Groundwater use in developing cities: policy issues arising from current trends

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Keywords Groundwater supplies · Urban development · Urban infrastructure · Private groundwater use

Context for policy analysis and definition

Growing importance of urban groundwater use

The objective of this essay is to promote dialogue on important policy issues for urban planning and development arising from increased dependence on groundwater for water-supply provision in developing cities. There is much indirect evidence (although no comprehensive data) to substantiate this trend, which is occurring in response to population growth, increasing per capita water use, higher ambient temperatures and reduced security of river intakes (due to quality degradation and climate change) having been facilitated by the modest cost of water wells and the fact that 'aquifers lie within a well's length of users'! (Foster et al. 1998).

Where urban centres are underlain and/or surrounded by high-yielding aquifers, this has allowed water utilities to expand mains water-supply incrementally at modest capital cost—usually resulting in better mains water-service levels, lower water-supply prices and less private in-situ use. However, there are rarely sufficient groundwater resources within urban areas themselves to satisfy municipal water-supply demands and resource sustainability (both quantity and quality) will often become an issue.

Growth in urban groundwater use is not restricted to cities with ready access to high-yielding aquifers but also widely occurs where the utility water supply is imported from considerable distance from a major surface water source. Here, private in-situ water-well construction has often increased rapidly as a result of poor (present or historic) municipal water-service levels and/or high water-supply prices. For example (Foster et al. 2010):

- In Peninsular India, water well use for urban residential self-supply is ubiquitous in the face of very poor utility water services (often 1-in-24 hours or less) and greatly reduces dependence on expensive tankered water supplies.
- In Brazil many cities experienced major private water-well drilling 15–20 years ago, in response to water-supply crises during extended drought, but such water wells continue because they provide a lower-cost water supply.
- In Sub-Saharan Africa, despite much higher unit costs of drilling, water wells (for direct water collection or reticulation to standposts) are widely the fastest growing source of urban water supply in the struggle to meet burgeoning demand.

Appraisal of groundwater: sanitation nexus

Urban groundwater quality is widely threatened by inadequately controlled pollution pressures, especially given the close connection between wastewater handling, disposal or reuse and underlying phreatic groundwater (Howard 2007). In-situ sanitation of urban areas presents a significant groundwater quality hazard, which must be recognised and managed. The hazard is further accentuated because self-supply from groundwater is generally more intensive where access is easiest—namely in the presence of shallow unconfined aquifers, which are the more vulnerable to pollution from the land surface.

In most aquifer types, except the extremely vulnerable, there will be sufficient natural groundwater protection to

Received: 12 April 2010 / Accepted: 15 November 2010
Published online: 17 December 2010

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 DOI 10.1007/s10040-010-0681-2

eliminate faecal pathogens in percolating wastewater from in-situ urban sanitation although the hazard can increase markedly with sub-standard water-well construction and/ or certain types of informal or illegal sanitation. However, elevated concentrations of N compounds (usually nitrate) and dissolved organic carbon (DOC) in groundwater will also be present to varying degrees according to the population density served by in-situ sanitation (Reynolds et al. 2002), and will persist (although generally to lesser degree) at depth in the aquifer. Such groundwater pollution widely persists for years after the source is removed, for example, by installation of main sewerage or another alternative sanitation system.

Groundwater contamination can be much reduced by dry or eco-sanitation units, in which urine is separated from faeces and not discharged to the ground. The deployment of such units is highly recommended for new urbanisation overlying a shallow aquifer, but has limitations as a universal solution to urban groundwater contamination since it is difficult to imagine retro-installation in large numbers of existing properties given the current capital cost of US$ 900/ unit and they will be unsuitable for certain cultural groups who use water for anal cleansing.

Policy issues relating to municipal groundwater use

Integrating groundwater into infrastructure decision-making

An integrated approach to municipal water services and urban development is required to avoid costly problems—and some of the main policy issues arising in relation to municipal groundwater use are given in Table 1. In developing cities, a frequent concern is that too much public water-supply abstraction is concentrated within urban municipal limits, leading to deep unstable cones of piezometric depression and causing secondary problems (induced pollution of contaminated surface water, saline-water intrusion and land subsidence).

Given the continuously evolving groundwater dynamics in urban areas, it is prudent to take an adaptive approach to resource management guided by numerical modelling, and based on continuous monitoring of groundwater levels and quality trends. This should permit evaluation of future scenarios and lead to more robust and sustainable solutions to municipal water supply (often involving conjunctive use of groundwater and surface water resources). In some cases, there may be a need to consider the potential loss of water-supply access of dug wells (on which poor marginalised urban dwellers depend) in areas of very shallow water table.

In cities with high dependence on groundwater, all reasonable opportunities for aquifer recharge enhancement should be pursued through infiltration from roofs/paved areas and collection of flood runoff to recharge basins/ponds. Much incidental recharge is often occurring by infiltration from stormwater drains and soakaways (Zhang and Kennedy 2006), although these need to be properly designed and maintained to operate as recharge enhancement structures and to minimise groundwater pollution risk.

Proactive land-use management to reduce groundwater pollution threats

To control or reduce the pollution threat to municipal water wells, it is essential to take a proactive approach on urban land use involving:

- Prioritising recently urbanised areas for coverage by mains sewerage or limiting density of new urbanisations with in-situ sanitation to contain nitrate contamination to tolerable levels
- Establishing municipal water-well protection/exclusion zones around any municipal sources that are favourably located to take advantage of parkland or low-density housing areas
- Using groundwater pollution hazard assessments to identify municipal water wells with an especially high risk of contamination from toxic synthetic organic substances

Table 1 Summary of major policy issues related to urban municipal groundwater use

Issue	Implications
Municipal water-supply benefits and risks	Groundwater use for municipal water supply has many benefits (including capacity to phase investments with growth in demand and high quality, requiring minimal treatment), but it comes with a need for integrated planning of urban land use, effluent discharges and solid-waste disposal to avoid insidious and near-irreversible pollution
Protected municipal wellfields	Since some degradation of groundwater quality in urban municipal water wells due to persistent pollutants is likely, it is necessary, in parallel, to develop ‘external wellfields’ and declare their capture areas as ‘protected zones’ to guarantee that a proportion of the total resource is of high quality and available for dilution or substitution
Conjunctive use with surface water	The rates of replenishment of aquifers may not be sufficient to meet the demands of larger cities sustainably and in this situation it is preferable to use available groundwater resources and large storage reserves conjunctively with surface-water sources—conserving groundwater for use during drought and other emergencies
Future drainage problems	Avoiding radical reductions in municipal water-well use (due to an increased offer of subsidised mains water supply or to quality deterioration/pollution rumours) with water-table rebound (to higher than the pre-urbanisation condition), which could result in potentially serious sanitary problems and infrastructure damage in lower-lying areas

 DOI 10.1007/s10040-010-0681-2

- Avoiding the creation of 'upstream' polluting discharges and making the best 'downstream' use of wastewater without compromising groundwater quality in existing municipal water wells and wellfields (Foster and Chilton 2004).

Development of protected 'external' municipal wellfields

Cities dependent upon groundwater for municipal water supply widely encounter problems of increasing and/or elevated concentrations of residual persistent urban contaminants (notably nitrate). The most cost-effective way of dealing with this type of problem is by dilution through mixing, which requires a secure and stable source of high-quality supply such as that produced from a suitably located and carefully protected 'external wellfield'.

In the developing world, promotion of external wellfields often encounters impediments related to fragmented administrative powers for land-use and pollution control between the numerous municipalities that often comprise metropolitan areas. There are no established procedures or incentives for the resource interests of an urban municipality to be assumed by a neighbouring rural municipality, such that adequate protection can be offered for the capture area of the external wellfield. This policy issue needs to be addressed as a priority.

Policy issues relating to urban private self-supply from groundwater

Evaluating the benefits and risks of in-situ residential use

In the developing world, in-situ private self-supply from groundwater widely represents a significant proportion of water actually received by users, and its presence, thus, has major implications for municipal water utilities. The motivation for the initial private capital investment in self-supply is usually triggered during periods of partial failure or highly inadequate municipal water-supply service—essentially as a coping strategy. However, continued use is essentially a cost-reduction strategy, since the actual (or perceived) cost of in-situ groundwater is lower than that of the applicable municipal water-supply tariff. In some cases, the initial investment itself is justified by cost reduction, where water well capital costs are modest when compared to cumulative municipal water-supply tariffs.

A broad assessment of private in-situ residential use from the public-administration perspective (Table 2) makes it evident that the weighting of pros and contras will vary considerably with hydrogeological setting—making policy formulation subject to local conditions.

Formulating balanced policy on urban in-situ residential use

The major policy question which emerges is whether (and under what circumstances) the risks (or inconveniences) of private in-situ residential water supply justify attempts to ban such use of groundwater. Historically, such bans (operated through local decrees) have been introduced to address specific problems:

- In eighteenth century London (UK), for specific faecally contaminated communal water wells to control and eliminate a major cholera outbreak
- During the 1980s in Caribbean capitals such as Nassau (Bahamas), with aquifers highly vulnerable to faecal contamination, as a precautionary measure to reduce the possibility of transmission of a continental-scale cholera epidemic
- In Bangkok (Thailand) during the 1990s, to reduce the level of groundwater abstraction from a highly confined aquifer which was causing land subsidence in areas exposed to tidal flooding (Buapeng and Foster 2008).

In these cases, the risks were such as to justify the measures taken. But the *Lei Federal de Saneamento 11.445* of Brazil (2008), a law establishing national guidelines for urban sanitation, is more questionable, some interpretations making all domestic urban groundwater use illegal, but in others, allowing new water wells only in areas where mains water supply is not freely available. The constitutionality of this law is under

Table 2 Advantages and disadvantages, from a public administration perspective, of urban private in-situ residential water supply from groundwater

Pros	Contras
Greatly improves access and reduces costs for some groups of users (but not directly for the poorest because without help they cannot generally afford the cost of water-well construction)	Interactions with in-situ sanitation can cause a public-health hazard and could make any waterborne epidemic more difficult to control
Especially appropriate for 'non quality-sensitive' uses—could be stimulated in this regard to reduce pressure on stretched municipal water supplies	May encounter sustainability problems in cities or towns where principal aquifer is significantly confined and/or mains water-supply leakage is relatively low
Reduces pressure on municipal water-utility supply and can be used to meet demands whose location or temporal peaks present difficulty	Can distort the technical and economic basis for municipal water-utility operations, with major implications for utility finance, tariffs and investments
Incidentally can recover a significant proportion of mains water-supply leakage	

challenge in some Brazilian states and it is likely to be abandoned because:

- If implementation is attempted it would present an intolerable strain on the municipal water-supply system in some cities
- It does not represent good use of scarce water resources, including the recovery of physical mains leakage losses which are very high in some cities
- It will further increase the illegality of urban private water-well use making the planning and management of urban water-supply provision more difficult
- It is unrealistic since water wells can be constructed in a few days, and once constructed, they can prove very difficult to identify
- It runs the risk of promoting abandonment of groundwater pumping with water-table rebound (which in low-lying cities could imply major costs).

Where the municipal water utility has excess developed resources and is subject to commercial incentives (putting financial consideration before social service), it may try to market substitution of mains water supply for private self-supply (to multi-residential properties, commercial and industrial users) rather than deploying its available surplus to improve the water supply to low-income areas, and this may distort a rational policy dialogue.

The large majority of private urban water wells in the developing world are either illegal or unregulated, a situation that is counterproductive for both the private user and the public administration; a more constructive approach would be (as far as possible and appropriate) to legalise such use. If the situation can be regularised it has a number of benefits:

- Urban groundwater users can receive sound information and advice relevant to their use (pollution risks/alerts, use precautions, etc.) and be protected against the impacts of excessive total abstraction and/or inadequate well spacing.
- Sanitary completion standards for water wells can be improved and their potential interaction with in-situ sanitation units (latrine, cesspools, septic tanks, etc.) reduced.
- The public administration will obtain better data on private use and have better relations with private users, which will, in turn, result in sounder groundwater resource assessments and more realistic municipal water-supply investments; ideally also public authorities should undertake periodic water analysis as a service to legal urban groundwater users (who pay a modest annual ‘water-resource fee’).

The most successful attempts to measure and then to regularise private use of urban groundwater have been in places (such as Recife and Fortaleza in Brazil) where the municipal utility has (understandably) argued for the levying of a volumetric water charge in respect of mains sewer use by private groundwater abstractors. This has resulted in municipal utilities drawing up comprehensive inventories of private water wells on multi-residential, commercial and industrial properties, and charging can be nominal by type/size of property or by metering which also generates valuable data for management and planning purposes.

Concluding remarks

Hydrogeological understanding of urban areas has increased greatly in the last 20 years, despite the inherent complexity and variability of such areas. But the application of this understanding to improve the security and efficiency of groundwater use for urban water-supply in the developing world is seriously impeded by some critical institutional factors and administrative arrangements which have been highlighted in this essay. Groundwater specialists need to be much more articulate in arguing for the reform of these arrangements and removal of these impediments if hydrogeological science is to play its proper role in urban infrastructure and land-use decision-making.

Acknowledgements This essay is a by-product of efforts by the World Bank Groundwater Management Advisory Team (GW-MATE), directed by the first author, to assist various national government agencies in developing nations (most notably those of Brazil and India) to formulate more appropriate policy on urban groundwater use. This work has benefited greatly by its presentation and discussion at the following series of regional or thematic conferences, co-sponsored by the International Association of Hydrogeologists (IAH) : Kampala (Uganda) in June 2008, Hannover (Germany) in October 2008, Natal (Brazil) in November 2008, Bangkok (Thailand) in February 2009 and Bogota (Colombia) in July 2009.

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 DOI 10.1007/s10040-010-0681-2