Sustainable groundwater use for developing country urban populations: lessons from Brazil

Rapid urbanisation in Brazil has led to heavy reliance on groundwater supplies, and as city growth has outstripped water supply and sanitation coverage, private wells are an important component of water supply. **STEPHEN FOSTER** and **RICARDO HIRATA** discuss the challenges surrounding urbanisation and sustainable groundwater management, including self-supply from private wells, using the example of Brazil's expanding urban population to show how groundwater reserves in developing countries can be secured to provide a safe, long-term water supply.

The 2010 census of Brazil revealed that 84% of the population of 191 million are urban dwellers – with some 77 million living in 100 cities of more than 0.25 million inhabitants. However, rapid urbanisation and steady economic growth in recent decades have not generally been accompanied by parallel rates of investment in water supply and sewerage infrastructure. Overall, these services reach only 79% and 44% of urban dwellers respectively.[1]

In larger metropolitan areas surface water is usually the major source of water supply, but it often has to be transported over considerable distances from outside the immediate watershed through increasingly complex and costly systems. But where cities are located close to highly productive aquifers (e.g. Natal, Ribeirão Preto, Belém, Maceió, Recife and Porto Velho) water service utilities depend heavily upon groundwater, and it is the sole source of mains water supply for 39% of urban municipalities. Elsewhere, utilities use groundwater as a complementary source, especially to supply peri-urban neighbourhoods. Thus, groundwater plays an important role in the public water supply of 52% of urban municipalities (equivalent to about 35% of the urban population) by means of 430,000 wells, with some 10,800 new wells per year, predominantly in small- to medium-sized towns.[2]

What is equally significant, but rarely acknowledged, is the phenomenon of private self-supply from groundwater, which widely represents a significant proportion of the water supply received by urban residential, commercial and industrial users.[3] Moreover, some major cities (e.g. São Paulo and Brasilia) have public water supply systems operating at the limit of their capacity and any increase of production will require major capital investment for surface water transfer from distant watersheds. In such cases, private wells form an important component of supplying additional demand and currently underpin water supply security.

Threats to groundwater use sustainability

Groundwater and urbanisation are intimately linked (Figure 1). Inadequately controlled groundwater abstraction can deplete aquifers, but the effect of urbanisation processes on the volumetric rates of local groundwater replenishment (and thus resource availability) can often be positive, due to recharge from water main leakage.[3] However, the widespread existence in urban areas of (potentially controllable but often still uncontrolled) contaminant discharges from leaking sewers poses a serious threat to groundwater quality, whose impact varies widely with natural aquifer pollution vulnerability.[3]

Thus, urban groundwater use sustainability is influenced by a complex array of interrelated decision making, which is rarely viewed on an integrated basis, but includes:

- Well drilling and use authorisation (by state-level government agencies)
- Provision of water supplies (by water utilities)
- Urban land use planning and authorisation (by municipal government offices)
- Installation of sewered sanitation (by water utilities)
- Disposal of liquid effluents and solid wastes (by environmental authorities, public health departments and water utilities).

Policy and management issues

The main issues related to urban groundwater use are summarised in Table 1.

Integrating groundwater into urban land and water management

There are numerous simple practical measures that could be undertaken as necessary by public administrations to improve the sustainability of groundwater use, including:

- Declaration of 'critical areas' where groundwater extraction must be constrained for the 'common good', through specific bans or conditions on new or replacement wells
- Prioritisation of selected recently urbanised districts for mains sewer coverage to protect their good quality groundwater from gradual degradation, and limiting the density of new urbanisation served by in-situ sanitation to contain groundwater nitrate contamination
- Establishment of groundwater source protection zones, around all utility wells that are favourably located to take advantage of parkland or low-density housing areas
- Imposition of better controls on the handling and disposal of industrial effluents and solid wastes to reduce the risk of aquifer pollution

In addition, and most importantly, the establishment of water utility wellfields outside cities (with capture areas being declared as ecological or drinking water protection zones) needs to be promoted as 'best engineering practice'. In the past the development of such wellfields has rarely occurred – because they are either not conceived as beneficial or because of administrative impediments related to fragmented powers for land use and pollution control, and between the numerous municipalities that comprise 'metropolitan areas'. These need to be addressed and it should be possible for procedures and incentives to be identified where the groundwater resource interest of a given urban municipality can be assumed by a neighbouring rural municipality, so that adequate protection to such investments can be provided.[3]

Given the continuous evolution of groundwater use in urban aquifers, and the significant hydrogeologic uncertainty in predicting its precise behaviour, it is desirable to adopt an adaptive management approach to urban groundwater resources – based on the continuous monitoring of groundwater levels and quality, and guided by a periodically updated numerical aquifer model. This could be used for evaluation of future scenarios and to facilitate the definition of 'capture zones' for public wells that require protection and / or for the identification of the most suitable areas for 'external wellfield' construction.

Promoting conjunctive use for water supply security

Groundwater and surface water present complementary characteristics and, as far as feasible, should be used conjunctively to overcome urban water supply problems and improve urban water supply security. Although 13% of Brazilian cities use both resources for public water supply, this has (for the most part) not been planned in an optimal way. Most commonly, utilities only construct new wells for base-load supply operation, especially in newly urbanised peripheral zones. The possibility of using natural groundwater storage across entire urban areas to provide greater water supply security during droughts is generally overlooked.

Moreover, municipal water utilities tend to focus mainly on well engineering and (with a few notable exceptions) have shown little interest in understanding and managing the local resource base – thus the criteria for well siting usually relates solely to meeting immediate water supply requirements at minimum cost and do not consider the optimal use of groundwater resources. This must change to meet future urban water supply challenges.[4]

Private groundwater use – maximising benefits whilst minimising risks

The initial investment of private capital for in-situ urban self-supply from groundwater is usually triggered during periods of partial failure of (or highly inadequate) water supply services, essentially as a 'coping strategy', but it is continued by some users after the supply improves, as a cost-reduction strategy, since the unit cost of groundwater to private well users is lower that the applicable municipal water supply tariff.[3] Also, many private well operators do not consistently account for their running costs, and on the outskirts of many cities public water supply coverage may not yet be available, and private groundwater use may be the only feasible alternative.

A broader assessment of urban well use practices is thus required by public administrations to formulate a balanced policy on private groundwater resource use (Table 2). If this assessment indicates serious hazards from groundwater pollution or overexploitation, the following management actions could be considered (as appropriate to local conditions):

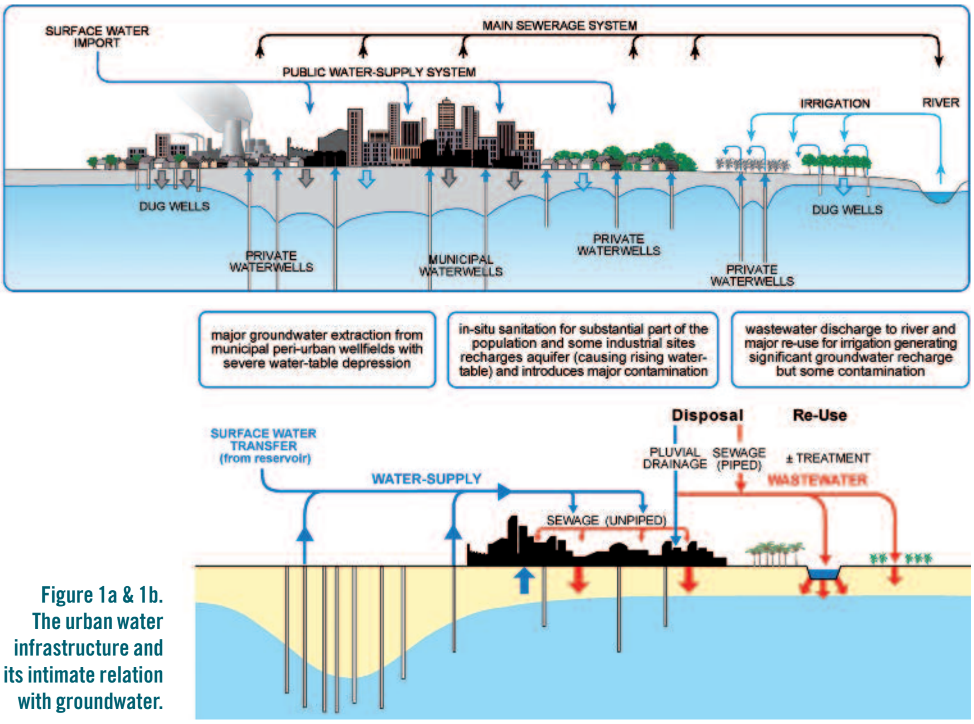


Figure 1a & 1b. The urban water infrastructure and its intimate relation with groundwater.

- Registering all multi-residential, commercial and industrial users (directly by metering or indirectly by estimated sewer discharge) for abstraction charges, so as to constrain use
- Issuing of water quality advice and / or health warnings to private well operators, and in severe pollution situations declaring sources unsuitable for potable and sensitive uses

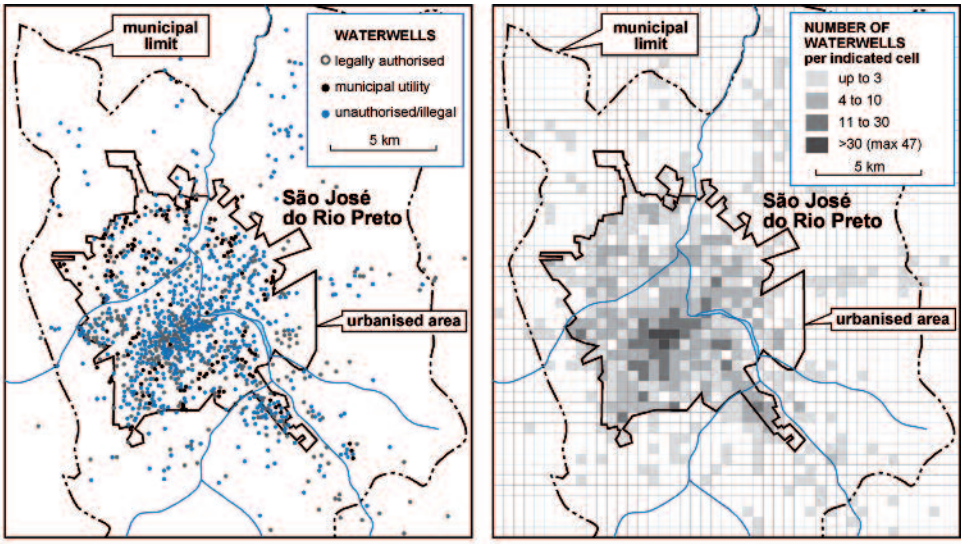
An important emerging policy question is under what circumstances the risks or inconveniences of private residential self-supply from groundwater in the urban environment might justify an attempt to ban such practice completely. Historically, urban private well use bans (or severe constraints) have been necessarily introduced as part of an effort to address the control of a specific waterborne disease outbreak (e.g. cholera in 19th Century London or in some Caribbean ports in the 1980s), or land subsidence and increased flood risk due to excessive groundwater abstraction (e.g. Bangkok and Jakarta since the 1990s).

In Brazil, groundwater abstraction constraints are currently imposed in specific zones of Ribeirão Preto and São José do Rio Preto (both in São Paulo State) to address problems of local overexploitation and continuous aquifer depletion (Figure 2), but the restrictions apply to all classes of use. In São Paulo City use constraints are in place for zones of (known to be hazardous) industrial groundwater contamination, but attempts have been made to keep most existing wells functioning, since complete replacement by mains water supply is not possible.

Private well use in urban areas poses a difficult challenge for water resource agencies in developing nations.[3] Modern well drilling techniques provide rapid access to groundwater for modest capital investment, making possible the existence of large numbers of users whose 'hardware' is soon hidden from view. To date, effective management of this situation has often been beyond the capacity of public administrations. Most private wells are thus at best unregulated and at worst illegal – which in the longer-run benefits neither the public administration nor the private user. To address this situation it will require the strengthening of the professional capacity and political mandate of water resource agencies, with judicious use of sanctions, but with the greatest emphasis on gaining civil society commitment through effective participatory mechanisms with incentives for self-monitoring.[5,6]

Concluding remarks

The importance of groundwater for urban water supply in Brazil is not yet reflected by sufficient investment in the management and protection of the resource base. Government, at all levels from municipal through state to federal, need to seek realistic policies and effective institutional arrangements to address these issues, and they will require the support of the political leadership, improved communication with and participation of stakeholders, and to be informed by sound hydrogeological science to meet this challenge.



GROUNDWATER CONTROL ZONE	WATER RESTRICTIONS
Low	new wells permitted (>600m distance from any public water-supply well)
Moderate	only new public water-supply well permitted
High	only replacement public water-supply wells permitted

Figure 2 : Groundwater restriction zones based on waterwell density in São José do Rio Preto.

In Brazil, state water resource agencies and river basin stakeholder committees are in the process of development nationwide, and the latter must be the initial forum for the necessary dialogue to improve the incorporation of groundwater resources into watershed planning generally. However, the members of such committees rarely have enough knowledge of groundwater issues or system behaviour and could reasonably be expected to delegate action to a specialist support group.[6] In this context the dynamics of urban development and its intimate relation with groundwater are such as to merit the formation of specifically-funded urban groundwater consortia for larger cities (involving the municipal government land use department, state government groundwater resource agency, the water service utility, local environment and public health departments, water user representatives and groundwater specialists from academia).

It is believed that the issues and approaches described in this article will find immediate resonance in the urban areas of numerous other countries in Latin America and South and East Asia, and increasingly in the future in Sub-Saharan Africa.●

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Table 1. Summary of the major policy issues associated with urban groundwater

Issue	Implications
Municipal water supply benefits	Groundwater use for municipal water supply has many benefits (including capacity to phase investments with demand growth and high quality requiring minimal treatment) but it usually comes with a need for integrated planning of urban land use, effluent discharges and solid waste disposal to avoid insidious and near irreversible degradation by pollution.
Protected municipal wellfields	Since some degradation of groundwater quality in urban municipal 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.
Private in-situ use benefits & hazards	Private in-situ use for urban residential, commercial and industrial water supply can have significant benefits not only to the user but to the community (reducing demand on utility supplies, providing water in areas or volumes difficult for the mains network, not using high quality mains water for garden irrigation and commercial / industrial cooling). These benefits need to be valued in terms of the marginal cost of providing a volumetrically equivalent alternative water supply – but poorly constructed and shallow urban wells can present a significant health hazard due to faecal contamination (in serious waterborne disease outbreaks) or chemical contamination (especially in areas without mains sewerage).
Water sector financial considerations	Widespread self supply can have major financial implications for water utilities, in terms of loss of revenue from potential water sales, difficulties of increasing average tariffs and recovering sewerage charges from those operating private wells.
Future drainage problems	Should abstraction radically diminish (due to an increased offer of subsidised mains water supply or to quality deterioration or pollution rumours), groundwater levels will rise progressively to higher than the pre-urbanisation condition, potentially with serious sanitary problems and infrastructure damage in lower lying areas.

Table 2 : A public administration overview of the pros and cons of private residential in-situ urban water supply from groundwater

Pros	Cons
Greatly improves access and reduces costs for some groups of users (but not generally for the poorest because without help they cannot afford the cost of well construction except in very shallow water-table areas).	Interactions with in-situ sanitation can cause a public health hazard and could make any waterborne epidemic more difficult to control, and also potentially hazardous where serious natural groundwater contamination is present.
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 the 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 difficulties.	Can distort the technical and economic basis for municipal water utility water operations with major implications for utility finance, tariffs and investments.
Incidentally can recover a significant proportion of mains water supply leakage.	

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About the authors

Stephen Foster has wide experience of groundwater management and protection in the EU and worldwide. He served as World Health Organisation-Groundwater Advisor for Latin America & Caribbean during 1986-89, World Bank-Groundwater Management Advisory Team (GW-MATE) Director during 2001-10, and is International Association of Hydrogeologists (IAH) Immediate Past President.

Ricardo Hirata is Professor of the University of São Paulo, Brasil and Director of the Groundwater Research Center (CEPAS). He has very extensive experience of groundwater evaluation and protection throughout Latin America and was a member of World Bank GW-MATE.