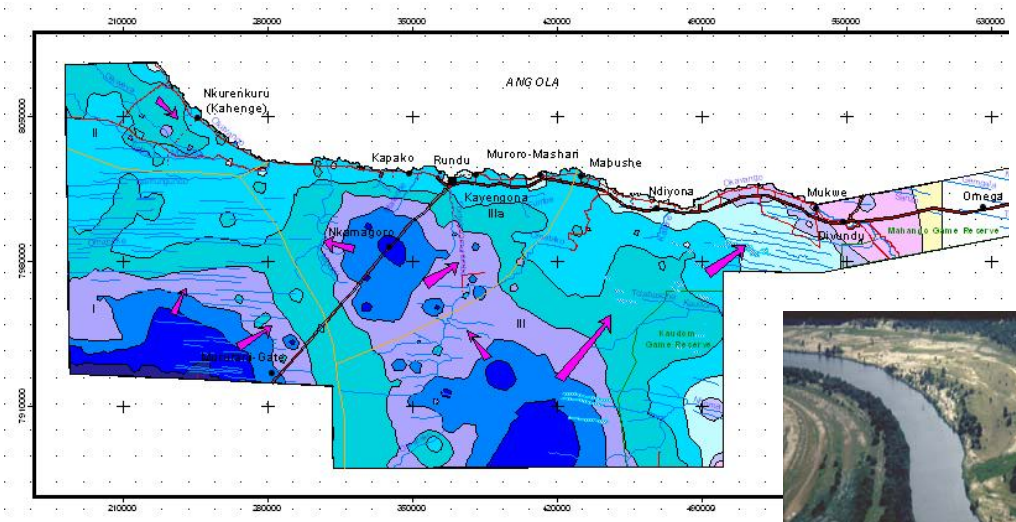
Kavango Region Namibia
Regional Monitoring Network Study



Preliminary Report

September 2011

Water Surveys (Botswana) (Pty.) Ltd.

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1 INTRODUCTION

Water Surveys Botswana were commissioned by SAREP (Southern African Regional Environmental Programme) to review all the relevant data on the Kavango Region of Namibia with a view to firstly designing a borehole monitoring network and secondly to providing water sampling protocols, sampling procedures/methods and analytical requirements.

This Preliminary Report deals with the first project objective – designing a regional monitoring network in particular the first 12 (twelve) priority sites.

1.1 BACKGROUND

The Kavango Region lies in north-eastern Nambia bordering the Caprivi and Botswana to the east and Angola to the north covering an area of approximately 48,500 square kilometers. A project area location map is presented as Figure 1.1. The following sections provide a brief summary of the physical and human environment of the Kavango Region.

1.1.1 Demographics

The population of the Kavango Region is predominantly rural with 72% of people residing in rural areas and 28% in urban areas. However, the population distribution is centred along the Okavango River, along the Grootfontein-Rundu road and decreases into the hinterland of the region (see Figure 1.2). The largest urban settlements are the capital Rundu and the towns of Nkurenkuru and Divundu.

The majority of the population practice subsistence farming both arable and livestock with some people utilizing natural resources (trees and fish) to supplement or make a living. Within the region six National Parks have been demarcated from the "communal" lands areas (see Figure 1.3 land use map).

1.1.2 Physiography, Climate & Drainage

The region is topographically fairly flat with elevations ranging from 1000 to 1200mamsl. The topography descends northwards towards the Okavango River and eastwards towards Botswana (Makgaikgadi Depression). On this general flat topography subtle changes occur due to longitudinal dunes and associated inter dunal depressions and "dry-fossil" river valleys known locally as the "omirambas"

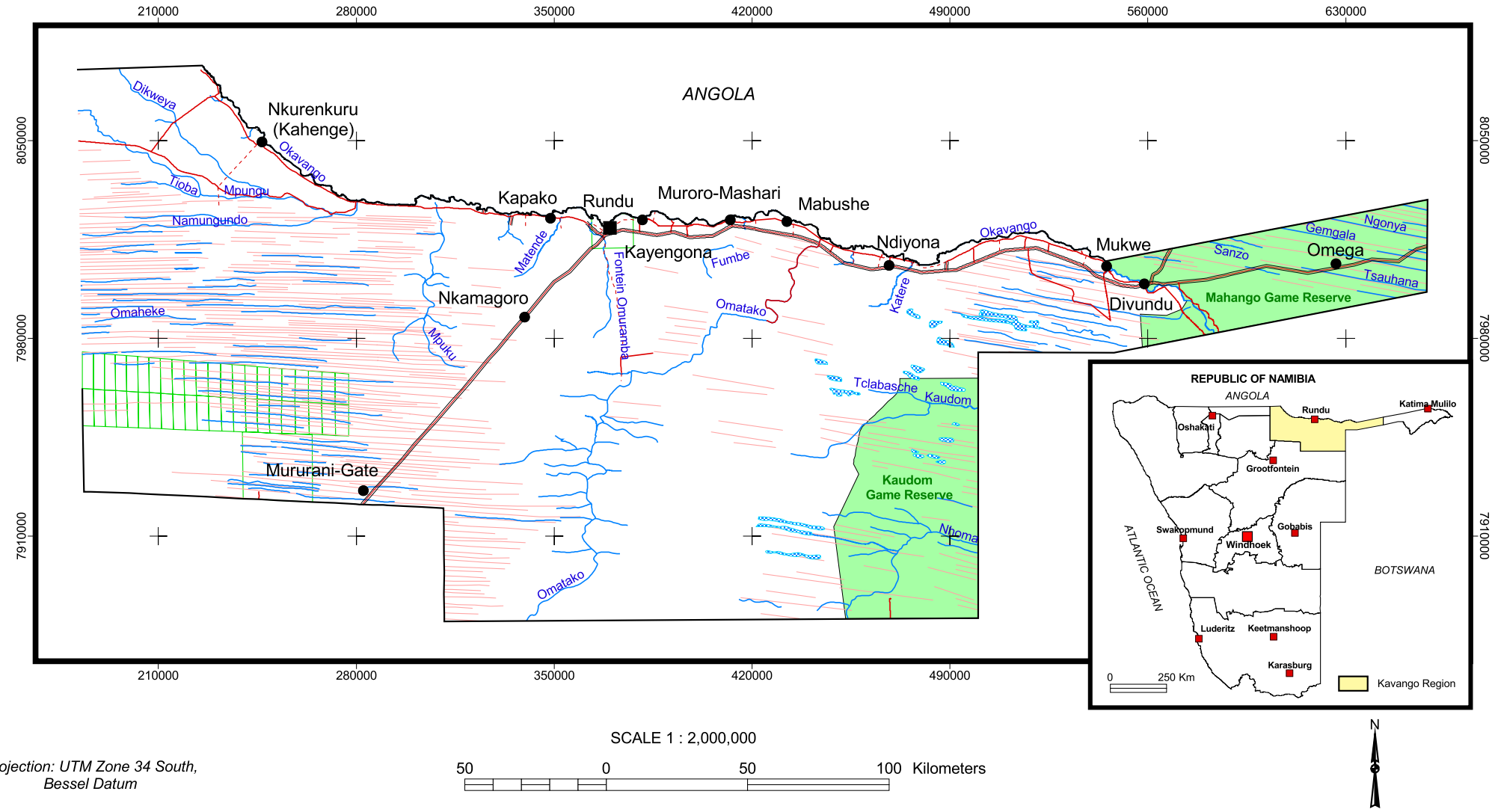
Within the Kavango region the vegetation can be divided into four main types:

- Broad leafed deciduous woodland.
- Shrubland.
- Grasslands
- Riverine.

The distribution of vegetation types is primarily controlled by the prevailing climatic conditions – decreasing rainfall northwards and soil type and by human activity. Five soil groups are recognized being arensols, fluviosols, calcisols, solenetz and anthosols

The Kavango area has two distinct drainage features the perennial Okavango River and the Omirambas, which generally drain eastwards. The main omurimba is the northerly draining Omuramba Omatako. Little to no flow occurs in the Omirambas, the little run-off that occurs produces isolated "ponded" areas, whilst flow from the Okavango can flow into the Omuramba Omatako for short distances at the confluence.

FIGURE 1.1: PROJECT AREA LOCATION MAP



SCALE 1 : 2,000,000

50 0 50 100 Kilometers

Projection: UTM Zone 34 South, Bessel Datum

DATA SOURCE

Roads, settlements, rivers, swamps, protected areas , administrative boundaries: Geohydrology Division, Ministry of Agriculture, Water & Forestry, Namibia

Water Surveys Botswana

LEGEND

- Town
- Settlement
- Pan
- Tarred road
- Gravel road
- Graded or sand earth road, track
- River / fossil river valley
- Dunes
- Farm
- Game reserve

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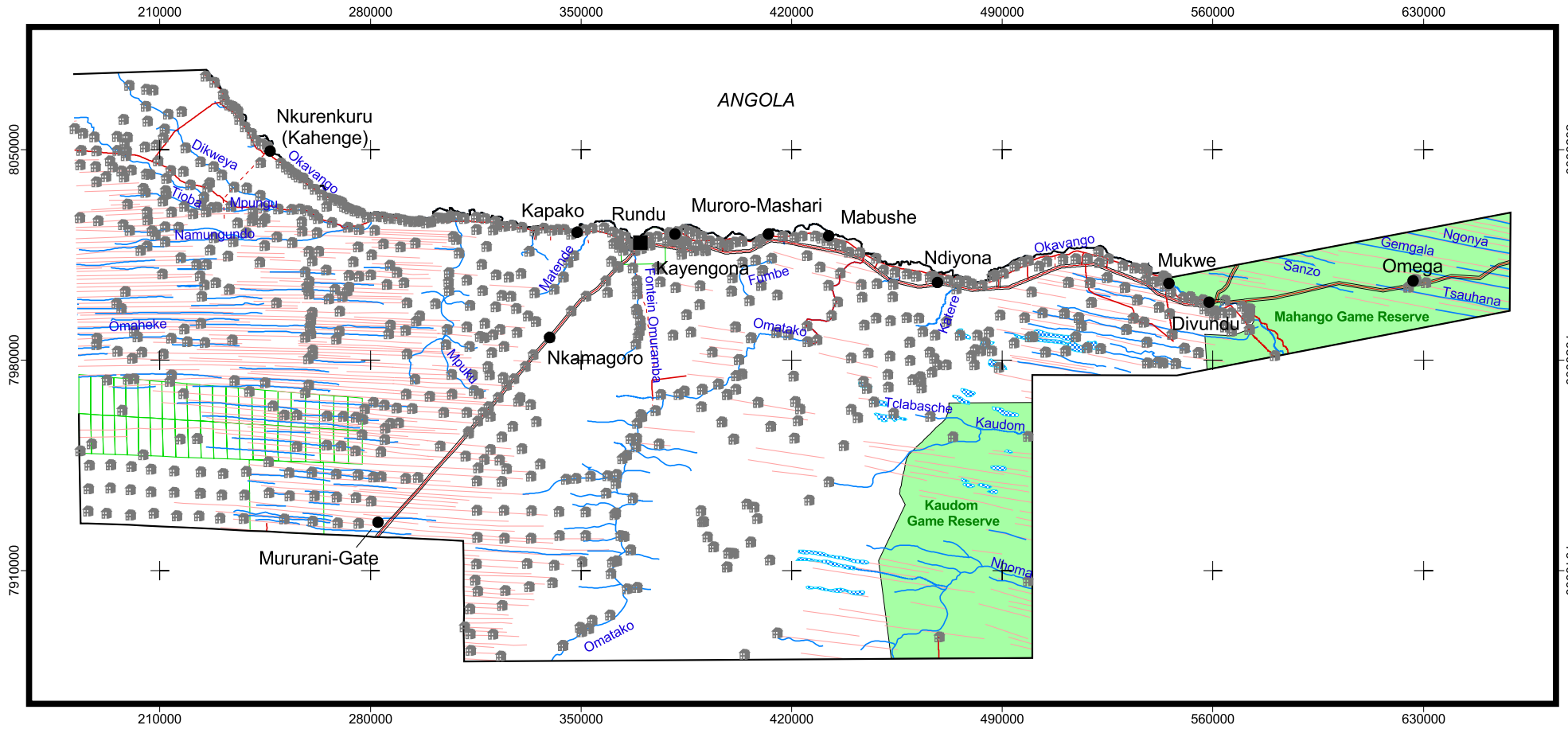
FIGURE 1.2: POPULATION DISTRIBUTION MAP



SCALE 1 : 2,000,000

50 0 50 100 Kilometers

N

Projection: UTM Zone 34 South, Bessel Datum

DATA SOURCE

Roads, settlements, rivers, swamps, protected areas , administrative boundaries: Geohydrology Division, Ministry of Agriculture, Water & Forestry, Namibia

Water Surveys Botswana

LEGEND

- Town
- Settlement
- Builtup area
- Tarred road
- Gravel road
- Graded or sand earth road, track
- River / fossil river valley
- Pan
- Dunes
- Farm
- Game reserve

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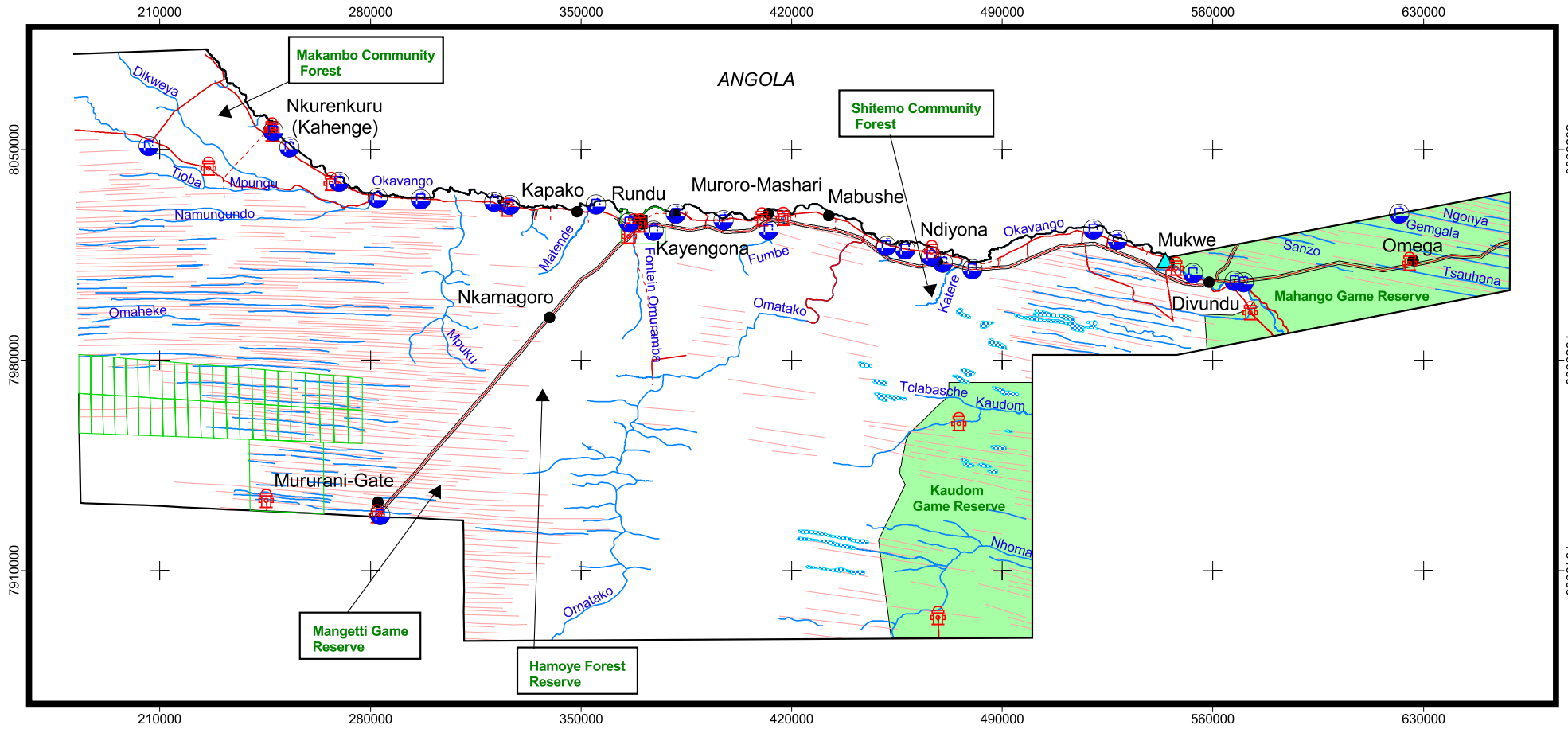
FIGURE 1.3: LANDUSE MAP



SCALE 1 : 2,000,000

50 0 50 100 Kilometers

Projection: UTM Zone 34 South, Bessel Datum

N

DATA SOURCE

Roads, settlements, rivers, swamps, protected areas , administrative boundaries: Geohydrology Division, Ministry of Agriculture, Water & Forestry, Namibia

Water Surveys Botswana

LEGEND

- Town
- Settlement
- Irrigation scheme
- Rain station
- Hydrostation
- Tarred road
- Gravel road
- Graded or sand earth road, track
- River / fossil river valley
- Dunes
- Farm
- Game reserve
- Pan

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The Okavango has one major tributary, the Rio Cuito, which contributes about 50% of its flow, and has a later flood peak and a more even flow than the Angolan "Okavango" known as the Rio Cubango. The flow in the Okavango follows a similar pattern to the rainfall, however peak river flows are slightly later in the year.

The Kavango region has a semi-arid climate with rainfall occurring during the summer months from September to April, primarily from December to March with the winter months being dry. Rainfall is related to the southward movement of the Inter Tropical Convergence Zone (ITCZ) during the summer months. Rainfall falls as high intensity localized thunder storms, though over recent years longer periods of frontal rainfall has occurred as in Botswana. The average rainfall varies from 450 to 600mm/year and decreases from the northern part of the district southwards.

Mean maximum temperatures are between 32 and 35^{o}C, during the summer months, with October being the warmest. During winter (May to August) the mean minimum temperatures is between 5 and 10^{o}C.

The region has an evaporation rate that amounts to about 1,950 mm per year, being four times the average rainfall i.e. a net loss. Evaporation is at its highest in September and October when temperatures are highest.

1.1.3 Water Supply

The perennial Okavango River is the major source of water for the population of the Kavango region with approximately 50% of the population getting water from the river (Lund 2002). Away from the river water is either from boreholes (25% of population) or dug wells (12%), with approximately 10% of the population in the Rundu urban area obtaining water from communal standpipes.

Groundwater is used for domestic and livestock watering. Borehole pumps (positive displacement and submersible) are powered by diesel engines, electric motors, solar or by wind or boreholes are equipped with hand pumps.

A borehole distribution map is presented as Figure 1.4.

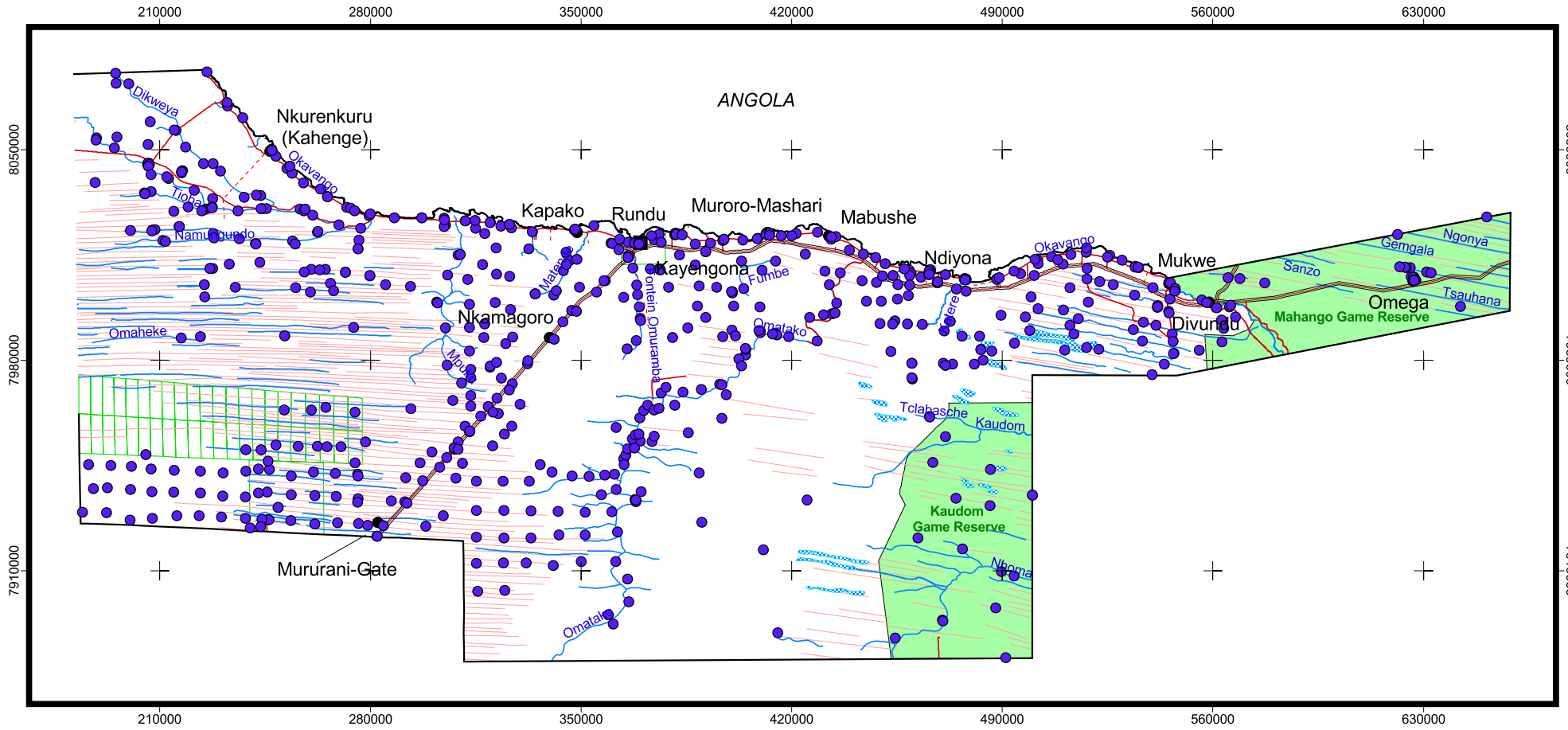
Rural water supplies are at present unmetered and as such abstraction volumes are unknown. However, it is possible to have a rough estimate of daily abstractions by knowing the pump size and the hours they are run or alternatively how long it takes to fill the storage reservoirs and how many times they are filled. Given the population density distribution abstraction is unlikely to be excessive and so resource depletion is unlikely. As part of the communal participation in water management, data on abstraction should be collected by the community.

2 GEOLOGY

A geology of map of the Kavango Region and covering northwestern Botswana is presented as Figure 2.1, whilst Table 1 summarizes the stratigraphy. The Kavango region falls within the Okavango sub-basin, which is part of the greater Kalahari basin, which covers northern Namibia, Botswana and southern Angola. The Kalahari Group uniformly blankets the whole district apart from a few areas of outcrop along the Okavango River near Rundu and between Mukwe and Bangani, and along the Nhoma River drainage within the Kaudom Park and at the border between the Kavango and Caprivi regions near Andara. The Kalahari increases in thickness northwestwards varying from <50m near the Botswana border to >400m thick.

The oldest rocks in the region are the Damaran meta-sediments comprising of dolomites, quartzites, shale and schist. Overlying the Damaran are the Etjo Sandstone (Lebung) and the Kalkrand Plateau

FIGURE 1.4: BOREHOLE LOCATION MAP



SCALE 1 : 2,000,000

50 0 50 100 Kilometers

Projection: UTM Zone 34 South, Bessel Datum

N

DATA SOURCE

Roads, settlements, rivers, borehole, protected areas , administrative boundaries: Geohydrology Division, Ministry of Agriculture, Water & Forestry, Namibia

Water Surveys Botswana

LEGEND

- Town
- Settlement
- Borehole
- Tarred road
- Gravel road
- Graded or sand earth road, track
- River / fossil river valley
- Pan
- Dunes
- Farm
- Game reserve

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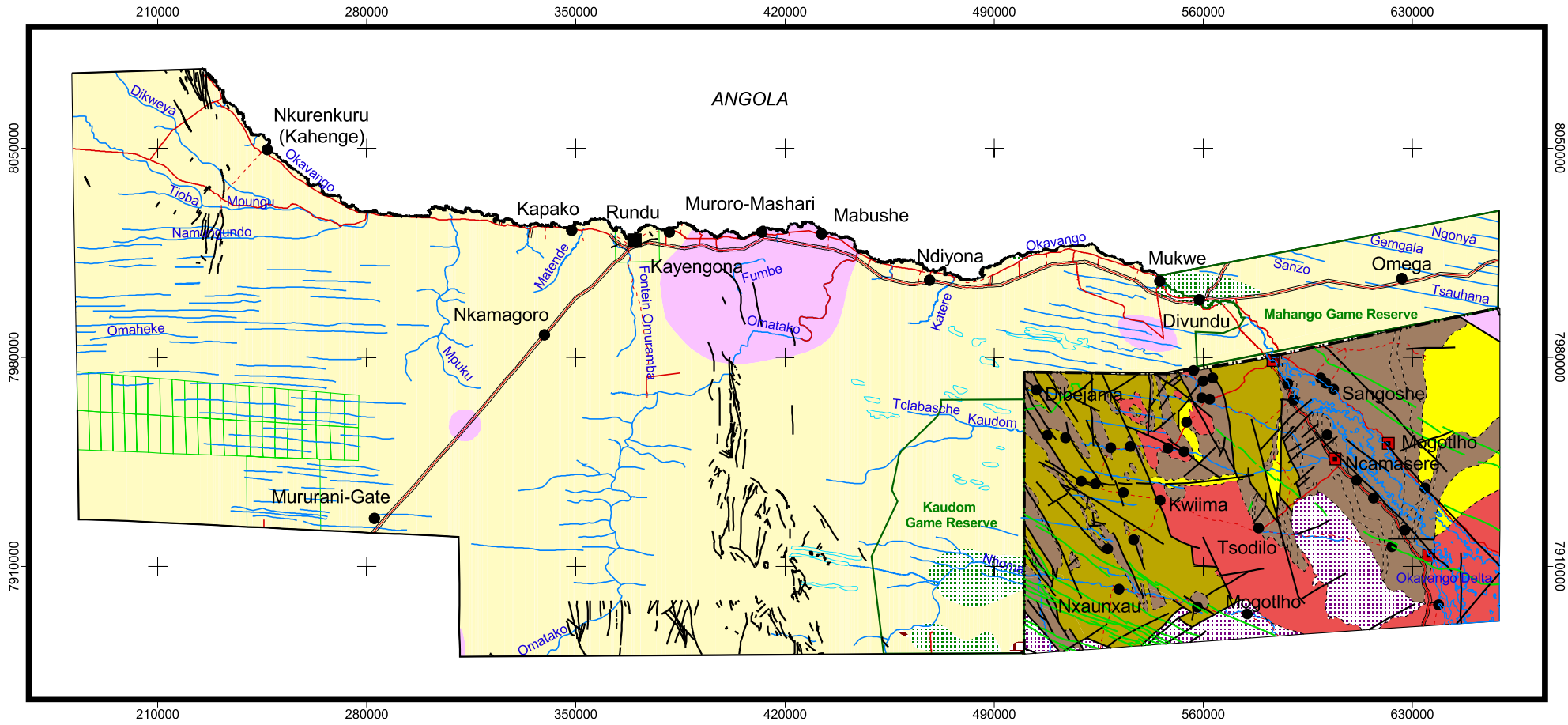
FIGURE 2.1: GEOLOGY MAP



SCALE 1 : 2,000,000

50 0 50 100 Kilometers

N

Projection: UTM Zone 34 South, Bessel Datum

DATA SOURCE

Geology, roads, settlements, rivers, swamps, protected areas , administrative boundaries: Geohydrology Division, Ministry of Agriculture, Water & Forestry, Namibia; and Botswana Government

Water Surveys Botswana

LEGEND

- Town
- Village
- Settlement
- Swamp, pan
- Border
- Tarred road
- Gravel road
- Graded or sand earth road, track
- River / fossil river valley
- Doleritic dyke
- Fault
- Geological contact
- Kalahari (Q)
- Karoo volcanics
- Karoo basalts
- Lebung Group
- Tsodilo Hills Group
- Xaudum Group
- Quangwadum Group
- Nosib
- Basement
- Farm
- Game reserve

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Basalts of Late Karoo age (equivalent to the Stormberg flood basalts of Botswana). Ecca Group sediments are absent or are as yet unproven from drilling.

The Kalahari Group comprises of unconsolidated to semi-consolidated aeolian and fluvial deposits and has been divided into three main units:

- Upper – comprising aeolian sands and fluvial sands.
- Middle - comprising fluvial sands with minor Aeolian sands.
- Lower – comprising of conglomerate, red clay with a carbonate cement.

The basin shows a main southeast-northwest trending axis (see Figure 2.1) with two subsidiary basin axes trending southwest-northeast. These trends are the same as the dominant basement trends of the Damaran Orogeny and the dolerite dyke trends which stretch across northern Namibia into Botswana.

The affects of the dolerite dyke intrusions on the groundwater flow regime of the regional Kalahari aquifer system is unknown. However, it is unlikely they act as barriers unless they come close to surface.

Table 1 – Stratigraphy of the Kavango Region (modified from Lund 2002)

Period	Super Group	Group	Formation	Description
Recent To Late Cretaceous	Kalahari	Upper	Kalahari Sand	Aeolian sand with ferricrete and silcrete
			Omatako	Ferricrete & ferruginous sandstone
		Middle	Eiseb	Sandy silcrete & calcrete with conglomerate bands
		Lower	Tsumkwe	Reworked sandy to clay rich conglomerate, basal scree with calcareous cement minor mudstone
				Dolerite dyke intrusives
Triassic to Jurassic	Karoo	Stormberg Lebung	Kalkrand Etjo Sandstone	Plateau Basalt Aeolian and fluviatile sandstone
Early Namibian	Damara	Nosib	Druchaus?	Feldspathic quartzites and shales

3 HYDROGEOLOGY

Table 2 below, taken from Lund, shows the major aquifer units and aquitards of the Kavango Region, whilst Figure 3.1 presents the hydrogeology map. Hydrogeologically, two aquifer types are present in the Kavango region. Firstly the primary porosity aquifers present in the Kalahari Group sediments, which occur throughout the region. Secondly, the secondary permeability aquifers (fractures/faults) of the Damaran meta-sediments and the Karoo basalts.

The Kalahari Group sediments constitute the most important aquifers being utilized for bulk water supply, in particular paleo-channels of the Okavango River and rural settlements (domestic & livestock).

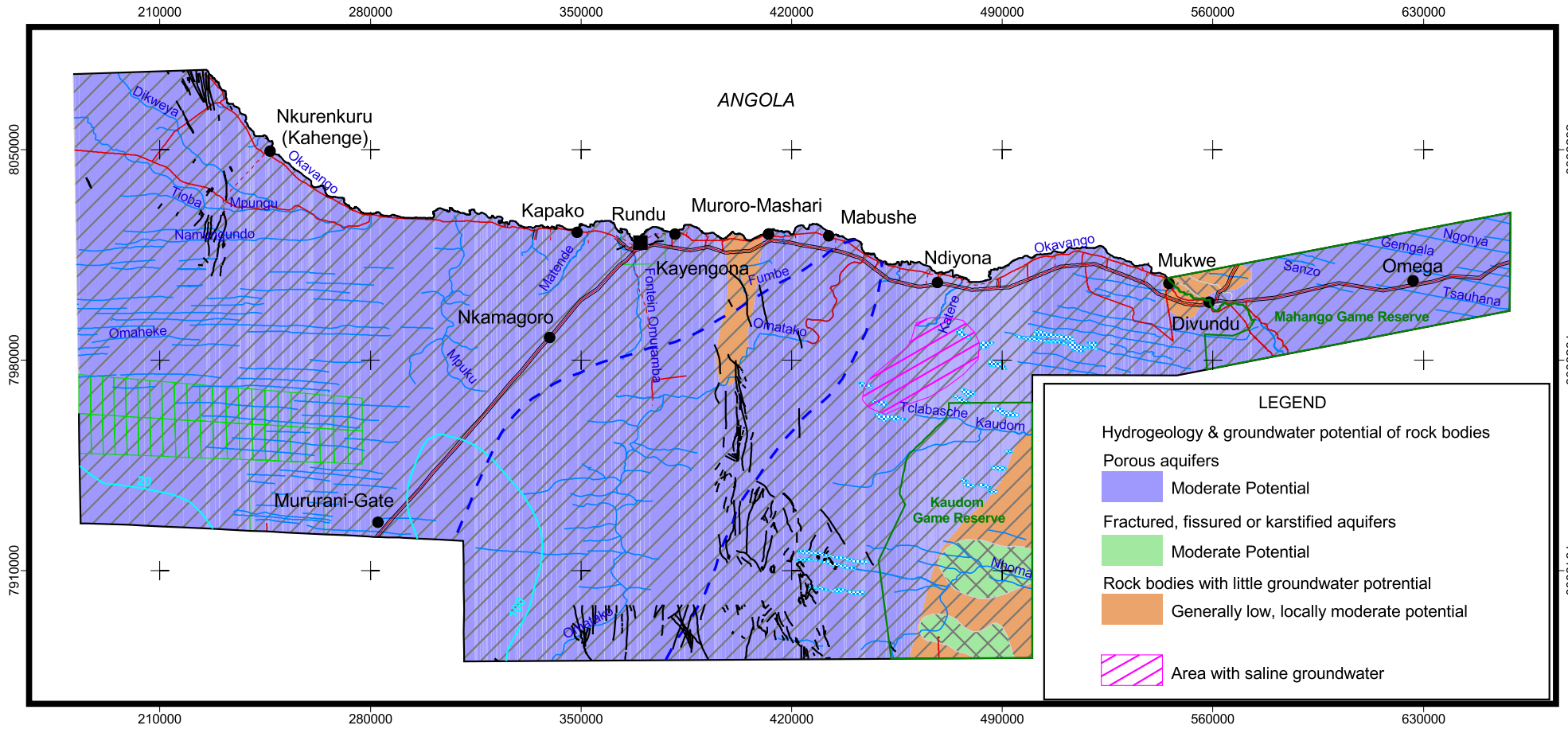
Table 2 – Aquifer & Aquitard Distribution of the Kavango Region (source Lund 2002)

Super Group	Group	Formation	Aquifer	Aquitard
Kalahari	Upper	Kalahari Sand	Aeolian sand, ferruginous sandstone	Ferricrete calcrete & clay layers
		Omatako	**Local perched aquifer**	Ferricrete calcrete & clay layers
	Middle	Eiseb	Sandy silcrete & calcrete with conglomerate bands **Main regional aquifer**	Minor clay layers
	Lower	Tsumkwe	Sandy conglomerate	Clay rich conglomerate, mudstone **Aquitard**
				Dolerite dyke intrusives
Karoo	Stormberg	Kalkrand		**Aquitard**
Damara	Nosib	Druchaus?		Quartzites and shales **Aquitard**

3.1 BOREHOLE YIELDS

Recorded borehole yields from the Kalahari are highly variable ranging from <1 to >70m^3/hr with the majority of boreholes yielding between 5 and 10m^3/hr. High yielding boreholes are recorded adjacent to the Okavango River and within the shallow aquifer southwest of Rundu. Low yielding boreholes are associated with areas of deep water table and where the Kalahari shows increased clay content and cementation. The success/yielding capacity of boreholes is thus related to location, formation and is also reported to be heavily influenced by the drilling method and borehole design (construction and material used). A borehole yield map is presented as Figure 3.2.

FIGURE 3.1: HYDROGEOLOGY MAP



SCALE 1 : 2,000,000

50 0 50 100 Kilometers

N

Projection: UTM Zone 34 South, Bessel Datum

DATA SOURCE
Hydrogeology, roads, settlements, rivers, swamps, protected areas , administrative boundaries: Geohydrology Division, Ministry of Agriculture, Water & Forestry, Namibia

Water Surveys Botswana

Town
Settlement
Pan
Game reserve
Farm

LEGEND
Tarred road
Gravel road
Graded or sand earth road, track
Groundwater divide
50 Depth to groundwater (mbgl)
River / fossil river valley
Fault

Main rock type of hydrogeological units
Unconsolidated sand & gravel
Non-porous sandstone, conglomerate, quartzite

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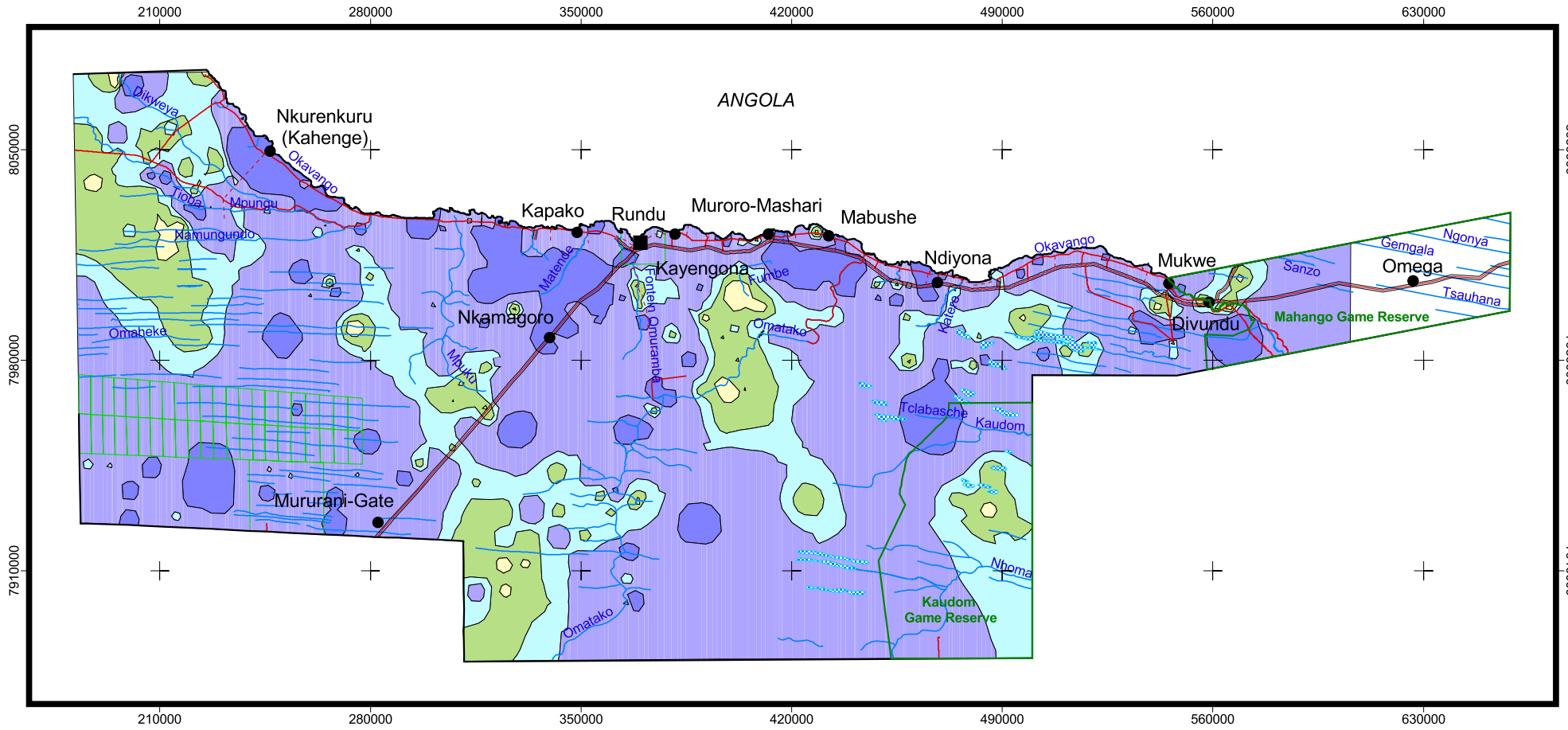
FIGURE 3.2: BOREHOLE YIELD MAP



SCALE 1 : 2,000,000

50 0 50 100 Kilometers

N

Projection: UTM Zone 34 South, Bessel Datum

DATA SOURCE

Borehole yield, roads, settlements, rivers, protected areas , administrative boundaries: Geohydrology Division, Ministry of Agriculture, Water & Forestry, Namibia

Water Surveys Botswana

LEGEND

- Town
- Settlement
- Pan
- Game reserve
- Tarred road
- Gravel road
- Graded or sand earth road, track
- River / fossil river valley

Borehole yield (m3/hr)

- 1
- 3
- 5
- 10
- 50

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3.2 GROUNDWATER FLOW & PIEZOMETRIC SURFACE

Regionally groundwater rest water levels vary from <20mbgl to >100mbgl. Along the Okavango River and in the eastern part of the district water levels are generally shallow being <50mbgl. However, along the Okavango sub-basin axis rest water levels are deeper being from 50mbgl to 130mbgl. The shallow and deeper rest water levels are a reflection of the different Kalahari aquifers being exploited; shallow being the Upper Kalahari whereas the deeper water levels found in the hinterland reflect the Middle Kalahari. Lund (2002) identified 3 main flow regimes and 1 sub-flow regime based on available piezometric data. A piezometric surface map is presented as Figure 3.3.

Regime 1

- Located in the southwestern part of the region.
- Shows a northerly flow trending towards the basin axis and onwards to the Okavango River and towards the Omuramba Mpungu.
- Flow driven by recharge from south of the Mangetti Block.
- Two recharge sources identified, firstly groundwater from the Otavi Mountains north of Grootfontein and secondly from calcareous Kalahari sediments between Abenab and the Kavango region border.
- Shallow gradient of 0.0003.

Regime 2:

- Located in the northwestern part of the region.
- North-south flow towards the Okavango River and towards the Omuramba Mpungu
- Recharge suggested being from Angola.
- Flat gradient.

Regime 3:

- Covers the major part of eastern Kavango.
- Recharge from northwest of Tsumkwe causes radial flow towards the Eiseb, Omatako and Okavango rivers.
- The Damaran metasediment outcrops in the Kaudom Park and near the Okavango River at Andara act as groundwater sinks rather recharge zones.
- Shallow gradient of 0.0003.

Sub-regime 3a

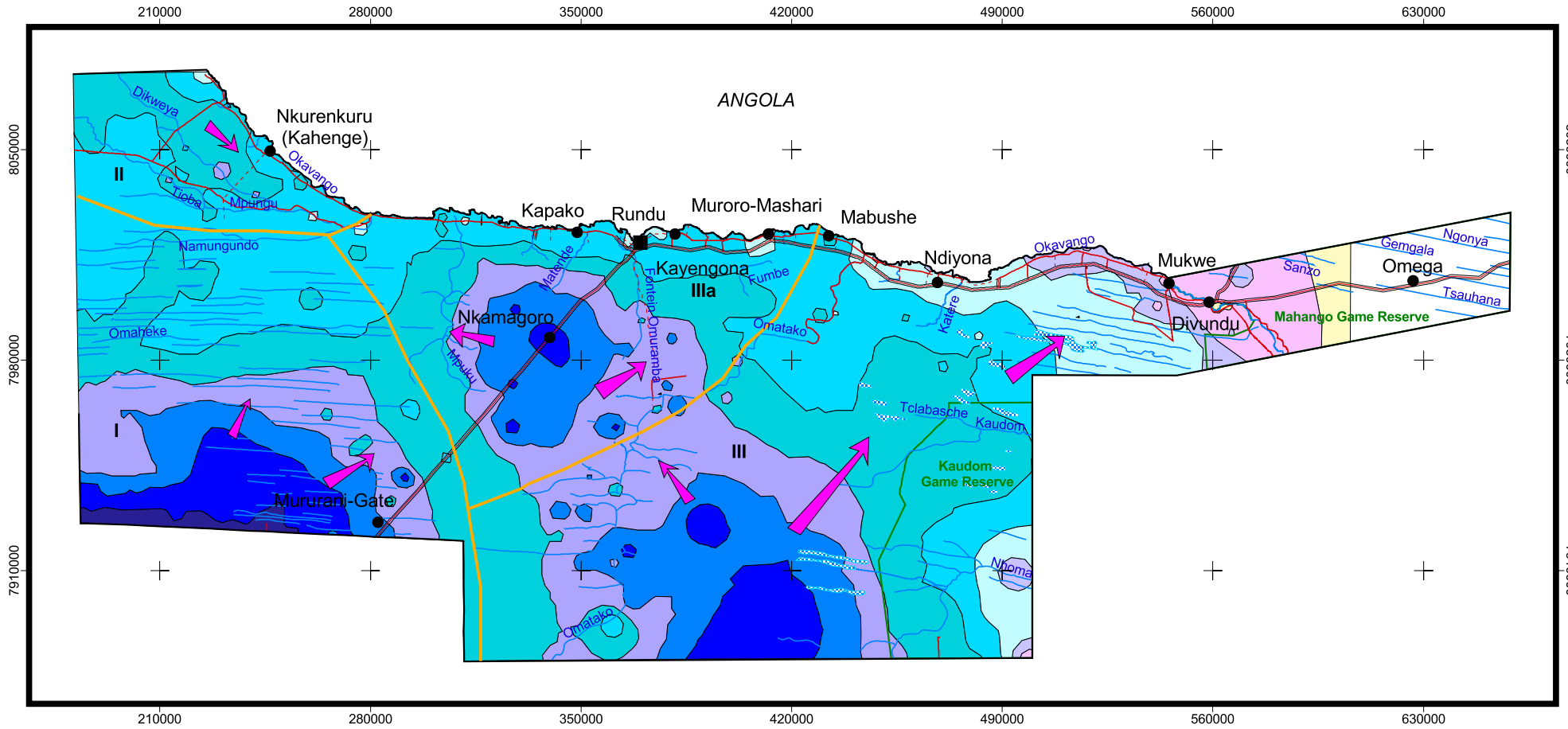
- Localized shallow Kalahari aquifer southwest of Rundu.
- Radial flow from a central recharge zone.

3.3 GROUNDWATER QUALITY

The water quality of the aquifers in the Kavango Region is generally very good with TDS (Total Dissolved Solids) being below 1000mg/l, with all major ions being within Namibian water quality standards. However, areas of elevated TDS (>1500mg/l) occur in isolated areas throughout the region. Very high TDS (>4000mg/l) is noted along the Okavango River. A TDS distribution map is presented as Figure 3.4.

Some of the areas of elevated TDS are associated with elevated sulphate and nitrate concentrations. Elevated sulphate is most probably as a result of dissolution of evaporates. The elevated nitrate away

FIGURE 3.3: PIEZOMETRIC SURFACE MAP



SCALE 1 : 2,000,000

50 0 50 100 Kilometers

Projection: UTM Zone 34 South, Bessel Datum

N

DATA SOURCE

Piezometric surface, roads, settlements, rivers, swamps, protected areas , administrative boundaries: Geohydrology Division, Ministry of Agriculture, Water & Forestry, Namibia

Water Surveys Botswana

LEGEND

- Town
- Settlement
- Pan
- Game reserve
- Tarred road
- Gravel road
- Graded or sand earth road, track
- River / fossil river valley
- Flow regime boundaries
- Groundwater flow direction

Piezometric surface (mamsl)

990
1010
1030
1050
1070
1090
1110
1130
1150
1310

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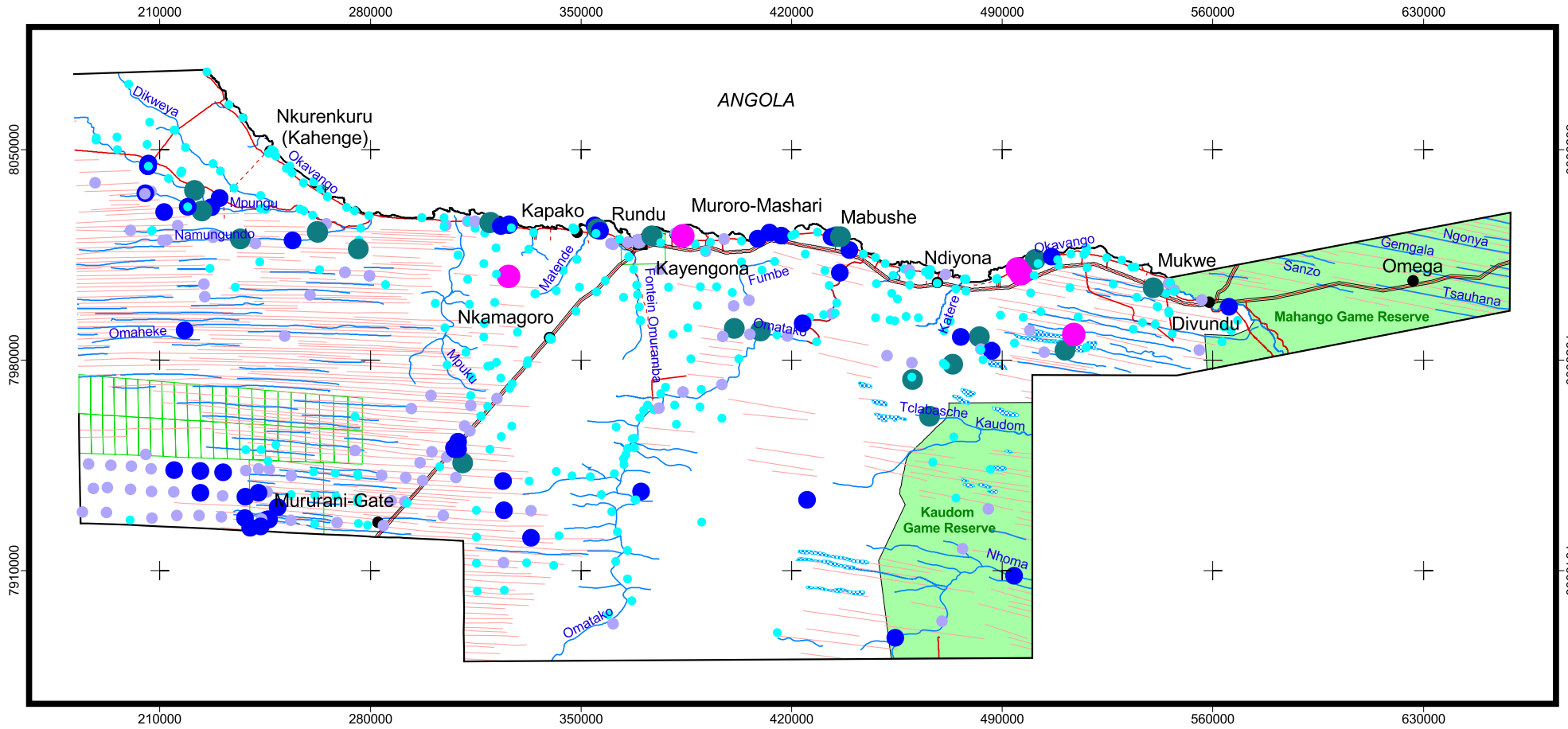
FIGURE 3.4: TDS DISTRIBUTION MAP



SCALE 1 : 2,000,000

50 0 50 100 Kilometers

N

Projection: UTM Zone 34 South, Bessel Datum

DATA SOURCE

TDS, roads, settlements, rivers, protected areas , administrative boundaries: Geohydrology Division, Ministry of Agriculture, Water & Forestry, Namibia

Water Surveys Botswana

LEGEND

Town

Settlement

Pan

TDS (mg/l)

0 - 500

500 - 1000

1000 - 2000

2000 - 5000

>5000

Tarred road

Gravel road

Graded or sand earth road, track

River / fossil river valley

Dunes

Farm

Game reserve

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from the Mangetti commercial farming area is not as a result of surface contamination but rather is related to past recharge events and is a natural occurrence.

Deep seated saline waters of the Lower Kalahari Tsumkwe Formation are postulated to rise up reactivated basement faults into the regional Middle/Upper Kalahari aquifer system. .

3.4 RECHARGE

Recharge to the Kalahari Group aquifers is indicated to be primarily by inflow from basement rocks adjacent to the Kavango region. The areas of basalt and Damaran meta-sediment outcrop within the region are not considered to be recharge sources. Direct infiltration is considered to be minimal due to evapotranspiration and evaporation rates being high. These two processes can lead to near surface salinization (salt concentration in sediments due to the unsaturated zone water flux) and any recharge waters could therefore show high a TDS. Localised infiltration could occur in the interdunal zones and in the omarimbas where they pond.

The groundwater flow gradient suggests that the Okavango River is not a recharge source. However, in Botswana, where a similar groundwater gradient towards the Okavango River exists, recharge from the river is indicated within its floodplain.

The recharge mechanisms of the Kavango region need to be verified by strategically placed monitoring boreholes.

4 OBJECTIVES OF REGIONAL GROUNDWATER MONITORING

The semi arid climatic conditions of the Kavango region and the fact that the majority of the population, away from the Okavango River, utilise groundwater makes it the most important water resource of the region. The Namibian government has invested significantly in groundwater development for the rural communities to ensure they have access to potable groundwater. However, no groundwater monitoring network exists in terms of quality, except for bulk water supplying Rundu or for groundwater levels.

The objective of a monitoring system is to provide information vital to the sustainable management of the groundwater resource and facilitate improved optimal use of the groundwater resources to avoid over development or water quality deterioration.

Groundwater replenishment or recharge determines the amount of groundwater that can sustainably be abstracted from an aquifer. Rainfall, either locally or regionally with some other factors, determines the amount of recharge in an aquifer. As a result the monitoring exercise encompasses groundwater level fluctuations and rainfall measurements. In most cases only years with high rainfall affect the groundwater surface, which may be restricted to recharge areas only. In addition, similar annual rainfalls can produce very different groundwater level responses. Therefore, the distribution of rainfall even on a daily basis is of high importance. In light of this rain gauges should be placed at schools with an adjacent monitoring borehole so that water level-rainfall relationships can be established.

4.1 WATER SAMPLE MONITORING

Given the size of the Kavango Region, the number and distribution of water points it is neither practical or economic to sample everyone on a regular basis. Therefore one has to take a representative sample throughout the area to monitor water quality on a regular basis.

Based on the existing data 600 sites have been selected for major/minor ion analysis and 70 for micro biological testing to set up a baseline data set. These locations are shown on Figure 4.1.

4.2 GROUNDWATER LEVEL MONITORING & SITE SELECTION

The first 12 (twelve) monitoring borehole locations have been selected on the following basis:

- To provide information on recharge from the Okavango River.
- To provide additional data to support the perceived regional recharge/flow mechanisms.
- To provide water level data in areas of greater abstraction.
- To provide baseline hydrochemical data for groundwater degradation due to ingress of saline waters.
- The different principal exploited aquifers – Upper and Middle Kalahari, bedrock
- Population distribution and therefore abstraction.
- Access.

Figure 4.2 shows the location of selected sites, whilst Table 3 identifies target aquifer and the reason for site selection.

Table 3 – Selected Monitoring Borehole Sites

Site Number	Location	Aquifer	Selection Criteria
1	Nkunrenkuru	Shallow Kalahari	Okavango River recharge near rain station
1a	Nkunrenkuru adjacent site 1	Deeper Kalahari	Relationship of shallow and deeper aquifers
2	Bangani	Shallow Kalahari	Okavango River recharge
2a	Bangani adjacent site 2	Deeper Kalaharir	Relationship of shallow and deeper aquifers
3	South Mangetti Farms	Deeper Kalahari	Recharge from dolomites, near rain station
4	North Mangetti Farms	Deeper Kalahari	Regional flow path and & tracking indications of nitrate pollution
5	Central regime 3	Middle Kalahari	Recharge
6	Southwest Regime 3A	Middle Kalahari	Regional flow regime from area 3 to 3a
7	Rundu	Shallow Kalahari	Inter relationship Okavango river and Kalahari
8	Rundu	Palaeo Okavango channels	Monitor large abstraction effects probably 3 boreholes required
9	Confluence Omatako & Okavango	Shallow Kalahari	Assess recharge
10, 11, 12		Middle Kalahari	Regional flow regime

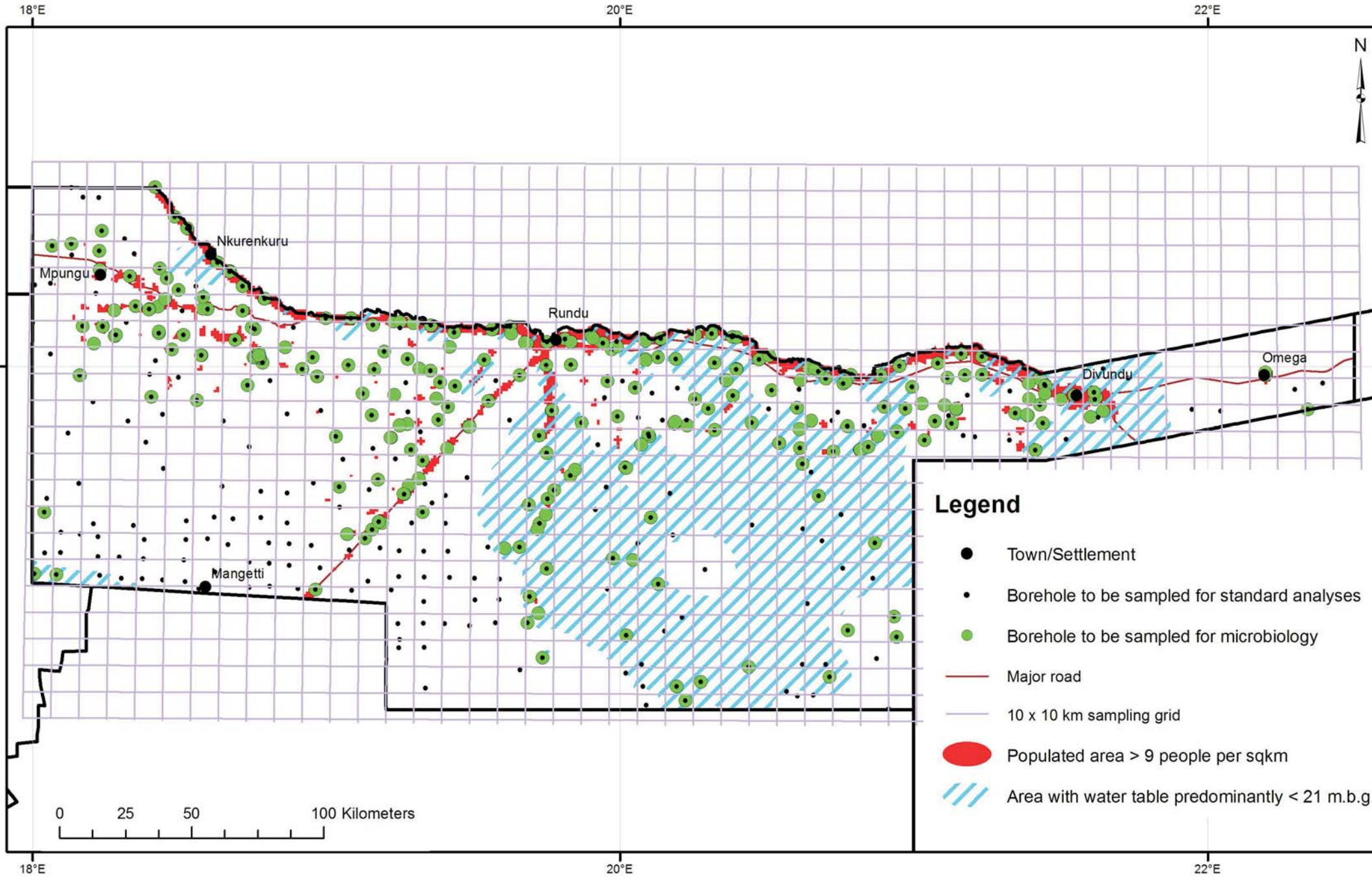
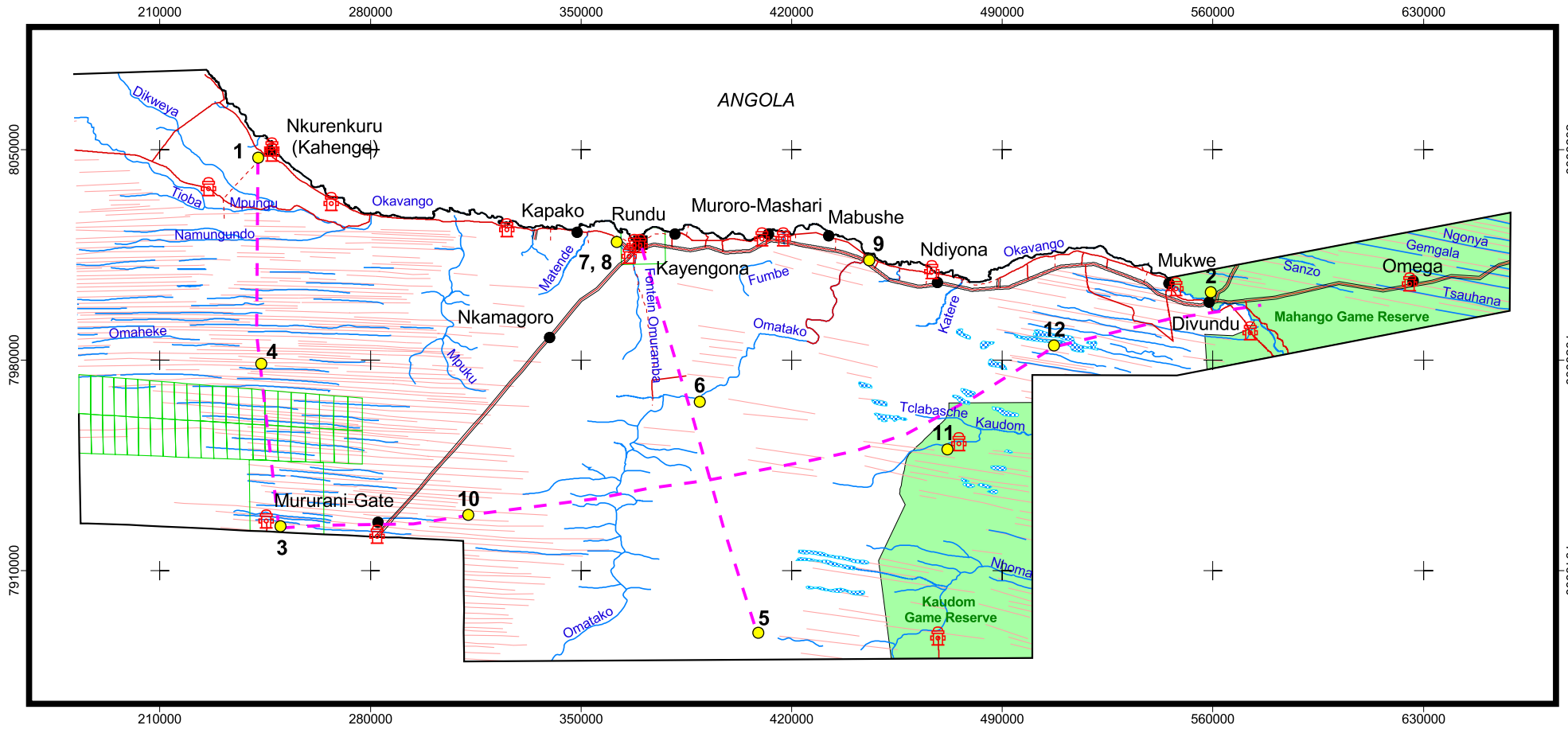


Figure 4.1 - Water Sampling Point Location Map (source Namibian Groundwater Resource Consultants)

FIGURE 4.2: MONITORING BOREHOLE SITE LOCATION MAP



SCALE 1 : 2,000,000

50 0 50 100 Kilometers

N

Projection: UTM Zone 34 South, Bessel Datum

DATA SOURCE

Roads, settlements, rivers, swamps, protected areas , administrative boundaries: Geohydrology Division, Ministry of Agriculture, Water & Forestry, Namibia

Water Surveys Botswana

LEGEND

- Town
- Settlement
- Monitoring borehole site
- Rain station
- Monitoring flow path section
- Tarred road
- Gravel road
- Graded or sand earth road, track
- River / fossil river valley
- Dunes
- Farm
- Game reserve
- Pan

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