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Groundwater, self-supply and poor urban dwellers
A review with case studies of Bangalore and Lusaka

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Acronyms and Abbreviations

AusAID	Australian Government Overseas Aid Program
BWSSB	Bangalore Water Supply and Sanitation Board
cf.	*confer*; compare
DHS	USAID's Demographic and Health Surveys
DTF	Devolution Trust Fund
ft^2	square feet
GBWASP	Greater Bangalore Water and Sanitation Project
JICA	Japan International Cooperation Agency
JMP	WHO and UNICEF's Joint Monitoring Programme
K	Zambian Kwacha, ZMK. ZMK 10,000 = US$2.13; € 1.60
km	kilometre/s/
l	litre/s/
LWSC	Lusaka Water and Sewerage Company
m	meter/s/
m^2	square meters
m^3	cubic meters
mbgl	meter/s/ below ground level
MDG	UN Millennium Development Goals
mg	milligram/s/
mm	millimetre/s/
MLD	million litres daily
NWASCO	National Water and Sanitation Council
PPP	Purchasing power parity
RDC	Residents' Development Committees
Rs.	Indian Rupees, INR. INR100 = USD2.22; € 1.64
RWH	rainwater harvesting
TMC	thousand million cubic metres
µg	microgram/s/
UN-HABITAT	United Nations Human Settlements Programme
UNICEF	The United Nations International Children's Fund
USAID	United States Agency for International Development
USD	United States dollar; $

Conversion rates as of May 1, 2010.

Definitions of Terms

Aquifer
An underground formation of soil, sand, rock, gravel or other material capable of storing and yielding water in exploitable quantities, and which allows water to move through it.

Bottled water
Considered an improved source of drinking water only when there is a secondary source of improved water for other uses than drinking, such as personal hygiene and cooking. Production of bottled water should be overseen by a competent national surveillance body.

Cart with small tank/drum
Refers to water sold by a provider who transports water into a community. The means of transport include hand carts, donkey carts and motorised carts.

Drinking water
Water used for domestic purposes, drinking, cooking and personal hygiene[1], and 'access' to drinking water means that the source is less than 1 km away from its place of use and that it is possible to reliably obtain at least 20 litres per member of a household per day.

Freshwater
Water above or under the soil surface that contains only minimal concentrations of dissolved salts and other total dissolved solids; sometimes also called sweet water. All freshwater ultimately comes from precipitation.

Groundwater
Water located beneath the ground surface, between the saturated soil and rock.

Lithology
A branch of geology that studies rocks: their origin and formation and mineral composition and classification.

Recharge
A hydrologic process (natural or man-made) in which water moves downward from the surface of the earth to form groundwater, by way of percolation through the vadose zone below plant roots.

Surface water
Water present above the soil surface, collecting on the ground or in a stream, river, lake, wetland, or ocean.

Water table
The depth at which soil pore spaces or fractures and voids in rock are completely saturated with water.

Improved water sources
Water from the following sources is considered 'improved': piped water into dwelling, plot or yard; public tap/standpipe; tubewell/borehole; protected dug well; protected spring; and rainwater collection (WHO-UNICEF, 2010).

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[1] It should be noted that the various surveys on which reporting of the progress towards attaining the MDGs are based regularly distinguish between water for drinking and for 'other purposes'.

Protected dug well
This is a dug well that is protected from runoff water by a well lining or casing that is raised above ground level and a platform that diverts spilled water away from the well. A protected dug well is also covered, so that bird droppings and animals cannot fall into the well.

Public tap or standpipe
This is a water point from which people can collect water. A standpipe is also known as a public standpost or fountain. Public standpipes can have one or more taps and are typically supported by brickwork, masonry or concrete. Both surface water and groundwater can be delivered.

Regolith
A layer of loose, heterogeneous material covering solid rock.

Safe drinking water
Water with microbial, chemical and physical characteristics that meet WHO guidelines or national standards on drinking water quality.

Sanitation
Refers to the principles and practice relating to the collection, removal, and disposal of human excreta, refuse and wastewater, as they impact upon users, operators and the environment.

Self-supply, direct and indirect groundwater use
In this paper a distinction is made between direct groundwater use from stand-alone wells (dug or boreholes), and indirect use. The latter refers to groundwater being supplied via the reticulated water supply system, mainly where the water supplier makes conjunctive use of water from both surface and groundwater sources.

For the very poorest, the act of self-supplying in the urban context means sourcing water from where it can be found. Those who self-supply water via wells use groundwater directly and the concept therefore coincides with that of direct groundwater use. Our definition of self-supply in the urban context is less comprehensive than that developed by the Rural Water Supply Network, which includes improvements to water supply through user investment in water treatment, supply construction and up-grading, and rainwater harvesting[2]; but our definition is also less restricted. Thus, we recognise as self-supply situations in which groundwater is fetched (or purchased) from shared wells and even other people's private wells, although the end-user makes no investment in the well or contributes to safeguarding the resource by rainwater harvesting or other means.

Self-supply according to our definition also does not rely on financial support from donors to implement programmes and packages, although it is acknowledged that boreholes can seldom be constructed without the financial, technical or other help from an outside actor.

Slums, peri-urban areas and low-income settlements
Slum residences are defined by the UN-HABITAT (2006) as lacking one or more of the following four amenities: (1) durable housing (a permanent structure providing protection from extreme weather); (2) sufficient living area (no more than three people sharing a room); (3) access to improved water (water that is sufficient, affordable and can be obtained without extreme effort); and (4) access to improved sanitation (a private toilet, or a public one shared with a reasonable number of people). In this paper, however, the terms 'slum' or 'peri-urban' are not used generically for residential areas where incomes are low and services are lack-

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2 For more information about how the self-supply approach has developed, see www.rwsn.ch.

ing; the terms have somewhat different meanings in the two cities described in this paper's case studies. In India, 'slum' is an official designation, though each state has its own legislation with definitions. For instance, according to the Karnataka Slum Areas (Improvement and Clearance) Act, 1973, which is applicable in the city of Bangalore, a 'slum area' means any area that is or is likely to be a source of danger to health, safety or convenience of the public of that area or of its neighbourhood, and is declared by the competent authority to be a slum area. While virtually all such slums are characterised by poverty and inadequate services, not all residences or neighbourhoods characterised by poverty and inadequate services are thus designated as slums. It needs to be recognised that a great deal of India's poor live in more or less temporary housing conditions that may never become officially declared 'slums'. In referring to India, our use of the term slums and slum dwellers therefore refers to a wider group of settlements and poor people that fulfil the UN-HABITAT criteria. In Zambia the same sorts of areas UN-HABITAT calls slums are officially referred to as 'peri-urban'. Although this term is also applied in many other countries, it can cause confusion as it seems to imply that these settlements are only found on the fringe of expanding cities. In our discussions of Lusaka we refer to such areas as compounds or low-income settlements. As stressed by UN-HABITAT (*ibid*.) it must be recognised that low household income is not the only factor contributing to the poverty of slums and other types of low-income settlements. Living conditions such as income, level of education, access to services and social as well as financial capital may also differ between slums in the same city and also within one and the same area.

Tanker water
Water either trucked to various communities or parts of the city and sold per container (pot, can or other receptacle), or delivered in bulk (wholesale) to households with underground sumps or equivalent storage facilities. The tankers can be a regular part of the public utility's service, and may distribute water pumped from wells or taken (sometimes illicitly) from the water network.

Tubewell or borehole (borewell)
This is a deep well that has been driven, bored or drilled, in order to reach groundwater supplies. Boreholes/tubewells are constructed with casing or pipes which prevent the small diameter hole from caving in, and protect the water source from infiltration by runoff water. Water is delivered from a tubewell or borehole through a pump. Boreholes/tubewells are usually protected by a platform around the well, which leads spilled water away from the borehole and prevents infiltration of runoff water at the well head.

Unimproved sanitary facilities
These are shared facilities of any type including pit latrines which use a rudimentary hole in the ground for excreta collection, and do not have a squatting slab, platform or seat.

Unimproved water sources
Water from the following sources is considered unimproved: unprotected dug well; unprotected spring; small cart with tank/drum; tanker truck; surface water (river, dam, stream, lake, pond); and bottled water (WHO-UNICEF, 2010).

Unprotected dug wells
These are wells for which at least one of the following conditions is true: 1) the well is not protected from runoff water; or 2) the well is not protected from bird droppings and animals.

EXECUTIVE SUMMARY

Introduction

Hundreds of millions of people in low-income urban settlements rely on wells for drinking and other domestic purposes. Efforts to enhance the quality, reliability and sustainability of these water sources receive little attention, locally and internationally. The implicit justification is that wells do not provide adequate water, but that little can be done to improve these supplies as they are essentially a residual that needs to be eliminated by the continued expansion of piped water systems. For the poorest urban households in many Asian and African countries, however, far from being a small and declining residual, these groundwater sources are vital. Of all the countries surveyed, this group reports the greatest dependence on wells as the main source of drinking water.

While it is hard to generalise about the possibilities for improving these groundwater supplies, hydrogeological assessments, water quality monitoring, point-of-use treatment, and the upgrading of sanitation facilities, among others, all have important roles to play if applied appropriately and in the right circumstances.

The objectives of this review are:

- to explore the extent to which urban dwellers, and especially those living in low-income areas, depend directly and indirectly on groundwater
- to explore the difficulties they face as a result
- to raise awareness of and emphasise the need for better integration of groundwater in the planning and management of urban water resources.

The paper is based on a review of literature, substantiated by two case studies of Bangalore, India, and Lusaka, Zambia, and discussions with experts. The study on Bangalore builds on PhD and post-doctoral research carried out by Jenny Grönwall during six field trips between 2005 and 2007 (Grönwall 2008) and in 2009. The Bangalore study included a survey of close to 300 households. The Lusaka study builds on research conducted by Martin Mulenga during field trips in 2004 (Mulenga, Manase et al. 2004) and 2010. In both cities, views were sought from people in the relevant authorities, NGOs and slum/low-income settlement areas. Field trips also allowed for observations of some of the development over the past four to six years, as well as insights into the general situation of other Indian and Zambian cities.

The conditions in Bangalore are fairly typical of cities in India and elsewhere which are underlain by low-yielding weathered crystalline bedrock, However, Lusaka's karst terrain creates a groundwater access problem which consists less in the quantities available and more in the poor quality of the water. Consequently, the two cities have responded differently to their different situations. Indeed, one of the lessons learned is that local hydrogeological conditions, together with the cultural and political situation, influences the strategies of the poor for accessing water, and the strategies of city governments and utilities for providing it. Our attempts to draw general conclusions must be tempered by this importance of locality.

In order to substantiate the literature and the two case studies, we analysed statistics from USAID's Demographic and Health Surveys (DHS) on people's sources of water for drinking and other domestic purposes, with the help of statisticians at the University of Southampton. The DHS, together with similar surveys, helps to evaluate progress towards the Millennium Development Goals' (MDGs).

Self-supply, and the direct and indirect use of groundwater

This paper is concerned primarily with what we define as the urban self-supply of water and the direct use of local wells by low-income households. *Direct use* refers to water drawn or pumped from wells, which is consumed by or delivered directly to households in the same neighbourhood. It is not mixed or delivered with other sources, as when a piped water network relies in part on groundwater. The well may be one's own or a community well, or someone else's. The water will often be available for free, but is sometimes purchased. It may be taken from a shallow dug well or pumped from a deep borehole. It may be used only by nearby households, or maybe distributed via pipes, trucks or carts to more distant households. The important point is that while such water is seldom taken into account or planned for in either water resource assessments or city water safety plans, it is often of vital importance to a large proportion of a city's inhabitants.

By *indirect use* of groundwater, we primarily mean groundwater provided through pipes, tubes and mains that forms part of a public or private utility's reticulated water supply system. This mostly means that the supplier makes conjunctive use of water from both surface water sources and aquifers. Where the utility takes water from well-fields or springs situated outside the city and trucks it to customers – including those living in low-income settlements and slums – it is also considered an indirect use of groundwater. Where there is conjunctive use of groundwater, city planners tend to have a better level of knowledge of the wells and groundwater conditions.

There can be no exact division between the two categories. Indirect use of groundwater may be monitored and measured by the utility that provides it, but it is not always categorised in official water statistics. Most direct use of groundwater is not monitored at all. Households with their own well are aware that they are using groundwater, but may be less aware of the quantities involved or whether the well can be depended on in the long term. Other groundwater users do not always know whether the water comes from aquifers or a surface water body if the water is delivered via a tap or container. Household surveys may ask whether households are using well water, but such surveys underestimate groundwater dependence because they neglect indirect groundwater use and do not identify all direct use.

Our definition of the self-supply of water in the urban context recognises that a large proportion of the urban poor depend directly on groundwater. Self-supply has become essential for those who are not served by the public utility, and for those who need to complement an inadequate supply received via the household connection. Sourcing water from aquifers via different kinds of wells is a local, small-scale method used where hydrogeological and other factors allow. Investments can be made to construct wells both at household and community level. The feasibility of digging shallow wells – together with space requirements – tends to determine whether individual or shared solutions are more common. Community boreholes and deeper dug wells may have been constructed by NGOs (sometimes in villages that have subsequently been merged with a growing adjacent city). Water from such wells is less likely to be distributed for free; users may have had to contribute financially both for their construction and subsequently for the water itself.

Our definition of self-supply has an area which is less clear-cut: it includes people who rely on groundwater via public taps and standpipes, or purchase it from a private vendor. Although these people do not have control over the source as they would if they had access to their own or a shared well, this practice is included in our definition of self-supply because they are not, or not adequately, served by the public system, and must therefore provide for their own needs.

There is a grey area also in regard to self-supply in the sense that poor people who rely on (ground)water via public taps and standpipes or purchase (ground)water from a private vendor are not so much in charge of the source as if they have access to their own or a shared well. Equally, they are not, or not adequately, served by the public system and must therefore provide for their own needs.

Trends in urban groundwater use

This paper draws on aggregate statistics produced and analysed specifically for this study. The survey evidence is based on USAID's Demographic and Health Surveys (DHS) on sources of water used for drinking purposes.

The analyses show that an estimated 269 million urban dwellers depend on wells as their principal source of drinking water. In urban Nigeria, it is estimated that almost 60 per cent of the population use local wells. This rapidly increasing trend seems to be partly due to people's need to self-supply for lack of alternative sources, and partly due to cheaper borehole drilling technologies. Many more urban dwellers in the surveyed countries can, however, be presumed to depend both directly, and even more indirectly, on groundwater distributed via taps (defined as 'piped water'). For instance, in urban Zambia only 18 per cent is officially reported to use wells, but our case study of Lusaka suggests that many more urban residents depend on wells. This under-reporting may be partly because many people with dug, shallow wells may not want to admit that they use them, since such wells are banned by the authorities.

It is difficult to discern a general trend from the very varied patterns of urban direct dependence on groundwater; there is great variation between the surveyed countries, especially in Sub-Saharan Africa and Asia. In principle, a reported increase in the use of groundwater could be a positive sign, reflecting projects and policies that are successfully expanding the number of wells, and thereby improving water access by poor people. There are, nevertheless, situations where increasing direct dependence on groundwater is a symptom of problems that need to be addressed.

Groundwater, the Millennium Development Goals and quality issues

In the quest to achieve Target 10 of the Millennium Development Goals – to halve the proportion of people without sustainable access to safe drinking water and basic sanitation by 2015 – proxy indicators are used to define 'improved' sources of water and sanitation. Groundwater distributed by pipes and taps, including public standpipes, is regarded as improved. Likewise, tubewells, deep boreholes and 'protected' dug wells and springs are improved sources of water. Unlined dug wells that are not protected from runoff surface water by being raised above the ground and equipped with a platform, or covered to protect it from bird droppings and animals, are defined as unimproved on the grounds of water safety. However, this definition is flawed, as even protected wells can yield non-potable water; indeed, where the groundwater is contaminated, an 'improved' well offers no real protection at all. Similarly, several latrine types, including some in the 'improved' sanitation categories, allow faecal matter to percolate out into the groundwater.

Many poor urban dwellers in African and Asian countries rely on getting water from open, shallow dug wells, often drawing it by hand. While these wells are considered 'unprotected', the fact that they provide easy access to water is actually advantageous for users' health: increased quantities of water promotes good hygiene, and can prevent the faecal-oral transmission of endemic diarrhoeal diseases.

However, good water quality is also important. Urban groundwater resources are highly vulnerable to pollution from human activities. For instance, in tropical Africa the incidence of childhood diarrhoea rises substantially during rainy seasons when pathogenic contamination of drinking water sources occurs. During the dry seasons, though, good availability of water rather than its quality tends to reduce the incidence of diarrhoeal disease.

During the rainy seasons in particular, there is thus a central nexus between the management of urban groundwater resources on the one hand, and the infrastructure for solid waste disposal, drainage, sanitation, and so on, on the other. The lack of water supply and sanitation coverage goes hand-in-hand in low-income settlements and the practice of using simple pit latrines (or open defecation) may have a detrimental impact on the local water source as most sewage and solid waste is discharged without treatment. Faecal matter containing pathogens may be washed straight into open wells, particularly during the rainy season. Contaminated water, including wastewater from latrines, may also pollute aquifers by seepage through the ground.

Considering that many people who live in slums and low-income areas would benefit from access to more water than is currently available to them, it is important not to discourage people from using water from 'unimproved' wells. Instead, the emphasis needs to be on maintaining this resource's quality, combined with education about hand-washing and other hygiene measures. Awareness-raising about the various transmission routes for diarrhoea and the importance of safe water storage in the home is often more vital than the quality of the water source used, as not all water used needs to be of potable standard. This is a lesson learned in Lusaka, where a large number of residents in the low-income areas have dug their own wells and thereby benefit from improved access to water within a short distance. Rather than the existence of shallow wells, environmental conditions such as the lack of sanitation, drainage, and solid waste disposal infrastructure, along with poor hygiene awareness, are to blame for ill-health. Diarrhoeal disease is endemic, and cholera outbreaks are regular, yet the use of chlorine or other water treatment methods is irregular.

The public health messages given to the residents of Lusaka's low-income settlements are contradictory: on the one hand, measures are taken to steer households from using their own, dug wells for fear of poor water quality; on the other, adequate water access is not provided. During cholera outbreaks, chlorine and soap is distributed, either subsidised or for free, by the health authority, foreign donors and NGOs. However, it is not uncommon to find NGOs promoting self-supply via wells.

Sustainable groundwater development

One assumption underlying this paper is that urban poor people's direct dependence on groundwater remains, but that this is not fully appreciated in planning and decision-making at strategic city level, or in the international debate on groundwater, water access, and poverty alleviation. In part, this may be because the poor as a group do not have a voice. It may also be due to the fact that groundwater is a hidden resource, out of sight, underground, and insufficiently monitored; it is also not fully accounted for in the DHS and other statistics.

While increased use of groundwater at the urban level is predicted as well as promoted by several experts in the field today, the problems of sinking water tables and over-extraction from aquifers are reported in many parts of the world. This is pronounced where abstraction rates increase rapidly and changing precipitation patterns – some of which are linked to climate change – affect aquifers' recharge possibilities.

Under-reporting water use from wells and springs, and especially the direct use of such sources, undermines the potential for informed research and debate on groundwater sustainability in the short as well as the long term. However, interpreting what 'sustainable' groundwater development may mean is a complex task since ecological, social as well as economic aspects should be taken into account. Determining how much water can be withdrawn from a given aquifer or aquifer system under or by a city before the abstration/recharge rate is deemed unsustainable depends on a multitude of factors. These include local hydrogeology; the climate system and future changes to it; scale and purpose of the withdrawals; alternative water sources; the potential of accurate monitoring and modelling, and political will to enforce measures. The natural background levels of, for example, arsenic, together with man-made contamination sources are important to take into account and deal with, as are the needs of the ecosystem.

The groundwater availability within a city can vary hugely because the aquifer conditions are rarely uniform. For instance, in Bangalore there is high dependence on groundwater and most wells are drilled to great depths in the characteristically low-yielding, weathered crystalline bedrock. The conditions are, however, highly variable and hence unpredictable. Many attempts to drill wells fail, and existing boreholes and tubewells are routinely reported to dry up. At the same time, a large number of landowners have not noticed any significant lowering of the water table despite continuous pumping and selling of water for 15 years.

Differences between two neighbouring wells may be explained by highly localised fissures and fractures. Some of the variability may also depend on the fact that urban aquifers usually receive additional recharge via substantially leaking pipes and water mains.

Whether or not there are risks of sinking water tables and aquifer depletion is also determined by what alternative water sources are available to different groups, both in socio-economic and in technical respects; and what quantities are being abstracted elsewhere from the same aquifer system, especially by large commercial abstractors, but also for irrigation. From the perspective of the generally water-deprived and under-served group of urban poor, temporary over-exploitation of aquifers may prove beneficial for development, health and well-being, provided that measures are taken to promote artificial recharge, rainwater harvesting, re-use, recycling, and in the long run perhaps reduced dependence on self-supply via wells.

Alarmist reports on water and groundwater scarcity and looming water crises seldom take all the above into account, and are, in many cases, not accompanied by consistent or easily assessable observations of the actual development. This does not serve a situation where growing urban populations require more water. Increased use of groundwater necessitates increased attention to the resource, based on a holistic view of availability, supply, demand and needs, and how the urban environment influences the dynamics of the water cycle.

Climate change and groundwater

The lack of data about groundwater resources also has implications for climate change research and policy-making. There are general uncertainties due to gaps in knowledge related to water including groundwater, which affect predictions of, for instance, altered precipitation patterns and how this may impact on aquifer recharge under a continuously changing climate. These uncertainties are critical since the climate system and groundwater storage are fundamental, integrated parts of the hydrological cycle and, in turn, of all life on Earth.

Experienced climate researchers have suggested that global reliable surface water supplies are likely to decrease due to increased temporal variations of river flow, which are in turn caused by increased precipitation variability and decreased snow and ice storage. It may therefore be beneficial to take advantage of the storage capacity of aquifers, and plan for increased groundwater withdrawals for different purposes, including urban water supplies. Climate change in areas affected by reduced (or periods of reduced) river flow may cause an increase in the use of groundwater, both direct and indirect. In this case it is already appropriate to take measures to enhance the recharge of local aquifers and to safeguard their quality.

Main messages and policy measures

Increased water availability is key to improved health. As a general message this paper wants to stress the importance of groundwater to poor urban dwellers who are often unserved and need to self-supply via wells. This direct dependence on groundwater needs to be acknowledged as a resource to be taken into account accurately in planning and integrated resource management at city level, and also in a larger, regional context.

This paper shows how lack of awareness of the importance of groundwater to poor urban dwellers, together with a lack of baseline data, obstructs a holistic view for planning and safeguarding groundwater resources in the short as well as the long term. Follow-up studies of urban self-supply are necessary, however. Local conditions must be understood, including an area's hydrogeology, how its wells are monitored, along with government policies, institutional capacity, and interventions carried out by foreign aid programmes and NGOs. Any measures taken need to be contextualised; for instance, rainwater harvesting and other aquifer recharge-inducing steps may be pertinent in most city environments where large amounts of water are drawn from wells, but in a city such as Lusaka such measures are largely irrelevant, due to the shallowness of its groundwater table for most parts of the year. Rather, it is more important to improve drainage possibilities in order to avoid floods during the rainy season. In all urban areas, steps need to be taken to protect both aquifers and wells from contamination.

The following is a selection of measures integrating local well water resources into urban water resource management. Its focus is on improving the situation for urban poor people:

		Strengths	Limitations
To prevent depletion of groundwater			
	Conduct hydrological assessment of aquifers	Improves knowledge; enables informed decisions	Lack of skilled manpower & equipment; costly
To increase well water quantity			
	Introduce rainwater harvesting and other artificial means of recharge	Increases recharge to wells & aquifers; balances withdrawals	Needs regulatory framework & control; costly. Dry periods restraints
	Increase number of wells	Increases volumes withdrawn & number of access points	Risk of sinking water table. Lack of skilled manpower & equipment; costly
To reduce groundwater contamination			
	Reduce open defecation and usage of pit latrines, especially unlined	Reduces risk of pathogens percolating into wells and aquifers	Necessitates alternative solutions; costly. Lack of space.
To improve well water quality at point-of-collection			
	Improve unprotected, dug wells by inner lining, platform and cover	Reduces contamination, seepage & risk of pathogens flushing into well	Lack of skilled manpower & equipment; costly. Does not protect deep aquifers
	Practise hygienic well use	Reduces risks of pathogens spreading	Needs normative framework & control.

Cont over

			Needs info/education; costly
To improve water quality at point-of-use			
	Chemical water treatment (chlorine, etc.)	Kills bacteria /viruses	Costly; time constrains. Needs info/education. Changes smell/ taste.
To improve groundwater distribution			
	Install hand- or electric pumps	Increases quantities. Reduces contamination from buckets	Costly; lack of skilled manpower & equipment. Risks over-extraction
To integrate urban well/groundwater into water resource management			
	Identify appropriate selection of measures (from above and others)	Facilitates contextualised & customised measures	Lack of baseline data. Lack of skilled manpower; costly

1 Groundwater dependence, health and equity implications

1.1 Introduction

The improvement of everyone's access to safe water for drinking and other domestic purposes constitutes a significant step in the fight against poverty. Yet millions of people in towns and cities have only inadequate access to water; some 141 million people are still estimated to rely on 'unimproved sources' of drinking water (WHO/UNICEF 2010). The vast majority of these live in unplanned areas and slums of low- and middle-income countries. This means crowded, high-density settlements that often lack permanent housing and secure tenure, mostly with no or inadequate access to basic sanitation and hygiene. Although in 2005 the lives of slum dwellers, as defined by UN-HABITAT, had improved in comparison to the conditions in 1990 in almost all developing regions (UN DESA 2009), the absolute number of slum dwellers in the developing world will have grown from 766.7 million in the year 2000 to an estimated 827.6 million in 2010 (Michell 2009). The plight of those living in slums is a sign of an increasing 'urban divide' (cf. UN-HABITAT 2010).

The total demand for urban services grows as the populations in towns and cities rises, as well as with new and higher requirements due to altered lifestyle choices. For cities the traditional way to meet this mounting demand for water has been the supply management approach: acquiring and distributing water from new (surface water) sources, often rivers and dams (reservoirs) situated at ever-increasing distances. With growing competition over available sources and escalating costs for treatment and distribution, this type of enhancement is losing favour as a policy. Planners and decision-makers are instead encouraged to curb demand, to encourage end-users to conserve water, such as introducing a range of incentives (cf. UNESCO 2003). However, a demand-side approach favouring conservation risks denying poor urban dwellers their need for *increased* water access and use (cf. McGranahan 2002).

Whatever the method, major investments into the water and sanitation sector are normally required when a city (or indeed a whole region or nation) grows and develops. The potential role of private actors to raise the capital needed and to improve performance was promoted especially during the 1990s. Full privatisation, Public-Private Partnerships[3] and commercialisation[4] are three alternatives to the traditional public sector being wholly responsible for supplying these infrastructure services. A different, but all the more vital role, is played by local, small-scale private suppliers - the water vendors. However, privatisation has also met with extensive criticism and has done little to secure the UN Millennium Development Goal (MDG) target of halving the number of people without sustainable access to safe drinking water and basic sanitation between the years 1990 and 2015 (Budds and McGranahan 2003; Cairncross 2003).[5]

Today we still face the reality that this MDG target is not likely to be fully achieved. Looking beyond the definitions of and the statistics behind the target (see Section 3 below), we find that it is mainly the better-off, well-planned parts of a city that are connected to a water distribution network and supplied potable water on a reasonably regular, reliable and affordable basis.
Urban inhabitants of low- and middle-income countries generally suffer from poor water service coverage in comparison to the developed world. For instance, there is no South Asian

[3] A Public-Private Partnership normally consist of any of a variety of contracts between a government or government authority and a private party where the latter provides a public service – or part of it – under a concession or, e.g., as a Build-Operate-Transfer arrangement.
[4] The term 'commercialisation' is normally used to describe a public utility that applies commercial principles to its own operations to improve its performance, Hukka and Katko (2003).
[5] Facts and definitions of this MDG target can be found at http://mdgs.un.org/unsd/mdg/Default.aspx.

country in which water is provided for the whole urban population, and in Sub-Saharan African cities, usually less than half the population is directly served by the public utility. Instead, a high dependency on groundwater is typical (Ruet, Saravanan et al. 2006; Adelana, Abiye et al. 2008; Hadipuro and Indriyanti 2009).

The urban poor are, by and large, especially vulnerable to unreliable access from both public utilities and private and informal sources. Although state governments are ultimately responsible to see to it that everyone's human right to water is met, this group is generally unserved by the water utilities and depend more on three other water sources: public standpipes (standposts or fountains; sometimes in the form of communal taps); small-scale private water providers (vendors); and/or household or communal wells. Being unserved by the public system even though a water supply network may be in place, poor urban dwellers in particular have to meet their own needs. *Self-supply* by accessing water from own or shared wells is often the choice they make.

From the point of view of the urban water utilities (public or private), groundwater may play a seasonal yet strategic supplementary role, depending on geographic and other conditions. Many towns and cities use groundwater *conjunctively* with water taken from rivers, reservoirs and other surface water bodies. The groundwater may be pumped from aquifers situated under the city, or from so-called well fields at some distance outside it. Distribution takes place via pipes, tubes and mains as part of the provider's reticulated water supply system. From the city planners' perspective, however, the groundwater resources may not seem important enough to be given special management consideration. This may in part be because the groundwater is not accounted for properly in their statistics, in turn due to insufficient monitoring. The water users, however – both consumers connected to the network and those accessing the utility's mix of surface and ground water by other means, such as kiosks – can be said to use this groundwater *indirectly*.

This is in contrasts to the situation where groundwater from local stand-alone wells is the only choice by necessity – such as among households not served by the water utilities' networks. Lack of service provision in most low-income settlements as well as in peri-urban city areas means that groundwater is used and depended upon *directly*. The wells may be dug or drilled (boreholes, tubewells); open or closed/covered; hand-drawn or equipped with handpumps or a motor (mainly electric submersible pumps) to lift the water. The wells may also be fitted with pipes and taps for distribution to more distant households, in which case the water to users may appear and be defined as 'piped' water or 'tap' water.

Dug wells in the urban environment are predominantly shallow, made at low cost in areas where the water table is high enough that water can be readily found at a depth of around three to 15 metres. Self-supply is therefore feasible for many poor people where the hydrogeological conditions are favourable and land rights and space permit the digging of wells, for instance in the owners' yards. Boreholes and tubewells are costlier both to create (drilling, equipping with pumping devices and so on), and to maintain, and as a result, poor urban dwellers may depend on water provided by other actors instead. These might include the utility's public standpipes or community-based taps, or an NGO or foreign donor that has created a water supply by drilling wells. However, water users without house connections must still provide for themselves and take a self-supply approach by fetching water from public standpipes or elsewhere.

Direct use of groundwater may also be the case where water is distributed by tanker-truck or similar. Though many of those relying directly on groundwater take it for free from their own or shared wells, others have to purchase it. A large share of water vendors in the world – private small-scale suppliers of water in bulk (wholesale) or per pot/can – sells water taken from wells, though there are few studies available to confirm this. For instance, in Bangalore the vendors are predominantly landowners with high-yielding tubewells who sell water distributed via 6,000-litre tankers,[6] whereas in Lusaka, the inhabitants of low-income settlements may sell water to neighbours from their own dug, shallow wells.

No exact division can be made between the two categories of groundwater use and dependence but it may still be useful to distinguish between them. The direct use of groundwater deserves focused attention (whether called self-supply or not); not only because this water is seldom taken into account or planned for in either water resource assessments or water safety plans, but because such a large group of poor urban dwellers rely on water from wells.

Indirect use of groundwater may be monitored and measured to various degrees by the utility that provides it, but is not always separated out in official water statistics. Most direct use of groundwater is, on the other hand, not monitored at all. Households with a well of their own are mostly aware that they are using groundwater, but may be less knowledgeable of the details of the well, the quantities drawn or whether the aquifer conditions may sustain long-term dependence on it. If the groundwater is delivered via a tap, tanker, can or other container, the users seldom know that the water comes from aquifers rather than a surface water body.

The role that groundwater as a resource plays for the urban poor remains largely unexplored. The growing body of literature on urban groundwater issues focuses on four main components: contamination, pollution and health problems; aspects of sustainability and the threats linked to over-extraction; issues relating to recharge (aquifer replenishment); and general planning, policy and management questions (cf. list in Naik, Tambe et al. 2008). The extent to which urban dwellers depend on groundwater, especially those living in low-income areas, and the difficulties they face as a result, has not been a topic of sustained research; nor has it been a topic of international policy debate.

There is thus a need for a better, more detailed understanding of urban reliance on groundwater and especially how this affects the most vulnerable sector of the population. This working paper seeks to shed light on the extent to which people living in low-income urban settlements depend on groundwater for drinking and for other domestic purposes; the ways and means they access it; the implications of a potential dependence on groundwater; and what this could mean in terms of policy and regulation. The paper draws from aggregate statistics produced specifically for the purpose of this study. It also builds on two case studies of Bangalore, India, and Lusaka, Zambia, in order to substantiate the limited amount of literature in the field. These studies serve to inform both the complex interpretation of 'sustainable' groundwater development, and the link between access to (ground)water from different sources, on the one hand, and sanitation, health and well-being, on the other.

One assumption underlying this paper is that urban use of and direct dependence on groundwater remains, but that this is not fully appreciated. In part, this may be because many – or even most – of those relying on groundwater belong to the poorest section of society. In some places, where using groundwater is not officially condoned, the poor may even fear that drawing attention to their use of groundwater will lose them access to it, rather than improving their water situation. In part, it may be because groundwater as a resource is hidden, not the least in the statistics. And in part, it may be because neither local authorities nor international development experts have much to say about what needs to be done. Finally, the neglect may also be because groundwater is often relied upon only indirectly, in which case the users are depending on the utility to continue providing it.

The following introductory section presents urban groundwater trends over the past fifteen years, highlighting the general lack of detailed data on groundwater. This section also calls attention to the poverty and health aspects of groundwater in the urban environment, by em-

[6] This is the case in India, where groundwater is seen as belonging to landowners while surface water is seen as belonging to the state.

phasising the complex but important relationship between access to water, sanitation facilities, hygiene, and health. There are issues of equity at stake as well, not least in relation to how groundwater is accessed: directly via one's own well or a shared one; or indirectly via the water supplier or some other actor distributing it.

Lastly, this introduction argues for a number of measures that need to be taken in order to sustain a continued and most probably increasing dependence on groundwater among the urban poor.

1.2 Trends in urban groundwater use and dependence

The overall demand for groundwater has increased dramatically over the past four decades, notably with the introduction of advanced drilling and pumping technology (Shah, Roy et al. 2003; Briscoe 2005; Edmunds 2008). About 15 years ago, some 50 per cent of all urban water use worldwide was attributed to well, spring and borehole sources, which translated into more than 1000 million urban dwellers in Asia alone (Clarke, Lawrence et al. 1996). More recently it has been suggested that groundwater is the primary source of drinking water to nearly half of the world's population and, as the dominant source of water to irrigated land, is also critical to global food security (IAH Commission on Groundwater and Climate Change 2010). In urban settings, the use of shallow groundwater sources for drinking and other domestic purposes is an especially common feature of many low-income communities in low- and middle-income countries. (Howard, Pedley et al. 2003).

It has been held that for many urban areas in Sub-Saharan Africa, groundwater is the preferred source for piped water supplies (Morris, Lawrence et al. 2003; Adelana, Abiye et al. 2008). In addition, rapid unplanned urban growth in Africa has led to unserviced housing where the residents often resort to groundwater as a source of inexpensive domestic water (Steiner 2006). Some 36 per cent of the Southern African Development Community (SADC) region's urban dwellers have been estimated to rely on groundwater (Molapo, Pandey et al. 2000, cited in Braune and Xu 2008), and at least 50 cities on the African continent could not function without the water provided by a local urban, peri-urban or more distant aquifer system (Morris, Lawrence et al. 2003).

In fact, more than half of the world's megacities (metropolitan areas with more than 10 million inhabitants) depend on groundwater, in the sense that it constitutes at least a quarter of these cities' water supply (cf. Morris, Lawrence et al. 2003).[7] Of China's 660 cities more than 400 rely on groundwater to some extent, and in the northern provinces of Hebei, Shanxi, Henan, Shandong, and Liaoning as well as the municipal region of Beijing, more than 50 per cent of the total water supply comes from groundwater (Chinese Ministry of Land and Resources 2005, cited in Sun, Jin et al. 2009). Among Latin American cities depending heavily on their aquifers are San José, Lima, Santiago and Buenos Aires, and in most of Asia, more than 50 per cent of the potable water is groundwater (Morris, Lawrence et al. 2003). It has been held that in India, half of the urban population depends on groundwater (Central Ground Water Board 2006; Indian Ministry of Water Resources 2006; Mall, Gupta et al. 2006).[8] Simultaneously, in Asia the bulk of groundwater use is in irrigated agriculture while in the rest of the world it is for urban and industrial purposes (Shah, Roy et al. 2003).

Although more exact numbers are difficult to come by today, urban groundwater dependence, both direct and indirect, seems to be increasing. Cheaper and better technologies, increased awareness of and knowledge on how to dig and drill wells, together with the sheer

[7] Bangkok, Beijing, Buenos Aires, Cairo, Dhaka, Jakarta, Kolkata, Lagos, London, Manila, Mexico City, New Delhi, São Paulo, Shanghai, and Teheran.
[8] This statement can be found in numerous government reports and research articles but the very source for this number is unknown.

urgency to source water locally are factors contributing to a growing number of wells in many cities in low- and middle-income countries. For instance, in Africa's arid and semi-arid regions, groundwater is seen as the most precious of natural resources and 'the only realistic and affordable means of providing reliable water supply, given 'the ephemeral nature of surface water' (Adelana and MacDonald 2008:1). The development of groundwater is therefore forecast to increase dramatically in an attempt to improve urban water supply coverage – especially if the MDGs are to have any chance of being achieved in this region (Adelana, Abiye et al. 2008; Foster, Tuinhof et al. 2008). However, the prospects for eradicating the backlog in water provision could be severely jeopardised by inadequate groundwater quality control and management (Xu and Usher 2006).

As will be analysed in Section 2 below, though, this dependence on groundwater for drinking and other household needs is not fully reflected in either the records kept and disseminated by water utilities, or in the official statistics reported, for instance for the MDGs. Groundwater can fail to show properly in the books even when the water utility in charge uses surface water and groundwater conjunctively, as is the case of Bangalore. The piped water in parts of the reticulated system may then be a mixture, and the groundwater may be used throughout the year or mainly during dry periods (whether seasons or years). The water users, for their part, depend on groundwater but only indirectly and may even be unaware of this. Water distributed via public standpipes and communal taps may also – wholly or to some extent – be taken from aquifers. However, this information is also not readily available.

Similarly, authorities' records of private wells – in rich and low-income countries alike – are scanty at best, typically lacking sound estimates of the number of wells in different areas, l*et al*one the quantity and quality of water they provide. It is inherently difficult to control citizens' groundwater abstractions, and few feel inclined to register their wells for fear of them being banned, or the water becoming taxed now or in the future. Hence, the extent of people depending directly on stand-alone wells – their own or shared ones – cannot be fully taken into account where data is not available.

Official statistics from various surveys on water sources, as linked to the MDGs, ask respondents to state their *main* source of drinking water (although other uses of water are probably just as important to health and hygiene, cf. Bostoen, Kolsky et al. 2007). In many of the surveys, a distinction is made foremost between piped and non-piped water. In some surveys, (direct) groundwater usage will only be reported separately if the respondent takes water mainly from a so-called unimproved, non-protected well. Since groundwater is – in some parts of the world – used primarily for purposes other than drinking, or as a back-up (either throughout the year, at peak demand, or during the dry season), the official statistics typically underestimate groundwater dependence, perhaps to a very large degree, because they neglect indirect groundwater use and do not capture all direct use.

Box 1: Trends in piped and unpiped water supply

A 2009 World Bank study for the Africa Infrastructure Country Diagnostic (AICD) was based on a new water supply and sanitation database compiled as part of the AICD. The AICD DHS[9]/MICS[10] 2007 database is a collection of primary data on institutional development and sector performance in 50 utilities across 23 countries in Sub-Saharan Africa and includes data from the DHS from 1990 to 2006. From this data, it was concluded that piped water reached more urban Africans than any other form of water supply (39 per cent), but not as large a share as it did in the early 1990s (50 per cent).

Cont over

[9] USAID's Demographic and Health Surveys.
[10] Multiple Indicators Cluster Surveys.

Analysis suggested that the majority of those who lacked access to utility water lived too far away from the reticulated water supply; most of the population growth due to urbanisation has occurred in unpiped peri-urban slum areas, and utilities have not been able to extend their networks fast enough (Banerjee, Skilling et al. 2009).

With a decreasing proportion of the urban population getting water from a utility, the share that accessed its water through wells and boreholes was conversely found to have risen by 1.5 per cent yearly. On average, groundwater was the primary source for 24 per cent of Africa's urban population, although in some countries (such as Chad, Mali, Nigeria and Sudan), it constituted the principal source of urban water supply (*ibid.*). The DHS survey evidence is in line with the 2009 World Bank findings (see sub-section 2.1 below), but shows an even higher figure for water accessed via wells and boreholes: the (weighted) average share of Sub-Saharan African households depending directly on wells was over 30 per cent.

It should also be noted that in some cities, notably in Sub-Saharan African countries including Lusaka, groundwater is used for irrigation in urban and peri-urban agriculture, both for subsistence farming and for growing cash crops. Many urban dwellers also use groundwater for their livestock. Both practices can be crucial for the livelihood of poor (and middle class) people (Cofie and Drechsel 2007; Drechsel and Varma 2007).

1.3 Aspects of poverty and health

Regardless of the source, access to safe water is an important indicator of poverty and it is well established that livelihood vulnerability, well-being and health are closely linked to the lack of adequate water (cf. Carter and Bevan 2008). This in turn depends on both the quantities consumed and used in the household, and the quality of the water. Together with a lack of proper sanitation facilities, diarrheal and other water and sanitation related diseases constitute the world's second most common cause of mortality in children under the age of five, after acute respiratory infections. A large proportion of these deaths, for instance those linked to diarrhoea, are preventable.

However, the relationship between water supply, sanitation facilities and human health is complex, and heavily mediated by human behaviour. Good hygiene behaviour, including hand-washing, disposal of children's faeces, food handling, and pest control, is likely to be more important in low-income areas where environmental exposure to pathogens is greater than in 'clean' areas. Water quantity is considered by some experts to be more important than water quality. This is because increased quantities of water promote good hygiene, and can prevent faecal-oral transmission of disease, mainly diarrhoea. The burden of disease that can be attributed specifically to poor water supplies, rather than to poor sanitation or hygiene, or all three, is not known (Rosen and Vincent 1999). Only when drinking water is the main source of infection will water quality be more important than quantity, and this is rarely the case in situations where diarrhoea is endemic (Bostoen, Kolsky et al. 2007).

Not only transmitted by ingested water, diarrhoea is caused by exposure to pathogenic microbes through various ways: person-to-person contact, contact with soil and surfaces contaminated with excreta, infected food, and flies and other animal hosts. Water-borne transmission is, however, likely to be of greater importance in some settings – either throughout the year or during the wet *or* the dry season. Different pathways may also interact with each other (Schmidt and Cairncross 2009a).

Diarrhoea rates are thus also influenced by weather and climate; transmission can be affected by temperature and rainfall extremes common during monsoon seasons. A negative association between monthly rainfall and diarrhoea morbidity rates has been found in a cross-sectional study, most likely explained by low rainfall leading to water scarcity (reduced availability), which in turn leads to the use of unprotected water sources and reduced hygiene practices (Lloyd, Kovats et al. 2007). On the other hand, in tropical Africa the incidence of diarrhoeal diseases has been found to rise substantially during rainy seasons as the greatest degree of pathogenic bacteria contamination of drinking water wells occurs after periods of heavy rainfall (Bordalo and Savva-Bordalo 2007; Taylor, Miret-Gaspa et al. 2009). In line with the latter, shallow groundwater sources in urban areas often show pronounced seasonal variations in microbiological quality, with a significant deterioration during the onset of the wet season that has been ascribed to contamination by on-site sanitation facilities such as pit latrines (Howard, Pedley et al. 2003).

Based on a review of the evidence regarding household water treatment interventions at point-of-use, researchers have advised against the implementation of large-scale water treatment programmes where diarrhoea is endemic, given the lack of unbiased, blinded studies that support such interventions. On the other hand, in situations of epidemic outbreaks of cholera in which water is a major transmission pathway, it is plausible that household treatment may be effective and can be recommended as a temporary measure (Schmidt and Cairncross 2009a; Schmidt and Cairncross 2009b). More generally, authorities, including international donors, should not make recommendations on point-of-use methods *in isolation from* interventions regarding sanitation, in the absence of strong local substantiation (Cairncross and Valdmanis 2006; Clasen, Schmidt et al. 2007; Schmidt and Cairncross 2009a; Schmidt and Cairncross 2009b).

It should also be noted that concerning cholera, the effect of chlorine as a household treatment method is poor when treating turbid water (containing suspended matter such as plankton). A combination of physical and physical-chemical filtering is therefore often vital during the rainy season. A piece of simple cloth, folded at least eight times, is able to filter out more than 99 per cent of the *V. cholerae* bacteria attached to plankton (Colwell, Huq et al. 2003).

Another aspect of poverty and health relate to the possibilities of point-of-use treatment and safe storage in the household. With regard to the former, in both Bangalore and Lusaka most poor people do not boil their drinking water because they find fuel too expensive and firewood hard to locate. However, when asked, most people claim that they do not think treatment is necessary. In Lusaka, where the quality of the groundwater is often substandard during the rainy season, chlorine is not always used, for a range of reasons, despite being distributed for free in some places or sold at subsidised prices.

Nonetheless, water treatment at point-of-use could become an important and integral part of programmes to reduce the health burden of groundwater during seasonal cholera outbreaks in Lusaka. Like in other parts of tropical African, it has been found that these occur mostly during the rainy seasons, and are strongly associated with the quantity of precipitation (Sasaki, Suzuki et al. 2009).

1.4 Aspects of equity

In dense urban settings marked by poverty and limited choices, the issues of water quality/quantity, health and hygiene call for a strong link between practices for water supply on the one hand, and sanitation facilities on the other. On average, health indicators for cities score better than for rural areas; concerted control measures, for example to arrest the spread of cholera, are facilitated by better access to medical treatment and safe water and sanitation in the urban environment – and possibly also by education and awareness campaigns. Nevertheless, while it is hidden behind aggregate statistics, the widening social and economic gap between groups living in urban areas results in significant health inequities. The WHO and the UN Population Fund estimate that one third of the urban population lives in slums today, and the numbers of urban poor in the cities of low- and middle-income nations are certain to swell in coming years (UNFPA 2007; WHO 2008). Being densely pop lated and often built at inferior sites, these slums are prone to fire, floods and landslides, and their inhabitants are disproportionately exposed to diseases such as diarrhoea partly due to the notorious lack of water, both in quality and quantity, and sanitation services. Additionally, access to primary health care is rudimentary at best (*ibid.*).

The increasing gap between the urban haves and the have-nots in many cases manifests itself in the queues of women and children waiting for water to be made accessible at point sources. Although water should be treated as a human right, with ensuing obligations on the nation state as the first hand provider (cf. Grönwall 2008), there is a long way to go before various inequities in water supply are overcome, as evidenced by the long way that is walked by these women and children fetching water.

As the gap between demand and supply for water in cities increases with rapid urban growth, water users at all income levels may find that they need to self-supply from different sources. Water is increasingly purchased from private vendors and as packaged water (in bottles of varying sizes). For the very poorest in society this practice is seldom affordable; they can buy at most very small amounts of vended water, and must also attempt to find water for free elsewhere. Meanwhile, as the number and extent of surface water bodies in the urban landscape diminishes and the quality of their water steadily decreases wells often become the only viable alternative for the majority of people in low-income urban settlements. Water from such sources can be more or less free of charge where conditions are favourable, or be considerably cheaper than water from alternative sources. Water from aquifers also tends to be of good quality as in comparison with surface water sources, although in the city environment anthropogenic sources of bacteriological and physicochemical contamination abound and pose an ever-increasing health risk. The resource vulnerability that this causes must be taken into account by the appropriate authorities (*cf.* articles in Xu and Usher 2006).

Self-supply with groundwater may not be an easy option for the poorest where geological and other conditions are such that wells must be drilled rather than dug; the costs of constructing a borehole are still relatively high, not least in Sub-Saharan Africa. The poorest section of society also tends to live in very densely populated areas where there is little space for the excavation of deeper dug wells (between five and 15 m in depth). In such cases, one alternative may be that an external actor, such as the state government at city level or the public utility in charge, or an NGO, steps in to drill boreholes. As the case study of Lusaka shows, though, capital contributions and user fees may be charged subsequently in exchange for water from such wells, partly in order to encourage the beneficiaries to engage in the operation and maintenance of the boreholes and pumps and thereby improve their functional sustainability (cf. Carter and Bevan 2008). This approach will most probably continue to be very common in Sub-Saharan Africa where finances are limited, the need for enhanced water access is vital, and the availability of groundwater is such that it constitutes a – or possibly the only – sustainable[11] resource at hand. Since the fees may prove prohibitive for the poorest section of society, cross-subsidies are important if everyone is to secure access to adequate water. In many low- and middle-income countries, however, the emphasis on cost-recovery has worked to undermine cross-subsidies, and public standpipes where water can be taken for free are becoming rare.[12]

1.5 Managing a hidden resource: taking measures to improve sustainable access

Experts in the field often point out that groundwater as a resource is a ‘hidden asset’ and therefore under-researched. Clearly, groundwater and its importance is less acknowledged,

[11] It should be noted that “sustainability” in terms of groundwater use is subject to debate, see sub-section 3.2.
[12] Although public standposts/pipes may once have signified free-of-charge water, it seems as if water from such sources has to be paid for in most countries other than India.

and also less understood, due to its being out of sight below ground. The resulting lack of data, and sometimes awareness, also has implications on climate change research and policy-making. This is critical, since both the climate system and groundwater storage are fundamental parts of the hydrological cycle.

Groundwater's invisible nature may result in local authorities having insufficient and inaccurate information, both about its occurrence in and around the city environment, and its use by city dwellers. There is almost inevitably a lack of detailed information on the prevailing hydrogeological conditions, records on the existing number of dug wells and boreholes, and the characteristics of these wells – including water table, abstraction rate, potential quality problems, and so on – and other data pertinent for planning, development, protection and conservation of the groundwater resources in the short as well as long term. Without knowledge of this kind, it is virtually impossible to track the impact of pollution and over-exploitation of groundwater, spatially and over time, in order to develop and implement evidence-based sustainability policies.

1.5.1 Groundwater dependence in Bangalore and Lusaka

Examples of these challenges are visible from the case studies of Bangalore and Lusaka. The table below summarises the relevant conditions for groundwater dependence in the two cities – full details are given in Section 4 of this review. As can be seen, the data available are in many cases based on fairly coarse estimations only, or no data at all are available.

Table 1: Comparison of groundwater dependence in Bangalore and Lusaka

Sl		**Bangalore**	**Lusaka**
1	City size	741 km^2	375 km^2
2	GDP, est.	US$ 69bn (2008)	N/A
3	No of inhabitants, estimated	7M	1.7M
4	No of official slum (informal) areas	473	35-40
5	Proportion of slum dwellers, estim.	20-35 %	65-70 %
6	Proportion connected to utility	< 50 %	< 35 %
7	Volume distributed by utility	Ca. 900,000 m^3/day	Ca. 210,000 m^3/day
8	Demand, estimated by utility	> 1,300,000 m^3/day	Ca. 400,000 m^3/day
9	Geological conditions, main rock	Granite	Limestone
10	No of utility wells	Ca. 10,000	Ca. 72
11	Proportion of water from utility wells	N/A	> 50 %
12	Volume pumped from utility wells/day	N/A	130,000 m^3
			Cont over
13	Main type of private wells, depth	Boreholes, 60-300 m	Dug wells, 2-5 m
14	No of private boreholes on record	> 110,000	Ca. 1,900
15	Volume from private boreholes/day	N/A	80,000-350,000 m^3
16	Volume from other private wells	(*negligible*)	N/A
17	Poor people's direct dependence	Via some standposts, utility tankers, vendors, shared wells	Via own dug wells & community-based wells, vendors
18	Poor people's indirect dependence	–	Piped water supply (house connections), communal taps, DTF kiosks

Sources: see Section 4 below.

Overview of conditions for groundwater dependence in Bangalore and Lusaka

In some critical respects, the prevailing conditions are fundamentally different in the cities studied: in Bangalore, groundwater is predominantly pumped from deep boreholes in the low-yielding crystalline bedrock by middle and upper class landowners and the public utility (and occasionally by a politician for the benefit of the poor). Many experience sinking water tables and wells that dry up, or fail even in the attempt to drill them, and the interpretation of the concept of a 'sustainable' groundwater development is at stake. In particular, people residing in the peri-urban areas of Bangalore have no alternative source of water other than purchasing it from someone with a good-yielding well. Slum dwellers rely mainly on irregular but essentially free water supplies from public standposts, some of which are connected to stand-alone wells, but are in this regard at the mercy of authorities that may change the policy at any time.

In Lusaka, the karst terrain makes for a groundwater table which is often extremely shallow, but the system of underground channels and cavities reduces and/or eliminates completely the attenuation of pollutants that would otherwise occur through natural filtration. Therefore the groundwater is essentially as easily polluted as surface water in a stream, especially in Lusaka's low-income settlements. This makes water quality a major problem, particularly during the wet season, and cholera outbreaks linked to oral-faecal transmission are common. Many among the poorest access their water from the kind of dug, shallow wells that are most at risk and can seldom afford to consume treated water. Their very sub-standard sanitation and hygiene conditions are also a major hazard. The authorities are concerned by the dug wells and the official policy is to close them down; yet almost nothing is done to improve the sanitation situation.

1.5.2 Policy issues and options

The contrasting conditions and uncertainties in Lusaka and Bangalore serve to emphasise the importance of understanding the local situation, including not only the local hydrogeology and other physical aspects of the water system, but also the institutional context. From a resource perspective, for example, measures relating to rainwater harvesting (RWH) are very pertinent in Bangalore, but largely irrelevant in Lusaka, where improved drainage is far more important. Alternatively, to give one of many possible institutional examples, the utility plays a bigger part in delivering water to the urban poor in Bangalore, partly because the piped water system is more extensive, and partly because self-dug shallow wells are not a serious option.

As shown in Table 2, there are a wide range of measures that can, in the right circumstances, be used to increase the quality and quantity of well water available to urban households, including those living in poverty. Whether these measures are appropriate depends on the local context, and also on the other measures being taken. Under most conditions, developing a coherent set of measures that will actually improve water condition in low-income areas is as much a governance challenge as a technical challenge. It is even more of a governance challenge if the beneficiaries are low-income households living in informal settlements, who are typically excluded from the formal markets and policies involving land, housing and services, except where they have managed to organize and engage constructively with local authorities (Mitlin and Satterthwaite 2004).

Table 2: An illustrative list of measures to increase the quality or quantity of groundwater for urban households and extend integrated water resource management

To prevent depletion of groundwater
- Conduct hydrological assessment of aquifers and estimate water balances
- Monitor changes in water table
- Register and license large scale groundwater users and enforce licence conditions
- Disseminate information on groundwater to appropriate media and decision-makers
- Undertake demand-side water conservation where demands are excessive
- Reduce or eliminate unessential water demand met by groundwater
- Limit drilling of wells affecting vulnerable aquifers (e.g. through licensing of contactors)
- Switch to alternative water resources
- Introduce rainwater harvesting and other artificial means of recharge
- Adapt planning procedures and drainage system to maintain groundwater recharge
- Promote mini-Sewage Treatment Plants and water re-use in apartment and office blocks

To increase the quantity of well water abstracted for use
- Increase number of wells
- Increase depth of wells and/or capacity of pumps
- Clean and maintain dug wells

To reduce groundwater contamination
- Identify pollution sources
- Define groundwater protection areas and enforce good practice within the zones
- Improve unprotected, dug wells by inner lining, platform and cover
- Stop leaking sewer pipes and open release of sewage
- Increase number of (improved) latrines
- Reduce open defecation and use of (esp. unlined) pit latrines
- Reduce groundwater water pollution from industrial and commercial sources
- Improve solid waste management systems

To improve well water quality at point-of-collection
- Clean and/or upgrade wells
- Close or limit use of wells that are contaminated or at high risk of contamination
- Drill boreholes to replace shallow wells (or in some cases drill deeper boreholes)
- Practise hygienic well use behaviour

To improve water quality at point-of-use
- Monitor quality of water at point-of-use
- Adopt hygienic water use practices
- Only use highest water quality for drinking and food preparation (especially for infants)
- Treat water at point-of-use – boiling, filtering, chemical treatment or UV light treatment

To improve groundwater distribution
- Install and maintain hand- or electric pumps

Cont over

• Construct local piped water network (e.g. though community organizations) • Improve water-carrying devices • Monitor quality of water at point-of-delivery to homes
To integrate urban well/groundwater into water resource management • Undertake technical assessment of groundwater resources • Provide technical, organizational and financial support for self-provisioning with wells • Ensure community representatives have an influential role in the management decisions • Identify means for supporting household and community groundwater self-provisioning • Adopt appropriate combination of regulations, community institutions, market mechanisms, technical support and advocacy • Create institutional basis for managing urban water resources (including for example groundwater units within public utilities and/or urban teams in IWRM organizations)

Some measures bring their own risks, and without local hydrological and/or health assessments it can be difficult to weigh up the risks of action versus inaction. More and deeper wells can increase groundwater quality and quantity, but under some conditions may lower the water table, resulting in declining water availability in the low-income settlements. In some conditions reducing the use of pit latrines may improve well water quality, while in others it may inadvertently increase open defecation, and therefore increase groundwater pollution. In some conditions, closing lightly contaminated wells may reduce exposure to faecal oral diseases by improving drinking water quality; in others it may increase exposure by reducing the amount of water available for washing. Again the effect of such measures depends on both the physical and institutional contexts.

Given the amount of attention devoted to assessing the water quality and availability for piped water systems, the lack of information relevant to urban self-provisioning with groundwater is striking. Even with quite comprehensive assessments and monitoring, weighing up the risks of the practical interventions listed in Table 3 could be difficult. However, the more obvious explanation for the general lack of information is the lack of any concerted demand, locally and internationally.

While utilities, and those trying to hold utilities to account, provide an obvious audience for information relevant to the piped water system, there is no equivalent audience for information relevant to self-provisioning with wells. Residents of informal settlements, who could probably benefit most from supportive policies, are not well positioned to use such information unless they are well organized, and can get at least some support from government agencies or NGOs that they can trust. Government authorities may not be interested in such information either, particularly if the existing consensus among policy elites is that urban households should not use wells, or that urban dwellers should not be allowed to live in informal settlements. Moreover, if the views against informal settlements are extreme, then the same information needed to support their residents in their quest for adequate water could be used instead to justify evictions or punitive limitations on groundwater.
Even when government officials are interested in assisting low-income households to gain better access to groundwater, it can be difficult to root these interests institutionally. Urban water utilities are typically organized around the objective of providing piped water supplies to bill-paying households. The governance challenge of improving self-provisioning from wells in informal settlements is radically different from that of managing and extending a piped water system. So is the governance challenge of regulating commercial well users and groundwater polluters, and of developing a monitoring programme that gets the right informa-

tion into the right hands and spawns a constructive public debate. There may be a range of government and non-governmental agencies who could take on particular tasks, but if the responsibilities for supporting more sustainable and equitable well use are distributed too widely, they are poorly motivated and uncoordinated. Moreover, as with more conventional urban services (World Bank 2003), unless pressure from well users is actually helping to drive them, significant improvements are unlikely to be forthcoming.

International policy debate in the water sector has also helped to divert attention from the governance challenge of supporting urban self-provisioning with wells. The two water governance issues that have received most attention in the international development arena in recent decades have been the appropriate role of the private sector in operating water utilities, and the scope for creating a better institutional basis for integrated water resource management. Whether they are publicly or privately operated, water utilities are inclined to focus on piped water supplies, and more generally on water systems over which they have direct responsibility, and rarely have much experience or incentive to help users secure their own water supplies. Organisations set up for integrated water resource management are familiar with the governance challenges of decentralized water self-providers, but tend to have a rural or basin-wide focus, and no experience working in the informal settlements of urban centres. Thus, as indicated in the title to Table 3, engaging with these issues would represent an appreciable extension of conventional integrated water resource management. Indeed, in many contexts these activities would be better situated within the context of a broader strategy for addressing water, sanitation and shelter, influenced as much as possible by the low-income residents themselves.

In short, while there is often much that can be done to improve access to well water for low income households, it is critical to choose the right measures and to support forms of governance that favour low-income households. This is a difficult challenge, and if urban well use were just a residual practice being displaced by piped water, it would not be worthwhile to mount an international response. As described in the following section, however, well water remains a critical resource, particularly for low income households. Moreover, policy challenges similar to those described above will require a serious effort to address deficiencies in informal settlements, and while these challenges are daunting they are by no means insurmountable.

2 Trends, statistics and household data on groundwater access

There are enormous uncertainties in the estimates of the Earth's total volume of groundwater reservoirs, ranging from 7 to 23 million km^3 (Kundzewicz and Döll 2009), which may explain why very little data on groundwater as a source for urban or domestic usage is available today. In the whole of Sub-Saharan Africa, for instance, there are no reliable, comprehensive statistics on groundwater use or related issues such as dependence, aquifer characteristics, recharge rate and infiltration capacity, general quality issues or even abstraction rates (Foster, Tuinhof et al. 2006).

Although lack of data and inherent complexities have so far ruled out any serious effort to construct global groundwater supply-demand balances, it is nevertheless important to document the changing patterns of groundwater dependence. Some such analyses can be made based on household surveys and population trends.
This section draws on USAID's Demographic and Health Surveys (DHS) undertaken in Sub-Saharan Africa (28 countries) South and Southeast Asia (8 countries) and Latin America and the Caribbean (seven countries). For each region, countries were only included if there had been a survey since 2000. The surveys are nationally representative, intended for use in monitoring and researching population and health-related topics. The standard DHS surveys are usually of between 5000 and 30,000 households in the country, with the urban and rural shares depending primarily on the level of urbanisation. They are typically undertaken about

every five years. Information of the households' water supplies is collected as part of a much larger household questionnaire, primarily because the quality and quantity of water a household uses is an important health determinant, particularly for infants and children. While there is some variation in the questions over the years and between countries, in the surveys summarised there were questions intended to reveal whether the household uses a local well as its main source of drinking water.

Section 2.1 below summarises DHS survey evidence on the use of wells by urban households in Sub-Saharan Africa, South and Southeast Asia, and Latin America (including the Caribbean). Section 2.2 examines some of the limitations of this sort of survey data for monitoring improvements in access to water and sanitation, and also for assessing household dependence on groundwater.

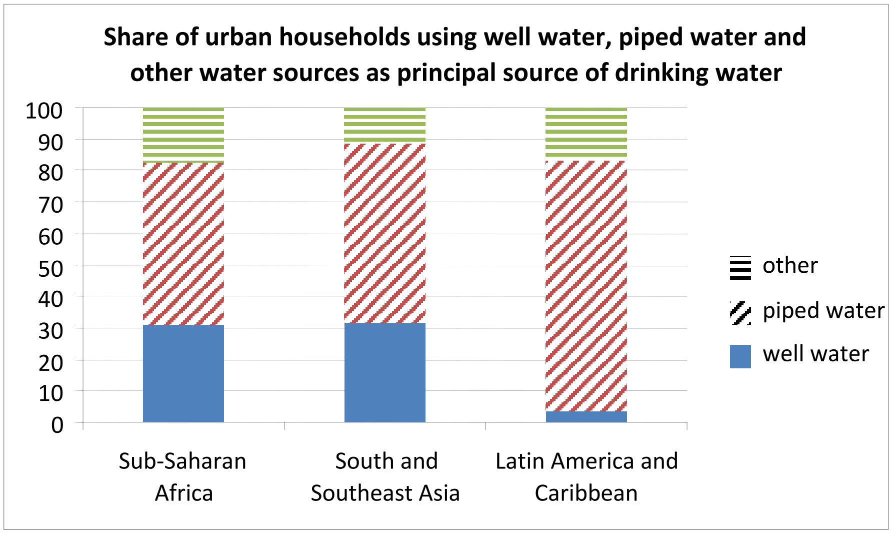
2.1 Survey evidence of urban households' dependence on nearby wells

In the surveyed countries alone, an estimated 269 million urban dwellers depend on nearby wells as their principal source of drinking water, and many more can be presumed to depend more indirectly on groundwater. In the Sub-Saharan African and Asian countries surveyed, the (weighted) average share of households depending directly on wells was over 30 per cent, while in the Latin American countries it was only about 3 per cent. In all regions, these shares are considerably lower than the rural shares, which are 50 per cent for Sub-Saharan Africa, 68 per cent for South and Southeast Asia, and 15 per cent for Latin America. For urban households, the shares are considerably higher among poorer households: the average for the lowest (country) wealth quintiles was 41 per cent in Sub-Saharan Africa, 50 per cent in South and Southeast Asia and 9 per cent in Latin America. The changing patterns of well use in those countries where multiple surveys have been conducted give no indication that the overall extent of well use is declining, although the urban households in wealthier countries do display less dependence on wells.

Overall patterns of urban household well use

Given that urban groundwater is rarely even mentioned in discussions of water access, it is striking that almost a third of urban dwellers surveyed in Asia and Sub-Saharan Africa depend mainly on nearby wells for their drinking water. This is illustrated in Figure 1, and summarised in Table 4, with more detailed figures provided in Table A1, Appendix A. These estimates imply that within the surveyed countries hundreds of millions of urban households depend on wells as their principal water source: approximately 66 million in the countries surveyed in Africa, 201 million in South and Southeast Asia, and two million in Latin America and the Caribbean. Since the surveyed countries only represent about 970 million of the estimated 2.3 billion urban dwellers in the 'less developed' countries of the world, and the 3.2 billion urban dwellers in the world as a whole, the actual number of urban well users is likely to be considerably higher.

Figure 1: Share of urban households using well water, piped water and other water sources as principal source of drinking water



Source: Table 3

Table 3: Principal household water source in Africa, Asia, Latin America and the Caribbean

	Principal household water source		
	Well water (% hhs)	**Piped water (% hhs)**	**Other (% hhs)**
Regional averages of DHS			
Sub-Saharan Africa	31	52	17
South and Southeast Asia	32	57	11
Latin America and Caribbean	3	80	17

Note: These regional estimates are population-weighted averages of country shares, based on the DHS surveys whose country-specific results are summarised in Appendix 1, Table A1.

Particularly in Sub-Saharan Africa and Asia, the averages hide considerable inter-country variation. Among the African countries, Namibia reportedly has almost no urban households relying on wells for drinking water, Gabon only 2 per cent, and Zimbabwe 3 per cent, while Liberia has 70 per cent and Nigeria 59 per cent. (Since Nigeria makes up almost 35 per cent of the combined population of the African countries included, its high percentage has a large influence on the regional average, which is weighted by population.) In Asia, the shares vary from 17 per cent in the Philippines to 69 per cent in Bangladesh. In Latin America, on the other hand, the share is well under 7 per cent everywhere except for Haiti, where it is 18 per cent.

Three of the factors that might be expected to explain variations in the urban share of households in a country that use wells are urban income, recent urban population growth and urban groundwater resources. Table 4 presents a matrix of correlation coefficients including the share of urban households in a country using well water as their principal water source (based on the statistics summarised above) and internationally available variables that are at least indirectly related to these factors: GDP per capita; the average urban population growth rate in the decade preceding the survey; the renewable internal freshwater resources per capita. Given that these GDP per capita and decadal urban population growth are only rough proxies for the factors that would be expected to influence the use of wells, and given that the renewable internal freshwater resources are an extremely poor proxy for urban groundwater resources, the results conform at least roughly to what would be expected.

Table 4: Correlation coefficients for share of households using wells as principal drinking water source and selected explanatory variables

	A	B	C	D
A	1.00			
B	-0.45***	1.00		
C	0.35**	-0.33*	1.00	
D	-0.13	0.64*	-0.09	1.00

A: Share of urban households relying on wells (Source: Appendix 1, Table A.1)
B: GDP per capita in (first) year of survey in constant US$ PPP (Source: World Bank, 2009)
C: Average annual rate of urban population growth in 10 years preceding the survey (Source: United Nations Population Division, 2010)
D: Renewable internal freshwater resources per capita estimated for 2007 (Source: World Bank, 2009)
*** Statistically significant - 99 per cent confidence
** Statistically significant – 95 per cent confidence
Note: the countries included in this analysis were the 43 listed in Table *A* of Appendix 1, with the exception of Zimbabwe, for which data on GDP were missing.

Income can be expected to increase a country's capacity to develop urban piped water systems, replacing well water use with piped water. Thus, Latin America is the wealthiest of the three regions, and Haiti one of its poorest countries, and that could explain why urban households in Latin American have the lowest dependence on wells, while within Latin America Haiti has the highest. Some of the differences within Sub-Saharan Africa and Asia could also be explained by income differences. Thus, Bangladesh with its 69 per cent is one of the poorest Asian countries, while Namibia and Zimbabwe have historically been some of the wealthiest among the Sub-Saharan African countries, which could explain their low shares. As indicated in Table 5, the statistical correlation (R) between national income and the urban share using wells is -0.45, which corroborates the expectation that reliance on wells declines as income increases. This is the highest of any of the correlation coefficients involving the share of households relying on wells, and is highly significant statistically, though it also suggests that per capita income only explains a small share of the variation in well water shares.

Rapid urban population growth, on the other hand, can make it difficult for utilities to increase the share of households with access to piped water. As illustrated in Table 5, there is indeed a positive and statistically significant correlation between rapid urban growth in the ten years preceding the survey and the share of households relying on well water. On the other hand, there is a similar, but inverse, correlation with income per capita. In effect, without undertaking more detailed analysis (and perhaps even then) it is difficult to disentangle the relationship between rapid urban population growth and well use from that between per capita income and well use. Moreover, rapid urban population growth itself is part of an epidemiological and urban transition that is itself closely tied to economic development (Montgomery 2008). Thus, this result should certainly not be taken as evidence that curbing urbanisation will in itself reduce the share of households using wells, l*et al*one improve water provision. Indeed, it is quite possible that at the national level rapid urbanization would be associated with declining use of wells.

Water resource availability can clearly influence the use of well water, but it is not particularly surprising that there is no statistically significant correlation between national renewable freshwater resources per capita and the share of urban households relying on wells as their principal drinking water source. It is local conditions that matter, especially for groundwater, and while more groundwater resources would be expected to be associated with well use, more surface water resources might have the opposite effect. What is more surprising is that there is a strong positive relationship between income per capita and freshwater resources per capita.

There are likely to be a range of other factors influencing the share of households that depend upon wells, including the quality of governance. These and other factors may also influence the quality and reliability of the well water. Unfortunately, analyzing such relationships are well beyond the scope of this brief overview, and most are beyond the scope of any studies relying on this sort of household data.

Urban-rural comparisons of well use

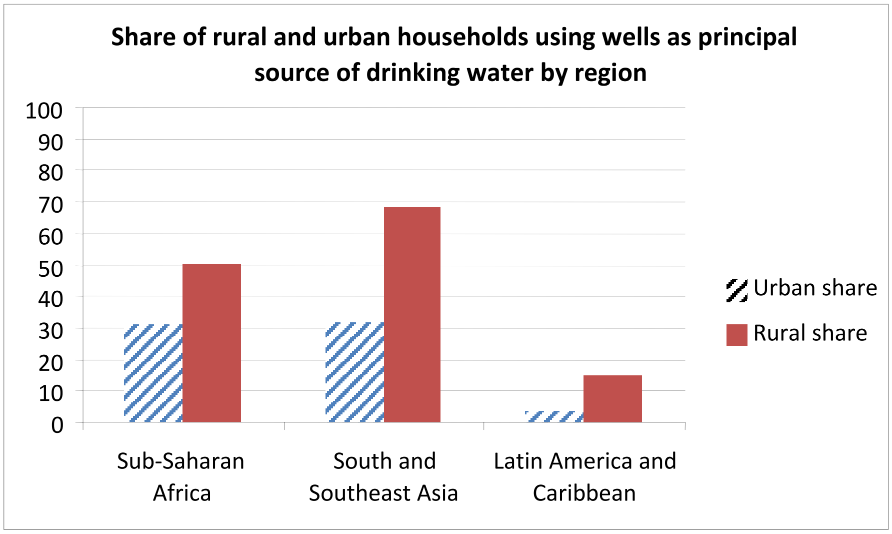
There are two principal reasons to expect urban dwellers to be less dependent on local wells than rural dwellers:

- Groundwater quality is typically worse in urban areas, as a result of all the concentrated pollution; and
- Piped water delivery is typically much less expensive in urban areas due to the shorter inter-household distances.

Experts sometimes argue, and authorities sometimes legislate, that urban dwellers should not use well water. In addition to quality problems, one of the reasons often given is that excessive abstraction will deplete local aquifers. As indicated elsewhere in this report, the information needed to evaluate such claims is lacking for many urban areas. Regardless, of such concerns, and in some cases the depletion of urban groundwater resources, would also be expected to decrease urban well use.

Rural groundwater dependence is indeed higher than urban dependence in almost all countries, with especially high rural urban differentials in Latin America, and the lowest differentials in Africa (See Figure 2, Table 6 and for the national figures Appendix A, Table A2). The average rural share is almost five times the urban share in Latin America, over twice the urban share in Asia. The Sub-Saharan African rural share, on the other hand, is only about 61 per cent higher than the urban share. Moreover in Liberia, Nigeria, and the Democratic Republic of Congo (as well as Haiti in the Caribbean) the urban shares are actually higher than the rural shares. This is in part because of the importance of direct access to surface water in the rural areas of these countries (33 per cent in Liberia, 31 per cent in Nigeria and 91 per cent in the Democratic Republic of Congo). Also, at 70 per cent and 59 per cent, Liberia and Nigeria have exceptionally high shares of urban households using wells.

Figure 2: Share of rural and urban households using wells as principal source of drinking water by region



Source: Table 5

Table 5: Comparing rural and urban shares of households using wells as their main water source – Africa, South and South East Asia, Latin America and the Caribbean

	Share of households using wells as their main water source	
	Urban (% of hhs)	Rural (% of hhs)
Regional averages		
Sub-Saharan Africa	31	45
South and Southeast Asia	32	52
Latin America and Caribbean	3	20

Note: These regional estimates are population-weighted averages of country shares, based on DHS surveys whose country-specific results are summarised in Appendix 1, Table A.2
Comparisons of well water use by wealth quintile[13]
Comparisons of well water use by wealth quintile[14]

One would also expect less affluent urban dwellers to be more dependent on wells than more affluent urban dwellers, for a variety of reasons, most of which explain why poor households do not get piped water when it is the preferred source:

[13] The wealth quintiles provided along with DHS surveys are based on data collected on household ownership of consumer items such as a "television and car; dwelling characteristics such as flooring material; type of drinking water source; toilet facilities; and other characteristics that are related to wealth status" (www.measuredhs.com/accesssurveys/Data_quality_use.cfm). Principal component analysis is used to generate weights, which are then used to rank households, and divide them into five categories from the poorest 20 percent to the wealthiest 20 percent. For this analysis, only urban households were included, and water related variables were excluded from the consumer items.

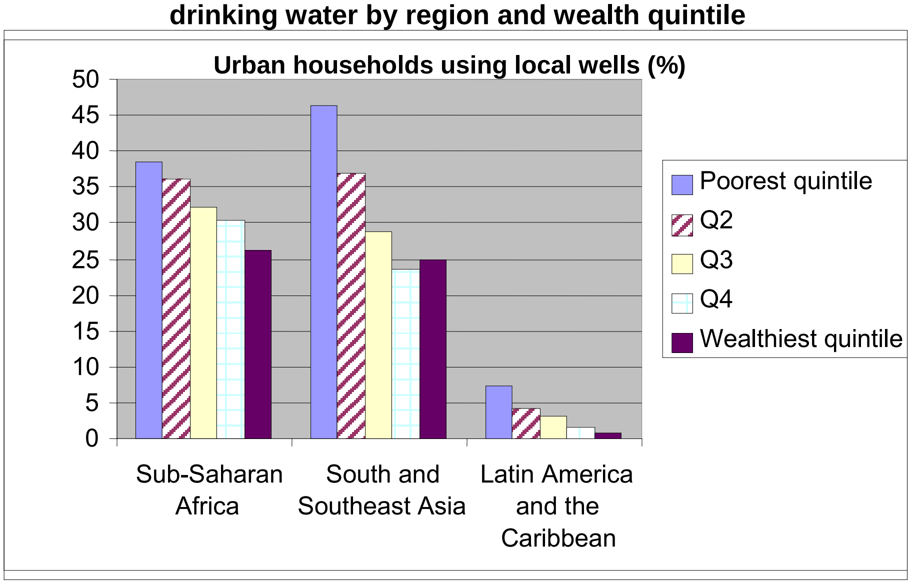
[14] The wealth quintiles provided along with DHS surveys are based on data collected on household ownership of consumer items such as a "television and car; dwelling characteristics such as flooring material; type of drinking water source; toilet facilities; and other characteristics that are related to wealth status" (www.measuredhs.com/accesssurveys/Data_quality_use.cfm). Principal component analysis is used to generate weights, which are then used to rank households, and divide them into five categories from the poorest 20 percent to the wealthiest 20 percent. For this analysis, only urban households were included, and water related variables were excluded from the consumer items.

- More affluent people are better able to pay to live in well-serviced neighbourhoods;
- Where piped water is available, more affluent people are better able to pay the connection costs; and
- Poor people are more likely to live in informal, illegal or marginal settlements where the piped water system is not available.

There are, of course, times and places where local well water is preferred to piped water, especially when the piped water network provides intermittent and poor quality water. Indeed, water from boreholes may be the more expensive alternative.

The results confirm that higher shares of urban dwellers in lower wealth quintiles are dependent on well water (see Figure 3, Table 7 and for national figures Appendix A, Table A.3) in nine of the countries in Sub-Saharan Africa. The two Sub-Saharan African countries with the smallest ratios between the poorest and wealthiest quintiles are Nigeria and Liberia, which have the highest overall dependence and still have high levels of dependence in the wealthiest quintile (53 per cent in Nigeria and 67 per cent in Liberia). Alternatively, the absolute differences are small in some of the countries with very little dependence on well water, such as Namibia.

Figure 3: Share of rural and urban households using wells as principal source of drinking water by region and wealth quintile



Source: Table 6

Table 6: Shares of urban households using wells as their principal drinking water source by wealth quintile

	Q1	Q2	Q3	Q4	Q5
Regional averages					
Sub-Saharan Africa	**39**	**36**	**32**	**30**	**26**
South and Southeast Asia	**46**	**37**	**29**	**24**	**25**
Latin America and Caribbean	**7**	**4**	**3**	**2**	**1**

Note: These regional estimates are population-weighted averages of the quintile shares presented for each country in Appendix A, Table A.3. Pakistan and Vietnam were omitted due to data problems.

These results showing such high well use among poor residents suggest even more strongly than do the national averages that if water resource management is to focus on the urban poor, it must take urban groundwater seriously.

Changes over time in use of water from wells

Since household and community wells are not generally the urban water source preferred by residents, l*et al*one by experts and governments, it is tempting to view dependence on wells as a negative thing. Thus, in addition to economy-wide difficulties, factors that might be expected to result in declining access to piped water, and indirectly increasing dependence on wells, include:

- Increasing urban poverty or inequality;
- A declining share of investment going into urban water networks; and
- Rapid urban population growth.

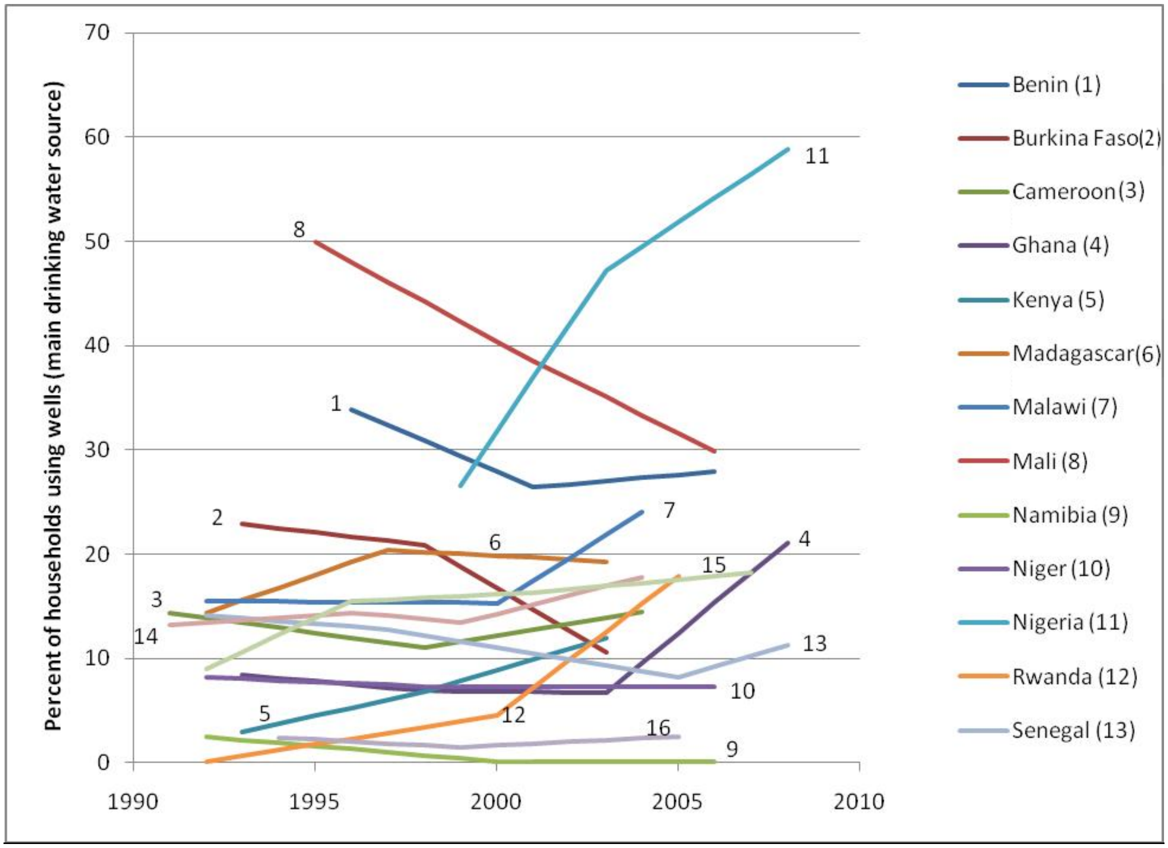
In practice, these could create negative synergies. Sharp social and economic inequalities can reduce the pressure to expand water infrastructure, and greatly amplify the effects of rapid urban population growth. Alternatively, concerns about rapid population growth can be used to justify policies restricting the expansion of services such as piped water, in the (possibly vain) hope of reducing the influx of low income migrants. As such, there are situations where increasing direct dependence on groundwater is a symptom of problems that need to be addressed if access to water is to improve.

In principle, however, increasing use of wells could be a positive sign. It could reflect the success of projects and policies expanding the number of wells to improve water access. Even if this only rarely explains past trends in well use by urban households, it is important to recognize that while increasing dependence on wells is usually a sign of trouble; this is because it usually reflects problems with other urban water sources. Policies that curtail well use could make matters much worse, even if they might seem to improve the statistics.

Of the countries whose most recent survey results were presented above, 16 in Sub-Saharan Africa, five in South and Southeast Asia and five in Latin America and the Caribbean had at least two previous surveys, and were included in the analysis presented here on changes over time. Overall, It is difficult to discern a general trend from the very wide array of different trajectories of urban direct groundwater dependence (see Figures 4-6 and Appendix A Table A.4). Over the periods they were surveyed, 14 of the countries experienced an increase in the urban share using wells, eleven experienced a decline, and one ended up at the same share. Those where well use increased were more concentrated in Sub-Saharan Africa, where nine of the 16 countries experienced increases.

As illustrated in Figure 4, in Nigeria the share of urban households using primarily well water increased from 27 per cent in 1999, to 47 per cent in 2003, to 59 per cent in 2008. This is a major shift, and given Nigeria's size this suggests that the overall household dependence on local wells in Sub-Saharan Africa has probably increased. On economic grounds alone, it is impossible to explain the rapidly increasing dependence on wells in urban Nigeria. Over the 1999-2008 period that this dependence increased, Nigeria's GDP per capita (constant 2005 US$ PPP) grew from US$1,419 to US$1,924. Over a comparable period, Mali experienced a comparable shift in dependence *in the opposite direction*: from 50 per cent in 1995/96 to 39 per cent in 2001 to 30 per cent in 2006. Yet Mali was also growing economically over this period: GDP increased from US$762 in 1995 to US$1,026 in 2006 (World Bank World Development Indicators).

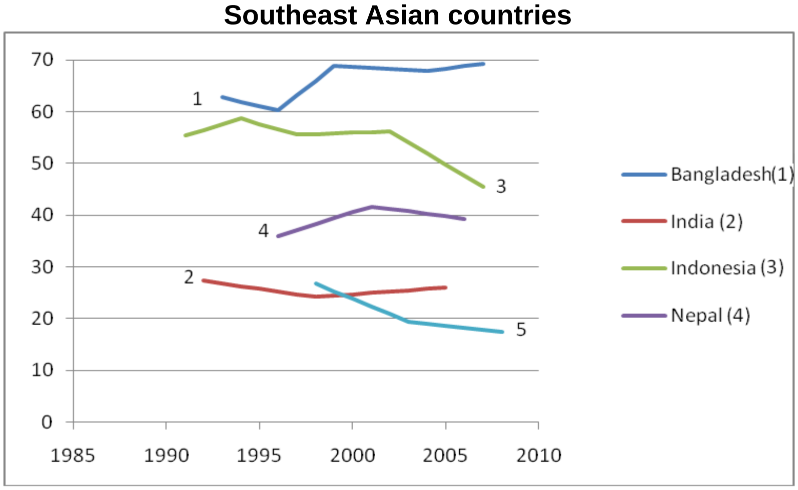
Figure 4: Changes in urban household well use over time in surveyed Sub-Saharan African countries



Source: Table A.4

Figure 5 indicates at least as much variation among the Asian countries presented, and no clear direction of movement. Also, as illustrated in Figure 6, while the Latin American countries, with the exception of Haiti, clearly display lower levels of urban well use than the Asian or Sub-Saharan African averages, they too show little overall direction of movement.

Figure 5: Changes in urban household well use over time in surveyed South and Southeast Asian countries



Source: Table A.4

2.2 The DHS and the MDGs

After the MDGs and the associated targets were decided by the world's governments, the international character and stewardship of them came to focus inordinate attention on developing internationally comparable indicators, attracting international finance, and finding an institutional form to promote (McGranahan 2007). The DHS data are therefore used – together with other national surveys[15] – for the WHO and UNICEF's Joint Monitoring Programme for Water Supply and Sanitation (JMP), which reports on the state of progress in reaching water and sanitation targets. The findings based on these surveys are fundamental in determining how far the development has come, how well money from donors and others was invested, whether the right policy recommendations have been made, in what regions more efforts seem to be needed, and so on.

Notes on the DHS design

There are, however, limitations to the design of the DHS (like similar surveys), especially when it comes to the questions on water supply. The survey only allows *the main source* of drinking water to be ticked (and in some countries the main source of water for other household purposes). From the formulations used to define various 'sources', it can be assumed that many respondents will have difficulty classifying what their main source constitutes according to the questionnaire, unless the interviewer explains the alternatives with examples from the local context. For instance, in the DHS 2007 the respondents in the city of Lusaka did not seem to have the option to answer that they purchase water from a 'kiosk', and therefore probably ticked 'Communal tap' for this alternative (see table below). Yet since 2003, buying water from a kiosk has become increasingly common among more than 65 per cent of the urban population living in Lusaka's low-income areas (see sub-section 4.2.3 below). In addition to this, the terminology used is not consistent from year to year and may also vary between different country surveys, which makes comparisons and trend analyses all the more difficult. Both of these issues can be seen in the following example of 'source of drinking water'[16] from the last four DHS surveys carried out in Zambia:

Table 7: Sources of drinking water in the DHSs for Zambia – 1992, 1996-97, 2001-02, 2007

DHS 1992; 1996-97	DHS 2001-02	DHS 2007
Piped into residence	Piped into dwelling	Piped into dwelling
	Piped into yard/plot	Piped into yard/plot
Public tap	Communal tap	Communal tap
	Piped to neighbour	
Well in residence	Open well in yard/plot	Open well in yard/plot
Public shallow well	Open public well	Open public well/borehole
	Open well at neighbour	
Public traditional well	Protected well in yard/plot	Protected well/borehole in yard/plot
	Protected public well	Protected public well
Spring	Spring	Spring

Source: DHS surveys, Zambia

[15] The JMP also uses other national statistical data, such as the Multiple Indicator Cluster Survey, the Living Standard Measurement Study, the Core Welfare Indicator Questionnaire, the World Health Survey, and the Household Budget Survey. However, definitions may differ between the surveys. For instance, the World Health Surveys make a distinction between 'piped' and 'other' sources (where the latter includes public standpipes, protected tube wells, bore well, dug wells, springs, rainwater, etc.) and 'no access to safe water' as a third category. On the contrary, the DHS and the MICS categorise 'public standpipes' as 'piped' water.

[16] In the last survey, the respondents could also choose different surface water alternatives; water from tanker truck or cart; bottled water; and other. Previous years, similar options were available.

Comparing with the DHS 2007 example from Zambia, 76.6 per cent of the urban water users in the country responded that they (mainly) take water from a piped source, whereas supposedly only 18.2 per cent use groundwater (from stand-alone open or protected wells; direct dependence on groundwater) – half the figure estimated for the SADC. However, it can be noted that in the city of Lusaka around 55 per cent of the 'piped' water distributed by the public utility is drawn from boreholes (indirect use of groundwater), and that the reticulated water in 'communal taps' comes from the same mix of sources. In other words, from the Zambia DHS alone it may seem as if the total dependence on water from wells is much less than in reality. It was also found during field work in Lusaka's settlements that people with dug wells may not want to admit that they use them, because such wells are banned by the authorities. Such a respondent may therefore state that the main source of water is any of the other options rather than ticking 'Open well in yard/plot' (see sub-section 4.2.3 below).

Together, these survey construction flaws cause groundwater to be under-accounted for as a source, and even with insights into the local context it is not possible to draw any far-reaching conclusions on groundwater use from the data. It has been pointed out that in general, both the monitoring of and statistics for urban groundwater use are very poor;estimates are often dated and usually based on many assumptions (Foster 2009; personal. communication, March 19, 2010).

Improved and unimproved groundwater sources

The latest official JMP statistics were published in March 2010.[17] With 87 per cent of the entire world's population, or approximately 5.9 billion people, using safe drinking water sources, the world may seem on track to meet or even exceed the target of the MDGs; for instance, more than 95 per cent of those living in urban India, Pakistan and China are reported to have access to safe drinking water today (WHO/UNICEF 2010). However, 884 million people are still estimated to lack access to safe drinking water and over 2.6 billion people are estimated to live without improved sanitation facilities. The worst affected region is Sub-Saharan Africa, where an average of only 83 per cent has access to safe drinking water. There are large disparities between the region's countries, as well as between the rural and the urban areas; people living in cities are typically better off.

To estimate access to 'safe' water JMP is required to use an MDG indicator, namely the proportion of the population using an 'improved' drinking water source (divided into urban and rural respondents). In defining what is an 'improved' source the JMP in turn distinguishes between a set of categories for approved water sources based on whether these provide water that is likely to be 'safe' and potable or not. An improved source is therefore "one that by the nature of its construction adequately protects the source from outside contamination, in particular with faecal matter" (WHO/UNICEF 2010:34): piped water; public taps/standpipes; tubewells/boreholes; protected dug wells and springs; and collected rainwater are all deemed suitable sources (see the definitions at the beginning of this paper). Sources seen as 'unimproved' include unprotected dug wells and springs; surface water; and private vendors using tanker trucks/carts.

A dug well is defined as improved if it is 'protected'. This, in turn, depends on the well being protected from runoff water by a well lining or casing that is raised above ground level and a platform that diverts spilled water away from the well, and covered to prevent bird dropping and animals to fall into it. In contrast, a dug well is 'unprotected' (and hence unimproved) if the well is not protected from runoff water and/or the well is not protected from bird droppings and animals.

[17] The latest updated statistical figures can be found at whqlib-doc.who.int/publications/2010/9789241563956_eng_Statistical_table.pdf.

Criticism against the DHS and thus the JMP can be made on many grounds. The 2010 JMP report is based on the UN Population Division's 2008 revision and on surveys conducted in the mid-2000s or earlier. The proportion of people reported to have access to water 'now' have most probably actually declined during the years since the data was collected due to very rapid rates of urban population growth (Foster 2008).

Furthermore, whereas the respondents can only tick the main source of water used, urban dwellers in developing countries in particular tend to make use of more than one source since their main choice may be unreliable for different reasons (cf. Montgomery, Stren et al. 2003). The fact is also often that the volumes of water available are insignificant – "no municipal water utility in either India or Pakistan provides a continuous water supply to all of its customers. Many towns in India supply water for two hours or less per day, with some areas receiving water on alternate days" (Tayler 2008:239). Water being provided from an improved source does not necessarily mean that the water is 'adequate'[18],[19] or that it comes from a sustainable resource. While a public tap (a standpipe or standpost) is considered an improved source of water, the distance to this tap, the limited time it may be open, the queues and the competition over the available water may prohibit users from maintaining a healthy standard of living simply because there is not an adequate amount of water available.

The WHO/UNICEF definition of 'access' to drinking water is based on the source being less than 1 km away from its place of use. There is a rural bias built in to this part of the definition, considering that urban dwellers will tend to have water sources closer to where they reside but will often, instead, have to queue for long periods of time in order to access water. The effort involved in fetching water in the urban environment is hence of a somewhat different kind and the definition of access should, preferably, also take this waiting time into consideration.

Access to water in urban areas also seems less problematic than under rural circumstances when it comes to defining what water sources are deemed 'safe'. A larger degree of wells may be 'protected' in towns and cities, but the water from a borehole or tubewell (just as much as water from a dug well which is duly lined, covered and so on) may give a highly contaminated yield due to natural and/or anthropogenic pollution of the groundwater – and yet still be considered an improved source. When tested, the drinking water obtained from many improved sources has not met the microbiological standards set by WHO and this problem is now increasingly acknowledged (UN DESA 2009). The DHS questions, however, leave no room to reflect the reality on the ground, where the quality of the water supplied is poor in many of the included countries (cf. Ruet, Saravanan et al. 2006; Gerlach and Franceys 2009).

In the latest update of the JMP report, the challenge of measuring quality is described as 'an elusive indicator'; "[t]he measurement of water safety indicators at the household level has to date been beset by technical and logistical difficulties and by high cost". A pilot survey including field test kits for testing the water quality of improved sources has therefore been carried out, and questions such as "what definitions would be meaningful and assist decision-makers in the process of improving the drinking water situation in the world?" will be addressed by a

[18] If the criteria were changed from improved to 'adequate', it has been estimated that three to four times more urban dwellers would be found to lack such provision. These were only 'indicative estimates', however, based on reviews of more than 200 studies of individual cities and smaller urban centres, see UN-HABITAT(2003).

[19] For instance in Malawi, it has been found that the actual water and sanitation access situation remains woefully inadequate in the informal settlements that are home to around 60 per cent of the country's urban population. Water is available only during a limited time per day and at a distance from the users' households (Manda, 2009). This is similar to the case for most poor who rely on public standposts, community taps and kiosks.

new JMP task force. Most nations lack data on this parameter today but water quality will have to be part of a revised target beyond 2015 (WHO/UNICEF 2010:31).

Nonetheless, improved testing of the quality of water from wells does not involve measures being taken to safeguard the resource. A sufficient level of protection would entail a fundamentally different approach to groundwater and to the concept of Integrated Water Resources Management at city level, tasks that are not under the auspices of the goals and target of the UN MDGs.

Finally, in relation to groundwater use and urban self-supply the improved–unimproved dichotomy can be dangerous. Many poor people would benefit from access to larger amounts of water than is currently available to them. This group should not be discouraged from using water from 'unimproved' wells. Instead, if the quality of the water from certain wells is found to be substandard and non-potable, this problem can be dealt with in a number of ways. Deterioration of the water quality should be prevented at all levels and by all means, and education about suitable point-of-use treatment, hand-washing, and other hygiene promoting activities are vital to raise awareness about the various transmission routes for diarrhoea and the importance of safe water storage in the home.

It is futile to think that poor people, if self-supplying from wells for lack of affordable or otherwise accessible alternatives, will discontinue their use of an available groundwater source because a well lacks a lining or other protection. It may also be an ultimately damaging policy to strive for the improvement of all unprotected wells to make them meet the JMP criteria. It is reasonable to believe that the costs of the efforts to achieve such quality improvements would mostly have to be met by the end users themselves. However, from a health perspective some studies have shown the advantages of having access to increased quantities of water (Esrey, Potash et al. 1991).

Box 2: Official statistics on access to improved water – a bunch of baloney?

To declare that only 141 million urban people are yet to access 'improved' drinking water is scornful of the hundreds of millions who lack access to adequate volumes of good-quality water on a regular basis. The system allows, however, for inflated numbers. Some Sub-Saharan African countries do remarkably well according to the official statistics. Ethiopia and Zimbabwe have reported that 98 and 99 per cent [*sic*] of their urban population, respectively, have access to safe water. The latter case is particularly astonishing. Under the current regime, Zimbabwe has witnessed a political and economic collapse and a long-drawn cholera epidemic has killed hundreds of people since the end of 2008. This is widely argued to be caused by the breakdown of basic water and sanitation services in the cities, which is based partly on ever-changing institutional responsibilities, and partly on financial constraints on operating and maintaining the infrastructure. In Bulawayo, Zimbabwe's second largest city, shortages of clean water caused by a lack of chemicals and leakages of mains have increased the demand for water from alternative sources, including dug, unprotected wells. Several NGOs and donors, including Oxfam, the World Water Vision and Sida, are working on easing the pressure on the water supply and sewerage systems that have broken down in the city. Hence, it is on the one hand highly unlikely that 99 per cent of the country's urbanites actually have access to water from improved sources, of which 88 percentage units are piped water, as reported. On the other hand, many respondents to the DHS and other surveys may have indicated piped water as being the 'main' source, for lack of alternatives.

Cont over

The 2006 Stockholm Water Prize Laureate, Asit K. Biswas, is harsh in his view of official statistics, the JMP definition, and the very likelihood of the MDG targets being met: "If somebody has a well in a town or village in the developing world and we put concrete around the well – nothing else – it becomes an 'improved source of water'; the quality is the same but you have 'improved' the physical structure, which has no impact ... They are not only underestimating the problem, they are giving the impression the problem is being solved. What I'm trying to say is: that's a bunch of baloney" (Jowit 2010). – Poor management, including corruption, interference by politicians and inexperience, will lead to a higher, rather than a lower, proportion of people lacking access to drinking water "in the sense [that] they will have water they can drink straight from the source" by 2015. The case for the sanitation target is even worse, according to Biswas (*ibid.*).

3 What characterises groundwater in urban areas?

Arranging sustainable water supply for cities in low- and middle-income countries is a challenge that can be met in various ways. During the 20th century, some advantages of groundwater over surface water for urban domestic use became clear. Lakes, ponds, streams and rivers were increasingly polluted with pathogens, parasites, chemicals and solid matter, rendering them less potable; ever rising withdrawals of river water upstream decreased the volumes reaching people living downstream; state regulations limiting the amounts to be drawn from rivers increased the competition over water distributed from them; the socio-economical and ecological costs of pumping water from growing distances were questioned; and so on. –In comparison, groundwater benefitted from a just-in-time (and 'just-in-place') nature as it could be accessed when needed, thereby decreasing the need to construct storage facilities and plan for dry seasons and periods. Being under individualised control, wells and entire groundwater systems also lack a strong and consistently implemented regulatory structure in many parts of the world. Added to this, the quality of groundwater is generally superior to that of surface water sources and often regarded as more pure. The choice of groundwater is often augmented by the fact that people settling or already residing at the outskirts of growing cities are seldom connected to the reticulated water supply and have no option but to source their own water from wells; their ability to do this adequately however depends on the hydrogeological conditions, and on several other factors. The same mostly applies to unplanned areas where the poorest of city dwellers live.

Box 3: Natural arsenic contamination of groundwater

The advantages of groundwater contributed to the decision by international agencies headed by the United Nations Children's Fund (UNICEF) to drill millions of tubewells in Bangladesh and West Bengal, India, at the beginning of the 1970s. The practice of drinking groundwater instead of harmful surface water saved many lives, but after twenty years it became clear that other complications had emerged. Plenty of research and technical interventions are carried out today on the quite severe health implications from arsenic (As) naturally occurring in the bedrock of these areas. Arsenic contamination of the water still poses an enormous risk in megacities such as Lahore and Kolkata.

Naturally occurring Fluoride (F^-) in the bedrock is another problem. It is more widespread in arid and semi-arid climates with little precipitation, because the dilution effect is thus lesser, the groundwater flow slower, and therefore time in which reaction with the bedrock can take place is longer.

In contemporary research in the field of groundwater in the urban environment, the issues of degradation and over-extraction are receiving much attention. The deterioration of groundwater quality due to anthropogenic factors is mainly linked to bad sanitation. This includes lack of and leakages from sewerage systems as well as improper treatment facilities, and inadequate solid waste disposal. Industrial discharges of chemicals and other effluents also pose problems to underlying aquifers over time especially at the outskirts of cities, particularly when appropriate regulations have not been introduced or are not being enforced.

Meanwhile, large withdrawals of groundwater have led to reduced availability of groundwater to poor people, by lowering of the water table. Withdrawals have also led to irreversible land subsidence in many cities worldwide. Another problem is the fact that much demographic growth takes place in coastal cities and leads to increasing risks of salt water intrusion. Salinity is by some researchers seen as the major threat to aquifer sustainability because it does not reduce naturally. Once salinised, the groundwater can only be made fit for drinking by energy-intensive desalination or by dilution (cf. Morris, Lawrence et al. 2003).

3.1 Hydrogeologic conditions for groundwater development

The major part of the available freshwater resources on Earth is located underground. Beneath the Earth's surface we find what is referred to as groundwater in aquifer formations functioning as reservoirs in different shapes and sizes. Between the zone of aeration, which forms the top layer under the surface, and the actual groundwater level, is also a layer of soil moisture ('green water') that is of great importance for trees and plants. Extracting water via their root systems, the green water is fundamental for food production and it thus forms an important part of the hydrological cycle. Groundwater is found beneath the level that is fully saturated, an often fluctuating level known as the water table. The saturated, unconsolidated layers of soils, silt, gravel and so on overlying the rock often makes a significant contribution to the yield obtained from a well.

The water in aquifers originates from local precipitation but also from other surface waters that infiltrate surface layers and percolate down to accumulate in pores, cavities, fractures and fault zones either in unconsolidated materials such as gravel, sand and clay, or in porous and permeable layers of rock. The groundwater can normally flow between interconnected fractures (cracks, joints and fissures) in bedrock but aquifers can suffer from these hydraulic connections being *discontinuous*, when little or no correlations exist between the water-bearing fractures. Discontinuous aquifers are generally unpredictable. Groundwater may also occur in *confined* aquifers beneath a non- or low-permeable unit or strata, typically a layer of clay. Groundwater situated below the water table is defined as sitting in unconfined aquifers. These features can make it difficult to generalise about groundwater availability and quality, even within a given city or neighbourhood.

The age of the water contained in an aquifer varies from months to millions of years (fossil groundwater), mainly, but not only, depending on the depth of the aquifer. Hence when groundwater is abstracted, the time needed for recharge to original levels may vary greatly. Recharging over a short time span means that the water levels have a dynamic ability to decline and rise naturally. Over long to very long time periods, natural groundwater systems are typically in a condition of dynamic equilibrium meaning that recharge and discharge are in balance. On the contrary, fossil groundwater should be regarded as forever pre-emptied once it has been pumped. Knowledge of the distribution and movement of water in soil and rock depends on several interacting factors, though, including biological, physical, chemical, meteorological and climatological. In spite of advanced modelling, uncertainties are still prevalent when forecasting groundwater occurrence (see below). This makes it difficult to determine whether existing or planned water abstraction will affect future availability, and whether further groundwater development can be deemed sustainable.

Groundwater availability, aquifer recharge potential and even the quality of the groundwater is, to a large extent, governed by the type of basement rock it occurs in. There are three main types of rock on Earth: sedimentary; igneous; and metamorphic. Rocks classified as *sedimentary* are found at or near Earth's surface and make up only about five per cent of its crust. It does, on the other hand, play a very important role from an aquifer point of view – especially if the rock is carbonate as in the case of limestone (which is found in Lusaka). Limestone and dolomite are often fissured and may be enlarged by solution processes to form well-developed solution cavities known as karst features, which can be likened to underground lakes and rivers. Other sedimentary rock types are shale and sandstone.

Igneous rocks are formed by magma or lava cooling and becoming solid, with or without crystallisation. Most igneous rock types are plutonic: solidified below the surface as intrusive rocks. The most abundant of these is granite (which is found in Bangalore), another being basalt. The character of igneous rock is nearly always massive, meaning that it lacks internal structures and thereby primary porosity. Groundwater is therefore only found in the upper, more or less weathered layers and in the zone beneath these layers where cracks, joints and fractures occur to various extents. The weathering processes increase the porosity and permeability of the rock but the effect decreases with depth. Fractures below 100 m from the surface almost always lack interconnectivity, and the aquifers are thus discontinuous.

Metamorphic rock is originally sedimentary or igneous rock (or another older metamorphic rock) that has been transformed due to temperature and pressure. Examples include gneiss, slate, marble, schist and quartzite. Like igneous rock, it is solid, dense and crystalline and hence cannot yield much groundwater as such. Aquifers exist in the weathered zone as well as in fractures.

Aquifers in hard, crystalline basement rock – both igneous and metamorphic – are hence low-yielding compared to sedimentary rock, and the available discharge per well ranges from less than 2-3 m^3/h up to 20 m^3/h. They also suffer from highly heterogeneous conditions. Parameters like storativity and transmissivity may show erratic variations within small distances and two neighbouring wells may exhibit greatly contrasting behaviour, such as only one of them yielding a significant amount (cf. Lachassagne 2008).

3.2 Safe yield, sustainability and uncertainties

How much water can be withdrawn from a given aquifer or aquifer system under or by a city before the abstraction-recharge rate should be deemed unsustainable? The answer depends on a multitude of factors including the scale of the abstractions, which is in turn connected to the purpose. But the question is complex if, in defining sustainability, we include ecologic, economic and social factors. For instance, the extensive use of groundwater from the confined sand/chalk aquifer of central London from the nineteenth century onwards had long-term negative consequences, with a lowered water table and springs and streams drying up, but it was economically beneficial for the development of the city as a major centre of population and manufacturing (Price 2002). Typically, crystalline bedrock means low-yielding and notoriously unpredictable aquifers, and wells that are less sustainable. All in all, domestic use of groundwater – essentially for drinking and cooking, basic hygiene and health – seems unproblematic compared to the volumes of water required for irrigation and industrial needs. However, individual wells drying up may have significant consequences for the users who depend on them.

The concepts 'safe yield', 'sustainable' groundwater use, and groundwater 'mining' are hotly debated among hydrogeologists, in part because there are no generally accepted definitions of any of these terms. For instance, it has commonly been held that abstractions from a groundwater system are 'safe' if the *average annual* rate of groundwater withdrawal does not exceed the rate of recharge, whereas others claim this to be a widespread misperception (Alley and Leake 2004; Zhou 2009). A water-balance must, for instance, be based on average annual withdrawals and recharge to take into account how groundwater supports river flows and water levels in surface water bodies and wetlands. –Other researchers are of the opinion that withdrawal of water from an aquifer's storage that exceeds the natural and induced recharge should not necessarily be regarded as *over*-exploitation or water 'mining' as it will not always result in falling water tables and decreasing yields from wells. In other words, a locally falling water table does not automatically imply over-exploitation of an entire aquifer (system), or that the water level is in continuous decline.

In terms of falling water tables, the rate at which this takes place is mainly a matter of climatic and hydrogeological conditions such as permeability, the aquifer's size and spatial extent, type of basement rock, and the dynamic equilibrium. Connectivity is another factor; when groundwater is abstracted from a given aquifer or aquifer system, groundwater drawdown is initially concentrated locally but spreads progressively to the whole system by inter-aquifer leakage (Custodio 2002). In addition, the total pressure on an area's groundwater system is significant, including the particular location and density of wells, as is the time span. Furthermore, when discussing safe yield and sustainability, the issue of potential depletion should be considered alongside issues of (mostly irreversible) water quality deterioration, as well as of socio-economical issues, equity and rights, and effects on ecosystem services. The complexities involved in estimating and modelling what can be considered safe and sustainable withdrawals of groundwater ultimately make the terms ambiguous, but also value-laden (Morris, Lawrence et al. 2003; Alley and Leake 2004; Zhou 2009).

The additional recharge that takes place in urban areas due to import of water through leaky pipes (see following sub-section) may rejuvenate local aquifers and aquifer systems with such amounts of water that abstraction becomes quite unproblematic (with the possible exception of crystalline bedrock). It has been held that under such conditions, the pumping of water from private wells alone will only very exceptionally tax resource availability; urban aquifers will usually only risk suffering from over-exploitation and depletion where they are used to meet the entire water demand, both utility and private (S. Foster, personal communication, March 19, 2010). In other words, in cities where inhabitants largely use wells to supplement surface water provided by the public utility, over-exploitation will not be a problem provided that there is sufficient understanding of the groundwater system in question, monitoring data is continuously gathered, regular evaluations of the development are carried out, measures such as rainwater harvesting to create additional recharge takes place, and the competent authority has the power to intervene should an area seem to require halting of the groundwater abstractions.

Many researchers hold that in the case of rapidly growing cities, temporary over-exploitation of aquifer storage is not necessarily undesirable. In the short run, it may enable them and their inhabitants to thrive and progress economically. To make such an approach strategically sustainable would, however, require the development of legislation and control that is in turn based on a sufficiently good understanding of the groundwater system and is applied jointly with a precautionary approach at the individual level (cf. Hiscock, Rivett et al. 2002). For instance, rooftop rainwater harvesting has been made mandatory in several Indian cities, often pressed for by NGOs that provide the decision-making authorities with the necessary scientific basis as well as technical know-how.[20]

Climate change researchers suggest that as reliable surface water supply is likely to decrease due to increased temporal variations of river flow (caused by increased precipitation variability and decreased snow or ice storage), it might be beneficial to take advantage of the storage capacity of aquifers and increase groundwater withdrawals. However, this option is only sustainable where groundwater withdrawals remain well below recharge, and is not viable where groundwater recharge is projected to decrease (Kundzewicz and Döll 2009). (See sub-section below on groundwater and climate change.)

[20] *See* www.arghyam.org/ and www.cseindia.org/.

An area's average precipitation, depth to the water table and geological features of the bedrock are the main factors that decide whether it is feasible – and economically reasonable – to dig or drill for groundwater. In dry and semi-arid areas and in inherently low-yielding crystalline rock terrain more thorough studies of the main lithological and regolith units, water flow, aquifer vulnerability, climatic prognosis, abstraction pressure, and so on, are important for the establishment of local and regional water budgets. The modelling techniques for quantitative (but also qualitative) estimations are constantly refined, "towards horizontally integrated studies in which environmental compartments interact with each other" as well as assessments of "the pressures facing groundwater resources associated with the direct and indirect effects of future climate and socio-economic change" (Holman 2006:638).

However, there is still a great deal of uncertainty in the models conducted to estimate groundwater occurrence and recharge potential in bedrock, especially crystalline bedrock with discontinuous aquifers. Holistic, systematic assessments based on mere well surveys are complicated, not least as it is difficult to establish the optimum number of monitoring wells, and their density in different conditions. Therefore, computations with detailed hydrological models at local, regional as well as global scale are relied upon instead, coupled with global ocean-atmosphere circulation models. Such models estimate the variation in land water storage by solving the water balance equation and are used to estimate climate change effects on groundwater storage (Bindoff, Willebrand et al. 2007). It should also be remembered that estimates of groundwater availability, recharge, abstraction potential, and so on – whether based solely on monitoring wells or also on modelling techniques – may be too expensive for low- and middle-income countries (and cities in such countries) to perform and process. Various techniques employed for groundwater estimates also require know-how and a general institutional capacity that may be stifled due to political disinterest.

Box 4: Groundwater modelling with GRACE

The most up-to-date method for estimating the rate of groundwater depletion is based predominantly on observations from NASA's Gravity Recovery and Climate Experiment (GRACE) satellites, and simulated soil-water variations from a data-integrating hydrological modelling system. GRACE identifies temporal variations of the Earth's gravity fields due to mass redistribution, including that of underground water masses in unconfined aquifers. The changes in gravity can be translated into a measurement of an equivalent change in water flow in the subsurface environment, including seasonal and relatively large-scale variations (Fukuda, Yamamoto et al. 2009).

For instance, six years of monthly GRACE gravity data for the federated states of Rajasthan, Punjab and Haryana in northwest India, including the national capital territory of Delhi, has produced a time series of water storage changes beneath the region's land surface. The researchers estimated that groundwater levels were declining by an average of one metre every three years (or 17.7 ± 4.5 km^3 per year). By their reckoning, 109 km^3 of groundwater had disappeared between 2002 and 2008, although there were no unusual trends in rainfall. The Indian Ministry of Water Resources, on the other hand, has measured the difference between the annual available recharge and annual withdrawals in the region and estimated that the annual deficit is only 13.2 km^3 (Central Ground Water Board 2006). NASA's results imply that the portion of irrigated water that supposedly replenishes the aquifers is less, and/or the rate of withdrawal is more, than the Indian government estimates, and that most of the groundwater withdrawn is lost[21] from the region as a result of increases in runoff and/or evapotranspiration (Rodell, Velicogna et al. 2009).

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[21] Water that is permanently lost from aquifers due to over-extraction eventually reaches the sea and the oceans through the atmosphere or surface flow, both of which result in sea level rise.

Based on these findings, the researchers warned that a collapse of agricultural output in northwest India (where irrigation accounts for about 95 per cent of the groundwater withdrawals) as well as severe shortages of potable water for its 114 million people are imminent, unless measures are taken to curb the current rates of water extraction. These rather drastic findings are questionable, though, taking into account the fact that the GRACE technique uses a fairly coarse spatial resolution and that the results are not well related to ground-based data (R Taylor, personal communication, March 8, 2010, cf. Chatterjee and Ram Purohit 2009).[22]Efforts have been made to develop GRACE to become applicable in urban settings as well, but the spatial resolution of its data is not considered anywhere near adequate for identifying groundwater variations on an urban scale (Fukuda, Yamamoto et al. 2009).

3.3 Groundwater recharge in urban areas

Groundwater is generally characterised by slow movement, accumulating in aquifers over long periods of time. The recharge, or replenishment, of an aquifer depends primarily on what organic materials lie above it. The soil layers act as natural filters to hinder or screen out substances that would otherwise be carried by the water down to the aquifer, but the more impermeable the soil, the less potential there is for recharge. The infiltration capacity of the soil (texture, grain size, porosity, and so on), its water-holding capacity, and the presence of residual deposits and vegetation cover on the bedrock are all key factors. Characteristics of the climate – precipitation, temperature and evapotranspiration – also determine how much recharge can take place (see following sub-section).

In a rural environment, rice fields that stand under water for long periods at a time usually contribute to groundwater recharge, as do seepage from many other traditional irrigation practices. Conversely, water that floods over bare land areas, for instance during the monsoon season, is generally lost as runoff to surface water bodies, used by plants elsewhere (transpiration), or is subject to evaporation before it can seep down to reach aquifers. The existence of saturated soil layers on top of the bedrock can be decisive, as they prevent water from flowing down to aquifers. In addition, gravitation directs the flow of surface water from higher areas to lower ones, especially in undulating terrain. The patterns of recharge are further complicated by extraction, such as pumping from wells.

Prior to research conducted from the mid-1980s onwards, it was assumed that cities reduced the recharge potential to underlying aquifers due to land-use changes, including the rapid disappearance of percolation tanks, and the widespread impermeabilisation (hardening) of surfaces for purposes such as buildings, pathways, paved roads, backyards and parking lots. However, since practically all cities import water from elsewhere to meet demand, the total amount of water (and eventually wastewater) that circulates actually increases. The indirect recharge increases because the subsurface infrastructure for water supply, sewage and storm water, together with various other underground water-holding constructions, tends to leak.[23] The subsurface in urban environments is now thought to have secondary porosities and perhaps a permeability distribution comparable to shallow karst settings, though the conduits and tunnels are developing more rapidly than natural karst. Over-irrigation of lawns, golf courses, and so on also contributes to a situation in which the recharge is as high as or higher than in equivalent rural areas (Lerner 2002; Garcia-Fresca and Sharp Jr. 2005).

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[22] The Indian Government's estimates of the country's groundwater resources are made for individual administration units known as blocks, the average area of which varies between 350 and 900 km^2, except for in the states of Karnataka, Andhra Pradesh and Maharashtra where the watershed is taken as the unit. The assessments are field-based, using a water level fluctuation technique for rainfall recharge estimation, Chatterjee and Ram Purohit 2009.

[23] This includes transmission losses, usually termed 'unaccounted-for water'.

For all the development in modelling techniques, it is also difficult to estimate urban recharge more exactly if only precipitation as a source is taken into account (Lerner 2002). The fact that most rapidly growing cities comprise vast peri-urban areas at their fringes makes it even more difficult to generalise for the sake of assessments. If parts of the peri-urban areas are unserved by water supply and/or sewerage infrastructure, then less drinking water is imported through leaking pipes and mains and there is hence no additional source of recharge (cf. Naik, Tambe et al. 2008 for the Indian city of Solapur).[24] On the contrary, though, residential and other areas in the peri-urban environment may still have fairly permeable soil surfaces, and there may be gardening and even small-scale agriculture taking place where excess irrigation water is applied. Rooftop runoff and stormwater will often infiltrate through soakaways if there are no drainage channels or sewerage pipes laid along roadsides and elsewhere. All these factors may contribute to localised direct recharge that differs from that found both in rural areas and more central urban areas.

Where wastewater infiltration occurs, water drawn from aquifers will often be sub-standard, as it contains pathogens, nitrates, and so on, presenting a potential health hazard (Foster and Chilton 2004). In low- and middle-income countries, on-site sanitation facilities with leaking soak-pit latrines, septic tanks, and so on, together with the absence of sewerage pipes that take the wastewater away, result in large volumes of local wastewater soaking into the soil, and eventually seeping into aquifers. This problem is worse in more arid climates and where water is imported from elsewhere.

Based on their study of a rapidly growing Indian city, Naik *et al*. have suggested that water harvesting structures for artificial recharge as well as for dilution of harmful chemical constituents may be a solution, and hold that "[g]roundwater quality deterioration is not due to urbanisation, but due to general apathy of the public towards this valuable resource. If there is adequate usage of groundwater, its natural circulation would increase and the quality deterioration could be checked" (Naik, Tambe et al. 2008:366). Nonetheless, the differences in groundwater flow pathways, through both consolidated and unconsolidated and semi- or unconfined layers, make for variations in vulnerability between and within cities. There is a growing and well-founded concern about urban groundwater pollution and the link between groundwater use trends and sanitation (cf. Foster 2008).

3.4 Groundwater and climate change

UN's Intergovernmental Panel on Climate Change (IPCC), the scientific body tasked with evaluating the risks of climate changes caused by human activities, has pointed to worrying gaps in knowledge, and in observational data, about climate change and water. Information on water-related impacts of climate change based on modelling of the hydrological cycle is especially inadequate with respect to groundwater, mainly due to the fact that knowledge of even current recharge is poor in both developed and developing countries. Moreover, there is considerable uncertainty in projected changes in the hydrological system – including precipitation projections. This arises from several factors: internal variability of the climate system; uncertainty in future greenhouse gas and aerosol emissions; the translation of these emissions into climate change by global climate models; and hydrological model uncertainty. The few studies of climate impacts on groundwater for various aquifers from which the IPCC could make its assumptions also showed very site-specific results (Kundzewicz, Mata et al. 2007; Bates, Kundzewicz et al. 2008).

Concerted efforts to increase the amount of data and make improved predictions are underway. Currently, however, there is not only limited coverage and duration of groundwater ob-

[24] Water may still be imported in bulk from private vendors, however, for instance to Indian households of the upper middle and upper classes. Leakages from their underground storage sumps might contribute substantial amounts to local aquifers.

servations but also continued difficulty in accessing available groundwater data (IAH Commission on Groundwater and Climate Change 2010).

Moreover, the difficulties associated with assessing uncertainties relate to the fact that water and climate change interact (cf. Taylor, Koussis et al. 2009). With a warming atmosphere, precipitation intensities are predicted to increase – but the spatial distribution remains highly uncertain for most of the world. The projection that precipitation is *increasing* applies to (according to all or nearly all models used) high latitudes and parts of the tropics. Meanwhile, in some sub-tropical and lower mid-latitude regions precipitation is predicted to *decrease* (according to all or nearly all models). Between these areas of fairly robust increase and decrease, even the signs of precipitation change were inconsistent across the models applied at the time of the IPCC's fourth assessment. For other aspects of the hydrological cycle, such as changes in evaporation, soil moisture and runoff which all have impacts on groundwater recharge, the relative spread in projections was similar to, or greater than, the changes in precipitation (Meehl, Stocker et al. 2007).

The main focus of the research on climate change and groundwater has been on quantifying the likely direct impacts of changing precipitation and temperature patterns by modelling recharge (Holman 2006). So far, limited and localised simulations and modelling suggest that climate change is "likely" to have a strong impact on saltwater intrusion into low-lying island aquifers (Bobba, Singh et al. 2000; Kundzewicz, Mata et al. 2007 Sec 3.4.2). Future research will hopefully show whether and to what extent such a scenario will also affect groundwater-dependent cities in the densely populated low-elevation coastal zone,[25] for instance Shanghai and Dhaka.

Empirical, albeit limited, observations from the humid tropics (in the Upper Nile Basin) suggest that a shift to more intensive rainfall may promote rather than restrict groundwater recharge in this region, although this may be offset by increased evapotranspiration associated with warmer atmospheres (Owor, Taylor et al. 2009; cf. Taylor, Miret-Gaspa et al. 2009). In estimations of how climate change may alter the long-term average recharge and thus renewable groundwater resources until the 2050s, all scenarios – irrespective of emission scenario and climate model used –"agree broadly" that groundwater recharge will increase in northern latitudes,[26] but will decrease strongly, by 30-70 per cent or even more, in some currently semi-arid zones. The latter areas include the Mediterranean, northeast Brazil and southwest Africa, but the uncertainties in regard to these estimations are still large (Döll 2009:5).

Apart from there being difficulties "clouding the prediction" of regional effects of future climate change on water resources, studies of these effects coupled with population growth on a regional and global scale suggest that population growth is likely to exert an impact on the world's water resources as great as or greater than global warming might (Vörösmarty, Green et al. 2000; Loaiciga 2009:10).

4 Case studies: Bangalore (India) and Lusaka (Zambia)

This paper examines the groundwater situation of two cities: Bangalore in India and Lusaka in Zambia. The countries share a history as colonies and parts of the British Empire; India until 1949 and Zambia until 1964. In both cities, the current infrastructure for water supply and sanitation was built after independence and both depend on a combination of water from

[25] General aspects of risk and vulnerability for low-elevation coastal zone cities due to climate change are treated by McGranahan, Balk, et al. (2007).
[26] The author notes that an unwanted rise of the groundwater table may cause infrastructure damage as well as soil and groundwater salinisation if the groundwater table is already close to the soil surface.

major rivers and groundwater, and face an overall shortage in supply. They are still undergoing rapid population growth and face significant budget shortfalls. They are both home to large numbers of low-income households living in sub-standard conditions – in what is generally referred to as slums in Bangalore and peri-urban areas (or settlements) in Lusaka. Planning and service delivery lag behind in these areas in particular.

However, the local contexts also differ in several respects. For a start, their hydrogeological conditions are very different. While India and Zambia are in large parts underlain by weathered, crystalline rock that does not yield much groundwater, Lusaka has a karstic topography, which renders very good aquifers. Another major difference is that Lusaka's water is more contaminated. As a result, in Bangalore policy implications relate mainly to water shortage, aquifer unpredictability and recharge measures, whereas in Lusaka, seasonal flooding, water quality and disease prevention measures are of relatively greater importance.

The case studies also serve to complement the statistical data from the DHS and JMP and thereby provide ground-truthing; they are a basis for analysing whether and how the situation in those cities compares to the national statistics of their respective countries.

4.1 Bangalore

India in South Asia covers over 3 million km^2 (Map 1). It is home to over 1.1 billion inhabitants and the annual demographic growth is almost 1.55 per cent. The country had an estimated GDP per capita at purchasing power parity of US$3,100 in 2009 (CIA 2009). At the last census (2001), over 70 per cent of India's population lived in villages, but the decadal growth was only 17.9 per cent in rural areas compared to 31.2 per cent in urban, indicating a slow but clear urbanisation trend. A quarter of the population is living below India's official poverty line (BPL), which equals around US$13 per month or less than half-a-dollar a day.[27] However, according to the international norm for 'extreme poverty' of one US dollar per day per capita, established by the World Bank and updated to US$1.25 for purchasing power parity terms (and US$2.50 for 'poverty'), the number of urban poor is higher than that estimated by using the domestic poverty line. In fact, the share of poor and extremely poor people in India would amount to about half of the population, if the World Bank goalpost was used.

With a 7,000km-long coast line (along the Bay of Bengal and the Arabian Sea), India's climate varies widely, from tropical monsoon in the south to temperate in the north. Likewise, the rainfall varies between 100 and 10,000 mm per year. India's utilisable freshwater resources are unevenly spread both seasonally and geographically. The northeast part of the country has large perennial rivers that tend to flood their valley regions at the peak of the monsoon, whereas the south of India is drier and with smaller river systems that run in relatively straight and shallow valleys. The once well-developed method of storing water in small reservoirs known as lakes and tanks (man-made ponds) are slowly being brought into use again. Rainwater harvesting is attracting renewed attention and even made mandatory in many cities. Nonetheless, it has been predicted that entire regions of the country face a bleak future in which water resources will be inadequate for large parts of the population.

[27] The definition of the BPL, and hence the estimation of the number of poor in India, is based on a daily calorie norm of 2,100 kcal (2,400 kcal for those living in rural areas but otherwise irrespective of age, sex or other relevant conditions). This is converted into the (state-specific) purchasing power of certain food items only, and households with purchasing power exceeding the amount of calories in a given basket of goods are thereby not defined as poor. In the state of Karnataka, the urban food basket is calculated to cost Rs.599.66 per capita per month whereas the rural poverty line is Rs.324.17, indicating a large difference in estimated costs depending on geographical location. The chosen mode of calculating the poverty line means that the possibility of paying for necessary living expenses such as rent, health care, clothing, education, etc. puts a person *above* the poverty line (unless he or she survives on very little energy). For more detailed criticism of India's poverty line, see Grönwall (2008); Bapat, M. (2009).

Growing towns and cities are likely to experience escalating water woes along with increasing competition between different sectors. The poor are in danger of losing out. Indian courts have interpreted drinking water to be a fundamental right under the Constitution (Art 21), but the court decisions expressing the authorities' obligations to provide water to every citizen are yet too few and too imprecise to clearly establish what this will mean in practice.

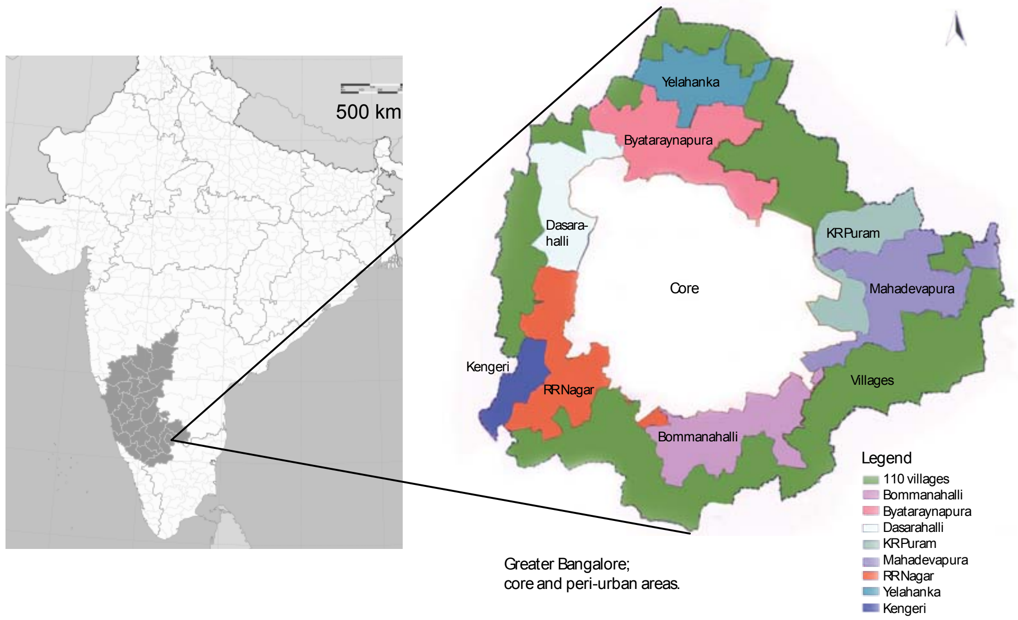
4.1.1 City profile

Bangalore, capital of the state of Karnataka in southern India, is home to approximately seven million inhabitants. It was once known as a quiet, lush town with an agreeable climate, but today it is known internationally as a hub for the IT sector (Sudhira, Ramachandra et al. 2007). Since the 1990s, the former 'Pensioners' Paradise' has come to attract well-educated software technicians from all over India and abroad, and the ensuing construction boom has in turn drawn migrants from poorer rural parts of Karnataka and neighbouring states. Since Karnataka is drought-prone and the agriculture mainly rain-fed, farmers and their families are also pushed to search for a better future in the city. The region normally has two distinctive rainy seasons: the southwest monsoon from June to September, followed by the northeast monsoon from October to November. Situated behind the tall mountain range called the Western Ghats, it sits in a rain shadow with a total precipitation of less than 1,000 mm yearly. Temperature-wise, Bangalore has perhaps the most even climate of the whole of India due to its high elevation (on average 920 m above mean sea level); temperatures typically range between 13-27°C during January, and 22-38°C in April and May.

The city of Bangalore has been in a state of transition for more than twenty years. It has grown, due both to natural population growth together with the immigration described above, and the expansion of the city's boundaries. In January 2007 it was decided to merge the then city of Bangalore with its eight surrounding municipalities and 110 'urbanised' villages to form Greater Bangalore, together covering 741 km^2. Thus, the city today consists of a core (often referred to as the 'BMP area') encircled by a vast peri-urban area (*see Figure 6*). The combined area of the villages is 224 km^2 but despite parts of the outskirts still having some rural characteristics, essentially no farming is taking place. It is difficult to estimate how many people became citizens of Bangalore with this stroke of the pen; during the last census in 2001 some 1.2 million people lived in the former municipalities and since these areas attract the majority of those migrating to Bangalore, the number of their inhabitants is probably substantially higher today. The city is witnessing urban sprawl, with low-income workers moving from one construction site to another, and gated communities as well as IT-business companies springing up. This has contributed greatly to the loss of farmland and of most of the previously well-protected green belt around the city; and the caused the tanks and natural lakes, once so important for the city's water supply and groundwater recharge, to diminish rapidly in number

Local ridges and valleys define how Bangalore is drained to the rivers Arkavathy, South Pennar (to the east), Shimsha (to the west) and North Pennar (to the north). The drainage pattern is also largely influenced by fracturing in the underlying rocks (Suresh 1999).

Figure 6: Map of India showing the location of Bangalore in the state of Karnataka



Source: India (cut), state of Karnataka from Wikipedia /Creative Commons.
Right: Greater Bangalore (not to scale), adapted from BBMP by Markku Pyykönen.

The city is administered by a municipal body known as the *Bruhat Bangalore Mahanagara Palike* (BBMP). The creation of Greater Bangalore meant considerable re-centralisation for the villages: overnight, the local, self-governance bodies had to hand over to one of India's largest corporations. The *Gram Panchayats* (village councils) that were previously in charge of and accountable for the water supply, subject to recommendations from the villagers, were replaced by one ward councillor per approximately 30,000 inhabitants.

Bangalore is a notable climber on the list of the world's largest city economies, projected to rank at number 55 by the year 2025. The estimated GDP in 2008 was US$69 billion by PPP (Hawksworth, Hoehn et al. 2009). Simultaneously, Bangalore today has 473 official slums, of which 204 are notified under the 1973 I&C Karnataka Slum Clearance Act (Karnataka Slum Clearance Board 2010). Title deeds are now being issued to residents of some of the older slums. However, the many slum dwellers' organisations working in the city hold that the actual number of small, unrecognised settlements is several times larger than the official number. Many of these areas have mushroomed in the outskirts of the city with the past decade's construction of new residential areas, countless office buildings and various infrastructure developments including a new airport. There is a large group of extremely poor people living in more or less temporary shelters (such as tents), some of whom are illegally squatting on private land, while others pay rent for occupying the land on which they have built their shelters and huts. Many families of day-wagers follow construction sites, and most slums and settlements are under a constant threat of demolition, although they may have existed in the same place for decades. The slum dwellers comprise somewhere between 20 and 35 per cent of Bangalore's total population, the uncertainty of this figure being due to official and scientific accounts' failure to include this large group of people living in temporary shelters.

4.1.2 Groundwater conditions

Large parts of India's aquifers are still unexploited and contain large reserves (Shah, Molden et al. 2001). However, the availability of groundwater varies greatly across the country. The Indo-Gangetic alluvium contains a productive and extensive aquifer system, and the coastal areas with their thick alluvium deposits have also formed high-yielding aquifers. However, deep tubewells have contributed to seawater intrusion in a number of locations. Two-thirds of India is characterized by hard, crystalline, consolidated formations, like granites-gneisses and other igneous and metamorphic rock assemblages, where the occurrence of groundwater is site-specific. There is a general scarcity of surface water sources in southern India (the peninsula), with river basins that are closing allowing little or no water to reach the sea at the mouth of the rivers. As a result, groundwater resources are subject to rapid exploitation. This is typically held as unsustainable, and in a growing number of regions the competent authorities have determined aquifer systems to be over-exploited. Declining yields are held to lead to increasing pumping costs and a competitive deepening of wells. Many parts of India also suffer from natural arsenic and fluoride occurrence and/or high levels of fertilisers, pesticides and sewage in the groundwater (Raju, Manasi et al. 2004; Chatterjee and Ram Purohit 2009).

The groundwater tables in India's cities are also generally thought to be falling due to water pumping. In New Delhi, roughly 50 per cent of the total water supply to end users comes from abstraction, which has reportedly caused the water table in the southern part to sink by tens of metres during recent decades (Maria 2006). Chennai, where about half of the water supplied by the public utility is groundwater, and where well fields are vital both for the public utility and private vendors, was the first Indian city to make rainwater harvesting and artificial recharge measures mandatory (*cf.* the Chennai Metropolitan Area Groundwater (Regulation) Amendment Act, 2002).

The rock formations in the Bangalore area consist mainly of gneiss and granitic gneisses that are thoroughly crystalline, extremely contorted, unfossiliferous, contrasted and faulted. Granites occur as plutonic intrusions, with coarse grained and porphyritic texture, and pegmatite veins. The gneisses are also often traversed by east-west and north-south trending dikes of dolerite. These particular characteristics have given rise to the name Peninsular Gneissic Complex (PGC), or sometimes Archaean complex.[28] In addition, laterite, a Pleistocene formation, exists in the high-altitude, northeast part of Bangalore (Wadia 1973; Radakrishna 2006).

Being of Archaean age and dating back more than 3,000 million years, the Indian peninsula has long been exposed to winds, humidity, monsoon rain, dry conditions, and so on. The crystalline rocks, though lacking primary porosity, have therefore undergone different degrees of secondary decomposition resulting in layers of weathered, semi-weathered and kaolinitised zones, as well as massive fractured rocks with fissures, cracks and joints (Department of Mines and Geology and Central Groundwater Board 2005). The highly weathered and porous rock formations are thought to extend to about 12 metres below ground level (mbgl), and at most 20mbgl in valleys, and this zone is generally clayey in the case of gneisses. At deeper levels there may be master joints that have been enlarged by dissolution and can extend to considerable depths, and faults may also occur. The fracture zones are generally hydraulically connected with the overlying weathered and saturated residuum (Department of Mines and Geology and Central Groundwater Board 2005; Radakrishna 2006).

Some 90 per cent of the soil coverage in the Bangalore region consists of red laterite and red, fine loamy and clayey soils, followed by lateritic soils (Suresh 1999). Its fine texture can result in low infiltration capacities and hence low groundwater recharge and high runoff due to the moderate-to-slow intrinsic impermeability, but where the soils are well-drained the recharge possibilities improves.

[28] A more detailed account can be found on Wikipedia; http://en.wikipedia.org/wiki/Peninsular_Gneiss (May 2010).

Research on the conditions of South India has led to questioning the established weathering model and process for hard, crystalline rock. Instead, a representative weathering profile for granites in the region shows the following: a thin layer of red soil (10-40 cm); a 1-3 m thick layer of sandy regolith, which is locally capped by a lateritic crust (more than 50 cm thick); a 10-15 metre thick layer of laminated saprolite (weathered rock); and fissured fresh granite that occupies the next 15-20 metres, where weathered granite and a few clayey minerals commonly partially fill up the fissures (Dewandel, Lachassagne et al. 2006). Both the soil and the fissured layer are thinner than in the established model, whereas the laminated layer is thicker. This is thought to result from a more recent weathering phase, a saprolitisation of the fissured layer (*ibid.*).

Generally, most of the productive aquifers are found in the fissured zone within 100 to 110mbgl, where there are sparse fissures in the bedrock (Suresh 1999). Nonetheless, fissures, fractures, fault zones and probably even master joints do also appear at a greater depth, thanks to the 3000 million years of multiphase weathering and erosion processes. A very large number of the public utility's deep tubewells are consequently drilled to depths of 200 metres and sometimes more than 300 metres in order to obtain a secure yield (BWSSB 2010). Likewise, many private wells are drilled down to the deep aquifers below 60 mbgl.

In a 2006 report, the Central Ground Water Board declared the groundwater resources of the Bangalore Urban District – 2,174 km^2 in extent, of which today's city of Bangalore covers 741 km^2 – to be over-exploited. This was based on an assessment of the abstractions for irrigation, domestic and industrial uses amounting to approximately 33,000 ha m/year and an estimated net annual groundwater availability of approximately 16,770 ha m/year (Central Ground Water Board 2008). The assessment therefore concluded that the area suffers from a huge overdraft, in which rapidly sinking groundwater levels and failing wells might be expected. However, this is a fairly coarse estimate of the entire region's groundwater development. It fails to take into account the added recharge of imported water and leaking pipes that takes place in the core city area at the very least, or the increase in rainwater harvesting. It also does not consider the high variability and unpredictability which generally characterise weathered and fractured crystalline bedrock.

Other groundwater measurements would seem to contradict the conclusions of this supply-and-demand balance. According to the data from the 22 measuring wells and 13 piezometers spread throughout the entire District, the post-monsoon depth to the water table was in general between 1.77mbgl and 12.02mbgl, showing a *rising* trend over the long term. The pre-monsoon water levels also showed a general *rise* in the Bangalore city area during the decade 1997- 2006[29], as well as in a few measuring wells during the post-monsoon period; though a falling trend was indicated in 13 wells, thus more than half. The general pre-monsoon depth of the water table ranged from two to less than 10mbgl, whereas a larger part of the District had water levels ranging from five to 10mbgl, and only small isolated patches in the north and northeast part of Bangalore suffered from a fluctuating water table, ranging between 10 and 20mbgl. The wells are monitored four times a year and the calculations of the overdraft of the groundwater resources are made on a watershed basis and appropriated for the three administrative units before the calculation of average numbers can be made (Central Ground Water Board 2008).

There are various explanations for the apparent contradiction between the well measurements in Bangalore and the assessment of the District's groundwater as over-developed. Aquifers in weathered crystalline will be unevenly distributed and have a highly varying degree of fault zones and inter-connectedness, possibly also master joints functioning as multi-aquifer systems. Some aquifers will be more prone to recharge from the overburden than others, and/or receive water from other aquifers to which they are well connected. This could

[29] A falling long-term trend was noted in the southern, rural part of the District (the Anekal *taluk*).

explain why there are wells at various locations that can be pumped for fairly large amounts of groundwater, while others are prone to depletion. During the 1990s, the yield from wells in the city ranged between 0.25 to 40m^3 per hour (Suresh 1999).

During fieldwork, the lead author of this paper came across private vendors who have been selling up to 12 m^3 of water a day from their wells for 15 years without seeing any noticeable drop in the water table. Generally, abstraction rates of less than 4 m^3 per hour indicate aquifers which are low-yielding, but possibly sustainable, with high transmissivity. The highest water table reported by some vendors was 42 metres (140 feet), but levels in the region of 100m, give or take 20 metres, were more common.

On the other hand, other vendors had experienced one well after the other drying up, and many people reported the wells by their houses or apartment blocks drying up or yielding barely any water, due to a falling water table. Some wells are affected mainly during the dry summer period, but many wells seem to have dried up permanently. Another group of people, notably in the peri-urban areas where there is no water supply from the Water Board (and hence little or no leakage from water mains), tell of futile attempts to tap groundwater conduits for new wells even at depths of 300 metres. Such households are forced to rely on private vendors bringing water in from other parts of the city.

Bangalore's underground drainage system covers most of the core city area but only a little more than half of the former municipalities. Although new sewerage pipes and channels are being laid with the help of World Bank funding, the extension of the system to the peri-urban areas is lagging behind. The sewerage system is undersized and the capacity of the six treatment plants is not sufficient; together, they have a planned capacity of about 700 million litres per day (MLD) by secondary treatment and only 70 MLD by tertiary treatment. No more than some 40 per cent of the core city is connected to any of these plants – remaining wastewater is either transported downstream to surface water bodies through open or semi-open drains that cross the city landscape, or else drains into the soil. A majority of the slum dwellers defecate by the open drains, or in fields, and so on. There are some 400 pay-per-use toilets in the city but they are generally considered filthy, badly maintained or too expensive by most of the poor. Some of the lakes and tanks in Bangalore now contain more sewage than freshwater, and all of this has produced a high level of contamination in the groundwater.

Samples from wells during 2003 and 2006 showed that the quality of Bangalore's groundwater is slightly sub-standard. The results found widespread and rising contamination, with traces of nitrate, iron, fluoride, pathogenic bacteria, and total dissolved solids to be above a desirable level, and sometimes above the permissible limit laid down by the Bureau of Indian Standards specification (IS 10500:1991) for drinking water. In 2003, levels of nitrate were found ranging up to 666 milligrams per litre (mg/l); the permissible limit is 50 mg/l. This level was exceeded in 35 per cent of samples. In 2006 the highest level found was 194 mg/l[30] (Department of Mines and Geology 2003; Department of Mines and Geology 2006).

Whereas the surface water distributed in Bangalore passes through a treatment plant on its way to the users, the groundwater – whether delivered by the public utility or by private vendors (see below) – is not treated. It is unclear to what extent its quality is tested, though some private vendors claim that they regularly send samples to laboratories. Outbreaks of cholera are rarely reported among the population and tend to be limited to small areas where sewage from leaking pipes has become mixed with surface water in the water supply pipes. Gastroenteritis is also only reported from time to time. Nevertheless, a health and hygiene

[30] The reason why the latter study showed remarkably lower levels of nitrate was not discussed but in 2006, only 34 samples were collected from the entire Bangalore Urban District, of which just a few in the city proper.

baseline survey conducted in one of Bangalore's slums in 2007 suggests that many of the poor children under five years of age suffer from diarrhoea (Byrd 2007 see sub-section 4.1.4). Unlike cholera, however, endemic diarrhoea is not a problem the authorities are notified of, or to which they seem obliged to respond. Inferior water quality is also only one of many transmission routes for diarrhoea.

4.1.3 Bangalore's water supply situation

Bangalore's transformation has resulted in a city that has outgrown itself many times, not least when it comes to supplying water to the city's new residents. Lacking a nearby perennial river, Bangalore used to depend on hundreds of lakes and man-made tanks for water supply and irrigation. Due to the demand for land, most of these water bodies have been converted into residential, commercial or other localities.

The public utility, the state-owned and semi-autonomous Bangalore Water Supply and Sanitation Board (BWSSB, or the Water Board) is charged with the general duty of managing the water supply and improving the existing supply of water. The Water Board was set up in the early 1960s, pressed for and financed by the World Bank, when a new water supply scheme was commissioned. In April 2009, 360,000 individual water connections to houses and apartments were registered (according to various representatives of the utility, in a personal communication). The households served are within the core city area, along with a few pockets in the former municipalities – residential areas for the employees of certain state companies that have long been connected to the water supply network. Some areas have also been supplied after infrastructure extensions carried out under the Greater Bangalore Water and Sanitation Project (see below). The 110 former villages added to the city in 2007 are situated outside the reach of the Water Board's reticulated network. Although some large IT companies and the new international airport, all situated in these former villages, have managed to get dedicated pipelines laid to their premises, this does not benefit any of those living nearby.

Bangalore is situated on a north-south trending ridge that divides the city between two river basins, and roughly only a third of the city is drained to the west by tributaries of the River Cauvery, the major water source for Bangalore. The raw water intake is about 100 kilometres away and the water is pumped against a head of some 500 metres; the cost of the electricity consumption equals more than half of the Water Board's budget. The river is shared with two downstream states and one Union territory and is therefore the object of a century-long dispute that, since 1990, has been handled by the Cauvery Water Disputes Tribunal. A final settlement, delivered in early 2007, was appealed against by all parties and has yet to be treated by the Tribunal as well as the Indian Supreme Court.[31] Meanwhile, a non-detailed agreement between the Ministry of Water Resources and the Government of Karnataka in 1997 allocates 19 thousand million m^3 (TMC), equalling 1,469 million litres daily (MLD) to the Bangalore Water Board from the Cauvery up till 2010, when a sharing agreement was supposed to have been long since settled by the Tribunal. It is unclear when – or in fact whether – the matter of water allocation will be finally decided on in this politically sensitive case.

Apart from River Cauvery, two reservoirs in the north-west, T.G. Halli and Hessarghatta, contribute with very small amounts of surface water to the distribution network. Both are on the verge of drying up because their catchment areas have been encroached upon as the city has grown outwards.

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[31] The Tribunal only recognised a third of Bangalore as being entitled to water from the Cauvery, as only that much of the city drains into the river, and suggested an allocation of 14.52 thousand million m^2 (TMC) per year to Bangalore for its drinking water needs.

Under the above-mentioned agreement between the Ministry of Water Resources and the Karnataka Government, the Water Board is allowed to pump up to 1,469 MLD from the Cauvery but is currently only drawing a maximum of 860 MLD. The demand is much higher, but the limitation lies in the diameter of the pipes together with insufficient booster pump capacity (and, in practice, daily power cuts). There are also large losses of water – possibly as large as 40 per cent of the raw water pumped from the river – that goes unaccounted for due to old and rusty pipes, illegal takings, and unregistered or badly metered connections.

The Board in effect takes a demand-side management approach to the water supply: it limits the distribution of water to just a few hours daily or, more commonly, every other day. Many customers with individual connections, as well as slum dwellers relying on standposts,[32] report that water is delivered only once in three days. Two groups appear to be less affected by the supply restrictions: it was discovered during fieldwork that those living along a water supply pipe seem better off, as are those living in streets and/or gated communities where influential VIPs live. Elevated areas, on the other hand, suffer from particularly low pressure, and it was found that slums connected to the network may be supplied with small amounts of water only once a fortnight.

Extensions of the water supply scheme are underway with a further increase of the trunk mains and feeder lines' capacity to ensure a regular supply; the last planned phase is to augment the supply with another 510 MLD by 2012. To supply the whole of the city's population with surface water from its network is a major challenge for the Board and it plans to provide water to those eventually connected for a few hours on every second or third day only.

Groundwater as a source for drinking water and other purposes

It is not possible to estimate with any certainty how large a proportion of Bangalore's population use groundwater; that is, how many depend directly and/or indirectly on water from wells. These uncertainties are compounded by the fact that a large group relies on groundwater as the main – and only – source, whereas others use it to supplement supply from the Water Board, either throughout the year or mainly during the dry summer months when the utility's distribution is sometimes diminished or disrupted for many days in a row. Yet another large group – the poor people who take water from public standposts – is provided with groundwater from some standposts and surface water from others.

The limits to the piped network system and its future extensions leave maybe half of today's population outside its reach. Those living in the peri-urban areas depend on, and for the foreseeable future will continue to depend on, their own wells or shared ones, or on private vendors selling their surplus groundwater. However, the proportion of citizens relying solely on groundwater may decrease once the extensions of the utility's distribution network are finished in around 2012.

In what used to be municipal areas surrounding the core city of Bangalore as well as in many of the former villages at the fringe, a network system for distribution of groundwater was in place, serving individual connections, shared metered tap points, and standposts. The Water Board resumed responsibility for these systems after Greater Bangalore came into being. It has since added a large number of new tubewells and standposts, some of which have dried up over the years. Therefore, in at least parts of these areas, groundwater and not surface water is supplied via the reticulated system. The way in which some of those living outside the core of the city depend indirectly on groundwater is somewhat difficult to measure, but most water thus distributed is metered and charged for.

[32] 'Public standpost' is the term commonly used in the Indian context for a standpipe.

The Water Board also utilises groundwater to augment the ordinary surface water supply. Some of this groundwater is distributed by tanker trucks to areas that – due to bad pressure, leaking pipes or other infrastructure-related problems – are temporarily not served. In total, the Board has around 10,500 wells spread all over the city. Of those, more than 3,000 bore-wells equipped with hand pumps and close to 7,000 with submersible, electric pumps have been identified by location (BWSSB 2010). New wells are regularly added to the list. As of April 2009, representatives of the Board reported a failure rate of 10-15 per cent for the new wells being drilled, which again suggests that the reliability of aquifers is unpredictable and varies throughout the Greater Bangalore area.

The Board does not collect data of the water table in its wells and hence cannot indicate whether it is decreasing, and if so, how rapidly. Measuring data are apparently not collected on, for instance, the total volumes abstracted from the Board's wells; in general, knowledge of the relevant groundwater conditions seems insufficient.

A 2004 study estimated that the number of private tubewells within the Bangalore Urban District had grown from 5,000 to around 400,000 in the previous three decades, indicating a rapidly increased dependence on groundwater. It was estimated that 750 MLD of groundwater was being extracted every day (Raju, Manasi et al. 2004). The Board keeps a record of costumers having a private well in order to charge them Rs.50 (Indian Rupees; Rs.50:US$1) monthly for the 'underground drainage connection' to which wastewater is discharged. At the end of January 2010, the number of such wells was 105,500 and during the year up to that day, the number grew by between 750 and 2,700 new wells a month (Ritesh 2010). However, the Water Board does not have customers in the former villages, and so many thousands of wells there go unregistered. No other authority is in charge of registering private wells and the total number is therefore unknown. What is clear is that new borewells[33] are drilled on a daily basis, by domestic and commercial users, as well as by the public utility.

During the early 2000s, city planners and decision-makers took measures to extend the piped water supply network to the municipalities which then lay outside the city boundaries. This caused severe depletion of the water table in these areas – or so the Central Ground Water Board concluded – and the Greater Bangalore Water and Sanitation Project (GBWASP) was formally launched at the end of 2003. It aimed to extend the infrastructure network, distributing water from River Cauvery, in order to decrease direct and indirect dependence on groundwater. However, much of both planning and execution took place before the merger between the core city with these municipalities and the 110 villages outside them, and the Water Board's jurisdiction, as well as that of the City Corporation is now greater in extent. Nevertheless, further extensions of the piped system, distributing surface water, are still not planned for the villages. This is in spite of their rapid population growth and increasing commercial activities.

Therefore, there is still essentially 100 per cent reliance on groundwater in the former villages that are not part of the Greater Bangalore Water and Sanitation Project; and the same applies in many areas coming under the Project, because the extensions of the network are only being completed slowly. There is insufficient surface water available now, as well as for the future, because the demand projections were severely underestimated.

The streets of Bangalore are full of tanker trucks: lorries transporting between 4,000 and 8,000 litres of groundwater each. A minority of these tankers belong to the Water Board. The rest are private vendors: land-owners acting as individual entrepreneurs and selling water in bulk, sometimes using one or more middlemen. The buyers pay between Rs.80 and 450 per tanker, depending on the season, whether the customer is a regular, the distance, and the part of town. Some vendors sell per pot or bucket to the poor who lack storage capacity,

[33] A borewell is the term commonly used in the Indian context for borehole.

normally charging Rs.1-2 for containers of about 13 litres, providing an important but very expensive service to poor households. All in all, these groundwater vendors constitute a life-line for very many in Bangalore, rich as well as poor, and their importance is steadily increasing

Public standposts and the pro-poor policy

Many of the Water Board's wells function as public standposts but there is little data on them. In 2009, representatives held that there were about 2,500 standposts with motorised pumps and a 'good yield' in the core city area, but also an unknown number of hand-pumped wells, of which some may have dried up. The number of standposts in the former municipalities and villages in the peri-urban area of Greater Bangalore seemed unknown at the time. There are also a large number of standposts that are connected to the reticulated water supply system and deliver surface water, but the pressure and hence amount of water available from these varies greatly, depending on their location in the city.

The water from public standposts is normally distributed by way of a 'water man' who is in charge of opening and closing the valves during the set time slots and days of the week. Nonetheless, the supply is often irregular and the 'water man' may demand a bribe from the users to do his job. During election times (both to the State Assemblies and to the federal *Lok Sabha*) many politicians become patrons of slum dwellers in an attempt to secure their votes (cf. Schenk 2001), and they either exert pressure on the Water Board to open stand-posts or personally arrange for wells to be drilled for the public. At times and in certain areas free water is also supplied by tanker by the Water Board.

The free delivery of water is a matter regulated in the Bangalore Water Supply and Sewerage Act, 1964, Sec 38 (1), albeit not in a detailed way. It is left unclear who is responsible for meeting the costs of this service. After the City Corporation decided in 2002 to stop funding free water delivery via the Water Board, the standposts were gradually closed.

Box 5: Public standposts in Bangalore

The closing down of public standposts that began sometime around 2003 became part of a drive to provide individual connections to the water network in slum households– but in practice, it was also to force them to take up metered connections. At this point in time, the Japanese Investment Bank was pressing the Water Board to decrease the volume of unaccounted-for (non-revenue water) lost between the raw-water intake from River Cauvery and the paying customers. This volume was calculated to be around 40 per cent. Although it was unclear how much depended on illegal and/or uncharged water distribution, or leakages and similar technical losses, closing down standposts was seen as an easy way of dealing with part of the problem.

Another influential role was played by the Australian donor AusAID, who wanted to implement a Water Supply and Environmental Sanitation Masterplan Project in Bangalore between 2000 and 2002. AusAID stressed the need for a Social Development Unit at the Water Board and to formulate a pro-poor policy. The idea of this project was that the Unit would connect three slums as a pilot, and that the lessons learnt would be mainstreamed into the ordinary approach and work of the Board. However, only about 25 slums came to benefit to any extent before the Unit was in effect closed down at the beginning of 2007 (Connors 2005; Grönwall 2008).

Thanks in part to the AusAID Project, Bangalore's slum dwellers can now become customers with the Water Board without a title deed – those, that is, who live in established settlements with *kutcha* houses[34]. In addition, there is now official acknowledgement that most slum dwellers cannot pay the connection fee, inspection charges, road cutting fee, sanitary charges, deposit, and the cost of a meter, which are all normally charged by the Water Board to a new consumer. The monthly tariff for the first $8m^3$ of water is, moreover, only Rs. 48 (US$1.08), a sum affordable to a large proportion of slum dwellers who may otherwise have had to pay much more to private vendors. The tariff plan is progressive and heavily subsidised. Tariff hikes announced to be introduced after the monsoon in 2010 will leave minimum users even better off: Rs.36 monthly for the first $10\ m^3$. Because of the now informal, yet institutionalised, pro-poor policy, some 45,000 people living in slums have been given the opportunity to connect to the water network by paying only around. Rs.500 (US$11.26) for the meter – and they can even share a connection with a neighbour if that is preferred. Moreover, the Board claims that some 22,000 illegal connections are now seen as 'allowed' (P.B. Ramamurthy and T. Venkatraju, personal communication, April 21, 2009).

However, in spite of this unofficial strategy of the Water Board's, the vast majority of slum dwellings thus connected can only afford a rudimentary tap at the outside of the house; and in slums visited during 2009 where connections had been installed, the water supply was only once or twice a fortnight, and the pressure then often so low that the water only came out as a trickle. The residents of these areas therefore continued to rely on standposts and private vendors – yet at the same time they are supposed to pay a monthly tariff to the Water Board. It is unclear how many slums and how many households now have reliable connections.

Box 6: The Greater Bangalore Water and Sanitation Project (GBWASP)

The GBWAS Project was based on the concept that every household was to pay a special capital contribution as well as additional charges to cover 20 per cent of the Water Board's costs, and initially no exception was made for poor or even slum dwellers: in a Government Order, the capital contribution was set at Rs. 8500 per domestic household.

After massive protests, including the Campaign Against Water Privatisation, the charge was recalculated based on property size, and differentiated for various categories of users (Government of Karnataka 2003; Government of Karnataka 2004). A committee was set up to handle issues associated with the urban poor following pressure from foreign donors on the Water Board to further its pro-poor policy, but only in 2005 was it recognised that a very large number of financially weak households were living in sites smaller than previously assumed, resulting in a new Government Order. This time, only sites measuring up to 600 ft^2 (55.74 m^2) were to be charged Rs.2,500 (Government of Karnataka 2005). Slum dwellers were made exempt in time, and in the pockets where water is now distributed, they should be able to opt for getting water supplied after having a meter installed and paying the set tariff thereafter.

4.1.4 Strategies for water access in Bangalore

Indian government authorities are aware, at national as well as state level, that groundwater is being drawn at excessive rates in many parts of the country; due to the hard rock conditions, pumping takes place from deep, often confined aquifers, at a rate not matched by recharge. The Central Ground Water Authority was constituted in 2007 with the remit to assess, regulate and control the development and management of India's groundwater resources. The main task has been to list 839 'over-exploited' aquifers and 226 'critical as-

[34] A *kutcha* house is a building with walls and/or roof made of material such as un-burnt bricks, bamboos, mud, grass, reeds, thatch, loosely packed stones, etc.

sessment units' throughout the entire country, and to issue prohibitions against constructing new groundwater structures in these areas without a permit.

The law regulating groundwater in India is a legacy of English rule, giving the property rights to water which percolates underground to the owner of the land above. Landowners are hence entitled to draw unlimited volumes of water from their own wells without prior permission or registration, regardless of the purpose (for details, cf. Grönwall 2008). In order to reform this situation, the union Ministry of Water Resources has drafted groundwater 'Model Bills', the latest in 2005. Their purpose is to form a template for state governments, who have the constitutional power to issue legislation in this area. A number of states have drawn up their own regulations, on rainwater harvesting; notifications of over-exploited areas; requirements for application for permits prior to digging and drilling new wells; registration of existing wells; and of all existing water 'users', to name a few. The Karnataka Ground Water (Regulation and Control of Development and Management) Bill, the latest of which was drafted in 2009,[35] follows this line. The enforcement of such rules pose a major problem, though, as shown by the example of the Karnataka Groundwater (Regulation for Protection of Sources of Drinking Water) Act, 1999. In force from 2003, it regulates the distance between a new and existing well that functions as a public drinking water source – thus those belonging to the Water Board – but it is largely ignored, at least in the city of Bangalore (V. Srikantaiah, personal communication, April 20, 2009).[36]

Rainwater harvesting (RWH) has been made mandatory (Karnataka Building Bye-laws 2003, No 32, Schedule XII), requiring that owners of new buildings with a plinth area exceeding 100 m^2 and built on a site measuring not less than $200m^2$ provide for water storage or recharging into the ground. Previously, the rules were mainly enforced through the Bangalore Water Board, who refused to connect new water service applicants who did not have the required RWH structures. An amendment of the Bangalore Water Supply and Sewerage Act, 1964 was, however, decided in August 2009 – to the effect that its customers are forced to install roof-top RWH and related underground storage.[37] Many components and challenges remain, but steps are being taken in the right direction to contribute to recharging the vulnerable aquifers of the region.

Not being situated by the coast or a major river, Bangalore has never been self-sufficient for water; ponds, lakes and rivers situated at an ever-increasing distance have always constituted the main sources. The Water Board is now building a new recycling water treatment plant. It proposes to treat 135 MLD of wastewater by ultra filtration and later blend it with the water of the T.G. Halli reservoir or any other surface water body from which raw water is taken. Moreover, re-use of water is encouraged at household level and was even made mandatory in some new apartment buildings for a short period: the Pollution Control Board required installation of basement sewage treatment plants (known as 'mini-STPs') before granting building permits for larger housing complexes, mostly gated communities in the peri-

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[35] At the time of writing, this Bill was put up at the web page of the Department of Mines and Geology (2010), retrieved 13 October 2010, mines.kar.nic.in/ but no further information was available.

[36] The Central Ground Water Board duly 'notified' the Bangalore Urban District in 2006, and registration of all groundwater abstraction structures with the competent authority (the Deputy Commissioner) is therefore mandatory now. New wells for commercial purposes need permission under the Act but the implementation is decided on a case-by-case basis and often depends on various political considerations, as shown by the appointment of a new chairman for the Karnataka Pollution Control Board during 2009, to replace one seen as too law-abiding.

[37] The rules apply to structures on buildings with a 'sital area' of $\geq 223\ m^2$ (2,400 ft^2). This equals a 60 x 40 feet plot (222 m^2). Failure to provide RWH structures on buildings may lead to the Board intervening to recover the cost from the owner or occupier, or even discontinue water deliveries. Some 54,000 buildings constructed during a nine-month period have been identified to come under the purview of the Act, BWSSB (2009), retrieved 1 November 2010, www.bwssb.org/pdf%20files/RWH%20regulations.pdf.

urban areas. After treatment of the wastewater from around 300 to 600 households in such decentralised, closed systems, the water was to be re-used for flushing toilets, washing cars and in the gardens. The actual outcome of this requirement varied, and the initiative does not seem to have been taken further after 2009 due to lack of political will.

Since the deliveries from the Water Board are irregular in almost all connected areas, large groups have to take to alternative strategies in meeting their daily needs. Ordinarily, customers are required to install an underground sump as a storage receptacle, as well as electric pumps with which to raise the water to a second receptacle situated on the roof of the top storey. Households rely on these private contrivances to store water, and on gravity to transport water from the uppermost point of the building during the frequent power cuts.

Meanwhile, poor people living in *kutcha* houses and in slums lack these storage systems, and even the space to store large amounts of water, typically using pots instead. The water in these may be sufficient to last a couple of days but rarely in enough quantities to maintain even a minimal level of hygiene and well-being.

Moreover, during fieldwork it was found that very few of Bangalore's slum dwellers treat their drinking water before consumption; most claim that there "is no need to". This is regardless of whether they take water from public standposts (which may distribute either treated surface water or local groundwater), use other types of shared wells, or rely on groundwater from private vendors. In contrast, a majority of those belonging to the middle and upper classes treat their water at home or buy bottled water for drinking. The most common methods used are candle filters, reverse osmosis devices and UV treatment, or a combination of those. Traditional filtering with a (usually single-layered) piece of cloth is practiced by some, but boiling is the preferred method among the poor. However, for the poorest households fuel is often too expensive and firewood too difficult to find. Instead, the girls and women in charge of handling water in the household rely on the look, smell and taste of the water to judge its quality. Since they often have to take water from more than one location, they also rely on their experience and on local beliefs about the quality of water from different sources.

Box 7: Water, health and hygiene in Bangalore

From an in-depth case study of a slum area in eastern Bangalore made for the NGO Water and Sanitation for Urban Poor, it was found that 77 per cent of the children less than five years old were affected by diarrhoea, and that intestinal worms affected more than 80 per cent of the residents. People's awareness of the need to treat water to remove harmful pathogens before consuming it was found to be very low. If the water was boiled – for children or during times of illness – it was because of doctors' orders to drink "hot" water in these cases (Byrd 2007:58). As in other similar studies from Bangalore (Grönwall 2008), the respondents held that they did not like the taste of water that had been boiled.

The cost of kerosene and/or difficulty of collecting firewood was a contributing factor. The perceptions of the cause-effect relationship between health, hygiene, water-handling and sanitation practices were generally ill-conceived among the poorly educated inhabitants of this slum. For instance, few washed their hands regularly and even fewer used soap. The drinking water was taken from (and paid for at) a private well to which they had to walk 150m, because the quality of the water from the public standposts within their area – including an open, abandoned well – was seen as inferior due to its salty taste.

Cont over

What little water could be obtained from the wells which these standposts constituted was found to have a very high nitrate content, whereas the water from the private well had a very high pathogenic bacteria content. The study concluded that although behavioural changes were needed at a household level such as improved hand hygiene and the use of existing latrines, interventions by the NGO would not suffice as long as the available water was contaminated (Byrd 2007).

Many poor households, and especially the large group of slum dwellers in Bangalore, have been subject to at least two different institutional policies regarding access to water in the last decade. Initially the policy was to close down public standposts in an effort to compel households, irrespective of income, to take up water supply connections. Subsequently, most public standposts were re-opened and many new ones added, as gradually the policy of forcing slum dwellers to become paying Water Board consumers was dropped in favour of the unofficial pro-poor policy, according to which connections can be taken up for the cost for the meter only.

The critical components of the AusAID Project and the GBWASP were implemented in the firm belief in that all poor people had a willingness – and ability – to pay for water services in line with the regular tariff scheme (the goal of conserving water through demand management seem to have been secondary). In 2009, the new chairman of the Water Board admitted that the poorest segment of the population was not likely to be able to afford the many different fees charged for an individual household connection, and that the Board therefore had a responsibility to make sure they were provided with water for free. Nevertheless, the poor people may not be able to rely on this new rights-based approach for long; instead, they risk being subject to financial and other water supply-related decisions that can change with the political colour of the state government.

4.2 Lusaka

Zambia is situated in southern Africa, landlocked between the Democratic Republic of the Congo, Angola, Namibia, Botswana, Zimbabwe, Mozambique, Malawi, and Tanzania, with a total land area of around 750,000km^2 (Figure 7). It has a projected population of close to 13 million inhabitants and the population growth rate is about 2.9 per cent yearly (Central Statistics Office 2009). Zambia is one of the most urbanised countries in southern Africa: between 35 and 40 per cent of the population live in urban areas, with an urbanisation rate estimated at 2.3 per cent annually between 2005 and 2010. The country suffers from high levels of poverty, including extreme poverty, and inequality, with an estimated GDP per capita at purchasing power parity of US$1500 in 2009. Excess mortality due to AIDS has reduced life expectancy to just 39 years, and the population's median age is 17 years. One in seven adults carries the HIV virus, and HIV prevalence is more than twice as high in urban areas than rural (ZDHS 2007).

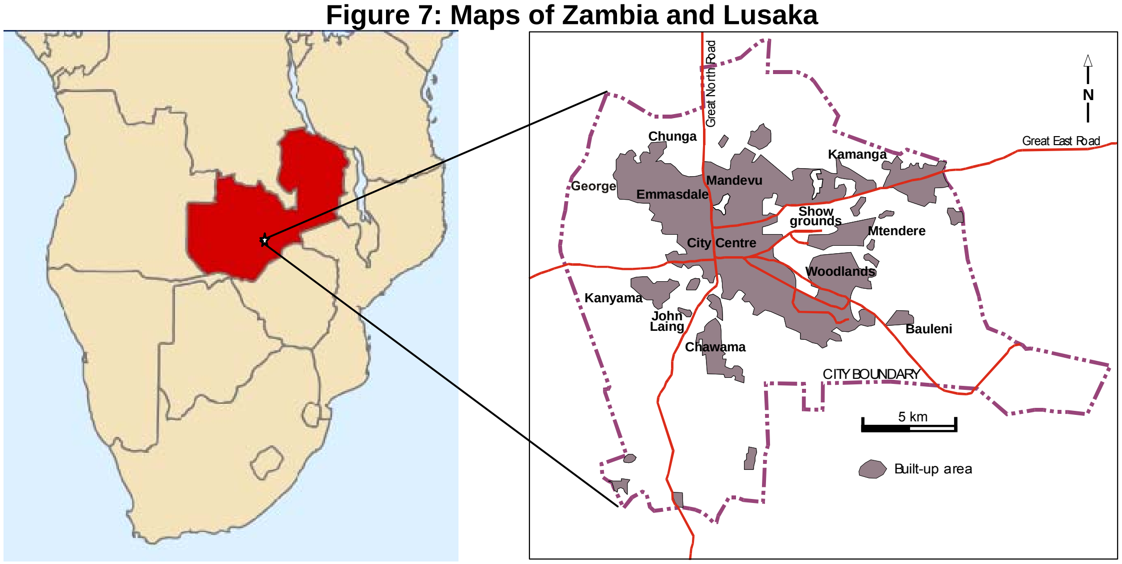
The landlocked terrain of Zambia consists mainly of a high plateau with some mountains and hills. The elevation varies from greater than 2300m in the Mafinga Hills on the northeast national border, down to 329m in the valley of the Zambezi River. The climate is tropical with variations depending on altitude. Annual rainfall averages 1010 mm, ranging between 750 and 1400 mm, and increases progressively from south to north. A distinct rainy season occurs from October to April. Average daily temperatures are around 18 to 20°C during the cool dry season (from May to August) and 35°C during the hot dry season (from September to November).

Zambia is endowed with good water resources; this is thanks, amongst other things, to the four main rivers, tributaries of the transboundary Zambezi River. The basin of the Zambezi covers around three-quarters of the country. Only smaller rivers tend to run dry seasonally.

4.2.1 City profile

Lusaka, the capital of Zambia, is situated on the central African plateau at about 1300m above sea level. It had an estimated population of 1.7 million inhabitants in 2009 (Central Statistics Office 2009) and is growing mainly due to immigration from the rest of the country, but also because of high internal population growth. The city was designed during colonial times for a population of 500,000 in an area of only 2.6 km^2; today it comprises 375 km^2. As for city planning, the last approved master plan came into force in 1978. Illegal site development, quarrying, and so on are common in the city (Lusaka City Council and Environmental Council of Zambia 2008).

Figure 7: Maps of Zambia and Lusaka



Sources: Zambia (from Wikipedia /Creative Commons). Right: Lusaka (from Nkhuwa 2003b).

The city has an average annual rainfall of 803mm and the runoff drains into several different watersheds: the Ngwerere and Chalimbana streams drain most of the northeast of the city into the Chongwe River (a tributary to the Zambezi River); and areas in the south and the northwest of the city are drained by the Chunga stream into the Kafue River, itself a tributary of the Zambezi River (Lusaka City Council and Environmental Council of Zambia 2008). The few perennial streams in the region are characterised by low flow especially during the dry season (Mpamba, Nkhuwa et al. 2008).

The vast majority of the population in the capital of Zambia – up to 70 per cent – lives in any of the city's 35 to 40 settlements or 'compounds', some of which are formal, with others classified as informal. These 'peri-urban areas' are officially classified in different groups, one of which is 'low-income areas'. These are residential areas which were once planned, but where densification later occurred, and water supply network maintenance has lagged behind. There are also squatter-type settlements that have not yet been legally recognised. Some former squatter settlements are declared as 'Improvement Areas' under the Housing (Statutory and Improvement Area) Act (Cap 194). Land tenure in all but the squatter areas is secured through the acquisition of licences that grant rights of occupancy for a 30-year period and are renewable. It is not unusual for squatter settlements to be demolished if they are situated illegally on private land (IUCN, Sida et al. 2004; DTF 2005; UN-HABITAT 2007).

These low-income settlements are located predominantly to the north, northwest, and south of Lusaka's central business district and formal residential areas. The dwellings are predominantly made of concrete block walls with corrugated iron or asbestos sheet roofs and a large number of them are equipped with backyards which can often fit a well (see below). Many areas are prone to flooding during the rainy season. The areas are all densely populated and lack well-functioning primary services such as water and electricity supply, sewerage systems and solid waste collection.

The Lusaka City Council, the Zambian capital's administrative body, holds that overcrowding, spontaneous constructions and lack of financial resources all make it difficult to provide services such as proper roads, street lighting, sanitation and drainage systems. These difficulties are compounded by the incapacity of the Local Authority to provide services, especially in squatter areas with unregistered households, from which little or no revenue is raised (Lusaka City Council and Environmental Council of Zambia 2008). The City Council has even declared that as long as residents who live in settlements on City Council land do not pay their accumulated 'ground rates', it will be unable to provide water facilities and other services.

Over the years, a number of donor agencies and NGOs have contributed both to research and/or building local solutions to the water supply deficiencies in Lusaka's various settlements. Among these are the Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ), which began work in a settlement 1980, the World Bank, the Japan International Cooperation Agency (JICA) and CARE. All these organisations have been instrumental in pressing for improvements together with the residents concerned, and those mentioned are all still involved in collaborative projects in Lusaka.

4.2.2 Groundwater conditions

The dominant rock type in Zambia – as in large parts of the African continent – is the low-yielding crystalline basement rock. However, residents of the Lusaka Plateau are better off. The city's rock formations consist of limestone/dolomitic marble in the southern half of the city and strongly folded and faulted schist and quartzite in the north, including the part of the city where the formal residential areas occur. Relatively small amounts of groundwater are abstracted from carbonates sequences in the schist aquifers, but the aquifers here tend to be uneven. The high-yielding limestone/marble, on the other hand, can be found to depths of 120 metres below the surface and due to carbonate dissolution (often extreme differential dissolution), karst topography has developed in the area. The Lusaka dolomite holds an integrated system of conduits, caves and subterranean channels and therefore constitutes the city's major aquifer, from which substantial volumes of groundwater is drawn. The trend of groundwater flow in the channels is south-east to north-west.

The water table is in some places situated at extremely shallow depths, ranging from 0.5 to 30 metres below the surface, but it is more typically at six to 15m. It has been observed to decline in some places, raising fears of over-exploitation (Nkhuwa 2003a; De Waele, Nyambe et al. 2004; Münch and Mayumbelo 2007; Mpamba, Nkhuwa et al. 2008). Observations from some boreholes indicate a long-term decreasing trend that risks leaving shallow wells dry during the dry season (JICA 2009), but that the water table is mainly decreasing in the formal residential areas where boreholes are drilled in schist and quartzite rock. By contrast, it seems that in several parts of the city the groundwater abstractions contribute to mitigate the yearly risks of flooding during the rainy season. Without constant pumping of water from the aquifers, continuous recharge would not be possible.

Karstification has resulted in an almost complete lack of surface drainage potential in Lusaka; rainwater drains easily into the fissures to reach the aquifers instead of forming runoff to surface streams. In addition, the presence of such a well-developed system of underground conduits, channels and cavities reduces and/or completely eliminates the attenuation of pollutants through natural filtration that would otherwise occur (Nkhuwa 2006). These two factors contribute to large groundwater volumes in the carbonate dolomites, but also to contamination occurring in the entire aquifer. With less opportunity for contaminants to be filtered out, groundwater in karst areas is essentially as easily polluted as water in a surface stream.

The thin soil layers of the Lusaka plateau consist predominantly of shallow Leptosol that covers especially the schist, and Phaeozems that covers especially the dolomite. The soil is normally coarse with low clay content. The conditions are unconfined and the topography generally flat. These features usually result in a decreased contact time for filtering of the water (a vital ecosystem service) and rapid recharge of the aquifers. These characteristics of the unconsolidated alluvium (soil layer) may increase the contamination problems.

Shallow wells, hand-dug from the soil and in caves, are common in the slum areas of Lusaka, and the water is hand-drawn from the vast majority of them. Many of the wells are of the open type, lacking brick or stone walls at the sides, whereas others have a lining and a covered construction. These wells need typically be only a few metres deep since the water table is generally extremely shallow in Lusaka.

The high water table also means that the yield from deep boreholes is high, although attempts to hit an aquifer while drilling for new boreholes may have less than a 50 per cent success rate in the karst (JICA 2009). A hydrogeologist with the Ministry of Energy and Water Development in Lusaka attributes borehole failure (in the schist and quartzite) to a lack of competent and experienced drilling supervision (H.N. Mpamba, personal communication, January 29, 2010). The water table has been found to fluctuate annually, with a gradual decrease during the dry season (JICA 2009).

In terms of the quality of Lusaka's groundwater, limited data suggest that the carbonate dolomite rock yields groundwater with low dissolved arsenic concentrations. Fluoride values above WHO's guideline value of 1.5 mg/l have been found in groundwater from parts of Lusaka (British Geological Survey 2001). Mercury levels have been detected, also exceeding WHO's previous guideline value of 1µg/l. Cemeteries and leakages from the commercial and industrial sectors also contribute to deterioration of water quality.

The main problem, though, is contamination of the water with faecal material, risking faecal-oral transmitted diseases. The groundwater taken from a dug, shallow well would normally originate from local precipitation that seeps more or less rapidly through the soil cover. However, Lusaka's shallow aquifers are also recharged from other sources including wastewater (or 'greywater') from dishwashing, laundry, bathing and pit latrines (at ground level as well as raised ones) percolating into the aquifers. Human pathogens in the groundwater are linked to the presence of pit latrines and open defecation close to wells. Leaks from septic tanks and sewers can also contaminate groundwater, though especially in informal settlements it is the absence of such infrastructure that is the greater problem. Furthermore, ammonia and nitrate-nitrogen may constitute quality issues. The lack of solid waste collection and the presence of some small gardens for food production contribute to the quality problems (Nkhuwa 2003a; De Waele, Nyambe et al. 2004; Münch and Mayumbelo 2007; JICA 2009).

The lack of a proper sewerage system outside the formal residential areas means that the majority of the population have to make their own sanitation facilities. The on-site pit latrines are normally simple constructions, four to six metres deep. Dried-up shallow wells are also often converted into pit latrines during the dry season (Münch and Mayumbelo 2007). Using the JMP terminology, some of the pit latrines common in Lusaka's low-income settlements are 'improved' (raised above the ground so as to prevent surface water entering the pit, equipped with squatting slab, and so on) but a great number of latrines are either more rudimentary holes in the ground, or constitute shared facilities.

The non-raised pit latrines in particular tend to get flooded during the rainy season and high concentrations of pathogens infiltrate the aquifers, contaminating the groundwater. Moreover, most of the latrines are unlined and thus constructed without waterproofing. Although this is not a criterion for considering the latrine ‘improved‘, the result is that any liquid from the excreta can rapidly find its way underground (Münch and Mayumbelo 2007). Since the latrines are typically situated close to wells, this contributes to frequent outbreaks of cholera, dysentery and other water-borne diseases, at least during the rainy season. A study of three low-income settlements in Lusaka found that the problem of dysentery and other diarrhoea was endemic in all of them (*ibid.*). Adequate quantities of water and good hygiene p, including hand-washing, are likely to be especially important when diarrhoea is endemic. Contaminated drinking water is also a risk and as indicated in Box 8 below, has been implicated in Lusaka’s cholera outbreaks. This is to be expected given the important role that faecal water contamination plays in the spread of cholera.

Box 8: Cholera outbreaks in Lusaka

From an in-depth study of a cholera outbreak in one of Lusaka’s low-income settlements (Sasaki, Suzuki et al. 2008), the age distribution of cholera patients and a GIS-plotted map showed that the leading age group was children below the age of five, although in the first stage of the outbreak almost all patients were adults. It was assumed that adults were transmitting the pathogen to young children by the interfamilial spread of infection through family contacts, and that this was accelerated under non-hygienic conditions. This suggests that good personal hygiene among adults should be promoted. On the other hand, a regression analysis found that the statistically significant risk factors for cholera were the lack of a latrine, and drinking water from open shallow wells. In a case-control study these factors were again found to be significant, along with not chlorinating the drinking water and not washing hands with soap and water. It was concluded that improving hygiene conditions must be a high priority for the long-term prevention of cholera. This would include the construction and maintenance of sewage disposal facilities, and more strategically planned drainage systems, especially to prevent flooding during the rainy season. Therefore, installing a sufficient number of toilets and facilities for excreta disposal would be the most suitable measure (ibid.; Sasaki, Suzuki et al. 2009).

4.2.3 Lusaka’s water supply situation

Prior to the 1990s, Zambia’s water and sewerage infrastructure was owned, maintained and extended by the central government while municipal authorities were responsible for the operation and delivery of urban water and sanitation services. Water tariffs in all the urban centres were heavily subsidised; charges were paid as part of rent and were mostly unnoticed by users. With the decline of the country’s economy, already underway during the 1970s, municipal operators suffered from low billing and revenue collection in addition to cuts in central government funding. Ageing infrastructure led to water losses, and with declining funding it could neither be upgraded nor extended to expanding city areas. Cost recovery policies eventually led to attempts at commercialisation of the water supply services, the passing of the Water and Sanitation Act in 1997 and the establishment of a regulatory authority, the National Water and Sanitation Council, NWASCO (Dagdeviren 2008).

The changes provided for the formation of new water and sanitation utilities to operate as commercial entities. The Lusaka Water and Sewerage Company (LWSC, hereafter the Water Company) was registered under the Companies Act in 1988 and started operations in 1990. It was transformed into a commercial utility in 2003 and is now a company wholly owned by the Lusaka City Council. It is in charge of a water supply network that services 71,417 connections[38] with a coverage of 34 per cent of the city (NWASCO 2009). The first phase of the water distribution system was commissioned in 1970; by 2007, around half of the Lusaka district was covered by the reticulated water supply. In addition, there are nine

[38] Including the Kafue, Luangwa and Chongwe districts which lie outside Lusaka.

so-called satellite systems distributing water from boreholes to some of the peri-urban areas (JICA 2009). Through World Bank funding, the distribution network has expanded, mainly to three districts south of Lusaka.

About half of the water distributed by the Water Company is pumped from the Kafue River over a distance of 65 km, via the Iolanda water treatment plant (rapid filtration)[39] and booster pumping stations (Mpamba, Nkhuwa et al. 2008). The production rate has been on average 200,000 to 220,000 cubic metres per day since 1993, of which 130,000m^3 is pumped from about 72 boreholes around the city. Fluctuations in water production capacity are mainly due to differences in the groundwater capacity between the dry and rainy season. Moreover, the Lusaka Water Company has the right to draw 200,000m^3 of water daily from the Kafue River,[40] but the actual utilisation capacity is only around half of this volume due to limited in-take facilities, leakages, power cuts and old equipment (JICA 2009).

It has been estimated that somewhere between 80,000 and 350,000m^3 of water is drawn daily from private boreholes and dug wells, for domestic and other purposes (De Waele, Nyambe et al. 2004; Lusaka City Council and Environmental Council of Zambia 2008). The Department of Water Affairs has records for some 1900 private boreholes but researchers assume there are at least as many unregistered boreholes constructed by private drillers, and that the city in total derives approximately 70 per cent of its water requirements from the karstic aquifers (De Waele, Nyambe et al. 2004; Mpamba, Hussen et al. 2008; Mpamba, Nkhuwa et al. 2008). The large number of shallow dug yard wells are not monitored, and are difficult to assess as they are very common and new ones are being dug all the time.

The estimated water demand for the city was 400,000m^3/day in 2008 (Lusaka City Council and Environmental Council of Zambia 2008), meaning that the Water Company would not be able to provide adequate water supply services to the city's population even if the existing supply system reached everyone. In practice, informal settlements are especially badly served. However, constraints are increasingly felt also by those residing in the formal areas of Lusaka. The Company estimates that 50 to 60 per cent of the water produced is unaccounted for. It may be lost on the way to customers due to leakages, burst pipes and vandalism of the old distribution network or due to illegal connections; or due to ineffective administration. About one third of the amount billed to residential customers, and especially to government institutions, still remained uncollected in 2005 (Dagdeviren 2008).

Most households connected to the network are equipped with meters and in the areas where meters are yet to be installed, customers are charged for their water consumption according to their housing category, and thus pay a fixed, flat monthly rate irrespective of the quantity of water they consume. This is partly done for the purpose of cross-subsidisation (cf. Dagdeviren 2008), but it is also used to explain some of the high volume of water that remains unaccounted for. However, the two most common payment methods in the settlements and low-cost areas are per month and per 20-litre container.

Both the federal NWASCO and the local Lusaka Water Company have policies on water supply and sanitation services in the settlements in order to define the roles and responsibilities of the utility, the communities (through designated representatives), and private operators including NGOs. The Water Company has set up a pro-poor department unit with a manager based at the company headquarters, and 13 other full-time staff members in the peri-urban field offices – it thus has the capacity for day-to-day operations and management. In spite of supposedly being 'pro-poor', the underlying concept is that water is supplied on the principle of cost-recovery and the communities have to organise themselves to collect the

[39] Delivered drinking water has to conform to the Department of Water Affairs' guidelines under the Ministry of Energy and Water Development. Groundwater is subject to treatment at the borewells.
[40] This water right is granted by the Ministry of Energy and Water Development.

revenues from their own water users (Government of the Republic of Zambia 2000; WSP 2009). The affordability of current tariffs continues to be a problem for the poorest of the poor such as unemployed and day-wagers, however; and as we will see, many have to rely on shallow dug wells, at least for non-drinking uses.

Sources of water for drinking and other household purposes

The sources from which the low-income settlements' residents access water vary from one settlement to another and from which part of the settlement one lives. The preferred source depends also on the intended use – for quality reasons drinking water tends to be taken from a narrower range of sources – and on how adequate and reliable a certain source is. The majority of the residents in the low-income settlements lack individual connections to the reticulated water supply system. The options instead include communal taps, public taps, water kiosks and community-based solutions, all of which commonly referred to as 'tap water', but also hand pumps (at stand-alone wells). Occasionally, water is purchased from private well owners in the neighbourhood (or, even more rarely, from tanker trucks) or taken from a so-called Dambo well (a swampy area). In all settlements, the problems with congestion – long queues and competition over the available water – are more or less severe. Together with the fact that water is only supplied intermittently and that the distances to the nearest water tap may be considered too long, this again leads to dug, shallow wells being the solution for many.

Where *communal taps* are installed, water is distributed from the Water Company's network and access is restricted to a defined user group that shares the costs; the taps are thus not open to the public. In 2008, the tariff was K8000 (Zambian Kwacha; equivalent to US$1.71) per month charged as a flat rate. The institutional setup is mainly such that Residents' Development Committees (RDCs) – entities registered under the Co-operative Societies Act, 1972 and based on voluntary work by its members – undertake the distribution of the water through a tap attendant and often also some kind of water committee. The RDCs are given logistical support from the Water Company, which has a set up a peri-urban unit for this purpose, as well as the City Council's Peri-Urban Section, and sometimes also from NGOs such as CARE International (UN-HABITAT 2007; JICA 2009). Supply is often erratic at the communal taps, mainly due to power cuts. There have been complaints that the repair of taps can take a long time, and that tap attendants sell water, or give water to non-members and relatives. At some places, these taps are very limited in capacity and poorly maintained due to lack of finance and also extensively vandalised, resulting in breakdown (IUCN, Sida et al. 2004). Since the water is only made available at specific times of the day, long queues are the rule rather than the exception.

Community-based water supply schemes exist in around ten settlements. These distribute groundwater from boreholes originally installed by NGOs such as CARE and JICA. Today they function as trusts that are established under the approval of the Lusaka City Council and registered with NWASCO. Representatives of both the City Council and the Water Company sit on the Board of Trustees, which acts as the decision maker for the water supply management. The households that are members of the user scheme mostly pay monthly for the water charges and here, too, water is only available at specific times of the day.

The cost recovery approach for the water supply enables the community to pay hiring costs, wages of tap attendants, maintain the water service and sometimes also invest in the replacement and expansion of the system. Where the community-based water schemes operate, there are usually also RDCs or other area-based organisations set up on behalf of the residents of the respective settlement, with support from the Lusaka City Council (UN-HABITAT 2007; JICA 2009). The system relies on full cost recovery and in spite of some cross-subsidisation it is probably not affordable for the poorest people; as indicated by a return to free but contaminated sources – in other words, shallow dug wells (Mattingly 2008).

Very little information used to be collected on the available water resources in the community-based water schemes and there was no monitoring of the boreholes, meaning that troubles in operation were difficult to identify. From NWASCO's point of view, there were problems with a lack of supervision in terms of water quality and pricing. In order to address these deficiencies NWASCO directed the Water Company to sign memorandums of understanding with the trusts to bring them under the regulatory framework and make the Company fully responsible for their operations. Agreements to this effect were signed in 2008 (JICA 2009; NWASCO 2009). It is yet too early to say what differences this may make, though it is very optimistic to expect a water utility to take responsibility for such community water supply systems.

Public taps from which water can be taken for free used to exist, especially in most of the settlements, but have become very rare. The Water Company has closed down one after the other, such as in New Kanyama Township in 2007, where new taps equipped with meters were opened instead, the water being charged for from then on. This led to violence as the residents protested against not being served with free water (Mwape 2007).

Hand pumps can be public or communal, and as they are fitted at non-motorised boreholes, water is taken from the site of the well. This is unlike most other borehole solutions, which are equipped with overhead tanks and pipes and can hence be defined as a 'piped' water source.

The most recent way to access water in settlements and low-cost areas is via *kiosks* where water can be purchased. They are normally[41] linked to the main water distribution network and run by the Lusaka Water and Sewerage Company, but in some areas they are linked to boreholes. These kiosks have private operators who have signed contracts with the Water Company, which is responsible for the supervision and maintenance of the system. The water is metered: households have a user-form and are either charged on a monthly basis (K10,000: US$ 2.14) or per container (K200 per 20 litres). As the kiosk system does not rely on an organised community structure such as an RDC, it may be appropriate where there is no such committee or the community is fractured due to political or other reasons. On the other hand, existing RDCs may be instrumental in making the kiosk system work. Another factor is that the technical distribution system allows for upgrading to higher service standards, including the possibility of individual household connections (NWASCO 2009). It is unclear whether this has been realised in any settlement to this date.

Kiosks are found in most of Lusaka's low-income settlements today – according to the Water Company, they exist in 90 per cent of the legal (or formal) settlements. Each kiosk is generally designed to cater for 60-80 households, but in practice their total number is insufficient in relation to household demands and the number of residents relying on them. Because the water is supplied from the general network it has undergone treatment and is, according to the Water Company, normally of good quality at the taps, unless damage has occurred to the infrastructure along the way to allow leakage. However, the density of the settlements usually prevents pipes from being laid except to their outskirts. This results in walking distances which are too long for many.

The alternative source of water, especially for the poorest section of urban dwellers in Lusaka, as in many other cities of Zambia, is from shallow dug wells. Although it is not possible to estimate the number of households who rely on these wells solely or to some extent, there are indications that this number is increasing. Interviews with tap leaders, NGO representatives, authorities and others suggest that there is a group of residents in the settlements – unemployed, day wagers, old people and others – who cannot afford to purchase any or only

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[41] There may also be other water vending points run by private operators or community-based organisations and referred to as "kiosks" although they are not run by the DTF.

very little of the water needed, and another group who may have initially purchased water from kiosks, community-based schemes, or similar, but who have eventually fallen behind with the payments. Yet another group consists of those who live at a great a distance from taps and kiosks, especially in areas where there is great competition for their water. For instance, in Ng'ombe Compound there is one communal tap per 220 households and the quality of the water distributed is often found to be poor; at least 50 per cent of the residents therefore depend on shallow wells. Finally, there are people who are of the opinion that water should not be charged for and/or prefer to supply their own needs by way of wells for other reasons.

Borehole drilling has increased among the middle and upper class in Lusaka's formal residential areas. The reason is mainly that the distribution from the Water Company is steadily becoming less reliable. Others among this group have instead dug wells, using the water for washing, construction and similar purposes to supplement their supply from the Water Company.

Dug wells normally give a reasonable to good yield throughout the year, since the water table is often extremely shallow in the karstic terrain of the city, and water is drawn in relatively small quantities. Many owners of dug wells in the low-income settlements even sell water to neighbours and others (normally charging up to K200 per 20 litres). Meanwhile, some borehole owners in the formal residential areas report a lowering of their water table as more boreholes are drilled in the vicinity, but no further detailed information is available.

Water quality and point-of-use treatment

From data collected by the DTF in 2004-2005 as well as for this review, it seems that the vast majority of those living in the low-income settlements do not treat their water at home before consumption. There are apparently several reasons for this, the main being the perception that 'tap water' (whether distributed by the Water Company via kiosks or communal taps, or by the community-based system) is of acceptable quality. Similarly, many are of the belief that their shallow wells are safe because they have drawn water from them for decades without any major consequences. It is unclear whether such beliefs are also common among families with infants, whose immune systems are generally weaker. Among the middle and upper class, however, many seem to trust the water taken from their own boreholes more than the tap water delivered to their homes by the Water Company.

The other main motive not to treat one's drinking water seems to be the very effort involved in mixing the chlorine (0.5 per cent *sodium hypochlorite* solution) with the household's water for disinfection, despite awareness campaigns and the clear instructions in text and graphics on the chlorine bottles.[42] Issues of taste were not raised by anyone against chlorination of the drinking water. Affordability should not be a reason since a 250ml bottle of chlorine is subsidised by USAID to cost K700 (US$ 0.14) which even the poorest should be able to pay; but prices between K1000-2000 are common and perceived as too high by the poorest when bought on a regular basis. The City Council, international aid agencies, NGOs and Christian churches do occasionally distribute bottles of chlorine for free mostly during the rainy season and whenever there is an outbreak of cholera, but it is unknown whether those most in need are reached by such campaigns. It was noted during the fieldwork that most households cannot afford soap and running water is rarely available for hand-washing.

Fatal cholera outbreaks occur every year, especially during the rainy season, and are taken very seriously by the authorities. During 2009, nearly two-thirds of the country's cholera

[42] The available solution, Clorin, comes in a bottle with a lid incorporating a small, built-in measuring scoop at the top for five-litre water containers, while the inside of the lid can be used for the more common 20-litre jerry cans.

cases were recorded in the Lusaka province. In 2010, the Ministry of Local Government and Housing released K986 million to the Lusaka City Council for cholera prevention, through education campaigns on health, hygiene and food safety; free chlorine distribution; clearing of streams; emptying of toilets; provision of temporary portable toilets, and so on. Normally, however, the pit latrine emptying service is out of reach for most people who live in Lusaka's unplanned compounds. It is not automatically taken care of by the City Council and a private arrangement with the Council is charged prohibitively at K350,000 (US$ 69) to empty one latrine. As a result, the groundwater that is relied on by the majority of those living in Lusaka risks further deterioration.

4.2.4 Strategies for water access in Lusaka

When the River Kafue's capacity has been too low to draw its water in sufficient quantities the drilling of wells has played a decisive role, both for the reticulated system and for local water distribution. Because the Lusaka region's few perennial surface streams are subject to impoundment for the sake of commercial farming, the aquifers are by some seen as "the obvious and cheapest water source option for all competing water users" in Lusaka (Mpamba, Nkhuwa et al. 2008:648). In opposition to this idea, Japanese JICA has concluded that further development of groundwater from the utility's wells should be limited in order not to disturb the balance between extraction and recharge.[43] Instead, it has estimated that the development potential of the Kafue River is such that it could meet increased water demand up to 2030, if the Water Company applied for increased rights to its water. It thus recommends surface water rather than more boreholes, providing that the water treatment plant's capacity is enlarged. Additionally, it stresses the need to recharge aquifers artificially, especially around the 'production boreholes' used by the Water Company (JICA 2009).

UNICEF Zambia has concluded that the MDG targets for water supply in the country are unlikely to be met through the work of conventional programmes at community level. It recommends an alternative approach including self-supply from wells, and encouraging households to develop their own infrastructure incrementally to improve water quality, quantity and/or accessibility. Evidence suggests that there is more willingness to invest in one's own private water supply than in a communal one (M. Munkonge, personal communication, January 27, 2010).

With NWASCO and the commercial water utilities, Zambia has built up a multi-layered institutional capacity for water supply and sanitation services. One important component is the Devolution Trust Fund, instituted under NWASCO in 2003 by the government in response to the MDGs and to the large numbers of people living in settlements and low-income urban areas without adequate access to safe water and sanitation. The DTF is a basket fund that makes grants available through applications by the country's commercial water utilities, and is in turn financed by foreign donors such as the World Bank, Danida and the EU. The DTF was created to contribute to capacity building among water providers who would probably otherwise not consider extending their services to poor areas. One example of a service that DTF can offer is consultancy in the development of the best sustainable methods of providing water and sanitation.[44] As noted above, the scope of the DTF includes water kiosks as the primary means of helping the urban poor to access reasonably priced water services. Between 2006 and 2010 the plan was to finance 700 water kiosks in eligible areas (excluding illegal settlements) all over the country (DTF 2005; NWASCO 2006; S Gonga, personal communication, January 26, 2010).

[43] Most dug, shallow wells are continuously recharged and do not face problems with over-extraction.
[44] Funding can also be sought from the Performance Enhancement Fund, which aims to enhance a utility's financial viability.

Water Watch Groups have been introduced by NWASCO in major Zambian cities to represent consumers in relation to NWASCO and the commercial water utilities regarding service quality. In Lusaka, a Watch Group has existed since 2002 to respond to complaints, to ensure that consumer rights are protected and that consumer obligations are explained (NWASCO 2003).The Watch Groups comprise members of the community from different consumer groups acting as volunteers; they represent all water customers including those who buy water from DTF kiosks. There is thus a rights-based and participatory approach built into the formal part of the system.

Zambia's legal system, much like India's, is based partly on common law inherited from British colonial rule, and partly on customary law. The latter applies less in cities than in rural areas where communal rights over land and water may still take precedence over those of the individual (cf. Phiri 2000). In the urban environment, the property rights to groundwater are more clearly vested in the President representing the nation state, as regulated by law, in the Water Act of 1948 (Cap 198). The Water Act lacks rules directly regulating groundwater and has therefore been subject to revisions, to address, amongst other things, the conditions and registration of borehole construction (Phiri 2000). However, no amendments along these lines have been made and landowners are therefore entitled to take as much groundwater as they like without permission. In practice, the same applies to those renting land.

The major problem in Lusaka is, however, not the quantities of water abstracted from the aquifers but water quality, and the ever-increasing degradation of the resource. The Environmental Protection and Pollution Control Act (No. 12 of 1990; Cap 204) uses a licensing system to control the discharge of effluents from industrial activities, but it does not cover the diffuse seepage from tens of thousands of pit latrines, or the general absence of solid waste disposal services.

The authorities and numerous NGOs have promoted the use of chlorine for many years, especially to treat drinking water from shallow wells.[45] Some well-owners claim to 'bleach' their wells by adding chlorine to them (a futile method according to hydrogeologists), and during outbreaks of cholera more people do chlorinate their water and also purchase tap water. But these sensitisation drives seem to have been unsuccessful. It seems inherently difficult to change people's behaviour, and hard to demonstrate the link between hygiene and health persuasively enough. This is particularly a problem because it concerns households' total hygiene practice, of which drinking water is only a part.

The authorities also advise digging shallow wells on ground which is higher than nearby pit latrines, and maintaining a distance between the units, to avoid water from the latrines finding its way into the wells and contaminating the groundwater (Chooma 2006). General adherence to this advice is low, although this is probably mainly due to space limitations. In response, public health officers (primarily from Lusaka City Council's Public Health Department) have been mandated to increasingly take any measures necessary to stop people from using shallow wells, even for washing; this may include burying wells. Some have been buried under the Disaster Mitigation Programme which falls under the Disaster Management Mitigation Unit in the Vice President's Office.

[45] UV treatment of drinking water in PET bottles (the SODIS method) is also encouraged, but the practice has not been taken up.

Box 9: Burying of wells

In January 2010, health authorities in the city of Kitwe in the Copper Belt area threatened to bury shallow wells in a township in order to avert further outbreaks of cholera and other contagious diseases. The residents were urged to choose treated drinking water from kiosks instead, which for the time being did not charge the normal fee.

The local Water Company also agreed to disconnect fewer non-paying consumers, as it was found that this led to the residents resorting to taking water from shallow wells instead. However, in this case, it may be more than just cost which influenced people's choice of untreated water: according to the news article, the residents "had a misconception that chlorinated water led to impotence". Information about the nature of chlorinated water, and how cholera is transmitted, were among measures taken to curb the further spread of the disease (Times of Zambia 2010).

In response to the authorities' campaigns to bury their wells, people resort to covering them in different ways. For instance in George Compound, one of the largest settlements in Lusaka, a tap attendant says that people have used quite innovative measures to hide their wells under flowering gardens and similar (Veronica Katulushi, personal communication, January 27, 2010).

UNICEF has stated that it does not agree that shallow wells should be buried and believes that, with good public health and hygiene education, people can be advised on how to treat water from such sources effectively. The feasibility of this approach relies on an enabling environment being created, including better policies; access to appropriate technologies and advice; and effective financial mechanisms and markets. UNICEF's campaign using a cartoon aimed at teaching children proper hygiene practices, and a bucket device for improved hand-washing, is in line with this approach (M. Munkonge, personal communication, January 27, 2010). Similarly, according to a representative, JICA considers the authorities' drive to bury wells to be too drastic, as well as counter-productive, when the settlement areas are badly served and the water tariffs too high for the majority of their residents. Pursuing this course of action could lead to civil unrest, and to the outbreak of other diseases caused by households lacking sufficient water. JICA believes that education about water treatment will suffice. The Agency also points out that in one of the settlements where it works; improved primary health care has been shown to contribute to the reduction of diarrhoeal diseases (Y. Shibuya, personal communication, January 29, 2010).

There are likely to be a number of reasons why so many rely on their own wells in the low-income settlements of a city such as Lusaka; and perhaps most of these reasons will remain, both in the short and long term, even if the Water Company decides to increase the availability of water via kiosks or community taps (through DTF funding or otherwise), or the community-based/trust schemes are multiplied. In other words, dealing with the quantity constrains and the congestion issue is an important step, but it may not be enough.

For one group of people, if there is water available in their own backyards, they may be discouraged from buying water from kiosks and similar by the distance and the queuing. People in this group would probably prefer individual house connections or maybe one common tap per five households to supply the quantities needed. Here, the constraining factor is not so much money as convenience.

Another significant group probably consists of those who cannot buy any – or only very little – water from kiosks and taps without suffering severe economic consequences, such as cutting back on an already insufficient diet. In spite of the potential health risks of using shallow wells where the water is not treated and living conditions are generally unhygienic, households may simply have no choice. For these households, groundwater is the natural choice, and without an intimate knowledge of their situation it is hard to say that it they are not right. The provision of water from community-based water schemes, kiosks and the like does not help this group much, if at all, unless it is heavily subsidised or given for free.

Improved water provision in a low-income settlement may lead to unwanted effects such as increased rents, which push the poorest households to seek other accommodation. In Lusaka, the introduction of community-based water schemes in some settlements led to a high level of mobility, suggesting that the poorest were beginning to be forced out by the rise in rent (Mattingly 2008). Even where rent does not increase, those who cannot raise the monthly water operation fees may be forced to begin (or continue) drawing water from shallow wells, ask for water from neighbours, or try to access water from free sources outside, to supplement what little water may be purchased per can.

Considering the fairly small quantities of water drawn for household needs in Lusaka's low-income settlements, there should be no risk of residents' dependence on groundwater leading to over-extraction; Lusaka's karstic conditions allow for well-connected aquifers and recharge from wastewater sources around the year. However, large commercial boreholes (for industrial or irrigation purposes) sharing aquifer systems with individual households do constitute a risk to Lusaka's groundwater sustainability. Contamination also continues to be a problem and needs to be dealt with in a variety of ways.

5 Conclusions

Most urban areas which are experiencing fast population growth find that the available water from more or less local sources falls short of overall demand. This often triggers plans to increase the volume of distributed water by locating new, untapped sources, often from rivers at an ever-increasing distance from the point of demand. However, the various costs – economical, political and ecological – for investing in new sources can be prohibitive, and financial institutions may not be interested in making funds and loans available for such expansions. The remaining alternatives for many expanding cities are water conservation; re-use, other efficiency-increasing methods; and sometimes also local groundwater sources. Because the bulk of the world's urbanisation is taking place in low- and middle-income countries, the challenge for these cities is all the greater. Urban growth and ever-increasing demands leave many water utilities unable to provide services to new, potential customers – or even to keep up service standards in areas and already covered – while maintaining existing networks and other infrastructure. City planners and policy-makers may be both unable and unwilling to address this problem. Therefore, it is likely that for the foreseeable future areas outside the core of cities, particularly informal and low-income settlements, will remain largely unserved by the utilities.

As the gap between demand and supply grows, water users from all income-levels may find that they need to self-supply from different sources. World-wide, water is increasingly purchased from different kinds of private vendors and as packaged water, in bottles of varying sizes. For the very poorest in society this practice is seldom affordable, except in such small amounts that their health, hygiene, well-being and general development potential is at stake. Many therefore resort to taking water from elsewhere. As the number and extent of surface water bodies in the urban landscape diminish and their water quality steadily decreases, the solution is often wells of various kinds. Water from wells can be more or less free of charge where conditions are favourable, or be considerably cheaper than water from alternative sources. Water from aquifers also tends to be of good quality, although human sources of contamination abound in the city environment and their ever-increasing presence is linked to waterborne and water-washed diseases.

Although this picture of urban development and coping strategies for water access is not new, the importance of groundwater seems to be growing and receiving more attention, at least in the literature. Recently, the role of groundwater for urban areas in Sub-Saharan Africa's arid and semi-arid regions has been highlighted. It may be the only source which could provide an affordable, reliable water supply, given both the predicted changes of surface water flow in a changing climate, and the needs of growing cities which face the problem of extending their infrastructure. The development of groundwater is therefore forecast to increase, in some areas quite dramatically.

Many lessons can be learned from the situations in the two cities included as case studies in this review – some very context-specific, others more general. One general lesson is that the complexities involved in water management in cities of low- and middle income countries are further compounded when groundwater dependence constitutes a significant component. Another is that major uncertainties abound due to a lack of acknowledgement that groundwater plays a significant role. Better awareness of its importance should lead to improved monitoring and assessment of prevailing conditions, and in turn make it possible to take charge of the situation for future development. Both Bangalore and Lusaka need to achieve this.

5.1 Bangalore and Lusaka – what can we learn?

Bangalore, the so-called Silicon Valley of India, is almost double the size of Zambia's capital, Lusaka, and both experience rapid population growth. The cities enjoy climates with distinct wet and dry seasons, average rainfall less than 1000 mm yearly and a monthly mean temperature above 18° C throughout the year. Their water supply utilities both distribute water taken from a major river at some distance from the city proper, but the volumes that can be pumped from these are limited by rights-systems as well as by frequent power cuts and insufficient infrastructure capacities (and financial constraints). Reticulated supply of groundwater takes place, but the groundwater availability depends on local hydrogeological conditions that differ fundamentally between Bangalore and Lusaka. Due to mixed bedrock formations there are also groundwater variations within the cities, such as the aquifers being unevenly spread in the landscape. A range of other factors contribute to differences in natural, added and artificial recharge, groundwater flow, the spread of contaminants in the water, and so on, between different areas of the two cities.

5.1.1 The role of groundwater for households

In terms of accessibility on a household scale, Bangalore's crystalline bedrock mostly necessitates the drilling of boreholes – sometimes down to a depth of more than 300 m – to encounter sufficient volumes of water in the weathered rock and in fault zones beneath. Bangalore has conditions which are mirrored in many parts of the world, not least in Sub-Saharan Africa. An important difference, though, is that boreholes construction is more expensive in African countries than India and China. This is mainly due to a lack of any economy of scale or competition in the field; the absence of a large private-sector market for drilling of domestic wells; high excise duty on imported drilling equipment; corruption; and inappropriate well design, including drilling to excessive depths (Foster, Tuinhof et al. 2008). India has witnessed a tubewell revolution as a result of the technical drilling developments some 30 years ago, heavily utilised within the agricultural sector but also in the domestic domain and not least in cities. Drilling for water is now feasible on a larger scale and deep tubewells are more common today than open, dug wells. In India, an electric and/or diesel-driven pumpset also comes at a relatively affordable price, in part due to returns to scale achieved in the agricultural sector.[46]

[46] The fact that electricity for farming purposes is subsidised in most Indian states (often related to political vote-banks) is of fundamental importance for the sustainability of India's future groundwater reliance, but lies outside the scope of this paper.

This has meant that groundwater in India is increasingly available for urban landowners even in hard rock terrain, though there is the risk that the aquifers below one's land may be unreliable and non-resilient. Nevertheless, in India just like other parts of the world, the poor section of society cannot afford to drill boreholes.[47] Bangalore's poor people therefore depend directly (and, to a very small extent, indirectly) on groundwater taken principally from *shared wells* – mainly in the form of public standposts – over which they have neither influence nor responsibility.

This group may also access groundwater via utility tankers or vendors. As such, though, whether it is groundwater or surface water may matter little to the users except to the extent that it is reflected in the quality or price. Many of those relying on water from standposts know to differentiate between them, on the grounds that some provide 'Cauvery water', meaning the Water Board has pumped it from the river. This is generally a preferred source as it has undergone treatment, which affects the taste and, for some, the perception of it being safer. This difference between standposts is, however, not being identified in surveys used to monitor access to water (for instance, the DHS surveys described above). It should also be recalled that all standposts are considered, in the JMP terminology, as improved sources – regardless of quality, quantities available or allowed, distance, or time spent queuing to collect the water – whereas water distributed via tankers (and mainly purchased from vendors) is seen as unimproved.

By contrast, the conditions in Lusaka – together with the fact that the peri-urban settlements are not as densely populated as slum areas in, for instance, India – make it feasible for most poor households to dig simple wells and access sufficient amounts of water to either substitute or complement water accessed (that is, purchased) from other sources. The karst terrain normally also allows for a very dense network of dug wells which give a small but consistent yield because of the extremely shallow water level and well-connected aquifer systems. At present the groundwater in Lusaka is fairly reliable in terms of yield, at least in the low-income areas where a large number of wells are hand-drawn. Were the wells to be upgraded and fitted with submersible pumps, though, the sustainability of the aquifer system might be in question. As described below, the role of the groundwater may be already limited due to contamination.

5.1.2 The role of groundwater for water providers

For the public utilities in these two cities, groundwater plays a decisive role; though much more so in Lusaka, where about 55 per cent of the water distributed in the network is drawn from just over 70 boreholes. In Bangalore, by contrast, the total amount of wells belonging to the Water Board now stands at over 10,000 and the number of deep wells drilled by the Board is growing, especially in the large peri-urban area added to the city in 2007. This is partly because the water supply infrastructure is inadequate and partly because the water available from the main source (River Cauvery) is insufficient. In comparison, Lusaka's peri-urban area also lacks a water supply infrastructure, but the approach of the city's Water Company is to supply water from the distribution network by extending it to a few selected tap points in the settlements, for instance at water kiosks. Extensions of the infrastructure are in both cases mainly financed by foreign means (loans in Bangalore, loans and development aid in Lusaka), but in part also by the end-users themselves by way of capital contributions and/or operation fees.

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[47] Several factors prevent the digging of shallow wells. The water table is often too low and fluctuates greatly between the seasons; land rights constitute another issue. The custom in India is to dig very wide open wells, for which there would be no space in a densely populated slum. The reason for this custom is often hydrogeological – a wide well provides storage capacity so that water can be drawn at a normal rate during the day, while the well refills slowly but continuously (R. Boak, personal communication, June 15).

When it comes to paying for water services, the situations currently look fundamentally different in the two cities. With the commercialisation of water and sanitation provision that came with a reform of the economy in Zambia at the end of the 1990s, the sector moved towards full cost recovery. As in Bangalore, tariffs were cross-subsidised, in principle to allow poor citizens access to reasonably affordable and mostly potable water. However, most of the public taps which once provided free water in Lusaka's low-income settlements are now closed, and the poorest are forced to take water from shallow dug wells instead. In Bangalore, the same development was underway with a drive to close down public standposts and make slum dwellers take up individual connections. However, foreign donors pressed for a pro-poor policy which took into account this large group's highly varying ability to pay.

Most of Bangalore's slum dwellers today depend on public standposts where water is more or less free – a situation no longer seen in cities such as Bombay (Mumbai) where mafia involvement in the city's water supply sector has led to every water user having to pay in one way or the other. However, in spite of the Water Board's recent pro-poor policy, they are in this respect at the mercy of the city's political decision-makers and the pricing approach may change without much prior notice or consultation. In addition, the quantities of water available may be small as well as irregularly provided – in spite of new boreholes being drilled by the Board – and not all of the poor have access to public standposts within a reasonable distance. Additionally, slum dwellers who have had the opportunity to take up household connections tend to suffer from very irregular supplies. This may result in water either being begged for among neighbours or purchased from private vendors. Either way, the limited volume of water that people can access has clear implications for health, living standards, and development potential. A revised pro-poor policy is needed, introducing accountability and acknowledging that a large proportion of the poor depend on groundwater through the public utility's standposts and/or via private vendors. Improved participation could be attained by, for instance, involving representatives of slums (including declared as well as non-declared slums) in decision-making regarding drilling of wells for new standposts, and the days/times for supply from existing ones. Previously, the 'voice' of this group has mainly been amplified by NGOs involved in the cause against further privatisation of the Water Board's services.

A revised pro-poor policy is also needed in Lusaka, mainly within NWASCO and the Water Company, but also among the charity-based NGOs and foreign donors. The proportion of poor is much higher than in Bangalore and the size of the settlements larger. Residents in many low-income areas rely (or have done previously) on NGOs, Christian churches and/or development aid agencies which drill boreholes and arrange community-based water supply schemes. These actors step in where the state has failed to take its full responsibility to ensure access to water, but many of them are/have been present for only a short period in each settlement and cannot be held accountable once they choose to leave. In addition, the poorest, who cannot afford the monthly fees and/or can seldom or never pay per jerry-can, are left to their own devices – in other words, the shallow wells. This practice may have implications for health, living standards and development potential, but in terms of accessing water, this group still retain a level of control over their private water resource. This also means that while members of this group are not much listened to currently by decision-makers and officials, the methods they employ to self-supply need to be recognised and approved of by the authorities. For instance, better insight is needed into how residents of low-income areas rely on wells directly and indirectly for drinking and/or other domestic purposes, throughout the year or mainly during the dry period, and what promotes or prevents the use of chlorine and other household water treatment, respectively.

5.1.3 Issues of quality, potability and health

In terms of groundwater quality in Bangalore and Lusaka, excess levels of nitrate, pathogens, and so on are detected in both cities; but this is only seen as a matter of real concern in Lusaka. Because of the shallow wells' proximity to the surface in Lusaka and the rapid recharge taking place through localised pathways, the water in such wells is prone to deterioration from faecally contaminated surface water related to poor sanitation and solid waste disposal facilities in the vicinity. This may strongly contribute to, for example, pathogen levels that may exceed WHO and national drinking water standards in the rainy season, and may constitute a risk for public health. During the rainy period of the year, water from the wells at risk is often avoided for drinking purposes, but instead it could be treated carefully in the household before consumption. As there are several causes behind diseases such as endemic diarrhoea, there is a lot of uncertainty regarding water-borne diseases and their transmission routes. Water from shallow wells in particular needs to undergo better monitoring and assessment.

The large volume of water pumped from boreholes and distributed via the reticulated system, including communal taps and kiosks, is chlorinated at the source but may become contaminated in the mains or at point-of-use. The authorities in Lusaka seek to prevent cholera outbreaks in a variety of ways, including encouraging people not to use the shallow wells at all, but do not seem to deal adequately with sewage and solid waste collection. It should be noted here that even if the dug wells were lined, covered and so on to fulfilll the definition of 'improved' in the UN's JMP vocabulary, the shallow groundwater would still be prone to contamination.

The mandated service providers have an interest in making people contribute towards capital investments in the water infrastructure and have probably been influential in the decision to gradually close down non-commercial public taps. For a large proportion of the poor the price of water is, nonetheless, too high and for lack of other options, many who can will continue to opt for a dug well in their own backyard.

Increasing the access to water from boreholes in Lusaka – mainly by making the water more affordable for the poorest and setting up more tap points evenly distributed in the settlements – would probably mean safer water and would therefore be a better contribution to improved health than water from shallow wells. Water from the latter will, meanwhile, remain easily accessible, cheap and sufficient on a daily basis. 'Safe' drinking water is also no protection against cholera and other common diseases, particularly in poor, dense and unhygienic environments.

5.1.4 Should the use of groundwater be further encouraged?

In Lusaka the majority of the water used – indirectly, as distributed by the utility, and directly via community supply schemes or when taken from private wells – comes from the city's aquifers. Although some argue for a decreased dependence on this resource, due to the risk of over-abstraction, or the threat to public health that the shallow wells pose due to their proximity to contamination sources such as pit latrines, there are only a few alternatives to continued conjunctive use of the groundwater. Increasing the volume of water pumped from River Kafue depends on renegotiating water rights together with making capital investments in infrastructure, including the water treatment plant. In the light of the insecure state of the river flow throughout different seasons and over prolonged dry periods – which climate change may increase – this might not be a viable solution. General efficiency improvements and a demand-side or conservation approach will probably have marginal effects considering that up to 70 per cent of the population of Lusaka lives in settlements and is already more or less deprived in terms of water services.

Given that the poor in Lusaka constitute such a large proportion of the city's population, there are reasons to believe that strictly enforcing the ban on shallow wells would impose such severe hardship that it may provoke riots. Rather, the authorities need to recognise that there may not always be a direct, causal link between the shallow wells and endemic diarrhoea, since there is a complex relationship between the source of water supply, sanitation facilities, general hygiene practices, and health. It is worth repeating that since access to water from shallow wells will often mean access to increased quantities of water, this should promote good hygiene which can, in turn, prevent faecal-oral transmission of diarrhoea. It is only when drinking water is established as the main source of infection that water quality becomes more important to health than quantity (cf. Bostoen, Kolsky et al. 2007).

The public health situation in Lusaka therefore stands to gain from the promotion of chlorine usage throughout the rainy season, in order to prevent the spread of the pathogenic bacteria involved when (or if) cholera breaks out. However, cholera is caused by direct faecal-oral contamination as well as through the ingestion of contaminated food – and water – and minimum hygiene and sanitation standards must thus be met to eliminate transmission routes. Moreover, since chlorine is less effective for treating turbid water, it should preferably be combined with physical and physical-chemical filtering during the rainy season. Furthermore, recommendations and restrictions on water supply sources alone are insufficient without interventions in the settlements' sanitation, including education on health, hand-washing, food hygiene, and so on (Cairncross and Valdmanis 2006; Clasen, Schmidt et al. 2007b; Schmidt and Cairncross 2009a; Schmidt and Cairncross 2009b).

Taking this into account, it is even less likely that burying all shallow wells will benefit the general health of the poor during the dry season when easy access to quantities of water may be of greater importance than quality. It can even be argued that burying wells in poor, peri-urban areas is scientifically ill-founded and dangerous from a socio-political point of view. Being endowed with such good-yielding aquifer conditions it seems probable that the city of Lusaka and its inhabitants will continue to use wells to fulfill growing demands for water – and this can be done, if only holistic measures to control pathogen pathways are used together with artificial recharge where needed.

On this subject, it is interesting to note that the authorities seem almost implacably opposed to people using their dug, shallow wells, while the international agencies and NGOs in Lusaka are less so. Perhaps this can be explained by the latter actors' greater presence on the ground, meaning they are better informed about the end-users and their needs for better access to adequate volumes of safe water. They may also have better knowledge, for instance of state-of-the-art technology and research findings concerning water and health. It may, on the other hand, be explained by the fact that donors and aid workers can focus on singular aspects of city planning and governance, and are seldom held accountable for the advice they give. In whichever case, the city's planners and decision-makers must develop clear policies for the provision of water supply and sanitation services that take into account the living conditions of the poorest, and not practice double standards in this regard.

The ability of an urban area (or rather its city planners) to cope with its water demand from external sources depends partly on its economic and political strength. Larger urban areas, which are backed by population mass, financial capacity and political influence, can attract surface water from a distance of hundreds of kilometres (cf. Patel and Krishnan 2008). In the cases of Bangalore as well as Lusaka, restriction on surface water availability is principally caused by the water rights allocated by the competent authorities, which limit the volume that can be pumped from the Cauvery and the Kafue rivers respectively. Research has shown that where competition exists between cities and agriculture, the cities tend to win (Molle and Berkoff 2006) – or at least certain urban-based interests are given more weight than agriculture. However, Bangalore's prospects for expanding its water rights are threatened by the fierce opposition from downstream states that seek to protect their agricultural interests. It is therefore similarly hard to imagine that the future holds a decreasing dependence on groundwater in Bangalore. The question of whether this is sustainable cannot be easily answered; it depends on very local hydrogeological conditions, as well as the policy views taken, in the short and long term, on economical development, regional realpolitik, ecological risks, equity aspects of access, and other values.

A ceiling on surface water availability – together with likely future alterations in precipitation intensities, and hence river flow variability, due to climate change – may inevitably lead to an ever-growing dependence on groundwater as urbanisation and population growth continues (and as water requirements per capita rise). In Bangalore, the Water Board takes a demand-side management approach by limiting, in most areas and during most of the year, the distribution of water to just a few hours on every other or third day. This includes public standposts, regardless of whether they distribute water from a well or are connected to the water supply network. Where the standposts are in fact wells, the practice of opening them (mostly by turning on the electricity, where it is available) for limited times of the day or week can be expected to have positive effects on the wells' resilience; in the meantime, the aquifers may be recharged naturally and/or from leaking pipes and rainwater harvesting structures.

The Bangalore Water Board's demand-side management means that a large number of households are subject to insecure supplies and resort to groundwater, either by constructing their own well or by buying water in bulk or per pot from a vendor with a good-yielding well. For some this is only necessary in the summer, whereas others will need it throughout the year. Hence, were the authorities in Bangalore to apply the relevant regulations strictly, controlling landowners' rights to their 'own' groundwater, this could affect up to half the population's access to water – rich and poor alike – although the precise extent cannot be estimated. The approach taken now, though, seems to focus more on implementing rainwater harvesting and thereby trying to balance the groundwater withdrawals by increasing recharge to attain sustainability. Yet, with the highly varying degrees of weathered, faulted and unconsolidated bedrock occurring in Bangalore, there is little or no way of accurately knowing the sustainable abstraction rate from a certain well, or where in the landscape wells risk depletion, or where the drilling of wells may even fail from the outset.

Both cities suffer from its groundwater resources not being sufficiently monitored (for Zambia, see findings by SADC 2009), but hydrogeological knowledge seems more advanced in Lusaka than Bangalore, or is at least better disseminated. Bangalore's hydrogeological and other conditions render the aquifers and the water availability highly unpredictable; but water flow and occurrence in a karstic environment like Lusaka's is also not easy to forecast with much certainty. Understanding the aquifer systems (by building a good conceptual model, including developing a robust water balance) is fundamental to improving the management of groundwater resources. This depends on good monitoring data from a well-designed monitoring network (R. Boak, personal communication, June 15, 2010).

5.2 The future for the urban poor's groundwater use

In many urban areas of the world there is an increasing trend in the use and direct dependence on groundwater, not least among the poor. This can be concluded based on several countries' DHS data from the past three survey years, together with general statements made in the recent literature and by groundwater experts, as well as on observations in the cities studied for this review.

While an increase in direct groundwater use is taking place in many cities of the world, universal coverage of water services – water provided by public utilities and/or at community level via a reticulated distribution system – is still generally seen as the goal (cf. Gerlach and Franceys 2009). In other words, piped tap-water is the norm.

This may partly be because JMP reporting distinguishes between 'piped' water and '*other* improved' sources. This implies that piped (or tap) water is surface water only, since the 'other' category lists sources such as protected wells and springs. As a result, indirect dependence on groundwater remains under-reported, but so does direct dependence: as the case studies of Bangalore and Lusaka show, poor people who rely on groundwater may often take it from a tap, locally known as a public standpost or community tap. Such water may be considered 'piped' although it is in fact from a stand-alone well. If the number of households depending on groundwater does not show up accurately in survey results, the significance of this resource risks going unrecognised, resulting in insufficient measures being taken to safeguard it for the future. If an increasingly large group of poor urban dwellers in many countries rely on accessing water from wells, a generally increased level of awareness and protection is needed.

This misleading distinction made by the JMP between 'piped' water and 'other' improved sources also implies that increased access to safe water can only be achieved by investments in large-scale piped infrastructure systems. This begs the question: why is there so little interest displayed in the aquifers located underneath or close to cities? Is groundwater perceived as an unruly resource because it is hidden, and the international research community (and local authorities) therefore lack information about it? Or is the fact that groundwater is often so easily accessible (with its just-in-time and just-in-place nature) a threat to those who invest in the expansion of water supply infrastructure?

Equally, the lack of interest in stand-alone wells should be questioned, especially the so-called unimproved wells. These are apparently seen as mere residuals that need to be eliminated by the continued expansion of piped water systems. Without neglecting the health concerns raised by unprotected dug wells, there is a need for a contextualised understanding of local conditions, and an acknowledgement of the scientific insights into water quality versus quantity, point-of-use treatment and safe storage, and hygiene practices at household level.

It is unlikely that a majority of urban households, especially in Sub-Saharan Africa, will be properly covered by piped supply in the foreseeable future. Such aspirations have long since been abandoned by NGOs in favour of a more realistic "some for all" approach (Howard, Bartram et al. 1999:91). In addition, it should be recognised that a dwelling with an individual water supply connection would entail a much higher rent and thus become unaffordable to many poor people in slum areas (ibid; cf. Mattingly 2008). In many low- and middle-income countries, striving for a reticulated distribution system that comprises all citizens – even if the water is taken from local boreholes –may be less worthwhile than acknowledging and promoting the existence of alternative sources. The end goal must be to ensure everyone's access to safe water, in sufficient amounts and at a sufficient frequency. However, including groundwater in the water provision equation means ensuring a certain level of sanitation and solid waste disposal facilities, as these factors are so closely related to the quality of the water.

5.2.1 Self-supply: meeting one's own need

Small-scale self-supply of water from aquifers is an option – or rather a necessity – for many of those not served in a reliable way and/or at an affordable cost by public utilities or others through individual connections, public standpipes or community taps. Poor urban dwellers are particularly vulnerable in this regard, sometimes despite the existence of a water supply network. This can be because they live in peri-urban areas to which the network has not been extended; or because they are not eligible for a connection and/or cannot afford to pay connection fees and so on up front. (Monthly bills for water services are less of a problem, at least if they can be paid in instalments or there are subsidies for low-volume consumption.)

Self-supply is also often chosen by those who are served inadequately by the public utility and need more water than is provided via their household connection.

Sourcing water from aquifers via different kinds of wells is a small-scale method applied locally with the help of low-cost technology. However, digging a well requires the right hydrogeological conditions, sufficient space requirements, land rights and other factors. Where the water table is too deep to dig shallow wells and it is too costly to drill boreholes, the cost of reaching groundwater may prove prohibitive for individual households. A shared, community well may be feasible, but its construction and subsequent maintenance may depend on whether loans, micro-loans or other funding are available, as well as the expertise to carry it out.

Community boreholes and deeper dug wells are sometimes constructed by the authority in charge of the water supply (such as the public utility) or by an NGO or church organisation active in the area (such as WaterAid). This often happens in villages that have become absorbed by a growing city. Water from such wells is seldom distributed for free; users may have had to contribute financially for its construction and later for the water service itself.

While there does not seem to be much research on urban water self-supply, this approach is increasingly promoted in rural Sub-Saharan Africa, mainly by the Rural Water Supply Network (see, for instance, Sutton 2009).[48] In one such study, self-supply is described as follows:

> "Self supply builds on the widespread desire of the rural poor to invest in solutions which benefit their small group or household directly, rather than as members of what are often scattered or discordant communities. Its components include improved availability of water from increased numbers of supplies (traditional source promotion, rainwater harvesting), improved water quality (source protection, improved water collection and storage practices, household water treatment), and improved water lifting for productive use.
>
> Self-supply offers the choice of technology, progressive upgrading, and replicability with little, if any, dependence on outside funds, enabling it to bring rapid and significant improvements to the lives of millions of people. It is complementary to communal supplies, allowing response to the communities which are too small to qualify for expensive protected supplies, and for those people in areas where groundwater is plentiful and most houses have their own convenient and 'personal' water source, which they are reluctant to abandon in favour of communal supplies over which they have no control and which are further from their homes" (Sutton 2004:1f).

The above definition departs from seeing the rural poor as self-organising, with minimal dependence on outside actors or funding. In some rural projects, however, notably those focusing on improving existing traditional water sources, the involvement of funding agencies would be crucial.

Many of these findings about rural self-supply can be applied to the urban context. In one study of a Nigerian city, self-supply systems were defined as 'privately owned household level water sources'. Initiatives at local level by individuals or households to improve their own water supplies were generally found to be unregulated, and lacking in the skills needed to investigate potential risks to water sources, leading to water quality problems (Kilanko-Oluwasanya 2009).

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[48] See the Rural Water Supply Network, www.rwsn.ch/prarticle.2005-10-25.9856177177/prarticle.2005-10-26.3194167899 (accessed June 2010).

Our definition of urban self-supply of water recognises that a large proportion of the urban poor depend directly on groundwater, providing for their basic and other water needs by using wells of different kinds. For this group, the act of self-supplying often simply means sourcing water from where it can be found. As in Kilanko-Oluwasanya's study, we therefore also recognise as self-supply the act of fetching (or purchasing) groundwater from shared wells and even other people's private wells. This is the case even though the end-user makes no investment in the well and does not contribute to safeguarding the resource by rainwater harvesting or other means.

There is a grey area in our definition of urban self-supply. Self-supply in the urban context may rely on financial support from donors to implement programmes and packages. In particular, the construction of shared wells such as boreholes can seldom be made without the financial, technical and other help from actors with the necessary means. People who rely on groundwater via public taps and standpipes or purchase it from a private vendor do not have the influence over the source that they would if they had access to their own or a shared well. However, they are not, or not adequately, served by the public system and consequently must therefore for their own needs; therefore we include this within the definition of self-supply.

Whether urban poor people use their own dug, shallow wells because they are forced to fend for themselves, or while waiting for water supply services to be offered to them (or indeed continue to use their existing wells although connected to the piped-water network to save money; Hadipuro and Indriyanti 2009), having a well of one's own provides freedom and great savings of time, energy, and often money. Shallow dug wells are often simple structures[49] that the users can construct and maintain themselves, meaning that their 'functional sustainability' is high; they can also be kept in a good state of repair in the long run (Carter and Bevan 2008).

A number of potential difficulties remain for those thus depending on groundwater. The reliability of the aquifers to yield water can be expressed as a success or failure at the point and time of construction. The sustainability of the well, once constructed, depends on increasing and changing types of demand; variability and intensity of precipitation; current and changing recharge potential; land use changes, and so on. Water availability may decrease due to the competitive construction and deepening of nearby wells and during dry periods (whether season or years) when recharge is insufficient. The uncertainties surrounding seasonal and intra-annual precipitation variability are also growing with anthropogenic climate change. In addition, most urban well-users will encounter inherent or gradually deteriorating water quality. Unprotected dug wells (lacking a raised inside lining or casing; and/or is reasonably sealed by a cement or concrete apron at the surface) do constitute a higher risk of contamination from sources of faecal matter such as on-site sanitation facilities and local solid waste. Measures to protect the aquifers as such from contamination are also vital, especially where the water table is shallow and the soil highly permeable. Cement and similar materials may be unaffordable, though, and it may be difficult to increase the distance between the waste disposal point or latrine and the well, in areas where space is limited.

Dug, unprotected wells can be upgraded at a later date by lining and covering; such work is done, for instance, in Zimbabwe where the public water supply and sanitation system has broken down from negligence and lack of funding during the recent regime. However, although the upgrading of unimproved dug wells seems an appropriate way to improve water

[49] Wells can normally be dug by hand in weathered regolith layers with clay, sand, gravel or mixed types of soils and with only small boulders present, where the water table is no deeper than 15 metres. For such a deep, hand-dug well the excavation would need to be about 1.5 metres in diameter, meaning that it may be impractical to dig deep new wells in densely populated urban areas (Richard Carter, pers. comm.). The extremely shallow dug wells in Lusaka are up to about five metres deep.

quality in theory, such measures may be too expensive, and will not prevent contamination of the groundwater as such. The water taken from wells may therefore remain unsafe from a potability point of view (R. Carter, personal communication, March 29, 2010). It is also untenable in most urban settlements and slum areas as there is too little space (D.C.W. Nkhuwa, personal communication, March 30, 2010).

Nonetheless, increased access to water from wells is more important than the water's quality. Water from wells that are not sufficiently protected may need more treatment at point-of-use, and may need to be supplemented by potable water from another source, at least during the rainy season and for children below the age of five whose immune systems are not fully developed. Domestic and local hygiene are all the more important in these cases. Furthermore, these responses need to be adopted by entire neighbourhoods or communities collectively where, for instance, faecal-oral diseases are endemic; otherwise it is difficult for individuals to protect themselves and their families (cf. McGranahan 2007).

The best option is for residents of low-income settlements to develop holistic measures themselves, in order to safeguard the resilience of aquifers, wells, and their own living environment.[50] Although government authorities cannot shy away from having primary responsibility to ensure *safe* water as a human right, in practice they will often fall short. Other actors who step in (NGOs, donors, and so on) will probably lack a holistic, long-term perspective and financial stability, but may instead contribute to building resilience and a higher degree of self-reliance in deprived urban neighbourhoods.

The concept of self-supply in the urban context proposed here is less comprehensive than that developed by the Rural Water Supply Network, whose approach includes improvements to water supply through user investment in household water treatment, well construction and up-grading, source protection and rainwater harvesting. The main aspects of this approach are, nevertheless, "not hardware. Self supply promotes enabling policies and government and NGO support to households and small communities which wish to invest in their own supplies" (Sutton 2004:2).This is the trend that we would also like to see in the urban environment. Further studies as well as actual policy implementation are needed in this regard.

5.2.2 Interventions: regulations and control for sustainability and equity

Regulating the use of groundwater is often seen as politically sensitive and therefore avoided. For instance, under Indian law as well as according to well-established community norms, a landlord is also seen as a 'water-lord' because there are essentially no limitations on a landowners' right to withdraw groundwater (Grönwall 2008). In many cities it may also be considered practically impossible or simply too costly to follow up regulations on private wells, due to their sheer numbers, especially those that are unregistered.[51] In spite of the fact that from a legal perspective groundwater is considered public property in many parts of the world, and therefore cannot be privately owned, policy-decisions relating to groundwater (amongst other things, to preserve groundwater quality, to conserve available resources or to otherwise control withdrawals from private wells) are often perceived by landowners as trespassing on their lawful right to access their 'own' groundwater. Similarly, when landowners and others have a vital dependence on groundwater, measures which seem to infringe on their access to it may lead to protests and social conflict.

[50] A discussion of community-driven and participatory measures lies outside the scope of this paper.
[51] In addition, it is interesting to note that developed countries often take this approach as well. For instance, in England and Wales small abstractions (less than $20m^3$/day) do not have to be licensed, and so are effectively unregulated. It therefore becomes difficult to develop accurate water balances (R. Boak, personal communication, June 15, 2010).

There are, nonetheless, calls to also make the registration of new and existing wells compulsory for urban wells used for household purposes alone (Foster, Tuinhof et al. 2008; Stephen Foster, personal communication, March 19, 2010; Richard Carter, personal communication, March 29, 2010). Information on the main lithological[52] and regolith units, water table depth and other relevant details may also need to become compulsory for these urban household wells. Though fairly poor compliance could be expected with these rules, even using costly control mechanisms, the improved monitoring of private wells would contribute substantially to the amount of data available and therefore increase knowledge levels to a more satisfactory degree.

Improved data collection about local hydrogeological conditions such as the water table, the regolith,[53] and so on, and regular monitoring of an increased number of wells would contribute substantially to an understanding of groundwater occurrence. With a greater wealth of knowledge comes an increased potential for improved management, a goal pertinent to all kinds of future groundwater use.

However, monitoring should not be done for its own sake. The institutional capacity to assess and process the information and disseminate it needs to be in place as well. Technical knowhow as well as soft skills, for instance the ability to teach good hygiene practice, is also needed. Today's general and specific gaps in knowledge about groundwater as a natural resource are an obstacle to implementing integrated, holistic measures. The problem can partly be attributed to groundwater posing special administrative problems for government authorities because the issues don't fit entirely within the mandate of a single department or even a single authority. As a resource, groundwater is therefore often far from being managed in a holistic manner. It therefore seems clear that the management of urban groundwater resources in both the short and long term depends on increasing state control – including introducing appropriate minimal drilling regulations, and sometimes even more far-reaching constraints in groundwater development – as well as improving state control, based on monitoring and well-data collection.

Management and good governance in relation to groundwater depend on the existence of political will to take measures. It should not, on the other hand, involve authorities seeking to prevent, close or ban urban wells (as in Lusaka) – at least where it cannot be established that water in the local aquifers is so contaminated that continued use of it constitutes a health hazard (S. Foster, personal communication, March 19, 2010). The authorities may regard such an intervention as the right thing to do to hinder outbreaks of water-borne and water-related diseases. However, to avoid accusations of double standards in their efforts to improve public health, the same guidelines for safe water must also apply to those who are not served by the public utility or equivalent. In a city like Lusaka, such a ban is likely to fail in any case; people with shallow dug wells are rather innovative at hiding them from health inspectors and surveyors when they feel they have no alternative.

There is a more realistic and pro-active way of handling a situation where a proportion of the population depends directly on groundwater that is deemed unsafe. That is to take into account alternative sources; to find the extent of actual point-of-use treatment of the water; and to adequately address all aspects of excreta and solid waste disposal in the local environment, effectively preventing disease and promoting well-being.

An integrated approach is equally important where groundwater abstractions deplete (or are estimated to deplete) the aquifers, but the question of sustainability is complex. The general potential for developing groundwater for urban domestic use may seem good in Sub-Saharan Africa if compared to irrigation, which relies on much larger volumes. There is an even greater contrast with aquifers under cities in India and several other South Asian countries, where high-technology drilling equipment has been used intensely, subjecting the aquifers to increasing pressure, for the past 30 years. For the sake of comparison, in Bangalore the Water Board draws water from more than 10,000 wells (mostly with submersible pumps) whereas in the whole of Uganda there are possibly around 20,000 boreholes, the vast majority of which are equipped with hand-pumps that yield only around 0.3 l/s (R. Taylor, personal communication, March 8, 2010). This helps to explain why, in cities like Bangalore with low-yielding crystalline bedrock, the competition over the available groundwater is so high that wells need to be drilled down to 200 metres and sometimes deeper to obtain the desired volume from faults and joints, until the rock becomes consolidated and is no longer water-bearing (aquiclude). With the continued competitive deepening and drilling of more wells, the cost of extracting groundwater will rise until the total yield becomes so low that it is no longer financially justifiable to continue deepening the wells.

As this paper has pointed out, groundwater remains a hidden asset in local, national and international planning and decision-making in spite of the increasing reliance on this resource, both directly and indirectly via a public utility. Cities where many of the inhabitants use water from stand-alone wells need to manage and protect the groundwater resources to a much higher degree than at present. Competent authorities must therefore intervene in various ways, by taking measures for the sake of safeguarding both public health and the environment, through information, awareness raising, education and guidelines as well as legislation. Particularly as groundwater is often of great importance to the urban poor, greater efforts need to be made to improve everyone's access to safe water from sustainable sources. The role of groundwater – whether it is self-supplied, a joint community solution or part of a utility's conjunctive use of various water sources – needs more attention and a higher level of protection.

The authors of this paper encountered a shortage of information on urban groundwater issues, underlining the fact that this area is inadequately researched. Scientists in the field stress the lack of baseline data on aquifers, groundwater and wells especially in low- and middle-income countries, and the International Association of Hydrogeologists have responded by setting up a Commission on groundwater and climate change, in an effort to gain more knowledge of the subject.[54] Increasingly, experts point out that further groundwater development is necessary, yet the role of groundwater for the urban poor continues to be neglected both by the research community and by the authorities. It is hoped that this paper will help to put a spotlight on the issue.

[54] See www.iah.org/gwclimate/gw_cc.html.

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APPENDIX A

Table A. 1 Principal urban household drinking water sources in Africa, South and Southeast Asia, and Latin America and the Caribbean

		Principal household water source		
	Urban population (10^3)	Well water (% hhs)	Piped water (% hhs)	Other (% hhs)
Liberia 2007	2,239	70	18	12
Nigeria 2008	73,108	59	20	21
Mozambique 2003	5,856	35	59	6
Chad 2004	2,434	32	42	26
Uganda 2001	3,103	32	63	5
Mali 2006	3,712	30	69	1
Guinea 2005	2,970	29	68	4
Benin 2006	3,536	28	66	6
Malawi 2004	2,175	24	74	2
Madagascar 03-04	5,115	19	65	16
Zambia 2007	4,206	18	77	5
Rwanda 2005	1,999	18	55	27
Tanzania 2004-05	9,313	18	68	15
Cameroon 2004	9,280	15	69	16
Angola 2006-07	9,483	14	43	43
Ghana 2008	11,947	13	66	21
Congo Dem Rep 2007	20,873	13	59	28
Kenya 2003	6,870	12	71	17
Burkina Faso 2003	2,303	11	89	1
Ethiopia 2005	12,687	8	90	2
Lesotho 2004	443	8	90	1
Senegal 2005	5,710	8	89	3
Niger 2006	2,248	7	91	2
Swaziland 2006-07	281	7	88	6
Congo (Brazzaville) 2005	2,172	6	87	7
Zimbabwe 2005-06	4,813	3	97	0
Gabon 2000	948	2	93	5
Namibia 2006-07	750	0	97	3
South and Southeast Asia (in inverse order of urban share using wells)				
Bangladesh 2007	42,162	69	30	1
Indonesia 2007	16,346	46	27	28
Nepal 2006	4,482	39	51	10
Cambodia 2000	2,161	37	35	28
Pakistan 2006-07	58,591	27	66	7
India 2005-06	333,438	26	71	3
Vietnam 2002	20,445	20	76	4
Philippines 2008	58,096	17	41	41
Latin America and the Caribbean (in inverse order of urban share using wells)				
Haiti 2005-06	3,974	18	52	30
Nicaragua 2001	2,846	7	91	3
Bolivia 2003	5,582	5	90	5
Peru 2000	18,141	4	88	8
Honduras 2005-06	3,177	2	49	49

Cont over

Colombia 2005	33,071	1	92	7
Dominican Rep 2007	6,653	1	18	82

Source: The urban population figures for each country in the survey year were taken from United Nations database (http://esa.un.org/unup/) and are based on United Nations Population Division (2008) *World Urbanization Prospects: The 2007 Revision*, United Nations Department of Economic and Social Affairs, New York. The urban household shares by principal drinking water source are from the Demographic and Health Surveys for the years mentioned (see http://www.measuredhs.com). The last category of supply groups includes surface water, rainwater, tanker truck water, and bottled water.

Table A. 2 Comparing rural and urban shares of households using wells as their main drinking water source - Africa, South and Southeast Asia and Latin America and the Caribbean

	Share of households using wells as their main water source	
	Urban (% hhs)	Rural (% hhs)
Sub-Saharan Africa		
Liberia 2007	70	67
Nigeria 2008	59	57
Mozambique 2003	35	73
Chad 2004	32	72
Uganda 2001	32	72
Mali 2006	30	87
Guinea 2005	29	58
Benin 2006	28	52
Malawi 2004	24	78
Madagascar 03-04	19	23
Zambia 2007	18	63
Rwanda 2005	18	20
Tanzania 2004-05	18	45
Cameroon 2004	15	46
Angola 2006-07	14	30
Ghana 2008	13	56
Congo Dem Rep 2007	13	6
Kenya 2003	12	21
Burkina Faso 2003	11	78
Ethiopia 2005	8	57
Lesotho 2004	8	38
Senegal 2005	8	55
Niger 2006	7	90
Swaziland 2006-07	7	27
Congo (Brazzaville) 2005	6	25
Zimbabwe 2005-06	3	73
Gabon 2000	2	21
Namibia 2006-07	0	26
South and Southeast Asia		
Bangladesh 2007	69	97
Indonesia 2007	46	57
Nepal 2006	39	42
		Cont over

Cambodia 2000	37	60
Pakistan 2006-07	27	69
India 2005-06	26	68
Vietnam 2002	20	63
Philippines 2008	17	42
Latin America and the Caribbean		
Haiti 2005-06	18	15
Nicaragua 2001	7	35
Bolivia 2003	5	20
Peru 2000	4	12
Honduras 2005-06	2	25
Colombia 2005	1	10
Dominican Rep 2007	1	5

Source: These estimates are from the Demographic and Health Surveys for the years mentioned (see http://www.measuredhs.com)

Table A. 3 Shares of urban households using wells as their principal drinking water source by wealth quintile

	Q1	Q2	Q3	Q4	Q5
Sub-Saharan Africa (in inverse order of urban share in poorest quintile using wells)					
Liberia 2007*	78	70	68	63	67
Nigeria 2008*	62	61	60	58	53
Mozambique 2003	60	53	30	26	9
Benin 2006	57	40	22	12	10
Uganda 2001	55	45	32	17	12
Guinea 2005	55	37	19	17	11
Mali 2006	55	46	29	15	6
Chad 2004	49	36	33	24	17
Angola 2006-07	41	18	8	4	1
Malawi 2004	39	48	18	10	3
Zambia 2007*	36	21	14	9	10
Madagascar 03-04*	34	20	20	11	12
Cameroon 2004	34	17	11	8	5
Kenya 2003	30	16	11	4	2
Tanzania 2004-05	30	23	14	14	8
Senegal 2005	29	7	3	2	0
Ghana 2008*	28	13	12	8	5
Ethiopia 2005*	25	12	3	1	0
Rwanda 2005	24	22	20	15	9
Burkina Faso 2003	22	13	11	4	1
Congo Dem Rep 2007	18	24	16	6	1
Swaziland 2006-07*	16	11	2	2	2
Lesotho 2004	16	11	7	6	2
Niger 2006	15	14	5	3	1
Congo (Brazzaville) 2005	12	9	3	2	2
Zimbabwe 2005-06*	10	1	0	1	1
Gabon 2000	6	3	2	1	0
Namibia 2006-07	1	0	0	0	0

Cont over

South and Southeast Asia (in inverse order of urban share in poorest quintile using wells)					
Bangladesh 2007*	97	90	53	62	45
Cambodia 2000	59	46	41	33	7
Indonesia 2007	58	52	40	46	28
Nepal 2006 *	54	57	46	14	17
India 2005-06	39	28	25	15	23
Philippines 2008 *	27	18	10	0	14
Latin America and Caribbean (in inverse order of urban share in poorest quintile using wells)					
Haiti 2005-06 *	27	24	21	13	8
Bolivia 2003*	16	5	3	1	0
Peru 2000 *	11	6	4	1	0
Nicaragua 2001*	11	13	8	5	0
Honduras 2005-06 *	6	3	2	1	1
Colombia 2005*	2	1	1	1	1
Dominican Rep 2007	1	1	0	0	0

Source: These estimates are from the Demographic and Health Surveys for the years mentioned (see http://www.measuredhs.com). The wealth quintiles are based on the DHS wealth index, applied to weighted DHS urban samples. Pakistan and Vietnam have been omitted from this table due to data problems.

Table A. 4 Survey results indicating changes in the shares of urban households depending primarily on well water for drinking between 1990 and 2008

	90	91	92	93	94	95	96	97	98	99	00	01	02	03	04	05	06	07	08
Sub-Saharan Africa																			
Benin							34					26					28		
Burkina Faso				23					21					11					
Cameroon		14							11						15				
Ghana				14					9					19					13
Kenya				3					7					12					
Madagascar			14					20						19					
Malawi			16								15				24				
Mali						50						39					30		
Namibia			3								0						0		
Niger			8						7								7		
Nigeria										27				47					59
Rwanda			0								5					18			
Senegal			14					13								8			11
Tanzania		13					14			13					18				
Zambia			9				16					16						18	
Zimbabwe					2					2						3			
South and Southeast Asia																			
Bangladesh				63			60			69					68			69	
India			27						24							26			
Indonesia		55			59			56					56					46	
Nepal							36					42					39		
Philippines									27					19					17
Latin America and the Caribbean																			
Bolivia					5				3					5					
Colombia	0					1					1					1			
Dominican Rep		0					0			0			1					1	
Haiti					10						9					18			
Peru		6					4				4								
Note: Only countries where at least three DHS surveys have been conducted between 1990 and 2008 are included in this table.																			

Source: The urban household shares using wells as their principal drinking water source are from the Demographic and Health Surveys for the years mentioned (see http://www.measuredhs.com).

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