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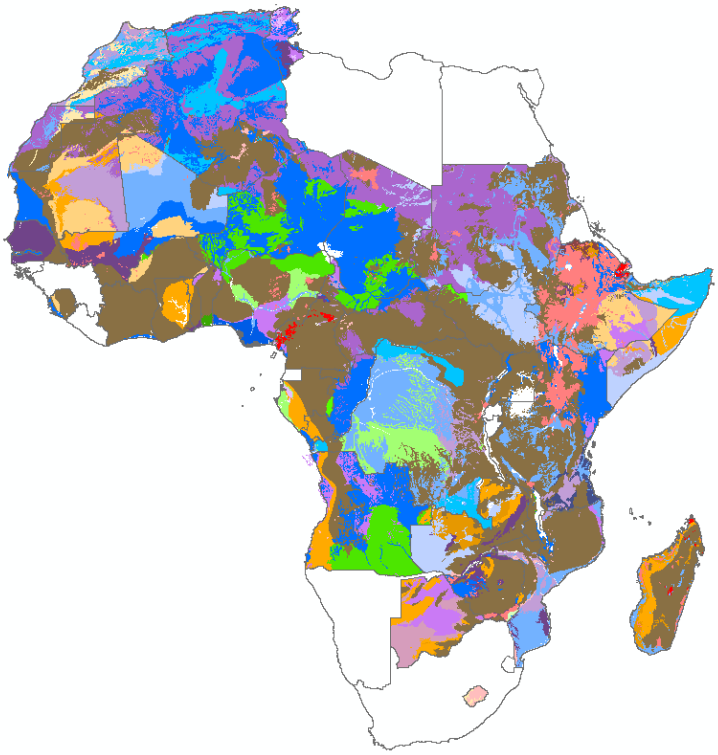
User Guide: Africa Groundwater Atlas Country Hydrogeology Maps, Version 1.1

Groundwater Programme

Open Report OR/19/035



BRITISH GEOLOGICAL SURVEY

GROUNDWATER PROGRAMME

OPEN REPORT OR/19/035

User Guide: Africa Groundwater Atlas Country Hydrogeology Maps, Version 1.1

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Foreword

This report is a published product of the Africa Groundwater Atlas project. This project was jointly funded by DFID, NERC and ESRC; supported by the International Association of Hydrogeologists (IAH); and carried out by the British Geological Survey (BGS) in partnership with hydrogeologists across Africa. It is a part of the Unlocking the Potential of Groundwater for the Poor (UPGro) Research Programme, which focuses on improving the evidence base around groundwater availability and management in sub-Saharan Africa, to enable the sustainable use of groundwater to benefit the poor.

The Africa Groundwater Atlas (referred to in this report as the *Atlas*) is an online resource that provides a summary of the groundwater resources of 51 African countries, and a gateway to further information. The Atlas is available at https://www.bgs.ac.uk/africagroundwateratlas/index.cfm.

The new 1:5 million scale hydrogeology (aquifer type and productivity) and geology (with particular relevance to hydrogeology) maps developed for the Atlas have been released as digital GIS maps for 38 countries in Africa. Version 1.0 of the dataset was released in 2019. Digital maps for a further 10 countries will be released at a later date.

This guide is written for users of these new digital country maps. It describes their format, scale, attributes and content, how they were developed and what underlying datasets they are based on.

A basic appreciation of Geographical Information System (GIS) terminology will help readers understand some of the information given here.

Acknowledgements

The author thanks the many individual co-authors of country pages in the Africa Groundwater Atlas, who advised on the development of these maps. They are referenced on the relevant Atlas country page and also on this page: http://earthwise.bgs.ac.uk/index.php/List_of_Authors.

Thanks are also due to BGS colleagues Jennifer Bow for GIS support with producing the final map shapefiles; Rob Smith and Gerry Wildman for support with licencing and data release; and Kirsty Upton and Melinda Lewis for reviewing this report.

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Summary

This report is the published product of the Africa Groundwater Atlas project. The project was jointly funded by DFID, NERC and ESRC; supported by the International Association of Hydrogeologists (IAH); and carried out by the British Geological Survey (BGS) in partnership with hydrogeologists across Africa. It is a part of the Unlocking the Potential of Groundwater for the Poor (UPGro) Research Programme, which focuses on improving the evidence base around groundwater availability and management in sub-Saharan Africa, to enable the sustainable use of groundwater to benefit the poor.

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This guide is written for users of these new digital country maps. It describes their format, scale, attributes and content, how they were developed and what underlying datasets they are based on.

A basic appreciation of Geographical Information System (GIS) terminology will help readers understand some of the information given here.

1 Background

The Africa Groundwater Atlas country hydrogeology maps (Version 1.0, 2019) are new digital maps produced as part of the UPGro Africa Groundwater Atlas project (referred to in this report as the *Atlas*).

The Africa Groundwater Atlas is an online resource that summarises the hydrogeology and groundwater resources of 51 African countries, and is a gateway to further information. The aim of the Atlas is to improve the availability and accessibility of high quality information on groundwater in Africa. The Atlas is available at https://www.bgs.ac.uk/africagroundwateratlas/index.cfm.

The Atlas includes the Africa Groundwater Literature Archive (available through the main Atlas at the link above, or directly at https://www.bgs.ac.uk/africagroundwateratlas/archive.cfm): a searchable database of literature about groundwater in Africa, including reports, journal articles and conference papers.

1.1 WHAT THE MAPS SHOW

The Atlas country hydrogeology maps provide an overview of the hydrogeology and geology of each of 48 countries in Africa, at 1:5 million scale. This initial release is for 38 countries.

The maps have two themes:

- **geology** with geological categories that reflect significant hydrogeological units (MacDonald et al. 2010); and
- **hydrogeology**, with categories that combine **aquifer type and productivity**. Definitions of aquifer type and aquifer productivity are given in the relevant sections below.

1.2 WHO MIGHT USE THIS DATASET

These maps are likely to be useful to people interested in groundwater resources, hydrogeology or geology of any of the relevant African countries.

1.3 DATASET FORMAT AND HOW TO VIEW THE DATA

The Atlas country hydrogeology maps are provided as free-to-download shapefiles (.shp), also known as ESRI 'shape' format. There is a single shapefile for each country, which contains attribute information for geology and hydrogeology themes in attribute tables.

Each shapefile is provided with layer files with legends for geology and hydrogeology, in English and, for selected countries, also in French or Portuguese.

These files can only be viewed in a Geographic Information System (GIS), such as ArcMap, QGIS or MapInfo. GIS software can be purchased from various vendors, and other free-to-use (open source) software is available online.

The maps are available to download at https://www.bgs.ac.uk/africagroundwateratlas/index.cfm.

2 Technical information

2.1 DEFINITIONS

The Atlas country hydrogeology maps provide a summary of the hydrogeology and geology for 48 countries in Africa. A total of 38 country maps have been released in an initial phase. An additional 10 will be released later.

Each map has two themes:

- **geology**, with geological categories that reflect significant hydrogeological units (MacDonald et al. 2010); and
- a **hydrogeology** classification that combines **aquifer type and productivity**.

For three countries in Africa, no Atlas country maps have been developed: Comoros, Namibia and South Africa. This is because:

- for Comoros: the base geology map at 1:5 million scale is not at a high enough resolution to provide useful information for the country.
- For Namibia and South Africa: other digital maps of geology and hydrogeology, developed outside the Africa Groundwater Atlas project, provide better, larger scale information for both these countries, so that developing new Atlas maps with less detail would not be helpful.

2.2 MAP SCALE

The maps provide a national-scale overview for each country, at a nominal scale of 1:5 million. This means that 1 cm on the maps is equivalent to 50 km on the ground. This makes them suitable for viewing at the following maximum sizes:

A2 – for the largest countries in Africa, such as Algeria and the Democratic Republic of Congo

A3 – for countries of a size similar to Sudan and Mali

A4 – for countries of a size similar to Kenya and Zambia

A5 – for countries of a size similar to Ghana and Tunisia

A6 – for the smallest countries in Africa, such as Burundi and Lesotho.

The maps are not suitable for providing detailed information on geology and hydrogeology at a sub-national (e.g. catchment) scale.

2.3 DATA AND ATTRIBUTE FIELD DESCRIPTIONS

Each map shapefile contains at least two attribute fields (Table 1), describing:

- geology, (both bedrock and superficial/unconsolidated geology), with geological categories that reflect significant hydrogeological units (MacDonald et al. 2010); and
- hydrogeology, as a combined classification of aquifer type and aquifer productivity.

Unconsolidated sediments: Three of the country maps (Botswana, Mauritania and Sudan) include an additional, third attribute field that highlights where very extensive unconsolidated sediments (largely dune sands) overlie bedrock (Table 1). For these maps only, the geology attribute field highlights only the underlying bedrock geology. Some other countries in Africa also have extensive covers of unconsolidated sediments, but in Version 1.0 this has not been shown separately, primarily because of: the complexity of displaying three dimensional geology on a two dimensional map; the availability of geological information and understanding; and the need to adapt each country map to reflect national approaches to geological categorisation.

The combination of aquifer type and aquifer productivity to classify the hydrogeology of each country provides a practical description that will be understood by hydrogeologists. Definitions of aquifer type and aquifer productivity are summarised in Tables 2 and 3, including a summary of the map attribute codes describing the combined hydrogeology categories.

Aquifer type is defined in terms of the hydrogeological environment, or the geological characteristics that largely control the nature of groundwater flow and storage in the aquifer. Four main categories have been distinguished, with subdivisions of some of the categories (Table 2). The key feature of the aquifer type classification is the dominant way that groundwater flows through, and is stored in, aquifers: e.g. in weathered zones; as intergranular (or matrix) flow through pores; through fractures; or through karstic (solution-enhanced) features.

Aquifer productivity has been estimated by using borehole yield data as a proxy, which are the most widely available data for aquifers in Africa. Available quantitative borehole yield data from across Africa were synthesised, and six main categories of aquifer productivity were distinguished, based on approximate ranges of yields (in litres/second or L/s) (Table 3). These ranges are assumed to relate to the average yields that would be obtained from a single, effectively sited and developed borehole, to an appropriate depth (which will vary depending on the aquifer type), in the relevant aquifer. In reality in most cases, the aquifer productivity categories used in the Atlas maps are a largely qualitative assessment, because of the scale at which these maps have been developed, the heterogeneity of most of the aquifers, and the limited availability of aquifer properties data. The category codes applied, therefore, often span more than one of the ranges shown in Table 3.

For each country, the hydrogeology codes are described in text form in the associated legend, saved as a layer file.

Table 1 Attribute fields in the Africa Groundwater Atlas country hydrogeology maps

Attribute field heading code	Explanation of attribute values
GLG	Geology: the geological descriptions reflect significant hydrogeological units at a national scale for each country, and where possible reflect geological nomenclature used (at this scale) in each country. The geological descriptions can include some or all of: geological age; lithological description; and whether sediment is consolidated or unconsolidated.
HGComb	Hydrogeology Combined: a combination of Aquifer Type (Table 2) and Aquifer Productivity (Table 3). Formed by: Aquifer Type Code-Aquifer Productivity Code. Some examples are: • *B-L Basement Aquifer – Low Productivity* • *CSF-M/H Consolidated Sedimentary Aquifer dominated by Fracture Flow – Moderate to High Productivity* • *CSIF-M(V) Consolidated Sedimentary Aquifer with mixed Intergranular and Fracture Flow – generally Moderate Productivity but noticeably variable* • *CSIFK-H/VH Consolidated Sedimentary Aquifer with mixed Intergranular and Fracture Flow and Karstic Flow – High to Very High Productivity* • *U-L/H Unconsolidated Sedimentary Aquifer– Low to High Productivity* • *U-H(*) Unconsolidated Sedimentary Aquifer – High Productivity (* denotes further information, which is described in the associated legend/layer file)*
UNCON	Extensive unconsolidated sediments overlying bedrock (currently only for Botswana, Mauritania and Sudan). Mainly aeolian / dune sands.

Table 2 Definitions and descriptions of aquifer type categories

Aquifer Type			
Aquifer type is defined in terms of the hydrogeological environment, or the geological characteristics that largely control the nature of groundwater flow and storage in the aquifer. Four main categories have been distinguished, with subdivisions of some categories.			
Category	**Subcategory**	**Definition**	**Attribute Field Code**
Unconsolidated Sedimentary		Unconsolidated sedimentary aquifers with dominantly intergranular flow	U
Consolidated Sedimentary	Consolidated Sedimentary Fracture	Aquifers with dominantly fracture flow	CSF
	Consolidated Sedimentary Intergranular	Aquifers with dominantly intergranular flow	CSI
	Consolidated Sedimentary Intergranular/Fracture	Aquifers with significant intergranular and fracture flow	CSIF
	Consolidated Sedimentary Karst (sometimes also Consolidated Sedimentary Fracture Karst or Consolidated Sedimentary Intergranular Fracture Karst)	Aquifers with significant karstic features (sometimes also with significant intergranular and/or fracture flow)	CSK (sometimes also CSFK or CSIFK)
Igneous	Igneous Intrusive	Intrusive igneous aquifers, often granitic	I
	Volcanic	Volcanic aquifers	V
Basement		Crystalline basement aquifers with typical weathered/fractured aquifer properties	B

Table 3 Definitions and descriptions of aquifer productivity categories

Aquifer Productivity		
Aquifer productivity is defined based on a synthesis of borehole yield data, which is the most widespread available data for aquifers in Africa. Six main categories have been distinguished, based on **approximate** ranges of yields (in litres/second or L/s). These ranges are assumed to relate to the average yields that would be obtained from a single, effectively sited and developed borehole in the relevant aquifer.		
Category	**Approximate range in yield (L/s)**	**Attribute Field Code**
Very High	> 20	VH
High	5 – 20	H
Moderate	2 – 5	M
Low to Moderate	0.5 – 2	LM
Low	0.1 – 0.5	L
Very Low	< 0.1	VL

2.4 HOW THE ATLAS COUNTRY HYDROGEOLOGY MAPS WERE CREATED

The Atlas country hydrogeology maps were developed by modifying and attributing a digital Africa-wide geology map at 1:5 million scale, using available hydrogeological and geological information.

The 1:5 million scale geology map was originally published by UNESCO (Furon and Lombard 1964), and was digitised by, and is made available through, the USGS (Persits et al., 2002). It can be accessed and downloaded in shapefile format via the USGS (details in References). The digitised geology map includes some linework defining coasts that was created using Esri© data, used with permission of Esri©.

This 1:5 million scale Africa-wide geology map (Furon and Lombard 1964, Persits et al, 2002) was used by the British Geological Survey to develop three Africa-wide quantitative groundwater maps, released in 2012 (Table 4). These are available to download in digital GIS-enabled format (as xyz tab-delimited text files) from the British Geological Survey (https://www.bgs.ac.uk/research/groundwater/international/africanGroundwater/maps.html) and can also be viewed in an online portal hosted by IGRAC (https://www.un-igrac.org/special-project/africa-groundwater-portal). These maps are underpinned by systematic data and literature reviews and case studies. More detail on their development is available on their download webpage (https://www.bgs.ac.uk/research/groundwater/international/africanGroundwater/maps.html) and in a number of documents, particularly MacDonald et al. (2010, 2012), and also Bonsor and MacDonald (2010a, 2010b, 2011).

Table 4 Africa-wide quantitative groundwater maps released by BGS in 2012 (For more information see https://www.bgs.ac.uk/research/groundwater/international/africanGroundwater/mapsDownload.html)

Map	Description
Groundwater (aquifer) productivity	The groundwater productivity map indicates what borehole yields can reasonably be expected in different hydrogeological units. The ranges indicate the approximate interquartile range of the yield of boreholes that have been sited and drilled using appropriate techniques.
Groundwater storage	Groundwater storage was estimated by combining estimates of saturated aquifer thickness and effective porosity of aquifers across Africa. For each aquifer flow/storage type an effective porosity range was assigned based on a series of studies across Africa and surrogates in other parts of the world.
Depth to groundwater	Depth to groundwater was modelled using an empirical rules-based approach, where depth to groundwater was assigned according to rainfall and aquifer type, as well as proximity to rivers.

The Atlas country hydrogeology maps are a further development of the Africa-wide quantitative groundwater maps released in 2012, using the hydrogeological understanding captured in those maps, and where possible incorporating additional geological and hydrogeological information from individual countries. They reflect current understanding of national geology and hydrogeology, given the scale of the geological base map linework and the availability of geological and hydrogeological information and, where possible, they reflect different national approaches to geological and hydrogeological categorisation.

Where possible, the maps have been validated in collaboration with hydrogeologists from the relevant countries who are co-authors on the relevant country pages of the Africa Groundwater Atlas (co-authors are referenced on the relevant Atlas country page and on this page http://earthwise.bgs.ac.uk/index.php/List_of_Authors).

2.4.1 Geology

Where relevant and possible, the geological classifications and descriptions in the Atlas country maps have been developed further from the modified geological base map (Persits et al. 2002) used to create the Africa-wide quantitative maps (MacDonald et al. 2010). Modifications were made to reflect additional geological understanding and nomenclature at a country level. The main modifications made are changes to geological formation names. Less often, changes were made to classifications of geological age or lithology.

2.4.2 Hydrogeology

Where relevant and possible, the aquifer type and aquifer productivity classifications used in the Africa-wide maps have been updated for the Atlas country maps, based on available hydrogeological information and understanding for each country. The main modifications are updates to the hydrogeological classifications based on new and/or more detailed available information at a country scale. Wherever possible, the maps have been validated by co-authors of the relevant country pages. The separate aquifer type and aquifer productivity classifications were combined to produce a new hydrogeological classification, as described in the previous section (*Technical Information: Data and attribute field descriptions*).

2.4.3 Clipping to country boundaries

The maps were clipped to each country using a digital map of country/national boundaries provided by and used with permission of GADM (GADM Version 3.6, country level (Level 0) boundaries).

2.5 MAP LEGENDS

An ESRI layer file (.lyr) accompanies each shapefile, providing legends for both geology and hydrogeology. In future we hope to add legend file types that can be used in GIS software other than ESRI Arc.

The map legends use consistent colours to represent similar geological units (on the basis of geological age and rock type) and similar hydrogeology (on the basis of aquifer type). Within the legend colours used for the hydrogeology maps, stronger (brighter) colours represent higher productivity aquifers and weaker (paler) colours represent lower productivity aquifers. The colours used for any individual geological unit or aquifer in one country are not necessarily identical to those for a similar aquifer in another country, but it is intended that similar enough colours have been used to allow more easy comparison between similar hydrogeological environments in different countries. A summary of the general legend colour schemes is given in Table 5.

Table 5 Summary of colour schemes for geology and hydrogeology legends

Geology	
General geological age / rock type	***Indicative colour***
Quaternary unconsolidated	Blue
Tertiary or Tertiary-Quaternary undivided sedimentary (often dominantly unconsolidated)	Yellow
Cretaceous sedimentary (also sometimes Upper Mesozoic-Tertiary)	Light Green
Early Mesozoic sedimentary	Mid Green
Palaeozoic sedimentary	Dark Green
Karstic sedimentary or limestone (where differentiated)	Turquoise
Volcanic (all ages)	Bright Red
Igneous intrusive or undivided	Mid Red
Precambrian basement undifferentiated or craton	Mid Brown
Precambrian Mobile/Orogenic Belt	Dark Brown
Precambrian metasedimentary	Pale Pink
Precambrian metavolcanics	Purple
Hydrogeology	
Within these legend colours, stronger (brighter) colours represent higher productivity aquifers and weaker (paler) colours represent lower productivity aquifers.	
Aquifer type	***Indicative colour***
Unconsolidated sedimentary	Blue
Consolidated Sedimentary Fracture	Orange
Consolidated Sedimentary Intergranular	Green
Consolidated Sedimentary Intergranular/Fracture	Purple
Consolidated Sedimentary Karst	Turquoise
Igneous (Intrusive or Volcanic)	Red
Basement	Brown

2.6 COVERAGE

Africa Groundwater Atlas country hydrogeology maps, Version 1.0, are currently available for 38 countries, as shown in Figure 1 and Table 6.

Figure 1 Countries for which Africa Groundwater Atlas country hydrogeology maps (Version 1.0) are available

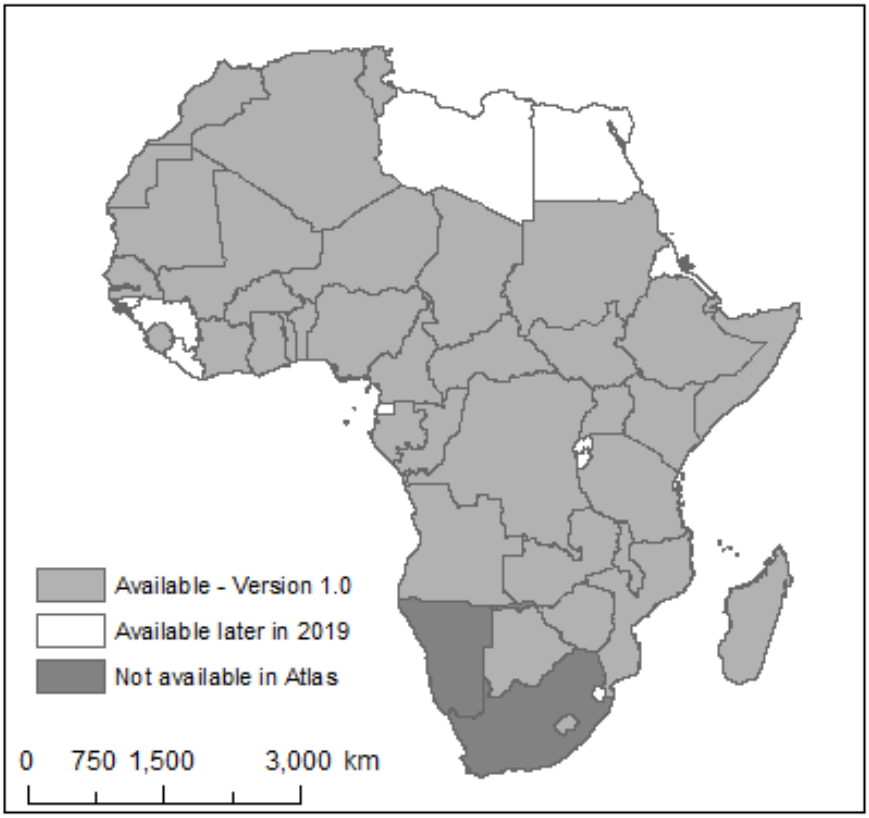

Table 6 Countries for which Africa Groundwater Atlas country hydrogeology maps (Version 1.0) are available, with legend language

Country	Legend Language[1]
Algeria	E, F
Angola	E, P
Benin	E, F
Botswana	E
Burkina Faso	E, F
Cameroon	E, F
Central African Republic	E, F
Chad	E, F
Cote d'Ivoire	E, F
Democratic Republic of the Congo	E, F
Djibouti	E, F
Ethiopia	E
Gabon	E, F
Gambia	E
Ghana	E
Kenya	E
Lesotho	E
Madagascar	E, F
Malawi	E
Mali	E, F
Mauritania	E, F
Morocco	E, F
Mozambique	E
Niger	E, F
Nigeria	E
Republic of the Congo	E, F
Senegal	E, F
Sierra Leone	E
Somalia	E
South Sudan	E
Sudan	E
Tanzania	E
Togo	E, F
Tunisia	E, F
Uganda	E
Western Sahara	E, F
Zambia	E
Zimbabwe	E

[1] E = English/anglais; F = French/français; P = Portuguese/Português

2.7 LIMITATIONS

The Atlas country hydrogeology maps provide a national (country) scale overview of the hydrogeology and geology, with geological categories that reflect significant hydrogeological units. They are suitable for viewing at sizes from A2 down to A6, depending on the size of the country (see the section Map Scale, above). They are not suitable for providing detailed information on geology and hydrogeology at a sub-national (e.g. catchment) scale.

Like all maps, the country hydrogeology maps are a two-dimensional representation of the complex three-dimensional hydrogeological reality. In most cases, the maps show the uppermost aquifer only. If there are other aquifers at depth, these are not shown. In some cases, where a major aquifer is overlain by relatively low permeability unconsolidated sediments (that don't form an important aquifer), the overlying unconsolidated sediments are not shown on the map.

The maps reflect current understanding of national geology and hydrogeology, given the scale of the geological base map linework and availability of geological and hydrogeological information.

Because the maps reflect hydrogeological and geological terminology used in individual countries, the names and descriptions of hydrogeological or geological units that cross country (national) borders may not agree on both sides of the border (resulting in some country border 'edges' that have different colours/attribution).

The maps do not necessarily show the same information as other hydrogeology or geology maps available for any country.

2.8 FUTURE DEVELOPMENT

The Atlas country hydrogeology maps (Version 1.0) may be updated in future. Any future updates will be made via the BGS website and supporting information provided.

2.9 FEEDBACK

Feedback from users is always welcome. Please provide any feedback, and report any errors or problems, to AfricaGwAtlas@bgs.ac.uk .

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GADM

The Africa Groundwater Atlas Country Hydrogeology Maps were clipped to each country using the country level (level 0) boundaries of GADM Version 3.6, used with permission of GADM.

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: https://envirolib.apps.nerc.ac.uk/olibcgi.

Bonsor H C and MacDonald A M. 2010a. *Groundwater and climate change in Africa : review of aquifer properties data.* British Geological Survey Internal Report IR/10/076. http://nora.nerc.ac.uk/id/eprint/501776/

Bonsor H C and MacDonald A M. 2010b. *Groundwater and climate change in Africa : review of recharge studies.* British Geological Survey Internal Report IR/10/075. http://nora.nerc.ac.uk/id/eprint/501776/

Bonsor H C and MacDonald A M. 2011. An initial estimate of depth to groundwater across Africa. British Geological Survey Open Report OR/11/067. http://nora.nerc.ac.uk/id/eprint/17907/

Furon R and Lombard J. 1964. Explanatory note: Geological Map of Africa (1/5,000,000) / Note explicative: carte geologique de l'Afrique (1/5,000,000). UNESCO and the Association for African Geological Surveys (ASGA). UNESCO, Paris, 1964.

MacDonald A M, Ó Dochartaigh B É, Bonsor H C, Davies J and Key R. 2010. *Developing quantitative aquifer maps for Africa.* British Geological Survey Internal Report IR/10/103. http://nora.nerc.ac.uk/id/eprint/501779/

MacDonald A M, Bonsor H C, Ó Dochartaigh B É and Taylor R G. 2012. Quantitative maps of groundwater resources in Africa. *Environmental Research Letters*, 7 (2), 024009. https://doi.org/10.1088/1748-9326/7/2/024009

Persits F, Ahlbrandt T, Tuttle M, Charpentier R, Brownfield M, and Takahashi K. 2002. Map showing geology, oil and gas fields and geologic provinces of Africa, Ver 2.0. USGS Open File report 97-470 A.

USGS. 2002. Surficial geology of Africa (geo7_2ag). Shapefile for download. https://certmapper.cr.usgs.gov/geoportal/catalog/search/resource/details.page?uuid=%7BC7E34C48-9BD9-45C6-AD08-E549CFB3715A%7D . Accessed 11 March 2019.