The Hydrogeology of Northern Agago County in Pader District, Uganda

Groundwater Programme

Open Report OR/08/040

BRITISH GEOLOGICAL SURVEY

GROUNDWATER PROGRAMME

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The Hydrogeology of Northern Agago County in Pader District, Uganda

M T Graham

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Latitude, Longitude

SW corner 33.1305E, 2.7182N
NE corner 33.6596E, 3.2992N

Front cover

View looking NNE from Parabong mountain, towards NE Parabongo and Paimol sub-counties

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Preface

Much of the work carried out in producing this report has been done on a voluntary basis. Travel to Uganda was funded by the author and the time spent in Uganda was as part of an annual leave allowance.

Office time to carry out preparatory work and to produce this report has been funded by the British Geological Survey (BGS).

Travel and subsistence costs within Uganda were met by GOAL.

Acknowledgements

The production of this report would not have been possible without the help of a number of individuals and organisations. Firstly, the author would like to thank Peter Goodfellow, Water and Sanitation Coordinator at GOAL Kalongo, for making this project possible, for providing much of the data used and for guidance on the local area. Thanks must also go to Chris Wardle, Programme Manager at GOAL Kalongo and all of the members of the Water and Sanitation Department working in the Kalongo office. I am indebted to the BGS, for their continued support throughout the project. In particular, I would like to thank Jeff Davies and Alan MacDonald, for the provision of advice and contacts regarding Ugandan hydrogeology. Finally, I would like to thank CESVI and the Ugandan Directorate of Water Development (DWD) in Entebbe, for the provision of additional data.

Contents

FIGURES

Summary

This report was produced to assist GOAL, an Irish NGO working in Uganda, in the provision of water supplies for displaced persons in Agago County, part of Pader District in the north of Uganda. The work contained within the report has been carried out on a voluntary basis, although considerable support has been provided by GOAL in the provision of travel and subsistence costs within Uganda, spanning the period from the 22nd September to the 12th October 2007. Funding for preparatory work and for the writing of this report was provided by the British Geological Survey (BGS).

The report describes the hydrogeology of five sub-counties (Lapono, Lukole, Paimol, Parabongo and Wol) within Agago County, which cover GOAL's area of operation for water and sanitation in Pader district. The area currently benefits from a large number of deep boreholes, although many of these have proved to be dry at the time of drilling. GOAL aims to meet the requirement for further water supplies largely through the provision of shallow, hand-dug wells.

There has been no systematic geological or hydrogeological survey of the area to date and geological maps are only available at scales of 1:1,000,000 and 1:1,250,000. Further data collection during this visit has been restricted by limited exposures of rock, a lack of drill cuttings and logistical difficulties arising from poor transport and continuing security concerns. In general, however, the study area can be divided into areas of deeply weathered crystalline basement and large inselbergs, exposing a range of high-grade metamorphic rocks.

Given the current emphasis on shallow well construction in the area, GIS layers of water strike data and predicted depth to water have been created. The depth to the first recorded water strikes appears to be largely controlled by the local topography and a map based on land surface curvature (rate of change in slope) has been used to highlight topographic depressions where water strikes are likely to be shallowest (negative curvature) and areas of raised ground where water strikes may be more than 50 m below the surface (positive curvature). Where the land surface curvature is below -0.001, recorded water strikes are uniformly within 40 m of the surface. Where the land surface curvature is greater than this, however, the depth to water strike is highly variable and recorded values range from 15 m to nearly 100 m below the surface.

These results suggest that deep boreholes remain the most viable option for water supplies in the majority of cases. While it is possible to highlight parts of the study area where water strikes are likely to be shallowest, groundwater in these areas may still be more than 20 m below the surface. As a result, shallow wells constructed in these areas would be unlikely to succeed.

Overall aquifer productivity has also been assessed and the study area has been divided into four domains with distinct hydrogeological characteristics. Transmissivity data from nearly 50 locations have been used in the delineation of these domains, along with topographic considerations. The low-lying, flat land in the southwest is shown to contain the most productive aquifers, while the areas close to the inselbergs in the north and east of the study area are shown to have aquifers with low productivity.

The available data show no correlation between aquifer productivity and the depth of weathering. This has implications for the continued use of resistivity surveys in identifying suitable drilling sites, as much of the value of this technique lies in identifying the depth of weathering.

1 Introduction

1.1 STUDY AREA

This report focuses on five sub-counties within Agago County, part of Pader District in northern Uganda (Figure 1). These sub-counties (Lapono, Lukole, Paimol, Parabongo and Wol) represent the main areas of operation of the Water and Sanitation Department of GOAL Kalongo.

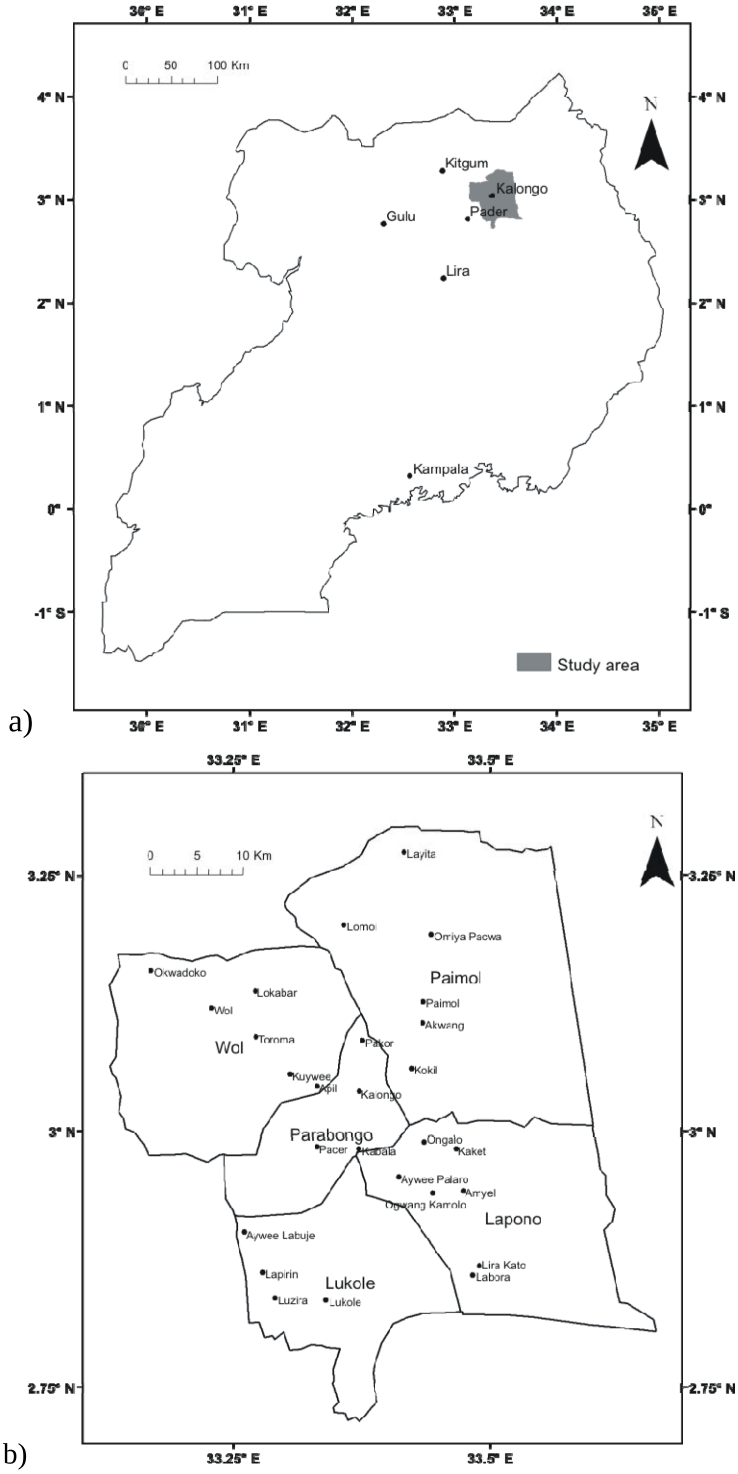

Figure 1: a) Map of Uganda showing the study area b) The five sub-counties which constitute GOAL's area of operation in Pader District.

1.2 EXISTING WATER SUPPLIES AND REQUIREMENTS

As part of the current trend of resettlement of displaced persons in Pader District, the provision of water supplies for new and existing communities is of crucial importance. Although the area benefits from annual precipitation of more than 1100 mm (FAO, 2002), surface water resources are vulnerable to contamination and high rates of evaporation during the dry season, which typically runs from November to March. Groundwater therefore represents the safest and most reliable source of drinking water for the majority of the local population.

The five sub-counties are currently served by more than 100 water boreholes, the majority of which are fitted with India Mark II hand pumps. The success of previous drilling in the area has been mixed, with yields of nearly 10 m^3/hour in some areas and dry boreholes in others.

Where possible, however, it is hoped that further requirements for water can be met by the construction of shallow wells, thereby reducing costs and increasing community involvement in water supply. In areas where this is not feasible, due to a lack of shallow groundwater, the drilling of deep boreholes will be considered.

1.3 PROJECT AIMS

This study has the following aims:

- To predict the likely depth to water across the five sub-counties, based on existing water strike data. The results will be presented in a GIS to highlight the areas where water strikes are likely to be shallowest.
- To assess the productivity of aquifers across the five sub-counties, based on existing pumping test data. A GIS layer will be produced to highlight hydrogeological domains with distinct characteristics.

2 Available Data

2.1 EXISTING DATA

A significant amount of data from drilling logs, pumping tests and VES (Vertical Electrical Sounding) surveys were available for the five sub-counties covered by this report. Much of it came from previous work commissioned by GOAL in the area, while additional data were provided by CESVI, an NGO also working extensively in Pader District, and the Ugandan DWD (Directorate of Water Development) in Entebbe.

Interpretation of the pumping test data allowed transmissivity values from 46 boreholes to be determined. These were entered into a database, along with information on water strikes, static water levels, rockhead, groundwater chemistry and lithology, before being converted into GIS layers to show the spatial distribution of the data. The transmissivity and water strike data provided the primary method of calibration in producing the final maps of aquifer productivity and predicted water strike depth (see Appendix 1 and 2).

Considerable effort was made to source existing geological maps of the area. A search of the archives of both the Ugandan DWD and the BGS found national maps at 1:1,000,000 and 1:1,250,000 scale, although these gave no detailed information on the area of interest, simply describing the local geology as either ‘unspecified basement complex’ (Geological Survey of Uganda, 1940) or ‘mainly undifferentiated acid gneisses’ (Geological Survey of Uganda, 1960). Further consultations with members of the WRMD’s (Water Resource Management Department) Groundwater Mapping Group confirmed that no larger scale geological maps of Pader District are currently available, although plans are in place to map the area over the next few years.

2.2 DATA COLLECTION

2.2.1 Overview

Field surveys were conducted as part of this project with the following main objectives:

- to obtain accurate GPS coordinates of existing boreholes referenced in consultants’ reports
- to expand on the limited geological information available for the local area

Assistance was provided in the former by GOAL’s UNHCR team, who are currently carrying out a survey of water sources in Agago. However, at the present time, exact coordinates are not available for all data points and the locations of some boreholes have been plotted at the centre of the nearest settlement. In settlements with a large number of boreholes and a wide variation in recorded yields, such as Omiya Pachwa, further information on these locations is of particular importance. Observations of the area’s geology are limited by continuing security concerns and transport limitations, the limited availability of drill cuttings from previous boreholes and poor exposure of bedrock, with rockhead in much of the region more than 40 m below the surface.

2.2.2 Geological Observations

Observed rock exposures in the area of interest are exclusively metamorphic and it appears that there have been at least two main phases of metmorphism. On Parabong mountain, near Kalongo, large quartz veins can be seen cutting through high-grade metamorphic rocks, the

Figure 2: Folded quartz vein on Parabong mountain, surrounded by medium-grained granulite.

Figure 3: Coarse-grained metamorphic rock with gneissose banding on Parabong mountain.

Figure 4: Coarse-grained granulite, with large quartz vein on Parabong mountain

presence of folded veins hinting at plastic deformation of the rock at very high temperatures (Figure 2).

Most rocks in the area in their unweathered state are medium or coarse-grained granulites or acidic gneisses, with varying degrees of foliation. The full range of grain sizes and textures may commonly be seen within a few tens of metres, making the determination of any regional trend in lithology difficult (Figures 2-4).

Many exposures of rock are heavily weathered, leading to red lateritic soils and white fragments of silcrete or calcrete. Above the unweathered rock, evidence from drilling logs and surface observations suggests that increased fracturing and weathering of the rock has created a profile typical of many tropical regions (Figures 5 and 6).


a)


b)

Figure 5: a) highly weathered soil profile, Kabala b) exposure of bedrock and broken, weathered rock on Parabong mountain.

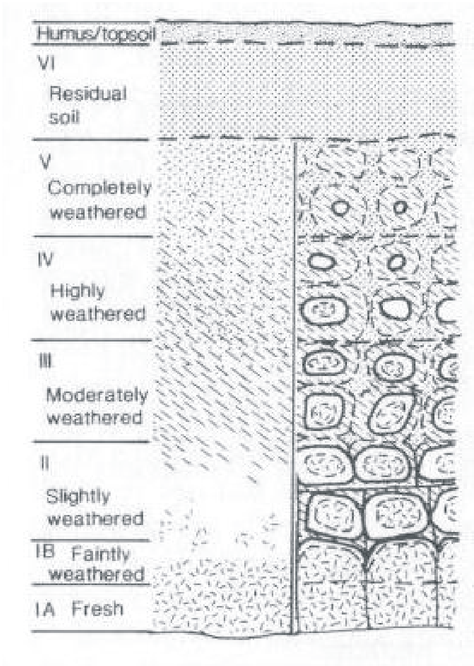

Figure 6: Idealised weathering profile (from Fookes, 1997)

3 Data Interpretation

3.1 OVERVIEW

3.1.1 Geology

The drilling logs appear to show the increased presence of sand and sandy clays in the vicinity of the Ogili-Parabongo mountain to the north of Kalongo (Figure 1b) and large volumes of sedimentation are to be expected given the high rainfall and relief in this area. Large volumes of sand can be seen to accumulate in these areas over the course of just a few days (Figure 8). Elsewhere, in areas of flatter topography, clays appear to dominate above the zone of weathered rock (saprolite).

Figure 7: Major deposits of sand near Ogili-Parabongo mountain.

In general, weathered rock is encountered within around 10 – 20 m of the surface, although this figure may vary rapidly over a small area in the vicinity of inselbergs (e.g. near Kalongo and Akado). Below depths of around 30 m, weathering of the rock is more limited, although intense fracturing may still occur.

The bedrock lithology has been recorded as granite in the majority of drilling logs, although these same rocks have occasionally been described as being fine-grained, which would by definition exclude them from being granite. Where grain size has been recorded, however, the majority of rocks are described as either medium or coarse-grained.

Due to the lack of availability of drill cuttings for inspection, it has not been possible to directly compare rock samples from across the study area and determine regional trends in the bedrock geology. Due to inconsistencies in the terminology used by drillers and apparently inaccurate identification of certain lithologies, any attempts to draw in-depth conclusions on the local geology from the drilling log data should be avoided.

The 'U'-shape of the majority of the available apparent resistivity curves (Figure 7) is typical of many weathered basement regions and supports the idea of a deep weathered zone. A highly resistive layer of topsoil commonly overlies less resistive layers, which corresponding drilling logs suggest are clay and sand. The increasing values of resistivity at greater depth are likely to correspond to weathered rock and then fresh rock. The phenomena of equivalence and suppression mean that precise lithologies and thicknesses of strata cannot be determined, however. This is highlighted by the fact that a thin intermediate layer of very low resistivity can give a similar shape of curve to a slightly thicker intermediate layer of moderately low resistivity (equivalence). The phenomenon of suppression prevents the determination of the depth at which fresh rock first occurs, as a gradual increase in resistivity with depth is practically indistinguishable from a sudden increase in resistivity between two discrete strata. Further details on these phenomena can be found in Telford et al. (1990).

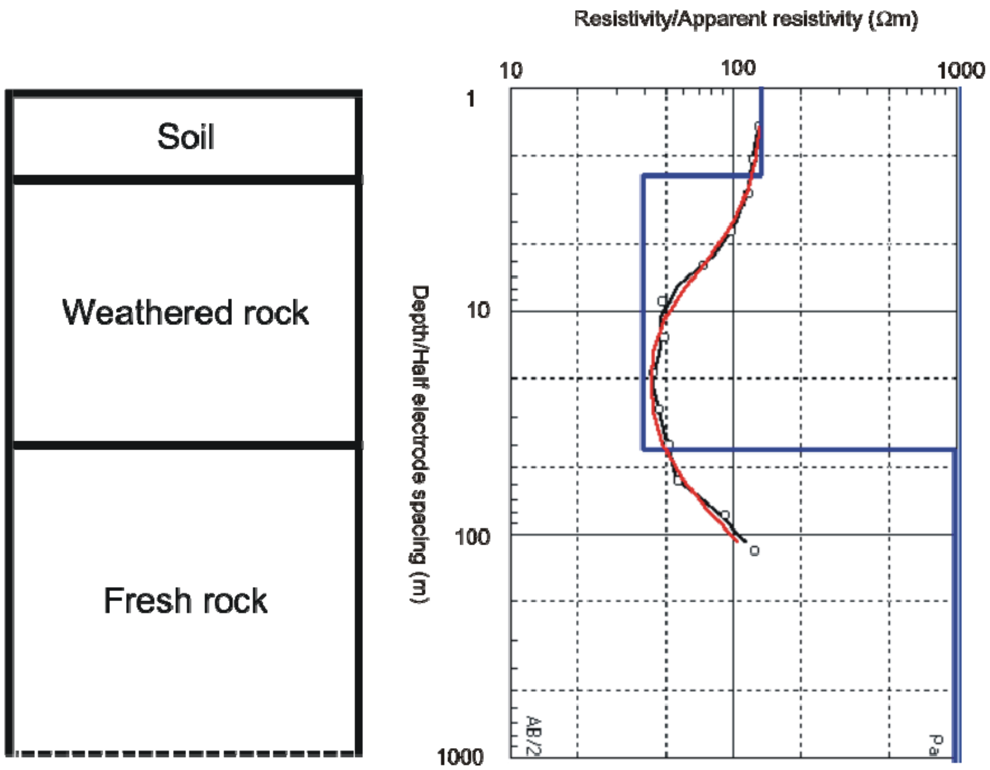

Figure 8: Typical resistivity profile and geological interpretation from Awelo, showing the characteristic 'U'-shape commonly seen in areas of deeply weathered basement.

An attempt was made to determine the depth of weathering from the drilling records. The use of vague terms such as 'moderately hard' or 'slightly fresh' rock by a variety of different drillers means that the depths determined using this method are prone to considerable error.

Correlations between resistivity profiles and borehole logs were hampered due to a general lack of borehole records at the locations of resistivity surveys, an absence of grid references for many of the survey sites and uncertainties in the degree of weathering from the borehole log descriptions.

3.1.2 Hydrogeology

Although there is an apparent lack of reliable geological information for much of the study area, the hydrogeological properties of the various rock types are likely to be similar. In their unweathered state, gneiss, granulite and granite are all hard, dense, crystalline rocks. Intergranular flow is likely to be non-existent and the flow of groundwater in the unweathered bedrock aquifer is likely to occur entirely through fractures within a few tens of metres of rockhead.

It is generally recognised that for a weathered basement aquifer to be considered productive, there must be a certain minimum thickness of weathering (Ackworth, 1987). Where there is a thick weathered zone above rockhead, the regolith may store considerable volumes of groundwater, due to its high porosity (Figure 9). In addition, there is likely to be sufficient fracturing of the rock in areas of deep weathering to allow significant groundwater flow. In some cases, however, weathering is sufficiently advanced that the zone close to rockhead is dominated by low permeability clays.

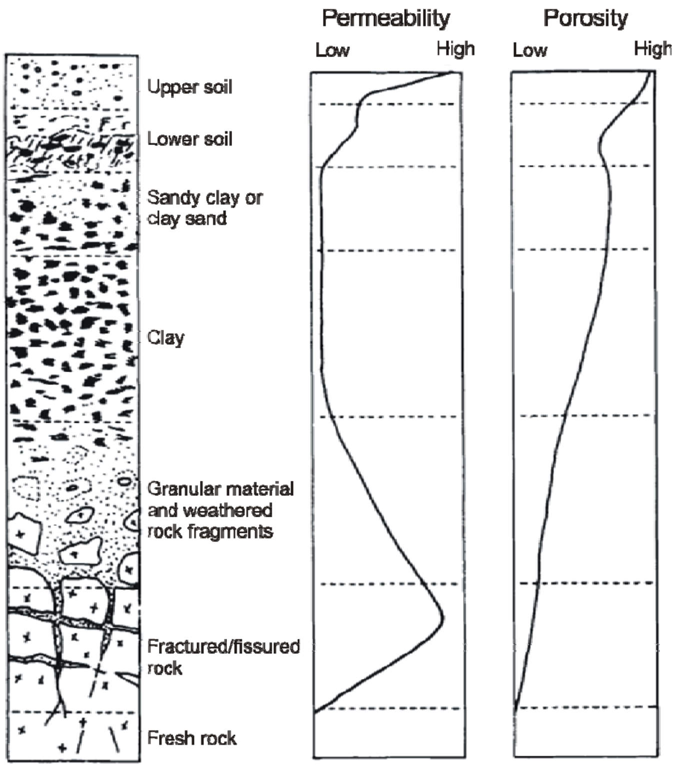

Figure 9: Variations in porosity and permeability with depth in weathered basement (Ackworth , 1987)

By correlating the lithological descriptions and penetration rates from the drilling logs with recorded water strike data, it appears that the majority of groundwater occurs either within fractures in the unweathered rock or within the zone of slight weathering a few metres above this. Although the more highly weathered material above this zone is unlikely to form the main aquifer unit, due to its low permeability, ‘leaky’ responses from some of the pumping tests suggest that these units may provide considerable additional storage of groundwater in some cases, supplementing the yields obtained from the more productive zone of fractured rock below (Figure 10). Previous studies of weathered basement regions in Uganda have suggested considerable flow of groundwater from the regolith to the bedrock aquifer (Taylor and Howard, 1997; Faillace, 1973).

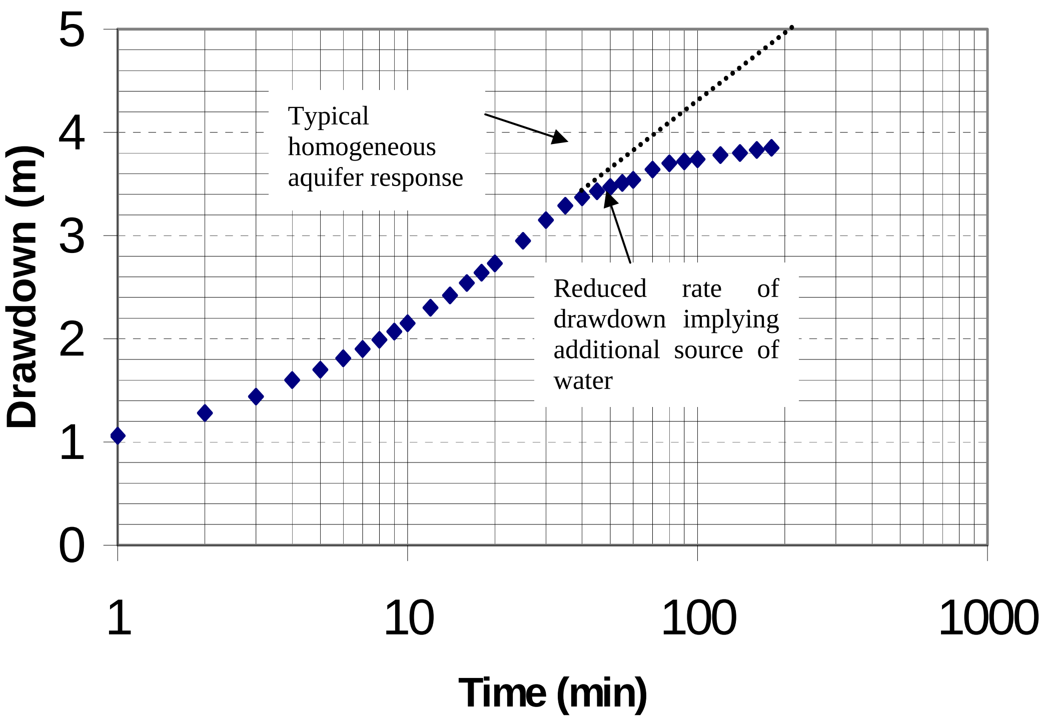

Figure 10: Leaky response in a pumping test at Lokabar

3.2 WATER STRIKE DEPTH

A GIS layer of first water strikes across the study area shows that their depth is largely controlled by the shape of the local topography (Figure 11). Using a DTM (Digital Terrain Model) of the area, produced by the GLCF (Global Land Cover Facility) at the University of Maryland, it was possible to produce a map of land surface curvature, where high positive values correspond to the top of hummocks or hill slopes and high negative values correspond to topographic depressions or the bases of slopes.

The deepest water strikes tend to occur on higher ground, either on inselbergs or interfluves, while shallower water strikes appear to correspond to river valleys or to the base of steep slopes. A graph of the results shows that of the 13 sites where the land surface curvature is less than -0.001, all are within 36 m of the surface and 12 are 15 m or more below the surface (Figure 12). The data are far more variable at greater values of land surface curvature, however, with 8 of the 17 first recorded water strikes at depths of more than 36 m. It is to be expected that water will naturally collect in topographic depressions, giving both shallower water strikes and shallower static water levels.

An initial map, produced with a spatial resolution of only 90 m, showed rapid variation in the shape of the land surface and poor correlation with the observed water strike data. However, ArcGIS allows spatial data of this type to be smoothed, by taking the mean values of curvature over a given radius, so that only large-scale features remain. It is these large-scale features which are more likely to dictate the flow and depth of groundwater. The exact radius was chosen by calibrating the topographic data with the observed water strike depths in the study area. It was found that smoothing over a radius of 13 cells (around 1200 m) gave a good fit to the data, while calibration was improved further by repeating the same smoothing operation.

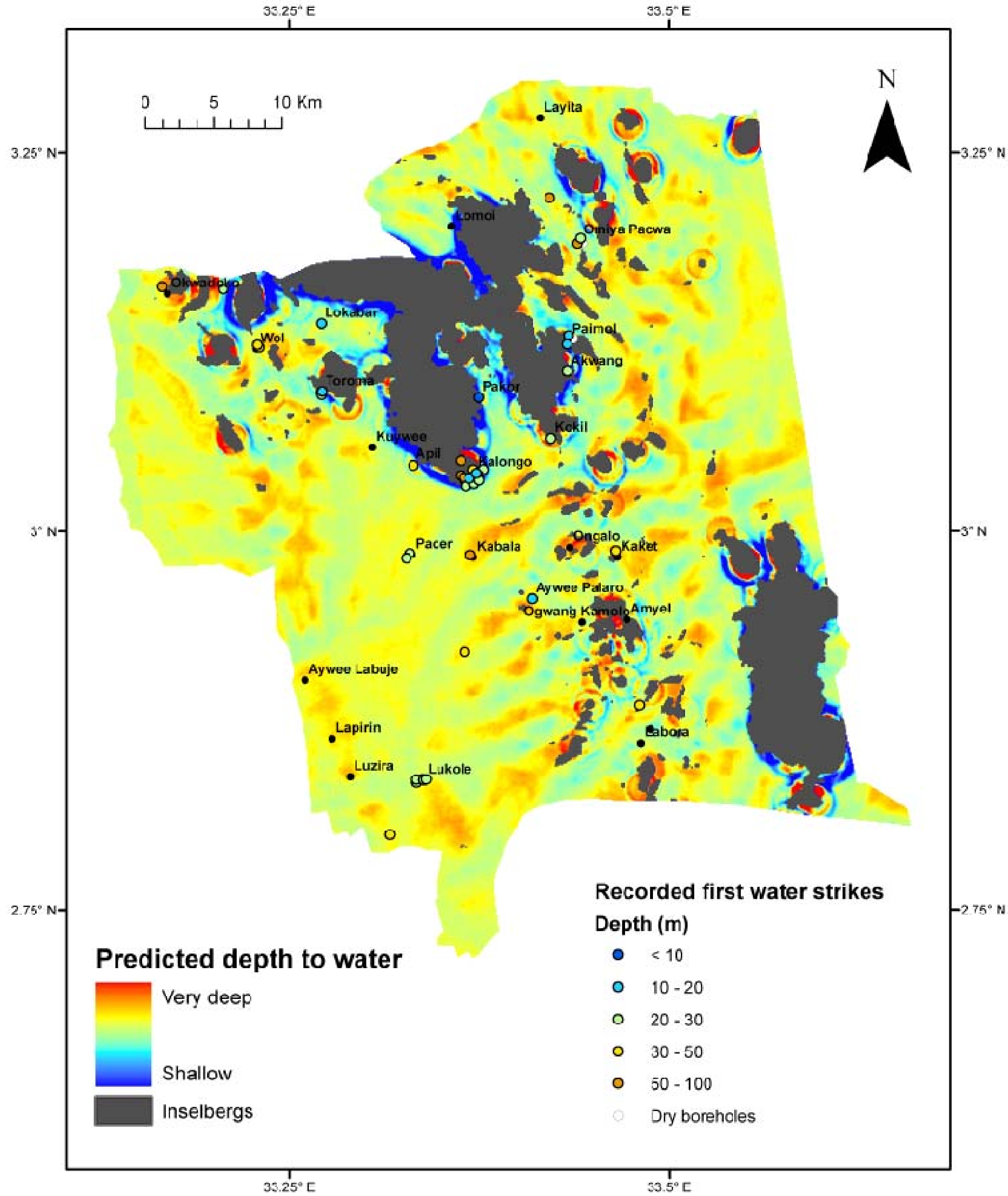

Figure 11: Predicted depth to water and recorded first water strikes across the study area

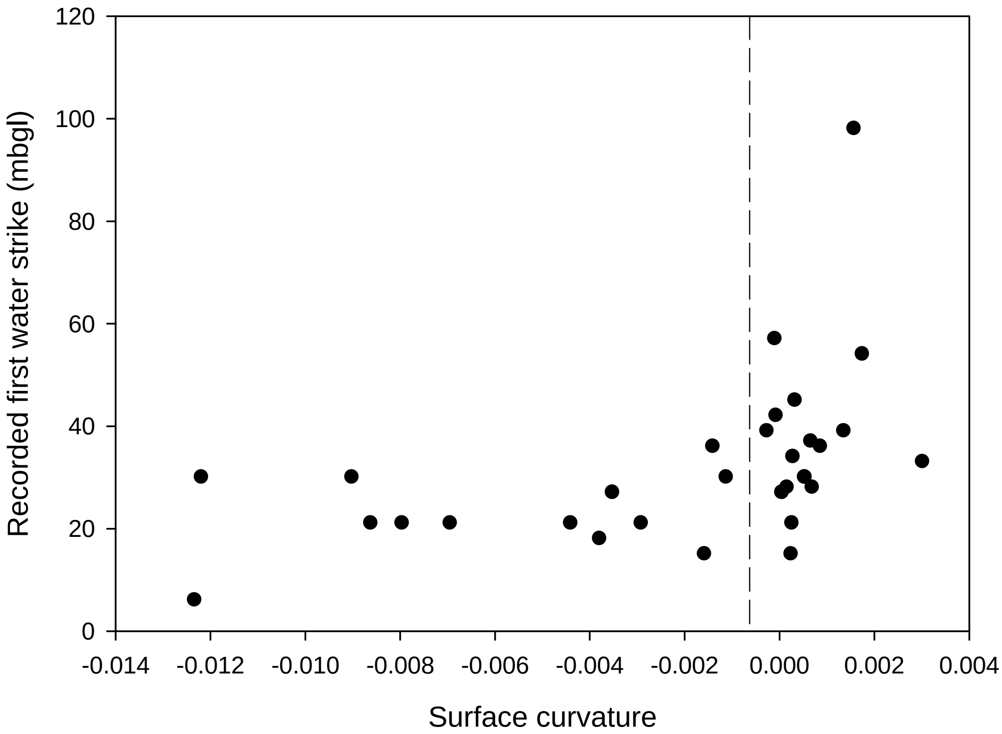

Figure 12: Depth to recorded first water strike versus land surface curvature. There is much greater variability in water strike depth above a curvature value of around -0.001.

Factors such as relief, slope, depth to bedrock and the nature of the regolith are likely to also have a major effect on the depth of the first water strike. A topographic depression in an area of high ground may overlie a thick unsaturated zone, while a small rise in the ground surface in a generally low-lying area may overlie a shallow water strike. The curvature of the land surface may be concave upwards near the base of inselbergs, although the local topographic gradient may still be large, inhibiting the accumulation of shallow groundwater. In areas of exposed bedrock or with an only slightly weathered regolith, major temporal and spatial variations in water strike depth may occur, due to changes in fracture density, rapid transmission of water through the fractures and a low bulk storage capacity. Conversely, topographic depressions with a thick overburden of clayey material may have shallow static water levels, but deep water strikes, due to the confinement of groundwater by low permeability material.

It is clear from the factors listed above that the criteria applied to the majority of the study area, where deep weathering dominates, cannot be reasonably applied to the inselbergs themselves. For this reason, inselbergs have been placed in a separate category, comprising all areas where the surface elevation drops by more than 50 m within a 1 km radius. These areas are characterised by major temporal and spatial variations in the depths to water and significant variations in yield; from very high following heavy rainfall, to almost zero where there has been minimal fracturing of the rock.

3.3 AQUIFER PRODUCTIVITY

Although yield values are sometimes used to assess the productivity of an aquifer, this is a far from ideal parameter to use for this purpose. Recorded yields are often dependent on the type of pump used and on the requirements of the client or user. These factors may lead to small yield values being recorded for extremely productive aquifers. On the other hand, high recorded yields may only be sustainable for the duration of a short pumping test.

As a result of these inadequacies, it is more common for hydrogeologists to assess the productivity of an aquifer through the use of transmissivity data. Transmissivity is essentially governed by both the permeability and thickness of the aquifer and is largely unaffected by the factors described above. Furthermore, unlike specific capacity data (yield per unit drawdown in water level), transmissivity data is largely independent of abstraction rate. Transmissivity values can be obtained from reasonable pumping test data and a large number of textbooks give further information on the theory behind this. A simple, but informative overview is given by MacDonald et al., 2005.

Although the depth of weathering represents a significant control over the productivity of some weathered basement aquifers, there appears to be no correlation between transmissivity and depth of weathering in the study area (Figure 13). This has implications for the use of resistivity as a tool for siting boreholes in the region, as much of the value of this technique is in determining the depth of weathering.

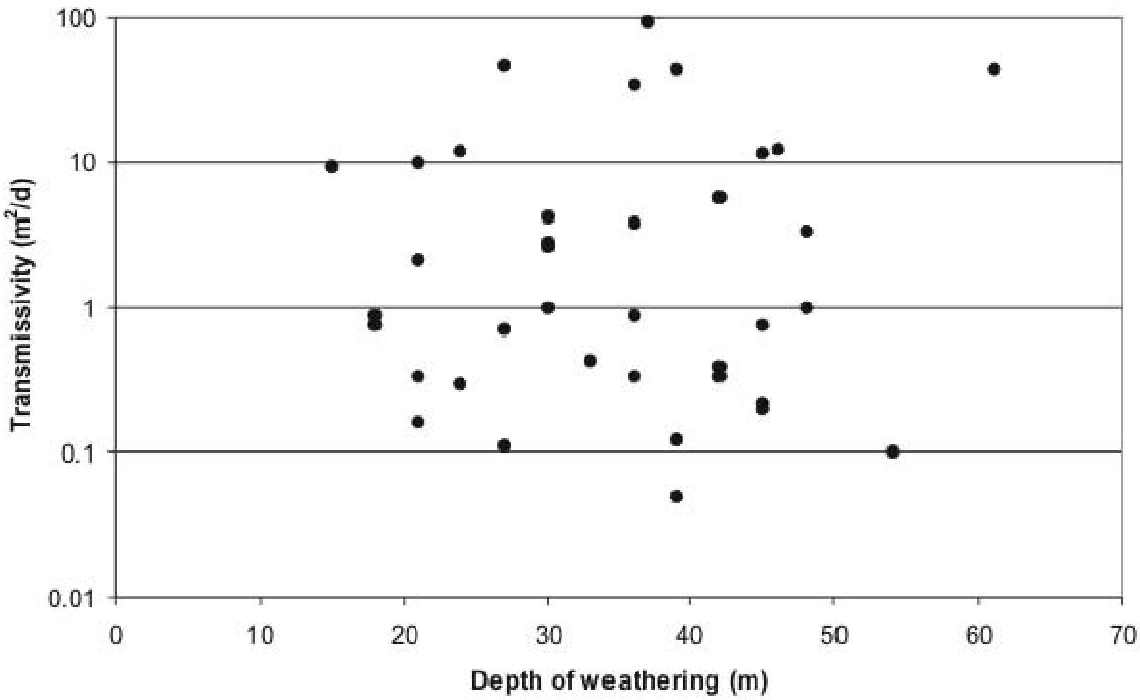

Figure 13: Graph of transmissivity versus depth of weathering, taken from lithological descriptions in the drilling logs

To assess the productivity of aquifers from across the study area, a GIS layer of transmissivity data at 46 locations has been used. Although aquifer productivity appears to be less sensitive to the local topography than the depth of water strikes, broad regional trends can clearly be seen, allowing the study area to be divided into four distinct hydrogeological domains (Figure 11):

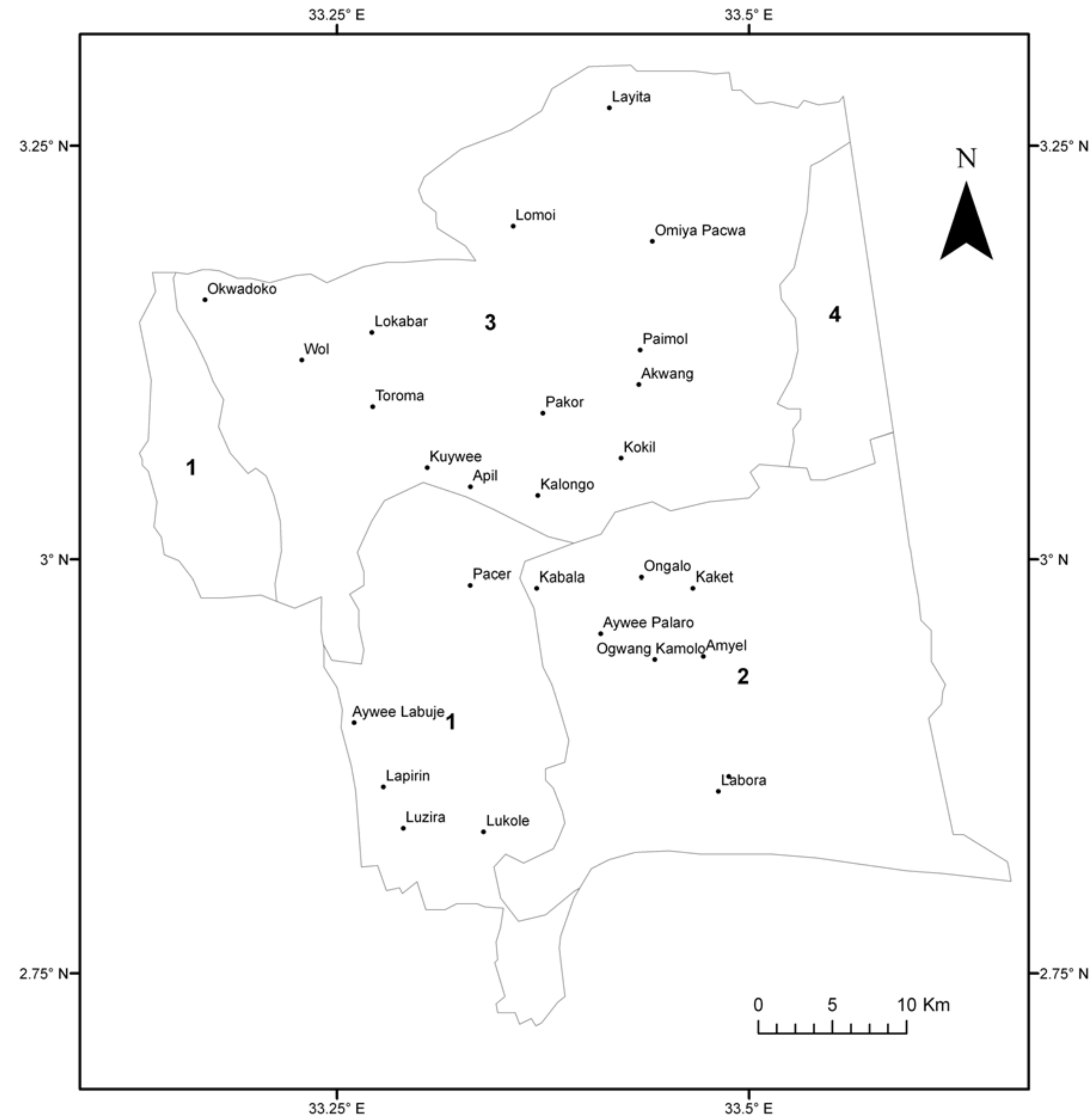

Figure 14: Hydrogeological domains assigned to the study area

- Domain 1: This domain covers western Parabongo, western Lukole and the extreme west of Wol sub-county. It is characterised by flat, low-lying topography and contains highly productive aquifers. Transmissivities of more than 25 m^2/d have been recorded at Pacer and Lukole, although water strikes may be very deep.

- Domain 2: As the land rises towards southeastern Parabongo, eastern Lukole and Lapono sub-counties, transmissivity values become lower overall and there appears to be increasing topographic control on aquifer productivity. A line of small inselbergs can be seen running from between Ongalo and Kaket in the north, past Amiel and re-emerging just to the south of Labora. On rises in the land surface to the west of this point, such as at Kabala and Aywee Palaro, recorded transmissivity values are very low, less than $1m^2/d$, and it may not be possible to supply more than 50 households from these boreholes. To the east of this line, recorded transmissivity values are higher than 1 m^2/d, and in the topographic depression at Lira Kato, transmissivities of more than 10 m^2/d have been recorded. The area is also characterised by deep, confined aquifers and recorded water strikes are generally far below the potentiometric surface.

- Domain 3: This domain covers the majority of Wol and Paimol sub-counties, as well as the far northern part of Parabongo sub-county. In the immediate vicinities of the inselbergs, such as at Kalongo, Pakor and Akwang, transmissivity values are commonly less than 1m^2/d, while flatter ground or small rises in the land surface nearby (within ~ 3 km) typically correlate with transmissivities of between 1 and 10 m^2/d (e.g. Wol, Lokabar and Omiya Pacwa). High transmissivities of over 10 m^2/d have been recorded in localised areas at the foot of slopes (e.g. Okwadoko, southern Akado, northern Paimol Muttu) or in small depressions between inselbergs (e.g. Toroma). The latter represent natural collection points for groundwater and may have been formed by increased fracturing of the rock, leading to locally higher permeabilities.
- Domain 4: No data are available for this domain, which covers the far eastern part of Paimol sub-county. Its overall geomorphology is markedly different from the adjoining regions 2 and 3 and it would appear from the fairly flat topography that the bedrock here is overlain by thick, unconsolidated deposits.

The spatial distribution of the available transmissivity data is shown in Figure 15, along with the outlines of each domain, land surface curvature and areas where bedrock is expected to lie at or near the surface (ie. inselbergs).

3.4 RECOMMENDATIONS

There appears to be limited potential for the development of shallow wells in the majority of the study area. Recorded water strikes are greater than 15 m deep in most places, with only a few sites near the base of inselbergs likely to have shallow groundwater for most of the year.

Deep boreholes therefore remain the best option for the majority of new water supplies. These are most likely to provide high yields in domain 1, as described above. Water strikes are likely to be shallowest in topographic depressions.

There is limited potential for managed aquifer recharge, as there appears to be limited storage capacity in the subsurface throughout the study area. Sand dams can often provide important sources of groundwater in sub-Saharan Africa and India, although these typically require narrow valleys, with high sediment accumulation. These features were not seen in the study area.

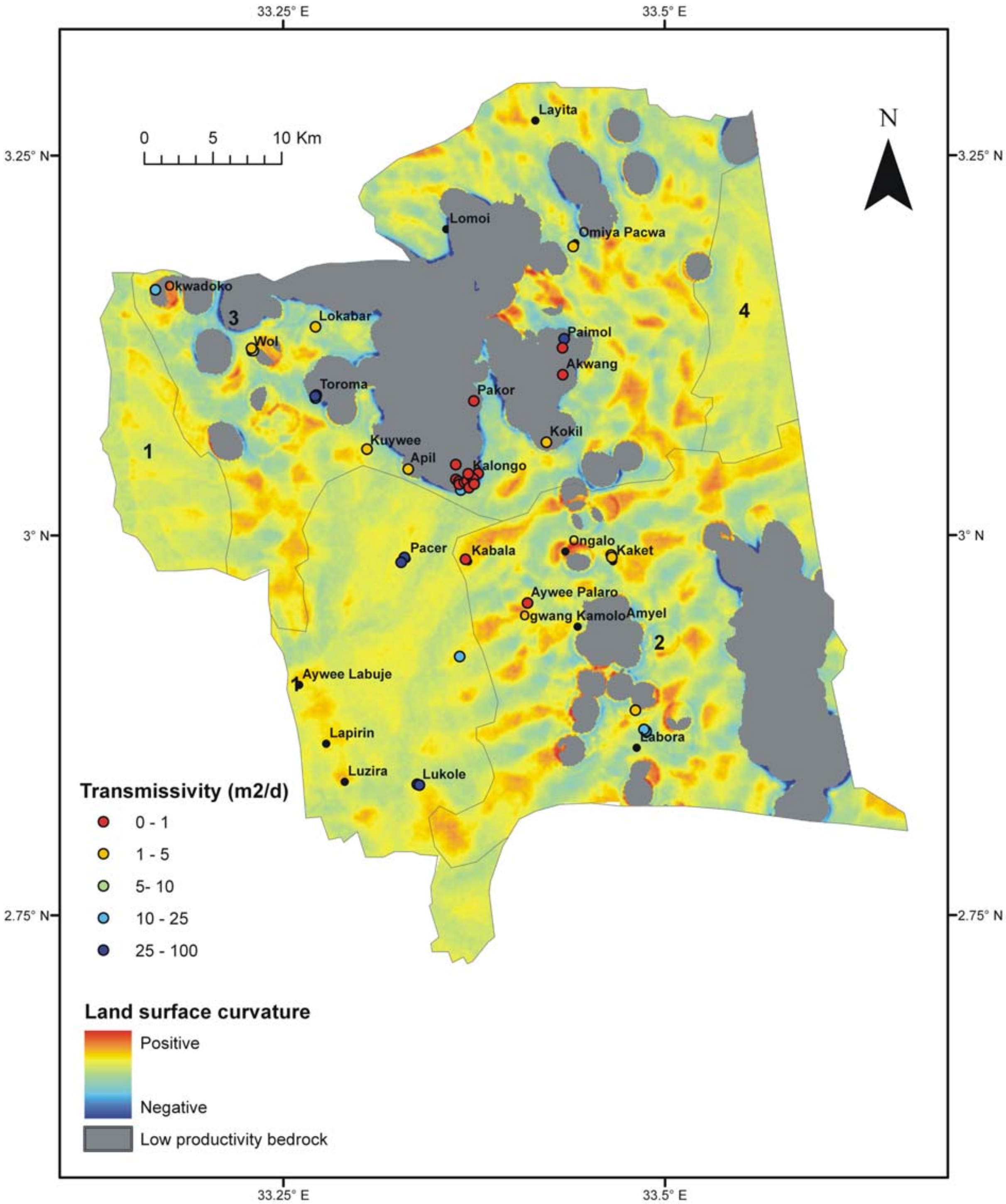

Figure 15: Transmissivity data and land surface curvature across the four hydrogeological domains.

4 Conclusions

- The first recorded water strike is 15 m or more below the surface in the vast majority of boreholes across the study area. Shallow wells are therefore unlikely to be viable in most localities.
- Where the land surface curvature is less than -0.001, recorded first water strikes are within 36 m of the surface.
- At sites where the land surface curvature is greater than 0.001, the depths of recorded first water strikes are highly variable. Nearly half of these sites have recorded first water strike depths of greater than 36 m.
- The available data show no correlation between the depth of weathering and aquifer productivity.
- Resistivity profiles from the study area suffer from a high degree of ambiguity, caused by equivalence and suppression. Even in the absence of such ambiguity, the use of this technique in determining the depth of weathering is likely to be of limited value, due to the lack of correlation with aquifer productivity.
- The majority of the most highly productive boreholes are located in western Parabongo and western Lukole, where flat, low-lying topography prevails. The extreme west of Wol sub-county is expected to contain similarly productive aquifers, although no pumping test data are currently available for this area.
- The least productive boreholes are typically located in the immediate vicinity of inselbergs, where groundwater is likely to occur only in a limited number of fractures and in a thin overlying weathered zone.
- A small number of highly productive boreholes have been drilled in the vicinity of inselbergs, in localised areas of deep weathering. It is likely that these aquifers receive considerable groundwater flow from the surrounding high ground and there may be a localised area of intensive fracturing of the bedrock at these sites.
- There is limited scope for managed aquifer recharge schemes due to limited storage in the subsurface and a lack of suitable locations for shallow schemes, such as sand dams.

References

Most of the references listed below are held in the Library of the British Geological Survey at Keyworth, Nottingham. Copies of the references may be purchased from the Library subject to the current copyright legislation.

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Appendix

Location	Borehole Ref.	Longitude	Latitude	Depth to First Water Strike (m)	Transmissivity (m^2/d)
Adunu W	DWD20475	33.3631	3.0367	62	0.10
Akado 4	DWD20478	33.3654	3.0335	33	0.39
Akado 5	DWD20479	33.3664	3.0298	30	12.20
Akado C1	DWD20480	33.3686	3.0348	15	0.12
Akado C2	DWD20481	33.3704	3.0357	24	0.11
Akado South	DWD20484	33.3718	3.0313	21	0.34
Akado W	DWD20476	33.363	3.0465	57	0.16
Akado W3	DWD20477	33.3651	3.0354	56	0.20
Akwang	DWD25153	33.4332	3.1056	24	0.33
Alupere W	DWD20482	33.3733	3.0382	18	0.05
Amref Kaket	WDD6384	33.4653	2.9855	-	4.45
Apil	DWD25149	33.3319	3.0435	39	3.87
Awelo	DWD24097	33.4807	2.8849	36	4.13
Aywee Palaro	DWD25151	33.4101	2.9554	15	0.30
Goal Kaket	DWD24096	33.4649	2.9869	33	2.93
Kabala		33.3694	2.9842	98	0.26
Kaciciro west	DWD20064	33.4422	3.1935	30	-
Kalongo	DWD20474	33.3778	3.0407	30	0.75
Kalongo Hospital	DWD20485	33.3712	3.0405	36	0.98
Kokil	DWD23521	33.4225	3.0612	36	2.65
Kokil 1	DWD23520	33.4225	3.0612	27	1.00
Kokil 2	DWD23522	33.4225	3.0612	30	-
Kokil 3	DWD23523	33.4225	3.0612	33	-
Kuywee		33.3049	3.0567	-	1.17
Labima	DWD15522	33.4216	3.2202	57	-
Lacan-kweri	DWD15978	33.3165	2.7994	45	-
Lira Kato 1	DWD21305	33.4876	2.8710	-	11.00
Lira Kato 2	DWD21308	33.4862	2.8722	-	23.00
Lokabar	DWD25152	33.2713	3.1372	15	2.11
Lukole 1	DWD21298	33.3339	2.834	28	-
Lukole 2	DWD21297	33.334	2.8358	30	-
Lukole 3	DWD21300	33.3378	2.8361	34	43.00
Lukole 4	DWD21296	33.3385	2.8356	30	-
Lukole 5	DWD21295	33.3392	2.8356	37	95.00

Location	Borehole Ref.	Longitude	Latitude	Depth to First Water Strike (m)	Transmissivity (m^2/d)
Lukole 6	DWD21299	33.3403	2.836	28	-
Mutto Camp 1	DWD21371	33.433	3.1234	18	0.33
Mutto Camp 2	DWD21372	33.4341	3.1293	15	43.92
Ngora	DWD15533	33.2068	3.16	21	-
Okwodoko	DWD24098	33.1664	3.1616	54	16.30
Olung	DWD22698	33.3656	2.9202	36	11.60
Omia Pacwa 1	DWD21373	33.44	3.19	36	0.86
Omia Pacwa 11	DWD21766	33.44	3.19	42	0.22
Omia Pacwa 12	DWD21767	33.44	3.19	66	2.78
Omia Pacwa 13	DWD21768	33.44	3.19	47	4.62
Omia Pacwa 14	DWD21769	33.4408	3.1896	42	9.34
Omia Pacwa 2	DWD21374	33.44	3.19	45	0.71
Pacer (barracks	DWD24099	33.3273	2.9822	21	59.68
Pacer (school)	DWD23554	33.3294	2.9854	27	34.31
Pakor	DWD25154	33.3749	3.0884	6	0.75
Toroma 1	DWD23524	33.2718	3.0923	18	10.00
Toroma 2	DWD23526	33.271	3.0916	27	46.00
Toroma 3	DWD23527	33.2713	3.0902	21	12.00
Wangomuka	DWD20486	33.3751	3.0337	21	0.43
Wangwiny	DWD20483	33.3746	3.037	21	0.88
Wol 2	DWD21376	33.2293	3.1231	42	3.35