification and assessment

RISK AND IMPACT EVALUATION														
IMPACTS	**4.6.1**	**4.6.2**	**4.6.3**	**4.6.4**	**4.6.5**	**4.6.6**	**4.6.7**	**4.6.8**	**4.6.9**	**4.6.10**	**4.6.11**	**4.6.12**	**4.6.13**	**4.6.14**
MEASURES:														
Nature, N	8	5	7	7	4	6	2	5	9	4	9	6	8	5
Extent, E	2	3	4	4	1	4	2	1	1	1	2	1	1	2
Duration, D	8	2	8	5	2	4	4	2	1	1	2	7	2	1
Magnitude, M	4	3	5	5	2	7	1	1	1	1	3	2	2	2
Reversibility, R	8	4	8	8	8	8	7	5	1	1	8	7	1	2
Likelihood, L	0.7	0.5	0.7	0.5	0.5	0.6	1	0.3	0.2	0.3	0.5	0.2	0.2	0.2
Consequence, C	270	88	241	238	133	207	63	104	39	19	295	178	37	45
Priority Factor, PF	189	44	169	119	67	124	63	31	8	6	148	36	7	9

4.6.1 Aquifer pollution vulnerability (APV)

The Namibian legal framework advocates and places stewardship responsibility on all parties involved in activities which may have negative affect the environment, in this regard particular reference is made to both the Water Act, Act No. 12 of 1956 and the Environmental Act, Act No.7 of 2007 with respect to the cardinal responsibility of protecting, preserving and sustainable use of water resources.

In recognition of these legal intruments, the consultant has adopted the **A**quifer Confinement **O**verburden and **D**epth to water table (AOD) index scheme to evaluate the pollution vulnerability of the aquifers in the study area.

Developed by Forster (1987), the AOD index scheme attempts to find the likelihood that a contaminant loaded at the ground surface will reach the water table of an aquifer given the nature of the aquifer, the nature and thickness of the aquifer's overburden.

The AOD index presented in **Table 4** is based on scales 1 to 10 of the Aquifer confinement, the Overburden strata in the unsaturated zone above the groundwater strikes, and Depth to the water table in unconfined aquifers.

Table 4: The APV for aquifers in the study area

Place	Depth to Water Table	Coordinates	Aquifer Confinement		Overlaying Strata		Depth		AOD	APV
			(m)	**Rating**	**(m)**	**Rating**	**(m) Rating**			
Upper Kalahari	Minimum		2	8	10	8	60	8	512	**Extreme**
Middle Kalahari	Minimum		40	4	95	4	100	4	64	**LOW**
Lower Kalahari	Minimum		120	2	150	2	200	2	8	**Low**

Allocation ratings as inferred from borehole logs are multiplied with each other to come up with AOD index. The indices reflect the following conditions:

- 0 – 150 Low APV
- 151 – 300 Moderate APV (Mod)
- 301 – 500 High APV
- >500 Extreme APV (Ext)

A primary appraisal of the proposed exploration site for groundwater Pollution Vulnerability (APV) using the AOD index framework indicates that during wetly seasons the APV of the upper Kalahari is extreme, whereas that of the middle and the upper Kalahari aquifers is low.

On the basis of aquifer pollution vulnerability (APV) evaluation, it can be concluded that the aquifer pollution vulnerability of the upper Kalahari in study area is extremely high due to elevated groundwater levels of some times less than 10 m.

This vulnerability largely relates to ground based activities which have the potential of polluting both surface and groundwater. In the context of the expected exploration drilling care should be exercised not to allow pollutants in this zone of the stratigraphy.

Mitigation:

- Cement casing should be applied to all holes to the base of groundwater protection (*depth where groundwater quality changes from no-saline to saline, 4000 mg/l*)

- Excavations for mounting of drilling rigs and other activities should be at least 3 m above the groundwater table. Wherever possible, such excavation should be properly lined to avoid percolation of contaminants into the upper Kalahari aquifer unit.

- A hydrocensus of local boreholes in a radius of 5 km around the sites is recommended for collection of base line physio-chemical, organic load and biological characteristics of groundwater, and of surface water.

4.6.2 Increased risk of flooding

The risk of flooding considering the paucity of the geographic footprint of the proposed drilling in combination with the low topographic slope of the area is low as can be seen in Table 3 above, this risk can however turn into the moderate risk zone with low impact between November and March in view of duration and area-coverage risk measures.

4.6.3 Impacts due to contaminated water discharge

Drilling rigs maintain cleanliness by washing oil remnants and other forms of dirty every now and then, and this waste should be collected in moveable chambers and disposed-off safely, but should this oil contaminated waste-water find other ways to either groundwater or surface water bodies, remedial actions are usually difficulty and expensive. However, sometimes oil spills occur and these can pose very high contamination risks to both surface and groundwater resources. In the study area, this risk increases during wet months of year from November to March and due to low topographic and groundwater gradients as well as the possible impact on water resources, vegetation and on aquatic life this risk is rated high and needs concerted attention.

Mitigation:

- Accessibility to spill prevention and response equipment, such equipment should be visible and accessible to all employees at any given time.
- Designated waste collection tanks should be away from waterways, and such isolation should be maintained at all times.
- Necessary response teams; such teams should be adequate to response to possible risk of contaminated water discharge if it threatens fresh water bodies.

4.6.4 Impacts due to oil tank bursts or/and pipe breaks

Although the likelihood of this risk is low, the impact if it happens is significant, for this reason, the risk is highlighted in Table 3 as a going concern of high priority and therefore special attention should be associated with efforts to make sure it does not happen.

Mitigation:

- Routine inspection to avoid overload of pressure and Leaks,
- Corrosion insulation and routine inspection of tank or pipes for evidence of corrosion.

4.6.5 Impacts due to vehicle fuel leaks

This risk is associated with leaks and fuel emissions from cars either parked or fuelling at the drilling site, these emissions and leaks have the potential of reaching both groundwater and surface water if there are active pathways. Even though the pathways to groundwater resources are not significant, those to surface water (during wet periods) taking into consideration the proximity of these sites to streams needs attention. However, this risk scores moderate in Table 3 due to its paucity and likelihood.

4.6.6 Impacts due to backwash water

This risk is closely related to risk 4.6.3, and scores high due its nature, and magnitude given that machines and cored samples need to be cleaned with considerable amounts of water. Another measure of significance is the reversibility of impacts if such incidents take place. It is common knowledge that polluted soil and polluted-water pollute water, and complete remedial is usually impossible and costly to the environment and in monetary terms.

Mitigation:

same as those under 4.6.3

4.6.7 Impacts due to loss of drainage area

This risk has moderate impact, in most measures it scores low, but if it occurs it is permanent. For this reason, it is rated moderate for this proposed drilling in that the site is within the immediate catchment of a stream.

Mitigation:

The design of the facility should be in such a way that none or minimum drainage area is disturbed or/and lost. What is important here is to maintain natural runoff patterns as natural as possible in view of effects to the structural integrity of other people's properties (*crop fields, homes, grazing, and travel tracks/path*) and in the interest of biotic dependencies on natural water flow.

4.6.8 Impacts due to Increased or reduced runoff

This risk scores moderate due to its nature and its low reversibility if it happens, however it scores low in all other aspects. Vegetation clearing and Paved area increases runoff and largely contribute to flood risk even during rainfall event which would otherwise pose no risk in natural environments. For this reason, this risk is considered low, and should be treated as such in monitoring and management plans.

4.6.9 Impacts due to drainage pattern disturbances

This risk is almost negligible due its small impacts with regard to extent, and duration if it happens; it has low magnitude and reversibility impacts.

4.6.10 Impacts due to Increase suspended load

This risk is almost negligible, and this is because there is little or no mobilization of suspended load in the long term, but should be considered during construction stage of proposed project.

4.6.11 Impacts due to increased risk of salinization

This risk scores 148 in Table 3, meaning that it is of high concern and particular attention should be paid to manage and mitigate it. Salinization generally speaks to increasing total dissolved solids (TDS) in water resources. In general, petroleum and gas contain high content of carbon, nitrogen, sulphur and metals like copper, nickel and vanadium. Therefore, exposure of petroleum/gas waste to water bodies raises the risk of elevated TDS and elevated content of heavy metals in water.

Mitigation:

Same as those under 4.6.3

4.6.12 Impacts due to disrupted groundwater flow/pathways

There are limited to no obvious groundwater flow/pathways in the study area, therefore, this risk is negligible.

4.6.13 Impacts due to elevated or reduced groundwater levels

It is envisaged that apart from the serious nature of the risk, the impact is low due to small extent, magnitude and reversibility of the risk should it occur.

Mitigation:

Groundwater withdrawal for drilling and other activities should be at the safe yield of production boreholes; therefore proper pump testing and data analysis for reliable estimates of safe yields of production boreholes should adhered to.

4.6.14 Impacts due to reduce recharge

Considering the paucity of the geographic footprint of the proposed site, this risk is negligible (**Table 3**).

5. Conclusion and recommendation

The endorheic drainage system in combination with drying and episodic rainfall climatic conditions created at the onset of the break-up of the Gondwanaland super-continent provided the coarse sediment river/stream channel bedload which forms the present day aquifers of the lower Karoo and lower Kalahari Groups of geological formations. At a local scale; the reactivation of old tectonic faults and the associated intrusion of basaltic igneous materials provided the impetus for high mass transport capacity of recent drainage system which forms the coarse stream channel bedload sediments relating to aquifers of the upper Kalahari Group.

In the context of the impact assessment of the risk posed by the proposed oil and gas exploration drilling in the study area, it is concluded that most of the risk categories are moderate to negligible if proposed measures are adhered to. However, the risks associated with: aquifer pollution vulnerability, impacts due to contaminated water discharge, impacts due to tank bursts or/and pipe breaks and that associated with impacts due to backwash water have high to moderate impacts with regard to water resources negative impacts in the study area. It is therefore recommended that the proposed mitigation measures be considered as integral part of the environmental management plan (EMP).

Long term and cumulative impacts will be limited if the exploration holes will have cement casing up to the Base of Groundwater Protection (BGWP) which is regarded as the depth at which groundwater quality changes from non-saline to saline (4000 mg/l). This principle also applies to saline stratigraphic horizons in sections above the BGWP.

In essence, the exploration hole should be materially isolated from the rest of its immediate surround by cement casing/grouting. Should it happen that the exploration hole still has a role to play after the exploration exercise, it should be properly closed on top; else total plugging of the exploration hole is recommended.

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