On-site sanitation and urban aquifer systems in Uganda

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Absence of microbial indicators from groundwater does not always mean absence of contamination. Research in sub-Saharan Africa warns against generalized assumptions — and solutions.

Glossary

cfu: colony forming units.

FC: faecal coliforms.

Attenuation: filtration by, and natural partitioning to, solid aquifer materials.

Die-off: microbes, unlike inorganic contaminants, have a finite life span, so we are only concerned with the distance they move in a groundwater system during their lifetime.

'Regional' aquifer: distances between recharge and discharge are in the order of kilometres.

'Local' aquifer: recharge/discharge distances of 10s/100s of metres.

Cased through the regolith: a solid casing within the borehole to the base of the weathered overburden, to prevent well collapse.

The comparative newness of urban centres in sub-Saharan Africa, associated with a short history of infrastructural (water and sewerage) and industrial development, has meant few detailed studies of urban groundwater quality in this region. Chronic problems associated with long-term urban groundwater usage, such as over-abstraction and contaminant loading, have either not occurred or are at an earlier stage than in other areas of the world. Hence, applied research has been low priority, particularly where resources for such research are limited. At the same time, groundwater development schemes routinely fail to collect and archive even basic data (e.g. drilling logs, hydrochemistry) — an alarming oversight in view of the rate of urban population growth and the reliance by many (particularly low-income) communities on untreated groundwater for domestic use.

Initial study of boreholes and protected springs

As part of a larger project to develop systems of water supply monitoring in Uganda, groundwater supplies were tested by the Roben Centre in four major towns — Kampala, Mbale, Soroti and Tororo. An initial assessment of 171 protected springs (out of the 259 total) in Kampala carried out during December 1997 and January 1998 (the wet season), showed that only two per cent were free of contamination; 65 per cent had coliform counts in excess of the Ugandan guideline for drinking water supplies (50cfu/100ml). Spring water quality varies with rainfall, with average microbial loading increasing significantly during high rainfall periods (though some supplies are highly contaminated throughout the year). Direct contamination may result from surface run-off due to inadequate protection (lack of fencing around the spring backfill, or eroded backfill, for example), or from rising water-tables which permit flooding of latrines and, therefore, a greater likelihood of microbial transport to the spring outlet. Sanitary inspection data for the 259 samples collected between December 1997 and May 1998 show a strong association between the degree of faecal contamination and the frequency of recorded faults relating to sanitary completion in the immediate vicinity (such as poor masonry or eroded backfill), although no strong association was observed between the degree of faecal contamination and the positioning of latrines within 30m and/or uphill.

These preliminary data suggest that the principal route for contamination of protected springs in Kampala is the immediate area surrounding the protection works, and that localized sources of faeces derived from surface water drains and watercourses are the major contributors to groundwater quality deterioration.[1]

In the other towns studied, boreholes equipped with handpumps are more commonly used. Initial data generally show a much lower degree of contamination than the Kampala springs — of 47 samples taken within the three towns over a three-month period, only six show microbiological contamination and only one has levels that may be considered as gross contamination (79FC/100ml). The protected springs in these towns show much higher contamination with only one source consistently showing zero FC/100ml. An association between the eroded backfill area and degree of contamination is noted, although there is less association between the state of the retaining wall and the contamination levels. Again, proximity of latrines does not appear to have an effect. As these data are predominately from the dry season, a definitive conclusion cannot be drawn, nor

1. Howard, G., P. Luyima, and J. Bartram, 'Small water supplies in urban areas of developing countries.' *Proceedings of WHO Symposium on the Economics, Technologies and Operations of Small Water Systems*, Washington, U.S., 10-13/5/98, 1999.
2. Morris, B.L., A.R. Lawrence, and M.E. Stuart, 'The impact of urbanisation on groundwater quality', Project summary report, *BGS Technical Report* WC/94/56, 1994.
3. van Ryneveld, M.B. and A. B. Fourie, 1997 (see Resources Guide).

comparisons made with levels of contamination in Kampala at this time.

Impacts of hydrogeology and population density

In a second study, a more detailed investigation of groundwater quality in two urban centres in Uganda is being carried out with Makerere University. This study, with sites in Iganga and Kampala, aims to establish the impact of on-site sanitation on groundwater quality under contrasting hydrogeological conditions and in areas of contrasting population density.

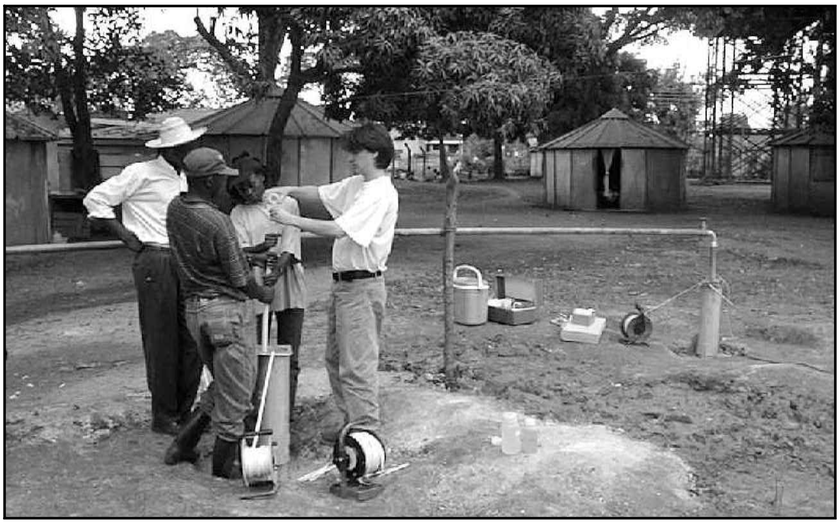
Iganga is a low relief area with a relatively thick layer of in-situ weathered rock (regolith), typically around 30m, and a typical depth to the water-table of 15m. Sampling in Iganga is undertaken from boreholes (equipped with handpumps) that are cased through the regolith. These draw water from storage at the base of the regolith, which may be regarded as a regional aquifer system, and are likely to reveal regional (that is, urban-wide) quality impacts rather than localized point sources (unless sanitary completion is poor).

Kampala has a more pronounced topography, resulting from long-term differential weathering of the underlying bedrock types. The weathered rock thickness is generally low, and shallow, localized groundwater flow systems exist. Sampling in Kampala is undertaken from protected springs tapping the shallow groundwater flow system. The quality of the spring water reflects land-use and pollution sources in a more localized area.

Inorganic evidence of contamination

Preliminary dry season data demonstrate several important points. Chloride (Cl) and nitrate (NO_3) values are generally higher in Iganga compared to rural groundwater, and the close correlation of the data demonstrates (with isolated exceptions) a single dominant source for both the Cl and NO_3. The ratio of NO_3 to Cl in the source of contamination is also high and indicative of a faecal origin.[2]

Standard microbiological analyses (for faecal coliforms and faecal streptococci) suggest a general absence of faecal microbial contamination in the boreholes sampled (although two dug wells consistently contain faecal coliforms). These results indicate that there is a dispersed loading of sewage contributing to the regional base flow of groundwater beneath Iganga (most likely from on-site sanitation facilities). It is not surprising that faecal indicator bacteria are largely absent, as the length of time between recharge and detection in base flow may be well in excess of their survival times. The thickness of the unsaturated zone and potential length of flow path within the saturated zone provides scope for extensive attenuation. It is important to note that there is clear (inorganic) evidence of faecal loading of the groundwater beneath Iganga. Had standard microbial species been used alone as indicators of faecal contamination, it would have been concluded that a faecal source was not present. As van Ryneveld and Fourie (1997)[3] emphasize, whilst the presence of *E. coli* indicates the presence of faecal contamination, its absence does not prove the absence of such contamination.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Recent field tests of virus movement through groundwater using bacteriophage (a non-pathogenic virus).

Contrasting population densities

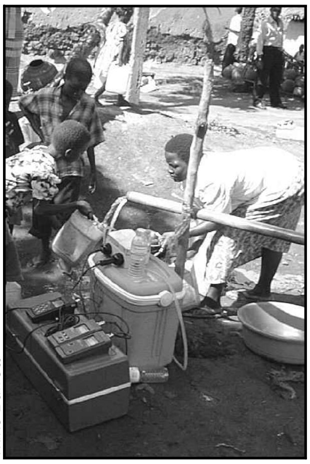
In Kampala two groups of sites are being studied — the first is in an area of high-density, low-income population, and the second is an area of low-density population, low/middle-income, with urban agriculture a major activity.

In both areas, standard faecal indicator bacteria counts are high, although contamination is generally worse in the high-density area (faecal coliform median dry season values of 544/100ml, as compared to 14/100ml in the low-density sites). The area where the population density is high shows a median value of 59mg/l of Cl, while the median values of

Aquifer type

The predominant aquifer type in much of sub-Saharan Africa is weathered crystalline rock (such as granite). Groundwater is transmitted by fractures in the bedrock and unconsolidated weathered materials in the overlying mantle (regolith). The weathered mantle may be tens of metres thick and highly variable in geological nature. The base of the mantle often consists of a poorly sorted, muddy sand — this is the most productive horizon (stratum or set of strata) within the weathered aquifer system, and may constitute an aquifer of regional extent. Recharge to the fractured basement is from storage at the base of the weathered mantle; the discontinuous nature of the fractures in the bedrock means that it cannot be considered as a regional aquifer. The non-uniform nature of weathered basement aquifers makes prediction of contaminant transport highly uncertain.

4. Gelinas, Y., H. Randall, L. Robidoux, and J.P. Schmit, 'Well water survey in two districts of Conakry (Republic of Guinea), and comparison with the piped city water', *Water Research*, 30: 1996, pp.2017-2026.
Malomo, S., V.A. Okufarasin, M.A. Olorunniwo, and A.A. Omode, 'Groundwater chemistry of weathered zone aquifers of an area underlain by basement complex rocks', *Journal of African Earth Sciences*, 11: 1990, pp.357-371.
Uma, K.O., 'Nitrates in shallow (regolith) aquifers around Sokoto Town, Nigeria', *Environmental Geology*, 21: 1993, pp.70-76.
Faillat, J.P., 'Origine des nitrates dans les nappes de fissures de la zone tropicale humide – exemple de la Côte D'Ivoire.' *Journal of Hydrology*, 113: 1990, pp.231-264.



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Further research is needed on the persistence and transport of sewerage contaminants.

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NO_3 are 67mg/l; this compares to a Cl value of 21mg/l and NO_3 values of 22mg/l in the low-density area. Whilst contamination in the low-density area is present, the impact is reduced.

The microbiological data and inorganic data do not correlate well — a number of sites have high microbiological counts but low NO_3, and vice versa. This may be explained in the context of the hydrogeological regime and likely contaminant entry point. As discussed above, for many springs it is likely that contamination is in the immediate area and thus high microbial counts are expected. As the groundwater flow system feeding the springs in Kampala is shallow and localized, it is likely that even where contamination sources are more distant, travel times to waterpoints are relatively short. The presence of NO_3 will be controlled by rate limitations on mineralization and nitrification and possible localized denitrification. Higher NO_3 concentrations are generally associated with higher population densities.[3]

Implications from research

Published urban groundwater studies from sub-Saharan Africa[4] indicate a close correlation between chloride and nitrate, suggesting a single primary source. The high NO_3 to Cl ratio is, furthermore, characteristic of sewage, and drinking water guidelines for NO_3 are exceeded at many locations. As water-borne sewerage systems are broadly absent at the sites studied, it is reasonable to attribute the presence of sewage in groundwater (along with inorganic degradation) to on-site sanitation.

Data from a number of studies links the degree of contamination by nitrate to population densities. In view of the rate of urbanization of sub-Saharan Africa, and the likelihood of increasing population density, continued use of on-site sanitation in urban areas is likely to lead to further inorganic deterioration of groundwater quality. As NO_3 is broadly conservative in oxidizing groundwater (typical of the weathered mantle), distance-based guidelines (as used for microbial species, reliant upon attenuation and die-off) for safe siting of on-site sanitation facilities are not applicable. The only means of preventing NO_3 loading is to locate the source outside the borehole/spring catchment area. Given the numerous boreholes/springs commonly existing within urban and urbanizing areas of sub-Saharan Africa, the cumulative catchment areas may cover the entire urban and peri-urban area.

Strategies to limit contamination

Contamination could potentially be limited to acceptable levels (i.e. drinking water limits) through urban planning. Avoiding overcrowding limits the intensity of sewage loading from on-site sanitation in the vicinity of boreholes/springs (i.e. ensuring regional aquifer throughflow is able to dilute recharge from on-site sanitation). However, this will not solve the problem in suburban areas that are already illegally inhabited. So long as nitrate in drinking water is considered to be a health hazard, sustainable development of high-density settlements employing on-site sanitation will necessitate groundwater treatment before consumption. Alternatively, water-borne sewerage systems could be used (although there is now much evidence from Europe that these do not entirely prevent sewage contamination of groundwater). Clearly, cost-benefit decision making and planning are necessary.

Pathogen contaminiation — an unknown quantity?

Microbiological aquifer quality is a more complex issue. Many of the surveys carried out show a localized presence of faecal indicator bacteria such as faecal coliforms and faecal streptococci, particularly in shallow, localized flow systems discharging to springs. This may be attributed both to direct contamination, through poor source protection, and also to loading from on-site sanitation.

Microbial faecal indicator species are often absent from deeper boreholes penetrating regional aquifer systems (their presence being limited by attenuation and die-off). The assumption in such cases is that on-site sanitation is not affecting the microbiological quality of groundwater. However, standard microbial indicators do not sufficiently represent the presence of pathogens in groundwater. Viruses, for example, have entirely different transport and survival characteristics in groundwater to bacteria (generally surviving longer and being more mobile). As routine analysis for species such as viruses is not carried out, it must be accepted that the extent of pathogen contamination of urban groundwater in sub-Saharan Africa is unknown. Until research establishes the transport and survival characteristics of actual pathogens, establishing guidelines for locating on-site sanitation facilities in relation to groundwater resources (with the aim of avoiding pathogenic contamination) will be subject to a large degree of uncertainty. Add to this the inherent uncertainty in predicting contaminant transport in weathered mantle systems (due to the high variability in geological, and hence hydrogeological, properties), and it may be postulated that any integrated on-site sanitation and groundwater management scheme will still require on-going monitoring to ensure acceptability. Simply to rely upon a safe distance based on local hydrogeological conditions remains fundamentally unsafe.

Maximizing benefits to public health

Faecal contamination of groundwater is only significant if a threat to human health is posed; it is possible that there may be contamination without posing such a risk (raised nitrate levels, though still complying with water quality standards, and an absence of pathogens). The resource management issue here would be whether the long-term trend was for nitrate levels to exceed quality standards. It is also important to note that research has yet to be carried out correlating the persistence and transport of standard microbial indicators (faecal coliforms and faecal streptococci) with actual pathogens. Whilst there are currently no better alternatives to these standard indicators, the assumption that an absence of indicator species equates to an absence of pathogens may be unsafe. Research at the Robens Centre (in collaboration with Birmingham University) into enterovirus occurrence and transport in groundwater is ongoing.

Whilst it is accepted that the provision of on-site sanitation facilities will have a positive impact on human health, it is equally clear that impacts on groundwater quality will result. Experience has shown that once contaminated, groundwater is often extremely costly to treat . To maximize public health benefits, an integrated approach to sanitation and groundwater management is required, based on a long-term cost-benefit decision-making process. It is vital to this process that further progress is made on the understanding of the persistence and transport of sewage contaminants in groundwater. ■

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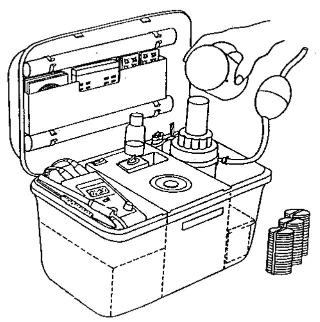

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