

Perspective

Global Policy Overview of Groundwater in Urban Development—A Tale of 10 Cities!

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Abstract: Urbanisation is the predominant global phenomenon of our time. This overview provides an assessment of the trends in both public and private use of groundwater for urban water-supply in 10 developing cities and their policy implications, which is based on the global experience during 2001–2012 of the World Bank—Groundwater Management Advisory Team (a multi-disciplinary team of groundwater specialists working long-term for the World Bank, with special funding principally from the Netherlands Government supplemented by the United Kingdom and Denmark), together with subsequent follow-up enquiries. The strategic assessment analyses both the benefits to water users and the broader community of groundwater use, and the associated risks in terms of (a) compromising resource sustainability, (b) impacting the built infrastructure, (c) public-health hazards arising from widespread groundwater pollution and (d) the economic distortion of water-sector investments.

Keywords: urban development; developing cities; groundwater policy; integrated management

1. Objective of This Overview

In the course of providing data analysis and investment advice to potential World Bank-funded urban water-supply and water-resource projects worldwide, the World Bank—Groundwater Management Advisory Team (GW-MATe) collected extensive evidence of fast-increasing dependence upon groundwater (for public and/or private water-supply) with both benefits and hazards to water users and the broader community, in the 10 developing cities that are the focus of this paper (Table 1). The detailed results of the GW-MATe technical surveys and policy diagnostics are available elsewhere [1,2] and thus the primary objective of the present paper is to provide a concise global overview of the results of that work, without entering into detail about each of the 10 cities nor about the methodologies employed.

Table 1. Summary of groundwater concerns and management approaches in 10 cities assessed.

CITY Country	POPULATION * Utility Water-Supply	MAIN ISSUES AND CONCERNS	MANAGEMENT APPROACH
BANGKOK Thailand [3]	8 million; 1200 Ml/d (5%–10% groundwater)	Municipal groundwater use constrained but massive private waterwell construction into the 1990s, causing land subsidence and other impacts	Water utility groundwater use drastically reduced; groundwater resource regulator empowered to control private waterwell use

Table 1. Cont.

CITY Country	POPULATION * Utility Water-Supply	MAIN ISSUES AND CONCERNS	MANAGEMENT APPROACH
LUCKNOW India [1]	3 million; 500 Ml/d (50% groundwater)	Declining water-table/well yields; in-situ sanitation causing high nitrate levels in a shallow aquifer; uncontrolled private waterwell drilling	Accidental/incidental conjunctive use by the water-service utility since 1973 but groundwater use requires adequate planning and new protected sources
AURANGABAD India [1]	1 million; 150 Ml/d (0% groundwater)	Poor utility water-service led to excessive private waterwell drilling in an aquifer of limited storage and polluted by universal in-situ sanitation	Supplementary water source needed; water-service utility needs to embrace private waterwell use (30+ Ml/d) and prioritise the sewerage system
LIMA Peru [2]	8 million; 1100 Ml/d (30% groundwater)	Declining groundwater levels/reserves and increasing saline intrusion from excessive water utility/industrial abstraction in the 1980s–1990s	The government commissioned a water utility who successfully controlled public/private waterwell use and implemented conjunctive management
BUENOS AIRES Argentina [1]	4 million; 500 Ml/d (20% groundwater) (reduced since 1990)	Utility/industrial waterwell use reduced in the late 1980s (due to pollution fears); strong water-table rebound caused groundwater flooding	Multi-stakeholder task-force on urban groundwater needed; some water-utility pumping must be maintained for water-supply/drainage purposes
NATAL Brazil [1]	1 million; 280 Ml/d (100% groundwater)	In-situ sanitation causing groundwater nitrate pollution widely to 50+ mg/L; seawater intrusion concerns	Water utility prioritising sewage for aquifer protection and harmonising private waterwell use (45 Ml/d)
RIBEIRÃO PRETO Brazil [4]	1 million; 500 Ml/d (100% groundwater)	Groundwater levels have fallen by 50+ m since 1970, with increased pumping costs and some pollution risks	Institutional agreement on urban waterwell drilling ban; improved monitoring and protection measures for public water-supply sources
ADDIS ABABA Ethiopia [5]	3 million; 400 Ml/d (50% groundwater)	Severe water-supply shortage being partly met by new deep wellfield development	Improved monitoring and management of limited groundwater resources needed to avoid conflicts
DAR-es-SALAAM Tanzania [5]	5 million; 350 Ml/d (10% groundwater)	Surface-water sources decreasing in reliability; major private waterwell use (80+ Ml/d) but aquifer widely polluted by in-situ sanitation	Developing major new municipal wellfields in rural areas with favourable groundwater conditions to the south
NAIROBI Kenya [5]	4 million; 500 Ml/d (10% groundwater)	Surface-water sources decreasing in reliability; major private waterwell drilling (90–280 Ml/d) but groundwater levels have fallen by 50+ m	Metering/charging of private waterwells, with a moratorium on drilling and licensing new waterwells

* approximate figure for water-service area (political boundaries render census data inappropriate).

2. Context for Policy Development

2.1. Drivers of Urban Groundwater

Dependence on groundwater for public and/or private water-supply is a fast-increasing phenomenon in developing cities [6–9], which is occurring in response to population growth, accelerating urbanisation, higher ambient temperatures, increasing per capita usage and reduced security of river intakes (due to increased pollution). This global trend has been facilitated by the reducing (and generally modest) cost of waterwell construction [10]. Today many cities—from across the EU and USA to Brazil, China, India, Mexico, Nigeria, Pakistan and Vietnam—exhibit a high level of dependence on groundwater for urban water-supply.

2.2. Major Issues Relating to Increased Groundwater Use

Those urban centres underlain and/or surrounded by high-yielding aquifers (e.g., Bangkok, Lima, Lucknow, Natal and Ribeirão Preto/Table 1) usually have better public water-service levels. However, there are rarely sufficient groundwater resources within urban areas themselves to satisfy the entire water demand of larger cities, and resource sustainability often becomes an issue with serious localised aquifer depletion, potentially causing quasi-irreversible side-effects (such as induced seepage of contaminated water, land subsidence and coastal saline intrusion) [1,11].

This situation is often exacerbated by groundwater quality deterioration due to inadequately controlled urban sanitation, given the close connection of wastewater handling, disposal and re-use with underlying shallow groundwater (e.g., Lucknow and Natal/Table 1). It is thus critical that groundwater quality is systematically monitored, and the risks posed by pollution carefully assessed and acted upon [10].

The use of groundwater is not restricted to cities with ready access to high-yielding aquifers, but also occurs widely where the public water-supply is imported from distant surface-water sources of low reliability and high cost (e.g., Aurangabad, Dar-es-Salaam and Nairobi/Table 1). In this situation, private in-situ waterwell construction often mushrooms, and self-supply from groundwater widely represents a significant proportion of water ‘actually received’ by users (widely 20%–30% of total water-supply and well above 50% in extreme cases).

3. Urban Interactions with Groundwater

Urbanisation modifies the groundwater flow and quality regime in underlying shallow aquifers by:

- substantially increasing recharge rates—since the reduction of infiltrating rainfall through land-surface impermeabilisation almost always is more than compensated for by water-mains leakage, infiltrating pluvial drainage and the incidental ‘return’ of wastewater from in-situ sanitation and sewer leakage, especially where the municipal water-supply is ‘imported from external sources’.
- greatly increased subsurface contaminant load, mainly from in-situ sanitation (in developing cities), and to lesser degree from sewer leakage and casual spillage/disposal of industrial and community chemicals.

These modifications are in continuous evolution. The processes combine to present numerous threats and some benefits for urban groundwater resources [8]—with the threats being more severe where shallow aquifers are used for private in-situ self-supply. In one sense, groundwater systems under cities represent ‘the ultimate sink’ for urban pollutants (with nitrates from wastewater and some synthetic hydrocarbons being very persistent), but in practice the extent to which the contaminant load impacts groundwater will vary widely with the vulnerability of the aquifer system.

In turn, man-made modifications to groundwater regimes can seriously impact urban infrastructure, with the impacts becoming more serious under unstable groundwater conditions:

- falling water-table due to excessive groundwater extraction, leading to land subsidence, building damage and increased surface-water flood risk (e.g., Bangkok/Table 1);
- water-table rebound, if groundwater use is abandoned for some reason such as serious pollution (e.g., Buenos Aires/Table 1), causing basement damage, groundwater flooding to transportation routes, malfunction of septic tanks and excessive inflows to deep collector sewers.

All of these problems can be very costly and surprisingly persistent—and while most are ‘predictable’ in theory, they are rarely ‘predicted’ in practice because of the widespread absence of an institution charged with the oversight and management of urban groundwater.

4. Integrating Groundwater into Urban Water and Land Management

Groundwater is far more significant in the water-supply of fast-developing cities than is widely appreciated, and is also the ‘invisible link’ between various facets of the urban infrastructure. Regrettably, many organisations concerned with urban water-supply and environmental management have a poor understanding of groundwater as a component of the urban water-cycle and one that always needs to be integrated into decisions on urban infrastructure planning and investment, whatever its status.

4.1. Conserving Groundwater Reserves for Water-Supply Security

In future, it will be important for the major groundwater storage of most aquifers to be used to improve urban water-supply security, as part of a strategy to cope with the pressures generated by urban growth and climate change.

First and foremost, there is widely a need to introduce effective demand management measures to constrain unnecessary use and to reduce ‘unaccounted for water’, and these need to be accompanied by managed aquifer recharge (from roof-drainage soakaways, permeable pavements and injection of excess surface water via lagoons or large wells) to maximise urban aquifer replenishment. All of this will require a ‘resource culture’ to be cultivated within water utilities.

Where existing groundwater development is excessive and beginning to cause land subsidence that may threaten the stability of urban infrastructure, there is a need to employ risk assessment techniques to identify potential problems [12,13].

It is important that schemes of conjunctive use of groundwater and surface-water sources (Figure 1) be pursued imaginatively, since most so-called ‘conjunctive use’ currently practised in developing cities amounts to a ‘piecemeal coping strategy’ rather than the more ‘optimised approaches’ that have been successfully implemented in Lima and Bangkok (Table 1).

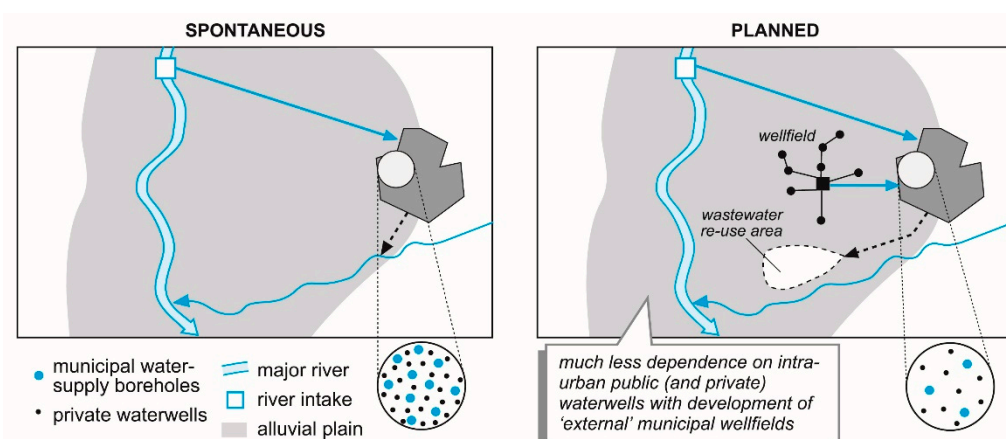


Figure 1. Planned and spontaneous conjunctive use for urban water-supply.

The development of external wellfields for utility water-supply (e.g., Addis Ababa, Dar-es-Salaam and Ribeirão Preto/Table 1) is another much needed policy response for the strategic use of groundwater. Investment in such wellfields and water delivery-mains requires insurance through declaring their ‘capture areas’ as drinking-water protection zones [14,15]. This often encounters administrative impediments related to fragmented powers between the municipalities comprising ‘metropolitan areas’, and improved governance arrangements and economic incentives need to be explored to overcome this problem.

Given the continuous evolution of groundwater use in ‘urban aquifers’, and some hydrogeologic uncertainty in predicting their precise behaviour, it is desirable to adopt an ‘adaptive management approach’ to urban groundwater resources. This should be based on continuous monitoring of groundwater levels and quality, and guided by a (periodically updated) numerical aquifer model.

4.2. Incorporating Groundwater into Sanitation and Drainage Planning

The groundwater–sanitation nexus is extremely relevant in developing nations, where extensive in-situ sanitation presents a significant groundwater quality hazard (Figure 2). It may be decades before the full extent of pollution becomes fully apparent because contamination of large aquifers is a gradual and insidious process. Thus, it is critically important to recognise the incipient signs of groundwater pollution through shallow aquifer monitoring and to put in place groundwater protection measures.

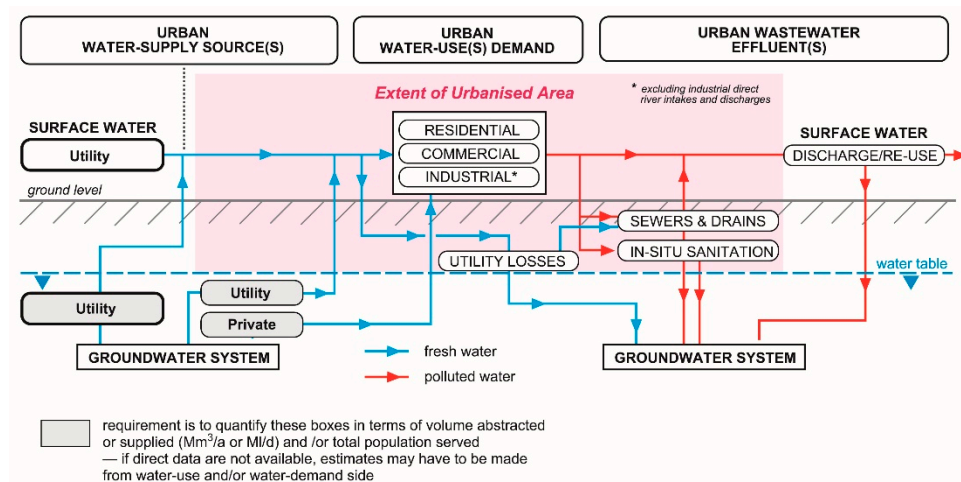


Figure 2. Groundwater relations within the urban water-cycle.

In most settings (except for shallow and vulnerable aquifers), there will be sufficient attenuation capacity to eliminate faecal pathogens from percolating wastewater, but the hazard increases markedly with inadequate waterwell construction and/or poor septage management, which are typical of anarchical fast-growing cities. However, troublesome levels of nitrogen compounds and dissolved organic carbon will arise to varying degrees, depending on the population density served by in-situ sanitation. For municipal water-supply, the problem is often dealt with by dilution through mixing, but this requires a secure source of high-quality water and also has absolute limitations because some wastewaters contain a wide array of pharmaceutical residues and industrial chemicals.

An integrated approach is required to reduce the cost and improve the security of the urban water infrastructure. There are numerous practical measures that can be taken to improve the sustainability of groundwater use, including:

- prioritisation of recently-urbanised districts for sewerage cover to protect their good-quality groundwater from gradual degradation;
- establishment of groundwater protection zones around utility waterwells favourably located to take advantage of parkland;
- imposition of better controls for the handling and disposal of industrial effluents and solid wastes to reduce the risk of aquifer pollution.

Groundwater pollution can be reduced by deploying dry (eco-sanitation) units, in which urine is separated from faeces, with both being recycled. The latter installations are recommended for new urban areas overlying shallow aquifers, but they are not the universal solution to groundwater contamination because large-scale retro-installation in existing dwellings is very costly.

An important corollary is making better use of increasing wastewater resources generated by wider sewer coverage—this could be through reuse for amenity and agricultural irrigation that is spatially planned and appropriately controlled so as to minimise public health hazards, including incidental pollution of groundwater in potable use [16].

4.3. Private In-Situ Groundwater Use—Reducing Risks and Improving Benefits

Private capital investment to access groundwater in situ for urban self-supply often mushrooms during periods of inadequate utility water-supply [1,17]. This is essentially a ‘coping strategy’ by multi-residential properties, and commercial and industrial enterprises. Water users tend to take their supply from multiple sources according to their availability and relative cost, with much more expensive tankered water as the last resort.

Private self-supply from groundwater is then likely to continue by many users as a ‘cost-reduction strategy’ when the availability of the utility supply improves. Although the ‘economy of scale’ can be poor, the cost of water-supply from this type of source often compares favourably with the tariffs implied by full cost-recovery for new utility surface water-supply schemes. Whether private residential groundwater use presents a serious threat to users will depend on the type of anthropogenic pollution (or natural contamination) present and the type of water-use concerned.

An emerging policy question is under what circumstances the risks or inconveniences of private residential self-supply from urban groundwater justify attempts to ban the practice. Many private waterwells are, at best, unregulated and at worst illegal. In the longer run, this is counterproductive for the private user and the public administration but can be regularised by management interventions such as:

- using advances in geographical positioning and data capture to locate waterwells;
- registering commercial/industrial users and residential use for apartment blocks/housing estates, and charging for groundwater use by waterwell pump capacity or metering discharges to sewers;
- issuing water-quality use advice and health warnings to private waterwell operators, and if pollution is severe, declaring sources unsuitable for potable use;
- gaining civil-society commitment through effective participatory mechanisms and incentives for ‘self-monitoring’.

4.4. Groundwater in Decentralised Urban Water-Service Provision

Given the escalating rates of urbanisation globally, new paradigms for water-service provision need to be found. ‘Closed-loop’ operations for suburbs of 10,000–50,000 population on a ‘decentralised basis’ would appear to be an attractive alternative, either managed by the water utility or a community organisation. Such systems can be operated to minimise infrastructure costs, energy use and water losses, since they reduce the distance between household use and water treatment [18]. They can also promote energy and nutrient recovery by converting the current liability of wastewater treatment into assets, through urine/faeces separation and re-use of the former as a fertiliser and the latter for energy generation.

The natural drought resilience and quality protection of deep waterwells means that they are well suited to be the water-supply source for decentralised closed-loop water-service systems. Since these systems treat wastewater as a resource, their installation should substantially reduce the urban subsurface contaminant load, and thus one major groundwater pollution threat. Nevertheless, it will also be necessary to put more local attention and effort into on-the-ground inspection and control of other forms of urban land and groundwater contamination (such as gasoline stations, small-scale motor shops, dry-cleaning laundries, etc.) to prevent the pollution and loss of key waterwell sources.

5. Filling the ‘Institutional Vacuum’ in Urban Groundwater

There is a clear need for groundwater considerations to be integrated into decision-making on infrastructure planning and investment, but institutional capacity to take the lead is often limited because:

- water-resource agencies rarely have the capacity to cope with urban development dynamics;
- urban water utilities are often ‘resource illiterate’ despite increasing groundwater dependence;

- urban land and environment departments have a poor understanding of groundwater.

As a consequence, the strategic importance of urban groundwater is not yet reflected by sufficient investment in management and protection of the resource base. Urban groundwater tends to affect everybody but is often the responsibility of ‘no body’. Municipal, provincial or state, and national governments need to find the political will and practical means to:

- constrain groundwater demand and limit abstraction by socio-economic and regulatory measures, so as to avoid excessive aquifer depletion and degradation;
- encourage the spread of groundwater abstraction for municipal water-supply over larger land areas, through the declaration of special conservation and/or protection areas;
- plan urban sanitation better and regulate the storage of industrial chemicals and handling of industrial effluents in the interest of much improved groundwater quality protection.

Governments, from national to local level, need to seek realistic policies and effective institutions to proactively manage urban groundwater resources. They will require political leadership and the engagement of major stakeholder groups. In pursuing these policies, it will be essential to make a critical appraisal of the actual and desirable roles of national/state water-resource and environment agencies, municipal water-service utilities, and municipal government offices responsible for land-use and industrial licenses—as well as the avenues of consultation and communication between them. This is required to address split institutional interests and responsibilities, and identify a mechanism for long-term periodic review and systematic action on urban groundwater.

Moreover, the dynamics of urban development and its relationship with groundwater are such as to merit the formation of a ‘cross-sector urban groundwater consortium’ (or standing committee) of all major stakeholders and regulatory departments/agencies. Such consortia should be tasked with communicating groundwater issues at the political and executive levels, and must be empowered and financed to define and implement a ‘priority action plan’. They must also be provided with a sound technical diagnosis from an appropriate group of institutional and university specialists.

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