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REPORT

Global Urban Growth and the Geography of Water Availability, Quality, and Delivery

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Abstract Globally, urban growth will add 1.5 billion people to cities by 2030, making the difficult task of urban water provisions even more challenging. In this article, we develop a conceptual framework of urban water provision as composed of three axes: water availability, water quality, and water delivery. For each axis, we calculate quantitative proxy measures for all cities with more than 50,000 residents, and then briefly discuss the strategies cities are using in response if they are deficient on one of the axes. We show that 523 million people are in cities where water availability may be an issue, 890 million people are in cities where water quality may be an issue, and 1.3 billion people are in cities where water delivery may be an issue. Tapping into groundwater is a widespread response, regardless of the management challenge, with many cities unsustainably using this resource. The strategies used by cities deficient on the water delivery axis are different than for cities deficient on the water quantity or water quality axis, as lack of financial resources pushes cities toward a different and potentially less effective set of strategies.

Keywords Aridity index · Global Rural/Urban Mapping Project · Gross-domestic product · Hydrosheds

INTRODUCTION

For the first time in history, more people live in cities than in rural areas. Cities are expected to add 1.5 billion inhabitants in the next 20 years, particularly in the developing world (UNPD 2007). With this major demographic transition, the challenge of providing fresh, safe drinking water to urban inhabitants takes on global urgency. This challenge is particularly daunting, as most freshwater systems are already stressed (Vörösmarty et al. 2010), and as urban growth is just one of several major challenges facing humans use of freshwater (Rockström and Karlberg 2010). This article analyses the geography of the challenge of urban water provision and the major strategies cities are taking to meet that challenge.

Provision of fresh, clean water to urban inhabitants entails three main issues, and cities can be placed along the three corresponding axes. Availability, the absolute amount of surface or groundwater within a region that can be sustainably appropriated for urban use, is largely a function of climatic setting. Delivery describes the challenge of providing available water to urban populations, usually via infrastructure such as piped water supplies, dams, canals, and wells. Water quality, the suitability for urban household uses, is the third axis in our framework. Water that is polluted either by upstream users or through pollution in situ must be treated and purified before use in urban households.

In this article, we conduct a global, quantitative analysis of proxy variables used to estimate water availability, delivery, and quantity (for more analysis of just the water availability axis, see McDonald et al., 2011). We describe the environmental and social factors that are currently most closely associated with poor scores on these three indices.

We supplement this global, quantitative analysis with a narrative description of three main management challenges. This narrative section allows us to address issues lacking comprehensive global data, but which are crucial for the delivery of water. Our three main management challenges correspond with poor scores on one of the three dimensions of water provision, and are not mutually exclusive (i.e., one city may face more than one of these challenges):

- Arid cities that are faced with very low water availability.

- Cities that face problems of water quality because of multiple upstream users.
- Fast-growing cities that lack the resources to deliver water to their residents.

For each of the three management challenges, we use scores on our three axes to map where those conditions are distributed globally and estimate how many cities and urban residents face each particular challenge. We then draw upon available literature and more detailed case study data for a subset of cities to examine how cities responded to each management challenge, using a narrative approach. We contrast two broad categories of solutions, those that focus on increasing water supply, and those that focus on wise use of existing supply.

MATERIALS AND METHODS

Global Analysis

One goal of our analysis is to provide a quantitative, spatially explicit measure of the three axes of urban water provision. However, the available global data on water use and delivery for most cities is rather limited. Accordingly, we developed proxy measurements that represent these three axes and seem likely to capture major trends, yet can be calculated globally. While these proxies are not the perfect measure of these three axes, they suffice for our goal of presenting the major geographic trends in urban water provision.

Our base demographic data on cities was taken from the Global Rural/Urban Mapping Project (GRUMP 2010), which consists of three datasets. A point shapefile contains information on hundreds of thousands of settlements. A linked grid shows the urban extents of tens of thousands of cities, based on nighttime light imagery (cf., Sutton et al. 2001; Small et al. 2005; Henderson et al. 2003) and other areal data. Finally, a population grid shows the population for both rural and urban areas, based on the urban extents and census data. Note that the algorithm that defines urban extents merges contiguous urban and suburban areas into one urban extent. For this study, we used all cities greater than 50,000 in population in 2000. This subset of cities contains 6,730 cities and 2.4 billion urban residents, 84% of the global urban population (UNPD 2007).

Temperature and precipitation are keys to water availability. We used UNEP's aridity index as a proxy measure of water availability, where the index is the ratio of precipitation to potential evapotranspiration. Aridity index data were taken from the Millennium Ecosystem Assessment (MEA 2005), originally created by UNEP/GRID for the World Atlas on Desertification (UNEP 1997b). One drawback with this proxy variable is that a city's score is determined solely from its local climate, so that a city in an arid climate able to draw ample water from a major river would still come out low (i.e. arid) on the aridity axis.

Water quality is often a serious hindrance for urban water use, yet no global datasets with complete coverage exist for measures of water quality. The most complete dataset with information on water quality internationally is the Water Quality Database of the Global Environmental Monitoring System (GEMS), which contains information on thousands of water quality measurements globally (GEMS and UNEP 2007; GEMS et al. 2008), but information would not be available in this dataset for the majority of the cities in our study area. Our central assumption in developing this proxy is that water quality is more likely to be an issue where there are more people upstream. Previous research has demonstrated significant and strong correlations between one measure of poor water quality, nitrate concentrations (NO_3-N mg l^{-1}), and population density (Peierls et al. 1991). It appears likely that other major water quality problems, whether microbial or chemical in nature (WHO 2008), will be greater in areas with higher upstream population density. Accordingly, we calculated the upstream population density (people/ha) for each city globally, using Hydrosheds (Lehner et al. 2008) as our digital elevation model and the GRUMP population grid, which includes both urban and rural populations.

Water delivery issues are extremely challenging to measure globally in a consistent way because there are no centralized databases on how cities get their water. Our central assumption in developing this proxy is that the greatest delivery problems will be in cities that are fast growing and have few financial resources. We defined a delivery axis as the number of new urban residents expected over the period 2000–2005 divided by the per-capita GDP. Because city-specific information on population growth or economic production is not available for most cities, we use national-level values for population growth rate (multiplied by city-specific population in 2000) and per-capita GDP. Although this estimate is imprecise, we believe it still captures a useful difference in delivery capacity between, for example, Phoenix, USA (delivery axis = 5.0) and Sana'a, Yemen (delivery axis = 146.1).

Management Challenges

Although the global analysis provides a broad-brush picture of the axes that are associated with the greatest urban water management challenges, water provision is a local issue and the responses that cities employ to meet these challenges are highly dependent on economic, social, and governance issues. We therefore sought out case studies of cities that face one or more of a set of management

Table 1 Management challenges

(1) Cities located in arid and semi-arid regions that potentially suffer from problems of water availability owing to climatic constraints
(2) Fast-growing cities that have limited resources for building infrastructure and other means of delivering water to residents
(3) Cities located along large rivers that have many other water users upstream, leading to poor water quality

challenges listed in Table 1. Each management challenge corresponds to an extreme score on one of our three axes. Note that management challenges are not mutually exclusive and a city can be, for example, in the "fast-growing" and "arid" categories. Our list of management challenges is not exhaustive: for particular cities other management challenges may be important.

This section of the article aims to make quantitative statements about the number of cities facing each challenge. This requires dividing our continuous proxy variable into discrete categories. Water availability was divided based on the aridity categories used by UNEP (1997b). For water quality, we based our categories of people/ha on the analysis of Peierls et al. (1991), which quantified a relationship between people/ha upstream and the concentration of NO_3, a common water pollutant. We acknowledge that the specific empirical relationship documented by Peierls et al. (1991) may not hold in all landscapes, but for the goals of our narrative section it is a useful rule-of-thumb for interpreting our proxy variable representing water quality. Finally, for our water delivery axis we used a roughly exponential series of breaks (i.e., 0.5, 1, 10, 100), to span the range of this axis.

Our choice of case study cities was highly opportunistic, seizing on cities with relevant data. We used the list of cities with extreme scores on an axis as a guide in our search, looking for a consistent set of information for each of our case study cities (Table 2). We also chose cities of varying wealth, contrasting the response strategies used by poor cities with those used by rich ones. Similarly, in our narrative we compare solutions involving building new public infrastructure with those where private markets or infrastructure have developed to provide water as well as with cities that have attempted to restore or strengthen ecosystem services. Although a brief summary cannot cover all strategies used, it can give readers an overview of the major strategies cities and their residents use to respond to each management challenge.

RESULTS

The Geography of the Three Axes

Availability

Seventy-four million people (3.1% of the population of cities > 50,000) live in hyperarid climates (aridity index < 0.05), and another 97 million (4.0% of urban population) live in arid climates (aridity index 0.05–0.2). Cumulatively, 21.7% of urban dwellers, some 523 million, live in climates that would at least be classified as semiarid (aridity index < 0.5). In the developed world these cities are clustered in the western United States, Australia, and parts of Spain (Fig. 1). In the developing world, most of these cities are located in northwestern Mexico, coastal Peru and Chile, North Africa, the Sahara, Namibia, the Middle East, and central Asia.

Quality

Fifty-three million people are in cities with an upstream population density greater than 19 people/ha, the threshold at which NO_3 concentrations may exceed 20 mg l^{-1} (twice the United States standard for drinking water), all located in Africa and Asia. A much larger number, 890 million (36.9% of population of cities > 50000), are in cities with an upstream population density greater than 5.5 people/ha,

Table 2 Information collected from case studies

Name of city cluster
Characteristics of populations involved, including poverty and slum dwellers
Typical sources of water (surface, ground, recycled, etc.)
Types of water shortage experienced (duration of supply, leakage, lack of connections, insufficient flow or groundwater table lowering)
Range of adaptations (private boreholes, commercial water sellers, bottled water, self storage, rooftop collections, fetching from standpipes or wells or river, desalination, recycling of treated waste water, dual water systems)
Prospects for the future (planned new installations, increased household level adaptation, water saving, leakage reduction, infrastructure maintenance and renewal)
Ecosystem impacts of present situations
Use of ecosystem services to ameliorate situation (encouraging infiltration, wetland restoration, etc.)

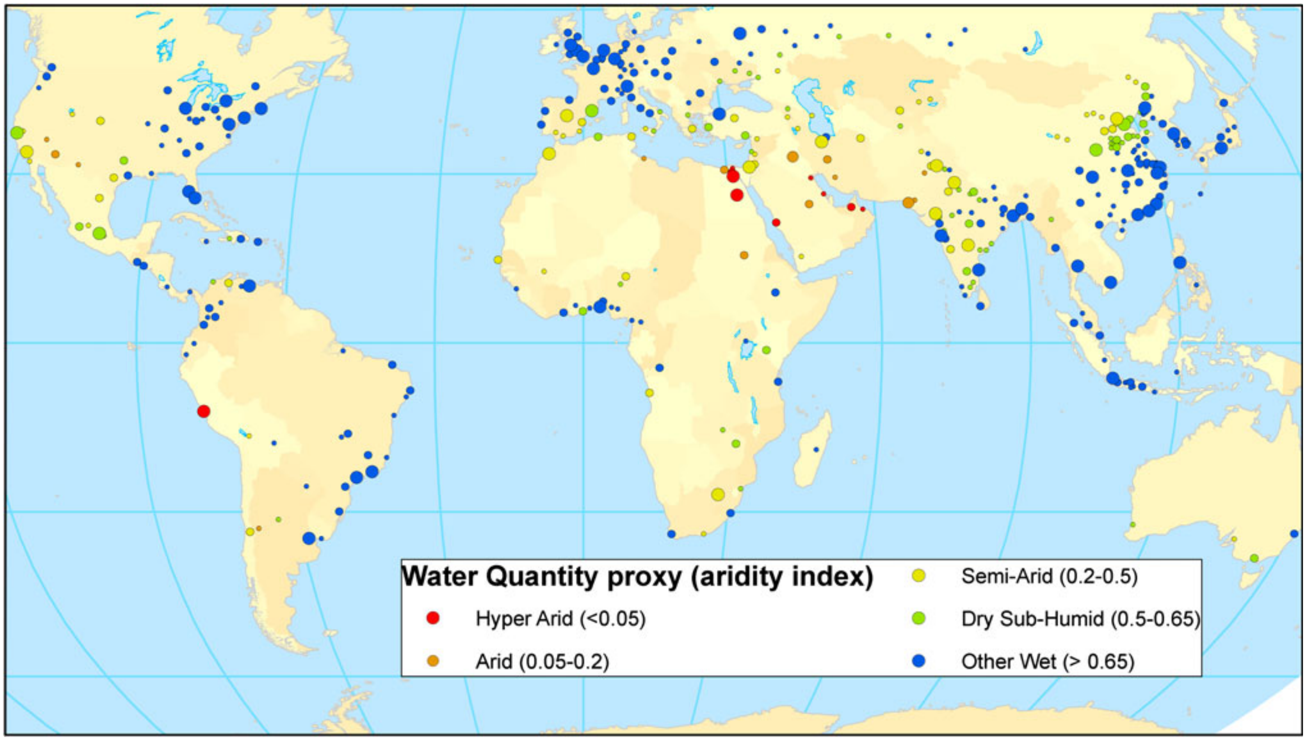

Fig. 1 Water availability for the world's cities. Water availability is measured by the aridity index, which is precipitation/potential evapotranspiration. For clarity, only cities with more than 1 million population are shown, and cities with medium (2–5 million) or large (>5 million population) are shown as medium or large *circles*

the threshold at which NO_3 concentrations may exceed the U.S. drinking water standard of 10 mg l^{-1}. Water quality issues affect all continents (Fig. 2), but tend to be concentrated in major river basins like the Ganges (India) and the Yellow River (China).

Delivery

Four hundred and forty-two million people (18.3% of population in cities > 50000) are in cities with more than 100 new residents per dollar of GDP per capita, a high score on our delivery axis that implies great challenges to meet future urban water provision. Cumulatively, 1.3 billion people (53.9% of all urban population) live in cities with more than 10 new residents per GDP per capita, mainly in sub-Saharan Africa, the Indian subcontinent, and Southeast Asia (Fig. 3). Nigeria has the greatest proportion of its cities in this delivery-challenged category. In contrast, some cities in developed countries have less than 0.5 new people per GDP per capita, and thus have roughly 20 times more financial capacity to deliver water to new urban residents than might a developing world city with 10 new people per GDP per capita.

Delivery-challenged cities have few financial resources to deliver water effectively to their residents. However, many such cities are making progress. For example, in 1995 only 74–81% of Dakar's population had access to safe drinking water, and only 58% of households had a piped connection. Today 98% of the people have access to safe drinking water, and 76% of households have a piped connection. It cost around $290 million in capital costs to give 1.6 million people new access to safe water, averaging $180/person (IDA 2010), relatively little money by the standards of the global economy.

The Strategies Adopted in the Three Categories of Cities

Cities have two broad sets of strategies to cope with insufficient water: strategies that involve building infrastructure to obtain more water than is currently available, and strategies that involve making wiser use of existing supplies, either by improving water-use efficiency or water quality. Cities that face one of our three management challenges tend to use particular strategies tailored to that challenge (Fig. 4). Strategies also vary in the degree to which they are centralized (adopted by the state or municipal authorities responsible to the main water supply) or decentralized (adopted by individual households, companies, or local communities). In general, cities that struggle with the Delivery management challenge tend to use more of the later, since resources or organization may be lacking for more centralized solutions.

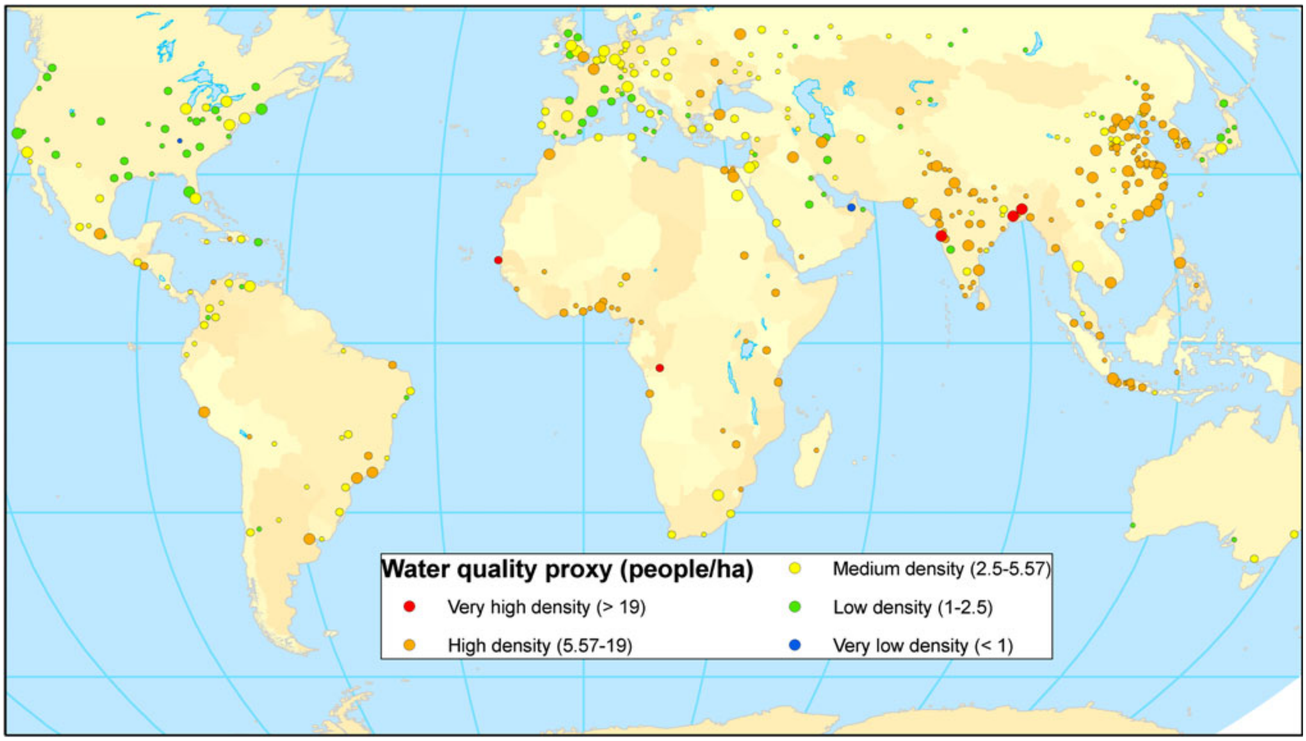

Fig. 2 Water quality for the world's city. Water quality is measured as the density of people in upstream contributing areas (people/km^2). For clarity, only cities with more than 1 million population are shown, and cities with medium (2–5 million) or large (>5 million population) are shown as medium or large *circles*

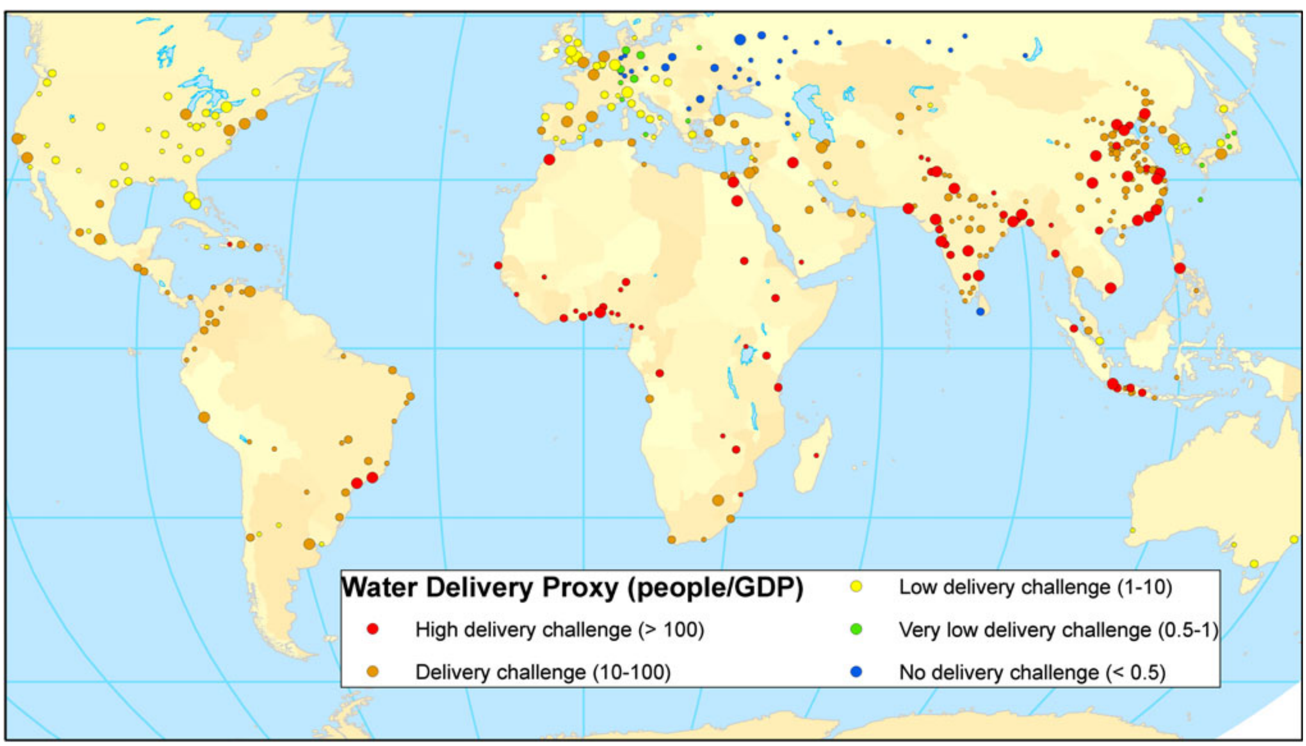

Fig. 3 Water delivery for the world's city. The ability of a city to delivery water to its citizens is measured as the number of people expected divided by per-capita GDP. For clarity, only cities with more than 1 million population are shown, and cities with medium (2–5 million) or large (>5 million population) are shown as medium or large *circles*

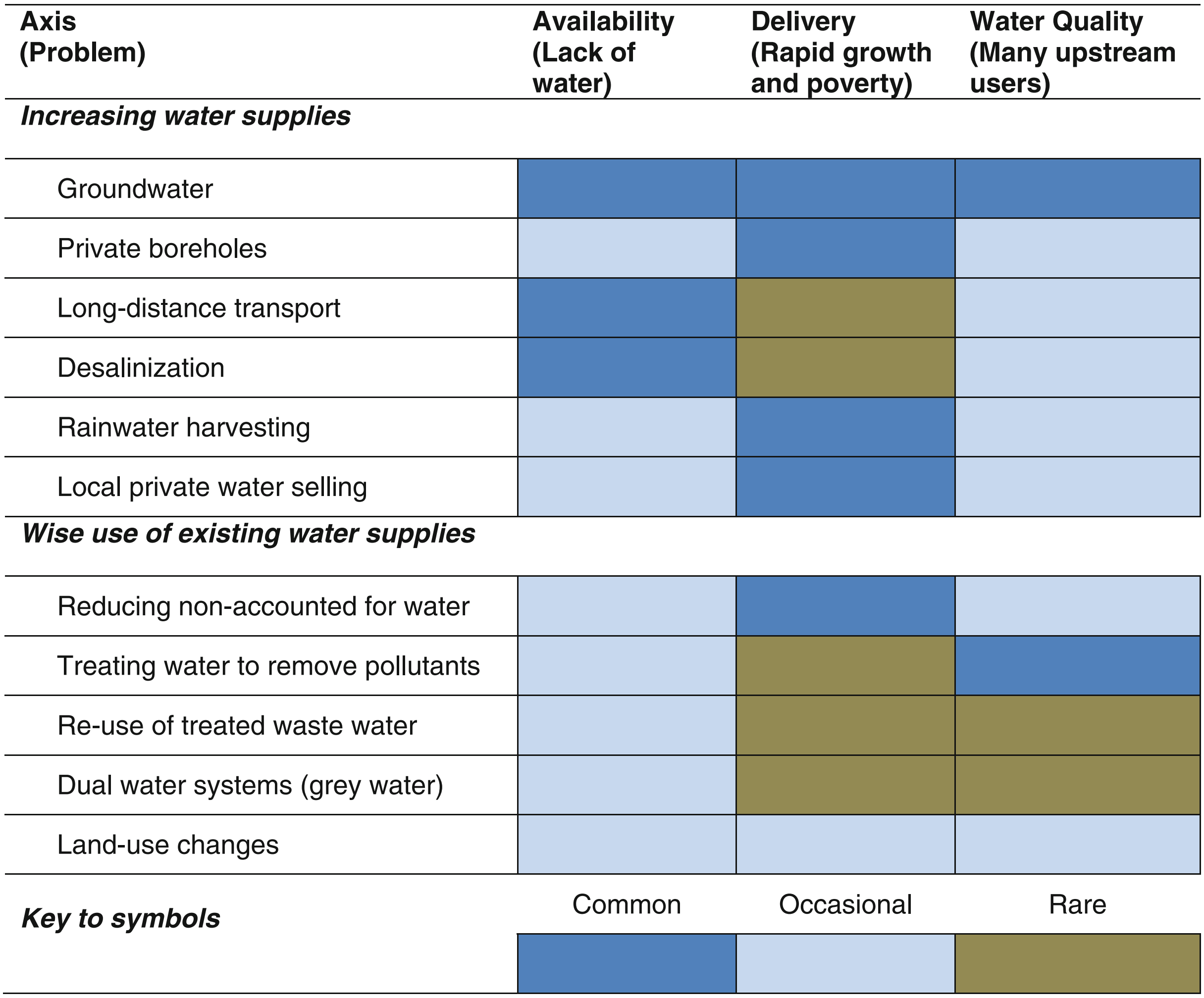

Fig. 4 Frequency of strategies used by cities in response to three major management challenges

Strategies to Increase Water Supply

Most cities turn to tapping into groundwater as the solution of choice to meet urban water needs in all three management challenge categories. Groundwater has long been used as the main supply in arid areas and, in conjunction with surface water, in large cities located along rivers. Groundwater use is not only a response to surface water shortages, but also water pollution and inadequate delivery. Cairo (Egypt), for example, abstracts about 72% of its supply from the Nile and 28% from groundwater, in part due to water quality problems (Shahin 1990).

In cities with inadequate public delivery systems, residents may install private wells or boreholes to obtain water. Today in wealthier cities, an abstraction license is required before water can be taken from an aquifer, but for decades, drilling a private borehole without any permit requirement has been a key strategy to overcome an unreliable public water supply. However, in Delhi, so much groundwater was being abstracted privately, to overcome issues with both quality and quantity of municipal supply, that the Delhi Jal Board, the body that gives borehole approvals, has to reduce the number of permits for boring tubewells (Anonymous 2008).

Groundwater use is sustainable if the rate of aquifer recharge is higher than the rates of withdrawals. However, for many arid cities, groundwater use far exceeds the low rates of aquifer recharge and groundwater levels are dropping. Mexico City has so overused its aquifer that the ground is subsiding 40 cm/year in some areas (Carrera-Hernandez and Gaskin 2007). Below Beijing, the water table has fallen by about 1 m a year since 1980 (Zhang et al. 2006). Many other fast-growing cities face similar problems, but globally the extent of this groundwater mining by cities is unknown. However, if even a significant fraction of cities in drylands are relying on groundwater abstraction, then our figures suggest that tens or hundreds of millions of people may be using their local groundwater unsustainably. Excess abstraction in Bangkok, for instance, has caused subsidence, damaging the foundations of valued historic buildings as well as producing localized flooding because rainwater gets trapped by changes in surface topography (Phienwej and Nutalaya 2005). Moreover, groundwater in many urban and peri-urban areas has been significantly affected by pollutants, particularly nitrate. For instance, surveys in India and Africa found that 20–50% of all wells had nitrate concentrations greater than 50 mg/l (UNEP, UN Water, and UN Habitat 2010).

Long-distance transport of water by canals or pipes is a common solution for cities facing the Availability management challenge, and occurs occasionally in cities facing the Water Quality challenge. The source of water is sometimes distant groundwater. The boldest such scheme is the Great Libyan Man-made River (Kuwairi 2006) which is abstracting water from ancient aquifers beneath the Sahara desert that are no longer recharged and carrying it to cities and farms along the Mediterranean coast.

More frequently, distance surface water sources are used, sometimes transferring water between river basins via man-made connections called interbasin transfers. Many large Indian cities, including Delhi, Mumbai and Chennai, already rely in part on interbasin transfers (Jain et al. 2007). China is proceeding with a south-north transfer (Liu 1998) which will ultimately transfer 45 billion m^3 from the Yangtze to farms and cities in the north (Zhang et al. 2009). Nairobi built the Thika Dam, 60 km from the city in the 1990s to double the piped water supply to the city (Syagga and Olima 1996). Lagos is planning a new pipeline to deliver water from the Oshun River. Interbasin water transfers continue to expand around the globe. Interbasin transfers involve multiple trade-offs, often damaging economic activities and freshwater ecosystems in the river basin that lost water while often economically benefiting others in the city capturing the water (Ghassemi and White 2007).

Reservoir systems which can capture and store seasonal runoff for year-round use are still a favored response to availability problems. In areas dependent on snow and glacier melt for water, like the Indus and Ganges, the Yellow and Yangtze Rivers or the Murray Basin in Australia, reservoirs have been the preferred means to capture water for urban use. China is planning 59 new reservoirs to collect water from shrinking glaciers in its western regions (Watts 2009). Many of these reservoir systems store water for use in distant basins, necessitating long-distance pipelines.

Rainwater harvesting is an ancient technique being adopted more widely in all three categories of city discussed in this article. It has the advantage of being decentralized, requiring low technological knowledge and relatively inexpensive. Harvested rainwater is primarily used for purposes other than drinking water, such as groundwater recharge and irrigation. Legislation requiring all properties above a certain size to harvest rain water has been passed in Banglalore, Ahmedabad, Chennia, New Delhi, Kanpur, Hyderabad and Mumbai. The Bangalore legislation (City of Bangalore 2009) requires every new house to have a rainwater harvesting system in order to get a piped drinking water connection. In the USA, tax incentives encourage rainwater harvesting in Texas and Arizona, and in Santa Fe, New Mexico, and Tuscon, Arizona, all new commercial developments are required to use harvested rainwater for watering their lawns and gardens (City of Tucson 2008).

Another common strategy employed in most cities in the developing world is to obtain water from private water sellers. Private water sellers are typically a more expensive solution that municipal supply, but emerge wherever municipal supplies are inadequate or unreliable. Local private water selling is widespread in Asia, Africa, and Latin America in all three categories of city discussed here. In poor cities that suffer from both water quality and water delivery issues, a two tiered system often develops, where richer residents can afford to buy clean water from private vendors while poor residents either endeavor to clean polluted surface waters or buy “pure” water in plastic bottles or sachets to drink at a high price from local vendors. In Port-Au-Prince (Haiti), the poor might be spending 20% of their income on water; in Onitsha (Nigeria) during the dry season 18%; and in Addis Ababa (Ethiopia) 9% (Bhatia and Falkenmark 1993). Poor people who buy sachets of water from local vendors face the risk that it may be of poor quality; cholera outbreaks have been linked to such water (Hutin et al. 2003). Most households increase storage, with tanks for the middle class and plastic bottles, jerry cans, or stone jars for poorer households (Bartlett 2003) but health risks may arise from deterioration in household storage (Hammad et al. 2008).

Strategies to More Wisely Use Existing Supplies

Leakage can represent a substantial loss from water delivery systems, and reducing unaccounted for water is a goal for many water supply systems. In wealthier cities, the main concern is to reduce leakage from old or damaged water mains and pipes. In Europe, Malta more than halved leakage, and the UK cut leakage by about one-third, between 1995 and 2001 (Lallana 2003). Riyadh was losing 60% of its water through leakage and is reducing that loss to 20% though increased monitoring of pipe pressures and flows. However, for cities facing the Delivery management challenge the problem stems not only from poor maintenance of the system, but also from illegal connections by residents or by water vendors who fill containers with water to sell to the poor (Gandy 2006). A much higher proportion of water in developing countries is unaccounted for than in developed countries (Kingdom et al. 2006). For example, in Lagos, Nigeria, between 40 and 90% of the piped supply is not accounted for (Global Water Intelligence 2010). In many places, particularly Africa, reduction of leakage and other losses is possibly a greater priority than making large new infrastructure development, but financial resources and government structures are limited to deal with maintenance issues.

Cities with water quality problems and adequate resources are able to treat polluted water before distributing to urban users and regulate sources of pollution (e.g., by constructing sewage treatment plants). However, most cities in the developing world and some in the developed world are currently unable to afford the tens or hundreds of millions of dollars required for water treatment. Most major infrastructure improvements in African cities are usually funded by international aid or loans that pay for building sewers or complex water treatment plants. This lack of water treatment is particular important because many cities in developing countries also lack adequate sanitation systems. While water use for sanitation is not the focus of this article, there are obvious connections between the lack of a sanitation system upstream and serious drinking water quality problems downstream.

Re-use of treated waste water to increase water use efficiency is expanding, usually as part of a broader program by a city facing the Water Availability management challenge. In Orange County, California (USA.), sewage water is treated by microfiltration, reverse osmosis and ultra-violet light with hydrogen peroxide disinfection before being used to replenish the groundwater aquifer. In Barbados, hotel effluent has been treated and used for landscaping irrigation (UNEP 1997a). In the Yarra Valley area, Australia, households are required either to use recycled water for secondary uses (not drinking) or to have solar water heating or carry out rainwater harvesting to reduce municipal water use (Kelly 2006).

Some cities have experimented with parallel pipe systems for potable and non-potable water as a way to decrease demand for water treatment. Both Gibraltar and Hong Kong have a second pipe network distributing sea water for flushing toilets, washing cars and other forms of cleaning (Chau 1993). Dual systems also exist at the household scale, particularly for "grey water" from roofs, such as in the Netherlands (Fernandes et al. 2006), although some projects have ended due to cross contamination between the grey and the drinking water (Oesterholt et al. 2007).

Another broad strategy is changing land-use to better take advantage of available freshwater which can help cities facing the availability or water quality management challenges. Depending on the change in land-use, it can either be a net positive for freshwater biodiversity, if hydrologic flows are restored, or a net negative, if hydrologic flows are further altered.

In arid climates, there are relatively few incentives for restoring or strengthening the role of natural ecosystems in water services provision rather than construct new infrastructure. However, in some cases changes in land management can save water, as in South Africa's Working for Water program where invasive non-native yet water hungry tree species are removed to increase available water. More commonly, cities simply obtain water that was allocated for other users, particularly the agricultural sector or the environment, effectively changing part of a watershed's land-use from agriculture to a less water-intensive use. For instance, many Colorado farmers have ceased production and sold their water rights to Denver and other cities (Kimball 2005).

Since water quality problems for an individual city are dependent upon upstream uses, land-use changes can also help improve water quality. Some cities have experimented with water treatment using natural systems, such as wetlands. For instance, in Kampala (Uganda) the Nakivubo wetlands have been restored to better act as a filter removing urban wastes before they reach the municipal water intake (Emerton et al. 1998).

DISCUSSION

Our results show the highly varied geography of urban water provisioning resulting from the overlay of water availability, water quality, and water delivery. Different issues matter in different places, with some unfortunate cities suffering from two or three of these management challenges. While perhaps obvious, an appreciation of this varied geography is important because international policy discussions often focus on only one of the three axes. For example, climate change discussions tend to focus on implications for water availability, ignoring issues of water quality and delivery which our results suggest affect more urban dwellers. Moreover, the response to an issue on one axis, like climate change's impact on water availability, will necessarily be governed by the social and economic situation of the city, and any response will likely also affect the other two axes. We hope this article motivates a broader discussion among policymakers of the complex interplay among the three axes of urban water provision.

Regardless of which management challenge a city faces, the first response of many cities seems to be increased use of groundwater. Groundwater use reduces immediate concerns about water availability and sometimes water quality, and because groundwater pumping is cheap it is affordable in most economic contexts. Given this heavy reliance on groundwater, it is surprising that more global datasets have not augmented the World Bank's review (Foster et al. 1998). More information is needed about which cities rely on groundwater for their municipal supply as well as the water budgets and recharge rates of their aquifers. Without better information on groundwater use, it is hard to know how many millions of people are in cities that are essentially mining groundwater in an unsustainable fashion. If even a fraction of cities facing the availability management challenge unsustainably pump groundwater, hundreds of millions of urban dwellers may have an unsustainable source of drinking water.

A second major trend is the importance of private sector solutions where local governments cannot meet demand for clean water. While some of these solutions are complementary to public strategies (e.g., rainwater harvesting, household water treatment), others may conflict with public projects, such as illegal water withdrawals from water supply systems and the drilling of private boreholes which can lead to groundwater table declines and land subsidence.

We identified two major categories of strategies that cities can use, increasing water supply or using existing supply more wisely. The latter has the potential to be used more widely than it is currently, and it seems likely to have less of a negative impact on freshwater ecosystems, already one of the most damaged habitat types on Earth. However, the scarcity of information on the use of strategies that seek to use existing supply more wisely makes it difficult to evaluate the frequency of such strategies or their cost relative to infrastructure-based solutions. While renewed interest in environmentally friendly solutions to problems of water provision has resulted in a number of excellent case studies, most cities do not document the extent to which, for example, they are dependent for forests or wetlands for water filtration. In contrast, detailed engineering data is usually available for infrastructure that increases water supply.

Regardless of whether cities are investing in infrastructure to increase water supply or trying to use existing supplies more wisely, it is clear that substantial financial resources will be required to address these management challenges in the future. One study estimated that from 2003 to 2025 necessary annual investments would exceed $180 billion per year (World Panel on Financing Water Infrastructure 2003). While our study cannot shed light on the cost of investment, we estimate that a significant number of people in cities are already facing water provisioning challenges, in the hundreds of millions for water availability and water delivery and more than a billion for water quality. Furthermore, our analysis of delivery challenges suggests that many cities will be unable to finance water delivery projects themselves, highlighting the need for substantial international funding. While plenty of possible solutions to water quantity and quality problems exist, including some that are relatively less harmful to the environment, they all take money and time to implement. For more than a billion people in cities facing water delivery challenges, both are in short supply.

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