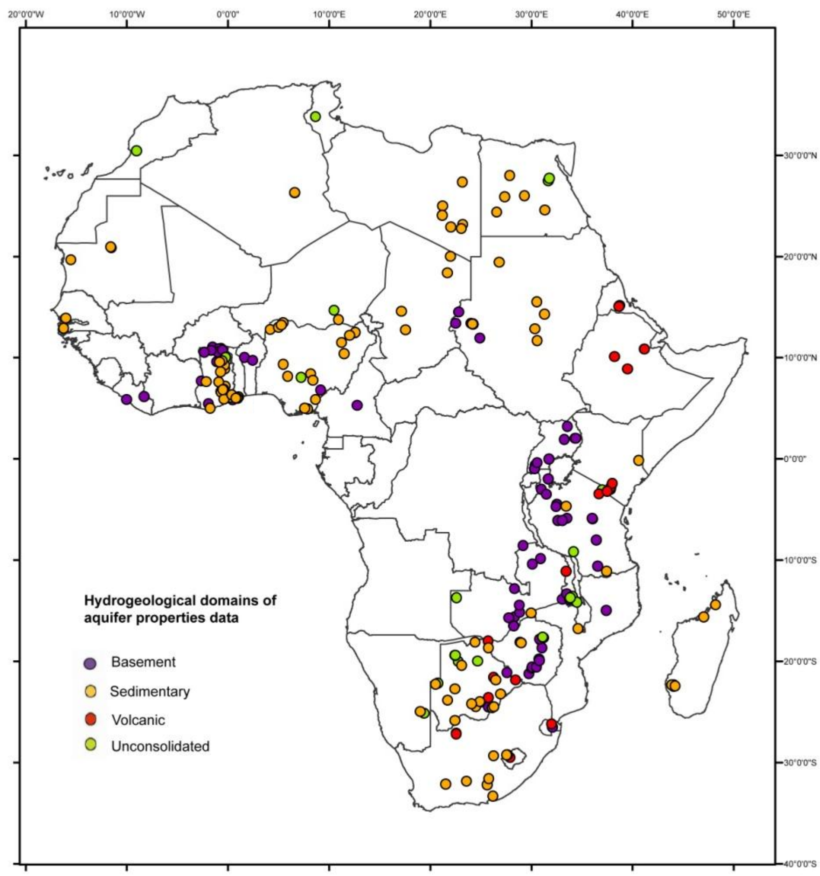
Groundwater and climate change in Africa: review of aquifer properties data

Groundwater Science Programmes

Internal Report IR/10/076



BRITISH GEOLOGICAL SURVEY

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INTERNAL REPORT IR/10/076

Groundwater and climate change in Africa: review of aquifer properties data

H C Bonsor and A M MacDonald

Keywords

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British Geological Survey offices

BGS Central Enquiries Desk

Tel 0115 936 3143 Fax 0115 936 3276

email enquiries@bgs.ac.uk

Kingsley Dunham Centre, Keyworth, Nottingham NG12 5GG

Tel 0115 936 3241 Fax 0115 936 3488
email sales@bgs.ac.uk

Murchison House, West Mains Road, Edinburgh EH9 3LA

Tel 0131 667 1000 Fax 0131 668 2683
email scotsales@bgs.ac.uk

Natural History Museum, Cromwell Road, London SW7 5BD

Tel 020 7589 4090 Fax 020 7584 8270
Tel 020 7942 5344/45 email bgslondon@bgs.ac.uk

Columbus House, Greenmeadow Springs, Tongwynlais, Cardiff CF15 7NE

Tel 029 2052 1962 Fax 029 2052 1963

Maclean Building, Crowmarsh Gifford, Wallingford OX10 8BB

Tel 01491 838800 Fax 01491 692345

Geological Survey of Northern Ireland, Colby House, Stranmillis Court, Belfast BT9 5BF

Tel 028 9038 8462 Fax 028 9038 8461

www.bgs.ac.uk/gsni/

Parent Body

Natural Environment Research Council, Polaris House, North Star Avenue, Swindon SN2 1EU

Tel 01793 411500 Fax 01793 411501
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Foreword

In 2010 the Department for International Development (DFID) commissioned a BGS-led team to undertake a one-year study aimed to improve understanding of the resilience of African groundwater to climate change and links to livelihoods. As part of this project, the research team undertook hydrogeological field studies in West and East Africa, examined the linkages between water use and household economy, and developed an aquifer resilience map for Africa using existing hydrological maps and data. This is one of a series of progress reports written for the project partners and steering group to help discussion.

This report describes the methodology and results of a systematic review of existing aquifer properties data from Africa, undertaken within the one-year project. The compiled data were used to attribute an aquifer properties map developed within the project. The data review was also one of a series of components within the project, which was used to strengthen the evidence base between climate change and aquifer resilience.

Acknowledgements

As with all projects we would like to thank are a number of BGS and external colleagues for their help and assistance:

Jeff Davies (BGS) for his invaluable assistance in sourcing grey literature, containing aquifer properties studies, and much data collated through his work with BGS.

The Project Steering Group, for their general comments and helpful insight with this work – Guy Howard (DFID); Stephen Foster (GWMATE); Mike Edmunds (UoOx), Declan Conway (UAE); Richard Carter (WaterAid); Vincent Casey (WaterAid); Richard Harding (CEH) and Tamiru Abiye (University of Witwatersrand, Johannesburg).

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1 Introduction

The review of aquifer properties data from Africa was conducted as part of a one year DFID-funded research programme, aimed at improving understanding of the impacts of climate change on groundwater resources and local livelihoods – see http://www.bgs.ac.uk/GWResilience/. The review was one of a series of components within the project, which was used to strengthen the evidence base between climate change and aquifer resilience. The overall outputs of the project were:

- **Two hydrogeological case studies in West and East Africa** – which assess the storage and availability of groundwater in different aquifers across different climate zones in Africa
- **A water use and livelihood case study** (analysis of Water Economy and Livelihoods (WELs) data, Ethiopia) – examining the linkages between water use and household economy
- **A review** of hydrogeological data for Africa
- **A map** of groundwater resilience to climate change in Africa

Data collated within the review were used to attribute an aquifer properties map of Africa. In total, 280 sets of aquifer properties data in Africa have been identified from 145 published and grey literature reports. This report is a progress report for the project partners and steering group to help discussion. The report describes the criteria used to identify and systematically review the studies. An initial analysis of the data is also provided in this report.

The relatively few studies identified by the review reflect the paucity of hydrogeological data within Africa. Quantitative aquifer properties data – transmissvity (T) and storage (S) data – are scarce within Africa, and as a result, this review compiled borehole yield data and qualitative review studies, as well as actual aquifer properties data.

2 The review of aquifer properties data in Africa

2.1 A COMPREHENSIVE REVIEW

Quantitative aquifer properties data – transmissvity (T) and storage (S) – are highly scarce for Africa, and often within grey literature. Due to scarcity of aquifer properties data in Africa, this review compiled borehole yield data and qualitative review studies, as well as actual aquifer properties data, so that the review was as comprehensive as possible.

2.2 THE SEARCH CRITERIA

Most of the studies identified by the review were found from an extensive web search using several of the main search engines – Web of Science, Science Direct, Google, Google scholar and Google books. The web search criteria utilised are outlined in Appendix 1. Each search generally pulled up between 5 000 and 30 000 hits (up to 100,000 hits), from which 1-4 aquifer properties studies might be sourced. Aquifer properties studies were identified from the web search results, using the following sifting approach:

- the title of item included the word "groundwater" or directly relates to groundwater potential, aquifers or aquifer parameters
- the title of item includes, or refers to, a geographic location or aquifer in Africa
- the item is within published scientific literature, or downloadable grey literature (e.g. a United Nations report, or a USGS technical document)

In general, only the first 100 hits were found to be relevant to any one search.

An initial sift of the studies identified was used to exclude any reports which did not:

- contain at least some information (qualitative or quantitative) relating to aquifer properties
- include some description of the geology

In addition to the web, aquifer properties data studies and databases (e.g. regional yield databases) were identified within grey literature (e.g. BGS field data reports, country water ministry reports) through individual researchers and organisations known to the project team. The same inclusion criteria were applied to the results of these more focused searches, as were to the web searches (see above). The review of grey literature is not exhaustive, and only the most accessible data and databases (e.g. BGS and WaterAid data) were included within this review. Future work would expand the grey literature review.

In total 280 aquifer properties datasets were identified from 145 reports in peer-reviewed and grey literature.

2.3 THE CONFIDENCE CRITERIA

A confidence rank was applied to all studies included within the review using set criteria (Tables 1 and 2). Due to the scarcity of T and S data within Africa, both yield data (used as a proxy for

T) and qualitative review studies – have been included within this review. Separate confidence criteria were applied to accommodate the qualitative and quantitative data types reviewed. In general, highest confidence was assigned to the data studies which provide reliable quantitative aquifer properties data (T and S), and regional qualitative review studies with a strong evidence-base.

1. *Data studies*

High confidence (1-2) was assigned to the data studies which estimate aquifer properties from: controlled pumping tests of more than 5 hours duration with observation boreholes (Table 1); from a large sample base (>20 boreholes); display at least some raw pumping test data; and include description of the regional geology and methods.

Moderate confidence (3-4) was assigned to aquifer properties data which are: derived from pumping tests of <5 hours duration; derived from a small sample base; or include insufficient information on the geology or methodology used. Modelled aquifer properties data were also evaluated to be of moderate confidence, due to lack of reliable hydrogeological field data available to develop and calibrate the models at an appropriate scale.

Low confidence (5) was assigned to aquifer properties data if: there is limited information on the methodology or geology of the study area; or, if there is no attempt to validate modelled aquifer properties data.

Studies were only excluded from the review if:

- the methodology of the study would lead to significant error in the derived aquifer properties estimates – e.g. if pumping tests were <1 hour duration;
- the source of the aquifer properties data was unknown;
- the geology of the study area was unknown; or
- there were gross errors in data interpretation – e.g. the derived data mean was outside the data range.

2. *Yield data*

Due to the scarcity of T and S data within Africa, yield data were included in the review as a proxy of T. Yield data are more widely available than T and S data in Africa, and have been shown to be a useful proxy for T data in various hydrogeological domains (e.g. Graham at al. 2009; Banks et al. 2005). Inclusion of the yield data ensured a much better spatial distribution of data, and the approach was found to be particularly useful in areas of low data availability. The data were assigned a lower confidence (3-4) than aquifer properties data. Table 1 outlines the criteria used to review yield data.

3. *Qualitative review studies*

Qualitative review studies of a hydrogeological domain, regional hydrogeology, or specific aquifers, were some of the most useful information sources identified by the review. Review studies, by their nature, are based on a wide range of data and field experience and as a result can provide more reliable geological and hydrogeological information than a small sampling survey. Whilst review studies often do not give quantitative aquifer properties data, they can provide a valuable description of how an aquifer system works.

Table 2 outlines the criteria used to review these studies. Highest confidence (1) was assigned to studies which include and reference several (>2) data sources for an aquifer or region, and provide a valuable overview of how the aquifer system works.

Confidence	Confidence rank	Criteria
High	1	• Aquifer properties data (T and S) are derived from controlled pumping tests (>5 hr duration) with observation boreholes; • Large sample base (>20 sites); • Good description of field methods, including raw data; • Description of site including geology and source *Plus any of the following:* • Inclusion of yield data within study, as a proxy comparison to pumping test data; • Recent study (T, S estimates <10 years old)
High-Medium	2	• Aquifer properties data (T only) are derived from controlled pumping tests >5 hr duration, but no observation boreholes; • Large sample base (>20 sites); • Good description of field methods; • Description of geology and source *Plus any of the following:* • Raw pumping test data • Comparison of study results, to other work within region; • Inclusion of yield data within study, as a proxy comparison to pumping test data; • Recent study (T estimate <10 years old)
Medium	3	• Aquifer properties data (T only) are derived from pumping tests (some <5hr duration), but little known to methods; *And/or:* • Aquifer properties data derived from production yields of boreholes and wells, *Plus 2 of the following:* • Small sample base within recharge area (<20); • Summary data only; • Some qualitative hydrogeological data ; • Limited description of geology and source; • Comparison of study results, to other work within region; • Inclusion of yield data within study, as a proxy comparison to pumping test data; • Modelled data, using sufficient accurate hydrogeological field-data; • Recent study (T estimate <10 years old)
Medium-Low	4	• Aquifer properties data derived from production yields of boreholes and wells, but no information to methods; • Summary data only, and small sample base; *Or:* • Modelled aquifer properties data, based on insufficient

		accurate field-data; *Plus any of the following:* • Small sample base (<20); • Limited description of geology and source; • No comparison of study results, to other work within region; • Dated study (>10 years)
Low	5	• The parameter is modelled, based on little, or no, accurate hydrogeological field-data • No comparison of study results, to other work within region, or proxy yield data; *Plus any of the following:* • Small sample base (<20); • Summary data only; • Little, or no, description of field or modelling methodology; • Limited description of the geology; • Dated study (>10 years)

Table 1 – Confidence criteria applied to data studies.

Confidence	Confidence rank	Criteria
High	1	• Qualitative hydrogeological information relating to a hydrogeological domain, or specific aquifer; • Strong evidence-base to review (several data sources); • Good description of data sources, and the methodology behind summary aquifer properties data; • Description of geology and source *Plus any of the following:* • Inclusion of yield data, comparison to summary T and S data; • Recent review (<30 years old)
Medium	2	• Qualitative information on the regional hydrogeology, the hydrogeological domain, or specific aquifer; • Moderate evidence base to review (max. 2 data sources); • Smaller review area; • Some description of data sources, but limited information to methodology of data *Plus any of the following:* • Inclusion of yield data, or modelled data, comparison to summary T and S data; • Recent data reviewed (<30 years old)
Low	3	• Limited qualitative information on the regional hydrogeology, the hydrogeological domain, or specific aquifer; • Weak evidence base (one data source), with limited, or no information to data sources and methodology; • Geographically small review area

Table 2 – Confidence criteria applied to aquifer review studies.

3 Aquifer properties data identified

In total, 280 aquifer properties studies from Africa were identified from 145 reports in peer-reviewed and grey literature. These studies provide data for many of the major sedimentary basins and basement aquifer domains in Africa, but there are limited aquifer properties data (quantitative or qualitative) for central and western Africa (e.g. the Taoudeni Basin) and from volcanic hydrogeological domains – Fig. 1. High confidence (1-2) data are scarce (only 18% of studies reviewed), with most (65%) of the identified studies containing either moderate confidence (3) aquifer properties data or qualitative estimates. The full reference list of reviewed aquifer properties studies are listed according to confidence rank in Appendix 2.

Due to the paucity of hydrogeological data within Africa, qualitative review studies and borehole yield data have been included within the review as well as actual aquifer properties data to achieve a better spatial distribution of data. This approach was found to be useful, particularly in regions of poor data availability. The confidence rank, systematically assigned to the data, ensures appropriate emphasis is placed on the different data.

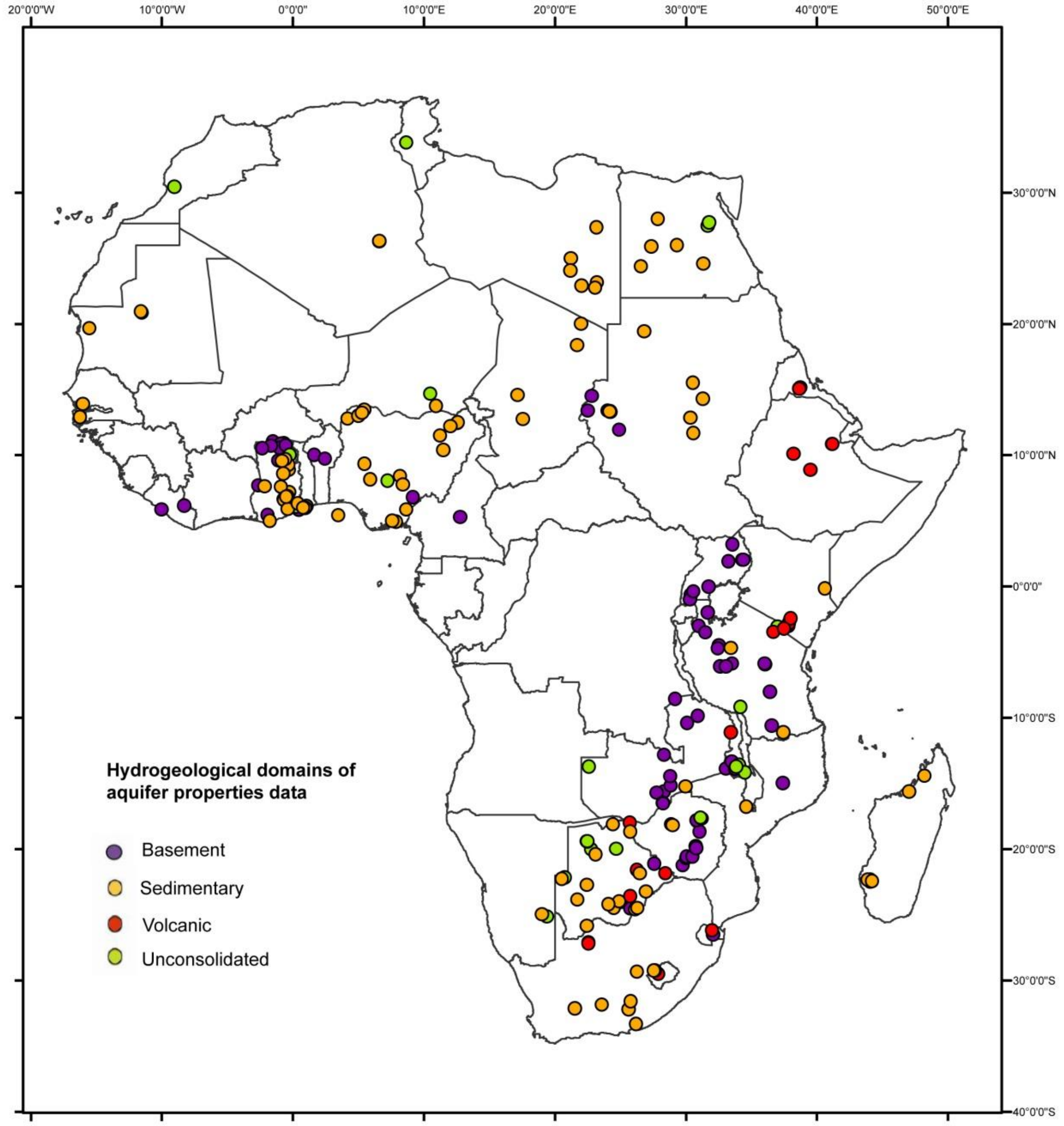

Fig. 1 – Spatial and geological distribution of reviewed aquifer properties data within Africa.

4 Preliminary analysis of yield data

Below we set out a preliminary analysis of borehole yield data collated from successful boreholes in basement geology across Africa.

Yield data are more widely available than T and S data in Africa, and have been shown to be a useful proxy for T data in various hydrogeological domains (e.g. Graham at al. 2009; Banks et al. 2005). The aim of this initial analysis was to see if it is possible to gain an insight, albeit crude, to the main control(s) on borehole yields.

Data sources

Yield data were collated from borehole databases identified during fieldwork by BGS and WaterAid in Africa over the last 15 years. In total, 2206 individual borehole yields within basement geology were identified by this review. Almost all the yield data were georeferenced. Fig. 2 illustrates the spatial distribution and frequency of the yield data.

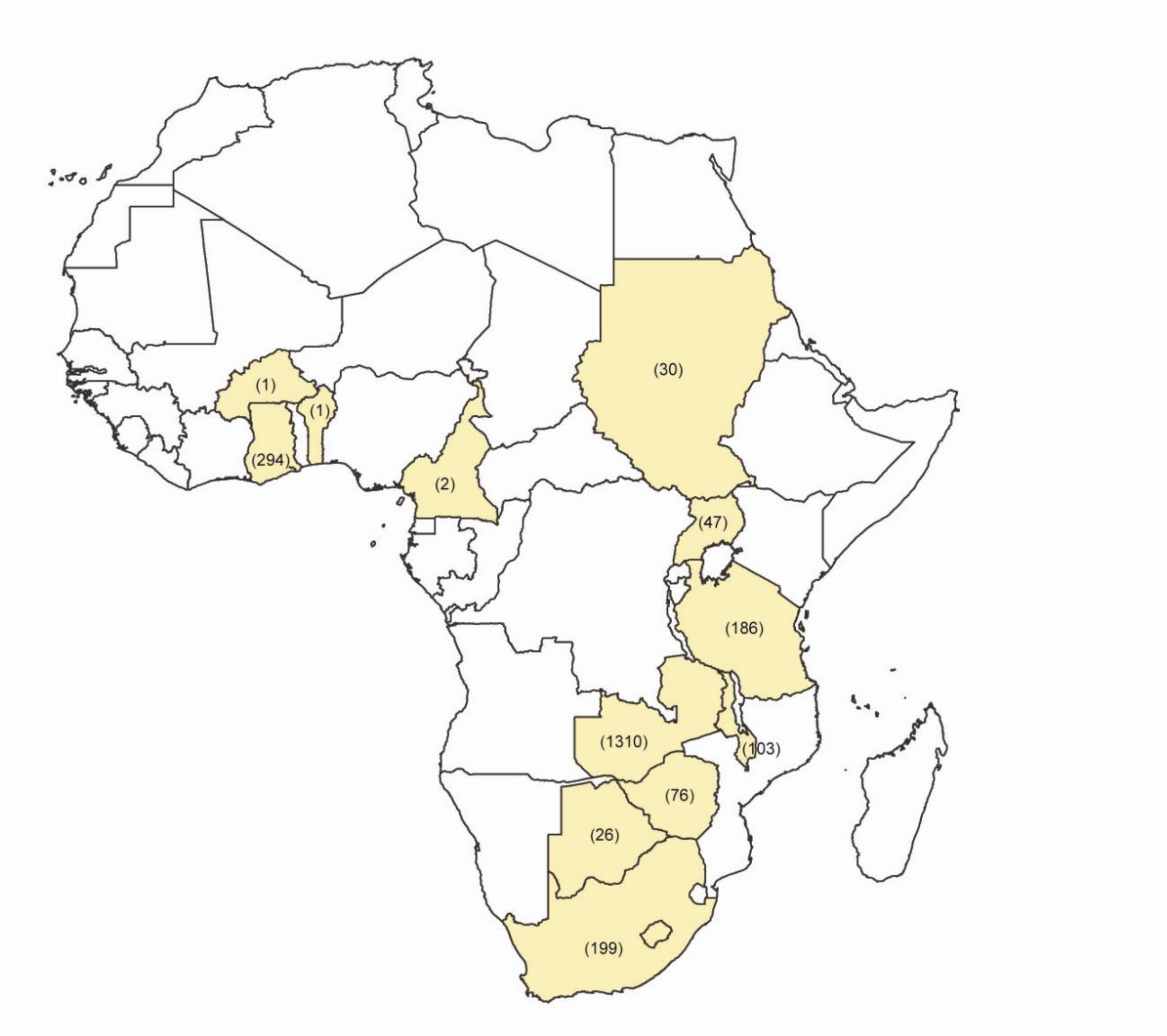

Fig. 2 – Distribution and number of yield data identified within Basement geology across Africa.

Initial analysis

Looking at the entire yield dataset, most basement yield values lie between 0.1 and 5 l/s, and the geometric mean is 0.94 l/s. The yield data display an approximate log normal distribution (Fig. 3), indicating a relatively broad range of yields as would be expected in other geologies – i.e. basement yields are not all low. An approximate log normal distribution of the data is also indicated when the yield data are analysed by rank percentile – Fig. 4. A straight line would be expected if the data were perfectly normally distributed on the log plot of yield rank percentile; the slightly curved line shown for the borehole yields indicates the slight skew to the data – Fig. 4.

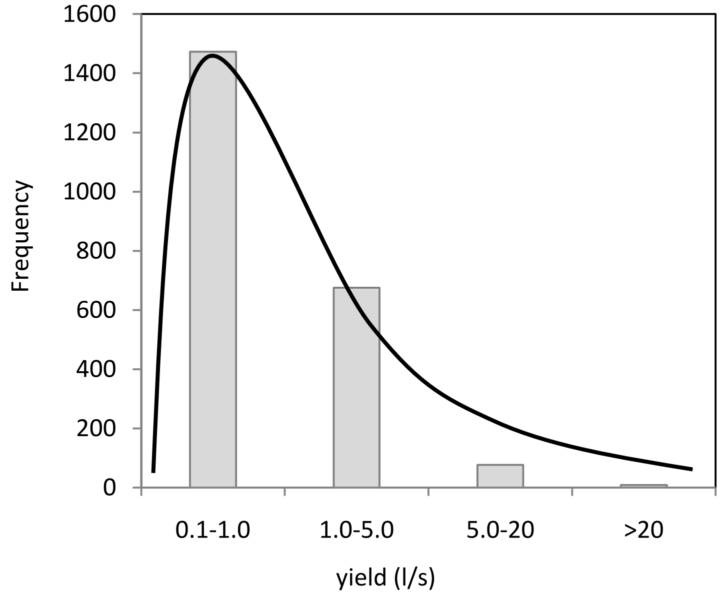

Fig. 3 – Probability distribution of the collated basement yield data. The data has an approximate log normal distribution.

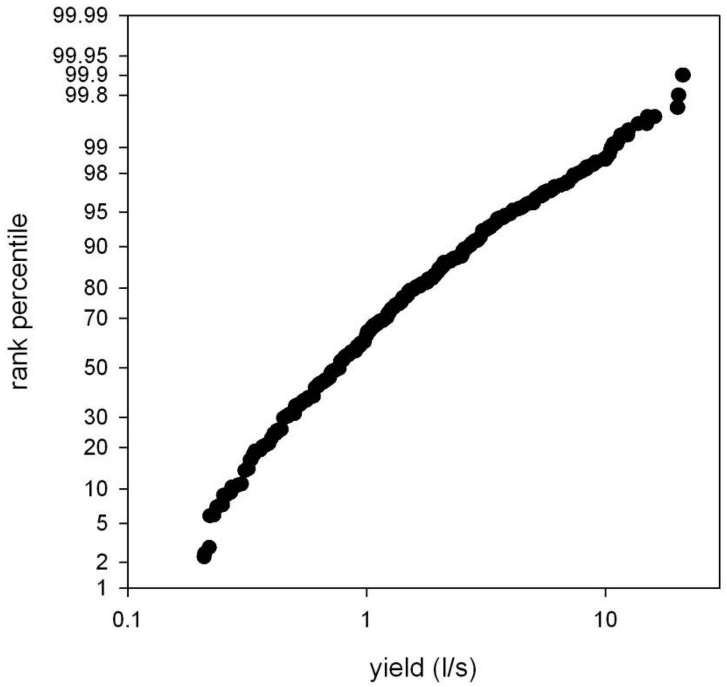

Fig. 4 – Rank percentile analysis of basement yields.

Yield and geology

Fig. 5 shows how borehole yield varies with different basement rock types. The median and interquartile range of yields within gneiss, granite and schists are indicated to be very similar, and the median yield in these rock types is approximately 0.8 l/s – Fig. 5. The probability distribution of the data also indicates a similar spread of yield values between the three rock types – Fig. 6.

The greatest spread of yields and the highest median yield (approx. 1.2/s) is shown within meta-sedimentary rocks. The lowest spread of yields and the lowest median yield (approx. 0.6 l/s) is observed from boreholes within basement regolith. The probability distribution of the yield data from these two rock types is distinct from the other basement rock types – Fig. 6.

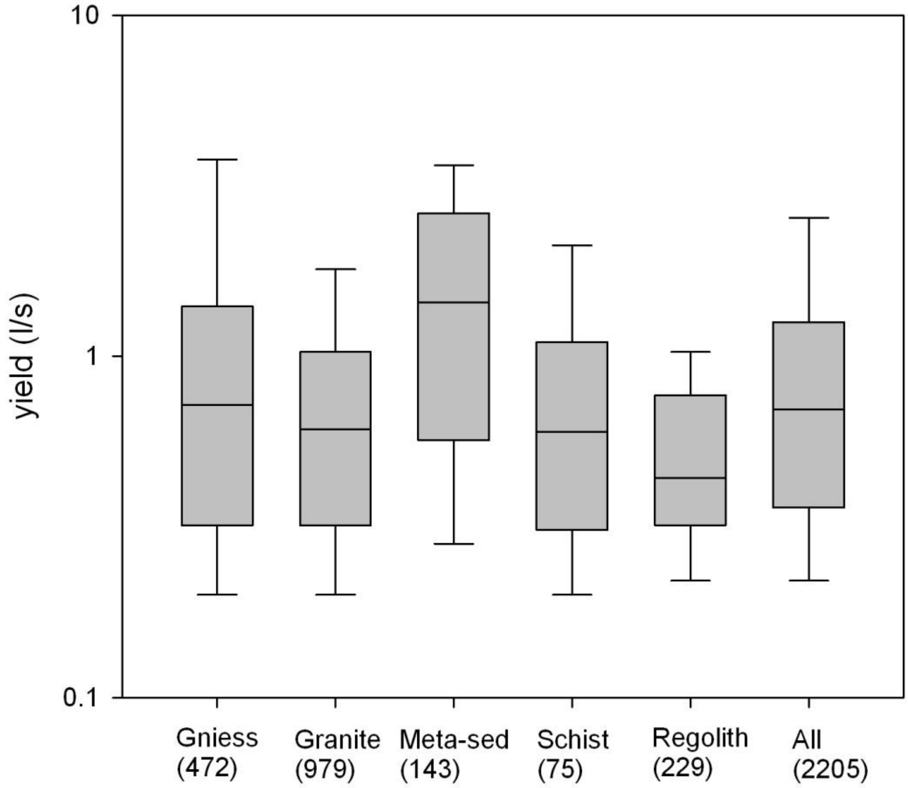

Fig. 5 – Box plot indicating the median and interquartile range of borehole yields within different basement rock types in Africa. The range displayed excludes outlier yields – the lowest value is still within 1.5 of the interquartile range of the lower quartile, and the highest datum is still within 1.5 of the upper quartile. Sample size is indicated by the numbers in brackets.

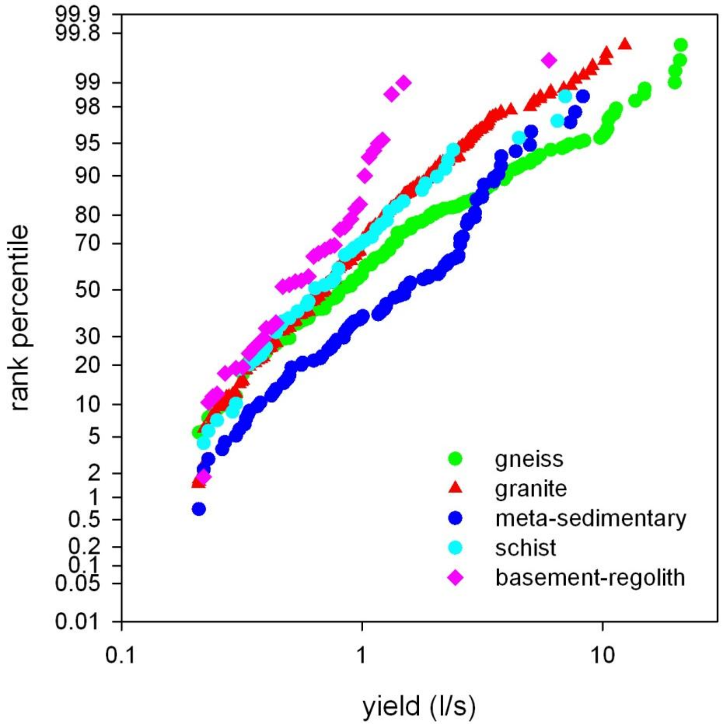

Fig. 6 – Rank percentile analysis of basement yield according to rock types.

Yield and climate

Fig. 7 shows how the collated basement yields (across all basement rock types) vary with climate. Fig. 8 shows how the yield data vary with climate according to different basement rock types.

In most basement rock types a slightly greater spread of yields and a higher median yield is observed in tropical wet regions (where annual rainfall exceeds 1000 mm/yr), than in seasonally wet regions (annual rainfall 500-1000 mm/yr) – Fig. 8. The exception to this is within schistose basement rock, where a higher median yield and a greater spread of yields is indicated within semi-arid climatic regions (annual rainfall <500 mm/yr) – Fig. 8. This trend is also indicated when yield data is collated for all basement rock types (Fig. 7) – however, the sample base for semi-arid regions is small.

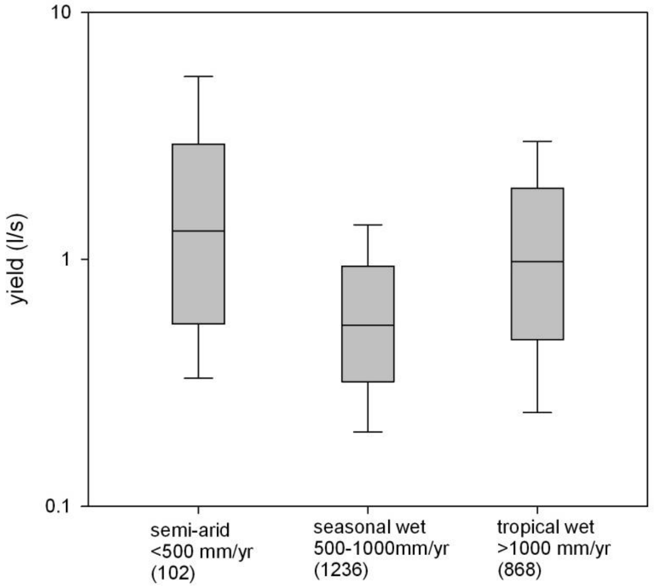

Fig. 7 – Variation in basement yields with climate, across all basement rock types**.**

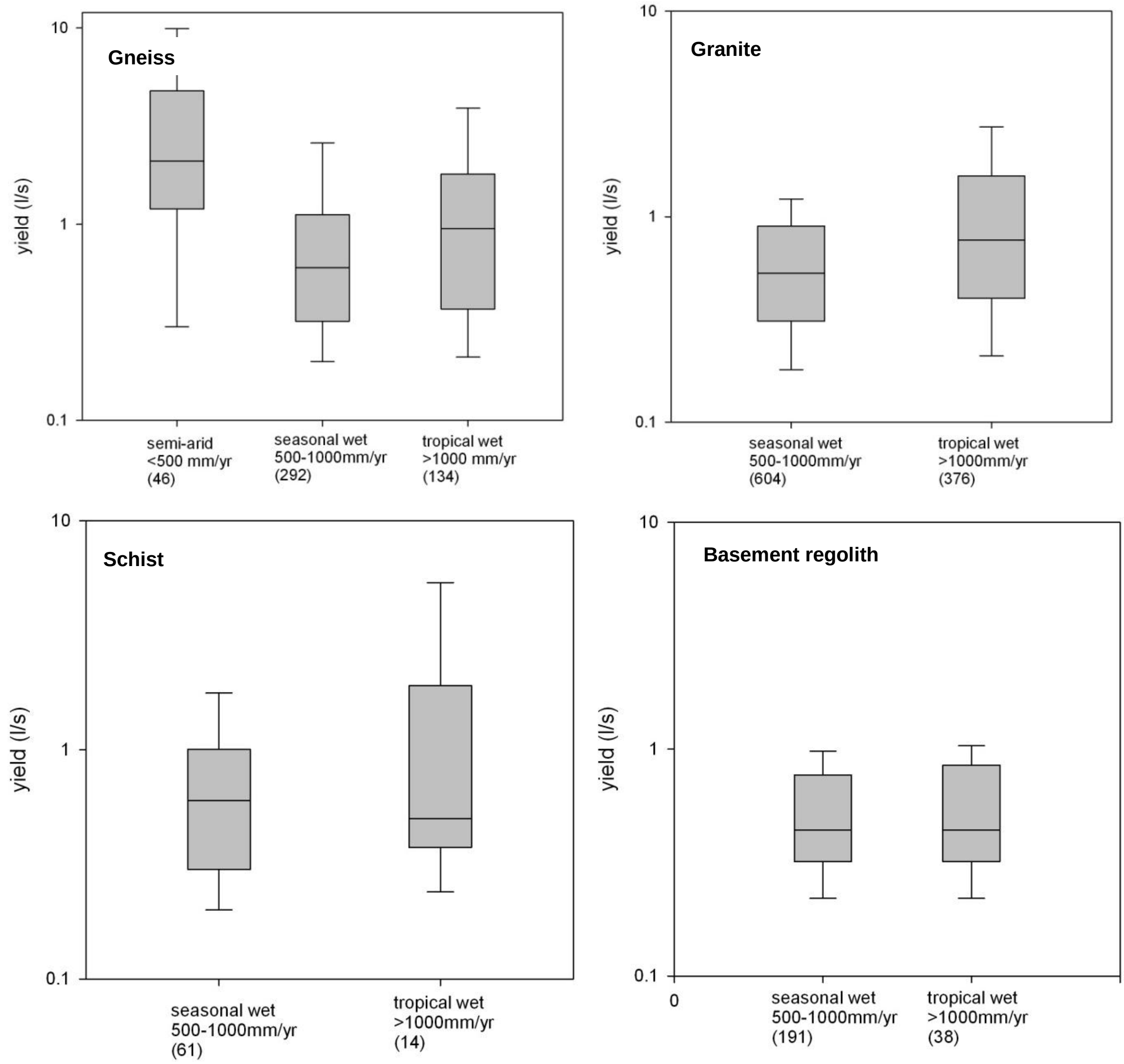

Fig. 8 – Variation in basement yields with climate, in different basement rock types**.**

Sampling bias and limitations

Results from this analysis should not be over-interpreted. Whilst the data provide a useful preliminary assessment into the controls on yield, there are clear limitations.

- The yield data are derived predominantly from seasonally wet or wet climate zones in Africa (Fig. 7) – i.e. in areas where average annual rainfall exceeds 500 mm/yr and where there are less than 6 dry months in a year. The yield data should not, therefore, be treated as typical yields for basement rocks in semi-arid regions.
- Different weathering of basement rocks in different climate zones might cause a basement rock type (e.g. 'granite) to differ significantly between climate zones. Comparison of yield data for a basement rock type (e.g. 'granite') across different climate zones should not, therefore, be over-interpreted.
- Yield data were analysed from successful boreholes. The yield data may therefore overestimate the productivity of basement geology.
- Borehole yields in Africa are often limited by the capacity of borehole pumps. The yield data may therefore underestimate the productivity of the basement aquifers where boreholes are successful.

References

British Geological Survey holds most of the references listed below, and copies may be obtained via the library service subject to copyright legislation (contact libuser@bgs.ac.uk for details). The library catalogue is available at: http://geolib.bgs.ac.uk.

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GRAHAM, M.T., BALL, D.F., Ó DOCHARTAIGH B.É. and MACDONALD, A.M. (2009), Using transmissivity, specific capacity and borehole yield data to assess the productivity of Scottish aquifers, *Quarterly Journal of Engineering Geology and Hydrogeology*, 42; 227-235.

Appendix 1

Table of search criteria used to identify aquifer properties data studies within web searches.

Search engine	**Search criteria**
Google, Google Scholar, and Google Books	Groundwater + Chad basin Aquifer + Chad Basin Pumping test + Chad Basin Groundwater + Kufra Basin Groundwater + Upper Nile Basin Groundwater + Senegal basin Senegal Basin aquifer Groundwater + Volta basin Groundwater + Taoudeni basin Groundwater + Iullemeden basin Groundwater + Sokoto Basin Groundwater + Congo Basin Groundwater + DRC basin Groundwater + Zaire Basin Congo aquifer Central Africa + groundwater Central Africa aquifers Groundwater + West African Coastal Basin West Africa coastal aquifers Groundwater + East Africa coastal basins East Africa coastal aquifers Groundwater + Kalahari basin Kalahari recharge Kalahari water supplies Groundwater + Karoo basin Karoo aquifer + groundwater Karoo aquifer basin Karoo water
Web of Science and Science Direct	Groundwater + Chad basin Aquifer + Chad Basin Pumping test + Chad Basin Groundwater + Kufra Basin Groundwater + Upper Nile Basin Groundwater + Senegal basin Senegal Basin aquifer Groundwater + Volta basin Groundwater + Taoudeni basin Groundwater + Iullemeden basin Groundwater + Sokoto Basin Groundwater + Congo Basin Groundwater + DRC basin Groundwater + Zaire Basin Congo aquifer Central Africa + groundwater Central Africa aquifers Groundwater + West African Coastal Basin West Africa coastal aquifers Groundwater + East Africa coastal basins East Africa coastal aquifers Groundwater + Kalahari basin Kalahari recharge Kalahari water supplies Groundwater + Karoo basin Karoo aquifer + groundwater Karoo aquifer basin

	Karoo water

Appendix 2

Table 1 – References of the aquifer properties data studies reviewed, according to confidence rank. Some references are assigned multiple confidence values – these are review papers or regional studies, which contain aquifer properties data relating to more than one aquifer.

Confidence rank	Study reference
1	Cheney CS, Rutter HK, Farr J and Phofuetsile, P (2006) Hydrogeological potential of the deep aquifer of the Kalahari, southwestern Botswana, QJEGH; 39, 303-312 Davies, J (1978) Jwaneng GW Resources Study - Area A - Final Report, Ministry of Mineral Resources, *unpublished* Jalludin M & Razach M (2004) Assessment of hydraulic properties of sedimentary and volcanic aquifer systems under arid conditions in the Republic of Djibouti (Horn of Africa), Hydrogeology Journal, 12; 159-170.
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