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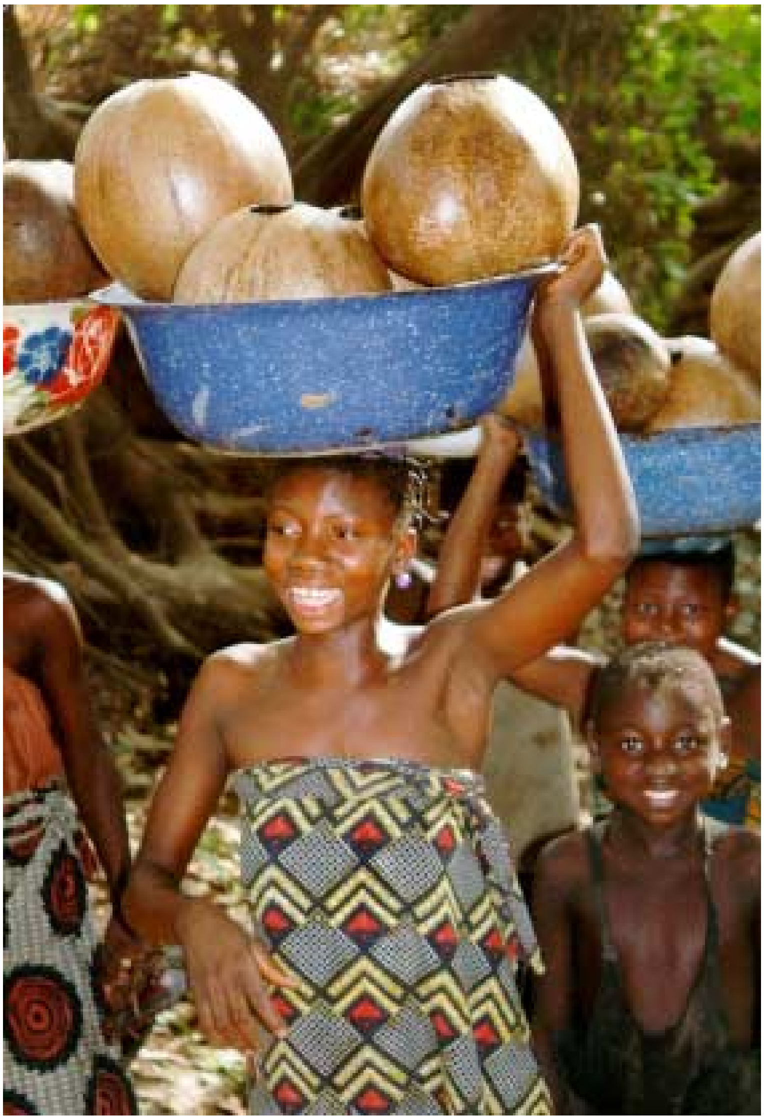
TECHNICAL REPORT WC/00/33
Overseas Geology Series

A brief review of groundwater for rural water supply in sub-Saharan Africa



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A Brief Review of Groundwater for Rural Water Supply in Sub-Saharan Africa

WEBSITE QUESTION 3

How does one set about assessing groundwater and then siting wells and boreholes for a rural water supply, especially in a developing country where resources are limited?

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A M MacDonald and J Davies

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Front cover illustration: collecting water in Benue State, Nigeria.

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Technical Glossary

Agglomerate	A volcanic rock made of angular pieces of rocks from explosive volcanic eruptions.
Aquifer	A rock formation that contains sufficient groundwater to be useful for water supply.
Basalt	A black igneous rock, normally the major component of lava flows.
Borehole	A cylindrical hole, usually greater than 20 m deep and 100 mm in diameter constructed by a drilling rig to allow groundwater to be abstracted from an aquifer.
Geophysics	Techniques which measure the physical properties of rocks without the expense of drilling boreholes. In favourable circumstances, results from geophysics surveys can be used to infer the presence of groundwater.
Ground conductivity	A simple geophysical technique which measures the bulk electrical conductivity of the ground by inducing and measuring electrical currents with two coils.
Palaeosoil	An ancient soil that is often preserved on being buried by lava.
Porosity	The ratio of void space in rock to the total rock volume – expressed as a percentage. Rocks with high porosity can store greater volumes of groundwater.
Pyroclastic rock	Generic term used for rocks formed by explosive volcanic eruptions.
Permeability	Rate of groundwater flow through a cross-section unit area of aquifer under a unit pressure gradient. Permeability is higher when there are interconnected fractures.
Resistivity	A well-established geophysical technique that gives a depth profile of the electrical resistivity of rocks at a site by passing electric currents though the ground.
Sandstone	A rock that is made from cemented sand grains, usually has a high potential for groundwater supplies.
Shallow well	A large diameter (usually greater than 1 m diameter) hole, dug to less than 20 m depth to access groundwater.
Siltstones and mudstones	Fine-grained rocks made of mud and or very fine-grained particles, which usually have low potential for groundwater supply.
Success rate (borehole drilling)	Imprecise term, normally taken as the number of successful boreholes divided by the total number of boreholes drilled – expressed as a percentage. However, different organisations have different measures for denoting a successful borehole.
Weathered zone	A layer of rock beneath the soil zone which has been altered by physical breakdown or chemical decomposition.
Yield	The volume of water provided by a well or borehole, measured in m^3/d or l/s.

List of Abbreviations

UNSA	Unconsolidated sedimentary aquifer
DFID	Department for International Development
BGS	British Geological Survey
NGO	Non Governmental Organisation
UNEP	United Nations Environment Programme
UNTCD	United Nations Technology Co-operation Department
SSA	Sub-Saharan Africa
ESRI	Environmental Systems Research Institute

Executive Summary

Groundwater has proved the most reliable resource for meeting rural water demand in sub-Saharan Africa. There are four main hydrogeological environments in SSA. Each of these broad categories requires different methods for finding and abstracting groundwater.

1. Crystalline basement occupies 40% of the land area of SSA; 220 million people live in rural areas underlain by crystalline basement rocks. Groundwater is found where the rocks have been significantly weathered or in underlying fracture zones. Borehole and well yields are generally low, but can be sufficient for rural demand.

2. Volcanic rocks occupy 6% of the land area of SSA, and sustain a rural population of 45 million, many of whom live in the drought stricken areas of the Horn of Africa. Groundwater is found within palaeosoils and fractures between lava flows. Yields can be high, and springs are important in highland areas.

3. Consolidated sedimentary rocks occupy 32% of the land area of SSA and sustain a rural population of 110 million. Significant groundwater is found within sandstones and limestones, which can be exploited for urban as well as rural supply. Mudstones however, (which account for about 65% of all sedimentary rocks) contain little groundwater, and careful study is required to develop water for community supply.

4. Unconsolidated sediments occupy 22% of the land area of SSA and sustain a rural population of 60 million. They are probably more important than these statistics suggest since they are present in most river valleys throughout Africa. Groundwater is found within sands and gravels.

Groundwater has excellent natural microbiological quality and generally adequate chemical quality for most uses. However problems can arise from the chemistry of groundwater in some circumstances, for example: high sulphate in some parts of the weathered basement and mudstones; hardness in limestone aquifers or sandstones cemented with carbonate material. Minor and trace constituents which make up about 1% of the solute content of natural waters can also sometimes lead to health problems or make the water unacceptable for human and animal consumption. For example: high fluoride in some volcanic aquifers; elevated iron and manganese where conditions are anoxic; high arsenic in some unconsolidated sediments and the lack of iodine in aquifers far from the sea.

Research and experience in some of these hydrogeological environments have enabled standard techniques to be developed for finding and abstracting groundwater. Geophysical techniques in particular have proved useful in many environments for siting wells and boreholes. However, much is still not known about groundwater in Africa. Some issues that demand more attention are:

- the age, recharge and sustainability of groundwater supplies in basement areas, particularly during drought;
- the existence of groundwater in poorly weathered crystalline basement and mudstone areas;
- sustainability of groundwater supplies from upland volcanic aquifers;
- overexploitation of groundwater in sedimentary basins;
- variations in natural quality and contamination of groundwater;
- appropriate (technical, economic and social) choice of water technology.

Co-ordinated groundwater research and data collection has become more difficult in SSA due to decentralisation and demand responsive approaches to the provision of rural water supplies. Information is rarely collected from the many thousands of boreholes drilled each year, with the result that the same costly mistakes are made time and again. However techniques are available to allow local institutions to collect high value data from ongoing drilling for little additional cost. The use of these techniques could allow local institutions to assess the nature of groundwater resources in their areas and, with proper documentation and networking, increase the knowledge base of groundwater in Africa. Budgets for groundwater research in Africa could then be targeted to issues that cannot be addressed by improved data collection from ongoing drilling. Such a scenario will only occur with the dissemination of simple techniques in groundwater resource assessment to those involved in rural water supply, and when the benefits of such assessments are seen within individual water projects.

1. INTRODUCTION

Groundwater is well suited to rural water supply in sub-Saharan Africa (SSA). The characteristics of groundwater differ in a number of ways from surface water. Since groundwater responds slowly to changes in rainfall, the impacts of droughts are often buffered (Calow *et al.,* 1997). In areas with a long dry season, groundwater is still available when sources such as rivers and streams have run dry. Groundwater is generally microbiologically uncontaminated and to a certain extent naturally protected from pollution. The resource is relatively cheap to develop, since large surface reservoirs are not required and water sources can usually be developed close to the demand (UNEP, 1996). These characteristics make groundwater well suited to the more demand responsive and participatory approaches that are being introduced into most rural water and sanitation programmes.

Where groundwater is readily available, wells and boreholes can be sited using mainly social criteria qualified by simple hydrogeological considerations. However, problems arise in areas where communities are underlain by difficult geological conditions, where groundwater resources are limited and hard to find. In these areas, simple 'rule of thumb' criteria are not sufficient to site sustainable wells and boreholes, and following an exclusively social approach, with minimal technical input, can lead to many dry wells and boreholes.

To have successful and sustainable rural water supply projects it is essential to understand the hydrogeological environment of the project area. Different methods are required for developing groundwater in different areas. For example, in some rock types dug wells are appropriate; in others, only boreholes will be sustainable. The hydrogeological conditions determine the technical capacity required for both finding and abstracting groundwater.

2. GROUNDWATER IN AFRICA

The availability of groundwater depends primarily on the geology. Groundwater is stored within pore spaces and fractures in rocks. Where the pores or fractures are interconnected, groundwater can flow easily and the rocks are said to be permeable. Fractured or porous rocks (such as sandstones and limestones) therefore have a high potential for groundwater development. The availability of groundwater also depends to a certain extent on the volume and intensity of rainfall. However, research suggests that recharge to groundwater can occur even in arid parts of Africa. Since the volume of groundwater abstracted for rural domestic water supply is generally low, recharge to the aquifers is less important than the geology in determining initial yields, but very important in determining sustainability.

The hydrogeology of SSA has been classified according to geological environment (see Figure 1). The classifications have been chosen and simplified in this way to reflect the different manner in which groundwater occurs, and the different techniques required for siting wells and boreholes. The four provinces are: Precambrian "basement" rocks; volcanic rocks; unconsolidated sediments; and consolidated sedimentary rocks. In basement rocks, groundwater generally occurs in the top few metres of weathered rock; in volcanic rocks, groundwater occurs in highly permeable zones between lava flows. Consolidated sediments contain groundwater in the pore spaces of sandstones or fractures and weathered zones within limestones. Unconsolidated sediments occur throughout Africa in valleys in addition to the large areas shown in Figure 1; groundwater is found within sands and gravels. Each province is discussed in more detail in the next section.

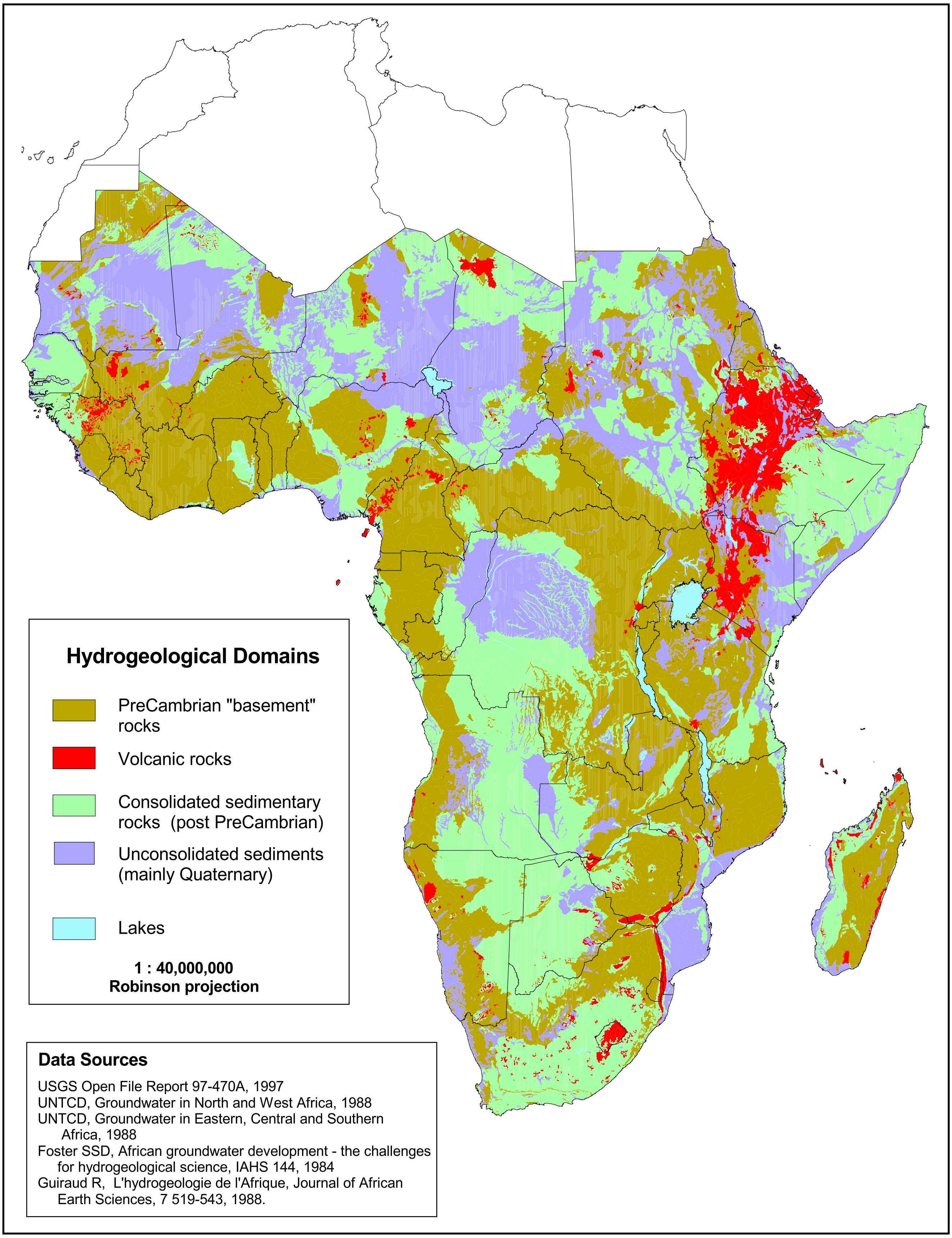

Figure 1 **The hydrogeological domains of sub-Saharan Africa.**

Groundwater has excellent natural microbiological quality and generally adequate chemical quality for most uses. Nine major chemical constituents (Na, Ca, Mg, K HCO_3, Cl, SO_4, NO_3 and Si) make up 99% of the solute content of natural groundwaters. The proportion of these constituents reflects the geology and history of the groundwater (Foster *et al*., 2000). Minor and trace constituents make up the remaining 1% of the total, and their presence (or absence) can occasionally give rise to health problems or make them unacceptable for human or animal use (Edmunds and Smedley, 1996). Health problems are associated with elevated concentrations of arsenic and fluoride, or the deficiency of iodine. In some places the total salt content of the water is high and makes the water unsuitable for drinking. Quality problems particularly associated with the different hydrogeological environments are discussed in the individual sections

Figure 1 shows the geographical distribution of the four hydrogeological environments of SSA. Basement rocks form the largest hydrogeological province, occupying 40% of the 23.6 million square kilometres of SSA (Figure 2); volcanic rocks are the smallest hydrogeological province with only 6% of the land area.

The relative importance of the hydrogeological provinces is best indicated by the rural population living in each one. As discussed above, the rural communities are most dependent on local resources for water supply, since transportation is prohibitively expensive and difficult to manage. Using data from the World Bank (2000) and ESRI (1996), an approximation was made of the distribution of rural population throughout SSA. Of these a large proportion of rural populations that live upon the major rock groups: up to 220 million people on the Precambrian basement; 45 million on volcanic rocks; 110 million on consolidated sedimentary rocks and 60 million on unconsolidated sediments (Figure 2), will be dependent upon water supplies obtained from these formations.

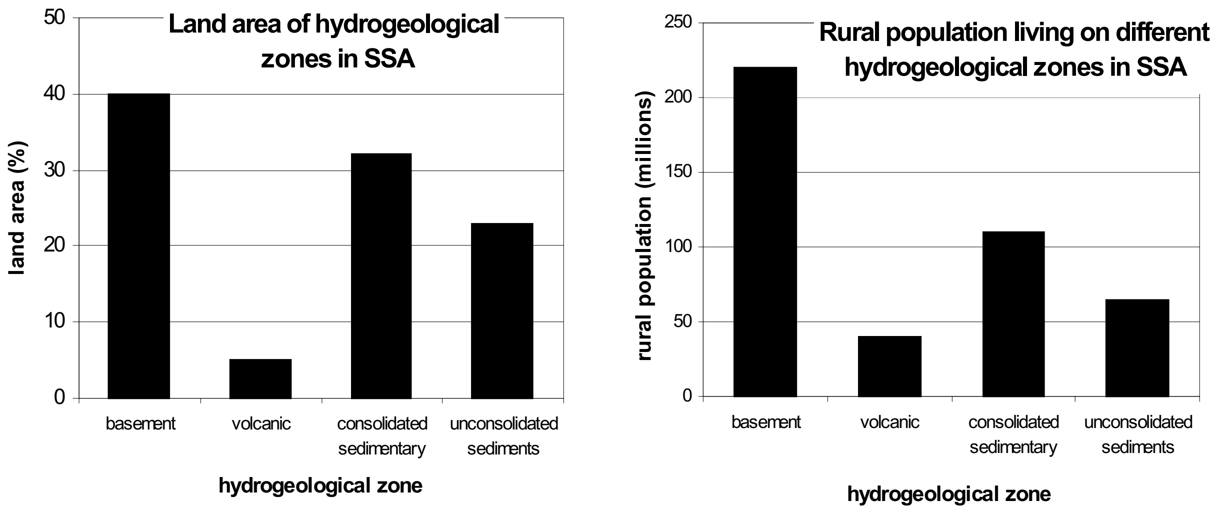

Figure 2 The land area and rural population of the different hydrogeological zones of SSA.