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Peri-Urban Conflicts over Groundwater due to Population Growth

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Abstract

The world's finite reserve of fresh, accessible water is under increasing stress from global population growth and unprecedented water demand from agriculture, industry and domestic users. Unless addressed, inadequate water supplies promise to undermine economic development, compromise food security, and threaten livelihoods in many of the world's cities. An escalating demand for groundwater, by far the world's largest accessible water resource, is especially worrisome as rates of groundwater abstraction are locally unsustainable and serious tensions over water can create conflict between major consumer groups. On one hand thirsty cities seek water to support industry and strive to meet its residents' drinking water and sanitation needs, while on the other hand, the agricultural sector, which already consumes some 70% of global groundwater, commands increasing volumes of water to irrigate the lands that feed the very same growing cities. It comes as no surprise that some of the globe's more serious water supply conflicts arise at the rural-urban interface of developing countries where anxiety over water supply is seriously compounded by explosive population growth and weak systems of governance.

Concern for megacity growth and the struggle to meet escalating water demand has been high on the global water sector agenda for several decades. The concern is especially true in water-scarce areas of southern Asia where peri-urban growth is most rapid and groundwater is frequently exploited in a haphazard, unregulated manner. In many cases, urban planning is seriously lacking and the plight of the peri-urban inhabitants is completely ignored. This needs to change. On the positive side, the past half century has seen significant advances in the hydrogeological sciences that underpin urban water supply. However, none of this valuable progress can be properly utilised without appropriate governance, governance that recognises the importance of pro-active urban planning and is able to fully integrate surface water, groundwater, land use and sanitation into the urban planning process.

Experience shows that developed world strategies for growth management are not readily transferrable to less developed countries where a serious disconnect commonly occurs between water management and urban planning. In many cases there is no urban planning at all. Solutions are not simple and the future looks daunting, but slow progress is starting to be made in many growing cities towards the development of appropriate groundwater resource management plans. Such plans are founded on a sound, quantitative understanding of the hydrogeologic setting, include pragmatic regulatory provisions that fully recognise the strong link between land use and groundwater quality and fully involve the interests of all stakeholders in decision-making and implementation. Where groundwater-dependent cities rely to a large extent on peri-urban wellfields, there is a growing recognition of the need to integrate the interests of peri-urban and rural communities to ensure resources are adequately protected and that the needs of both sets of users are adequately met. Important first steps include increased public awareness for the role of groundwater and encouragement of close dialogue between user groups. It is also important to ensure data are exchanged between agencies that have an interest in water management and protection. The starting point for co-management is co-operation.

1. Urban growth as a cause of tension and conflict

Global population growth, sustained for many decades (Fig. 1) has placed an immense burden on the world's finite reserve of fresh, accessible water. Many countries, particularly in Asia, face intense competition between agriculture, industry and domestic users for scarce water supplies, raising concerns for economic growth, food security, livelihoods, poverty reduction and the health of ecosystems. An escalating demand for groundwater, by far the world's largest source of fresh accessible water, is especially worrisome as rates of groundwater abstraction are locally unsustainable (Jones, 2011) and serious tensions over water can ignite conflict between major consumer groups. The rivalry can be particularly intense between:

- The agricultural sector for which irrigation already uses around 70% of available reserves, much of it to fuel Asia's "green agricultural revolution" (Evenson and Gollin, 2003; Giordano and Villholth, 2007; Jones, 2010), and
- Growing towns and cities which today house over half the world's population and increasingly seek water to support industry, supply drinking water and provide adequate sanitation (Chilton, 1997; 1999; Howard, 2004; 2007).

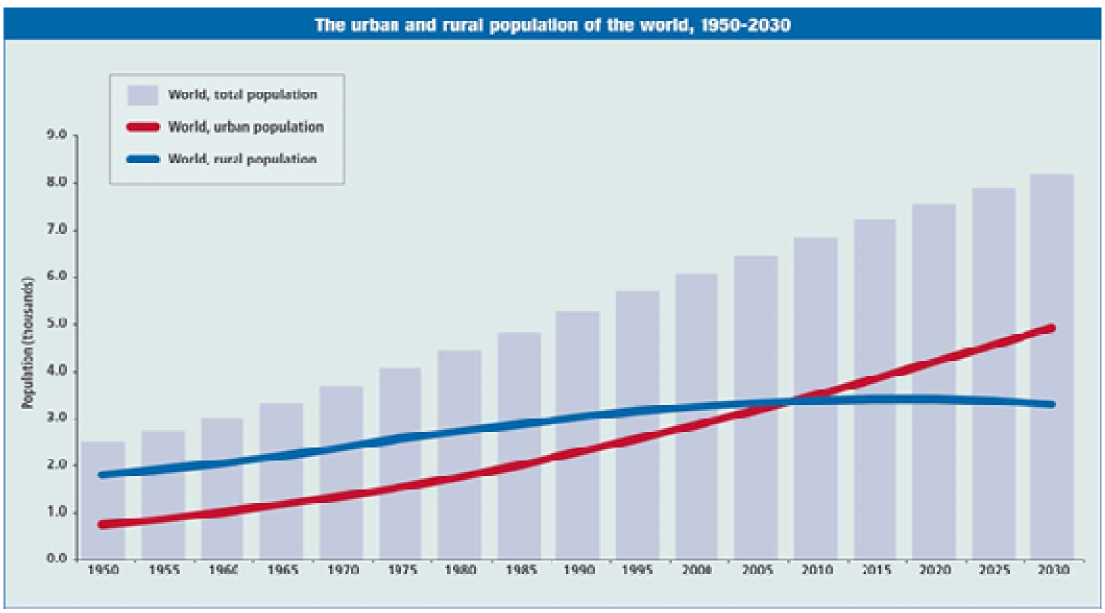

Fig 1. Urban and rural population growth as compared to the world population for the period 1950 to 2030 (modified after the UN, 2006).

Over the next twenty years, the global population is expected to increase from 7 to 8 million with the proportion of those living in urban areas expected to approach 60%. Most of this growth will occur in low- to middle-income countries in Asia where a continued supply of good quality water is essential for sustained social and economic development. Growing tensions are an inevitable product of rapid urban population growth, and peri-urban areas (Fig. 2) at the rural-urban interface (RUI) lie at the heart of the combat zone. In this context, Janakarajan et al. (2006) suggest that conflict begins when opposition is expressed by at least two categories of actors whose interests are temporarily or fundamentally divergent. They suggest that tensions escalate into conflicts when verbal, legal or physical confrontations lead to one of the parties implementing a credible threat. Most conflicts involve some combination of economic, environmental, social or political issue.

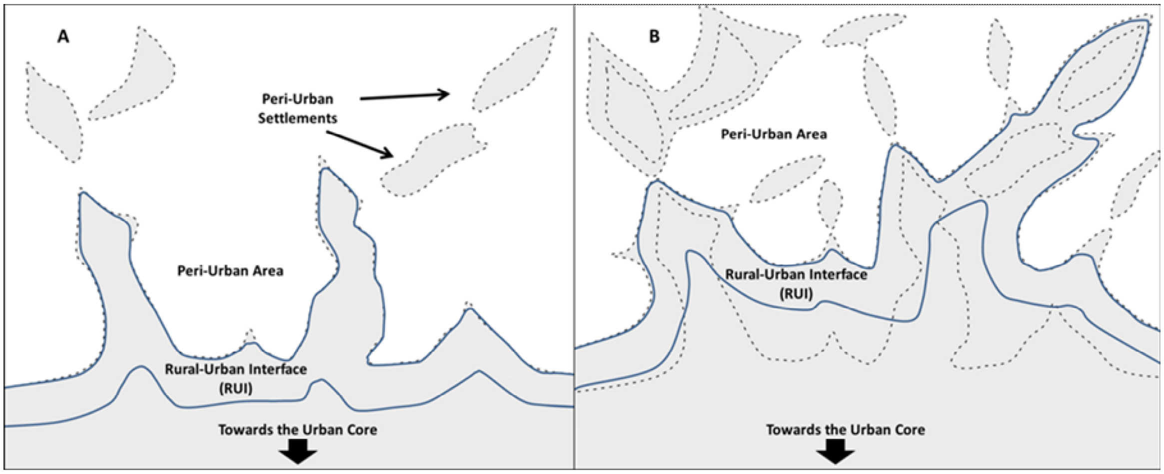

Fig 2. Two stages of urban expansion (A and B). In each case, shaded areas are populated. The rural-urban interface (between the two solid lines) and the peri-urban area are shown. It should be noted how peri-urban settlements eventually get absorbed into the urban area and new, peri-urban settlements grow.

Much of the world's population growth has taken place in the past 40-50 years. Back in 1950, cities with over 1 million people numbered just 75. Twenty five years later, only New York, Tokyo and Mexico City had grown to "megacity" status with populations exceeding 10 million. By the year 2010, the number of megacities reached 21 (UN, 2010a), and this is expected to rise to 29 over the next 15 years. At present, megacity growth appears to be greatest in Dhaka (Bangladesh), Lagos (Nigeria), and Karachi (Pakistan) where annual population growth rates exceed 2% (UN, 2010b). Growing marginally more slowly are the Indian megacities of Delhi, Kolkata and Mumbai, and the capital of the Philippines, Manila. Over time, city growth can dramatically change the social and economic demographics of a country. For example, thirty years ago, less than 20% of the population of China lived in cities. By 2011, over 50% of China's population lived in urban areas, and this number is expected to reach 70% by 2030.

2. Water services in peri-urban settlements and at the rural-urban interface

It is those living in peri-urban areas close to the rural urban interface RUI (Fig. 2) who are most seriously affected by rapid urban growth. In some cases, growth rates are driven by the natural excess of births over deaths, but they can be strongly influenced in many countries by an influx of migrants who are trying to escape rural poverty or are fleeing from political uprisings or an environmental crisis. At other times, rural inhabitants living just beyond the RUI are simply absorbed into urban principalities as urban boundaries expand and agricultural lands become consumed by housing, industrial estates and sites for dumping urban waste. Whatever the catalyst for growth, it is the peri-urban lands where the highest rates of growth normally occur. According to Akrofi and Whittal (2011), key characteristics of peri-urban lands are:

- High levels of land speculation.
- Informal, unplanned settlement growth due to weak municipal authorities and confused, ill-defined mandates of public, private and civil society leaders.
- Rapidly changing land use practices, often incompatible, and with little or no security of tenure.

- Inadequate water services (water supply and sanitation) triggering the emergence of informal service providers.

In many cases groundwater represents the only viable option when a sustained water supply is required (Foster et al., 2000).

Since there is no international agreement on how to define "urban settlements" in terms of where they begin and where they end, assignments of government responsibility readily become just as obscure. As a result, many peri-urban areas are simply neglected by urban planners and remain unregulated and poorly serviced (Ahmed and Alabaster, 2011). Residents are easily frustrated by their inability to influence allocation of services including water. This is where the seeds of tension and conflict are sown. Peri-urban areas and the rural-urban interface are veritable breeding grounds for conflict as they bring into co-existence groups with diverse socio-cultural and economic backgrounds, disparate hopes and aspirations, and very little, if any, opportunity to instigate change.

The most dire problems frequently occur in densely populated, peri-urban settlements characterised by foul, sub-standard living conditions with no security of tenure (i.e. "slums") (Black, 1994). In some cities, two-thirds of the population live in slums. Slums result from a pernicious combination of weak governance, underinvestment in basic infrastructure, poor planning to accommodate growth, infrastructure standards that are unaffordable by the poor, and insufficient public transportation that restricts mobility and restricts access to work. In some parts of the world, rapidly growing urban slums not only impact human health, and environmental sustainability but also threaten both national and international security. The vast majority of slum dwellers have low social status, poor self-esteem and no political representation and influence at the decision-making level.

Many peri-urban slums areas are totally neglected by city planners and completely lack essential services. Degradation of water quality due to the unregulated disposal of industrial, domestic and human waste is rife. The majority of large cities enjoy the benefits of at least some water and sanitation infrastructure in their central areas, and in many cases, this is being improved and expanded by private companies or public utility commissions (PUCs), both of which can expect significant cost recoveries in the form of service tariffs or taxes. Peri-urban slums seriously lack comparable infrastructure and services, and are frequently obliged to use water sources that are unsafe, unreliable and sometimes difficult to access on a regular or continuous basis. Sanitation, where available, tends to be limited to latrines that are often shared with so many others that access is difficult and hygiene maintenance is impractical. Unsafe drinking water and inadequate sanitation have dire implications for human health, particularly the well-being of children and the elderly.

Discord over water is obviously very common in the urban environment (e.g. UNESCO, 2006) with conflicts triggered by numerous issues. Based on their studies in India, Janakarajan et al. (2006) suggest that the root causes of conflict are normally associated with:

- Concerns over quantity, with conflicts developing between either sectors or users (e.g. municipality versus industry or private users; urban versus peri-urban or rural);
- Quality issues, with conflicts arising from the threat of water that is potentially unpotable (e.g. Nagaraj, 2005);
- Regular access to water, with conflicts being generated over water rights, price, or simply physical accessibility to a water source.

3. The urban groundwater challenge - case examples from India

Examples of the urban groundwater challenge can be found throughout the world. In India, notable examples of urban water supply difficulties include Chennai, Delhi and Aurangabad. Consideration of these case examples can give a brief, but valuable insight to the types of challenge faced, the complexities that need to be considered, and how we should move forward.

Most cities in India suffer from a severe shortage of water, a problem that is seriously exacerbated by high rates of population growth. Much of the growth is experienced in peri-urban areas where agricultural land is being rapidly converted to housing (mostly unplanned), and to industrial plants and waste disposal sites (for both solid and liquid waste). Peri-urban areas receive very few water services and this results in the spontaneous emergence of unregulated shallow-well exploitation of groundwater, mostly by private operators (Janakarajan, 2005).

Throughout India, groundwater supply issues are much more problematical in cities sited on the low-storage and often poorly transmissive, hard-rock aquifers of peninsular India than they are in cities and large towns located on the Indo-Gangetic alluvial floodplains. For example, water scarcity issues in Lucknow City (pop. 2.9 million) on the Central Ganga alluvial plain tend to be more associated with the city's ageing, leaking, and regionally inefficient water reticulation system than by the availability of groundwater from thick, productive alluvial sand aquifers. (Foster and Choudhary, 2009).

3.1 National Capital Territory of Delhi, India

In the National Capital Territory of Delhi (NCT), (pop. 16.7 million), the water supply is unreliable, unequally distributed and far below international standards. For example, according to recent reports, residents of the influential, wealthy Nangloi Jat area receive around 270 litres per person per day from the municipality while residents in poorer villages, without political power and wealth, a few miles from Nangloi Jat, receive less than 5 litres per person per day. Janakarajan et al. (2006) suggest that the public water supply undertaking (the Delhi Jal Board, DJB) is simply unable to meet the city's water and wastewater needs. A recent report by the Comptroller and Auditor General of India, the official auditor of India's public sector, estimates that about 4 million Delhi residents, mostly in poorer communities, lack a piped water supply and rely exclusively on relatively expensive tanker water.

The effects of water supply mismanagement are mostly felt by the urban poor in city slums where supplies average just 27 litres per person per day (Llorente, 2002). In contrast, Delhi's upper middle-class readily pay around $50 for a delivery of 6000 litres of water to top up their home's depleted water tank, via private companies that are not licenced by the government. The Delhi Human Development Report 2013, recently released by the city's government, suggested that hours of queuing at water points have become a common occurrence in the slums of Delhi and brawls around water tanker trucks are on the rise.

In Delhi, as throughout India, the natural reaction of consumers to the rationing of water supplies, inefficient delivery of municipal services and lax regulations has been to develop compensatory strategies. These strategies have been described as "decentralised governance structures" and can be either formal or informal. With "formal strategies", private operators sell water via water tankers. Due to the weak regulatory framework, the quality of this water cannot be guaranteed and some opportunistic companies resell public water or fill their trucks with untreated groundwater from illegal wells. While the more reputable private operators would endorse stricter regulations, they have received little support from the government. They struggle to provide services which are safe, reliable and affordable. "Informal" coping strategies are developed by the poor and rich alike. The poor are more likely to steal water directly from the public distribution network via illegal connections, while higher income households will most likely install roof-top storage tanks and/or drill tube wells, usually unlicensed, for in-situ supply. In some areas, the use of unlicensed, low-cost water wells for residential self-supply has risen dramatically and has threatened to deplete the underlying aquifer. It would seem that neither the formal nor informal "coping" strategies can be considered sustainable in the longer term from social, economic and environmental standpoints.

All the decentralised water supply solutions endure a relatively high cost, given the fact that water is essentially free. One proposed solution deserving serious consideration would institutionalise and, thus, formalise local community participation in water i.e. "self-help". Such an approach would be beneficial in several ways:

- it would internalise costs and accounting, and help maintain transparency;
- local residents would be able to ensure decentralised water supply installations are adequately maintained;
- rights of access would be ensured;
- it would facilitate a more responsible and effective management of the resource including early detection of system leaks and improved management of demand.

The arrangement would need considerable institutional and regulatory improvements including the establishment of mechanisms for consultation, negotiation and decision-making.

Janakarajan et al. (2006) recommend that the first goal should be to simplify the existing institutional framework and redefine jurisdictional responsibilities so as to improve coordination between the various decision levels, avoid duplication of tasks and limit discretionary powers. The second goal would be to establish a broad-based regulatory framework that would involve representation by all stakeholders at all levels and scales, empowered to make democratic decisions. Last, but by no means least, they recommend major governance reforms that would stem and perhaps reverse the present technocratic, top-down approach to service provision.

3.2 Chennai, India

When it comes to water supply, the city of Chennai is one of the most seriously troubled cities in India (Janakarajan, 2005). The Chennai Metropolitan Water Supply and Sewerage Board (Metro Water Board or MWB) supplies less than 50% of the population's estimated water needs. As in most Indian cities, groundwater from shallow tube-wells helps to fill the demand gap (Zérah, 2000) but the city's aquifers are seriously stressed and the situation is unsustainable. In some coastal areas, water levels have declined to such low levels that seawater is actively intruding. To the north of the city, seawater has migrated in land by a remarkable 16 km. At present, there appears to be no viable solution to Chennai's water supply crisis. Although various megaprojects have been proposed involving major inter-basin transfers of water, the costs are simply prohibitive.

During the past two decades, Chennai has relied heavily on the import of water from public wells and agricultural wells located in peri-urban villages. At present, Chennai uses about 100 million litres per day which is supplied by city boreholes, the Poondi, Tamarapakka, Flood Plains, Kannigaiper and Panjetty wellfields situated to the northwest just beyond the Chennai Metropolitan area, and the Minjur and Southern Coastal Aquifer well fields that can be found within the Metropolitan area to the north and south of the city, respectively. As observed by Janakarajan et al. (2006) the importation of groundwater from peri-urban areas can create serious tensions. These include:

1) Impacts on poverty and livelihoods. The abstraction of groundwater from common lands in peri-urban villages has been ongoing since 1969 when the MWB installed 10 wells in the common lands of a village just outside Chennai and brought water into the city via a pipeline to solve a growing water crisis. Furthermore, the MWB insisted that farmers in surrounding villages sell the water they pumped from their irrigation wells, demands that according to Gambiez and Lacour (2003) were met with mixed reaction. The farmers fell into essentially three groups:
   A) those who simply refused to sell water to the MWB.
   B) those who owned wells and sold their water to the MWB;
   C) those who did not own wells and purchased their water from farmers in group A) for their irrigation needs.

   Gambiez and Lacour's analysis showed that farmers in group A) suffered only a slight loss of income, primarily due to a reduction in cultivated area that is common in peri-urban areas where population growth results in the conversion of rural land to urban. By comparison, groups B) and C) were significantly affected, the former for the better, and the latter for the worse. Between 2000 and 2001, farmers selling their water to the MWB (group B) needed to reduce their irrigated area by 43 per cent, but generated an 80% increase in revenue for the period 1999-2002. Clearly, the water sales business proved immensely more rewarding than farming. In comparison Group C) (the dependent farmers) saw a considerable reduction in both irrigated land and farming income. This example illustrates how a seemingly innocuous agreement, initiated by a public undertaking, can have very serious social and economic repercussions.

2) Tensions over the weak regulatory framework. When Chennai's major sources of water supply started to decline in the1980's, passage of the Chennai Metropolitan Area Ground Water (Regulation) Act gave the MWB full licensing power to control private well construction and groundwater extraction. The Act's primary purpose was to ensure that groundwater was used exclusively for domestic needs and prevent the common practice of trucking groundwater to private markets. Twenty five years later, it transpires that the MWB has been the main violator of the Act, being responsible for much of the groundwater overexploitation in peri-urban villages that the legislation was supposed to deter. In fact, the MWB persists in this practice, expanding its "catchment area" to include peri-urban areas lying 50 km or more from the city. The MWB also appears to operate its tanker trucks without license while many private tanker truck companies complain that their permit applications are being ignored. In such situations it becomes inevitable that regulations get flouted, even amongst normally law-abiding citizens. Many water trucks are now operated illegally and, in terms of permits to drill water wells, the legislation is also widely disregarded. Many industries pump water in contravention of the Act knowing that enforcement of regulations is weak or non-existent and the likelihood of prosecution is minimal.

Finding long-term solutions to Chennai's water supply problems will be clearly very difficult. There has, at least, been some success in creating a meaningful dialogue on the subject through the formation of a multi-stakeholders platform (MSP) designed to create multi-stakeholder dialogue (MSD). For Chennai, a 65-member multi-stakeholder committee was initially established involving water users from both urban and peri-urban areas. It included farmers (both water sellers and non-water sellers), landless agricultural labourers, women self-help groups, NGOs, researchers, lawyers, urban water consumers and a few government officials. More members were added at subsequent committee meetings. The MSD process has tackled several important key issues including declining water tables, declining agricultural activities, emerging livelihood problems, seawater intrusion, water quality degradation, water and soil pollution, aggregate mining and resident's growing unrest. In future, the challenge will be to engage the MWB and similar government agencies in an effort to seek resolutions.

3.3 Aurangabad, India

Aurangabad City, Maharashtra State, has grown rapidly in recent decades and now has a population of nearly 1.2 million. The city was one of several studied by the World Bank's Groundwater Management Advisory Team (GW-MATE) (Foster et al., 2010a; 2010b; 2010c), in its decade-long strategic assessment of trends in the public and private use of groundwater for urban water-supply in developing cities. A key purpose of this study was to determine the types of practical response required for more rational and secure use of the groundwater resource.

Aurangabad lies on the extensive Deccan Traps flood basalts that form poorly transmissive, low storage aquifers across a vast area of west-central India. As a result, the city relies heavily on surface water drawn from Jayakwadi Reservoir, as its primary supply of water. Despite the large size of the reservoir, the supply is unreliable due to shortages of electrical power required to lift the water almost 200m over a distance of 45 km. The city also lacks local storage capacity to augment the service in times of difficulty. As a consequence, most residential properties and many commercial/institutional water users have turned to private wells and/or tankered water to supplement the municipal supply (Foster and Mandavkar, 2008; Foster et al., 2010c). Groundwater levels within the city are generally 6 to 10 m bgl (below ground level) but may fall below the shallow, more permeable, weathered zone late in the dry season due to storage depletion. Field surveys conducted in 2007-08 (Foster and Mandavkar, 2008; Foster et al., 2010c) revealed that private residential use of groundwater increases significantly each year during February-April and may be 20-50% higher by May-June. This has significantly reduced reliance on relatively expensive tanker supplies. Average household consumption was found to be approximately 200 litres per day per person with groundwater representing a significant proportion. Economic analysis showed that private groundwater use cost around US$ 0.15 to 0.24/m^3 representing a considerable saving over tanker water which cost the consumer close to US$ 1.33/m^3. The average cost of private groundwater compared closely to the real cost of the highly unreliable municipal supply (US$ 0.16/m^3) but in reality was more expensive as the municipality absorbed much of the real cost, supplying highly inconvenienced users at a flat rate that translates to an average price of just US$ 0.03/m^3.

A key GW-MATE message here is that residential users, when stressed by the local municipality's failure to meet their water needs, are prepared to take matters into their own hands and drill private (or community) wells. This is a "coping strategy", not unlike that seen in Delhi, motivated in part by the fact that shallow waterwells (even in low yielding aquifers) are relatively inexpensive to install and significantly more cost-effective than tanker supplies. In future, Aurangabad could improve supplies to its growing population by doubling its imported water-supply from around 150 Ml/d or more to over 300 Ml/d but this would require a substantial upfront investment and would incur high recurring costs. Given that the likelihood of significant cost recovery is very low, the local municipality attempted to introduce volumetric charging, a move that was met with staunch resistance. Ironically, private access to groundwater, now well entrenched, that was driven by the failure of the municipality to supply adequate water, will now make it considerably more difficult for the municipality to raise, through cost recovery, the funds it needs to make amends with an improved water supply.

The GW-MATE work in Aurangabad clearly demonstrates the important role of private self-supply from groundwater in water-stressed cities, an unofficial activity that can be seen in many of the world's growing urban centres, but is extremely hard to quantify and document with sound data. According to Foster et al. (2010c), key policy recommendations that flow from the Aurangabad study include the following:

- access to shallow groundwater will significantly affect the 'willingness to pay' for improvements to municipal supply for residential users and thus must influence the financial viability of any proposed 'imported' water-supply schemes;
- when planning future mains sewerage improvements, the prevalent use and operational cost of groundwater from private wells should be carefully considered;
- in evaluating the benefits and risks of in-situ groundwater use, microbiological and chemical quality should be carefully considered with relevant guidance provided;
- the use of urban groundwater is perfectly logical, especially for meeting the demand for sanitary and laundry purposes, where a more expensive treated water-supply may not be justified;
- municipal authorities should provide further fiscal incentive and technical guidance to promote private action on roof and pavement water harvesting for aquifer recharge enhancement and for the reduction of groundwater pollution risk from wastewater disposal and hazardous substances.

GW-MATE further notes the presence of an "institutional vacuum" in India when it comes to urban groundwater resource use, which must be filled if realistic, robust policies are to be developed and implemented. Thus, in Aurangabad, GW-MATE recommended that a 'standing committee on groundwater' be established to formulate workable policies on private groundwater use. This committee would be drawn from the Aurangabad Municipal Corporation and relevant state government departments and agencies.

4. Urban groundwater supply – the broader challenge

Urban-rural tensions are an inevitable consequence of growth, and a common cause of these tensions is "water scarcity" i.e. the lack of access to an adequate supply of good quality water. Tensions due to water scarcity are heightened in peri-urban areas where urban, industrial and agricultural users directly compete for the same resource. At other times, water scarcity is more the result of inefficient, poorly maintained water distribution systems (piped and tankered supply) than any limitations on the size and quality of the water resource. It is largely the latter that has prompted the steep increase of private in-situ use of water wells in many cities.

If rapid growth of the world's rapidly cities is to be sustained, adequate supplies of potable water will be required on a sustainable basis. This will not be easy, particularly given that many cities in developing countries lack political and societal stability and few financial resources for technological innovation and essential infrastructure. The basic options, however, are profoundly simple (Sharp, 1997; Howard and Gelo, 2002; Howard, 2012):

- Increase the available water supply;
- Moderate water demand (demand management);
- Manage available water resources much more efficiently.

4.1 Increasing water availability

The availability of the water supply can be increased in various ways. For example:

- Locating and developing new groundwater resources and/or resource mining;
- Augmenting aquifer recharge using "aquifer recharge management" (artificial recharge);
- Blending of water of varying quality.

Finding and developing new groundwater resources may not be feasible in all cities, but in many cities, it is a solution that is too often overlooked in favour of surface water that is often brought in at great cost from remote sources. In dry regions of the world, groundwater mining (intensive use) always remains a viable option, at least in the short term, as it can support economic growth while allowing deferral of investment in dams and desalination plants. It is not a decision that should be taken lightly, however. It needs to be realistically evaluated, and groundwater production must be carefully controlled and monitored. There must also be a viable long-term plan for the provision of alternative water supplies when the groundwater resources are depleted. All developed countries have benefited from time to time from groundwater mining, albeit often due to ignorance of the potential risks than through a carefully prepared and appropriately costed production strategy.

A more permanent water supply solution is to increase the size of the resource through "managed aquifer recharge" (MAR) (Ward and Dillon, 2011). Urbanising a parcel of land actually creates additional water since plant transpiration is significantly reduced. The overall effect is to generate excessive volumes of stormwater runoff which, properly managed, can be introduced into the subsurface for storage and subsequent beneficial use. The artificial replenishment of aquifers is not limited to stormwater; modern MAR technologies demonstrate success with appropriately treated wastewater which can be "polished" to potable standards during passage in the sub-surface.

It should also be recognised that the vast majority of water used globally does not need to meet potable water quality standards. In many cities, too much high quality, potable water is used for various industrial, agricultural and urban purposes when substandard quality water would readily suffice. In effect, if non-potable water could be used to meet at least some industrial, agricultural and urban needs, significantly more potable water would be available to meet human demand for safe water. In some situations, inferior quality water can be used to meet potable needs by blending it with good quality water in such a way that the final blend meets water quality guidelines. Examples may include the blending of water with elevated levels of nitrate or fluoride with water that is free of these chemicals, such that the resulting blends meets appropriate water quality standards.

4.2 Demand management

Demand for groundwater can be reduced by:

- Water conservation (e.g. using technologies that need less water to accomplish the same task);
- Controlling the number, depth and yield of wells through issuance of well construction licences and permits to take water;
- Limiting physical accessibility to municipal supplies to certain periods of the day;
- Cost structuring e.g. water metering and tariffs.

In many developing countries, per capita water use is already very low and there are few opportunities for significant savings to be made at the domestic level by adopting water conservation practices unless major incentives for reducing water use are introduced. While some savings can be realised by limiting access to water to just a few hours each day, as is commonly practiced in India (Limaye, 1997), this does not prevent excessive usage during those times water is available.

In terms of communal and municipal wells, demands on the aquifer can be constrained through controls on pumping rates. Morris et al. (1997) suggest, however, that stringent controls on water well drilling (through construction licenses) is far more effective than controls on rates of pumping (via water permits) for wells that are already installed. Moreover, many argue that there is little value in regulating water usage if laws are not enforced and violators are not prosecuted. Limaye (1997) observes that the greater the number of rules and regulations, then the greater the level of illegal activity.

The most effective means of reducing water demand is through the use of water tariffs. Pricing water based on the quality and quantity of water pumped at the wellhead provides an incentive for more effective demand management including the reduction of water-mains leakage. It does little, however, to promote water conservation at the level of the consumer unless the charges can be made equitable based on actual usage. This needs individual metering which has been shown to be an effective means of reducing wastage. A common problem with domestic metering is the administrative burden; inevitably, many fees are unrecovered. Metering may also prove counter-productive if tariffs are greater than the user can realistically afford. Excessive water costs will tend to promote illegal activity or simply lead to poor sanitation and impact health.

4.3 More efficient management of the resource

There are limits to which urban water supply can be increased and demand reduced. This is why urban groundwater resource management has become a major focus of attention in recent decades. Sound management of our groundwater systems must be underpinned by good science, including a full, quantitative understanding of the hydrogeologic setting. It is the role of the scientist to address perceived problems and generate solutions that can be used by resource managers (Barber, 1997). Management practice then evolves by incorporating scientific developments into a strategy to achieve best-available practice. On a positive note, the science of urban hydrogeology is well advanced and a wealth of excellent ground and surface water modelling tools have been developed for performing such tasks as:

- Recharge calculation and water budget estimates;
- Aquifer vulnerability assessments and identifying well head protection areas (WHPAs) that are most in need of land use controls;
- Predicting contaminant travel direction and travel times;
- Determining "optimal" sites for well location and well pumping rates, and
- Identifying options for conjunctive use of surface water and ground water.

Despite a lack of reliable data for many urban areas, models can greatly assist in the testing and evaluation of alternative strategies for groundwater resource management. They can also assist with decision-making, although "assist" is a key word here since the development of appropriate management plans is as much social as it is technical. It is a process that demands political commitment and strong social consensus. Where reliable data are somewhat lacking, Burke and Moench (2000) stress that waiting for data is not a valid excuse to delay action.

Most now recognise that strategies for urban groundwater management are most effective when they:

- are developed in close co-operation with all relevant stakeholders, and
- fully acknowledge local economic, social and political conditions.

This philosophy applies equally to aquifer [water quality] protection plans that should be regarded as an integral component of groundwater management. Historically, most water projects in developing countries have used a "top down" management approach that rarely considers the interests and needs of the individual users, but simply satisfies the immediate goals and longer-term objectives of government officials, consultants and support agencies. In the poorest countries, the needs and interests of stakeholders, including community users, are widely ignored.

According to the principle of participatory management, first introduced at the 1992 Dublin International Conference on Water and the Environment, the development of water policy should adopt a participatory approach that involves users, planners, and policy makers at all levels. Most importantly, the participatory approach requires that decisions be taken at the lowest appropriate level which, in practice, means that local and regional agencies representing community interests must be fully involved. All stakeholders must feel comfortable that their needs are being met as workable solutions will not be found without the full agreement and support of all levels of government, industry and the population at large. In effect, current problems with urban groundwater management will not be resolved until governments start to work with groundwater users and refrain from trying to regulate and control them.

5. The need for improved urban groundwater governance

Few groundwater-dependent cities are able to secure an adequate water supply from within its city limits, but those that do have such fortune need to maximise the quantity of the available resource while maintaining adequate water quality. This can be difficult there is often a vacuum of responsibility for urban groundwater that, in turn, leads to a serious lack of accountability. For example, groundwater use sustainability can be greatly influenced by a wide range of local developmental decisions, which are rarely examined in a sufficiently holistic way. The types of decision that need to be better integrated include (Foster et al. (2010b):

- urbanisation and land-use planning (by municipal government offices);
- production and distribution of water supplies (by municipal water-service utilities and public-health departments);
- installation of sewered sanitation, disposition of liquid effluents and solid wastes (by environmental authorities, public-health departments and municipal water-service utilities).

Without integrated decision-making, responsibility for the sustainability of groundwater supply is divided between a number of organisations, none of which is normally willing or, in fact, capable of taking leadership for coordinated management action.

Quite evidently, groundwater is a key component of the urban water cycle in many of the world's cities and there is an urgent need to integrate groundwater into urban land use planning, water supply and waste management, whatever its status (Table 1). Groundwater is far more significant in the water supply of developing cities and towns than is appreciated. However, government organisations responsible for urban water-supply and environmental management rarely pay appropriate heed to groundwater and its unique attributes. Until structures of governance fully acknowledge the importance of groundwater and the valuable role it plays in cities (Foster et al., 2010a), effective and sustainable management of urban groundwater will remain a distant aspiration.

Table 1. Summary of major policy issues associated with urban groundwater (modified after Foster et al., 2010b).

ISSUE	IMPLICATIONS
Municipal Water-Supply Benefits	Groundwater use for municipal water-supply has many benefits (including capacity to phase investments according to demand growth, and generally 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 irreversible degradation by pollution.
Private In-Situ Use Benefits & Hazards	Private in-situ use for urban residential, commercial and industrial water-supply can benefit both the user and the community (e.g. 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) and these benefits need to be valued in terms of the marginal cost of providing a volumetrically-equivalent alternative water-supply – but note, poor construction of shallow urban waterwells can present a significant health hazard due to fecal contamination or chemical contamination (especially in areas without mains sewerage).
Water-Sector Financial Considerations	Widespread self-supply can have serious financial implications for water-service utilities, e.g. loss of revenue from potential water sales, difficulties of increasing average tariffs and recovering sewer-use charges from those operating private waterwells.
Conjunctive Use with Surface Water	Where rates of aquifer replenishment are insufficient to meet the demands of larger cities sustainably, 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	Should abstraction radically diminish (due to an increased availability of subsidised mains water-supply or to quality deterioration or pollution concerns) groundwater levels will rise progressively to higher than the pre-urbanisation condition, potentially with serious sanitary problems and infrastructure damage in lower-lying areas.
Protected Municipal Wellfields	Since some degradation of groundwater quality in urban municipal waterwells due to persistent pollutants is inevitable, there is a need to develop 'external wellfields' in parallel, protecting their capture areas from contamination to guarantee that a proportion of the total resource is of high quality and available for blending or substitution.

Most groundwater-dependent cities are ultimately reliant on external aquifers over which they may enjoy little, if any, jurisdiction or influence. Recognising the huge demand for groundwater in rural areas to meet agricultural needs, an unhealthy competition for the resource is emerging in many towns and cities, with those living at the rural-urban interface (RUI) and in peri-urban areas at the heart of the conflict. Not surprisingly, there are two diametrically opposed perspectives to this urban-rural issue.

Rural communities believe that the economic and power dynamics of this competition leaves them at a disadvantage because they cannot generate comparable financial returns or are less represented in positions of power (lobby groups, politics etc.) and unable to influence water allocation. Studies have shown, for example, that water exported from rural areas to urban centres leads to food insecurity and unemployment (IFAD, 2001). Farmers well recognise that contamination of groundwater represents the greatest threat to their livelihoods and that groundwater used in rural areas on the periphery of cities is seriously threatened by polluted urban runoff or leaching of contaminated water from urban pollutant sources (Nagaraj, 2005). They find that regulation of groundwater is very difficult due to the number of players involved. NGOs, foreign government assistance programs and private companies often act independently and work with different government ministries when implementing their agendas. The lack of co-ordination prevents responsible resource management and promotes depletion of aquifers. Individual rural users who typically use their shallow wells for domestic supply and small-scale livelihoods are the first to be affected by lowered water tables.

From an urban water supply perspective, many cities believe that activities in peri-urban and rural areas pose a serious threat to the sustainability of their supply. For example, over-pumping often invites groundwater salinisation, and agriculture can lead to contamination by fertilisers, pesticides, herbicides and, in some cases, wastewater. They recognise, as a "best management practice", the need to protect peri-urban wellfields through regulation e.g. with their capture areas declared as ecological or drinking-water protection zones. They find, however, that any attempt to establish procedures and incentives for resource protection often encounters administrative impediments related to fragmented powers of land-use and pollution control. Too often, there is an enormous disconnect between water and land use regulations.

6. Conclusion

At the global scale, the economic opportunities afforded by urban growth are seriously tempered by the social challenges growth brings (SIWI, 2011). Most of the world's urban growth occurs in low- and middle- income countries where relatively prosperous, well-serviced urban cores are surrounded by an expanding sprawl of under-serviced suburbs and peri-urban slums. In many cases, these areas support the vast majority of the urban population but are seriously neglected when it comes to pro-active land use planning and the provision of adequate sanitation and drinking water services. It has become clear that developed world solutions for dealing with growing cities are not readily transferable to less developed countries where a serious disconnect occurs between water managers and urban planners. In many cases there is no urban planning at all. Without the planning of urban space and infrastructure, opportunities to provide adequate water and sanitation services are seriously compromised; the classical, centralised method of delivering water services will often fail. The potential benefits of decentralising services also fail to be realised with affluent residents enjoying much greater accessibility to services than the poor or those from rural areas. In the face of rapid urban growth, the future looks daunting but slow progress is starting to be made in many growing cities towards the development of appropriate groundwater resource management plans. Such plans are founded on a sound, quantitative understanding of the hydrogeologic setting, include pragmatic regulatory provisions that fully recognise the strong link between land use and groundwater quality, and fully involve the interests of all stakeholders in decision-making and implementation.

Where groundwater-dependent cities depend on external "peri-urban" wellfields, there is a growing recognition of the need to integrate the interests of peri-urban and rural communities to ensure resources are adequately protected and that the needs of both sets of users are adequately met. Important first steps include increased public awareness for the role of groundwater and encouragement of close dialogue between user groups. It is also important to ensure data are exchanged between agencies that have an interest in water management and protection. The starting point for co-management is co-operation.

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