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Megacities and Water Management

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ABSTRACT *Efficient and equitable water, wastewater and stormwater management for the megacities is becoming an increasingly complex task. When accelerating water scarcities and pollution in and around urban centres are superimposed on issues like continuing urbanization, lack of investment funds for constructing and maintaining water infrastructures, high public debts, inefficient resources allocation processes, inadequate management capacities, poor governance, inappropriate institutional frameworks and inadequate legal and regulatory regimes, water management in the megacities poses a daunting task in the future. This paper will focus on water management in its totality in megacities, including their technical, social, economic, legal, institutional and environmental dimensions through a series of case studies from different megacities of the world.*

Introduction

Cities grow ever faster. Cities grow ever bigger. Imagine a middle-sized town of 200 000 inhabitants. With so many people the world's urban population increases in one day. In one month this growth is almost 6 million and in a year around 70 million. This implies that rural areas must supply escalating amounts of food, energy and many other commodities to towns and cities. Mass flows grow rapidly, distorting ecosystems, as do markets, distorting ages-old social systems.

One of the most striking aspects of urbanization is the growth of very large urban centres. Whereas in 1985 there were 31 megacities, i.e. urban agglomerations with more than 5 million inhabitants, the number had grown to 40 by 2000, and this is expected to grow to 58 by the year 2015. Their population growth is equally dramatic; between 1985 and 2015, from 273 to 617 million. The annual increment to megacities is 9 million, which means 25 000 persons per day. Megacities will double in number and population size between 1985 and 2015. This growth is partly the result of a modification of the administrative boundaries, i.e. some of the annual increment of 9 million consists of people who are living in an area that previously was outside the megacity boundary but which has become incorporated into the megacity.

The rapid growth of the megacities in the developing world has posed major water planning and management changes. In 1994, of the 10 largest cities of the world, only

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three were in developed countries. By 2015, only two, Tokyo and New York, are expected to stay in this list. However, whereas Tokyo's population is estimated to increase by less than 5% during this period, cities like Jakarta, Karachi, Lagos and Dhaka are expected to grow by 60% to 75%.

Urbanization and growth of megacities are not new phenomena: cities such as London or New York started to grow in the 19th century. However, two important differences should be noted which have made the urbanization process (and provision of water supply, sanitation and stormwater disposal services in the megacities) of the developing world fundamentally different from their counterparts in the developed world one century earlier (Biswas *et al.*, 2004).

The first difference is the rate of growth. The development of the megacities in the developed world was a gradual process. For example, much of the population growth in cities such as London and New York was spread over a century. This enabled these cities to progressively and effectively develop the necessary infrastructures and management capacities for all their water-related activities and services.

In contrast, the megacities of the developing world witnessed explosive growth during the post-1950 period, and especially after 1960. For example, the population of Mexico City Metropolitan Area increased from 3.1 million in 1950 to 13.4 million in 1980, a 425% increase in only 30 years. This expansion continues still as the City's population has now exceeded 18 million. Such megacities were simply unable to manage such explosive growth rates. They had to run faster and faster to stay in the same place. The fastest growing megacities are expected to grow more than fourfold in 25 years. Such cities include Dhaka (Bangladesh), Lagos (Nigeria), Guatemala (Guatemala) and Jinxi (China). The dimension of the urbanization development is striking, whether considered either from the standpoint of megacity growth, augmentation of the urbanization level or from the growth rates of urban population.

The second major difference is that as the megacities of the industrialized countries expanded, their economies were growing concomitantly. Accordingly, these urban centres were economically able to harness financial and human resources to provide their residents with the necessary water-related services (Biswas *et al.*, 2004).

In stark contrast, economies of the developing world have mostly performed poorly during the period of this rapid urbanization. High public debts, inefficient resource allocation, poor governance, lack of investment capital and inadequate management capacities have ensured that the necessary infrastructures could not be built on time, and the existing facilities could not be properly maintained.

The urban poverty problem is massive and increasing. Whereas the number of the urban poor is approximated to be around 1 billion today, it is expected to double by 2030. After UN HABITAT (2004), the humble UN target defined in the Millennium Development Goals to reduce the number of slum dwellers to half is likely to remain a dream. What seems more likely is that the number of slum dwellers will double. Slum upgrading policies, particularly in bigger urban agglomerations are therefore expected to become very important in the coming decades, stirring also the water sector. Figure 1 contains UN HABITAT estimations of the percentages of urban slum populations in the countries and regions of the case study cities.

How these excessively large and rapidly growing urban centres manage water in all its aspects is the question that is elaborated and summarized in this paper. The particular focus is how the water sector addresses the present and future challenges and how sustainable the approaches are. This analysis summarizes the situation in eight megacities

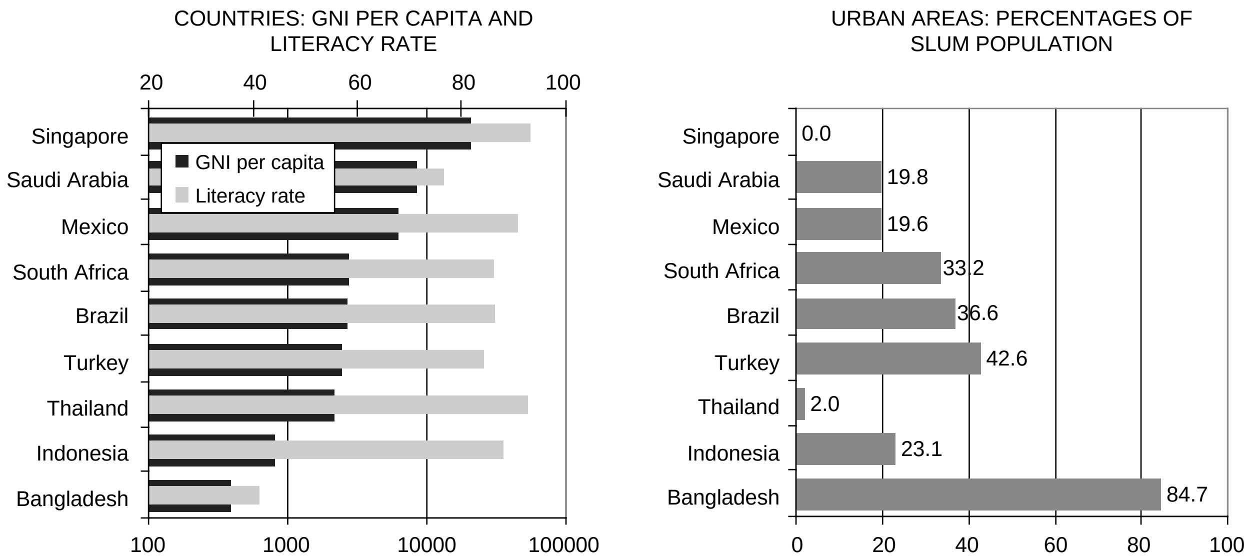

Figure 1. Left: Gross National Income per capita in US$ and adult literacy rate (over 15 years) in 2000 (World Bank, 2004). Right: Percentage of urban slum population by country. *Source:* UN HABITAT (2003a).

worldwide. Those cities are Dhaka, São Paulo, Mexico City Metropolitan Area, Jakarta, Johannesburg, Istanbul, Riyadh and Singapore.

There have been a number of recent analyses on this topic by organizations such as UN HABITAT (2003a), 2003b, 2004) and development banks. However, the authors of this paper feel that the magnitude and importance of this problem is not properly comprehended and the urbanization problem has been absolutely inadequately addressed in recent key events related to water policies, such as the World Summit on Sustainable Development of Johannesburg in 2002 as well as the three World Water Forums (from 1997 to 2003).

Megacities and Water

As the cities grow, their water and wastewater disposal requirements grow as well. Water management was not a serious problem as long as population numbers were low and concentrations of the people were not high. As the population increased dramatically in the last 50 years, and the rate of urbanization began to accelerate, the provision of clean water and safe disposal of wastewater and stormwater in the megacities of developing countries became increasingly more complex and serious (Biswas *et al.*, 2004).

Continuing urbanization poses a major challenge in providing adequate water services to the megacities, but its importance and contribution towards the development of stronger and more stable national economies should not be underestimated. In 2000 it was estimated that the urban areas of the developing world, which contained some 30% of the total population, contributed nearly 60% of the total GDP and played an equally important role in terms of social development and cultural enhancement. Thus, the urbanization process presents both opportunities and challenges.

The main problem of megacities often stems from the fact that the rates of urbanization have often far exceeded the capacities of the national and local governments to plan and manage the demographic transition efficiently, equitably and sustainably. Living conditions are particularly harsh for the large part of the urban population, maybe about a third, who live in areas which are not planned and where public services are lacking or are rudimentary. Quite often the authorities have been reluctant to recognize these mushrooming parts of the cities and have also been hestitant, or unable, to extend social services, including water and sanitation, to the population in these areas. People in these informal areas, however, constitute a pool of labour and they play a very important role in the economic growth of cities. At the same time, the deplorable living conditions are a threat not only to the quality of life in these areas, but to a stable functioning of the city as a whole (Lundqvist *et al.,* 2003). The high growth rates of megacities have simply overwhelmed the limited capacities and resources of the responsible governments at all levels. There is thus an urgent need for additional water and sanitation services, either from government but more probably in partnership with other responsible actors (Biswas *et al.*, 2004).

These developments have resulted in extensive air, water, land and noise pollution, which have major impacts on the health and welfare of the megacity dwellers. The problem is further compounded by skewed income distribution, high unemployment and underemployment, pervasive corruption and increasing crime rates.

Provision of clean drinking water, wastewater collection and disposal and stormwater disposal have now become serious problems for most megacities, ranging from Manila to Mexico City, and Kolkata to Cairo. Indeed, there is also a mounting need to improve services to industry and service sectors. Fortunately, in many urban centres, progress is being made, new and innovative approaches are being successfully applied, and water institutions in certain countries are undergoing radical transformation. Many of these success stories, even with the current information and communication revolution, are mostly unknown and undocumented.

Besides water supply, sanitation, stormwater and waste management, water is fundamental to megacities in several other aspects too. The number of humans exposed to floods tripled from 1970s to 1990s, being around 2 billion today. The major factor behind this development is the congestion of hundreds of millions of people in mushrooming cities on deltas and floodplains of flood-prone tropical rivers. Interestingly, a considerable number of desert and semi-desert megacities are also currently growing at an incredible pace. These cities have the opposite problems with water—they feel scarcity very concretely in their everyday lives (Biswas *et al.*, 2004).

Cities eat enormous amounts of food that they import from countryside, often far away. Megacities alone import as much virtual water as what crosses national borders in all the international food trade. Likewise, megacities import massive quantities of energy. On average, a megacity dweller consumes 5 to 10 more times the amount of energy than the national average. All agendas say that the growing energy production should be covered by renewable sources. In urban conditions, this means practically hydropower or bioenergy. Both of these energy sources rely absolutely on water (Varis, 2006, this volume).

Water in Eight Megacities

The situation and future prospects of the eight rapidly expanding case-study megacities in various parts of the developing world have been summarized in this volume. Those cities are the following (author's name in brackets): Jakarta (Lanti), Dhaka (Haq), Johannesburg (Turton *et al.*), São Paulo (Braga *et al.*), Mexico City Metropolitan Area (Tortajada), Riyadh (Abderrahman, 2006), Istanbul (Altinbilek) and Singapore (Tortajada).

Jakarta

The capital of Indonesia, Jakarta, is the biggest megacity in Southeast Asia. It is located on the highly crowded island of Java, which has around 120 million inhabitants on only 132 000 km^2, making Java one of the most densely populated areas in the world with its 910 inhabitants per km^2.

Jakarta has an official population of 10 million inhabitants, but its actual population is probably higher. The number of seasonal residents and commuters was already 1.15 million in 1985 (UN, 1989). The city quadrupled its population between 1975 and 1995.

Twenty to twenty-five per cent of the housing in Jakarta is on a temporary basis, in so-called kampung areas, and other 4–5% lives scattered on river banks and other comparable plots of land (McCartney, 2004). The kampungs now have a semi-legitimate status.

The water distribution network of Jakarta was originally built by the Dutch to supply water for 0.5 million inhabitants. Although extended, it cannot cover the whole city area. Due to rapid population growth, development in new industries and large-scale real estate construction, there is a rapid increase in water demand.

The water supply services are operated by two privatized companies, the French Ondeo for the Western Sector and the British Thames Water for the Eastern Sector. This

Table 1. Comparison between expected and achieved indicators of water supply in Jakarta after privatization in 1998

	Condition in 1996	Condition expected in 2002	Achievement in 2002
Groundwater over-abstraction	Severe	Reduced	No significant reduction
Service coverage	41%	70%	44.2% (West) 62.2% (East)
Share of non-revenue water	57%	35%	44%
Water sold	176 million m^3/year	342 million m^3/year	255 million m^3/year

Source: Lanti (2006, this volume).

arrangement has been operational since 1998 when the Provincial Government of Jakarta decided to privatize its water supply operations.

In 1996 the plan was that the private operators would increase the water supply coverage from 40% to 70% of the households by 2002. However, this target remained very far from reality, as did the other targets (Table 1).

Several reasons contributed to this failure to meet goals, including the following:

- The Asian financial crisis, which cut the value of the local currency remarkably against foreign currencies.
- Restrictions to adjust the tariffs for full cost recovery. Despite this, the tariffs went up by 2.5-fold in 2001–04.
- Ambiguous status of former and present government workers in the private companies.
- Lack of fulfilling the obligations on both the government and the private side.

During this period, the average per capita consumption remained at 156 litres per day.

The domestic waste disposal system is highly underdeveloped in Jakarta. The coverage of the sewerage service was to a mere 1.9% of the population in 2001. The only wastewater treatment technology used in this context consists of aerated lagoons. The city has about 1 million septic tanks that cover around 39% of the population, 20% use pit latrines and the remaining 59% discharge their waste directly into dikes, canals and rivers. Highly polluted canals and rivers are used widely as a water source for cooking and washing (Lanti, 2006, this volume).

The extension of the water supply faces severe problems. Over-abstraction of groundwater has already caused remarkable saltwater intrusion into the main aquifers. Surface waters, which are utilized in the water supply, are often so polluted that they are considered worse than the water running through sewage treatment systems in many countries. Network leakages are huge. The water supply companies must make profits, so they focus extensions of the network to households who can pay. Standpipes on kampungs have received attention by the governments but progress is slow. Where there are standpipes, there are often illegitimate vendors selling water to the poorest urban households at over 10 times the official price (Lanti, 2006, this volume).

The area is prone to seasonal floods that raise water into the streets. Wide-reaching groundwater pollution has been observed due to poor waste management. As a response, existing drains have been re-directed in some locations to provide a faster passage of the water into the sea. Pilot scale studies for the construction of a sewer system have already been made since the 1980s (UN, 1989) but not much has happened.

Dhaka

It is not easy to imagine a more water-affluent megacity than Dhaka. Dhaka receives 2000 mm of rainfall annually. It is located close to the convolution of the mighty Ganges, Brahmaputra and Meghna rivers and it is frequently flooded, often catastrophically. These three rivers constitute the world's second biggest river system with an annual discharge 25 times that of the Nile. However, Dhaka is one of the most challenging megacities in its water management.

Dhaka is the political and economic centre of Bangladesh. The country has more than 130 million people in an area of 147 540 km^2 making it extremely crowded. Dhaka's population is approaching 15 million with a growth rate of around 5% per year. Bangladesh is one of the poorest countries of the world with 44% of people living below the poverty line. It has been estimated that around one-quarter of Dhaka's population live in slums (UN HABITAT, 2003b).

The water supply and sewerage services have been allocated to one single public authority. It now supplies 0.51 km^3 of water per year against the demand of 0.73 km^3, serving around 72% of the city dwellers. The quality of the supplied water is very much in question. Almost 1000 private wells abstract another 0.35 km^3 per year of groundwater, mainly for industrial purposes. Groundwater is used far beyond the sustainable rate and this groundwater mining puts a serious strain on the environment. The groundwater table has gone down 20 to 30 m in the past three decades and continues to sink 1 to 2 m per year (Zahid *et al.*, 2004). Fortunately, the groundwater used by Dhaka is free from arsenic.

Seventy per cent of the population has adequate sanitation and 30% are served by sewer networks. Only one sewage treatment plant exists, with a treatment capacity of 49 000 domestic connections. This is not a great deal for a megacity of the size of Dhaka. Over one-quarter of population lacks adequate sanitation altogether (Haq, 2006, this volume).

The share of unaccounted-for-water is around 53%. It has gradually decreased from the level of 75% in 1980. There are currently important discussions on various water management issues such as the cost recovery of water services through tariff regulation, increased involvement of the private sector to water management etc. in order to bring more efficiency and transparency to the water sector of Dhaka (Haq, 2006, this volume).

Serious surface and groundwater pollution with detrimental effects on public health follow from the massive infrastructure shortcomings in water supply and sanitation. They are reinforced by occasional and often dramatic flooding, which raises the water level to streets and dwellings. Stormwater management systems have been developed but not at pace with the growing population, particularly for the Eastern part of Dhaka with a population of 3 million (Ahmad & Kamal, 2004). Several decades ago, the city was covered by a canal network of 24 canals and included a large area of natural wetland. This system was able to keep flood damage fairly low. The unplanned and largely illegal sprawl of the city ever since has led to the situation in which no proper stormwater infrastructure exists. The most important flood protection system today is the Dhaka Western Embankment which is able to keep about half of the city area virtually flood-free (Haq, 2006, this volume).

Johannesburg

Johannesburg is not a megacity according to the UN definition and according to the UN (2002) statistics with its population of 2.4 million in 2005. However, as Turton *et al.* (2006, this volume) point out, the infrastructure and the water management system that serves Johannesburg is also serving several other cities and settlements that have a total population of around 10 million. The system also serves massive industries such as coal and steel and that part of South Africa accounts for 10% of all economic activity of the African continent. Accordingly, Johannesburg is a part of an agglomeration that can easily be called a megacity.

In hydrological terms, Southern Africa is a very challenging region for sustaining such a large agglomeration of human population and industries, particularly in the location of Johannesburg. Even though the total annual rainfall in the uplands where Johannesburg is located totals reaches up to 600 mm on average, the evaporation losses are 1600 mm and the conversion of rainfall to river flow is exceptionally low (see also Basson *et al.*, 1997). In addition, the rainfall variability is very high which makes exploitation of water still more complicated.

Johannesburg is located on a ridge, which is at the headwaters of two major international rivers, the Orange and the Limpopo. The city is thus not by a major river that it could use, but instead its activities have international hydropolitical consequences. The reason why the city has such a very unfavourable geographical location is due to the fact that Johannesburg originally grew around gold mines (Turton *et al.*, 2006, this volume).

How then is the greater Johannesburg area able to manage its water? The solution is extensive indeed. Several dams have been constructed and rivers have been interlinked. In fact, all major rivers in South Africa are now interlinked and considerable water transfers take place between river basins. This causes growing tensions, even internationally. The most important of these transfer systems to Greater Johannesburg is the one that brings water from five large dams in the Lesotho Highlands, through a channel to the Vaal River and then to the Vaal Dam which is the major source of water of Johannesburg. The distance from Lesotho to the city approaches 500 km. In addition, three other large dams have been constructed to facilitate a sufficient water supply to the greater Johannesburg area.

Rand Water, the company responsible for this system, now supplies around 3.3 km^3 of water per year. The supply capacity has recently grown much faster than the demand and consequently there is a considerable overcapacity of up to 60% of demand in the region. The demand projections have been overly high due to lower economic growth than anticipated, an increase in HIV/AIDS and the success in demand management. Despite improved demand management, the share of unaccounted-for-water is still over 50%. On the other hand, such an overcapacity allows good possibilities for risk management, which is very important in the climatic conditions of Johannesburg area. The area is subjected to several other considerable risks such as health risks from HIV/AIDS, potential conflicts, environmental risks and so forth (Turton *et al.* 2006, this volume).

The high share of unaccounted-for-water is not merely a technical issue. Instead, it reflects the enormous social contrasts of the city, which have their roots in ethnic disparities that are dramatic and existed even before the apartheid era. As one of the many reflections, the crime rate in Johannesburg is higher than in any African city that has been recorded in UNCHS statistics (UN HABITAT, 2004).

The water infrastructure is fairly developed in Johannesburg. In 1995, 80% of dwellings had a piped water as well as sewer connection (UN HABITAT, 2003b).

What about the environment? Environmental problems, particularly groundwater quality problems due to mines and mine dumps, and surface water problems due to municipal wastewaters, are all escalating. In the South African part of the Limpopo Basin, for example, there are over 1000 abandoned mines that are a source of heavy metals, sulphur and associated acidity problems etc., which yield serious local and international problems to water users and to the environment. Municipal wastewaters are the cause of growing eutrophication, which have equally wide-reaching effects downstream.

All in all, the Johannesburg case challenges the notion of river basin management very clearly. A great deal of technical innovation has been used to provide this endemically water-scarce city with sufficient water over large distances. However, the social and environmental problems are not solved and in fact they are escalating. At the same time, the dependency and, in a way, the vulnerability of the Johannesburg area to problems with this highly technical system, has grown extremely high. Turton *et al.* (2006, this volume) point out that the future is governed by very high uncertainties and the ingenuity of people to be able to adapt to conditions, which may change enormously in a very short time, is the key of the successful survival of this urban agglomeration.

São Paulo

In one century, São Paulo has grown sixtyfold, from a city of 300 000 inhabitants to a megalopolis of 18 million. It has become the major economic centre of Brazil, accounting for 27% of the national GDP. Like Johannesburg, this megacity is also located in highlands, but it enjoys 2.4 times the rainfall of Johannesburg. Therefore, it does not have a water scarcity problem of the same dimension as Johannesburg. However, due to the enormous size of this megacity, and to its location in a relatively small basin of the upper Tietê river, São Paulo also is totally dependent on large-scale interbasin water transfers. The first of these systems is now more than a century old. Since then the water and energy requirements of São Paulo have incubated the interlinking of several rivers as well as the construction of a high number of reservoirs. This construction work keeps going at a high pace. Crucial to the energy supply of São Paulo are the hydropower plants that make use of the 750 m high slope from the highlands to the coast in the vicinity of the metropolitan area (Braga *et al*., 2006, this volume).

As in Johannesburg, one single utility, SABESP, operates this huge infrastructure. At present, it provides 67 m^3/s of drinking water to the city, which is 2.1 km^3 annually. The system includes 8 water treatment plants, 1472 km of main canals, 159 pumping stations, 198 urban reservoirs and 25 000 km of distribution lines (Braga *et al.*, 2006, this volume).

The surface area of the upper Tietê river basin is concurrently about 44% urban. The hydrology of the basin has been totally modified from its natural conditions and the consequent environmental problems have become massive. Floods are a serious problem and they constantly worsen as the land becomes less permeable, while at the same time people keep developing settlements on the floodplains. The design flows have grown dramatically, for instance in the Tamanduatei river they have grown fivefold in less than a century. Heavy building work continues to construct more retention basins and, combined with the basin restoration plans, the flood problem is being addressed in a substantial way.

However, the flood problems continue to be extremely critical throughout the wet season from December to March, and the people are therefore frightened.

The first wastewater collection networks and treatment plants were constructed to São Paulo in the 1950s. However, they are now totally insufficient because they have not been extended to keep pace with the city growth. The environmental conditions of the Tietê river became unbearable in the 1980s. Environmental movements and the media, including several AM radio stations, became powerful enough to influence the policies in two ways. First, some of the environmental problems of the São Paulo area were transferred downstream and a public voice in those areas grew accordingly. Second, the so-called Tietê project began, with the aim of constructing sufficient wastewater treatment capacity to cut substantially the effluent load to the receiving waters. The project has now resulted in a situation in which around one-third of the wastewaters are treated and the plan is to have sufficient capacity to treat the wastewaters from 18 million people by 2015. However, by that time the city will be far bigger than 18 million.

Braga *et al.* (2006, this volume) point out the importance of having an integrated approach to water management in megacities such as São Paulo. The traditional, fragmented approach has proved to be insufficient. Even though there is a body of knowledge, skill, an institutional framework and further capacity to deal with water and sanitation, another to deal with flood management, and still another with housing or with transportation, etc., there must be integration and interaction between all of them.

In this respect the recent developments in São Paulo shows positive signs. The politically influential class is more receptive to open discussion and to the advice of professionals and the public than before. The educational level has increased substantially. However, in order to successfully meet the excessive environmental and social problems due to the ever-growing megacity of São Paulo, the institutional challenges are tremendous (Braga *et al.*, 2006, this volume).

Mexico City Metropolitan Area

The Mexico City Metropolitan Area, which includes Mexico City and more than 30 municipalities of the State of Mexico, is 2240 m above sea level. According to the UN (2002) it had 18.1 million inhabitants in 2000, but a more realistic figure is 24 million (Tortajada, 2003). The region receives relatively little rainfall, only just over 700 mm per year. Hence, the provision of an adequate water supply calls for a massive infrastructure including water transfer systems and exploitation of groundwater, both on a huge scale. The rapid growth of this area has caused a decline in the quality of life, becoming overcrowded, immensely polluted and has a serious shortage of basic amenities such as water.

The Metropolitan Area falls under two federal administrative areas, the Federal District (DF), and the State of Mexico. In the former, 93.5% and in the latter, 84.2% of population are served with water, either with direct house connections or common faucets in the neighbourhood (INEGI, 2000). Daily water supply per capita in these areas is 230 and 297 litres respectively. The actual supply is significantly less because this figure includes the water used by industries and services as well as leakages of over 40% and various unauthorized uses. The eastern part is particularly short of a water supply.

More than 5% of people still have to buy their water from water trucks. These poorest people use 6 to 25% of their income to purchase their daily water. The price they have to pay for water is around five times higher than those who have a registered domestic connection.

The water used in the city depends predominantly on local groundwater aquifers and the supply from long-distance surface water transfer systems. Each year 0.9 km^3 is abstracted from local sources including groundwater, springs and snowmelt water. The other important sources of water are the Lerma-Balsas and Cutzamala river basins. The water supply system has 16 dams with a total storage capacity of 0.2 km^3.

Mexico City Metropolitan Area produces an annual average of 2.3 million m^3 of wastewater. Although 65 treatment plants have already been installed, a mere 9% of wastewater is being treated.

The National Water Commission, together with the governments of the Federal District and the State of Mexico, are responsible for organizing the huge water infrastructure of the Mexico City Metropolitan Area.

Tortajada (2003) points out that despite of the immense infrastructure, no strategies for the integrated management of water resources exist. As a result, severe shortcomings in maintenance and systematic infrastructure development subsist. Occasional heavy rains have caused some rivers—now open sewers—to flood in inhabited areas and it is usually poor people who are exposed to health risks. Equally, cracks in sewer canals have caused wastewater to flood in dwelling areas.

A long-term regional strategy is urgently needed. The involvement of all stakeholders in the development of a strategy for sustainable development of the Metropolitan Area is seen as a necessity by Tortajada (2006b, this volume). Such a plan should include socio–economic development, poverty alleviation, quality of life and water and wastewater management.

The federal government has promoted the growth of other urban centres in the country, but with limited success. The baseline is that the construction of an infrastructure with an appropriate plan to bring more and more water to the Metropolitan Area is not a socio–economically feasible and environmentally sustainable solution. The costs are rocketing and the benefits will predominantly go to the well-off proportion of the population. The neglected environmental deterioration in terms of lowering the groundwater level, land subsidence and degradation, as well as deterioration of surface and groundwater quality, works against the sustainability of this megacity.

Riyadh

According to the United Nations (2002) projections, the capital of Saudi Arabia, Riyadh (or ArRiyadh) is one of the most rapidly growing cities of the world, and it is fast approaching the milestone of a population of 5 million (Varis, 2006, this volume, Figure 5). Since 1970, its population has grown tenfold. Such a growth rate introduces remarkable challenges to all aspects of city management, which in Riyadh's case are multiplied by the harsh climatic conditions since it receives only around 100 mm of precipitation each year. It has no river, nor coast. UN HABITAT (2003a) estimates that 20% of the Saudi Arabian urban population lives in slums.

Riyadh has been one of the hubs of Saudi Arabia's rapid economic development and growth in the past three decades. The massive oil revenues have lubricated this growth; the country is the world's biggest exporter of crude oil with over 15% of global exports (IEA, 2003) and the fossil fuel trade brings around US$60 billion annually to Saudi Arabia as export earnings (UNDP, 2004). These earnings allow very different solutions for the water sector, in comparison to most of the cases in this volume.

It is very common that economic growth results in decreasing population growth. In Saudi Arabia, this has not been the case and the Kingdom's population has grown threefold since 1970. The growth is expected to continue, and doubling of the population is expected within the next 20 years. With an increase of the share of the urban population, this inevitably means a remarkably rapid expansion of urban centres. The urban population of Saudi Arabia was 3.7 million in 1970, 15 million in 2004, and this is projected to escalate up to 33 million by 2025 (Abderrahman, 2006, this volume). Domestic water demands have grown almost tenfold from 1970, and they keep mounting.

Riyadh's local Water Directorate has successfully managed to cope with the huge challenges that come with domestic water supply since it covers around 98% of the population of the city. Riyadh consumed 0.56 km^3 of water in 2000. For decades the local groundwater resources have been insufficient to meet the demands of the city. Today, around 47% of raw water is extracted from groundwater, but most of the water is pumped considerable distances from distant groundwater fields, for example, the newly developed Al Honai fields are at a distance of 218 km from the city. A considerable amount of the groundwater is too salty to be used without a reverse osmosis treatment, and the aquifers exploited are predominantly non-renewable. Riyadh gets over half of its water from seawater through a large-scale desalination plant at Al-Jubail on the Arab Gulf coast. The desalinated water reaches the city through pipes of 466 km of length.

These solutions are highly expensive, both in terms of investment and operation. The Water Directorate receives only 2.5% of its revenues from water tariffs, and has considerable challenges in financing the extension of water supplies in order to meet the growing demand. By 2022, it has been estimated that the finances needed to meet the rising demands of Riyadh will reach US$29 billion. Clearly, the water system in Riyadh is only sustainable as long as the enormous necessary finances are available.

Whereas the city has been successful in providing water supply services for almost all of its dwellers, the situation is not the same for sanitation and wastewater treatment. The sewerage network covers one-third of the city's territory for 56% of the population. Three tertiary-level wastewater treatment plants are in use and they have a capacity of 0.147 km^3 per year, which accounts for one-quarter of the supplied water.

As well as struggling with the enormous financial and technical challenges to supply water to the expanding desert city and treating the used water, the contemporary water policies include notable measures to enhance the recycling of used water and using an increasing share of it in agricultural production. The policies will streamline and centralize the governance system to become more functional, through water awareness and capacity building campaigns and programmes to the public and the professionals, by reducing leakages and managing the demands for water. They will also address the adverse effects of the water use for the environment, particularly to the shallow aquifers in the vicinity of the city (Abderrahman, 2006, this volume).

Istanbul

The historical city of Byzantium-Constantinople-Istanbul has a history spanning 2700 years and the history of the innovative water supply systems are equally as old.

The population of the city passed the 1 million milestone 100 years ago, and after that Istanbul's population doubled within 70 years (Standl, 2003). However, it only took a further 13 years for the population to increase by another 1 million. Since 1980 Istanbul's population growth has been phenomenal. The population doubled from 2.8 to 5.5 million in only five years, and has thereafter needed only four years to attract 1 million more inhabitants. Most newcomers are migrants from Anatolia. Istanbul now has 11.5 million people, and is projected to approach 15.5 million by 2040 (Altinbilek, 2006, this volume). The city is the economic centre of Turkey; 40% of Turkish industry is located in Istanbul.

The expansion of the city in the past three decades has strained the water infrastructure in a notable way. As the city grew an astronomic 14.6% per year in the early 1980s, which was far faster than expected, and growth slowed down at only a modest pace, Istanbul faced severe water shortages in the early 1990s. Turkey still has a momentous slum problem due to rapid expansion of the cities; around 43% of the country's urban population lives in slums (UN HABITAT, 2003a).

In terms of water supply, Istanbul has a challenging location both geologically and geographically. It has an unfavourable geology for aquifers and a hilly terrain. The city lies on both sides of the Bosporus Strait, partly in Asia (around one-third of the population), and partly in Europe. The water supply of the city was already based on the use of large aqueducts in Roman times; the largest system, which was finished in the year 324, was 242 km long. The Roman systems have been in ruins for several centuries. However, many of the Ottoman systems that were constructed from the 15th century onwards are still operational and the largest of them has a capacity of 17,334 m^3/day. This water feeds public fountains, wells, water tanks and public Turkish baths (Altinbilek, 2006, this volume).

The water infrastructure was gradually expanded over centuries. Through the construction of dams and pipelines, the city received 0.41 km^3 more water in 1974 than it did in 1884. However, after that the population expansion led to severe water shortages. Between 1974 and 1994, the capacity only grew by 0.16 km^2, but the population grew by 5.8 million. This means an increment of 76 litres per newcomer per day, which is by far too little for urban uses. The city planners of Istanbul now design the systems for a consumption level for 250 litres per day.

However, Istanbul's water infrastructure saw a massive investment and improvement after that. The supply capacity has been doubled by the considerable extension of the large-scale water transfer systems, particularly on the Asian side. This improvement can at least partly be attributed to the Istanbul Water and Sewage Administration, which was established in 1994, and as well as rapidly implementing new transmission lines, has since been able to improve the quantity and quality of water supplies significantly, and modernize corroded systems which has reduced leakages (Standl, 2003). The share of unaccounted-for water has decreased from over 50% to 34%, which in Istanbul's case includes many public water uses by mosques, public baths, cemeteries and fire hydrants, besides losses due to leakages etc. With this definition, the target for the city's unaccounted-for water is not zero or close to zero but around 25% (Altinbilek, 2006, this volume).

The sanitation and wastewater treatment infrastructure has also undergone a rapid extension and improvement in the past 10 years. In 1993, only 9.3% of the city's wastewaters were treated. By 1996, the number had gone up to 16%, and through a very extensive investment programme, a level of 95% had already been achieved in 2002.

The volume treated grew almost tenfold between 1993 and 2004 (Altinbilek, 2006, this volume).

Istanbul provides a very encouraging success story of how the vast capacity problems of water and sanitation services of a rapidly expanding megacity can be turned into a highly functional system with a high level of services, technology, environmental gains and public acceptance (see Eroglu *et al.*, 2001). It has required institutional reform and the setting-up of an independent public agency (Istanbul Water and Sewerage Administration, ISKI), a great deal of political commitment, massive funding (facilitated by a new tariff structure and additional public funding), as well as technological and other implementation capacity.

Singapore

Another success story is that of Singapore. This city-state in Southeast Asia has evolved from a low-income harbour town to a showcase of high-level, ultramodern technologies in only a few decades. The water sector has been one part of this development, since, as Tortajada (2006a, this volume) points out, the water management institutions can only be as efficient as its management in other economic sectors.

Singapore now has around 4.3 million people on its islands of 700 km^2 of surface area. Water is extremely scarce in Singapore because the total renewable freshwater resources of the country are only 0.60 km^2, which means only 140 m^3 per capita per year (Segal, 2004). So, Singapore imports around half of its daily-consumed water.

After gaining independence from Malaysia in 1965, the two countries had a dispute over water, but they reached a long-term agreement that is in force until 2011. Singapore would like to extend the deal even beyond 2061 but Malaysia has demanded a much higher price for water than at present (15 to 20 times the current tariff), and so far the question is open.

Singapore's policy has therefore been to increase the domestic water security by various means (Tortajada, 2006a, this volume):

- Supply management
  - Protection of water sources. Catchment management receives a growing emphasis and strictly protected areas today cover almost 5% of the whole territory of the city. Protected and partly-protected areas cover a total of half of the land area, but is expected to increase to two-thirds by 2009.
  - Reuse of wastewater. All of the population are connected to the sewage network and all wastewater is collected and treated. An increasing part of the treated wastewater is reclaimed and further purified by dual-membrane and ultraviolet treatment, and supplied thereafter to industrial and commercial customers. By 2010, this NEWater approach is planned to account for 15–20% of Singapore's needs, since the water can be produced at the cost, which is only 40% of the cost of desalinated water.
  - Desalination: The first desalination plant was opened in 2005 and it has the capacity to produce 0.04 km^3 per year. The cost per m^3 has been as low as US$0.48. Desalination is expected to increase in the future.
  - Reducing unaccounted-for water. Whereas in most Asian urban centres this quota ranges between 40% and 60%, Singapore has been able to decrease this from 9.5% in 1990 to 5% today.
- Demand management. The refinement of the tariff system has been the main reason for the gradual decrease of unit water consumption.

- Governance factors
  - Human resources. Singapore has developed a professional staff policy, which is seemingly free of the typical problems of Asian utilities, which include political connections, nepotism, narrow and undisciplined expertise and overstaffing.
  - Corruption. Singapore has been able to create a strong anti-corruption legislation and culture.
  - Autonomy. The Public Utilities Board of Singapore manages the whole water cycle of Singapore, and it has developed a holistic policy for the water sector. It has a high level of institutional autonomy with clear-cut responsibilities.

Conclusions

Are megacities sustainable in terms of their highly diverse water related aspects (cf. Varis & Somlyódy, 1997)? At the United Nations World Summit on Sustainable Development in Johannesburg in 2002, it was understood that sustainable development should encompass balanced economic, environmental and social development under the prevalence of good governance and public participation. The case studies open a very broad and diverse spectrum of problems, challenges and solutions (Figure 2).

Sustainability was the baseline of Tortajada's (2006b, this volume) analysis on water management in the Mexico City Metropolitan Area. She concluded that the region is on an unsustainable path, due to the past overemphasis on supply management and on the physical infrastructure. Social, environmental and economic policies have been and remain inferior to the needs, as well as long-term strategies. Integration is dramatically missing in the case of the two Latino giants, Mexico City and São Paulo (Braga *et al.*, 2006, this volume; Tortajada, 2006b, this volume). Riyadh's water sector has evolved in a direction that is extremely dependent on massive financial input, which largely comes from oil export earnings. The vulnerability to financial and trade disturbances is hence elevated. Singapore struggles with the dependency of its hi-tech water infrastructure on imported water, and tries to find sustainability and decrease the political vulnerability of its system through producing water (Tortajada, 2006a, this volume). Dhaka is desperately short of finance and the capacity to provide the necessary water infrastructure to its inhabitants (Haq, 2006, this volume). Jakarta struggles with capacity shortcomings and institutional problems, which have not been eased by the privatization of the water sector in the 1990s (Lanti, 2006, this volume). Istanbul shows one path towards sustainable water management because the city has been subjected to massive investment in its water infrastructure and related environmental fields, as a consequence of strong political commitment to solving the city's water crisis of the early 1990s (Altinbilek, 2006, this volume). Johannesburg is in many ways on a similar path (Turton *et al.* 2006, this volume).

There is no question that the expansion of megacities implies the requirement of the provision of a water infrastructure to an extremely fast growing system (Braga, *et al.*, 2006, this volume; Lundqvist *et al.*, 2005). Whereas this is obviously the largest construction challenge and undertaking that the mankind has ever faced, this is not by far the whole picture (cf. Varis, 2006, this volume; Chapagain & Hoekstra, 2004), namely:

- The water issue in megacities is much more than a question of infrastructure (Varis, 2006, this volume).

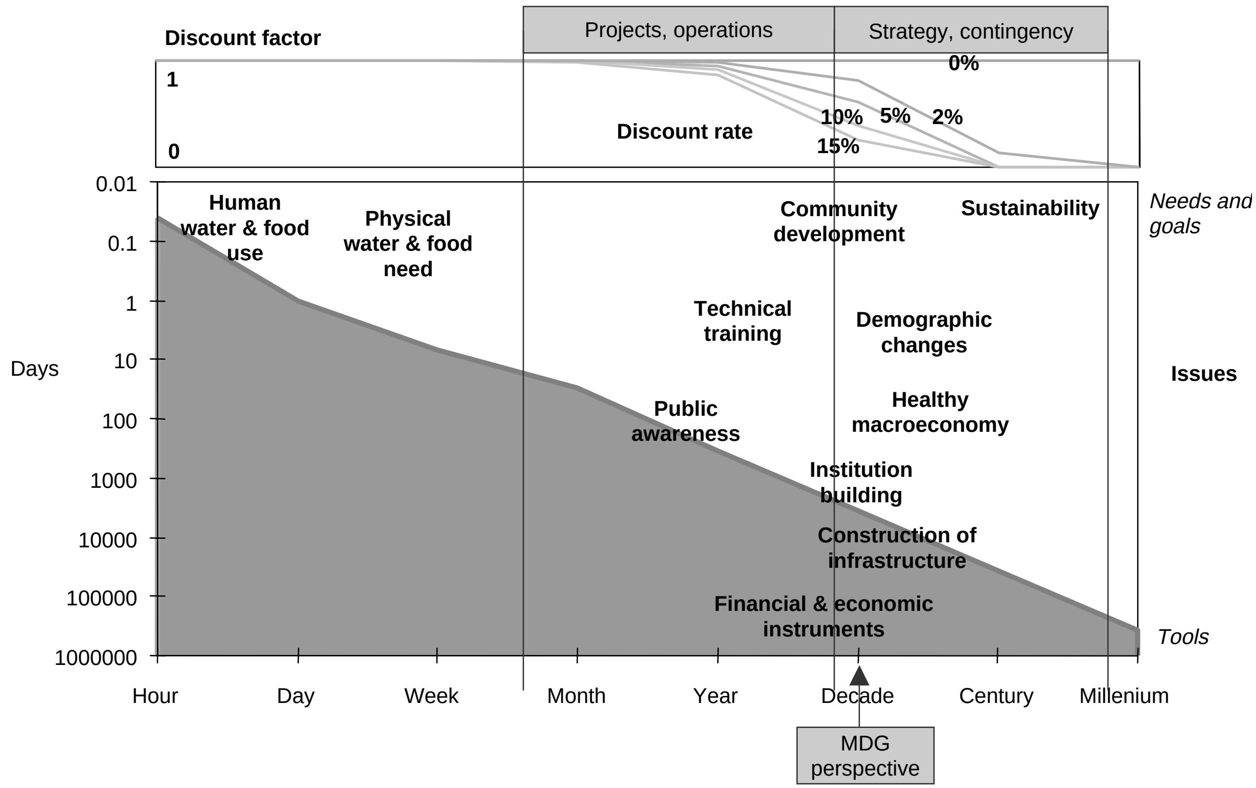

Figure 2. Sustainable development of megacities needs a long-term perspective, sound strategies and political commitment that go far beyond financial rationality or Millennium Development Goal perspective. *Source:* adapted from Varis & Somlyódy (1997).

- Water is not the only aspect of infrastructure development and provision in megacities: transportation, energy, housing, real estate, etc. planning should be developed and managed in an integrated way.
- Provision of water for the various sectors has the highest priority, and rightly so. But unless the challenges of 'water-after-use' is being attended, public health problems and serious economic repercussions from deteriorating water and environmental quality will increase and make sustainability of cities a mirage.
- The water footprint of a megacity goes far beyond the city limits. The world's megacities already import an amount of food comparable to the total international food trade. A bulk of this food has been produced using irrigation. They also import massive amounts of other resources such as energy, metals and fibre products etc., which are produced with huge interruptions to the hydrologic system, both qualitative and quantitative.
- The sources of many urban problems are rooted in the inadequate development of rural areas, which creates a high rural push type of migration pressure.
- A sustainable megacity needs a flourishing economy, strong social and environmental policies, a powerful and just governance system and adequate mechanisms for public participation. All these aspects are intertwined with the various roles of water in megacity development, and the water sector is often an important contributor to all these.
- Sustainable development of megacities needs a long-term perspective, sound strategies and political commitment that goes far beyond financial rationality or the Millennium Development Goal perspective.
- Equally important is a massive investment in infrastructure, including the water infrastructure, as the case studies have clearly shown.
- The IWRM concept should recognize the crucial role of large urban areas in which market links are even global and jurisdictions constitute a complex entity (many megacities are semi-autonomous areas). In this framework, talking about basin scale water management is insufficient. Integration is crucial as was pointed out by Tortajada (2006a,b, this volume) and Braga *et al.*, 2006, this volume. In the megacity context, issues such as those elaborated by Varis (2006, this volume; particularly Table 5) are rudimentary, albeit absent in the present IWRM definitions.
- Megacities are dramatic cases of urbanization and water related challenges, but it must be recognized that most megacities are national or even regional economical and political centres which gives them tools to approach their problems, which are superior to most medium sized cities.

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