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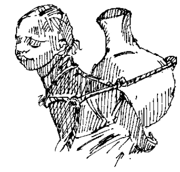
INTEGRATED DEVELOPMENT FOR WATER SUPPLY AND SANITATION



Urban groundwater development in sub-Saharan Africa

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THE URBAN POPULATION of sub-Saharan Africa is growing at a faster rate than in any other region in the world. Efforts to supply potable water to rapidly urbanising centres commonly target groundwater on account of its perceived potability that necessarily avoids the high treatment costs which are associated with surface-water sources. Groundwater is supplied through spring discharges, manually pumped wells (<0.2L/s), and more intensively pumped, production boreholes (>0.2L/s). Despite the costs of constructing groundwater-fed waterworks, the impact and viability of abstraction are unknown and typically subject to cursory assessments prior to development. Furthermore, the susceptibility of groundwater-fed water supplies to contamination in the urban environment, where the subsurface acts not only as a supply of water but also a repository for sewage and industrial effluent, has not been rigorously studied. This paper highlights key uncertainties regarding weathered aquifer systems in sub-Saharan Africa such as hydraulic conductivity, aquifer storage, recharge, contaminant attenuation and drawdown due to pumping which affect the development of groundwater in the urban environment. Recommendations for research to improve understanding of urban groundwater development in this setting are provided.

Development of urban water supplies

Towns and cities in sub-Saharan Africa are in a period of great transition. Despite the fact that sub-Saharan Africa is one of the least urbanised areas in the world (Clark, 1998), it is where urban growth is most rapid. This shift (Figure 1) is driven by dramatic increases in population and a steady migration of rural dwellers to the urban environment (White, 1989). Along with rapid growth in urban populations, there is a commensurate rise in demand for potable water that typically far exceeds the capacity of existing facilities. Development and expansion of urban water supplies are required quickly and at a minimum of cost. The user community is increasingly being asked to pay for and manage its water supply so simple low-cost technologies are necessary not only to facilitate the adoption of the water supply but also to promote its financial and technical viability.

The stringent criteria, highlighted above, for developing urban water supplies in sub-Saharan Africa appear to be met by groundwater. Groundwater is often potable, at source, thereby avoiding the cost and technical requirements of treatment. In most environments, groundwater is also widely distributed and enables the source to be situated close to the demand. This reduces the cost of pipeworks and permits a desirable level of flexibility in rapidly urbanising centres that are characterised by a proliferation of unplanned, low-income settlements. Development of groundwater-fed water supplies which includes the protection of spring discharges and the drilling of boreholes, seems furthermore, to be relatively simple and well understood. In practice however, urban groundwater development is complicated by highly variable hydrogeological conditions and management of this resource is fraught with uncertainty. This latter issue is of fundamental and perhaps ethical importance as communities pay for and adopt groundwater-fed water supplies for which the viability and susceptibility to contamination are very poorly understood. This paper gives an account of current knowledge of the dominant aquifer in this region and highlights key uncertainties related to urban groundwater development. Recommendations for further research are also provided.

Hydrogeological environment - deeply weathered crystalline rock

Much of sub-Saharan Africa is underlain by Precambrian crystalline rock (Figure 1). These formations have been subjected to long-term weathering which is evident from thick mantles of weathered rock that overlie bedrock. Aquifers occur in the fractured bedrock and at the base of the unconsolidated overburden (Figure 2) where coarser bedrock fragments predominate (Taylor and Howard, 1999a). Due, in part, to the urgent need for which urban water supplies and to presumptions regarding the distribution of groundwater and its long-term viability, only cursory assessments of groundwater in this environment are conducted prior to development. There is, consequently, very limited understanding of (i) the impact of urban groundwater development on the subsurface environment, (ii) the long-term viability of this resource and (iii) the susceptibility of constructed sources to contamination.

Impact of groundwater abstraction

The hydraulic impact of groundwater abstraction on the subsurface environment depends upon the transmissivity (T) and storage (storativity, specific yield) of the aquifer as well as the applied pumping rate. To date, only a limited number of hydrogeological studies in sub-Saharan Africa have been published but these show that aquifers in the overburden and bedrock are heterogeneous and anisotropic. Estimates of transmissivity commonly vary over

Table 1. Transmissivity determinations in fractured crystalline rock.

T range (m^2/d)	No. sites	Location	Ref.
5 - 60	25	Botswana	1
0.8 - 90	129	Zimbabwe	2
0.07 - 250	65	Uganda	3-5

(1) Buckley and Zeil (1984)
(2) Houston and Lewis (1988)
(3) Howard and others (1992)
(4) Taylor and Howard (1998)
(5) Taylor and Howard (1999b)

Table 2. Transmissivity determinations in the weathered mantle (regolith).

T range (m^2/d)	No. sites	Location	Ref.
0.2 - 20	215	Malawi	1
0.04 - 170	45	Uganda	2-4
1 - 60	91	Zimbabwe	1

(1) Chilton and Foster (1995)
(2) Taylor and Howard (1995a)
(3) Taylor and Howard (1998)
(4) Taylor and Howard (1999b)

three or more orders of magnitude both spatially (Tables 1 and 2) and vertically within each aquifer (Howard and others, 1992; Taylor and Howard, 1999b). The storage properties of each aquifer unit are undefined. Fractures in the crystalline bedrock are, nonetheless, often discontinuous and inherently possess such a low storativity that prolonged or intensive abstraction from this aquifer depends upon leakage from the more porous overburden (Taylor and Howard, 1998; 1999b). Production borehole

Table 3. Estimates of groundwater recharge in sub-Saharan Africa.

Estimate (mm/yr.)	Method	Location	Ref.
172	baseflow sep.	Ghana	1
50 - 60	soil infiltration	Kenya	2
10-16	Cl mass balance	Tanzania	3
15-120	*several*	Uganda	4
80 - 281	soil moisture bal.	Zambia	5
12	Cl mass balance	Zimbabwe	6

(1) Asomaning (1992)
(2) Singh and others (1984)
(3) Nkotagu (1996)
(4) Taylor and Howard (1999c)
(5) Houston (1982)
(6) Houston (1990)

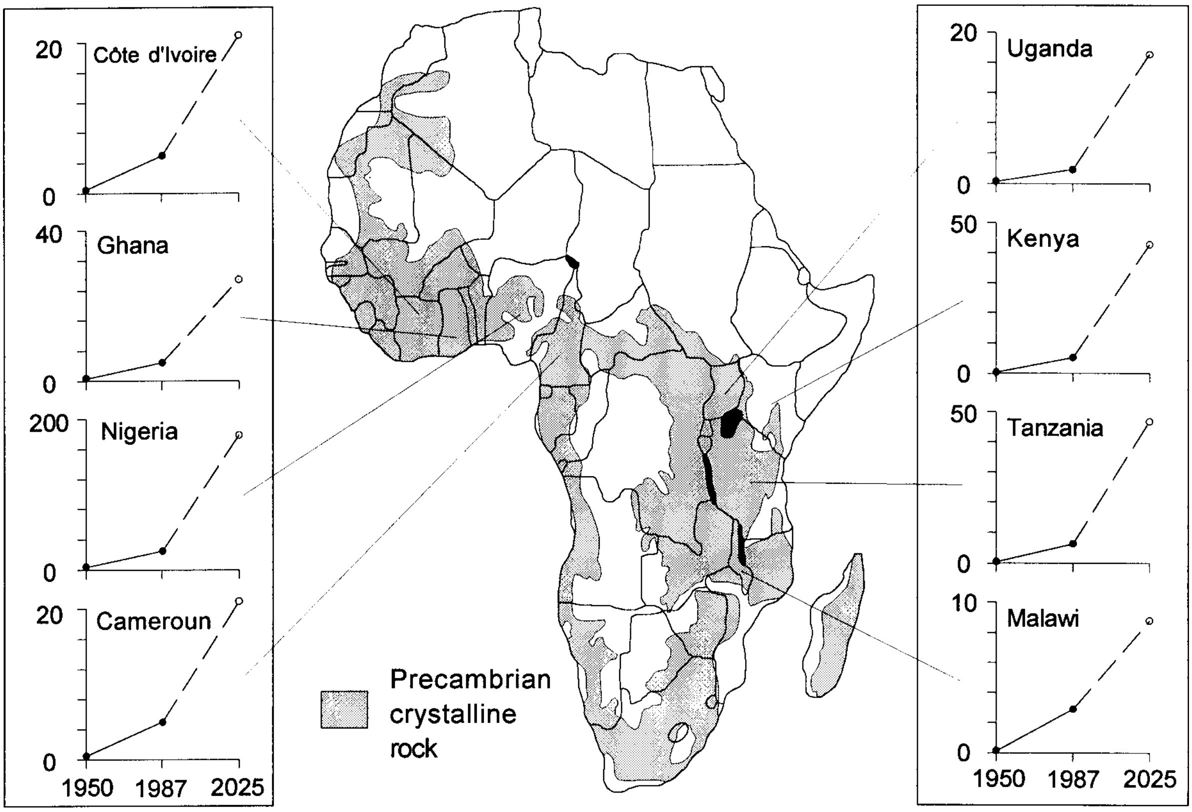

Figure 1. Urban population growth (United Nations, 1987) and the distribution of Precambrian crystalline rock in sub-Saharan Africa (Key, 1992). Plots are of urban populations in millions versus time: 1950; 1987 (solid line) and 2025 (projected, dashed line).

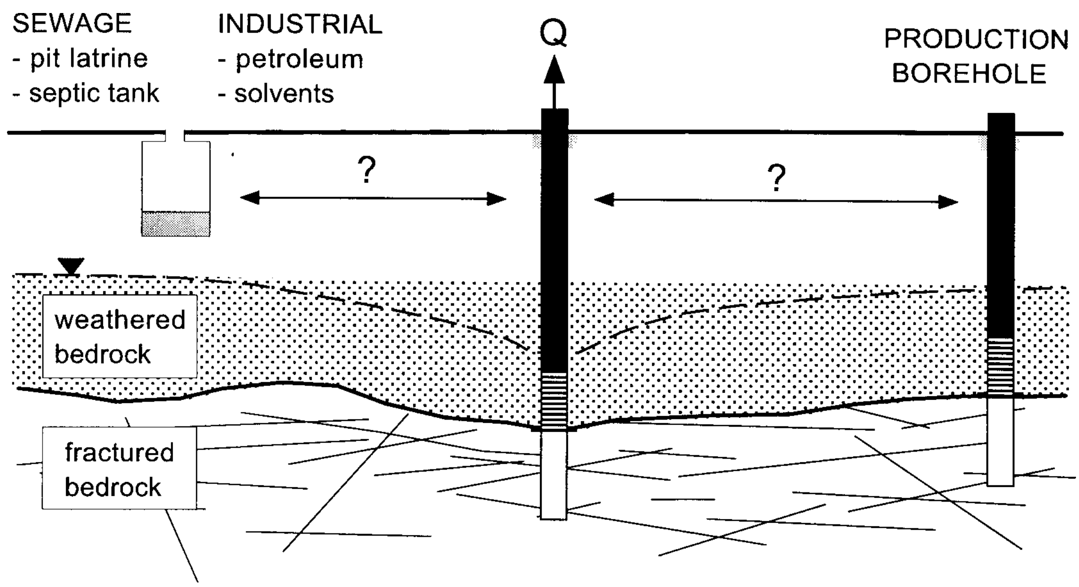

Figure 2. Cross-sectional representation of the overburden and bedrock aquifers including potential contaminant sources and competitve abstraction points

designs for groundwater-fed piped water supplies recognise this fact and typically impose a connection between the aquifers by drawing groundwater from both units (Figure 2). During a recent long-term (5 day) pumping test in the overburden aquifer in Uganda, one of the first reliable estimates of specific yield (0.10) for this aquifer was derived from drawdown recorded in an adjacent monitoring well (Taylor and others, 1999) . Until further research of this kind is conducted, the distance, even roughly, that is required between a pumping borehole and an adjacent waterpoint to prevent competitive abstraction from an adjacent borehole or undesirable reductions in spring discharges (Figure 2), will remain unknown.

Viability of urban groundwater development

From a resource perspective, the long-term viability of urban groundwater development relies upon regular input of water to the subsurface as groundwater recharge. It should be accepted that groundwater consumption of any magnitude represents a 'debit' from the water balance and subsequent re-routing of the natural flow regime as industrial and domestic effluent (sewage). There is, therefore, no universal concept of 'safe' or 'sustainable' yield and these terms require careful definition. Published studies of groundwater recharge in sub-Saharan Africa demonstrate a wide range of fluxes (Table 3) which depend upon a variety of parameters including precipitation, soil type, evapotranspiration and surface topography, as well as the method used to estimate recharge. Because each method (soil-moisture balance, baseflow separation, chloride mass balance, etc.) functions upon numerous assumptions, recharge estimates require corroboration using several methods. It is worth noting that recent studies show that the rate of recharge depends upon the number and magnitude of heavy rain events (Sandström, 1995; Taylor and Howard, 1996). Therefore, crude recharge estimates which presume recharge constitutes some fraction of the total annual volume of rainfall, are likely to be erroneous. To complicate recharge assessments in urban environments, the extent of impermeable surfaces, which reduce infiltration of rainfall, tends to increase with urban growth. In urban areas with reticulated water and sewerage networks, reduction in rainfall-fed recharge may, however, be supplemented through leakage from buried sewer and pressurised water mains (Lerner, 1986; Barrett and others, 1999a). Despite potentially complex recharge pathways, there is an ecological and, perhaps, legal obligation to assess groundwater recharge and consequently, the reduction in river flow and spring discharges that is expected from the development of urban groundwater.

Susceptibility of urban groundwater to contamination

In sub-Saharan Africa, groundwater-fed water supplies are highly susceptible to contamination in the urban environment because the subsurface is also used as a repository for sewage and industrial effluent. Construction of sewerage networks and wastewater treatment facilities are costly and are generally not included as part of low-cost urban groundwater development schemes. Instead, efforts are directed at developing upon low-cost, on-site sanitation facilities such as pit latrines and septic tanks which rely upon the natural attenuating and degradational properties of the overburden. Sewage-derived contamination of groundwater has, however, been identified (Taylor and Howard, 1995b; Barrett and others, 1999b). Contamination from industrial pollution such as leaky underground fuel storage tanks, which is well documented in more industrialised regions, is unknown in sub-Saharan Africa. Efforts to protect groundwater-fed waterpoints through definition of Wellhead Protection Areas (WHPAs) in weathered crystalline have been made (Taylor and Howard, 1995a). However, until data regarding the dispersivity and effective porosity exist for weathered aquifer systems, and retardation factors for key contaminants in this environment are defined, WHPAs will necessarily be based on numerous crude assumptions and remain highly tentative. Recent work (Taylor and others, 1999) using chloride and bacteriophage as tracers of contaminant transport in weathered aquifers provides an estimate of dispersivity (0.04m) and demonstrates the retardation of bacteriophage, relative to chloride, in the overburden aquifer.

Recommendations for further research

Significant gaps in existing knowledge of weathered aquifer systems and their development in sub-Saharan Africa have been discussed. Recognising that user communities have the long-term responsibility of managing and protecting these groundwater resources, further research is clearly required.

- Long-term (4-7 day) pumping tests are required with drawdown carefully monitored at a network of wells in both aquifers in order to determine the hydraulic impact of urban groundwater development on weathered aquifers.
- Evaluations of groundwater recharge in sub-Saharan Africa commonly lack physical measurements of water movement, particularly in the soil zone. As soil-moisture balance models have been shown to provide reasonable estimates of rainfall-fed recharge, calibration of these estimates with field measurements soil moisture is necessary. Resolution of the contribution of mains leakage to the urban water balance is also required.
- Contaminant / pathogen transport characteristics of weathered aquifer systems are the least well understood. Tracer tests involving chloride, nitrate, and microbial species such as bacteriophage are necessary in order to simulate and estimate contaminant transport in weathered aquifers. There is also a need to investigate the possibilities of viral and industrial contamination (fuel / solvent storage) of urban groundwater.

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