Groundwater protection in sub-Saharan Africa

Richard Taylor

In sub-Saharan Africa, projected increases in the development of groundwater and pollutant discharges to the subsurface will inevitably magnify the risk of degrading the quality and quantity of available groundwater resources. Groundwater protection will consequently prove an essential component of efforts to develop groundwater resources sustainably in this region.

In sub-Saharan Africa, effective protection of groundwater resources will become increasingly important this century as groundwater plays a critical role in efforts to alleviate endemic poverty. In order to extend drinking water supplies and low-cost sanitation to everyone, not only will groundwater need to be further developed, but also the subsurface will be used for the disposal of sewage. Rapid urban growth and the intensification of agriculture in sub-Saharan Africa over the next few decades will, furthermore, place unprecedented demand upon groundwater resources, yet simultaneously threaten its quality and quantity. The health implications are explicitly recognized by the World Health Organisation, which will publish a monograph, *Protecting groundwater for human health*, later this year (2005).

Drawing primarily from experience in east and southern Africa, this article discusses current strategies for protecting groundwater resources and key challenges to their implementation in sub-Saharan Africa.

Groundwater protection

Groundwater protection involves restrictions in land use in areas where pollutant releases are able to contaminate underlying aquifers or a specific water source, be it a well or a spring. Land-use restrictions may include, for example, prohibition of pollutant sources such as pit latrines or the application of fertilizers. This enables control of both diffuse sources of pollution to groundwater (such as the application of pesticides or fertilizers) and point sources of pollution to groundwater (such as industrial effluents) though the latter are more commonly regulated by permits and penalties.

Groundwater protection also includes regulation of the magnitude of abstraction in order to promote its sustainable use and to avoid 'competitive abstraction' – a situation where its use for one purpose restricts its use for another (Figure 1). This is particularly important in sub-Saharan Africa – the most rapidly urbanizing region in the world.

In many countries, restrictions in land use and groundwater abstraction become more stringent the closer one is to the source (Figure 2). In the immediate vicinity of a well or spring (zone I), neither polluting activities nor abstraction are permitted. In a more expansive zone that accounts for the attenuation of pollutants in the aquifer through adsorption, degradation, and dilution (zone II), pollutant discharges are restricted such that they do not lead to unacceptable pollutant concentrations in the discharge of the well or spring. Larger, less restrictive zones on a catchment scale (zone III) are designed to guard against long-term degradation of the quality and quantity of groundwater.

Delineation of protection zones

Delineation of land areas to be protected from polluting activities and competitive abstraction is problematic and fraught with uncertainty. Currently, a range of methods is used to delineate protection areas, and these vary widely in their sophistication and the data

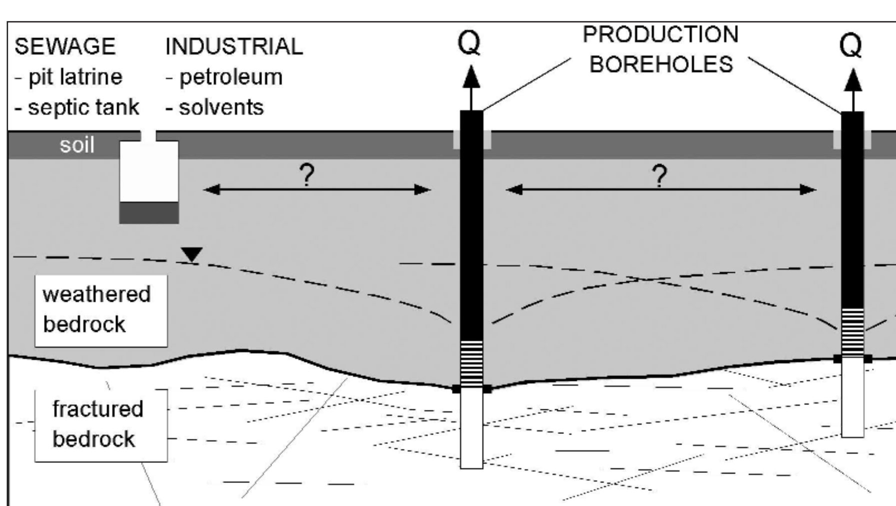

Figure 1 Schematic representation of the uncertainty in protection zones for boreholes in an unconfined weathered and fissured crystalline rock aquifer system. Dotted lines show water level in the overburden aquifer

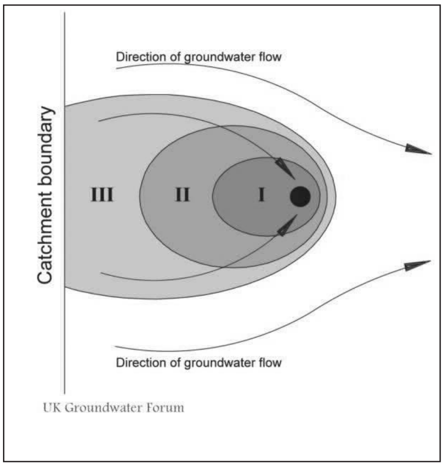

Figure 2 Schematic representation of source protection zones around a borehole source (black dot) (reprinted from UK Groundwater Forum)

required for their formulation. For details beyond this general summary, consult reviews of wellhead protection areas (WHPAs) or groundwater protection zones (GPZs) listed at the end of this article.

The most basic groundwater protection area is a minimum setback distance between a pollutant source and a water source. As the distance is fixed (and somewhat arbitrary) regardless of the abstraction rate or spring discharge, setback distances are simple to apply but may prove either ineffectual or unnecessarily conservative.

Slightly more sophisticated and commonly applied approaches define protection areas using simple equations (analytical models) of groundwater flow around a well or spring. The zone, commonly a radial distance, around a water source is constrained by a time of travel criterion based upon the presumed survival of pathogenic bacteria like *Escherichia coli* in groundwater. This is typically presumed to be somewhere between 25 and 50 days. Bacteria following longer flowpaths are presumed to die off before reaching the well or spring discharge. Other methods of defining protection zones include mapping of aquifer extent and computer modelling of groundwater flow. Data requirements and technical expertise increase with the sophistication of the method, so simpler methods are more widely and regularly applied.

Deterministic approaches

In sub-Saharan Africa, as in many other regions, protection of groundwater has, to date, focused on individual water sources rather than the wider resource, though recent initiatives in some countries, such as licensing of groundwater abstraction and mapping of aquifer areas, provide a basis for this wider approach. Where practised, groundwater protection has primarily focused on the threat posed by sewage to handpumped wells or springs. This stems historically from the region's predominantly rural population and the limited number of areas where industrial activity and intensification of agriculture occur.

In 1980,[1] minimum setback distances of between 10 and 15 m were suggested in order to reduce the likelihood of faecal-oral transmission of microbial pathogens between pit latrines and wells or springs. These source-protection zones were considered provisional and pragmatic, rather than scientifically justified, but have since been applied rather blindly in the absence of further research, particularly in sub-Saharan Africa. A recent project funded by the Department for International Development (UK), *Assessing the risks to groundwater of on-site sanitation*,[2] extended this work and developed simple procedures for the delineation of source-protection zones using analytical models and time of travel criteria of between 25 and 50 days.

There are inherent limitations to deterministic approaches. Two fundamental assumptions underlie source-protection zones derived using analytical or numerical models of groundwater flow and time-of-travel criteria:

- pathogenic bacteria and viruses are transported by the average (bulk) velocity of flowing groundwater; and
- pathogenic bacteria and viruses survive less than 50 days in groundwater.

Regarding the first assumption, there is considerable field evidence that a tiny proportion of micro-organisms, applied in aquifers deliberately as tracers or incidentally via leaky sewers, can move much more rapidly than the mean (bulk) velocity of groundwater.[3] This is observed during field-tracing experiments and evident from the detection of sewage-derived bacteria and viruses in groundwater tens of metres below ground.[4] Velocity differences are exaggerated in fissured aquifers with preferential pathways for groundwater flow. In the weathered and fissured crystalline (basement) rock aquifer system of Uganda – a system that underlies 40 per cent of sub-Saharan Africa – chemical tracers show that borehole samples consist of groundwater with a residency in the subsurface that ranges from decades to just months.[5]

The second assumption, pertaining to presumed survival times for sewage-derived micro-organisms in groundwater, is also questionable. Survival times vary considerably depending upon the organism and environmental conditions. Faecal viruses, for example, can survive in groundwater considerably longer than the 50-day criterion[3]. Thus, despite implementation of a source-protection zone, it is critical to recognize the vulnerability of untreated groundwater supplies to microbial contamination through rapid transport of pathogenic micro-organisms, particularly viruses, since disease can result from their acute ingestion in low concentrations.

Risk-based approaches

An alternative, reflexive approach to source protection is to prioritize the risks to water quality (and quantity) and evaluate the efficacy of interventions. A set of formal procedures including sanitary risk surveys and field testing of standard bacteriological indicators of sewage contamination has been developed in order to protect water sources from gross microbial contamination.[6]

Identification of the sanitary risks most frequently associated with gross bacteriological contamination can prioritize local interventions to reduce its occurrence. A survey of 32 wells in Lichinga, Mozambique[7] demonstrates that the presence of livestock within 10 m of the well is more frequently associated with gross contamination (>100cfu/100ml) by faecal bacteria than the existence of pit latrines within 30 m of the well. Similar research involving 25 springs in Kampala, Uganda[8] shows that faulty masonry and poor hygiene conditions are more strongly correlated to microbial contamination than the proximity of on-site sanitation (Figure 3). In urban areas of sub-Saharan Africa, elimination of the major risks to groundwater quality is probably more feasible than rigid imposition of a specific protection zone.

Risk-based approaches, described above, feature two key limitations. One, microbial pathogens can occur in groundwater in the absence of standard bacteriological indicators of sewage contamination, including thermotolerant coliforms (TTCs). Two, chemical risks to water quality are not considered. The origin of high nitrate concentrations, for instance, is unlikely to be traced to long-term sewage-loading in cities or fertilizer application in rural areas through localized surveys of chemical risks.

Intensification of abstraction

Historically, groundwater abstraction in sub-Saharan Africa has occurred primarily in rural areas and been of low intensity, usually achieved via handpumps. Widespread development of groundwater (untreated apart from chlorination) as a low-cost source of potable water for town water supplies in sub-Saharan Africa has recently intensified abstraction. Little is known, however, of the impact of intensive abstraction on developed aquifers including weathered and fissured crystalline (basement) rock aquifer systems. Anecdotal evidence exists of dried-up shallow wells and springs in the vicinity of production boreholes and wellfields, but fundamental hydrogeological characteristics remain poorly defined. In semi-arid countries, which are dependent upon groundwater for domestic water supplies and irrigation systems, groundwater protection zones will prove especially useful to prevent or help to resolve inevitable conflicts over groundwater uses.

Enforcement

Groundwater protection measures can only be effective if they are maintained. Protection zones not only need to be understood but also require a supportive political and legal framework for their enforcement. In sub-Saharan Africa where conflicts between much-needed development and environmental protection are acute, implementation of groundwater protection zones faces significant socio-political obstacles, in addition to the technical challenges described above. A participatory approach, in which direct beneficiaries (household users, agriculture, industry), intermediaries (those involved in water supply and public health) and policy makers drive the process to design and implement measures to protect groundwater, will prove essential.

Future considerations

Continued, rapid urbanization in the first half of the twenty-first century will increase dependence upon local groundwater resources and on-site sanitation as development of centralized, reticulated water and sewerage systems are unable to keep pace with population growth. Risk-based approaches to source protection may prove effective in controlling microbial contamination of water sources but long-term loading of sewage through on-site sanitation (and leaky sewers) is likely to lead to unacceptable nitrate concentrations in shallow, accessible groundwater for domestic consumption.

A key future challenge to groundwater protection is the intensification of agriculture that is central to the poverty alleviation strategies of many nations in sub-Saharan Africa. Use of fertilizers and pesticides, and increased groundwater abstraction, have the potential to degrade significantly the quality and quantity of groundwater resources. Growth in industry and associated effluent discharges will also present new chemical risks (e.g. solvents, metals) to groundwater quality. The extent of current industrial contamination is poorly understood as monitoring is expensive and restricted by the limited availability of necessary analytical facilities.

Groundwater protection measures that constrain growth in housing provision, agricultural productivity or industry will require very careful argument. The most persuasive case is that remediation of contaminated groundwater is more difficult and more expensive than protection.

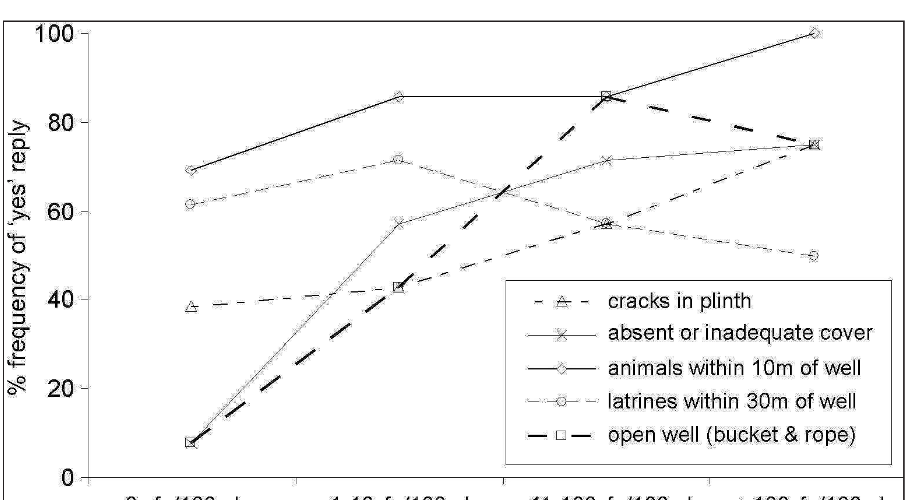

Figure 3 Frequency of the most significant risks (%) to water quality versus observed thermotolerant coliform bacteria counts in sampled wells from Lichinga, Mozambique[7]

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