Botswana Geoscience Institute
Excellence in Geoscience

RAMOTSWA URBAN GEOTECHNICAL INVESTIGATIONS FINAL REPORT

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Authors:
Jackson Matsaunyane
Portia Letlole
Kealeboga Daniel
Phemo Moleje

Editor :
Dr Esau Masuku

Botswana Geoscience Institute

Postal Address: Private Bag 0014, Lobatse, Botswana
Physical Address: Plot 11566, Khama Avenue 1, Lobatse, Botswana
Telephone: +267 533 0327 / 533 0428
Fax: +267 533 4295
Email: info@bgi.org.bw
Web: www.bgi.org.bw

REPORT PROVISIONS

This report contains findings of a geotechnical mapping project undertaken to assess suitability of areas earmarked for development in parts of Ramotswa, Boatle (along A1) and Otse.

The work involved description of different soil and rock profiles as well as laboratory testing to investigate the engineering properties and their implications on residential development.

The work did not include a hydrological study, which is a critical component in mapping natural constraints to urban development because the Institution does not have capacity to undertake such study.

The investigations were conducted in accordance with acceptable geoscientific and engineering practice. It is however impossible to guarantee that isolated poor foundation horizons have not been missed due to the size of the areas and frequency of sampling.

Although there is high confidence in the accuracy of the provided information, some variations in geotechnical conditions can be expected during localised site-specific investigations at design and construction stage.

Land developers need to appoint competent engineers for the assessment of site-specific geotechnical conditions prior to development. Information from this study is however, still a very valuable generic tool to guide land use planning. The suitability maps provided are subject to revision once a hydrological flood risk assessment has been undertaken.

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1 INTRODUCTION

Malete Sub-Landboard engaged Botswana Geoscience Institute (BGI) to undertake geotechnical investigation of three (3) areas earmarked for development in Ramotswa, Boatle and Otse villages. The total areal coverage of the project site is 362 ha. The purpose of investigations of this nature is to assess the suitability of the areas for development based on the evaluation of geotechnical, geological, hydrogeological and topographical aspects. However, the focus in this study was to provide a broad overview of geotechnical conditions and identify potential geohazards at a scale of 1:10000 within the areas of interest. The report and geotechnical suitability map will provide guidance on land-use planning of the project area. BGI started working on this project in June 2020, and completed it in January 2021.

1.1 SITE DESCRIPTIONS

Ramotswa and Otse are located in the South East District (SED), 40 and 50 km respectively south of the capital Gaborone (Figure 1). Despite being one of the smallest districts in Botswana in area, it is by far the most densely populated (Population Census, 2011). Ramotswa is the administrative headquarters of the SED.

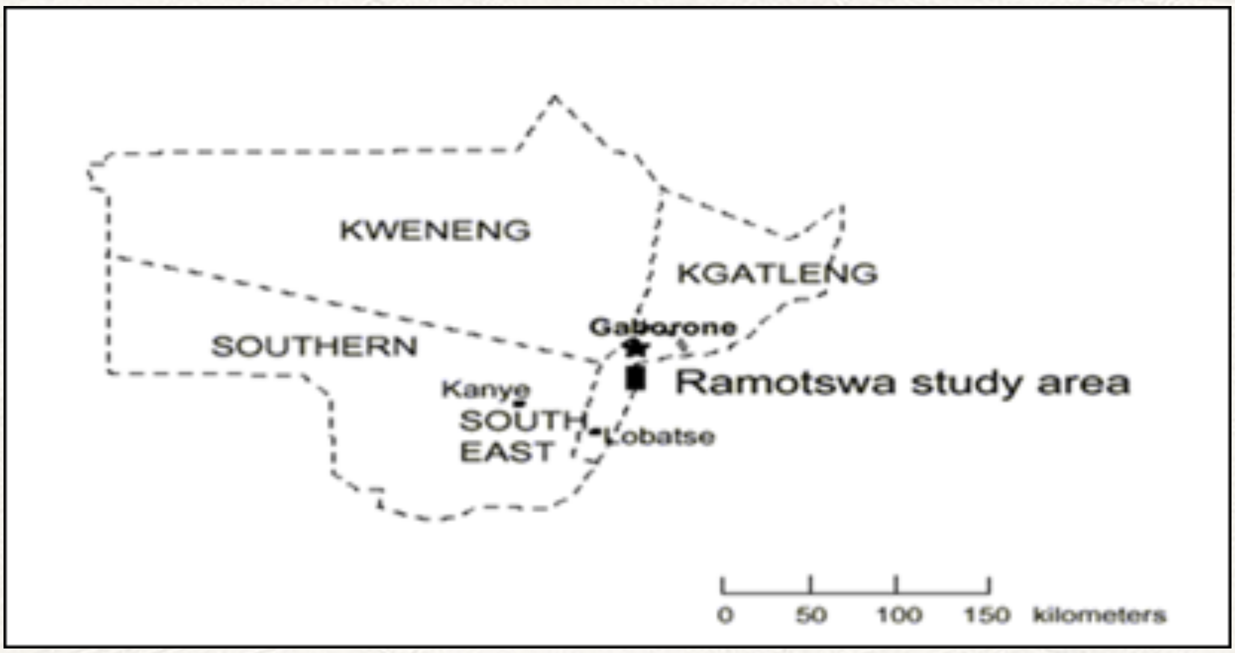

Figure 1: Regional Context of Project Location

1.2 Climatic Conditions

Ramotswa and Otse like most of the country experience a semi-arid climate that is characterised by low and erratic rainfall, both in time and space, occurring mainly as isolated convection showers. The annual average rainfall is 483mm. The long-term minimum rainfall recorded is 266mm, while the maximum recorded is 1073mm. The rainy season spans between the months of November to March. Most of the rain falls in short, high intensity spells. The high intensity events occasionally result in flash floods especially in Boatle and Ramotswa. In 2006 the villages of Taung and Ramotswa experienced severe flooding leaving the villages cut-off and stranded on either side of the Taung bridge. More recently the flooding of Potsane River also experienced flooding and caused disruptions to the daily lives of people in the Ramotswa area.

Mean minimum temperatures vary from 16˚C to 20˚C (winter/summer) with the lowest temperatures occurring in June/July. Mean maximum temperatures range from 25˚C to 34˚C with the peaks in October/November, sometimes reaching extremes of 41˚C.

1.3 Area 1 – Boatle

1.3.1 Location

The study area 1 – Boatle is located along A1 highway and forms the western boundary of the greater Ramotswa planning area (Figure 2). The area is narrow in shape strangled between the A1 highway and the Taung river, covering 211 hectares of land.

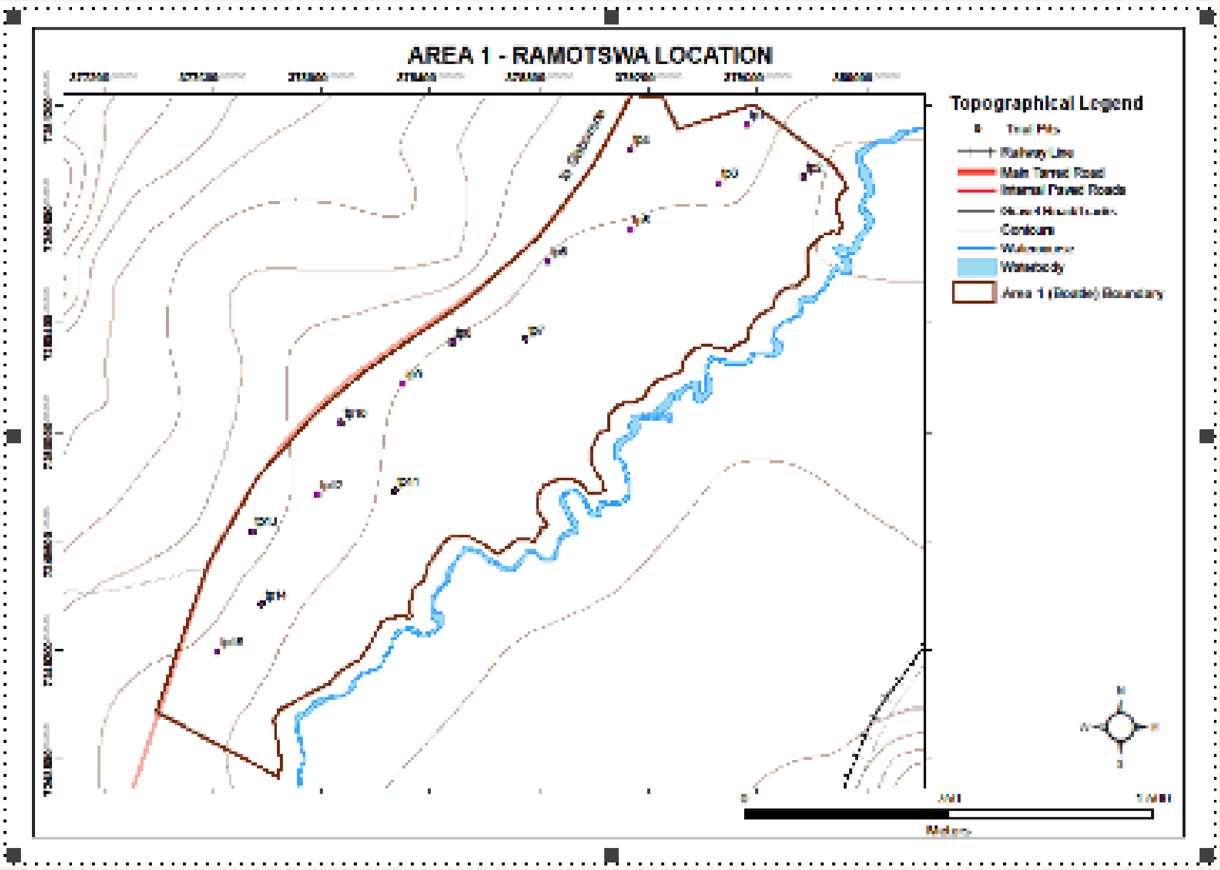

Figure 2: Area 1- Boatle

1.3 Area 1 – Boatle

1.3.2 Topography and Drainage

The topography of the area is generally flat and gently sloping to the east and north-eastern direction towards Taung River. Various minor tributaries that drain into the Taung river incise the area in the eastern direction. These ephemeral streams occasionally flood the surrounding plains during periods of substantial rainfall. There are a few isolated inselbergs occasionally rising abruptly from the surrounding plains. The area is 1040m above mean sea level.

1.3.3 Soils and Vegetation

Ramotswa and Otse form part of the Hardveld Savanna (Bekker et al, 1991). The vegetation ranges from shrub savannah to tree savannah dominated by acacia trees. The Hardveld is characterised by denser and more diverse vegetation due to higher precipitation and heavier soil texture and higher nutrient content. Much thicker vegetation is found along the drainage channels. Typically, on these river channels/valleys are species such as camel thorn trees.

Area 1 is overlain by both residual and transported soils. Properties of the residual material can be related to those of the underlying parent rock. Transported soils are found mainly along the drainage channels, as alluvial deposits occurring as clayey-sands and sandy-clays.

1.4 Area 2 – Ramotswa

1.4.1 Location

The proposed development area 2 (139 hectares) is located in the southern part of Ramotswa next to Kelemogile Junior Secondary School (Figure 3). There are new developments within the area and some of the structures are already showing signs of distress.

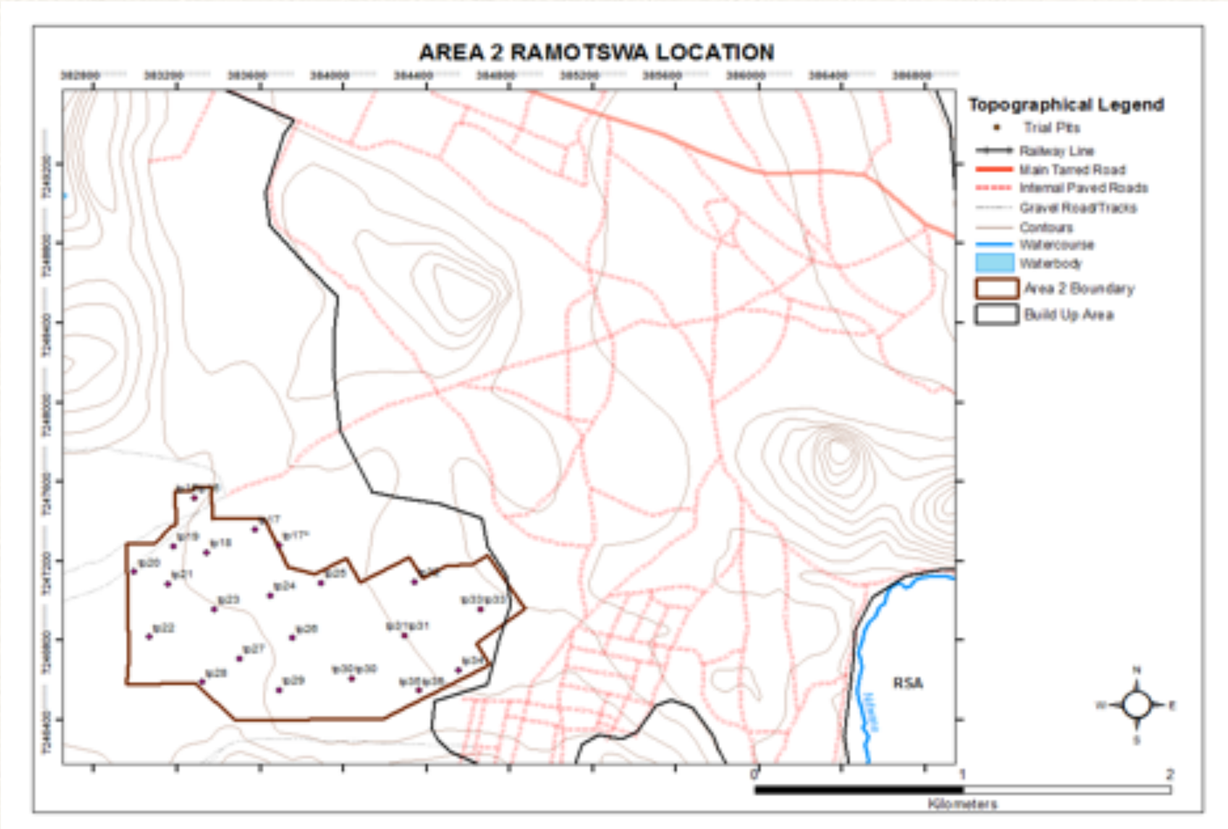

Figure 3: Area 2 – Ramotswa

1.4.2 Topography and Drainage

The project area is generally flat with gentle faced inselbergs of more weathering resistant rocks of the Transvaal Supergroup rocks, predominantly the Black Reef Quartzite. The elevation ranges from 1040 to 1050m above mean sea level with the land surface sloping gently from the southwest to the north and east. The area is drained by various cross-cutting small streams and gullies forming a dendritic surface drainage pattern. The most prominent stream runs in the North –Eastern direction towards Notwane River.

1.4.3 Soils and Vegetation

Ramotswa is part of the Hardveld Savanna (Bekker et al, 1991). The vegetation ranges from shrub savanna to tree savanna dominated by acacia trees. The Hardveld is characterised by denser and more diverse vegetation due to higher precipitation and heavier soil texture and higher nutrient content. The thicker vegetation is found along the drainage channels. Typically, on these river channels/valleys are species such as camel thorn trees.

The soils found in area 2 are mostly transported with smaller portions classified as products of the underlying geology. Along the drainage channels and flood plains, the transported alluvial soil can be classified as sandy-silty clays to silty-clay to clays. Fine colluvium were observed on the surface near outcrops.

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1.5 Otse

1.5.1 Location

The Otse project area is located on the flat plain on the foot of Maladiepe hill. Nywane River forms the eastern boundary of the project area (Figure 4). The proposed development area is 12ha.

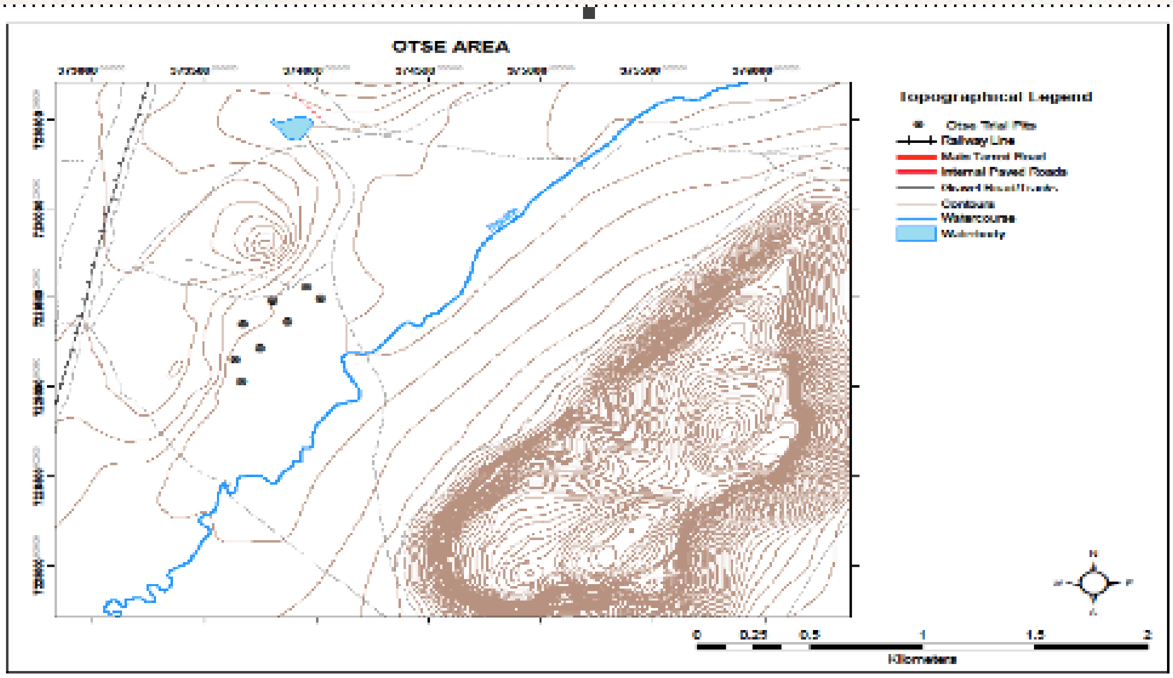

Figure 4: Otse Location

1.5.2 Topography and Drainage

The area is a flat erosional plain, in between the two hills of Maladiepe and Manyelanong with its steep sided faces. Nywane River, which forms part of the Notwane river drainage system is the major drainage channel.

The soil cover is alluvial, aeolian as well as those of pedogenic origin. Soils are shallow to deep fine-grained, moderate to well drained, sands, sandy-clay, clay-silts and clays, especially towards the Nnywane River. Vegetation ranges from shrub savannah to tree savannah dominated by acacia. Denser and more diverse vegetation is due to higher precipitation and heavier soil texture and well as higher nutrient content.

1.6 Geology

The oldest rocks are the Archaean Basement complex rocks of the Kaapvaal craton, approximately 3000 Ma. In the project areas, these rocks are represented by the Kanye and Lobatse Volcanic Formations. These rocks are overlain by younger sedimentary rocks of the Transvaal and Waterberg Supergroups, deposited between 2500 and 1700 Ma. They consist of various lithologies such as sandstones, shales, conglomerates and quartzites, reflecting the different cycles of transgression and regression during the sedimentation process. The climatic N value (Weinert, 1980) of the region is greater than 5 indicating that mechanical disintegration is the predominant form of rock weathering.

1.6.1 Area 1 – Boatle

The area is underlain by rocks of Lobatse Volcanics (Figure 5), represented by the Mogobane Formation greywackes and black siltstones as well as the basal Nywane Formation tuffs, lavas, agglomerates and porphyries that are locally layered with argillites.

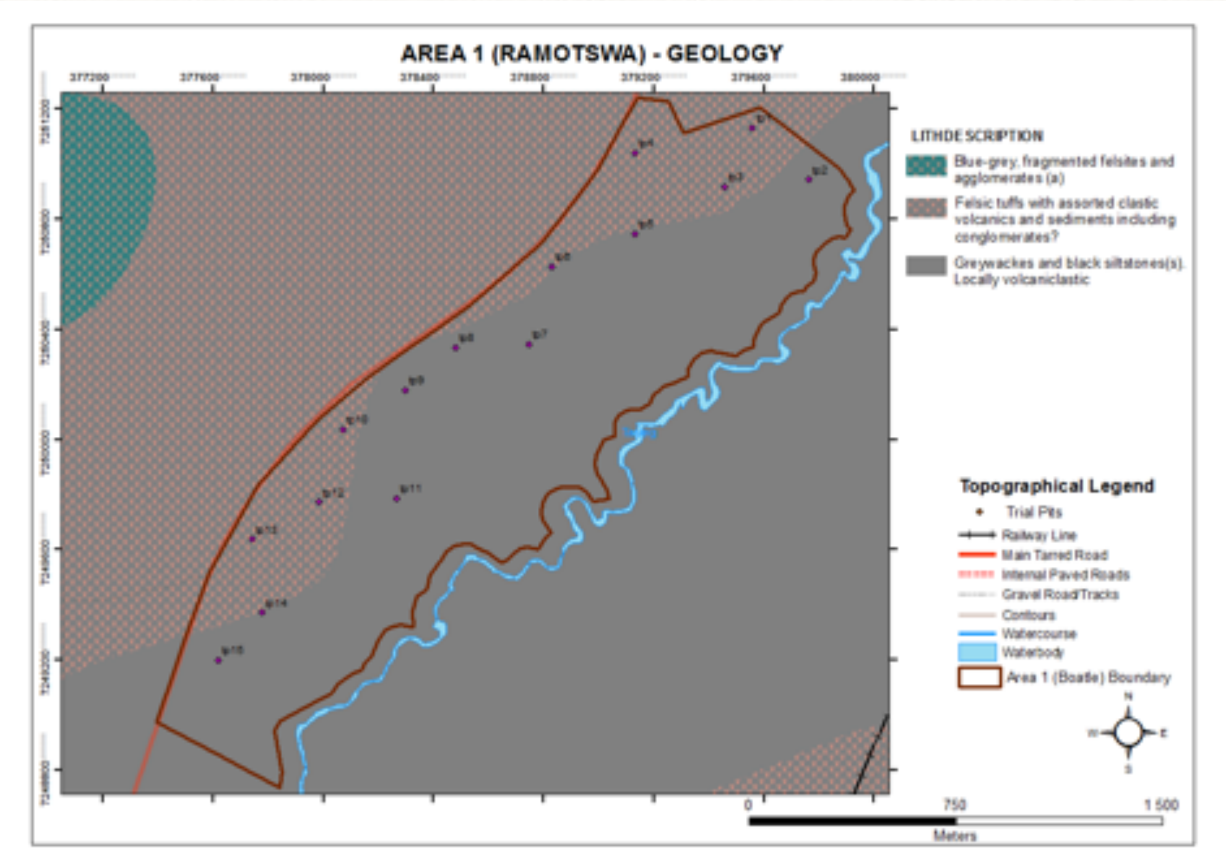

Figure 5: Geology of area 1 – Boatle

1.6.2 Area 2 – Ramotswa

The geology of Area 2 in Ramotswa comprises rocks of the Transvaal Supergroup (Figure 6, largely represented by the Black Reef Quartzite, Ramotswa Dolomite and Ramotswa Shale Formations. The Black Reef Quartzite lies at the bottom of the succession and consists of argillaceous inter-layers and a basal conglomerate. It is overlain by the Ramotswa Dolomites, which are characterized by massive dolomites with minor chert. These dolomites are internally homogeneous and are very susceptible to weathering. Ramotswa Shale Formation is the top most formation and consists of a sequence of ferruginous argillites. The Ramotswa Shale Formation rocks are strongly jointed, with hematite coating (Key, 1983).

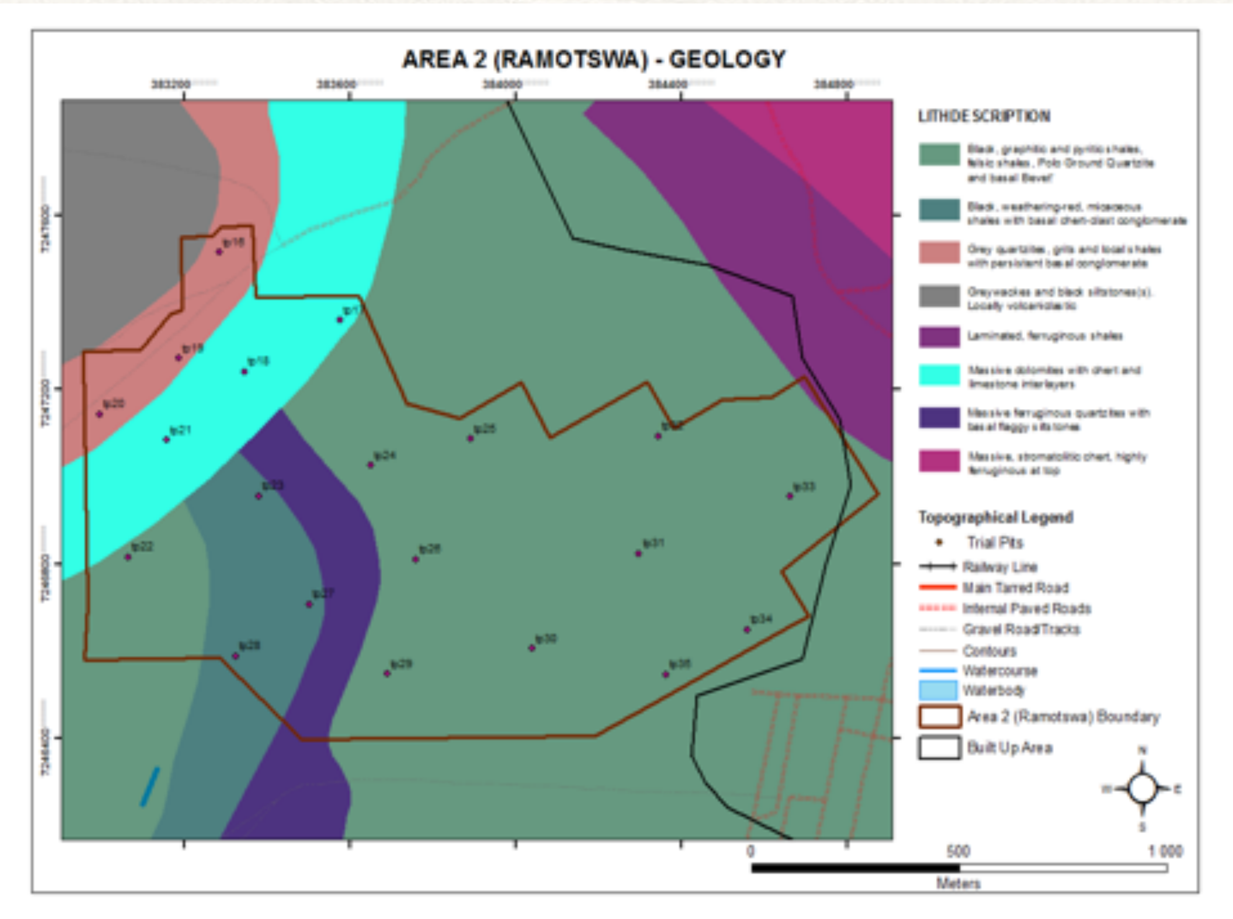

Figure 6: Geology of Area 2 – Ramotswa

1.6.3 Area 3 - Otse

The project area is underlain by two formations of the Otse Group (Manyelanong and Maladiepe Formations, Figure 7). These units comprise of red sandstones and conglomerate layers. Although the project area is on the foot of Maladiepe hill, the bedrock appears to be deeply buried as it was not encountered during trial pitting. The geology map presented is an extract from the Lobatse QDS 2525B.

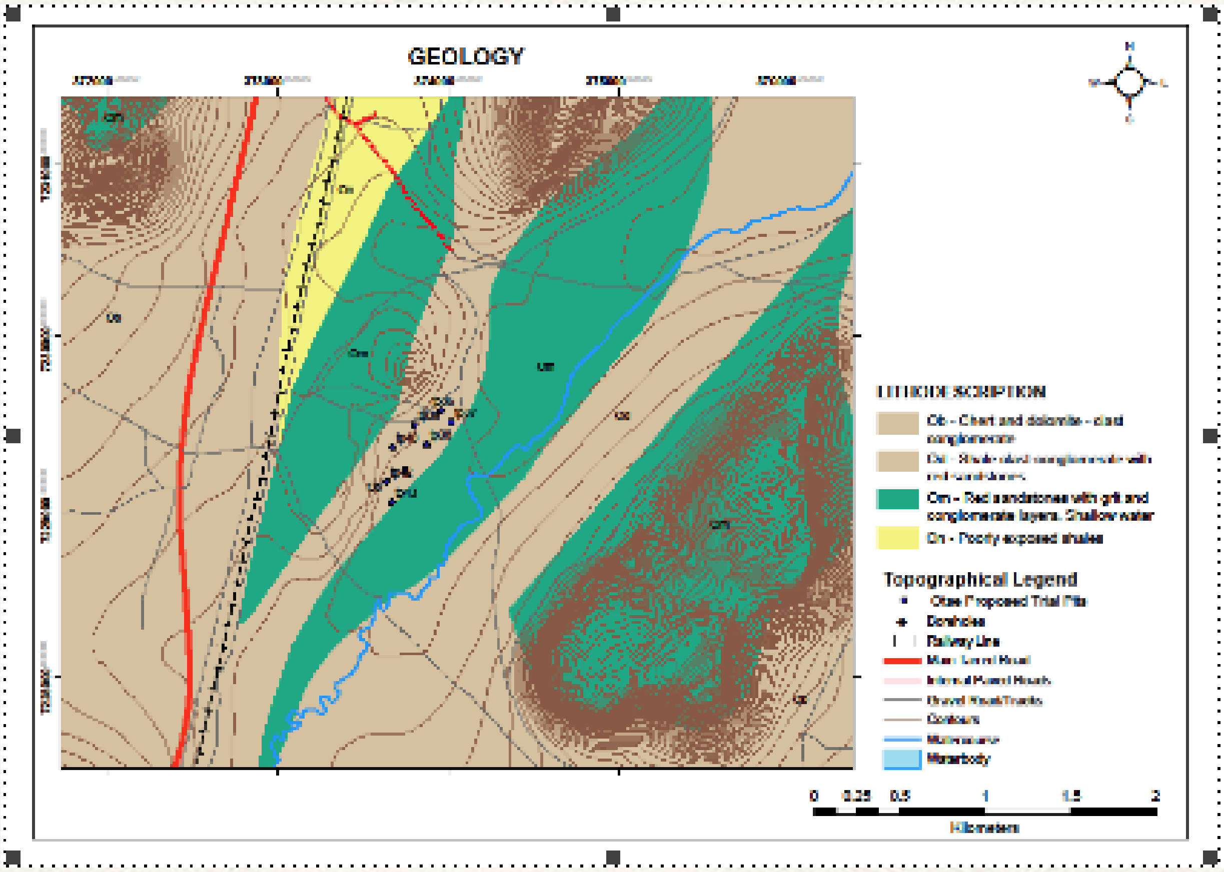

Figure 7: Geology of Otse Area

2 METHODOLOGY

Geotechnical mapping of the areas focused on investigation of soil strata at shallow depths within the zone where soil properties are of significance to normal infrastructure development, construction and land-use planning decisions. Investigations were conducted in accordance with the Guidelines for Urban Engineering Geological Investigations by Van Rooy et al, (2001), and classified in accordance with Geotechnical Classification System for Township Development by Partridge et al., (1993). The assessment entailed; Desktop study and site reconnaissance survey, in-situ testing, trial pitting, sampling, and laboratory testing.

Table 1 :Geotechnical Classification System by Partridge et al,(1993)

	Parameter	CLASS 1 (Most Favourable)	CLASS 2 (Intermediate)	CLASS 3 (Least Favourable)
A	Collapsible Soil	Surface collapse horizon<750mm thick	Collapse horizon >750mm thick	
B	Seepage	Water table permanently deeper than 1.5m below surface	Permanent or seasonal water table within 1.5m of surface	Swamps and marshes
C	Active Soil	Low heave potential	Medium heave potential	High heave potential
D	Highly Compressible Soil	<2.5mm differential settlement expected	Recent estuarine sediments and highly organic soils (2.5-15mm potential differential settlement expected)	Where likely to be subject to additional consolidation due to dewatering (>15mm differential settlement expected)
E	Erodability of soil	Low	Moderately dispersive soil; fissured clay; thick colluvium; residual soils of intermediate texture on moderate slopes	Highly dispersive soil; fissured clay; thick colluvium; residual soils of intermediate texture on steep slopes
F	Difficulty of excavation to 1.5m deep	<10% hardpan or boulder calcrete	10-50% hardpan or boulder calcrete	> 50% hardpan or boulder calcrete
G	Undermined Ground	Where depth of undermining is >100m in reasonably competent rock (except where total extraction mining has been practiced)	Old undermined areas where slope closure has ceased	Where the depth of undermining is <100m or where total-extraction mining has been practised.
H	(Dolomite) Instability of areas of soluble rocks		Possibly unstable	Possible unstable
I	Steep slopes	Slope <6	Slope <6 - 15%	Slope>15%
J	Areas of unstable natural slopes	Low risk	Intermediate risk	High Risk (especially in areas subject to seismic activity and intense tropical storms)
K	Areas subject to seismic activity	100 year maximum probability of <5 Mod. Mercalli intensity	100 year maximum probability of 5-8 Mod. Mercalli intensity	100 year maximum probability of >8 Mod. Mercalli intensity (especially in areas of deep fine textured soil, subject to liquefaction and unstable stones.
L	Areas subject to flooding	Areas above 1 in 50 yr flood line with slope>1%	Areas above 1 in 50yr flood line with slope<1%	Areas below 1 in 50yr flood line

3 RESULTS AND ANALYSIS

Geotechnical mapping of the areas focused on investigation of soil strata at shallow depths within the zone where soil properties are of significance to normal infrastructure development, construction and land-use planning decisions. Investigations were conducted in accordance with the Guidelines for Urban Engineering Geological Investigations by Van Rooy et al, (2001), and classified in accordance with Geotechnical Classification System for Township Development by Partridge et al., (1993). The assessment entailed; Desktop study and site reconnaissance survey, in-situ testing, trial pitting, sampling, and laboratory testing.

3.1 AREA 1 – BOATLE ALONG A1

3.1.1 Test pit Profiles

The detailed descriptions of soil profiles for this area are presented in log sheets in Appendix A. Typical profiles encountered are summarised as;

i) Coarse Colluvium

Colluvium deposits of various sizes ranging from sub-rounded to angular quartzite boulders, pebbles to gravelly material were encountered in more than 70 % of the pits in this area. This material is visible at shallow depths along the A1 and extends to depths of 2.3 m. Their presence is mainly influenced by the presence of quartzitic outcrops in the vicinity of the area. In terms of consistency, the material generally of loose and in some instances medium dense due to weakly developed ferricrete cementation

ii) Alluvium

This material was encountered along tributaries of Taung river dissecting the area in the South Eastern direction towards the main drainage channel. This material is represented by trial pits 6, 8 and 11 where it was generally described as; dry, greyish brown, firm, microshattered slightly ferriginised silty clay at depths ranging between 0 and 2 m. Evidence of termite activity from anthills and pinholed structures were also noted.

iii) Pebble Marker

A pebble marker was encountered at a number of pits mostly underlying the transported alluvial material. It was generally described as; slightly moist, greyish brown, loose quarzitic pebbles and boulders with slightly ironised angular to sub-rounded clasts.

iv) Weathered Mudstones

Highly weathered to moderately weathered mudstones were encountered close to A1 road at a number of trial pits such as TPs 13,15, 10 and 5. These were mostly underlying the quartzitic colluvium and alluvial clays sands at depths ranging between 1m- 3.2m where the rock is more competent.

v) Quartzite

Slightly weathered quartzite excavating as a well graded gravel was encountered at a depth of 0.9 – 2.3m underlying weakly developed pedogenic material.

3.1.2 RESULTS AND ANALYSIS

The summary of laboratory test results for Area 1 are displayed on Table 2 below. Samples were taken at depths of 0.9 to 2.8 m, which is generally within zone of influence of normal residential structures (shallow foundations). The results indicate that the gravelly material encountered (gravelly colluvium and weathered mudstones) had percentages of fines ranging between 11 and 26%. The fines (silts and clays) had variable PIs ranging between 5 and 14.6 and the material classifies mostly as silty and clayey gravels (GC and GC-GM) as per Unified Soil Classification system (USCS). Most gravels are of poor quality (G9 and 10) since they are mostly weathered mudstones as indicated by low CBR values except at TP 3.

The transported alluvial deposits classified as clayey sands (SC) and sandy/silty clays (CL). This material recorded high Plasticity Indices (PIs) and Linear Shrinkage (LS) in the orders of 20 and 10 % respectively and low grading modulus (GM) values (mostly <1).

Table 2: Laboratory test results for Area 1

TP No	Sample Depth (m)	% composition			GM	PI	LS %	CBR at				Classification	
		Gravel	Sand	Fines				90%	95%	98%	AASHTO	USCS	TRH144
TP3B	0.9-2.3	74	15	11	2.47	9.4	5.3	23	63	75	A-2-4(0)	GW	G5
TP4	0-1.1	5	31	64	0.57	20.1	10	7	12	13	A-7-6(20)	CL	G9
TP5A	0-1.23	24	46	30	1.47	11	8	3	3	4	A-7-6(20)	SC	G10
TP6A	0-1.83	8	34	58	0.66	18.2	9.3	-	-	-	A-6 (16)	CL	-
TP8B	0.8-2.75	9	29	62	0.61	10.3	3.3	3	5	6	A-6(16)	CL	G10
TP11	1.7-2.9	66	9	25	0.66	4.2	3.3	4	5	8	A-1-b(0)	GC-GM	G10
TP12	2.5-3.2	63	16	12	2.13	7.9	4	4	7	10	A-2-4	GC	G10
TP13	2-2.77	67	21	12	2.36	5	2.7	3	5	7	A-1 a(0)	GM	G10
TP15	0.95-3	64	10	26	2.09	14.6	7.3	15	25	40	A-2-6 (4)	GC-GM	G7

3.1.3 Geotechnical Classification

Based on the assessment of physical environment, close examination of the material during test pitting and laboratory test results, the following constraints to development are present;

i) Collapsible Soils:

Although no collapse potential test was conducted at the site, it was observed that the coarse colluvium classifying as gravelly material may be liable to collapse due to its voided structure. Without proper improvement of the founding ground, differential settlement is likely to happen. The constraint was classified as **intermediate (Class 2A)**

ii) Seepage:

No seepage was encountered in any trial pit. However, area was classified as **least favourable (Class 3B)** since it is covered with swamps and mashes especially along the Taung river flood plains and its tributaries. Ferricrete development in some areas indicate likelihood of seasonal groundwater perching.

iii) Active soils:

Alluvial silty clays, clayey sands with PIs and LS greater than 12 and 8% respectively are present in some pits and these are likely to undergo heaving with seasonal moisture variation. This constraint was classified as **Least Favourable (Class 3C)** taking into consideration the environment within which these soils are located (flood plains).

iv) Flooding:

Although the hydrological study has not yet been conducted to identify areas prone to flooding, it is envisaged that the risk is high based on close proximity to Taung river flood plain.

3.1.4 Conclusion And Recommendations

Based on the constraints identified, the following can be concluded about the suitability of site for development and foundation recommendations;

i) Most of the area (76%) is covered by alluvial clayey material with moderate to high PIs and low California Bearing Ratio (CBR) values (mostly G10) at founding depth of most residential buildings (0.8 to 1m). Such materials have low bearing capacities and likely to cause structural distress due to differential heaving/settlement. Although there are ground improvement and use of rigid foundation options, such interventions are unlikely to make the area habitable due to the mashy and swampy environment of the Taung river flood plain. This area is therefore considered unsuitable for development, and this needs further substantiation through a flood risk assessment study.

ii) Areas that could potentially be considered with cautions are small portions (23.7% of the total area) within 400 m along A1 and adjacent to the built up area in the North Eastern side. These areas are mostly covered by loose coarse colluvium at founding depths underlain by weathered mudstones.

The coarse colluvium was loose to medium dense with collapsible fabric hence likely to result in differential settlement if no precautions are taken. For a normal strip footing is recommended that base of foundation trenches be compacted to densify the voided structure of the gravelly material and improve the in-situ bearing capacity. Testing must be done to achieve at least 93 % MOD AASHTO and ensure uniform consistency before foundation placement.

In instances where highly weathered mudstones are encountered at shallow depths, it is recommended that the material be excavated to 1.5*B (width of the footing). This material should be replaced by competent material (G5 or better), compacted to a minimum of 93% MOD AASHTO in layers of 150 mm.

It is also recommended that due to bioturbation in the area, anthill treatment would be necessary before foundation placement.

Table 3: Geotechnical Classification for Area 1

Geotechnical Classification	Area (ha)
Most Favourable	0
Intermediate	50 (23.7%)
Least Favourable	161 (76.3%)

3.2 AREA 2- RAMOTSWA

3.2.1 Test pit Profiles

The detailed descriptions of soil profiles for this area are presented in log sheets in Appendix A. Typical profiles encountered are summarised;

i) Alluvial Clays

This horizon covers a large part of the study area and was encountered at least half of the pits along small tributaries in the North Eastern direction. It can be generally described as dry to slightly Moist greyish black, firm, shuttered to stiff clay at depths ranging between 0 and 2.3 m. The area appeared to be poorly drained with observable dessication cracks on the surface, which are good indicators of presence of problematic heaving clays.

ii) Pedogenic material – Mostly ferricrete and occasionally calcrete

A ferricrete horizon described as dry reddish yellow, loose to dense Intact well developed ferricrete was encountered at shallow depths of 0.2 to 1.2 m at TP 29. The excavator was unable to excavate beyond 1.2m at this pit. In other areas it was mostly weakly developed and underlying transported material at depths of 1.1m. Weakly developed calcrete was encountered on few occasions at the pebble markers underlying transported material.

iii) Pebble marker

A pebble marker was encountered in a number of pits, mostly underlying transported alluvial clays at depths of 0.8 to 2.3 m. It was mostly rounded to subrounded calcretised and occasionally ferroginised quarzitic pebbles. This layer separates transported and residual material.

iv) Coarse Colluvium

This profile was encountered at TP 33 at a depth of 0 to 1.1 m. Its deposition was mainly influenced by the surrounding quartzite outcrop hence described as; dry reddish brown loose intact gravelly sand with clasts, boulders and angular pebbles of various sizes.

v) Weathered Shales

Weathered shales were encountered mostly underlying the pebble marker, coarse colluvium and transported alluvial clays and outcropping at only TP16. The horizon was generally described as yellowish brown highly weathered to moderately weathered laminated shales extending to depths of 2.1 to 3.1 m.

3.2.2 Results and Analysis

Laboratory test results for Area 2 located in Ramotswa are displayed in Table 4. The results indicate that most of the material in the first 1.5 m below ground described as alluvial clays classified as clay (CL) as per USCS. The material has high percentage of fines ranging between 54% to 78% and medium to high plasticity values ranging between 17.4 and 26. As indicated by the surface dessication cracks in the field, the clay horizon exhibited high shrinkage based on the linear shrinkage values ranging between 7 to 13.3%.

Most of the underlying material described above as pedogenic, pebble marker and weathered shale classified as Clayey Sands (SC) and Clayey Gravels (GC). The plasticity values were generally varied between between 10 (maginal) and 26 (high). From a few CBR tests conducted, it can generally be deduced that these gravels do not qualify as good founding material (mostly G10).

Table 6 : Laboratory Test Results for Area 3

TP No	Sample Depth (m)	% composition			GM	PI %	LS %	CBR at				Classification	
		Gravel	Sand	Fines				90%	95%	98%	AASHTO	USCS	TRH144
TP36A	0.00-0.85	6	68	26	1.07	NP	-	-	-	-	A-2-4(0)	SM	-
TP36B	0.85-2.26	21	41	38	1.15	NP	-	3	3	4	A4 (8)	SM	G10
TP37A	0.00-1.85	0	18	82	0.23	13.9	7.3	-	-	-	A-6(16)	CL	
TP37B	1.85-2.7	3	29	68	0.48	18.5	9.3	3	3	4	A-6 (16)	CL	G10
TP38A	0.00-1.7	5	46	49	0.74	24.1	13.3	-	-	-	A-7-6	SC	
TP38B	1.7-2.85	2	47	51	0.68	10.5	5.3	-	-	-	A-7-5	CL	-
TP39B	0.82-2.45	24	52	24	1.44	NP	-	7	9	19	A-2-4	SM	G8
TP40B	1.4-2.45	7	52	41	0.93	10.5	5.7	3	3	4	A-6 (16)	SM	G10
TP41B	1.1-2.6	58	20	22	2.03	2.9	1.9	7	9	13	A-1-b(0)	GM	G9
TP43B	0.4-2.6	5	55	40	0.92	12	5	3	3	3	A-6 (16)	SC	G10

3.2.3 Geotechnical Classification

The following constraints and their classification based on the pit profiles, laboratory test results and the depositional environment within which these soils exists are summarized below;

i) **Collapsible soils:** Coarse colluvium with open voided fabric can be expected at shallow depths in areas around TP 33 and 35. This constraint can be classified as intermediate (class 2A) since they extend to depths greater than 750 mm and can potentially cause differential settlement.

ii) **Seepage:** No seepage was encountered in any test pit. Pedogenic material were encountered in some pits within the first 1.5 m indicating potential groundwater perching. It is predicted that 70% of the area is likely to be swampy and marshy during heavy rains because of poor drainage and hence classified as **least favourable (class 3B).**

iii) **Active soils:** The first observable evidence of the presence of these problematic soils was the presence of desiccation cracks on poorly drained dark greyish surficial soils covering 70% of the area. These were confirmed as silty clays, clayey sands and clayey gravels with high plasticity and linear shrinkage values and likely to undergo heaving with seasonal moisture variation. This constraint was classified as **Least Favourable (Class 3C).**

iv) **Flooding:** There is high possibility of flooding in this area due the presence of poorly drained Notwane river tributaries identified. This needs further confirmation through a hydrological study to establish a 1:50 flood line.

Table 4: Laboratory Test Results for Area 2

TP No	Sample Depth (m)	% composition			GM	PI %	LS %	CBR at				Classification	
		Gravel	Sand	Fines				90%	95%	98%	AASHTO	USCS	TRH144
TP17A	0-1.6	2	24	74	0.34	14.4	7.3	-	-	-	A-6 (16)	CL	-
TP17B	1.85-3.1	52	23	25	1.94	25.9	13.3	-	-	-	A-2-6(4)	GC	-
TP18B	2.00-3.00	0	66	34	0.88	14	6.7	-	-	-	A-2-6(4)	SC	-
TP19A	0-1.50	2	51	47	0.73	10.6	5.3	-	-	-	A-6 (16)	SC	
TP20A	0-1.4	2	61	37	0.87	10	6.7	-	-	-	A-6 (16)	SC	
TP20B	1.4-3	7	51	42	0.94	10.3	6.7	-	-	-	A-6 (16)	SC	-
TP24A	0-2.00	2	47	51	0.57	17.4	8.7	-	-	-	A-7-5(20)	CL	-
TP24B	2.00-2.65	70	10	20	2.25	13.2	7	3	3	4	A-2-6 (4)	GC	G10
TP27B	1.1-1.6	5	74	21	1.1	10.1	7	10	11	13	A-2-6 (4)	SC	G8
TP30A	0-0.82	10	21	61	0.64	19.8	10	-	-	-	A-6 (16)	CL	
TP30A*	0-2.3	12	10	78	0.48	18	8.7	-	-	-	A-6 (16)	CL	-
TP30B*	2.3-2.8	29	17	54	1.12	10.5	5.3	3	3	4	A-6 (4)	CL	G10
TP31A	0-1.45	3	18	79	0.3	25.9	13.3	-	-	-	A-7-5 (20)	CL	-
TP33A	0.4-1.1	10	36	54	0.73	12	5.3	-	-	-	A-6 (16)	CL	-
TP33B	1.1-2.2	41	32	27	1.71	10.3	4	-	-	-	A-2-6	GC	-
T35B	1.2-2.2	45	21	34	1.65	14.2	8	-	-	-	A-2-7 (4)	GC	-

3.2.4 Conclusion And Recommendations

The results indicate that most of the area (71%) is covered by high plasticity clayey soils with potential to cause heaving and low bearing capacity (G8 to G10) as indicated by cracking of houses in some areas. This alluvial material was transported by poorly defined streams running in the North Eastern direction. The material extends to depths of 1 to 2.3 m, which implies that its poor engineering properties will affect structures built on it. This problem will further be exacerbated by poor drainage due to clay sensitivity to water ingress. Importation of good quality material (G5) in strip foundation trenches, adoption of other foundation methods such as stiffened rafts and provision of storm water drain system can minimize the problem. It is however envisaged these options would be costly to the client and developers. Therefore, it is recommended that this area should be considered **unsuitable** and hence avoided.

The area that is considered habitable is a relatively small and covers 24 ha (ie 30 % of the whole area). Areas classified as **intermediat**e are restricted to the boundaries of the area. Soil improvement will be required by use of competent material (G5) in foundation trenches to improve bearing capacity.

For the area classified as **Most Favourable** around TPs 27 and 29, foundation can be placed on the shallow well-developed ferricrete. However, pedocretes like ferricrete are subject to lateral variability (Blight et al., 2012) and foundation exploration at design level may require trenching.

Table 5: Geotechnical Classification for Area 2

Geotechnical Classification	Area (ha)
Most Favourable	16 (11%)
Intermediate	24 (18%)
Least Favourable	99 (71%)

3.3 Area 3- Otse

3.3.1 Test pit Profiles

The detailed descriptions of soil profiles for this area are presented in log sheets in Appendix A. Typical profiles and ground conditions expected are summarised below;

i) Fine Colluvium

Since the area is located at the foot of the sandstone outcrop, fine colluvium material generally described as dry light brownish sandy silt was encountered at depths varying between 0 and 1.8 m. This material was occasionally ferroginised with pinholed structures due to bioturbation.

ii) Alluvial Clays

These soils were generally restricted to the South Western part of the area around TPs 37 and 38 towards the Nywane river floodplain. The material was generally described as greyish black firm clay with depths ranging from 0 to 1.85 m.

iii) Weakly Developed Ferricrete

This horizon underlies both the sandy silts and clays at variable depths ranging between 0.4 and 2.6m. It was generally described as orange brown pinholed weakly developed ferricrete excavating as gravelly sand. No rock formation was encountered which indicates that most of the reworked material was mostly transported

3.3.2 Results And Analysis

Table 6 below shows results for indicator tests, CBR and material classification. The results indicate that most of the surficial material between 0 and 1.8 m had high percentage of fines (ie material < 0.075mm) and sandy material with low grading modulus (GM).

In most of the pits the classifications ranged between silty sands (SM) and clays sands (SC). This material had plasticity index (PI) ranging between non-plastic to 10. Clays (CL) were encountered at alluvial horizons at TPs 37 and 38. High plasticity values of 18.5 and 24 were recorded at those pits indicative of a material that is likely to undergo heaving. The gravelly material due to iron cementation in the weakly developed ferricrete horizon classified as gravelly silty sand (SM) and silty gravel (GM) with low bearing capacities indicated by the classification (G8 to G10).

Laboratory Test Results for Area 3

TP	Sample	% composition			GM	PI	LS	CBR at				Classification	
No	Depth (m)	Gravel	Sand	Fines		%	%	90%	95%	98%	AASHTO	USCS	TRH144
TP36A	0.00-0.85	6	68	26	1.07	NP	-	-	-	-	A-2-4(0)	SM	-
TP36B	0.85-2.26	21	41	38	1.15	NP	-	3	3	4	A4 (8)	SM	G10
TP37A	0.00-1.85	0	18	82	0.23	13.9	7.3	-	-	-	A-6(16)	CL	
TP37B	1.85-2.7	3	29	68	0.48	18.5	9.3	3	3	4	A-6 (16)	CL	G10
TP38A	0.00-1.7	5	46	49	0.74	24.1	13.3	-	-	-	A-7-6	SC	
TP38B	1.7-2.85	2	47	51	0.68	10.5	5.3	-	-	-	A-7-5	CL	-
TP39B	0.82-2.45	24	52	24	1.44	NP	-	7	9	19	A-2-4	SM	G8
TP40B	1.4-2.45	7	52	41	0.93	10.5	5.7	3	3	4	A-6 (16)	SM	G10
TP41B	1.1-2.6	58	20	22	2.03	2.9	1.9	7	9	13	A-1-b(0)	GM	G9
TP43B	0.4-2.6	5	55	40	0.92	12	5	3	3	3	A-6 (16)	SC	G10

3.3.3 GEOTECHNICAL CLASSIFICATION

Based on the assessment of the area, which entailed site walkover, test pit profiling and sample laboratory results, the following constraints can be expected in the Otse area;

i) **Collapsible Soils:** Although no collapse potential test was conducted, the persistent occurrence of material with pin-holed structure due to termite activity in the transported horizon indicates collapsible material. Since the horizon extent to depths > 750mm, the collapse potential was classified as intermediate (Class 2A).

ii) **Seepage:** No seepage was encountered in any trial pits. However, occurrence of ferruginous nodules and weakly developed ferricrete indicates historic fluctuating water table at localised areas. The constraint was therefore classified as **intermediate (Class 2B)**.

iii) **Active Soils:** From examination of pit profiles, TPs 37 and 38 are located in clays with high heaving potential. This was confirmed by plasticity index values ranging between 14 and 24 and high linear shrinkage values 9 and 13%. This constraint was classified as **Least Favourable (Class 3C)** based on the nature of the clays encountered in that environment.

iv) **Flooding:** Although the area is a low-lying area sandwiched between the sandstone outcrops and the Nywane river flood plain, the area relatively drains well compared to other areas downstream as confirmed by the residents. However, the risk of flooding will need to be confirmed by a hydrological study.

3.3.4 CONCLUSION AND RECOMMENDATIONS

Most of the area (91.6%) is covered by fine colluvium classifying as silty sand extending to founding depths greater than 0.8m. This material will not be suitable as a foundation material due to low bearing capacity (mostly G10) and potential collapsibility. No shallow bedrock was encountered. Moreover, bioactivity appears to be very prominent in the area. It is therefore recommended that for a single storey structure, precautions are necessary through improvement of founding material and drainage control around the houses. This would require excavation of transported colluvium and replacement with competent material (G5) to depths of 1.5*width of footing. The foundation trenches would require anthill treatment and compaction of borrowed material to minimum of 93% MOD AASHTO in layers of 150 mm. It is envisaged that precautionary measures recommended will improve the habitability of the area and therefore classified as **intermediate.**

A small portion of the area (8.3%) at TPs 37 and 38 approaching the Nywane flood plain has high plasticity clay material with low bearing capacity making it **unfavourable** for development

Table 7: Geotechnical Classification for Area 3

Geotechnical Classification	Area (ha)
Most Suitable	0
Intermediate	11 (91.6%)
Least Suitable	1 (8.3%)

4 REFERENCES

ASTM D2487-06, Standard Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System), ASTM International, West Conshocken, PA, 2006

Bekker, R.P., De Wit, P.V. 1991. Contribution to the vegetation classification of Botswana. FAO/UNDP/GOB Soil Mapping and Advisory Services Project. Gaborone, Botswana

Blight GE., Leong EC., 2012. Mechanics of Residual Soils, Taylor & Francis Group, London
Committee of State Road Authorities.,1985. Guidelines for Road Construction Materials, TRH 14, Department of Transport, Pretoria.

Guidelines for Soil and Rock Logging in South Africa, 2nd Impression 2001, eds. A.B.A. Brink and R.M.H. Bruin, Proceedings, Geoterminology Workshop organised by AEG, SAICE and SAIEG, 1990.

Key, R.M. 1983. The geology of the area around Gaborone and Lobatse, Kwaneng, Kgatleng, Southern and South east Districts. Gaborone, Botswana, Department of Geological Surveys (DGS), Ministry of Minerals Resources and Water Affairs

Partridge, T.C., Wood, C.K., Brink, A.B.A., 1993. Priorities for urban expansion within the PWV metropolitan region: The primacy of geotechnical constraints. South African Geographical Journal

Van Rooy, J L., Stiff, J S (2001) Guidelines for Urban Engineering Geological Investigations in South Africa, Bulletin of Engineering Geology and environment

Weinert H. H., 1980 . Natural Road Construction Materials of Southern Africa. H& R Academia. Capetown

5 APPENDICES

APPENDIX A- Soil Profiles

APPENDIX B- Laboratory Test Results

APPENDIX C – Suitability Map

APPENDIX D- Soil Profile Photographs

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