DEVELOPING GROUNDWATER FOR SECURE RURAL WATER SUPPLIES IN AFRICA

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Abstract: In sub-Saharan Africa 85% of those without access to safe water live in rural areas where the consequent poverty and ill health disproportionately affect women and children. The widespread development of groundwater is the most affordable and sustainable way of improving access to secure water for the rural poor on the scale required to achieve current coverage targets. However, groundwater resources vary considerably across the continent, and the sustainable development of the resource depends on an accurate understanding of the hydrogeology. To develop secure water supplies, the quantity, quality and sustainability of groundwater resources must be known to ensure that key decisions are informed by knowledge of resource conditions. Communities must also be involved at every stage of the process and given the authority to manage and maintain sources. There is a danger that the current pressure to achieve ambitious coverage targets will result in short cuts being taken and, although many new sources are constructed, they will not be secure.

Keywords: groundwater; Africa; water supply

Introduction

In 2004 there were still at least 1100 million people across the world who did not have access to safe, clean drinking water [1]. Many of these people live in rural areas and are among the poorest and most vulnerable to be found anywhere in the world. Without clean water, people's health and livelihoods can be severely affected; children's (particularly girls') education suffers as the daily tasks of survival take precedence over all other concerns. Faced with this depressing reality, the international community has set ambitious Millennium Development Goals (MDGs) to reduce by half the number of people without clean water by 2015 [2].

In this context, the need for sustainable development and management of groundwater cannot be overstated. Across large swathes of Africa, South America and Asia, groundwater provides the only realistic water supply option for meeting dispersed rural demand [3]. Alternative water resources can be unreliable and expensive to develop: surface water (if available) is prone to contamination and often seasonal; rainwater harvesting can be expensive and requires good rainfall throughout the year. Groundwater, however, can be found in most environments. It generally requires no prior treatment since it is naturally protected from contamination; it does not vary significantly seasonally and is often drought resistant. Also it lends itself to the principles of community management – it can be found close to the point of demand and be developed incrementally (and often at low cost). However, the resource is not invulnerable: with the ability to pump out large quantities of water, and the advent of particularly persistent contaminants, the resource needs to be protected and managed. Table 1 summarises the advantages of groundwater for rural water supply, with some qualifications.

In this paper we discuss the groundwater resources in Africa, and the steps required to develop secure rural water supplies.

Groundwater resources in Africa

Groundwater occurrence depends primarily on geology, geomorphology/weathering and rainfall (both current and historic). The interplay of these three factors gives rise to complex hydrogeological environments with countless variations in the quantity, quality, ease of access and renewability of groundwater resources.

Rainfall is highly variable across Africa. Annual rainfall varies from negligible over parts of the Sahara, to almost 10,000 mm in the Gulf of Guinea (Figure 1). As a consequence of this great variability, the hydrology of Africa is probably the most variable and challenging of all populated continents - demonstrated by the low runoff/rainfall coefficient (0.23) [5]. This illustrates the high evaporation, and low volume of water flowing in rivers. The great variability in rainfall, and in particular the long dry season (>5 months) over much of Africa, increases reliance on groundwater storage for water supply. Recharge to groundwater in wet periods is naturally stored, and can be abstracted in times of drought. There is no simple direct relationship between average annual rainfall and recharge, and significant recharge (10 - 50 mm) can still occur where annual rainfall is less than 500 mm [6][7][8].

Table 1 Advantages and limitations of groundwater [4]

ADVANTAGE OF GROUNDWATER	QUALIFYING LIMITATIONS
Groundwater is often available close to where it is required	Considerable effort may be needed in some situations to locate suitable sites
Groundwater can be developed relatively cheaply and progressively to meet demand with lower capital investment than many surface water schemes	As overall coverage increases, the more difficult areas which are left can become more costly to supply
Groundwater generally has excellent natural quality, and is usually adequate for potable supply with little or no treatment	Naturally-occurring quality constraints are becoming more widely observed
Groundwater generally has a protective cover provided by the soil and unsaturated zone	As development increases more rapidly, the threat of pollution from human activities needs to be assessed in relation to the nature of the protective cover

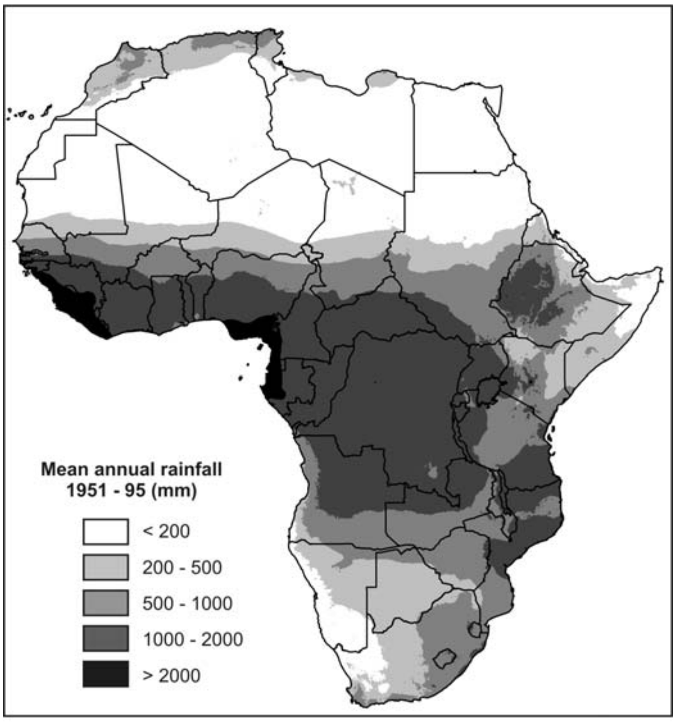


Figure 1. Average annual rainfall for Africa for the period 1951 – 1995 [9]

The available groundwater resources are best described by considering the geology and constructing a hydrogeological map – which classifies the geology into units in which groundwater is likely to occur in a similar way. A simplified hydrogeological map for Africa is shown in Figure 2 based on a synthesis of studies [10][11][12][13][14] and using the 1:5,000,000 scale geological map of Africa as a base [15][16]. The four different environments are: Precambrian “basement” rocks, volcanic rocks, unconsolidated sediments, and consolidated sedimentary rocks. Roughly 34% of the land surface is underlain by heterogeneous Precambrian basement; 37% by consolidated sedimentary rocks; 25% by unconsolidated sediments; and 4% by volcanic rocks [17]. Groundwater occurrence in each hydrogeological environment is described below and illustrated in Figure 3.

Precambrian basement rocks comprise crystalline igneous and metamorphic rocks over 550 million years old. Unweathered and non-fractured basement rocks contain negligible quantities of groundwater. Significant aquifers however, develop within the weathered overburden and fractured bedrock [18].

Consolidated sedimentary rocks, particularly large sandstone basins, can store considerable volumes of groundwater, but in arid regions, much of the groundwater can be non-renewable, having been recharged when the area received considerably more rainfall. Also, sedimentary rocks are highly variable and can comprise low permeability mudstone and shale as well as more permeable sandstones and limestones [14],[19].

Unconsolidated sediments form some of the most productive aquifers in Africa. They cover approximately 25% of the land surface of Africa (Figure 2). However, this is probably an underestimate of their true importance since only the thickest and most extensive deposits are shown on the map. Unconsolidated sediments are also present in many river valleys throughout Africa [11].

Volcanic rocks occupy only 4% of the land area of Africa and are found in east and southern Africa where they can form important aquifer systems. However, despite their small extent, they are highly significant aquifers since they underlie much of the poorest and drought stricken areas of Africa. The groundwater potential of volcanic rocks varies considerably, reflecting the complexity of the geology [20].

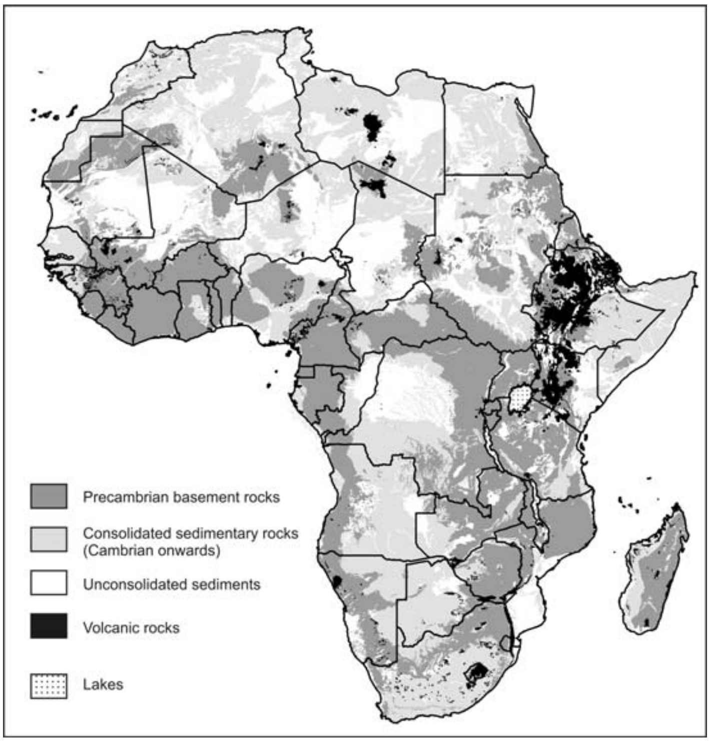
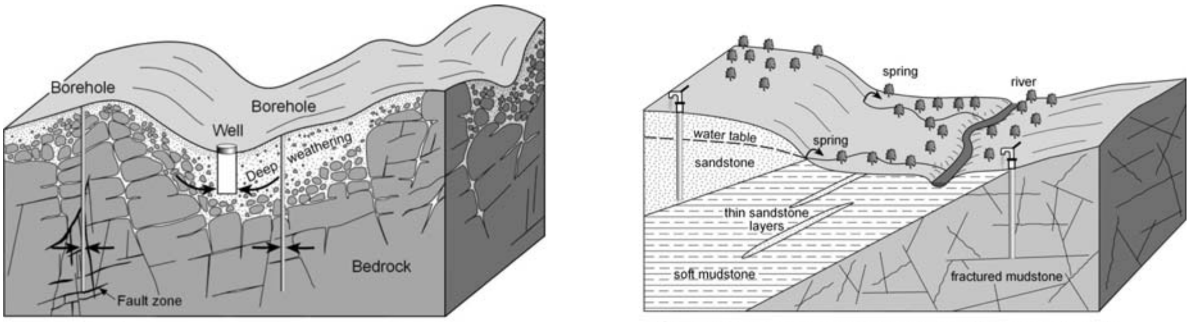
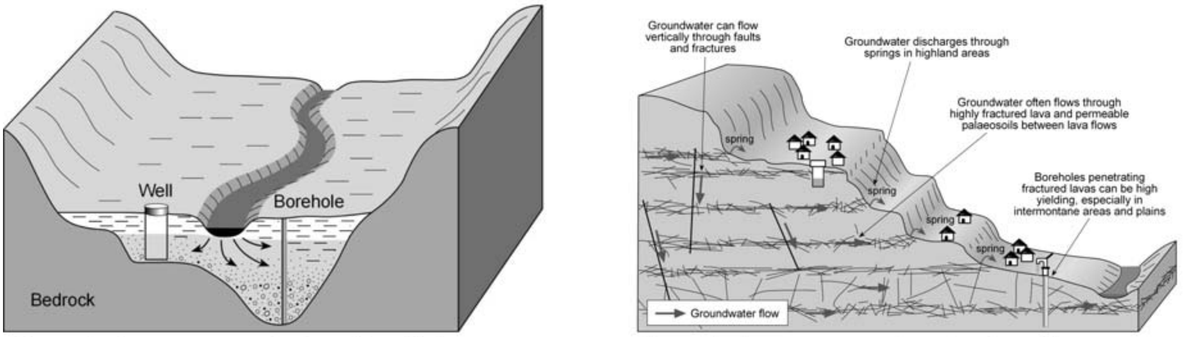


Figure 2. The hydrogeological environments of Africa [14]



Groundwater occurrence in basement rocks
Groundwater occurrence in sedimentary rocks



Groundwater occurrence in riverside alluvium
Groundwater occurrence in volcanic rocks

Figure 3. Groundwater occurrence in different African environments [4]

Developing secure supplies

Water security is fundamental to eliminating poverty. Only with reliable safe water supplies can households build sustainable livelihoods as time is freed up to concentrate on income generating activities, and water is put to productive uses. Some of the factors that constitute a secure supply are:

- the water is of sufficient quantity to meet all requirements;
- the water is safe to drink and does not represent a health risk;
- the supply is reliable all year round, and also in times of drought, when demand can be high;
- the water is accessible to all in a community and within a reasonable distance of all households (usually within 1 km)
- the supply is affordable and can be easily maintained.

To achieve a secure groundwater supply the following factors must be incorporated into any rural water supply project or programme.

Boreholes or wells should be sited effectively

Any groundwater source should be located where the groundwater resources are sufficient and able to meet the demands put upon it. Modest investment in resource assessment and siting techniques can pay dividends in terms of higher drilling success rates and higher yielding (more reliable) sources [4]. Simple tests can also be carried out to assess the performance of a well or borehole once it has been constructed, providing valuable information on how the source will behave during drought [21]. If a single source cannot meet peak dry season or drought demand, further village sources may need to be developed. In the longer term this is more cost effective than trying to cope with water shortage when drought arrives [22].

In some areas, for example on major alluvial plains with abundant rainfall, groundwater may be widely available at relatively shallow depths. In these areas, little or no hydrogeological investigation is necessary as wells or boreholes may be successful wherever they are developed. Siting can therefore be determined by the local population alone. In environments which are more geologically heterogeneous, however, investigations ranging from simple field observation to more costly exploratory drilling and surveying may be necessary to ensure success (see Table 2). Where investigations help reduce the number of unsuccessful wells drilled, cost savings may be significant, more than covering the cost of the investigation procedure (Figure 4).

Table 2 The costs and benefits of different borehole siting methods

	GROUNDWATER EXPLORATION TECHNIQUE	COSTS	NOTES
One off cost	**Reconnaissance** Gathering background maps and information on the geological and hydrogeological conditions	A one off cost – several weeks time of a project member or consultant. More expensive (but not prohibitively so) if data have to be generated from satellite images, field mapping etc.	Essential first step for understanding the groundwater resources.
↓ increasing costs per borehole	**Hydrogeological fieldwork** Siting using an experienced eye by examining the rocks and geomorphology in an area Discussion with local communities	Requires a well trained engineer to visit the community	Objective is to 'ground-truth' results gathered from reconnaissance
	Geophysical surveying : Resistivity, Electromagnetic, seismic, etc (see [4] overview) Must be combined with reconnaissance data and hydrogeological fieldwork	Equipment varies in price but is generally < \$US 20 k. A well trained geophysics team will need at least 1 day in each community.	Important to have good analysis of the data. Investment in training staff often beneficial.
	Exploratory drilling Drill exploratory boreholes in a community – often combined with hydrogeological fieldwork and geophysics.	Costs equivalent to drilling a dry borehole, but considerably reduced if the team has control over their own rig. Could be a one off cost if the exploratory drilling leads to better interpretation of geophysics	The only way to 'prove' that groundwater occurs in an area. Requires careful facilitation to ensure that communities do not get frustrated by drilling of 'test' boreholes.

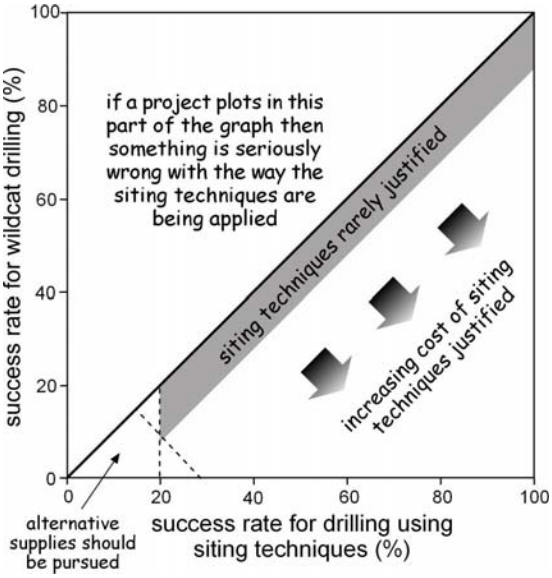


Figure 4. A summary of the circumstances when siting techniques can be economically justified. Wildcat drilling is random drilling using no siting techniques [4].

<u>*Maintenance: communities must participate at all stages*</u>

The need for community participation in the planning and implementation of rural water supply projects became increasingly apparent in the 1980s. Governments and donors realised that that they could no longer afford centralised operation and maintenance systems, and that existing top down approaches were not creating sustainable water supply systems. As a consequence, the idea that beneficiaries, or users, needed to be involved with the ongoing *maintenance* of systems began to be more widely discussed. Hence, ideas about community participation were initially fairly restricted: most attention was focussed on trying to get communities to raise funds to help with the upkeep of their water systems.

Community *management* in rural water supply, however, goes some way beyond participation. There is no fixed definition or simple formulae, but a key feature is the nature and breadth of decision-making, and the responsibility for executing those decisions being more with the community. Community *management* in rural water supply, as opposed to *participation*, therefore, implies [23]:

- The community has legitimate authority and effective control over management of the water supply system and over the use of water.
- The community commits resources towards both the implementation and upkeep of the system(s).
- Supporting agencies provide advice and technical support, but key decisions about participation in a project, and about the type, level and location of services, are made *with* the community.
- Development of people – individual and community empowerment – is a parallel goal. Community management is people-centred: the principal concern is with people's livelihoods, not the resources they use or the technologies employed.

Despite its obvious appeal, however, community management is more complex than might first appear. Community decision-making, for example, does not always reflect the interests of poorer, more marginalised groups; hence community management does not, in itself, guarantee that the needs of all households are met. Why is this so? A key point is that communities are not homogeneous, in terms of the interests, expectations and power of different individuals to influence community decisions [4]. Care needs to be taken to ensure the needs of all groups – especially women, children and the poor who may have little or no community voice - are factored into decisions on service provision. A project has an important role to play here in making sure that these voices are heard.

Water supplies should be engineered appropriately

As the provision of rural water supply becomes increasingly decentralised, budget holders (who are often based in district or local government) have little knowledge about the complexities of groundwater investigations and borehole development. This makes it difficult for them to judge whether supplies are engineered appropriately for the terrain [4]. As a consequence, there are many examples of boreholes or wells that have been poorly constructed and stopped working after a short time, or never worked at all. Conversely sources can be over-engineered at great cost,to the detriment of other, unserved communities.

As a general guideline, boreholes should be designed to meet the following criteria:

- borehole efficiency is maximized (high pumping from small diameter boreholes can lead to friction losses and deep drawdowns);
- sand inflow to the borehole is kept to a minimum (this can quickly wear out pumps);
- materials are of sufficient quality to last at least 25 years;
- any contaminated sources or aquifers, or zones of undesirable water quality, should be sealed off from the borehole.

Obviously these factors have to be balanced with the cost of the borehole. Drilling a large diameter borehole to 100 m and lining it with expensive stainless steel screen could cost as much as ten narrow diameter boreholes drilled to 50 m and completed with uPVC screen and casing. Also, it is important to know whether the borehole is likely to be successful before installing expensive screen and casing.

There have been recent moves to make borehole drilling more cost effective and fit for purpose [24]. This involves using smaller less costly drilling rigs to drill reduced (100 – 150 mm) diameter boreholes completed with plastic screens and casing. These designs, where coupled with a good understanding of the groundwater resources and good siting techniques (see above) can give high quality sources at much reduced cost.

The quality of the water must be known

Groundwater has traditionally been regarded as having good natural quality. For most of the geological environments this is true, but this does not mean that natural groundwater quality is always good. The natural quality can vary from one rock type to another and also within aquifers along groundwater flow paths. Because groundwater movement can be so slow, and residence times long, there is scope for chemical interaction between the water and the rock material through which it passes. Natural groundwater quality changes start in the soil, where infiltrating rainfall equilibrates with carbon dioxide to produce weak carbonic acid which can remove soluble minerals from the underlying rocks.

Nine major chemical constituents - sodium (Na), calcium (Ca), magnesium (Mg), potassium (K), bicarbonate (HCO_3), chloride (Cl), sulphate (SO_4), nitrate (NO_3) and silicon (Si) – make up about 99% of the solute content of natural groundwaters. The concentrations of these constituents give groundwaters their hydrochemical characterisation, and the proportions reflect the geological origin and groundwater flow regime [25]. However, it is the presence (or absence) of the remaining 1% - the minor and trace elements – that can occasionally give rise to health problems or make the water unacceptable for human use. Figure 5 indicates which chemicals are essential for humans and which are harmful. Of particular concern in East Africa are elevated concentrations of fluoride [26]. Although arsenic has not yet been widely detected, the lack of monitoring does not mean that the problem is absent [25],[27].

To ensure secure water supplies, the quality of the water must be assessed at the time of construction and some method of regular monitoring for a selection of boreholes to identify any degradation. Currently in Africa this does not occur, and without a major incentive from donors or government it is unlikely that thorough groundwater quality monitoring will be taken seriously.

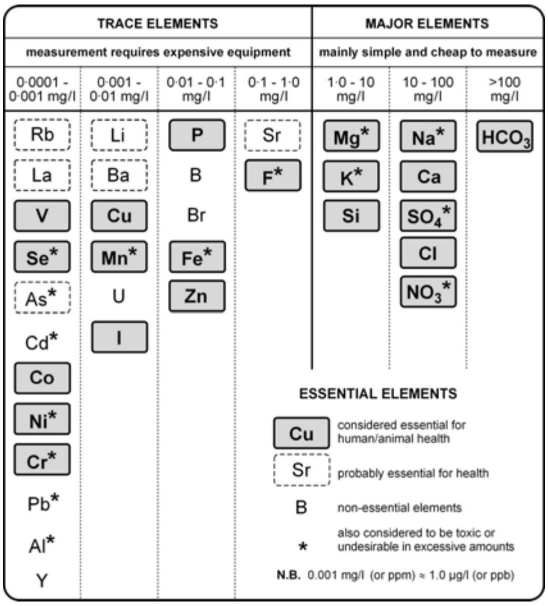


Figure 5. The health effects of different constituents found in groundwater [3][25].

Supplies and groundwater resources must be protected from contamination

Water quality can deteriorate through contamination of the local groundwater, or direct contamination of the water supply itself. Rural water supplies can be particularly vulnerable since they are often shallow and have hazards close by – such as pit latrines, or animal watering troughs etc. (Figure 6).

To minimise the risk of contamination of the water supply, the supply must be well constructed, and sources of contamination kept away. Community management of a source using simple guidelines can help to keep animals away from a supply and minimised any standing water. Sanitary inspections provide an easy but effective, risk-based approach to monitoring wellhead protection [28]. The use of standardised and quantifiable approaches makes it possible to compare the results obtained by different inspectors, allows an overall risk score to be developed, identifies priority sites for remedial actions and permits comparisons between different supply types.

In rural Africa, the increase in the use and construction of household latrines poses a considerable threat to the groundwater supplies. Contaminants can migrate vertically to the aquifer and then to the borehole, or more dangerously, horizontally through permeable soils to poorly constructed supplies (see Figure 6). Some methods are available to help site latrines an appropriate distance from water supplies to help reduce contamination [29].

Groundwater vulnerable techniques are well developed in most northern countries to help inform land use planning and exclude the most polluting activities from vulnerable aquifers. Such techniques are difficult to apply on an African context due to a general absence of government legislation enforcement, but some recent efforts at vulnerability mapping are being made [17],[30].

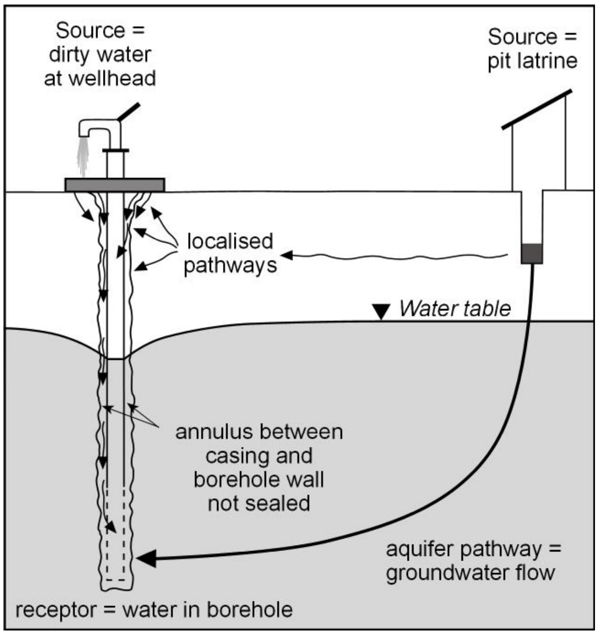


Figure 6. The source→pathway→receptor concept for groundwater pollution [29]

Conclusions

Over much of Africa, developing groundwater offers the only realistic and affordable way to meet coverage targets and improve access to water. However, to build secure groundwater supplies takes time. The groundwater resources must be understood, and boreholes/wells developed in a way that is appropriate to the hydrogeology – to ensure long term availability of the water. It is also important to know the quality of the water (to ensure it is fit to drink) and protect the water supply and local groundwater resource from contamination. Equally important as these engineering and resource aspects is the need for community participation in the long term management of the source to enable the source to be maintained for the benefit of all.

The current pressure to reach the targets set out in the Millennium Development Goals, and dramatically increase the rate of borehole construction across Africa may mean that many communities do not get access to *secure* water supplies. The pressure to meet short term coverage targets will inevitably lead to short cuts in both groundwater resources assessment and the involvement of communities. As a consequence there is a very real danger that although new water supplies are constructed, they will not be secure, and as a consequence soon fail the communities they are meant to serve.

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