Implications of Urban Development for Water Demand, Wastewater Generation and Reuse in Water-Stressed Cities

Case studies from South Asia and sub-Saharan Africa

By

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ABSTRACT

Urbanisation has become one of the strongest drivers of growing challenges in the fields of food security, human health and water resources management. Water management is especially more difficult in rapidly growing cities in non-industrialised countries where local authorities typically have insufficient financial and managerial capacities to respond to the basic needs of its citizens. This PhD thesis addresses the research needs for growing cities in non-industrialised countries and their impact on current and future urban water demand, wastewater generation and reuse. It is argued that demographic growth and investments in water supply and sanitation infrastructure are increasingly influencing upstream and downstream water users and the environment in the water basin. Cross-comparative case study methodology was applied, having quantitative and qualitative research components. The qualitative research involved data collection through semi-structured interviews of local experts while the quantitative research consists of data collection from literature and simple urban water balance modelling. The cities of Accra [Ghana], Hyderabad [India] and Addis Ababa [Ethiopia] were selected as case studies.

The cities share a number of characteristics typical for the current state of the water system and are detrimental factors for future development. A series of water supply expansion projects were carried out in an effort to keep up with fast rising water demands. Similar investments in sanitation and wastewater disposal, however, were not made, due a lack of priority and indistinct governmental responsibilities. Despite considerable expansion of wastewater treatment to be expected in all cities, the untreated wastewater volume will continue to rise in two cases. Depending on the downstream setting, a considerable fraction of this wastewater is reused in urban agriculture (up to 90%). This has not only brought huge benefits to many farmers but also entailed health risks from exposure to pathogens and environmental degradation. Cities have shifted their use from groundwater to surface water and moved away further from the city to exploit new water sources. However, the latter crucially depends on the financial capacity of the water utility to invest in expansion projects.

The presented cases have shown that cities are increasingly influencing the upstream and downstream areas through urban water withdrawal and disposal of wastewater and stormwater. The

institutional environment and state of water resources are considered detrimental in the future development of water supply and sanitation in these cities. The combination of tools applied in this research is found to be an appropriate and effective methodology to investigate the urban water balance of fast growing water-stressed cities in developing countries. Urban water balance modelling and scenario development are very suitable tools for local planners and decision makers to adopt and apply in their respective cities.

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LIST OF ABBREVIATIONS

AAU	Addis Ababa University
AAWSA	Addis Ababa Water Supply and Sewerage Authority
AfDB	African Development Bank
AMA	Accra Metropolitan Area
APPCB	Andhra Pradesh Pollution Control Board
ATMA	Accra Tema Metropolitan Area
AVRL	Aqua Vitens Rand Limited
BOD	Biological Oxygen Demand
CPCB	Central Pollution Control Board
DHS	Demographic and Health Survey
DPSIR	Driving forces, Pressures, State, Impacts and Responses
EPA	Environmental Pollution Authority (Ethiopia)
EPA	Environmental Protection Agency (India)
GAR	Greater Accra Region
GIS	Geographic Information System
GWCL	Ghana Water Company Limited
GWSC	Ghana Water and Sewerage Corporation
HCES	Household Centred Environmental Sanitation
HMWSSB	Hyderabad Metropolitan Water Supply and Sewerage Board
HUDA	Hyderabad Urban Development Agency
IUWM	Integrated Urban Water Management
IUWRM	Integrated Urban Water Resources Management
IWMI	International Water Management Institute
IWRM	Integrated Water Resources Management
KLERP	Korle Lagoon Ecological Restoration Project
lpcd	litres per capita per day
MCH	Municipal Corporation of Hyderabad
MDG	Millennium Development Goal
PSP	Private Sector Participation
PURC	Public Utilities Regulatory Commission

SBPDA	Sanitation Beautification and Parks Development Agency
SMURF	System for Monitoring Urban Functionalities
STP	Sewage Treatment Plant
SWE	small-scale water enterprises
SWITCH	Sustainable Water Management in the City of the Future
TSS	Tema Sewerage System
TSS	Total Suspended Solids
UNCSD	United Nations Commission on Sustainable Development
UVQ	Urban Volume and Quality
VENSIM	Ventana Systems Environment©
WRC	Water Resources Commission

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1. INTRODUCTION

1.1 BACKGROUND TO THE RESEARCH

Since the second half of the 20th century, the process of urbanisation has been one of the most fundamental drivers that contribute to the growing challenges in the field of food security, human health and management of water resources. The growing concentration of the world population in increasingly densifying urban areas also poses a challenge to the provision of potable water and the disposal of solid and liquid waste. In industrialised countries where population growth has stabilised, sufficient financial and managerial capacity now exists to deal with it. Many governments of non-industrialised countries however are currently facing high growth rates of the urban population; 3.2% in Africa and 2.3% Asia versus less than 0.5% in the more developed regions (UN 2004). These governments are having insufficient managerial and financial resources to provide urban areas with adequate water supply and sanitation services. The near absence of treatment of domestic and industrial wastewater is also causing the pollution of water sources in and around cities, entailing risks to human health and environmental degradation.

Increases in both water supply and subsequent wastewater generation entail higher fluxes on the water balance, which may burden the physical water system (supply and disposal side) and may outpace existing water management capacities. Unless wastewater treatment sees expansion on a similar scale, the growing wastewater volume could pose a higher burden on human health and the environment. The reuse of wastewater in urban and peri-urban irrigated agriculture could reduce to some extent the pressing water stress that exists in the city since freshwater is saved when residual water is reused.

1.2 RATIONALE AND CONTEXT OF RESEARCH

Research rationale

Fast population growth and expansion of cities in developing countries is a relatively new phenomenon. Research on the implications of urbanisation in typical low-income urban agglomerations for the management of urban water resources has only recently started to gain attention. This type of research is considered as needed, given the expected impact of urban growth and urban water use on the city and basin water balance in developing countries (Niemczynowicz 1999b; Lundqvist et al. 2003; Sahely et al. 2005; Biswas 2006a; Varis 2006). Findings based on this type of research could eventually contribute to improving urban water management and planning capacities, and the development of policy, in order to anticipate water crises.

Decision makers in urban water planning and policy in cities in developing countries often lack sufficient analytical capacities to anticipate to the rapid demographic changes of their cities. The data and analytical tools that are needed to understand the dynamics of the urban water system are often of poor quality, unreliable and scattered across different institutions. Current planning in these cities is not well enough rationalised and are not adjusted to plausible scenarios. Assessments of plausible urban development scenarios and research on their consequences to the urban water balance could help understanding the urban water system dynamics in a context of low-data availability. Also, the cities have little history planning and modelling, which limits the opportunities to draw on previous experiences. Lessons may be learned from experiences in cities in a similar context. At the same time, economic water scarcity is apparent in these under-managed cities and physical limits to water availability may be approaching in basins from which these cities withdraw water.

The situation of water-stressed cities as drawn above supports the urgency to test, apply and disseminate urban water planning and management tools for decision support in cities in developing countries.

Research context

The research is embedded in three thematic areas, namely basin water management, urban water supply and wastewater disposal, and agricultural water use (Figure 1). Basin water management is related to the cities' assessment with the 'cities-in-a-basin-context. Urban water supply and wastewater disposal are addressed in relation to urban water demand, by applying urban water balance modelling. Agricultural water use is addressed through examining urban wastewater irrigation and possible competition between urban water use and agriculture.

The physical domain of this research was set in three cities in different countries, namely Hyderabad in India, Addis Ababa in Ethiopia and Accra in Ghana. The three cities were chosen for reasons of research interest and practical feasibility. In terms of research, the three cities are interesting for the following reasons: all cities [a] undergo fast urban growth and development, [b] have serious water issues and deficiencies in planning, and [c] management of water is greatly constrained by insufficient financial and institutional capacities. Fieldwork was coordinated and facilitated from local offices of the International Water Management Institute (IWMI). The presence of IWMI offices in each of the three cities was an added advantage, as the existing knowledge networks could be used for data collection.

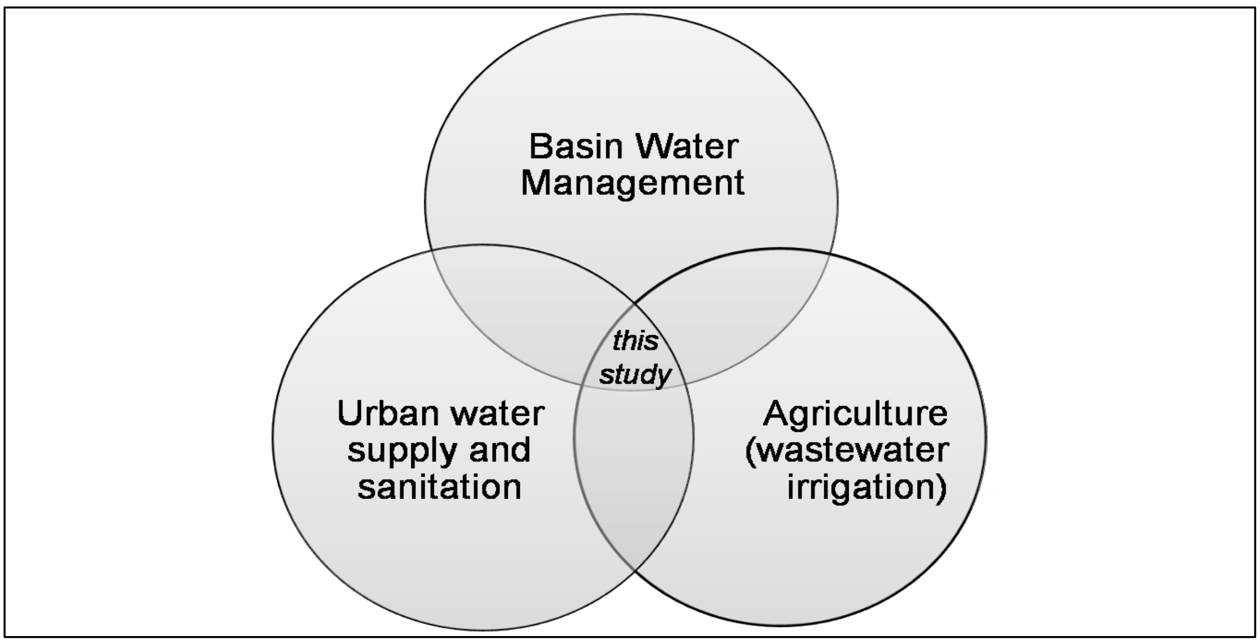

Figure 1. Venn diagram of the research context; convergence of three research areas.

1.3 RESEARCH DESIGN

1.3.1 Research Aim

The aim of this research is to develop and validate a mix of effective research tools for investigating the urban water balance of fast growing water-stressed cities in developing countries with limited data available.

This mix consists of the following tools:

1. Historical analysis
2. Semi-structured interviews
3. Urban water balance modelling
4. Scenario development
5. Comparative analysis (by triangulation)

The term *mix* implies here that the tools are necessary *ingredients* in order to produce a multi-disciplinary methodology. The tools also complement each other and are used simultaneously in order to reach the research objectives. A detailed description of the research tools is given in section chapter three (3.3).

The tools listed above have been applied to specific research objectives (see next section). The rationale behind applying this set of tools is based on the argument that in order to truly understand the urban water system, it should be approached as a case study including multi-disciplinary tools. This multi-disciplinary approach is based on (1) hydrological water balance modelling, and (2) socio-economic assessment of the processes that underlie the management of urban infrastructure and services.

The research design has a specific focus on large cities in developing countries and was applied in three cities that share the same characteristics as mentioned previously in the research context. This analysis researches the links between urban water and basin water availability and attempts to reveal the possible limits to urban development. The dynamics of the urban water balance is regarded as a powerful and effective tool to gain insight into the possible ways in which cities increasingly influence water availability in the catchment. In this research the urban water balance is modelled using the open source software VENSIM, which has the potential to provide practical decision support to local planners, practitioners and policy makers.

1.3.2 Research Objectives

The aim of this research was reached through five research objectives, which were investigated through applying the five research tools listed in the previous section. The objectives, as listed below, are supported with a short rationale and mentioning of the specific tools that were applied to address them.

1. **To understand the temporal development of water supply and sanitation in the cities, and assess current needs through evaluating urban water supply and sanitation development as they relate to demographic growth.**

City population growth and industrialisation possibly in addition to growing per capita domestic water demand increase water demand at the city level. The growing city water demand has been the main push factor for upgrading water supply for growing cities. Predicting future water-related developments requires an understanding of the past and an assessment of the present situation. Historical analysis and semi-structured interviewing were applied in order to reach this objective.

2. To compose an urban water balance on the basis of the most important urban water flows.

The development of urban water supply and sanitation has an impact on water flows within and around cities. The water balance as a concept can be used to get a better understanding of the various water flows that enter and leave the city boundaries and thereby better target interventions in the existing system or improve design for new systems. Urban water balance modelling was applied in order to reach this objective.

3. To predict water demand for different scenarios of demographic growth, change in living standards, and options for water and sanitation investments.

The analysis of future water demand will give insight into the maximum additional volume of water that is needed to meet growing urban water demands. Future urban water demand can be modelled with current data on urban water coupled with an understanding of the institutional and physical environments. Scenario analysis was applied in order to reach this objective.

4. To assess the implications of different scenarios of development and the consequent wastewater flows, for wastewater irrigation potential and risks.

At present, most of the wastewater generated in the cities is discharged without treatment, before it is partly reused in agriculture. The impact of different scenarios generated from objective 3 will be utilised to understand the implications for wastewater irrigation. The emphasis will be on the 'potential' for irrigation, based merely on the availability of wastewater. In order to reach this objective, the research tools scenario analysis and urban water balance modelling were used.

5. To assess the impact of the urban water balance on water availability for agriculture at the basin level.

Assessment of the future urban water balance from a basin perspective can provide insight into the extent to which urban water demands will affect water availability for agriculture. In order to reach this objective, the research tools scenario analysis and urban water balance modelling have been applied.

1.4 THESIS STRUCTURE

The thesis has a straightforward and classic structure (Figure 2). The first chapter, the introduction, gives the background to the research, and lays out the research aim and objectives. Chapter two, the literature review, describes the body of related research carried out to date. The next chapter, the methodology, sets out the methods and approaches that were used for carrying out the research. The following three chapters (4-6), represent the results section. Each chapter represents one of the three case studies done, namely Hyderabad (chapter 4), Accra (chapter 5) and Addis Ababa (chapter 6). Chapter 7 discusses the results; and how the findings compare with those in the existing literature described in chapter 2. It also compares the results between the city case studies and tries to conceptualise the findings into a framework. It further describes to what extent the research can be applied elsewhere. The final chapter (8) draws conclusions based on the research results.

Links between the chapters

Each chapter presented, follows a logical order in the thesis. Some of the chapters link back to previous chapters, which are briefly described here. The literature review (chapter 2) and research methodology (chapter 3) emerge from the research context and design, respectively, presented in the introduction (chapter 1). Each of the results of chapters 4-6 presents the findings from the case studies based on methodology described in chapter 3. The results chapters follow the same structure and order as the research objectives and questions presented in the introduction. The next chapter, the discussion, compares the results of each case study presented earlier. The last chapter, the conclusion is linked with both the results chapters and the discussion as it extracts and formulates the key findings based upon the results and the discussion sections.

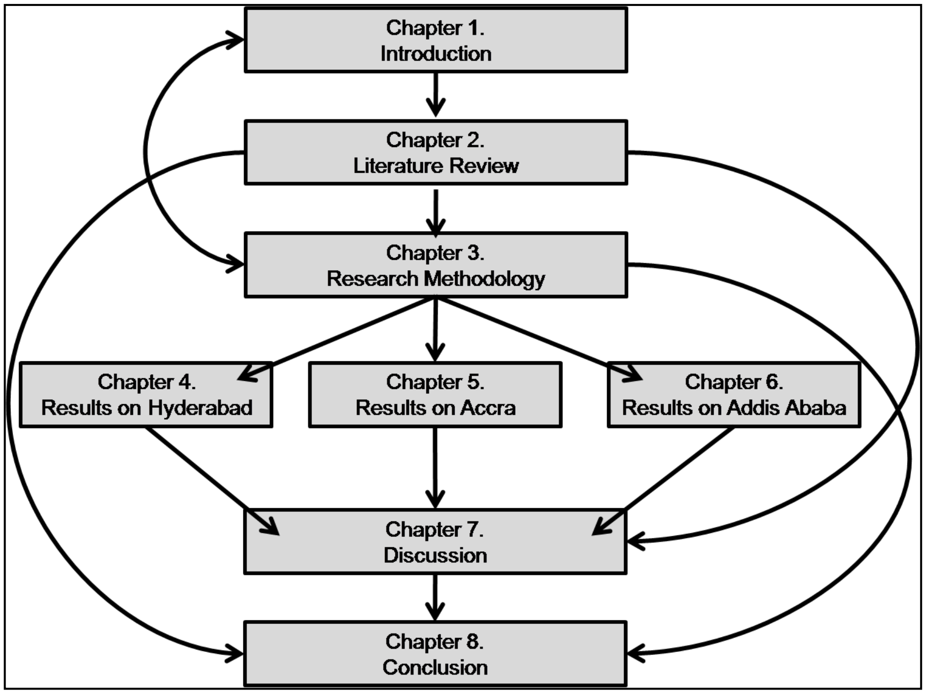

Figure 2. Structure of the thesis and links between chapters.

2. REVIEW OF URBAN DEVELOPMENT AND WATER RESOURCES USE

2.1 CHAPTER INTRODUCTION

This chapter provides an overview of literature published on urban water in relation to urbanisation, water demand and wastewater generation and reuse for cities in developing countries.

This PhD research addresses a relatively new research area in integrated urban water management (IUWM) which was founded in cities in the West. It is observed that lessons learnt in the West are applied to improve water management in cities in developing countries. At the end of the 1990s, researchers began arguing that components of the urban water system should not be regarded as separate units, but as an integral part of the whole urban system. Also there is a growing body of research that focuses on interaction of the urban area with a larger spatial area, crosses the urban-rural interface thereby impacting other use sectors and water availability at the basin level (Molden and Sakthivadivel 1999; Molle and Berkoff 2006). It is agreed among most researchers that a merely technocratic approach to urban water issues is not sufficient to deal with the current water-related issues. Catchy terms like capacity-building, sustainability and decision support are referred to as tools for 'improvement' of water management. However, the new school of IUWM is still in development; links between demographic growth, water supply, urban waste generation and reuse options in cities in developing countries have not been fully addressed. Debate exists as to which solutions would be most appropriate for very typical problems. Piped sewage infrastructure with centralised treatment or on-site sanitation facilities? How feasible is dry sanitation in low-income areas? What are the implications of different scenarios for water demand, supply and wastewater disposal in the larger context?

Essentially, more policy-support research in this area is needed on water provision and wastewater disposal which is better adapted to the prevailing conditions of growing cities in developing countries.

Water in cities as case studies

The water situation in cities has been discussed by continent for Africa (Showers 2002; Sibanda 2002; UN-Water/Africa 2006). A background paper on economic development and infrastructure (including water and sanitation) in Africa has been produced by (Weiss 2003). For Latin America, a comprehensive assessment of cities in relation to water has been provided by (Anton 1993). Asia seems to be the furthest ahead when it comes to availability of literature on water in cities. The Asian Development Bank has published a report with sector profiles of 18 Asian cities. Basic data like supply coverage, water price and 'per capita production' of water are provided (ADB 2004). The data give good indications of the performance of city water utilities in the selection of cities, although it remains merely a technocratic assessment of the water situation. Another ADB report assesses the sustainability of urbanisation in relation to those cities assessed for 12 Asian countries that are considered cases of good practice with the aim to disseminate cases of 'good practice'. Water is discussed as part of urban infrastructure and environmental issues (ADB 2006). The authors conclude that with further expansion of cities in Asia, environmental conditions will worsen if there is a shortfall in infrastructure. Technical solutions to the provision of most environmental services like water are well known, but can only be implemented through increased infrastructural investment and better maintenance, which require effective governance. The successful city case studies demonstrate the importance of enabling environments, good local governance and management to achieve sustainable development outcomes.

2.2 URBAN WATER MANAGEMENT IN DEVELOPING COUNTRIES; REVIEW OF TYPICAL ISSUES

The basics of urban water management do not differ fundamentally between industrialised and non-industrialised countries. However, a mix of economic, political, social and environmental factors is more pressing, making water management in developing countries far more challenging. These issues will be discussed in this chapter.

In non-industrialised countries, urban water supply and disposal are typically characterized by low-revenue for services delivered by water management companies. High water transmission and distribution losses, poor or no maintenance of systems (linked to low revenues) and poor or no treatment of wastewater are typical features. Water supply through the piped network is often intermittent and quality standards may not be secured. Figures for urban water supply and sanitation coverage are much lower than in industrialised countries. Coverage should also be interpreted with caution; it does not always mean that a toilet is available at home or that it is actually functioning. In sub-Saharan Africa, 62% of the urban population lives in slums, while this is 43% in South Asia (UN-Habitat 2008c). Conditions of water supply and sanitation are generally poor in these informal settlements. Water supply is driven by supply-oriented management and limited by the physical capacities of the water treatment, -supply and -distribution system. Those urban and (most of the) peri-urban areas not covered by the piped network are served by a variety of dynamic private water vendors who fill in the gap (Cudjoe and Okonski 2006; Kjellen and McGranahan 2006). In the absence of an underground sewerage network, wastewater is usually disposed through open gutters that drain into bigger channels or a river that runs through the city (Bahri 1999; Scott *et al.* 2004a; Raschid-Sally and Jayakody 2008). Open gutters create a direct health risk to the residents, as wastewater contains pathogens. Wastewater may end up in a lake, sea, and river or in the groundwater. Maintenance budget allocation and spending on the water supply and sewerage network are usually low, which is why most finances are directed to emergency operations and crisis management.

The trajectory of water supply and sanitation infrastructural development may be considered instructive in the light of structural and typical urban water issues faced in developing countries. Conventional western- type wastewater disposal and treatment are increasingly considered inappropriate for cities in developing countries (Niemczynowicz 1992; Niemczynowicz 1994; Varis and Somlyody 1997; Wright 1997; Zurbrügg et al. 2004). Suggested directions for infrastructural development in cities in developing countries remain equivocal. Conventional infrastructural development is considered inappropriate and only reaches the high- and middle-income areas in cities. A more sustainable approach to wastewater disposal and treatment is based on a set of technological alternatives provided that the economic, financial and institutional aspects are well- addressed.

The seventh Millennium Development Goal (MDG) is to ensure environmental sustainability. This goal includes target 10 to "*reduce by half the proportion of people without sustainable access to safe drinking water, by 2015*" (UN 2001). Target 11 is to have achieved a significant improvement in the lives of at least 100 million slum dwellers. One indicator of reaching this target is the proportion of people with access to improved sanitation. These goals have triggered a lot of attention and commitment from donors, governmental institutes and researchers. Concerns exist that, if the current trend continues to 2015, this target is not going to be met for sub-Saharan Africa, as the total number of people without proper water supply and sanitation are only increasing (WHO&UNICEF 2006).

One of the important notes to be drawn from the above is the fact that urban water issues typically have a multi-sectoral character in cause and impact. In this chapter, current issues are discussed by sector or discipline.

2.2.1 Population dynamics

The twentieth century has witnessed the most rapid population growth in human history. The highest growth rates can be seen now in the less-developed regions as it will be in the near future. Between 2005 and 2010 the total number people living in urban areas will exceed those living in rural areas. In the developing world, this equilibrium is expected to be reached between 2015 and 2020 with the medium- growth scenario (UN 2002). The urban population, or city population, has been growing for centuries and is expected to grow further in the next 25 years (Figure 3). Nearly all of the population growth is projected to take place in developing countries. Within developing countries, most growth will take place among the urban population. From 2005, out of the 1.9 billion additional people in the world to be expected in 2030, 1.3 billion or 71% will be living in urban areas in developing countries. Part of the growth of the urban population is the result of migration from rural areas. Urbanisation in developing countries is posing huge challenges for many aspects of sustainability of cities (Cohen 2006; UN-Habitat 2008c), which will be discussed in more detail further on.

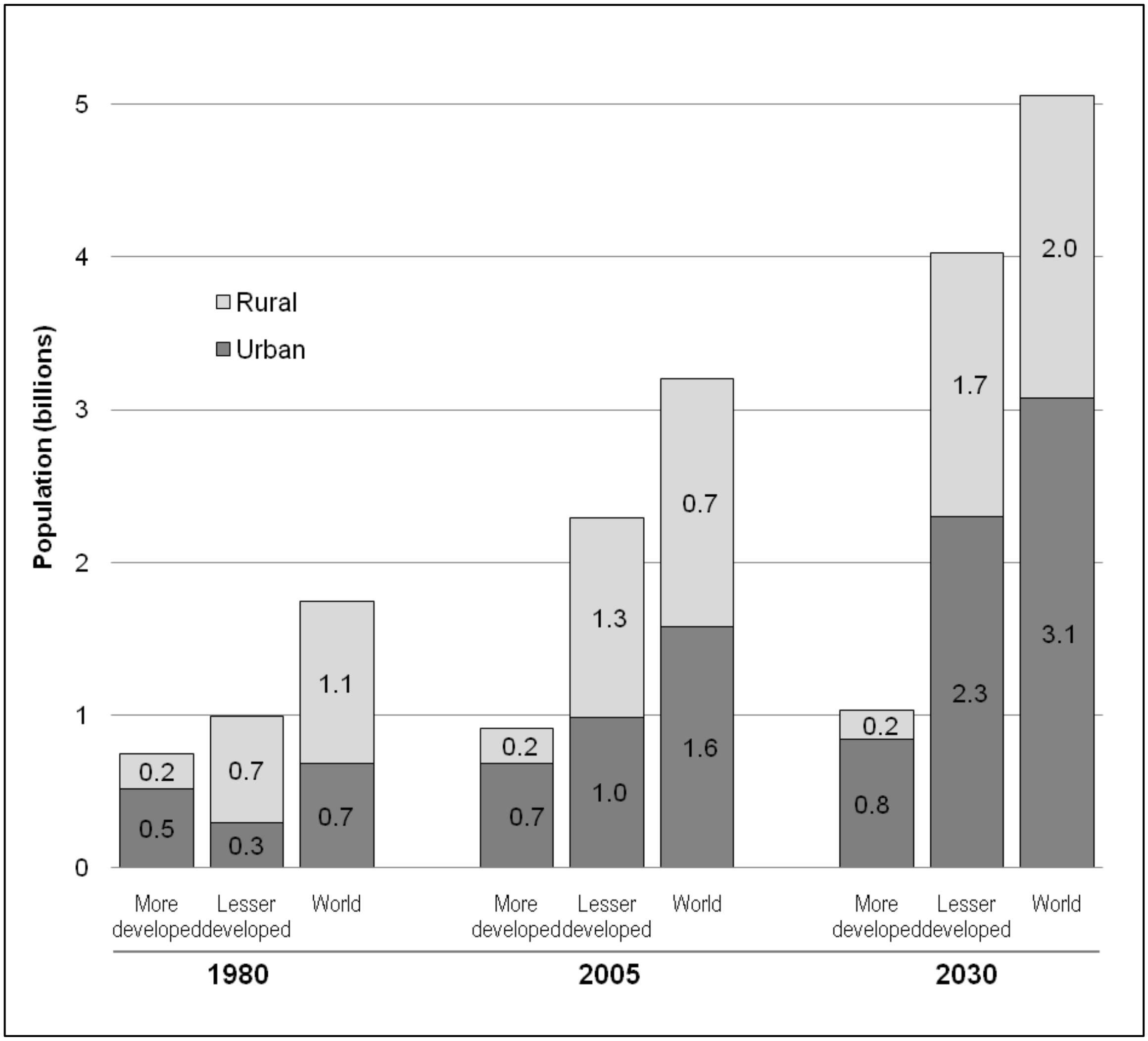

Figure 3. Urban population growth in the world and the more and less developed world in 1980, 2005 and 2030.

Source: Adapted from (UN 2006).

Population growth and economic development increase demand for water resources, so water management, especially the provision of safe drinking water and sanitation facilities, has become a priority in the sustainability agenda (UNFPA 2003). As a consequence of urbanization and economic development in urban areas, political priority is shifting from the rural to the urban areas.

The total population of a fast-growing city is generally considered difficult to estimate. There may be a systematic under-reporting of the population living in slums and other informal settlements. First of all, census data may be dated and *actual* or *present* population data may only be derived from extrapolation of most recent official data with urban growth estimates. Also, political boundaries of the urban area may have not been updated with newly urbanized areas in the peri-urban fringe (UN-Habitat 2008c). This difference can be significant with major implications for water and sanitation issues, which will be discussed further on.

2.2.2 Water stress in cities

Water stress has been concisely defined by Falkenmark *et al.*, (1989) as "*a too large population per unit of water available from the water cycle*". A clear difference exists between water stress and water scarcity, based on a shared indicator of a total volume of available water divided by a population number that uses this water. Water scarcity has been labelled to countries that face a condition in which the annual availability of internal renewable freshwater is 1,000 m^3 or less per person. Water stress, is a condition where annual availability of internal renewable freshwater is between 1,000 and 1,667 m^3 per person (Rijsberman 2006). Water stress and scarcity indicators have so far been applied to countries, regions and water basins.

IWMI distinguishes between physical and economic water scarcity (Comprehensive Assessment of Water Management in Agriculture 2007). Physical water scarcity occurs when there is simply not enough water to meet all demands. Hydraulic water infrastructure is fully developed, but demand is exceeding the total available water sources. Economic water scarcity is caused by a lack of investments in water or a lack of human capacity to satisfy the demand for water. The functioning of institutions is given as a main cause of economic water scarcity. According to their classification, Ghana and Ethiopia experience economic water scarcity, while the Krishna Basin in India is 'approaching physical water scarcity' (Comprehensive Assessment of Water Management in Agriculture 2007). In addition to domestic, industrial and agricultural water requirements there has been increasing recognition of environmental water needs.

Although water shortage in cities has been discussed extensively in literature, the application of water stress and scarcity indicators in cities seems still unexplored. A relatively simple calculation of difference between urban water supply and demand gives a good indication. Furthermore, irregularity of water supply, is a good indicator as well as figures for actual per capita water use compared to standards for basic water needs (UN-Habitat 2003, UN-Habitat 2008c).

2.2.3 Data availability, reliability and definitions for water and sanitation coverage

The quality of water supply and sanitation services in a country, region or urban settlement is an important indicator of its stage in economic development. The most common indicator used to rate the water and sanitation situation is the percentage coverage of adequate water supply and sewerage. However, different interpretations go around on what is adequate. Also, the level and quality of water and sanitation services are ‘politically charged’, which makes it prone to the use of data and the drawing of conclusions that do not reflect the actual situation. Statistics seem to include regular overestimations of “safe water supply and adequate sanitation cover” and data are often deficient due to inaccuracy and the use of inappropriate criteria to define what is “safe” and “adequate” (UN-Habitat 2001). This is a serious difficulty when assessing current situations and improvement plans for water provision and sanitation in the developing world. Also, different institutions use different definitions of what is safe and what is adequate (Satterthwaite and McGranahan 2007). Evidence for inaccurate use of statistics comes from comparisons of official data with detailed city case studies. Inaccuracies may have the following reasons, among others;

- Often, figures are dated by 5-10 years, portraying a brighter picture than the much-changed present situation.
- Statistics on coverage of water and sanitation services seem higher than they actually are when they are based on the official urban area instead of the real urban area.
- Installed capacity for treatment of wastewater and potable water can easily hide much lower numbers of actual wastewater treatment systems; a large fraction of installed treatment systems do not work for various reasons.
- Officially improved household water and sanitation facilities are wrongly counted as improved, when water supply is generally lacking.
- Sometimes lower coverage is presented to help raise funds.

‘Objective’ city case studies can indicate the reliability of these data and provide more accurate and reliable data in return. Water and sanitation-data are important as they are used by governments, NGOs and donors to support their policy agendas for development and development aid related to water.

Contradictory urban boundaries

Another problem related to data, or more definitions, is the issue of what is defined as an urban area; political boundaries of the urban area are often in contradiction with the actual urban area based on population density. Cohen (Cohen 2004) states that the size of a cities' population is a function of how and where the city administrative boundaries are drawn. This can be quite arbitrary and may not include large numbers of people contiguous to the city "proper" at urban levels of residential density but who fall outside of the city administrative boundaries. This difference can be significant (millions in mega-cities). A resulting impact on water and sanitation issues is that urban water governors cannot be held accountable for providing water and other services as this urban area of expansion is not within their authority. For example in Accra, the urban area with administrative boundaries is 185 km^2. However, a simple Geographic Information System (GIS) exercise using satellite images calculates an urban ('built up') area of 422 km^2 (Natcho 2006). Residents in these areas of expansion depend on alternative sources of water and ad hoc sanitation arrangements (see section 5.1). Then there is also the issue of daily commuters into the city which is definitely putting additional stress on the available water and sanitation services in the city.

2.2.4 Technical issues

Technical issues are those issues that could be 'theoretically' solved by merely technical measures. The following issues are most common in cities in developing countries and can be found in general literature. Between brackets are technical solutions that would work if all other factors were ideal and supportive.

- *High* physical losses in the piped water supply and distribution network [fixing leakages and setting up leakage monitoring systems].
- Irregular supply and low pressure in the piped water supply and distribution network [fixing leakages and increasing pipe or pumping capacities].
- Poor drainage, causing recurrent flooding of storm- and wastewater into residential areas [improve drainage system].
- Piped distribution network is not covering the 'real' urban area [extend piped network].
- Insufficient installed capacities for treatment, pumping and distribution to satisfy all urban dwellers [upgrade installed capacities].

2.2.5 Institutional issues

Much literature deals with the existing constraints to upgrade water and sanitation systems or to increase coverage. Based on city case studies in Africa, (Cudjoe and Okonski 2006) particularly point at the governmental system that should be held responsible for failing to provide enough good-quality water. At the same time, the authors seem to be adverse to *bottom-up* decentralised solutions to the supply of water and sanitation. They recommend that governments should undertake simple policy reforms to enable decentralised entrepreneurial activities to solve existing urban water supply and sanitation problems.

The different urban water flows (primarily piped supply, stormwater and sewage water) have traditionally been managed under separate governmental unities. A lack of coordination between these responsible governmental authorities can cause problems on the ground. For example, extension of the piped water supply system that is not accompanied with a proper sewerage infrastructure is likely to cause accumulation of wastewater that may pollute groundwater and surface water and, in addition, create risks to human health.

A structural problem in fast-growing cities is poor planning of water infrastructure and poor institutional capacities (Niemczynowicz 1999b; UN-Habitat 2003; Cohen 2004; Biswas 2006b). Implications of these problems appear at different levels. Unregulated construction of houses around cities without any water supply or sewerage infrastructure makes water provision and wastewater problematic in these areas (for example Accra in (Yankson et al. 2004). At the city level, installed water treatment and supply capacity are not able to meet growing urban demands. At the regional or national level, realistic strategic plans that foresee and meet future water demands are often lacking.

Transparency and corruption are additional factors that both undermine and indicate the effectiveness of the institutional environment. Corruption is a common phenomenon and undermines the provision of public services. The water sector is no exception. As analysed thoroughly by (Plummer and Cross 2006) for Africa, causes for corruption are founded in historical, political and societal realities. The main impact of corruption on the functioning of water and sanitation delivery is that it is wasting a large fraction of the available budget through ‘leakage’. Regional or country-specific estimates of leakage for Africa are lacking, but 20-35% (Davis 2003) based on South Asia provides a good indication of the scale in the water sector. To reduce corruption, a mix of entry points that works on parallel fronts and different levels is efficient and will probably be effective, according to (Shordt et al. 2006).

2.2.6 Social issues

Historical and cultural factors are usually overlooked in the development sector, and the water sector is again no exception. The balancing of indigenous peoples' outlooks, philosophies and views with modern technologies and environmental concerns has often not been successful (Akiwumi 1998). A clear demonstration of this is the non-existent or poor functioning of high-tech western-style wastewater treatment plants in developing countries. In many cases, this copy-paste format has proven not to work well in environments where high-tech infrastructure has not yet become a tradition. Large-scale piped water systems and central water treatment systems often have severe management problems (NWP 2006). The issue of inequitable allocation of water between users in a city is less adequately addressed than other issues (Johnstone *et al.* 1999). Social issues come in where access to water is discussed in relation to urban poverty (Noll *et al.* 2000; Bayliss 2002; Weiss 2003; Addo-Yobo and Njiru 2006). Access to water can be the underlying cause of social conflicts in an environment of water scarcity where water supply authorities fail to reach all their citizens (Turton and Ohlsson 1999).

2.2.7 Financial issues

In the absence of foreign aid or investment, managing the urban water infrastructure is a financial challenge in developing countries. High costs to maintain supply and infrastructure and poor revenue are common causes that create financial problems (Varis and Somlyody 1997). Cost recovery for services is often a challenge, but different approaches exist (Briscoe 1995). Presently there is a lot of discussion on private- sector participation in the water sector. Poor performance of public water supply utilities is often used as a reason to privatise partly or completely the governance of urban water supply. Some advocate privatisation (Brook Cowen and Tyran 1999; Noll *et al.* 2000; WorldBank 2006a) while others argue against it or point at failures of such current practices (Bayliss 2002; Hall and Lobina 2006; Nellis 2006; Prasad *et al.* 2006). (Johnstone et al. 1999) are neutral to this, but address the issue of how best to meet environmental and social objectives, given globaly increased private-sector participation in urban water supply and sanitation.

The so-called Camdessus report, a joint initiative of the Global Water Partnership and the World Water Council, was presented at the 3rd World Water Forum in Kyoto in 2003 (Winpenny 2003). The central question in the report was how to find appropriate financial resources to achieve the two MDGs for water access and sanitation. They have listed a set of priorities for financing the water and sanitation sector in developing countries:

- Host governments should be clear on their strategies and priorities in the water sector.
- Facilities in place should be used as financial vehicles, replenished and empowered as necessary.
- Proposals for new agencies, funds and schemes should be urgently studied and their feasibility and implementation mapped out, with sponsors identified.
- Policy changes and reforms to institutions likely to have longer lead times should be set in motion.

2.2.8 Environmental Issues

Environmental issues can emerge within the urban area, where humans and the ecosystem are threatened or damaged by polluted water. The environment can also be affected at the larger scale, when cities change the hydrological cycle up to the water basin level. When compared to the ‘natural’ situation, the paved and built-up area has reduced infiltration of precipitation and recharge to the groundwater. Water that does not infiltrate or evaporate turns into run-off. The generated run-off is imposing fast peak-flows and challenging the urban drainage system not to be overloaded or locked to cause flooding. As (Niemczynowicz 1999b) puts it, the city influences the run-off pattern and the state of the ecological systems not only within the city area but also in and around a whole river system downstream.

The Water for African Cities Programme initiated in 1999 by UN-Habitat had a focus on the environment; “to protect the continent's threatened water resources and aquatic ecosystems from the increasing volume of land-based pollution from the cities” (UN-Habitat 2005). This programme was the first comprehensive initiative to support African countries to manage the growing urban water crisis. Improper wastewater disposal systems often create unhygienic situations and health risks. In the absence of a piped sewerage system, waste and wastewater are often disposed of through open drains that were constructed for stormwater drainage. As a consequence, receiving water bodies have become heavily polluted, for example in Abidjan (Obrist *et al.* 2006), Accra (Karikari *et al.* 2006) and Addis Ababa (Melaku *et al.* 2007).

Urban pollution and its impact on water quality is a main feature of environmental degradation. Water quality concerns exist for all water bodies in and around large cities in developing countries where an effective pollution-control policy has yet to be established. Water quality can be an issue at the downstream water supply site, within the city (polluted drains) or in water bodies downstream of the city. Environmental issues are fundamental to water-borne human health risks and ecosystem degradation beyond the city boundaries.

Closing remarks

Many cases from the developing world illustrate that keeping up the infrastructure coverage with the expansion of urban area is often an unrealistic target. Most cities in sub-Saharan Africa face a time lag of a few decades. One of the points from the previous discussion is that the gap between demand and supply of basic services like water can be explained by a range of common factors. It is important to be aware of social and financial issues in the urban water sector when studying any aspect of urban water management. However, they will not be part of further analyses in this research.

2.3 CONCEPTUAL APPROACHES TO URBAN WATER MANAGEMENT

Processes and interactions of water in the urban environment have been described by various authors who use conceptual frameworks for the functioning of the water cycle or water balance (Hellstrom *et al.* 2000; CSIRO&AWA 2004; Hardy *et al.* 2005; UNESCO 2005).

Integrated urban water management (IUWM) or integrated urban water resources management (IUWRM) is being advocated by institutes like UN-Habitat and donors, and appears in projects that follow this approach. Examples of projects are Sustainable Water Management in the City of the Future (SWITCH project[1]) and URAdapt. Due to the different approach needed to improve water and

[1] http://www.switchurbanwater.eu/ and http://uradapt.iwmi.org/home.aspx

sanitation in urban areas as compared to the rural areas, it is often treated separately, as in (Moriarty et al. 2004).

Many pleas have been made for changing conventional approaches to more innovative ones. An interesting report that came out of the 17th Aquasan Workshop in June 2001 (Skat Foundation 2002) explains rather conceptually the impact of paradigms on the planning and management of water supply and sanitation projects. (Eiswirth et al. 2000) discuss new development scenarios for sustainable urban water systems with the given problems of the conventional ones, such as heavy demand on supply catchments, escalating costs for infrastructural investment and environmental problems caused by wastewater disposal into natural water bodies. Approaches and dimensions of urban water (supply, urban distribution and water after use) are well discussed by (Lundqvist et al. 2003). Another response to problems of conventional water and sanitation systems is the Household Centred Environmental Sanitation (HCES) approach that was developed (Schertenleib and Morel 2003).

2.3.1 Sustainability of urban water systems

The on-going discussion on the pros and cons of different urban water systems in different contexts has been described both conceptually as well as with case studies. A good conceptual comparison can be found in (Varis and Somlyody 1997). The concept of sustainability was first introduced in the famous Brundtland report in 1987. The discussion on the sustainability of urban water systems started more recently. Discussions can be found for different aspects like environmental (Jeppsson and Hellstrom 2002; Schertenleib 2005; IRC 2006), economic (Varis and Somlyody 1997; Fane et al. 2005; Hjerpe 2005) and the social impacts of institutional water reforms or interventions on the urban poor (Noll *et al.* 2000; Bayliss 2002).

As mentioned earlier, it is being disputed widely whether the conventional western type provision and treatment of water are suitable for developing countries. However, this is not much reflected in literature. A study from (OECD 2004) on 'financing urban water and environmental infrastructure for all' advocates that more money is needed to reach the MDGs. Unfortunately, any discussion on the financial and environmental sustainability of conventional water systems or alternatives is lacking in the report. Authors who do address this issue are (Solo et al. 1993; Varis and Somlyody 1997; Eiswirth et al. 2000; Nhapi and Gijzen 2004).

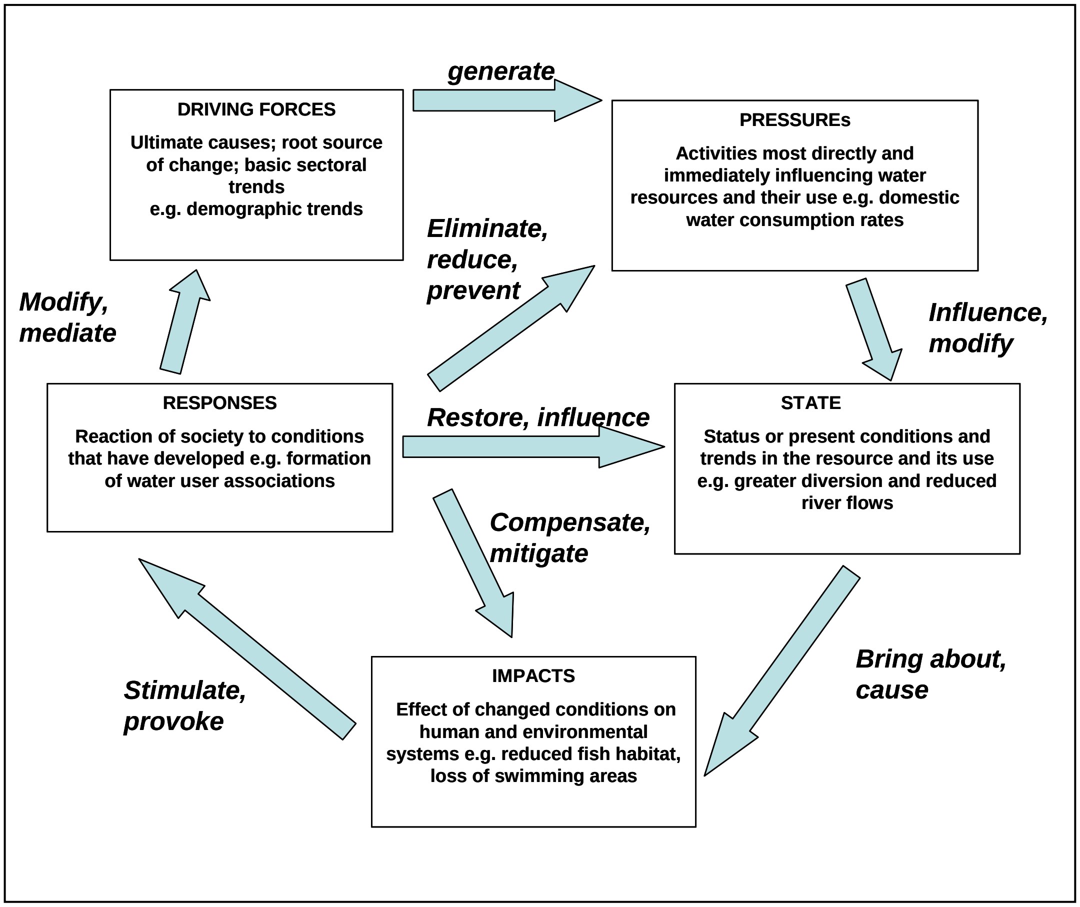

Figure 4. **The DPSIR framework.**

Source: **(OECD 2003)**

The concept of sustainability has been widely used and can be applied to water systems to assess their functionality and impact in the future, in space and in other systems. The DPSIR framework developed by (OECD 2003), provides a general framework for the interaction of human activities with its environment (Figure 4). DPSIR stands for: driving forces, pressures, state, impacts and responses. Driving forces are the economic and cultural forces driving human activities, which change pressures on the environment. Pressures are the stresses that these human activities place on the environment. State (of the environment), is the condition of the environment. Impacts refer to the effects of environmental degradation. Responses are societies' responses to the state of the environmental. The United Nations Commission on Sustainable Development (UNCSD) has defined a list of 130 indicators, which have been proposed for use by countries in their decision-making processes and for international comparisons (UNCSD 1996). Approximately 20 indicators deal with water and wastewater issues. This approach has been criticized for different reasons, such as not giving enough attention to ecological functions and the lack of benchmarks for comparison (Lundin 1999). Assessing the sustainability of an urban water system is always linked with the criteria that are set. Strategies are often proposed to make the system more sustainable. Three strategies are often proposed; integrating water supply and wastewater systems, moving towards decentralized demand-side infrastructure planning and implementing regulatory reforms.

2.3.2 Ecological sanitation

Ecosanitation is based on the systematic implementation of reuse and recycling of nutrients and water as a hygienically safe, closed-loop and holistic alternative to conventional sanitation solutions (GTZ/IWA 2003). A first concept of ecological or environmental sanitation has been introduced by (Esrey and Habricht 1986) as a response to the negative environmental impact of conventional sanitation. Organisations have elaborated on this concept, using similar phrasings (SIDA 1998; SEI 2004) such as a conceptual approach (UNESCO/IHP/GTZ 2006), or case studies (IRC 2006). Many conferences have been devoted to this concept (WSSCC 1999; GTZ 2001; CSIR 2005). A clear voice on the need for a change of conventional sanitation to more sustainable (environmental) sanitation was given by (Schertenleib 2005). Guidelines on the implementation of eco-sanitation facilities are given by, for example, (Franceys et al. 1992). In summary, ecological sanitation has the following distinct features, as compared to conventional sanitation;

- Reducing the environmental impact of wastewater disposal by recycling.
- Reducing water demand for sanitation.
- Attempting to close the nutrient cycle.
- Does not require a sewerage system or centralised wastewater treatment.

2.3.3 Sanitation and the urban water cycle

The importance of sanitation to general development has been pointed out by many institutes and in many publications (WHO&UNICEF 2006). Causal linkages with health (Esrey and Habricht 1986; WHO 2003; IFRC 2006), poverty (UNFPA 2003; UNDP 2006; WHO&UNICEF 2006) and overall development are paramount. Non-conventional and smart solutions are needed to tackle the challenge of service provision for urban sanitation (Raschid-Sally 2006). The water and sanitation sector has not engaged sufficiently with integrated water resources management (IWRM) (Moriarty and Butterworth 2003). The linkages are not yet recognized in policy planning at the local, regional or basin level. Good studies on the linkages and the need for recognition in policy and planning have been carried out with particular emphasis on hydrological and institutional aspects (Smits 2005) and sustainable environmental sanitation (SIDA 1998; GTZ 2001; SEI 2004; Zurbrügg *et al.* 2004; IRC 2006).

2.3.4 Urban-rural linkages

Literature that describes water linkages between urban and rural areas is not found in abundance. The increasing impact that activities and demands from growing cities have on their rural hinterlands has been discussed by many authors such as (Mumford 1956; DDSMS 1996; Showers 2002; Molle and Berkoff 2006). Showers (2002) gives a good overview of African cities and their water linkages with the rural area. Mumford (1956) predicted that limitations in water supply from remoter areas will hinder further urban growth long before food supply would do.

Competition between urban, domestic, industrial water use and agricultural use has been the subject of much literature. The impact of urban water use on agriculture has been described thoroughly by Molle and Berkhoff (2006) with many case studies. Examples of water that is virtually pulled out of agriculture to the city are provided by Scott et al. (2001) for Mexico and van Rooijen et al. (2005) for Hyderabad, India.

Urban water that returns as wastewater is often used in agriculture within the urban or peri-urban area or in the rural area. Examples are given by Zerah (2005) for cities in India and Beijing. Wolf et al. (2003) show the case of Beijing and links agricultural production with water quality issues. Thompson et al. describe the changes in urban water use in nine East African urban centres between 1967 and 1997. Important findings were that urban water scarcity has increased, using indicators of time spent on collecting water (increased), per capita water use and reliability of water supply (both decreased).

One way to express a city’s dependency or impact on the surrounding area is with the so-called water footprint, which is part of the ‘ecological footprint’. Jenerette et al. (2006) present an application to cities in the USA.

Niemczynowicz (1999b) states that a fundamental connection exists between agricultural development and actions to be taken in the sanitation sector and organic waste management, especially in urban areas. Nutrients from households should be used in rural and urban agriculture for food production. This requires the development of new water and sanitation system solutions and “*a real* *partnership between rural and urban sectors*" (Bahri 1999). Also more research is needed to improve our understanding of the strong rural-urban linkages that exist for food, nutrients and water (Niemczynowicz 1999; (Niemczynowicz 1999a; Drechsel et al. 2007). To make valid recommendations about these solutions, it is necessary to test options for likely and potential water and sanitation development within an urban area.

2.3.5 Urban water modelling

The basin level has often been used as the spatial scale of analysis in urban water management. The method of water accounting to asses use and productivity of water in a basin has been described well by Molden and Sakthivadivel (1999).

The application of an urban water model that simulates water and nutrient flows has been provided by Erni et al. (2010) for Kumasi, Ghana. Hardy *et al*. (2005) present the Urban Cycle model with a modelling exercise for Sydney, Australia. AquaCycle is a model that is able to simulate interactions between water supply, stormwater and wastewater. Successful testing of this model was done by Mitchell et al. (2001) for the Woden Valley urban catchment in Canberra, Australia. However, surprisingly, no discussion can be found on the need and applicability for cities in developing countries. A tool for sophisticated modelling of substances in wastewater and stormwater called SEWSYS (Ahlman and Svensson 2005) examines diffuse and non-point source pollution. The method of Material Flow Analyses is applied and advocated as a tool to assist local planners and decision makers in developing countries that operate in water and sanitation in Montangero et al. (2004) for Viet Tri, Viet Nam.

The modelling approach Urban Volume and Quality (UVQ), developed by CSIRO, is the integration of the potable supply-wastewater distribution network with the rainfall-run-off network into a single framework. The model represents water and contaminant flows through the existing water, wastewater and stormwater systems from source to discharge point; however, it is confined to the urban area. A comprehensive description of model use has been provided for the city of Rastatt in Germany (Klinger et al. 2006).

Developing countries typically have poor-quality data sets, if available. These quality constraints limit the use of sophisticated hydrological models in any context. This means that local planners and policy makers are often confronted with poor information to support their decision making. There is a general lack of comprehensive information on the urban area (like population, water supply, etc.). Easy-to-use software to model urban water flows provides local water planners with an effective tool to get insight into interactions between urban water management and the environment outside the urban boundaries. This can imply withdrawal from upstream reservoirs and the use of wastewater in agriculture downstream. For the two reasons mentioned, a simple model is effective and appropriate both for use by researchers and local planners.

Currently, most urban water software are not designed for integrated urban water planning and do not apply to different circumstances in developing countries. A good example of a planning and decision support tool is given with a programme called System for Monitoring Urban Functionalities (SMURF) (Repetti et al. 2006). It is promoted as a tool for supporting participatory planning and knowledge-sharing between stakeholders in African cities, with an experimental application for the city of Thies, Senegal. No special reference is made to water, but it is considered as part of the urban environment. Another tool, SANEX was developed by Thomas Loetscher in 1999 and is called 'A Simple Expert System for Evaluating Sanitation Systems in Developing Countries'. It can be useful as a tool for decision support for urban water planners and policy makers. A useful conceptual analysis of scenarios for cities in Brazil has been described by Soares et al. (2005). This kind of easy-to-use software is needed and should be further developed and provided large-scale among stakeholders in expanding cities in developing countries.

2.3.6 Urban water supply and wastewater scenarios

Modelling is often associated with having many parameters, input data and a complex model that produces results which are difficult to comprehend. To get insight into dimensions of scale and impact of urban water scenarios, simple models and even back-of-the-envelope calculations can already bring useful insights. A good illustration of this can be found for the city of Harare in Zimbabwe by (Nhapi and Hoko 2002). The authors show the effects of a set of measures based upon the so called 'Cleaner Production Approach' on water demand, wastewater and nutrient flows. This approach uses elements that target a better use and reuse of materials in order to reduce pollution and water use. The authors conclude that the cleaner production approach could substantially reduce current water pollution and long-term scarcity problems. This is a nice conclusion but it also lacks strength and is not adding value to the on-going research; feasibility of implementing this approach was not addressed simultaneously in their study.

Scenarios for urban water supply can be calculated with different growth rates and per capita water use patterns (van Rooijen *et al.* 2005). Scenarios for water supply appear in municipal development and strategic plans of water supply authorities. Increases in water demand are usually foreseen in plans to increase installed capacity for water withdrawals, treatment and distribution. However, problems with financing of these projects are often causing delays in their execution. Increasing demands are forcing authorities to be creative in meeting those future demands, by increasing withdrawals from existing sources or by tapping from new sources. Scenarios for water supply may affect other users or the environment in closing basins.

Many directions are proposed in literature for treatment of wastewater disposal. The volume of wastewater and possible change of quality (as a result of changing sanitary systems) is not well addressed. The environmental effects or possible alternatives of, for example, dumping of most of the wastewater into the Ocean in coastal Accra (Obuobie *et al.* 2006) has so far not been investigated.

2.4 FUTURE DIRECTIONS IN URBAN WATER MANAGEMENT

New trends and concepts in research applied to development are urban water demand management, decentralisation and eco-sanitation. Rainwater harvesting is promoted as a tool for water saving and to mitigate flood risks as a result of heavy rainfall events. Alternative water supply, like small-scale water enterprises (SWEs) is also promoted as it is filling up gaps between supply and demand, especially in poor areas and in the urban fringe (e.g. for Accra: Mime Consult Ltd (2004)). All these concepts are a response to water scarcity, environmental concerns and socio-economic constrains of the conventional urban water systems.

Sustainability criteria are being applied widely to assess the quality of current urban water systems. However, many are confined to, and tested in, cities in industrialised countries (Eiswirth et al. 2000; Hellstrom et al. 2004; Souvent and Moon 2005; Klinger et al. 2006). Examples of authors who address sustainability of urban water in cities in developing countries have been given earlier (Varis and Somlyody 1997; Wright 1997; Zurbrügg et al. 2004). Related to the sustainability is the spatiotemporal dimension of urban water use. The spatial dimension can be understood as the upstream and downstream links of city water use with the hydrological cycle and other users (also referred to as the basin approach). Temporal impact can imply looking at future scenarios of urban water use, using different factors that are likely to steer development of the cities' water demand and use of sanitation facility.

2.5 Discussion

Institutes that model urban water systems (water supply, wastewater and stormwater) seem to be primarily concerned with high-tech systems that are present in cities of the industrialised world. Very few model descriptions were found that discuss their feasibility for cities in developing countries, even though a clear need for easy-to-use models for planners and governors in developing countries is heard. This gives justification for carrying out scientific studies and modelling exercises for cities in this context.

Not much literature discusses the impact of water and sanitation infrastructural development on city water demand and wastewater production. At the lower level however, there are many documents that give standards of water use for different household facilities like toilets and showers. Their discussion on the reduction or increase of water use due to changes in source or facilities is merely confined to the household level and often related to water costs, reliability and access.

Since the mid-1990s, a growing group of people has been arguing for environmental or ecological sanitation as a solution to environmental concerns with conventional types of sanitation. Even with environmental sanitation, a growing urban population will demand far more water, calling for larger withdrawals from distant surface water sources or groundwater. The flush toilet, a symbol of conventional western household sanitation, is being installed for the better-off people in developing countries. A challenge lies in the implementation of water saving measures or, ideally, skipping the phase of high water-consuming water equipment that is gradually disappearing from industrialised countries.

Conventional solutions to increasing water and sanitation coverage rates in urban areas lie in the extension and upgrading of the existing piped network. The construction (or cement) industry has a major interest in a continuation of these water infrastructural projects. Local authorities may still advocate the conventional path for water infrastructural development, instead of choosing non-conventional water supply, stormwater and wastewater alternatives.

There are many good reasons for increasing the so-called “improved” urban water supply and sanitation coverage. However, many constraints and debates exist on the definition of ‘improved” and “coverage”. Also, data usually derived from governmental statistics are unreliable. The water situation, expressed with numbers for improved water supply and sanitation coverage, may not approach the actual situation. As these numbers are used to shape aid-policy agendas, their reliability should be better checked, for example with ‘independent’ case studies, surveys or samples. The need for carrying out urban water case studies has been recommended in various sources of literature.

3. METHODOLOGY

This chapter describes the methodology used for carrying out the research. This chapter starts with a justification of the research methodology, followed by a description of research tools that were applied. The chapter ends with a discussion of the validity, reliability and ethics of this research.

3.1 CHAPTER INTRODUCTION

The research applied case study methodology, which consists of both quantitative and qualitative research components. The qualitative research component involved the collection of data and information through expert consultation, using semi-structured interviews while the quantitative research consisted of data collection from secondary literature sources and urban water balance modelling. The research was carried out in four phases; selection of cities, data collection, modelling and data analysis, and writing. Data collection, consultation of local stakeholders and field visits took place in the selected cities; Accra, Hyderabad and Addis Ababa.

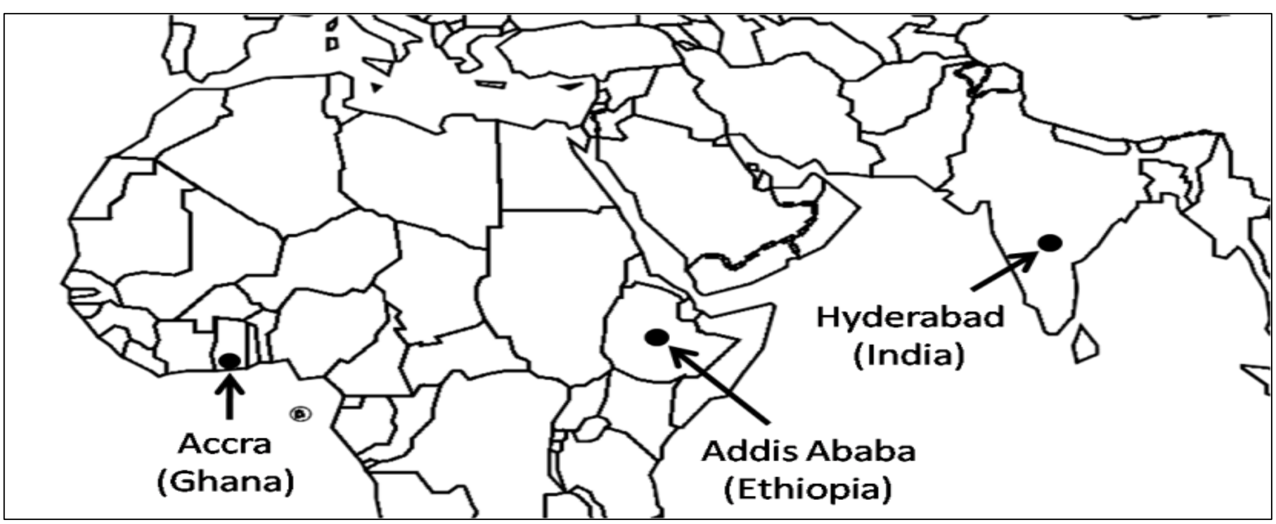

Figure 5. Location of the cities chosen as case studies.

Data were collected on-site in Addis Ababa (June-Sept. 2008, June 2009), Hyderabad (June 2004, July-Sept. 2007) and discontinuously in Accra (May 2007-May 2009). The host institute (in all cases IWMI) provided office space and practical as well as intellectual support for carrying out the fieldwork. Local expertise from persons or institutes was sought (Table 1). During the period of fieldwork, discussion with stakeholders, donors and institutions took place primarily to establish contacts, inform them of the research, and to make use of their knowledge.

This research applied a mix of research tools to the following research questions:

6. How did urban water supply and sanitation develop in the cities, as they relate to demographic growth?
7. What are the most important urban water flows that compose the urban water balance?
8. What are the scenarios for water demand, based on different scenarios of demographic growth and change in living standards?
9. What are the implications of different urban development scenarios and the consequent wastewater flows, for wastewater irrigation potential and risks?
10. What is the impact of future urban water use scenarios on water availability for agriculture at the basin level?

3.2 JUSTIFICATION OF THE RESEARCH METHODOLOGY

The presented research is embedded in the domain of research where the larger global research areas of urban water management, water resources management and urban agriculture (figure 1), overlap. In the section on problem definition it has been argued that the problems associated with urban growth and urban water management are typical for growing cities in developing countries. One difficulty faced when designing this research was finding an appropriate methodology and evidence. A city-level analysis of cities in developing countries alone is constrained by a lack of accurate local data. The option chosen to gather data in three cities allowed for triangulation. This has the advantage of filling weaknesses or gaps in data for a specific city by using similar data from the other cities. This is strengthening the overall quality of the results. The fact that the cities chosen are located in different world regions is considered to give more justification for drawing generic conclusions for low-income cities at the global level.

The reason for choosing this *mix* of different research tools is because the background and nature of the defined problems (as discussed in section 1.1 and 1.2) cannot be assessed with one or two tools alone. Another reason is that results that are produced from application of one tool could be used to verify results acquired from other tools. The mix of tools accommodates both qualitative as quantitative research methodologies. The rationale behind choosing both types of methodologies is that it is assumed that neither application of a qualitative or quantitative methodology alone would be sufficient to understand urban water systems and related issues in low-income water-stressed cities. In other words, a most comprehensive assessment is needed in order to understand urban water issues in this context. Therefore, urban water balance modelling, semi-structured interviews and scenario-historical- and comparative analysis, was found to be the most appropriate set of tools to answer the research questions.

The research tools used in the PhD research (Figure 6) are all part of the multiple-case study methodology. A case study can be defined as '*a unit of human activity embedded in the real world, which can only be studied or understood in context and exists in the here and now. The case study merges in with its context so that precise boundaries are difficult to draw'* (Gillham 2000). This research has embraced the city as the unit of the case study. Choosing the case study methodology has allowed the author to retain the holistic and meaningful characteristics of real-time events, as described by Yin (2003).

The need for case studies that touch this research area has been expressed in literature (Niemczynowicz 1999b; UN-Habitat 2001).

The three cities selected are Accra in Ghana, Hyderabad in India and Addis Ababa in Ethiopia (Figure 5). The analyses of two cities in Africa and one in Asia are, to some extent, considered to be representative of these continents and the main characteristic of cities (coastal/inland, dry/wet climate). Criteria for selection were the present or potential severity of urban water issues, representation of a geographical context, local demand, the advantage of present data from previous work and the presence of an office and network to carry out the fieldwork. Also, synergy with other projects was a criterion. The three cities were finally selected in agreement with supervisors at Loughborough University and IWMI.

3.2.1 Comparative analysis

Results of the three case studies are cross-compared using simple comparative analysis as one of the research tools. The comparative analysis is based on the development pathway of each city, for water supply and sanitation. The general sustainability of the water systems is compared, and additional information derived from local and expert opinion is used. The comparative analysis is the final part of the research analysis, and aims to reach the fifth and last research objective; to develop a framework for analysing water and sanitation development trajectories of cities and their impact on basin water resources.

3.3 RESEARCH TOOLS

This section discusses the tools that were applied for answering the research questions that address the subsequent objectives of the research (Figure 6). Most research tools served more than one objective. The tools will be discussed in the same order as listed below:

Historical analysis
Semi-structured interviews
Urban water balance modelling
Scenario development
Comparative analysis (triangulation)

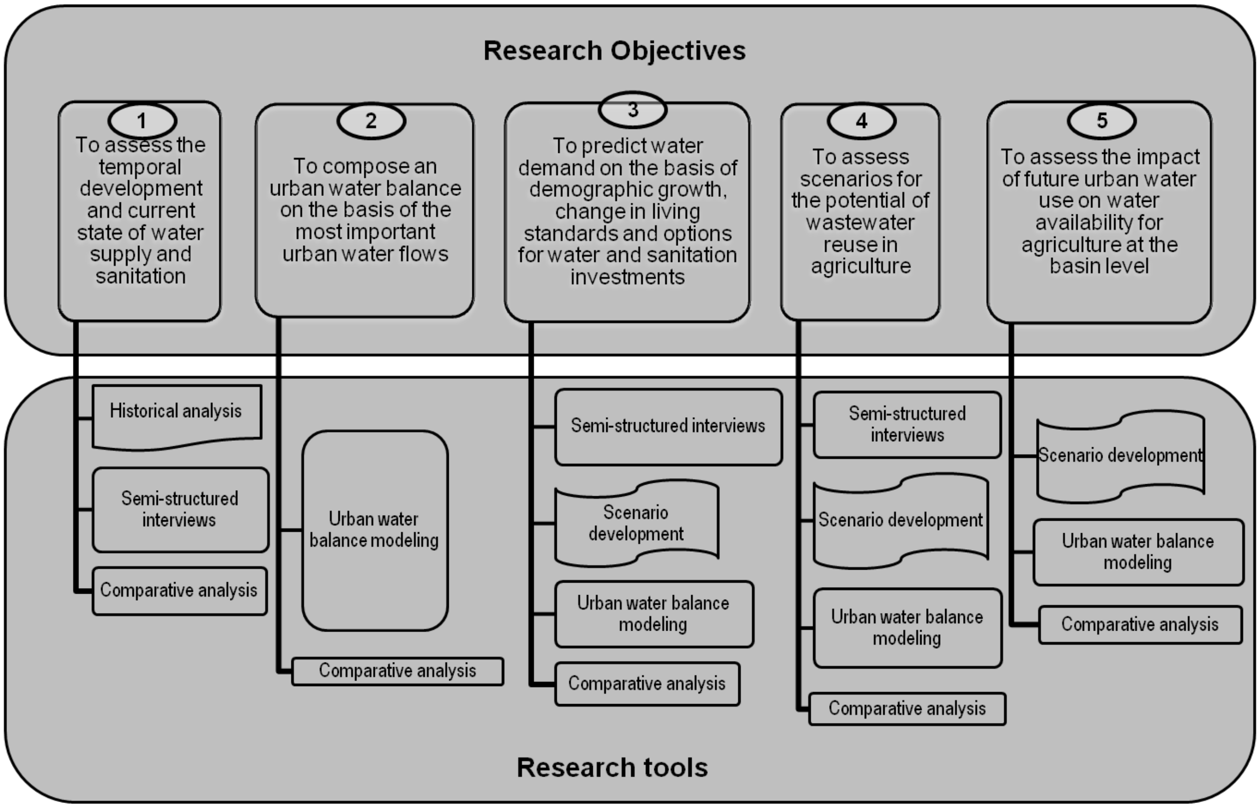

Figure 6. **Research tools that were applied to reach the specific research objectives.**

Data collection

Local data collection was needed as much as available in order to carry the historical analysis, urban water balance modelling and scenario development. Data were gathered through different channels. Primary data were collected via semi-structured interviews with the selected experts in the cities. Secondary data were derived from literature sources (published and grey literature), collected personally in the cities and derived from sources on the Internet. Data collection from individuals at the various institutes was time-consuming due to the bureaucratic systems (official letters needed, etc.) and necessary travel through the cities. Data were also requested though email correspondence with professionals in policy, planning, and research, working at the local, regional and international level. Literature was digitally archived, using the Endnote 8 programme, and categorized by city and related geographical focus, whether city-, country- or region-specific, or international. Literature found in hard copy was photocopied where needed.

3.3.1 Historical analysis

The course of developments around population growth, water and sanitation infrastructure and services and its management were compiled for the three cities. Related data were found mostly in local literature and from interviews with experts. Population growth and the development of water supply and sanitation services were traced roughly from the year 1950. A combination of local and international literature sources was used. The historical analyses contributed to answering mainly research question one.

3.3.2 Semi-structured interviews

One component of the data collection during fieldwork was the holding of semi-structured interviews with individuals regarded as key experts on certain aspects of the situation. Their input was considered useful for the gathering of related information. The semi-structured organisation of the interviews was chosen for its flexibility and 'natural character', compared to a structured interview that follows a fixed set of questions. Statements made in the results section are supported by findings from these interviews, cited as personal communication. Below are listed the organisations that were visited for the holding of interviews.

Table 1. Local organisations that were visited for the semi-structured interviews.

Accra		Addis Ababa		Hyderabad	
Organisation	Role	Organisation	Role	Organisation	Role
Ghana Water Company Limited	Management of urban water supply	Addis Ababa Water and Sewerage Authority	Management of urban water supply and wastewater	Hyderabad Metropolitan Water Supply and Sewerage Board	Management of urban water supply and wastewater
Aqua Vitens Rand Limited	'Operator' Urban Water Supply	Bureau of Urban Agriculture	Provision of support to urban farmers	Greater Hyderabad Municipal Corporation	Urban infrastructure planning and development
Accra Metropolitan area	Municipal governance	Addis Ababa University	Research on wastewater irrigation	Andhra Pradesh Pollution Control Board	Enhancement of environmental governance
Kwame Nkrumah University of Science of Technology	Research on urban water management.	Ethiopian Environmental Protection Authority	Environmental governance (regional and federal level)	Centre for Social and Economic Studies	Research on social and economic aspects of urban water issues
Environmental Protection Agency	Environmental governance at federal and regional level	Ministry of Water Resources	Governance of water resources	Jawaharlal Nehru Technological University, Hyderabad	Research on urban water management
Ghana Statistical Service	Publication of official statistics	Tahal Group	Design of Addis Water Supply Project Proposal	National Institute of Urban Affairs	Research on urban development and management
Water Research Institute	Research on water	African Development Bank (AfDB)	Projects on urban water supply and sanitation	Centre for Science and Environment	Research and advocacy on environmental issues
Water Resources Commission	Regulation of use of water resources	World Bank	Funding institute of Addis water supply project	Government of Andhra Pradesh, Directorate of Economics and Statistics	Collection, analysis and interpretation of statistical data
Public Utilities Regulatory Commission	Regulation of water tariffs	United Nations Environmental Programme	Funding Akaki River Cleaning Project	Centre de Sciences Humaines	French Research Institute on Urban Dynamics
Water and Sanitation Monitoring	Enhancing water and sanitation monitoring and	United Nations Human Settlements	Water for African Cities Programme	International Water Management Institute	Research on basin water management and wastewater

Platform	knowledge-sharing	Programme			irrigation
Earth Water Global	Design of Accra Water Supply Project Proposal	International Livestock Research Institute	Research on basin water management		
International Water Management Institute	Research on water management	International Water Management Institute	Research on water management		

3.3.3 Urban Water Balance Modelling

The urban water balance modelling was done in order to reach objectives 2-5. This section discusses the urban water balance modelling part, followed by a discussion of the scenario development, in section 3.3.4 of this chapter.

The VENSIM model

The Ventana Systems Environment (VENSIM) model was chosen for application in this research. VENSIM is a visual modelling tool that serves to conceptualize, document, simulate, analyse and optimise models of dynamic systems (VENSIM 1998). The model was found to fit well with the features and outputs required for the research; it is simple, easy-to-use and allows for flexibility since it is user-built. The fact that the three cities have varying physical environments (such as urban area) was accounted for with the use of an input data sheet, linked with the model. The VENSIM tool has been used in a broad range of disciplines; for constructing models of business, and scientific, environmental, and social systems. The model is constructed by entering and defining causal relationships between system variables. This information is used by the equation editor to define these relationships as formulas. The model can be changed, tested and analysed throughout the building process and the model allows its user to thoroughly explore the behaviour of the model.

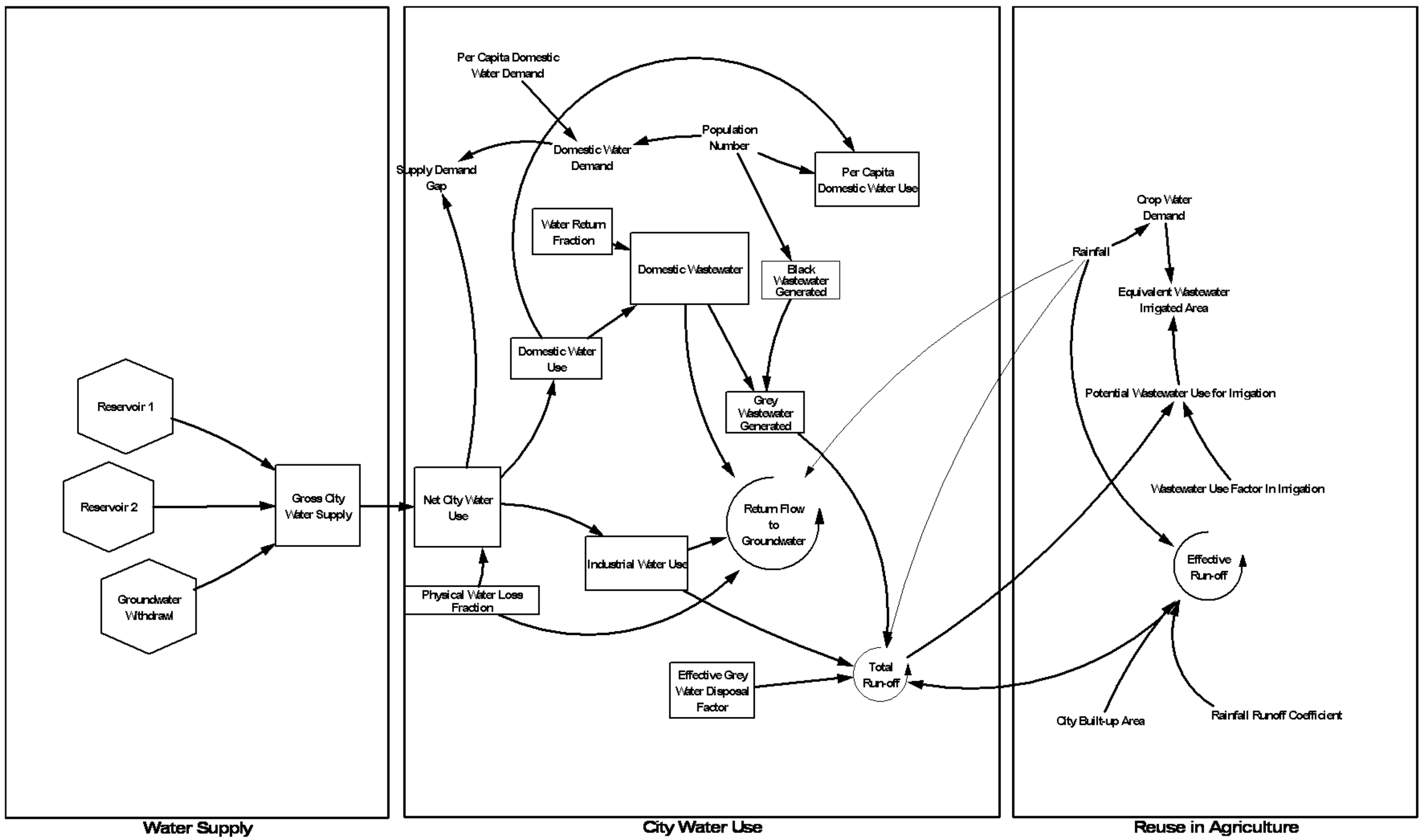

Figure 7. **Layout of the urban water model built in VENSIM.**

Figure 7 displays the layout of the model, which has integrated the links between water supply (left box), city water use (centre box) and reuse in agriculture (right box) across the urban-rural divide. The time frame of the model was set at 1950-2030. Model results were imported into excel and visualised in graphs. The flexible nature of the model makes it relatively easy to apply it in different cities.

Model input data

The model runs on a set of input data most of whose values are different for each city. Some of the input data were modified to run the scenarios. Some data remain constant during the modelling period, while others always behave as variables (Table 2). Model inputs consisted of climatic data (rainfall and evaporation) and demographic data (water supply, population, urban surface area, water demand). In the absence of local data, assumptions were made, based on data and information from cities in a comparable context or calculated based on other data. For example, per capita water use is often unreliable because of poor measurements calculated from water production records and population estimates. The best estimate was based upon a combination of local and international literature, assumptions and expert opinion.

Table 2. General model input data for the urban water modelling.

Input data	Unit	Type
Water supply	m^3	Variable
Population	No.	Variable
Rainfall and evapotranspiration	mm	Variable
Urban surface area	km^2	Variable
Domestic water demand	Litres per capita per day	Variable
Physical water loss fraction	-/-	Constant/Variable
Industrial water use fraction	-/-	Constant/Variable
Water return fraction	-/-	Constant/Variable
Rainfall run-off coefficient	-/-	Constant/Variable

Data on water supply were derived from the respective water utilities. Water supply records spanned different periods of time, as can be observed below:

Table 3. Metadata for formal water production for Accra, Addis Ababa and Hyderabad.

	Period of data	Time step	Specified by source	Data source
Accra	1996-2007	month	yes	AVRL (2006)
Addis Ababa	1998-2004	year	no	UN-Habitat (2007)
Hyderabad	1980-2004	month	yes	HMWSSB (Unpublished)

Historical population data and projections based on growth rates were derived from local (GHMC 2005; GSS 2005; Melesse 2005) and international literature sources for all cities (UN 2004; UN-Habitat 2008c). For all cites, times series for rainfall and evaporation were used for the available period, from single meteorological stations within the city (Table 4).

Table 4. Metadata for rainfall and evaporation.

City	Period for which data were found/used		
	Rainfall	Evaporation	Source for both
Accra	1970-2005	1961-2004	Station 23016ACC, Accra
Addis Ababa	1980-2008	1982-2008	ILRI station, Addis Ababa
Hyderabad	1974-2004	1974-2004	ICRISAT station, Patancheru

The spatial boundary of the model was determined on the basis of the assessment of the size of the urban or built-up surface area. Changes in the urban area were derived from results of GIS exercises reported in literature. Growth prior to and beyond these years was extrapolated from growth change during this period. For Accra, estimations were based on Landsat-TM satellite images for the years 1985, 1991, and 2002, presented by (Yankson et al. 2004). Growth of the Addis Ababa urban area was based on data from the municipality presented in (Melesse 2005). Expansion of the built-up area in Hyderabad was taken predominantly from GIS data in (Iyer et al. 2007).

Domestic water demand knows various interpretations and also varies widely per area. In this research, present domestic water demand was primarily based upon standards set by the respective water supply authority in each city. These values have been compared with those found in international literature. Water demand scenarios were set, based upon available water supply plans, expert opinion and international literature.

Physical water losses have been defined as “water lost from the distribution system through leaking pipes, joints, and fittings, leakage from reservoirs and tanks; reservoirs overflows; and improperly open drains or system blow-offs” (Sturm *et al.* 2008). In other words, the physical water loss fraction is the fraction of water produced that is lost during supply and distribution to the end users. This unit is widely used by water utilities as a parameter for performance. The value was therefore derived solely from the respective water utility. It will be compared with common values found in international literature. In the water balance modelling, this value was set constant, since it does not play a direct role in the scenarios.

The industrial water use fraction is the fraction of total water used by industries. This value was derived from information available at the respective utility in charge of urban water supply. This parameter is especially important for the assessment of the potential of wastewater reuse in agriculture, which is the subject of the fourth objective. The fraction of net water supplied to end users that returns as wastewater, is referred to as water return fraction. This value was not found available at all water supply utilities and was set based on estimations found in local and international literature.

The rainfall run-off coefficient expresses the fraction of rainfall that converts into run-off. This coefficient is greatly determined by the characteristics of the soil. In the modelling, a generic fraction was estimated and applied at the city-level water balance. At the city level, the fraction of green or unpaved area becomes an important parameter for estimation of the rainfall run-off fraction. The size of the green area was determined based on locally available maps, GIS imagery, knowledge from local experts and international literature.

Main components of the model

To calculate processes like run-off, infiltration and crop water requirements, data of rainfall and ET have been used over the period of 1950-2030. Real data have been used for 1950-2003. For the future rainfall and ET, data have been generated with a simulation model. The water balance is based on annual values for water flows into and out of the city. The model components have values that either change or remain constant over time. Some components can be independent from others, derived by calculation from other components (parameters) or can originate from real data. The symbols reflect the type of model component: water flow, water source, water use or factor/coefficient.

Water Sources

All cities receive water from different sources that are represented as separate input data under the box ‘Water Sources’. Time series are based on measured water production records at the treatment plants where and when available. Where records were not available, less precise data were used, based upon yearly deliveries only. Future deliveries are based upon any existing project plans and the assumption that present water sources in use will stay available in similar quantities. Water that is supplied informally, independent from operations of the water utility, is not accounted for in the water balance due to lack of data. This also includes rainwater harvesting since the scale of this practice is unknown.

Urban Water Use

The box ‘City Water Use’ does not represent the actual water use because it does not take into account water losses, which are in the range of 25-33% of gross water production. Domestic water demand is calculated from total population multiplied by the daily per capita water demand that may or may not include industrial demand. Water shortage is expressed with the supply demand gap, which is calculated by dividing the difference between city water demand and supply, by city water demand (see equation 3, section 3.4).

River and/or drain outflow

This component represents the water leaving the urban water system through surface water flow, which is a series of drains entering either lagoons (Accra Consensus) or rivers (Addis Ababa and Hyderabad). In the absence of real-time values, the values for this are part of the modelling results. The outflow component consists of excess stormwater, wastewater and some physical distribution losses. Before this water leaves the system, some of it is reused in irrigation within the urban area. In Addis Ababa and Hyderabad a fraction of this water is used for irrigation further downstream from the urban area. In the model, the water flow is translated into a theoretical potential area that can be irrigated with wastewater, based on crop- demand factors.

Groundwater

Groundwater is an essential part of the urban water balance, due to interaction through percolation and groundwater extraction. However, the behaviour of the groundwater level is complex; it is interacting with groundwater outside the urban area which is difficult to track and predict. Therefore, in this research, the storage level of groundwater is not assessed and the groundwater component is only represented as groundwater withdrawal and percolation.

Wastewater use in irrigation

This box represents wastewater use in irrigation. It is partly situated downstream of the urban zone in the case of Hyderabad and Addis Ababa. Wastewater use is dependent on water flow from drains and rivers. The 'equivalent wastewater irrigated area' is calculated from the wastewater volume available and a use factor governing availability for agriculture and crop water demand determined by crop type, rainfall, ET, Kc and crop intensity. The box 'Equivalent Wastewater Irrigated Area' gives a rough indication of the potential size of wastewater irrigated area that could be used in the future. It should be noted that any interpretation of this theoretical calculation should be done with some reservations for accuracy.

Further considerations on the water balance model in VENSIM

It is important to describe in detail the uncertainties and to justify the assumptions made in the model. The following comments are made on the balance and model:

- One of the research objectives is to illustrate the current practice and future potential of wastewater irrigation in and around cities. In a further elaboration of the model, wastewater output and potential irrigated area could be better refined.
- It is not well known what the fate of the supply and distribution losses is. The possible routes are infiltration, illegal use, evaporation and flow through the drainage system. Since the loss fraction is considerable, both in relative and absolute terms, the fate of these losses should be studied in more detail. Some of the infiltration could be considered as groundwater recharge and thus compensate, to some extent, for withdrawals (next bullet point), which is an equally unknown factor.
- In all three cities very little is known about informal groundwater withdrawal for urban use (number and location of wells and the intensity of pumping). The groundwater withdrawal component is therefore only based on an estimation and subsequent growth rate when making future projections.
- The water return fraction, currently based on literature could be better estimated, based on real measurements. This could also reveal significant differences between the cities.

- The model is run with time steps of one year over a period of 80 years spanning between 1950 and 2030, resulting in 80 time steps representing 80 years. The annual time step does not show intra-annual variation in weather.
- So far, the influence of low reservoir inflows (due to low rainfall in the catchment) on urban water supply has not been considered in the model.
- The model has the potential to be scaled up, to schematise and represent the whole basin including agricultural area and other urban agglomerations.
- The model could be further improved by applying it in other cities.

3.3.4 Scenario development

The methodology used for the development of scenarios is discussed in this section. Scenario development was an important component of the modelling and was therefore done in conjunction with the modelling. The previously discussed historical analysis and semi-structured interviews contributed to the development of scenarios. Scenario development was applied as a tool in order to reach objectives 3-5.

A scenario can be defined “a plausible and internally-consistent description of a possible future situation, a story about the way an area or domain of interest might turn out at some specified time in the future” (Batchelor and Butterworth 2008). A scenario could also be defined as a story on how a certain area or subject is likely to change over time. For the scenario development, projections were made based on growth patterns, future city plans and expert opinion. Quantitative data were collected and processed as input to be fed into the model. Main categories of data are population number, land use (maps), urban water flows (water supply, wastewater-generation, -treatment, and -reuse), rainfall and river flow into and out of the city. The water utility provided data related to formal water supply. Data on water and sanitation were found and cross-compared. Model input data are compared with, and supported by, a literature review, estimations and assumptions.

Drivers to urban development

Dynamic water balance modelling has proven to be a useful tool in urban water resources management. This modelling can imply a simulation of the present situation, but a future situation can also be predicted with the use of scenarios. The following factors were identified as drivers to urban development in cities in sub-Saharan Africa and South Asia, and were used to generate scenarios for urban development:

- Population growth
- Per capita water demand
- Urban water supply capacity
- Sanitation and wastewater treatment capacity
- Basin water availability
- Climate change (affecting drivers 2 and 5)

The above listed drivers are briefly discussed below:

Population growth

Population growth is one of the demographic processes that will be a key determinant for water demand projections. The actual population growth as it will occur, will also greatly determine the volume of wastewater generation at the city level. Specifically for each case city, scenarios for population growth have been defined, based on available literature. The modelled scenarios for population growth have resulted in population change for each city in the modelled period.

Per capita water demand

Besides population growth, per capita water demand also determines water demand at the city level. In the literature review in chapter 2 it was made clear that the term “water demand” is subject to many different definitions and interpretations. For this factor, a set of two scenarios, were developed based upon local literature and expert opinion. Per capita water demand estimations differ for each city.

Urban water supply

For each city, at least two scenarios were developed for growth and expansion of urban water supply. The scenarios are based upon available information on water supply plans, derived from local reports and expert opinion. Among other factors, the pathway of urban water supply development strongly depends on the financial situation of the respective water supply authority/utility and the prevalent climate for funding by external donors.

Sanitation and wastewater treatment

Similar to the urban water supply scenarios, scenarios for wastewater treatment depend on the financial climate within and outside the water supply authority. For each city, two scenarios were developed, based on local plans for sanitation improvement and wastewater treatment as well as on expert opinion.

Basin water availability

When looking at the water availability from the different sources, in some cases new water sources have to be exploited to satisfy higher water demands to be expected in the future. The current model is not equipped to investigate this scenario. However, model results, in particular urban water demand scenarios can be, and were, compared with basin water availability. It is expected that in the future, other water sources may be exploited, further away from the city and outside the basin border. It is instructive to investigate water availability changes when projects will or will not be carried out. This could indicate the city's vulnerability in terms of water supply if long-distance water supply would be cut off due to conflicts or an extreme sequence of dry months. The assessment of this scenario was set in order to reach the fifth research objective: to assess the impact of future urban water use on water availability for agriculture at the basin level.

Climate change

Climate change is indirectly accounted for in the scenario analysis by testing two different figures for basin water availability. These figures are 50% and 75% dependable flows, based on historic time series data of river run-off of both Volta and Densu Basin. Due to the lack of actual downscaled climate change data, the water availability scenarios are not directly derived from climate change scenarios, but instead are based on recorded time series data for water availability.

Scenarios of development

Three main scenarios were developed, based on different projections of population growth and per capita water demand. The scenarios are:

1. Business-as-usual
2. Water savings
3. Accelerated growth
4.

The business as usual scenario reflects forecasts of moderate population growth and per capita water demand. The water savings scenario reflects a similar population growth, however with a slowdown of the growth in per capita water demand. The accelerated growth scenario reflects high and maximum projections for population growth and per capita water demand.

The scenarios are analysed in the case study results chapters (4, 5 and 6) with reference to the six drivers identified above.

Potential of wastewater reuse in agriculture

One of the scenarios being assessed for each city is the use of wastewater in agriculture. This scenario analysis is done based on potentially available water volume calculated from the urban water balance. Since water quality can become a major constraint to wastewater reuse, this is discussed extensively in the results chapters. The reuse of wastewater in cities has several benefits; reduction of water demand and hereby water-stress, water retention (hereby reducing/delaying flood discharges), food security, and income generation.

In the cities investigated most urban and peri-urban farming is not formally planned and practised with irrigation using marginal water from polluted urban surface waters referred to here as wastewater. The potential for planned wastewater reuse in agriculture does not merely depend on the availability of wastewater. It also depends on the availability of land. These two factors are being considered with reference to the three general urban development scenarios discussed in the next section. Other factors determining the potential of wastewater reuse in agriculture are the perception of farmers and the regulatory framework in place. The characteristics of urban agriculture and the scenarios determining future potential will be discussed in the case study chapters.

Equations used

For the composition of the urban water balance and the water balance modelling, the following equations were used.

[1] Net City Water Use	$WU_{nc} = WU_{gc} * (1-WL)$

where,

WU_{nc} = Net City Water Use [m^3yr^{-1}]

WU_{gc} = Gross City Water Use [m^3yr^{-1}]

WL = Physical Water Loss Fraction [-]

[2] Per Capita Domestic Water use $WU_{pcd} = WU_{dom} / N_{pop} / 30.42$

where,

WU_{pcd} = Per Capita Domestic Water Use [lpcd]

WU_{dom} = Total Domestic Water Use [$m^3\ yr^{-1}$]

N_{pop} = Population Number

[3] Water Supply Demand Gap $WSD\text{-}gap = (1-WS/WD) * 100$

where,

$WSD\text{-}gap$ = Water Supply Demand Gap [(%]

WS = Water Supply [lpcd]

WD = Water Demand [lpcd]

[4] Stormwater run-off $Q_{run\text{-}off} = A_c * 1 \cdot 10^6 * (P / 1000) * RRC$

where,

$Q_{run\text{-}off}$ = Stormwater Run-off [$m^3\ yr^{-1}$]

A_c = Urban Area of City [km^2]

P = Percipitation [$mm\ yr^{-1}$]

RRC = Rainfall Runoff Coefficient [-]

[5] Total wastewater generation $Q_{ww} = WUnc * WRF$

where,

Q_{ww} = Total Wastewater Generation [$m^3\ yr^{-1}$]

WU_{nc}	= Net City Water Use	[m^3 yr^{-1}]
WRF	= Water Return Fraction	[-]

[6] Wastewater treatment fraction $WW_{TF} = Q_{ww} / TC_{installed} *100$

where,

WW_{TF}	= Wastewater treatment fraction	[-/-]
Qww	= Total Wastewater Generation	[m^3 yr^{-1}]
$TC_{installed}$	= Installed wastewater Treatment Capacity	[m^3 yr^{-1}]

[7] Untreated wastewater volume $WW_{untreated} = Qww * (1-WWTF)$

where,

$WW_{untreated}$	= Untreated Wastewater volume	[m^3 yr^{-1}]
Q_{ww}	= Total Wastewater Generation	[m^3 yr^{-1}]
WW_{TF}	= Wastewater treatment fraction	[-/-]

[8] Weighted distance of water source to the city $D_{weighted} = (\sum D_i * V_i) / \sum V_i$

where,

$D_{weighted}$	= weighted Distance of water source to city	[km]
D_i	= Distance of source to city	[km]
V_i	= Gross Water volume supplied to city	[$m^3 yr^{-1}$]
i	= Water source i	

3.4 VALIDITY AND RELIABILITY OF THE RESEARCH

In order to strive for the research to be objective and credible, two indicators are often applied, namely, validity and reliability. Therefore, the two indicators were used as quality protection throughout the research process. Research validity can be defined as "*the quality of fit between an observation and the basis on which it is made*", while research reliability can be defined as "*the extent* *to which a measurement procedure yields the same answer however and whenever it is carried out*" (Kirk and Miller 1986). Validity and reliability of this research were borne in mind in a few ways. Standard and well-proven research tools were used, namely the urban water balance and system dynamics modelling. Both tools were based on well-established concepts and a set of equations suited for reproduction. Assumptions made in this research were supported with arguments as much as possible. There has been regular and consistent peer feedback from experts at various locations at the stage of research design and throughout the research process. The application of the VENSIM modelling tool and urban water balance in (van Rooijen et al. 2005) provided much support for the design of this research.

The quality of local data was verified by checking it with local and international experts, and data from the other city cases. Scenarios for the model were developed based on local literature and expert opinion. To safeguard quality and level of reality, assumptions and parameters of the scenarios were compared with sources from international literature. The model and all of its components were checked by modelling experts and were improved when possible. Results from modelling were compared with values found in general literature in order to verify the level of reality that the modelling results contain.

3.5 ETHICAL CONSIDERATIONS

Carrying out research may entail ethical dilemmas, issues, challenges or constrains, especially when research is directly or indirectly related to animal or human subjects. This however was generally not the case in this type of research. The only way where ethics came in was when performing field visits and semi-structured interviews. In these cases, the following points were taken into consideration:

- Communication with all experts, both local and international, was done with much respect for the interviewee and the respective institution. Any approached person was briefly introduced to the background and aims of the research.
- The information or data provided by individuals were kept confidential when this was asked for. Reference to this information and data was done accordingly.

4. CASE: HYDERABAD

This chapter will discuss the case of Hyderabad presenting the results that answer research question numbers 1-5 presented in Chapter 1. After a general introduction to Hyderabad, the institutional setting is outlined together with a discussion of the prevailing water issues in Hyderabad and its influence on the basin.

4.1 CHAPTER INTRODUCTION

Hyderabad is located in the state of Andhra Pradesh in Southern India (Figure 8). It is the largest city and state capital of Andhra Pradesh and the sixth largest city in India, with an estimated population of 6.8 million in 2010 (UN-Habitat 2008c). The urban area of Hyderabad has shown a densification and expansion which has accelerated since the early 1990s (GHMC 2005; Taubenböck *et al.* 2007). Few literature sources give figures for the built-up area of Hyderabad, ranging widely from 264 to 587 km^2 (Table 5). The figures for built-up area are the result of GIS methods. The wide variation in these estimates is likely to be caused by different methodologies used for the classification of land cover.

Table 5. Surface area and population of Hyderabad urban area using political and physical delineations.

	Surface area (km2)	Population (millions)	Source
Politically delineated area			
Hyderabad urban agglomeration	778	5.7 (2001)	(GHMC 2005)

Municipal Corporation of Hyderabad (MCH)	173	3.6 (2001)	(GHMC 2005)
Surrounding municipalities	419	1.7 (2001)	(GHMC 2005)
Built-up area2	313 (2004)		(Yuanije and Zomer 2004)
	587 (1996)		(Ramachandraiah & Prasad 2004)
	409 (2001)		(Krishna et al. Unpublished)
	264 (2001)		(Taubenböck et al. 2007)

Hyderabad lies in the Musi River Catchment, which is a sub-basin of the much larger Krishna Basin (Figure 8). Until the late 1950's, this catchment provided the predominant source of water for the city. Like all large cities in India, Hyderabad is a water stressed city having a structural water shortage. Intermittent water supply schemes are in place with domestic water supplied for only a few hours a day. Despite non-continuous water supply, water supply coverage in large Indian cities is generally high, at around 90% (Planning-Commission 2001; WSP 2003; NIUA 2005; World Bank 2006b; GOI and ADB 2007). Average water supply in Indian cities amounts to 180 litres per capita per day (lpcd) (NIUA 2005), however actual domestic use is much lower when industrial use and physical water losses are taken into account. Indian cities are also characterised by a relatively high fraction (over one-third) of the population living in informal settlements, often referred to as slums (UN-Habitat 2008c). Slum dwellers have a much lower water consumption than those in middle- and high-income residential areas, due to poor and informal water supply services provided to them (Bhandari and Khare 2006; Kjellen and McGranahan 2006). Wastewater treatment in Hyderabad (currently 5% of total wastewater generated) is lower than average for metropolitan cities in India (41%) (NIUA 2005).

[2] Based upon satellite images. The high discrepancy between the two figures for 2001 is due to different methodologies used for classification of land cover.

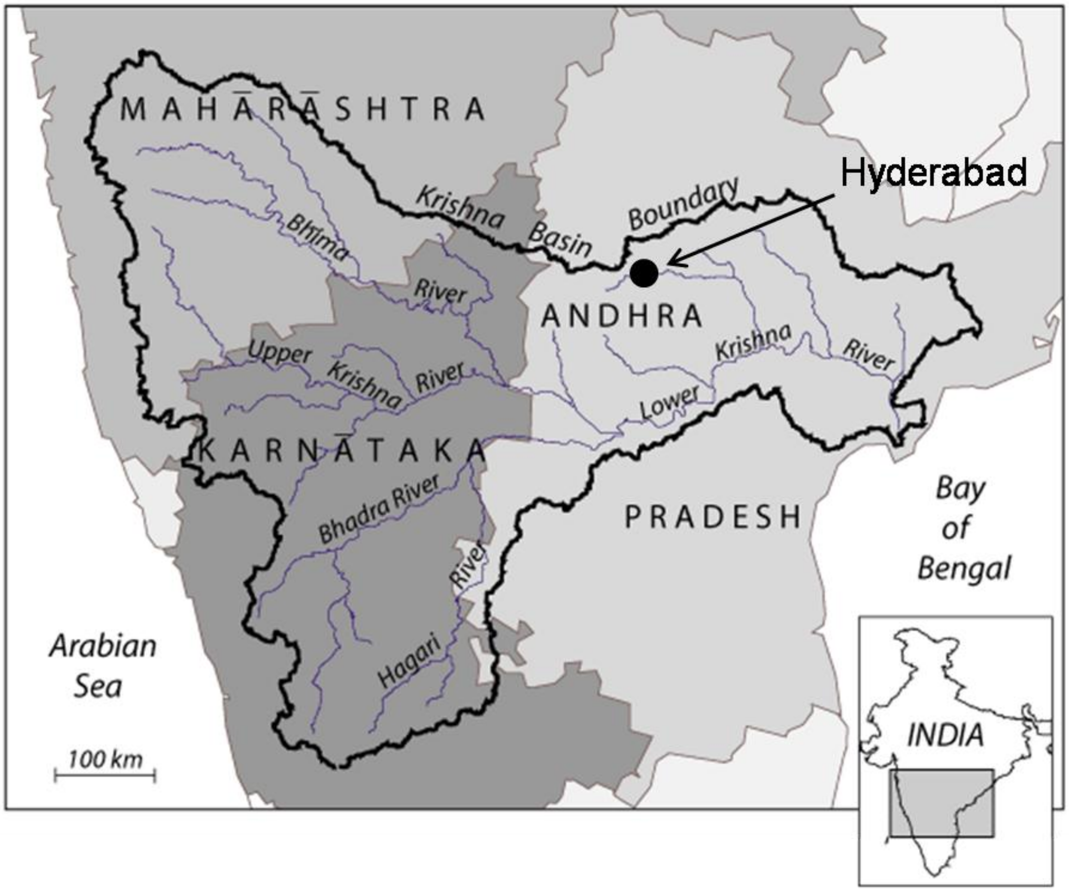

Figure 8. **Location of Hyderabad in India, Andhra Pradesh and the Krishna Basin.**

Source: Modified after (Biggs et al. 2007)

The Hyderabad Urban Agglomeration consists of the Municipal Corporation of Hyderabad (MCH), Secunderabad cantonment, ten surrounding municipalities and some few smaller settlements (Figure 9). With 605 km^2 the urban area surrounding the MCH area is actually much larger in size than MCH itself, which is only 173 km^2. The discrepancies between the politically defined urban area and the physically built-up area of Hyderabad are compared in Table 5.

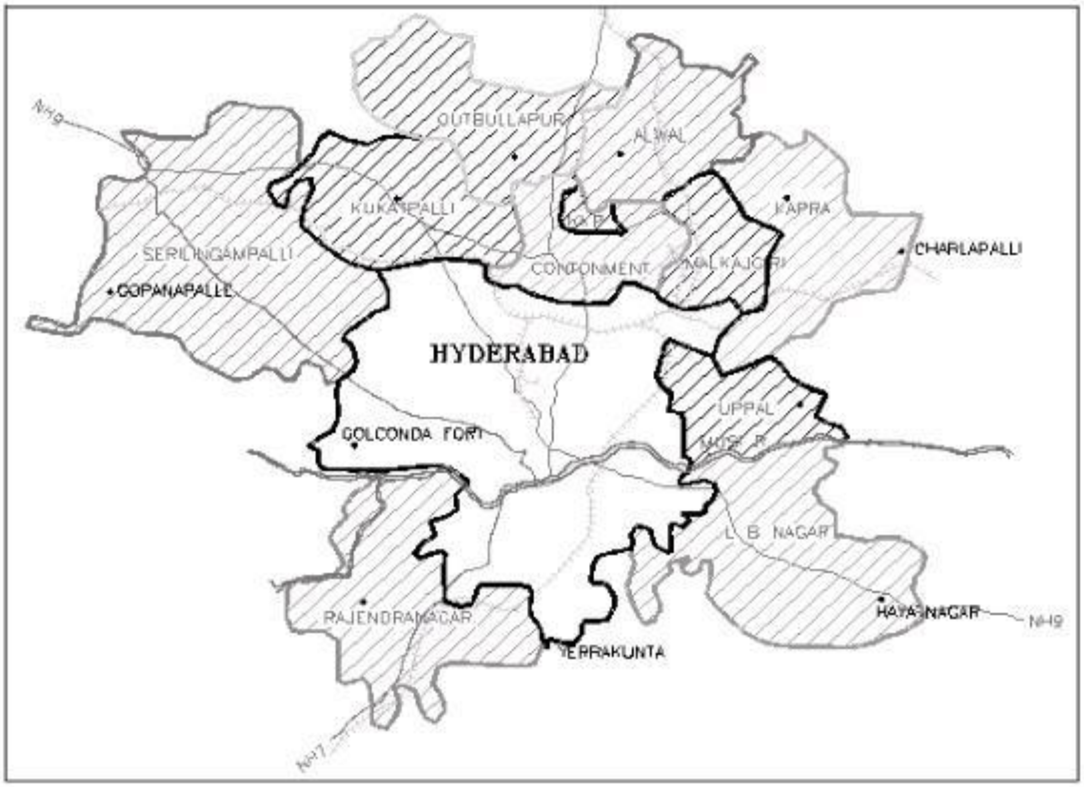

Figure 9. Map of the Hyderabad urban agglomeration consisting of the Municipal Corporation of Hyderabad and ten surrounding municipalities

Source: (HMWSSB 2005)

Present-day Hyderabad is undergoing rapid urban development as a result of fast economic and demographic growth. The metropolis has established itself as the new *IT hub* or *software capital* of India and is expanding. The service sector is expanding fast, with a growing middle class that benefits, and few benefits left for its poor urban counterpart (Ramachandraiah and Bawa 2000; Baru 2007). There is also an increasing sense of environmental awareness among the middle class. They represent the critical mass that is putting pressure on the government to improve the urban environment through organisations, online forums and other networks and media (Ramani 2004; Srinivasan 2004).

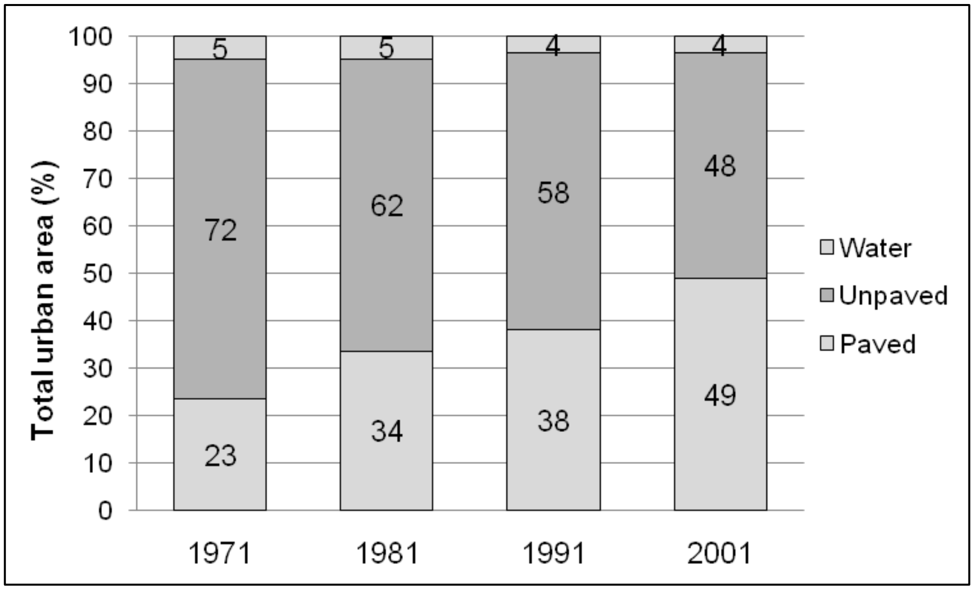

Figure 10. **Land-cover change in the Hyderabad urban area during 1971-2001.**

Source: (Iyer et al. 2007)

One feature of urban expansion and development in Hyderabad is that the green areas and water bodies are shrinking, in number and surface area. The fraction of unpaved area reduced from 72 to 48% during 1971-2001, while the fraction of water bodies shrank by 10 km^2 from 5 to 4% over the same period (Figure 10). The on-going reduction in permeable area has contributed to the worsening of floods striking the city during every rainy season (Ramachandraiah and Prasad 2004; GHMC 2005; Chigurupati 2009). The Hyderabad Urban Development Agency (HUDA) is actively preserving the remaining open spaces by developing them into public parks, in an effort to improve the urban environment (GHMC 2005).

4.1.1 Institutional setting of the urban water sector in India, Andhra Pradesh and Hyderabad

Federal level

In 1974, the Water Prevention and Control of Pollution Act was passed, which can be considered as the first major environmental legislation in India. It led to the formation of the Central Board for the Prevention and Control of Water Pollution now known as Central Pollution Control Board (CPCB). The CPCB is the national apex body for assessment, monitoring, and control of air and water pollution.

State and municipal level

Water supply and wastewater disposal are under the authority of the Hyderabad Metropolitan Water Supply and Sewerage Board (HMWSSB). Prior to 1987, Hyderabad had separate institutions for water supply and wastewater disposal. Water supply was managed by the Public Health Engineering Department of the Government of Andhra Pradesh and sewerage was dealt with by the Municipal Corporation of Hyderabad (MCH). The reform into a single institution was encouraged by the World Bank as a means to enable greater financial and operational autonomy as well as to enable better accountability to its customers. The two spearheads of the water authority are to increase efficiency of its operations and to improve the quality of services to customers (Kabeer 2004; CSH 2008; Davis *et al.* 2008). Initially, the HMWSSB services were confined to the MCH area. In 1995, the board decided to extend its services to the ten municipalities adjoining Hyderabad. The main argument was that population growth projections revealed that 45% of the metropolitan population would be residing outside the MCH area by 2001. In 1996, the municipalities handed over the water supply and sewerage operations to HMWSSB.

The state-level authority of the CPCB, the Andhra Pradesh Pollution Control Board (APPCB) was formed two years after the CPCB was formed.[3] APPCB plays the primary role in implementing environmental policies and regulations and developing a framework to

[3] http://appcb.ap.nic.in/aboutus/about_us.htm

manage both wastes and natural resources more efficiently in the state of Andhra Pradesh. Industries are now obliged to treat their effluents to acceptable water quality standards. However, there is not sufficient institutional capacity for law enforcement which has left most industries to continue to dump their effluents into the urban environment (CPCB and MoEF 2003; Ramani 2004).

Maintenance of the stormwater drainage system is under the authority of the municipal corporations. These entities are responsible for the planning and construction of drainage infrastructure in areas of urban expansion. Also they are responsible for widening and cleaning of drains to reduce urban floods (Anonymous 2008; CMED 2010).

4.2 TEMPORAL DEVELOPMENT OF WATER SUPPLY AND SANITATION IN HYDERABAD

This section aims to answer the first research question. It will discuss the development of water supply and sanitation in relation to urban growth, from the second half of the last century until the present.

4.2.1 Water supply development in Hyderabad

Early sources of water for the population of Hyderabad were groundwater and water directly taken from the Musi River. Throughout the first half of the 20th century, reservoirs were built around the city for protection against floods and for securing water sources for irrigation. Urban water supply from these new sources became increasingly necessary with increasing demands (Figure 11).

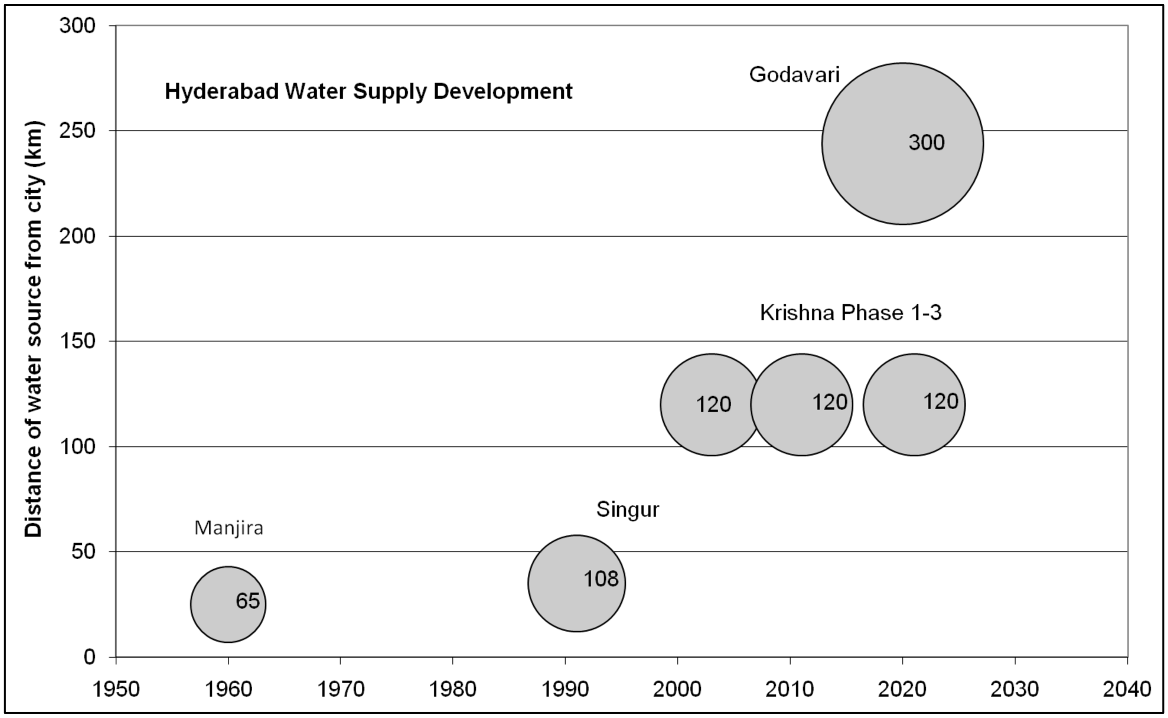

Figure 11. Water supply development to Hyderabad during 1950-2040.

Bubble size and number depict (additional) annual volume supplied to the city, in 10^6 m^3.

Source of data: **(HMWSSB Unpublished)**

As a prime response to serious flood events of the Musi River into the city, a dam was constructed in 1920 that formed the Osman Sagar Reservoir. The completion of the dam and subsequent formation of the reservoir enabled local authorities to put in place the first form of organised water supply to the citizens of Hyderabad. Later, in 1927, a dam was built on the second Musi tributary flowing into Hyderabad, which created the Himayat Sagar Reservoir (Figure 14). Until the 1960s, these two surface water sources were sufficient to serve the growing urban population. Groundwater from wells scattered across the city was also used (Venkateswara-Rao and Rao 1998), accounting for 6% of total water use in 1950. More recent groundwater withdrawal for urban water use was estimated at 113,000 m^3d^{-1} (GoAP 2003), which is 14% of total supply. The future scale of use may slow down due to deterioration of water quality as a result of pollution (CPCB 2002; Venkateswara Rao 2004). Based on plans for further expansion of supply from surface water sources, the share of groundwater in total urban water supply will reduce to 9% by 2030.

From the 1960s onwards, additional water sources were exploited, located further away from the city and outside the local catchment area. Larger volumes of water were withdrawn and supplied to Hyderabad, in an attempt to meet growing urban water demands (Figure 12). In 1960, water started to be pumped from the Manjira Reservoir, located 15 km away from the city. In 1991, additional water from the Singur Reservoir doubled annual urban water supply to over $200 \cdot 10^6$ m^3. Just into the 21st century when, once more, the existing sources became incapable of quenching Hyderabad's growing thirst, new water sources were sought. The ambitious Krishna water supply project was generally considered a relief for Hyderabad's water stress. It could also lower demands on existing sources, to the benefit of agricultural water use (Anonymous 2005a). In March 2003, pumping started from the Nagarjuna Sagar Reservoir from a distance of more than 120 km away from the city. The project consists of three phases, having an incremental water supply expansion each of $120 \cdot 10^6$ m^3 in the years 2003, 2010 and 2020 (Figure 12).

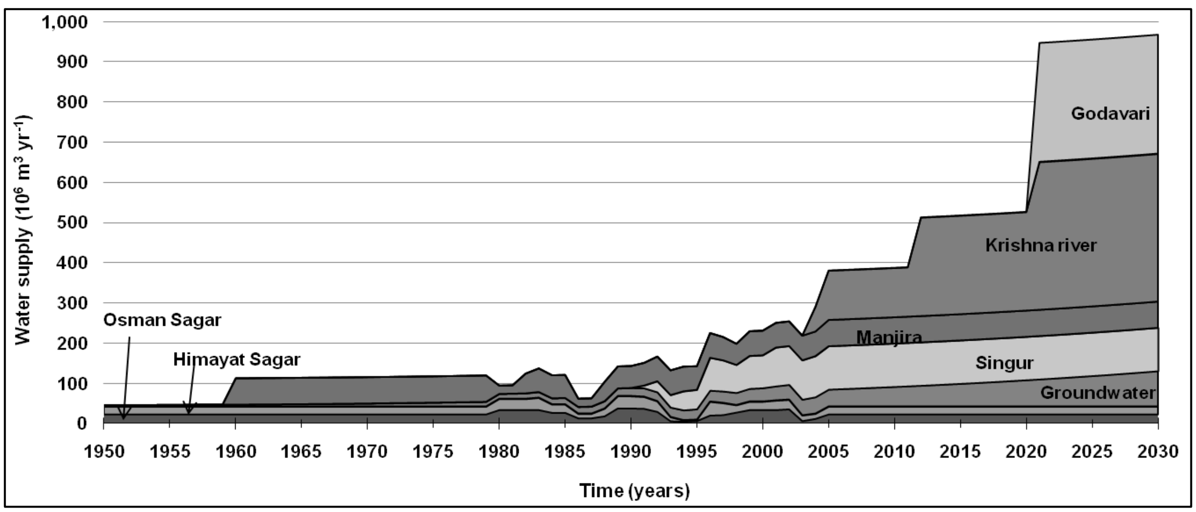

Figure 12. Water supply development to Hyderabad during 1950-2030.

Source: Adapted from van Rooijen et al. (2005)

As discussed earlier, Hyderabad's reliance on local water sources changed in the 1950s when supply shifted fast to sources outside the Musi Sub-Basin (Figure 13). Since the year 2005, water from the Krishna River has accounted for the single biggest water source in volume, located 120 km away from the city. For the future, a total annual volume of $300 \cdot 10^6 m^3$ of water is planned to be supplied from the Godavari River, which is located outside the Krishna Basin at a distance of 240 km from Hyderabad.

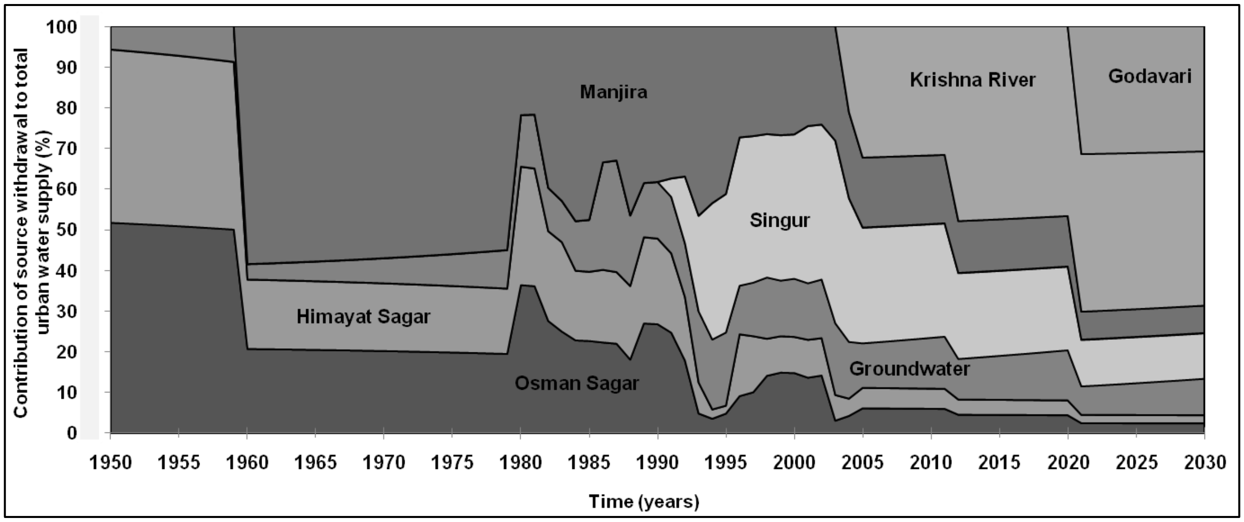

Figure 13. **Contribution of water sources to total water supply.**

Source: adapted from van Rooijen et al. **(2005)**.

The scale of the ambitious Krishna and Godavari projects gives an indication of the prevailing economic incentive to carry them out. As discussed in the introduction, Hyderabad has undergone major economic growth and the merging of an urban middle-class, which has created higher economic demand for water.

4.2.2 Sanitation facilities in Hyderabad

In Hyderabad, 41% of the population is connected to the sewerage system, while another 40% uses a septic tank or at least a pit latrine (GHMC 2005; IIPS 2007). The first sewers were laid in 1931, designed to cover an area of 54 km^2 across the cities of Hyderabad and Secunderabad, with a capacity to serve nearly half a million people. Much later, in 1985, the sewerage system was extended with the addition of five major sewer lines. Officially, the sewer system covers 95% of the area covered with piped water supply. Of the inner urban area (MCH) 70% is covered, while 20% of the ten surrounding municipalities is covered. A minor part of the population (~20%) does not use any sanitation facility and defecates in a bush, on fields or straight into the gutter. While this fraction for open defecation is minor, it does have a major impact on public health and the environment.

The municipalities of the Hyderabad urban area do not have sufficient funds to expand the sewerage system and upgrade wastewater treatment plants. New projects are initiated by local authorities or as part of donor programmes, such as the development of on-site sanitation or improved public sanitation blocks.

4.2.3 Deterioration and disappearance of urban ponds

This section discusses the traditional functions, deterioration gradual disappearance of ponds in Hyderabad. Ponds are small water bodies that are traditionally used for water supply, irrigation and storage of excess run-off. Early reports on anthropogenic disturbance of the quality of natural water bodies in Hyderabad exist for fresh water ponds (Rao 1971) and the Musi River (Venkateswarlu 1969). In the past, Hyderabad counted more than 500 artificial and natural ponds and lakes ranging in size from tenths of a square metre to hundreds of hectares. Some lakes were interconnected so that, during intense rainfall events, higher lakes overflowed to lakes lower down the watershed. Many ponds have been gradually filled up with household waste while large lakes have decreased in size. The dumping of solid waste in the ponds created pollution of water and soil in and around the ponds. For example, the Hussain Sagar Lake shrank from 550 ha to 349 ha due to encroachments by private and public agencies (Ramachandraiah and Prasad 2004). The deterioration and disappearance of Hyderabad's lakes have contributed to the degradation of the urban environment. The reduction in ponds resulted in less infiltration which is said to have contributed to a lowering of the groundwater level. The buffer capacity function that ponds used to have for storing run-off has also reduced, hence making floods worse. Public awareness, integrated urban water management, effective legislation to protect urban lakes and adequate institutional arrangements are necessary to restore the lakes and reduce flooding (Ramachandraiah and Prasad 2004; Verhagen 2005; Chigurupati 2009).

4.3 THE URBAN WATER BALANCE OF HYDERABAD

This section discusses the main components of the urban water balance for the city of Hyderabad and provides estimations of the main water flows in the present situation. This section discusses the second research question; what are the most important urban water flows that compose the urban water balance?

The main constituents of the urban water balance are part of two fundamental and mixed processes; the water supply and wastewater disposal system, and the rainfall-stormwater-drainage system. The sketch below depicts the water balance with some extent of geographical representation of the actual situation (Figure 14).

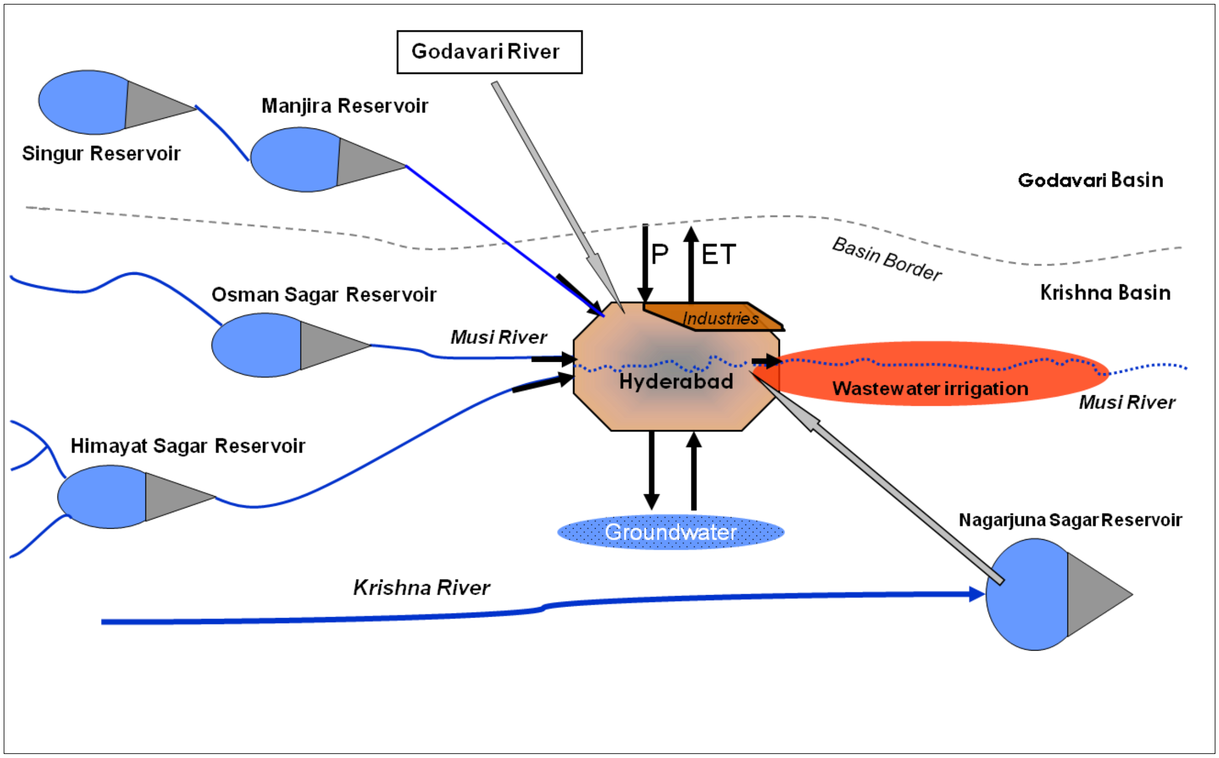

Figure 14. Water balance of Hyderabad.

4.3.1 Water flows into the Hyderabad urban area

Water enters the urban water balance in three ways; namely direct rainfall, piped supply and groundwater withdrawal. Unlike the case of Accra and Addis Ababa, there is no water inflow through river run-off, since the main Musi River is blocked upstream. In terms of annual volumes, water input through rainfall ($331 \cdot 10^6 m^3$) is less than piped water supply ($380 \cdot 10^6 m^3$). Groundwater withdrawal was estimated at $40 \cdot 10^6 m^3$, but this value is very uncertain since there are no records of the number of boreholes and pumping rates. In summation, the total annual volume of water entering the urban area was estimated at $751 \cdot 10^6 m^3$ (Table 6).

4.3.2 Water flow out of the urban area

Water leaves the urban domain in four major ways; evapotranspiration, percolation, stormwater run-off and wastewater disposal. Evapotranspiration consisting of evaporation and transpiration amounts to $279 \cdot 10^6 m^3$, and originates from water supply ($196 \cdot 10^6 m^3$) and rainfall ($83 \cdot 10^6 m^3$). Evapotranspiration from water supply is calculated from the sum of water supply and groundwater withdrawal, minus leakage from piped network and wastewater disposal. Evaporation from rainfall is calculated from rainfall ($331 \cdot 10^6 m^3$) minus natural percolation ($33 \cdot 10^6 m^3$) and storm water run-off ($215 \cdot 10^6 m^3$). The share of physical water losses is relatively high, 30% of gross supply or $114 \cdot 10^6 m^3$. The fate of this water in the urban water system is not well known (Kabeer 2004). In the water balance it is accounted for as percolation (10% of losses) and evaporation (90% of losses). However, there are two other possible pathways that are not included due to lack of data. A significant fraction may already be lost in the water supply system before it reaches the urban area. Secondly, a large fraction may be used illegally by citizens. The city has a stormwater drainage system that conveys excess stormwater ($215 \cdot 10^6 m^3$) and disposes of untreated wastewater into the Musi River ($213 \cdot 10^6 m^3$).

Table 6. Components and annual volumes of the Hyderabad urban water balance.

Inflows			Outflows		
Component	Symbol	Volume ($10^6 m^3 yr^{-1}$)	Component	Symbol	Volume ($10^6 m^3 yr^{-1}$)
Rainfall	R	331	Evaporation and transpiration	ET	279
			Evapotranspiration from water supply (196)		
			Evaporation from rainfall (83)		
Water supply	WS	380	Percolation	P	44
			Leakage from piped network (11)		
River run-off	RR	0	Natural percolation (33)		
			Storm water run-off	SWR	215
Groundwater withdrawal	GW	40	Wastewater disposal	WWD	213
Total	IN	751	Total	OUT	751

Discussion of results

The water balance presented here consists of several coarse estimates and calculations that are meant to provide insight into the pathways and scales of the different water flows running through Hyderabad. The water balance shows that the volume of piped water supply and rainfall are in the same order of magnitude. At the same time, the city's 'effluents' (stormwater run-off and wastewater disposal) have a comparable volume. Another finding is that groundwater recharge through percolation shows a net surplus of $107 \cdot 10^6 m^3$ per year, which contradict earlier findings of a steady decline of the groundwater table in the Musi Sub-Basin (Venkateswara-Rao 2004; Massuel *et al.* 2007). Informal domestic and agricultural use of groundwater may be the primer reason for this discrepancy. However, in this study this unknown component is not accounted for, due to a lack of data.

4.4 SCENARIOS FOR URBAN WATER DEMAND

This section deals with scenarios for urban water demand in Hyderabad. The results presented here aim at answering the third research question; what are the scenarios for water demand, based on different scenarios of demographic growth and change in living standards?

As was made clear in the introduction, Hyderabad is undergoing rapid urban development pushed by population growth and economic development, which is likely to continue over the next decades. More people will demand more water for domestic use. Additional changes in individual lifestyles, income level and type of access to water supply, have an effect on per capita water demand. Besides domestic use, industries are likely to further expand, with consequences for industrial water requirements. The Andhra Pradesh water vision mentions a current *water- scarce situation* (1,400 $m^3 cap^{-1} yr^{-1}$) likely to turn into a *close to severe water-scarce* scenario (1,150 $m^3 cap^{-1} yr^{-1}$) by 2021 (GoAP 2003). The current gap between supply and demand is 56% (equation [4], section 3.3.4). This section will discuss the three scenarios in relation to urban water demand in Hyderabad. The same three scenarios have been introduced earlier, in the methodology chapter:

1. Business-as-usual

2. Water savings
3. Accelerated growth

The business as usual scenario reflects forecasts of moderate population growth and per capita water demand. The water savings scenario reflects a similar population growth, however with a slowdown of the growth in per capita water demand. The accelerated growth scenario reflects high and maximum projections for population growth and per capita water demand.

Water demand has been estimated in several documents, for the city level and has been aggregated by sector. In some cases it is not clear whether numbers represented accounted for water losses or industrial use. Also, documents lacked a reference to population numbers used to either calculate city water demand or per capita water demand. In the selected literature, water demand is in the range of 442-730 and 553-1,013·$10^6 m^3$, respectively, in 2011 and 2021 (Saleth and Dinar 1997; CDM 2004; Kabeer 2004; HMWSSB 2005; George *et al.* 2008; Davis n.d.) (Table 7). Per capita water demand for 2011 is between 140 and 160 lpcd. For the development of scenarios for water demand, the current (2010) water demand was set at 160 lpcd. This number includes non-domestic water uses and accounts of physical water losses in the supply and distribution system. No information was found on past water demand. However, for 1915 and 1947, water supply has been reported to be similar to current rates, with per capita water supply of 90 and 109 lpcd, respectively (Chettri and Bowonder 1983).

Table 7. Water demand estimations for Hyderabad.

Per capita water demand (lpcd)	City water demand (106m3)		Source
2011	2011	2021	
148	442	553	(HMWSSB 2005)
140*	520		(George et al. 2008)
	777	1,013	(Saleth and Dinar 1997)**
160	477		(Kabeer 2004)
	730	949	(Davis n.d.)
	632	706	(CDM 2004)

*Including 20% water demand for industries. **Including 15% water demand for industries.

Future scenarios for water demand are based on growth rates for population and changes in per capita water demand. Population growth forecasts for Hyderabad range between 2 and 3% growth per year. The projections for per capita water demand include all urban end uses (most notably ~20% industrial water use) and physical water losses (16% of gross supply). The demand decrease in the *water savings* scenario incorporates water-demand management options, such as reduction in water losses (utility level) and rainwater harvesting (household level). Future changes in water demand have been accounted for in the three scenarios, using increases in growth of 0.5 and 1.6 for respectively the business-as-usual and accelerated growth scenarios. The water savings scenario foresees a growth stagnation of per capita water demand (Table 8).

Table 8. Projected growth rates for population and per capita water demand in Hyderabad during 2010-2030.

Scenarios	Projected annual population growth rate (%)[1]	Projected annual growth rate of per capita water demand (%)[2]
Business-as-usual	2.0	0.50
Water savings	2.0	0.00
Accelerated growth	3.0	1.60

*Water losses and non-domestic water demand are accounted for in the values mentioned.

1. Based on (George et al. 2008; UN-Habitat 2008c)

2. Based on: (Saleth and Dinar 1997; HMWSSB 2005; Kumar 2007; George et al. 2008; Davis n.d.)

The demand scenarios show increases of urban water demand from $436{\cdot}10^6 m^3$ in 2010 to between 600-1,100$\cdot10^6 m^3$ in 2030 (Figure 15). The values presented here are indicative of the range of water demand that can be expected for Hyderabad, until the year 2030.

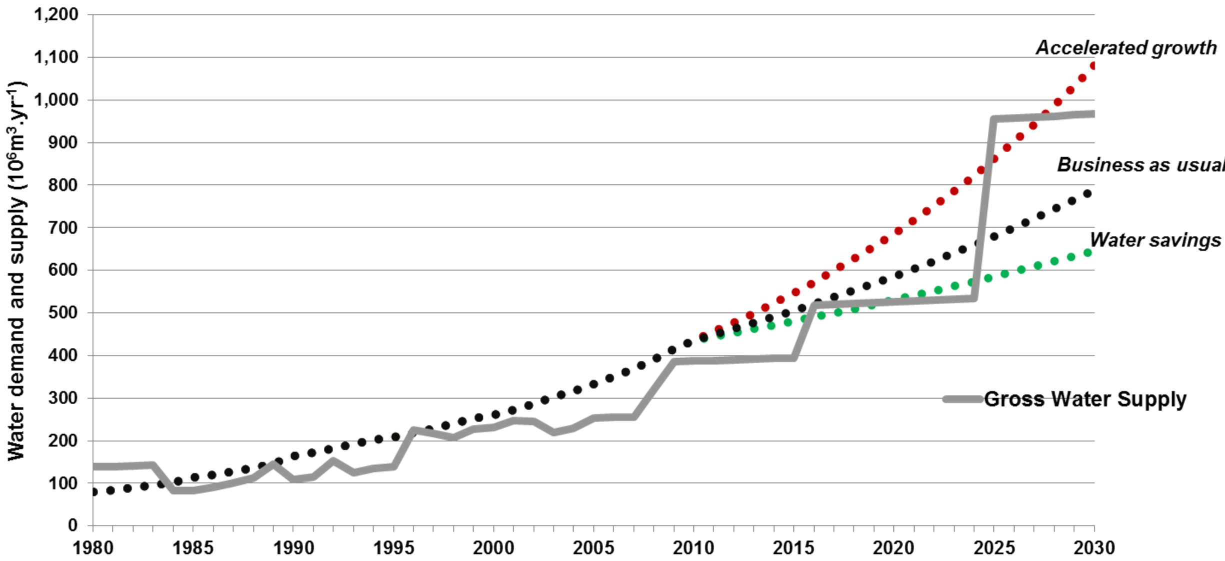

Figure 15. Gross water supply and water demand scenarios for Hyderabad during 2010-2030.

The scenario analysis for water demand in Hyderabad has indicated that a wide range in water demand is projected. Water demand in the accelerated growth scenario is nearly double the projected water demand in the water savings scenario. Gross water supply is likely to satisfy demand in two out of three investigated scenarios, however it would be insufficient to meet water demand in the *accelerated growth* scenario. The relatively wide range of demand projections that are presented here, gives an indication of the preparedness that is required by local planners and policy makers. The projections require major efforts for planning of urban water supply and water demand management.

4.5 WASTEWATER USE IN AGRICULTURE

This section discusses the scenarios for the use of urban wastewater in agriculture. The results contribute to answering the fourth research question: what are implications of different scenarios of urban development and the consequent wastewater flows, for wastewater irrigation potential and risks?

The past temporal growth and development of Hyderabad have entailed a clear expansion of irrigated area downstream of the city. This is mainly due to the increasing water volume generated by the city, availability of land and the favourable locations of big food markets offered by the city. The growth in wastewater volume has been the result of increased urban run-off and wastewater disposal in a fairly equal proportion (van Rooijen *et al.* 2005; Ramachandraiah and Vedakumar 2007; George *et al.* 2008). After sketching out the current situation, this sub-chapter discusses future scenarios for wastewater generation, reuse potential and risks. The scenarios are based on the three urban development scenarios designed and described in the methodology chapter (section 3.3.4).

4.5.1 Current situation

Wastewater is being used in Hyderabad wherever land is available. The most visible place is the banks of the Musi River on a length of 27 km (Figure 16). Agriculture is also being practised within the urban area on open spaces and in home gardens. Figure 16 shows the boundaries of Hyderabad (joint with Secunderabad), with the Musi River flowing from East to West. On the West side of Hyderabad, the Musi is damned by the Osman Sagar and Himayat Sagar dams. On the East side of Hyderabad, wastewater irrigated areas are visible on both sides of the river (depicted as grey shaded area).

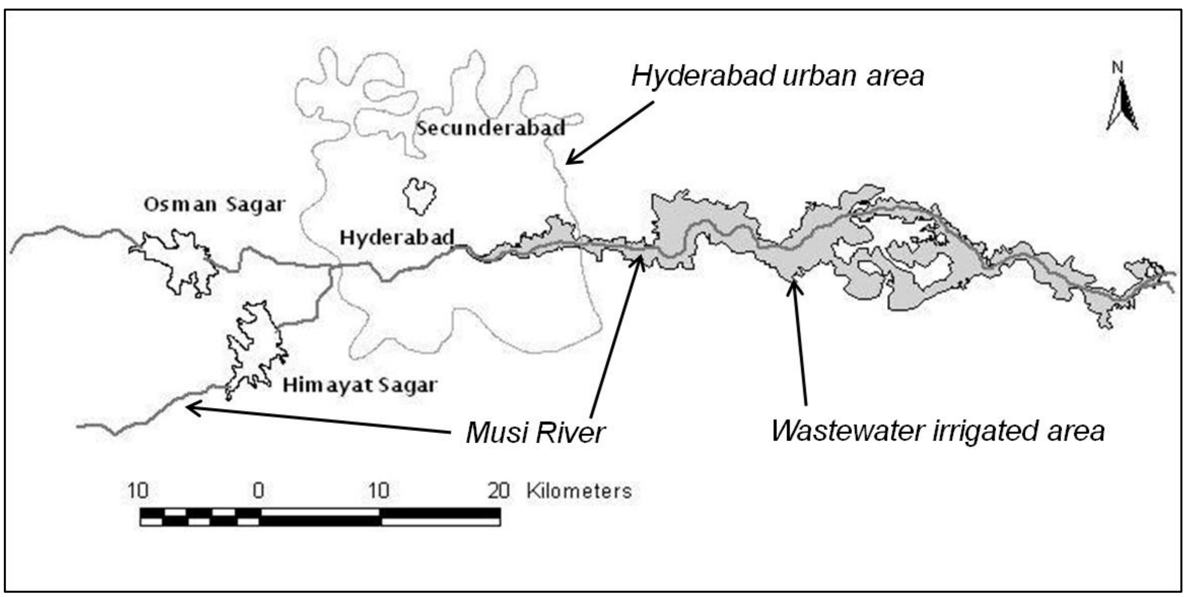

Figure 16. Map of Hyderabad urban area, Musi River and wastewater irrigated area.

The water used is usually a mix of stormwater, and black- and grey wastewater available from drains, tanks and the river. The Musi River downstream of the city has a series of 22 weirs that lift the water level and store the water. The weirs are known to have existed at least since the 11th century, when they were first reported (Ensink 2004). From these points, water is diverted to irrigation canals on both banks of the Musi. It has been argued that the irrigation infrastructure and irrigation practices actually contribute to the natural purification process of the water. The check-dams increase the retention time, thereby increasing the level of treatment. Also the overflow from the dam head favours re-aeration of the water. The water is filtered when it is being applied on the fields; the drainage water has significantly more clarity than the original supplied water which indicates a drop in the level of suspended solids (Figure 17) (Ensink *et al.* 2006).

Figure 17. Collected water samples from the Musi River at distances of 0-40 km downstream of Hyderabad.

Further downstream is from left to right.

Source: Ensink et al. (2006).

Within the city itself, farmers cultivate a variety of crops, some green vegetables as well as coconut, banana, and paragrass (*Brachiaria mutica*), the last of which is a fodder crop used to feed water buffalos (Buechler *et al.* 2002). It is important to distinguish the different levels of health risks by type of crop consumed. Consumption of coconut and banana do not pose health risks when consumed, in contrast to crops (such as tomato) of which the peel is usually consumed as well. Leafy vegetables such as salad and spinach entail more potential health risks, due to their large surface area on which pathogens can be found when irrigated with contaminated water. Also, households cultivate crops, mostly vegetables, in their gardens. Estimations of the total area currently under irrigation in the city vary between 100 and 500 ha. Downstream of the city, paragrass and rice are extensively cultivated on a total estimated area of 8,000 ha. The thousands of farmers who are involved in irrigation with wastewater gain a substantial income that is essential for their livelihoods (Buechler and Devi 2003). A more accurate estimate of the number of farmers involved was not found, however it has been estimated that the livelihoods of approximately 150,000 people are directly or indirectly supported (Buechler et al. 2002). There are substantial health risks for those that are in close contact with wastewater. Studies have shown that farmers irrigating with wastewater have a higher prevalence of hookworm and intestinal nematode infections, compared to farmers who use freshwater (Ensink *et al.* 2006; Ensink *et al.* 2008).

The government has no regulations in place on the use of wastewater in irrigated agriculture and it has so far been tolerated but not promoted. The municipal government does acknowledge the benefits of urban agriculture to livelihoods and food security, and has shown interest to include this land use in its city development programme. Their own interest here is to make Hyderabad greener by planting more trees and conserving the few green open spaces that are left in the city. Hyderabad was also the venue for an international meeting of research experts who discussed the use of wastewater in agriculture in 2002. The experts group agreed on a set of statements related to the sustainable use of wastewater in irrigated agriculture, that resulted in the Hyderabad Declaration on the use of wastewater in agriculture (Various authors 2002). One of the main agreements was that wastewater reuse in agriculture should be promoted while minimizing risks to human health and the environment.

The water-stressed situation in Hyderabad facilitates water conservation and reuse. Hyderabad is a good example of how urban development has entailed a growing volume wastewater volume and growing wastewater irrigated area downstream of the city in response. The future of wastewater irrigated agriculture in Hyderabad holds both risks to human health environment and opportunities for livelihoods and urban food security. Salt accumulation in agricultural soils is limiting rice yields, a process which is occurring along the Musi, and which is causing a shift to the more salt-tolerant paragrass in response (McCartney *et al.* 2008). Moving downstream from Hyderabad and with improving water quality (Figure 17), it can be observed that paragrass is gradually being replaced by paddy cultivation. Furthermore, heavy metals from industrial effluents are present in the Musi water, which leads to accumulation in the environment and health risks for farmers and crop consumers (Gerwe 2004; Chary *et al.* 2008). A large and very polluting industrial zone is located in Patancheru, to the north of Hyderabad. Toxic effluents are released into a sub-river of the Manjira, which is not connected to the Musi Catchment (Shivkumar and Biksham 1995). However, a proposal has been prepared that would link effluents from this industrial zone to the municipal drainage system, hereby letting these effluents flow into the Musi River. This would have great consequences for Musi water users along the Musi River. The future of wastewater irrigation will immensely depend on the development of industries in Hyderabad and the level of pollution control measures that will be effectively enforced by the local authorities.

Another factor contributing to the sustainability of wastewater irrigation is the way in which wastewater is going to be disposed of in the future. Ambitious plans are now being executed to build wastewater treatment plants aiming to treat 590,000 m^3 d^{-1} (GHMC 2005), which could treat 73% of the total generated wastewater volume in 2020 (Van Rooijen et al. 2010). With treatment capacities having increased in the future, the volume of wastewater effluents will reduce to some extent, due to evaporative losses occurring during wastewater treatment. The quality of the water used by farmers will generally improve, with a reduction of Biological Oxygen Demand (BOD), pathogens and Total Suspended Solids (TSS). The construction of wastewater treatment plants is part of recent initiatives to *conserve* the Musi River and transform the riverfront into attractive recreational areas (HMWSSB 2002; Anonymous 2005b; Ramachandraiah and Vedakumar 2007). The Musi beautification project has already been criticised for not providing integrated solutions to the Musi River and Hyderabad’s water management (Ramachandraiah and Vedakumar 2007). One of the shortcomings identified is the fact that the plan does not consider the wider catchment area of the Musi. There is no mentioning of industrial pollution- control plans without which the Musi will remain polluted. It does not consider the people making use of the fertile river banks to grow crops either. An execution of the Musi beautification project would mean that these people would need to be evicted. However, the report does not mention this, and compensation structures for these affected farmers have not been accounted for.

Based on water demand projections calculated for the three urban development scenarios, resulting wastewater flows have been calculated, using equation [5] section 3.3.4 (see Table 9).

Table 9. Projections for wastewater volumes based on urban development scenarios for Hyderabad, for 2010, 2020 and 2030

Year	Projected wastewater generation by urban development scenario (MCM yr^{-1})		
	Business-as-usual	Water savings	Accelerated growth
2010	244	244	244
2020	328	297	384
2030	442	362	605

The figures presented are based on equation [5] listed in section 3.3.4.

During the period 2010-2030, steep increases can be expected in the volume of wastewater generated, in all the three urban development scenarios described here. However, these numbers are based on scenarios for water demand. The estimations for wastewater generation are based on the assumption that water demand will be fully met. The scale of actual volumes that will be generated depends on the volume of water supply. Future water supply will depend on investment scenarios for water supply expansion. However, actual water supply plans for Hyderabad is likely to meet demand in all three scenarios for water demand. Within the investigated time frame of 20 years, wastewater volumes are expected to increase from 244 MCM yr^{-1} currently (2010), to 442, 362 and 605 MCM yr^{-1}, in the business-as-usual, water savings, and accelerated-growth scenario, respectively.

In Hyderabad, wastewater is already being used in irrigated agriculture on a large scale, in terms of irrigated area and crop production (Van Rooijen et al 2005). The city provides farmers on the river banks inside and downstream off the urban area with year-round water containing nutrients that enhance crop growth. The potential for wastewater reuse in agriculture is high in all three urban development scenarios, when taken from merely a water availability perspective. The extent to which wastewater irrigated agriculture will be expanded, depends on various factors:

- the level of industrial pollution control and related environmental degradation of agricultural soils,
- developments in wastewater treatment and -disposal infrastructure,

- the policy environment, influenced by civil society,
- annual climate variability and related basin water availability.

Even though the development of most factors are difficult to predict, wastewater reuse in agriculture in Hyderabad’s case is more likely to expand than reduce, given Hyderabad’s favourable climate for reuse (dry) and geography of city, Musi River and downstream agricultural area (Figure 16).

4.6 BASIN-LEVEL INFLUENCES OF URBAN WATER USE

This section explores the water links that Hyderabad has with the basin in which it is located. Research question five (section 3.1) is sought to be answered, which is; what is the impact of urban water use on water availability for agriculture at the basin level?

Hyderabad is located in the lower part of the Krishna Basin which is the fifth largest river system in India in terms of drainage area (258,514 km^2) and annual discharge (69.8 km^3yr^{-1}) (Kumar *et al.* 2005). The basin extends over three states in fairly equal proportions, namely Andhra Pradesh, Karnataka and Maharashtra. Hyderabad is by far the largest city in the basin, followed by Pune, which is another million plus city located in the state Maharashtra. The basin has a low level of urbanisation, with a population density of 258 persons km^{-2} and 66% of its population living in villages in 2001 (Table 10). Although the urban population in the basin represents 34% of the total population; their share in total domestic water use in the basin is 60%, due to their higher per capita water use (Van Rooijen et al 2009). Table 10 shows that expected urbanisation in the basin will lead to higher domestic water demands as a result of increasing average per capita water demands, apart from mere population growth. The spatially concentrated nature of urban water use will require more effort to bring more water into urban areas, especially when local water sources are already fully committed.

Table 10. Population distribution over size classes and estimated per capita water use in the Krishna Basin.

City size class	Number	Population number		Per capita water use	Total domestic water use	
		(million)	(%)	(lpcd)	(106m3)	(%)
Million plus: Hyderabad + Pune	2	9.6 (6.0+3.6)	14.1 (9+5)	80 in Hyderabad / 180 in Pune	412 (175+237)	25
Cities (>100,000)	28	9.5	14.0	120	416	25
Towns (20,000-99,999)	96	4.2	6.2	100	153	9
Villages (<19,999)	1,617	44.8	65.8	40	654	40
Total/average		68.1	100	66	1,635	100

Source: van Rooijen et al. *(2009).*

The Krishna Basin is considered a closed basin, which means that all the available water has been allocated for certain end uses. The water-stressed situation has led to competition for water, and water transfers from agriculture to urban use (Lakshimipathi 2001; Celio and Giordano 2007; Celio 2008). Developments in the basin, such as urbanisation and industrialisation are expected to put further water demands on available water resources (van Rooijen et al. 2009; van Rooijen et al. 2010). This finding was further explored by modelling basin development scenarios against water availability in the basin. The development scenarios are, as mentioned earlier, *business as usual*, *accelerated growth* and *water savings.* For these three scenarios, specific growth rates were used to model water use for three sectors that are considered most dominant: domestic, industrial and agro-industrial water use.

To quantify scenarios for basin water availability, two figures were used based on empirical time series of run-off data and the calculated 75% and 50% dependable flow, derived from (Sajjan 2005). The 75% therefore represents a dry year, while the 50% represents an average climatic year in the basin. The dependable flow gives information on the statistical likeliness of a certain run-off to occur in the future, based on a historical period of runoff data. 75% dependable flow means, a run-off that is exceeded in 75% of the years. The 50% dependable flow is equal to the mean flow.

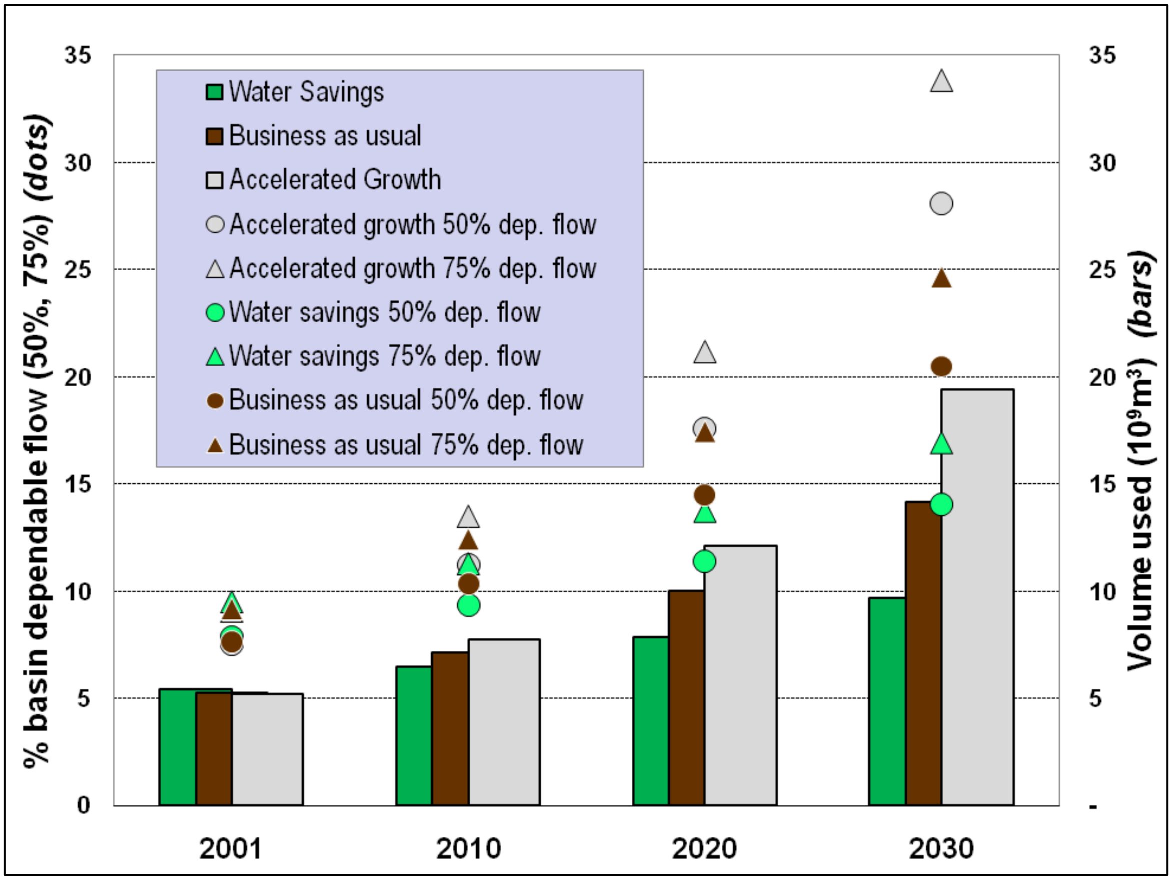

Figure 18. Water use volumes and proportions of 50% and 75% dependable flow in three scenarios for the Krishna Basin during in 2001, 2010, 2020 and 2030.

The bars represent volumes of water used (right y-axis). The dots represent fractions of 50% and 75% basin dependable flow (left y-axis). The differently coloured bars and dots represent the three different scenarios. Source: van Rooijen et al. (2009)

The results show that non-agricultural water use in the basin accounted for 5.2 billion m^3 $year^{-1}$ ($5.2x10^9m^3yr^{-1}$) in 2001, which is 7.5 and 9.1%, respectively, of the 50% and 75% dependable flow (Figure 18). Maximum increases can be expected to reach 7.7, 12.1 and $19.4{\cdot}10^9m^3yr^{-1}$, respectively, for 2010, 2020 and 2030. This would account for 13.5 (2010), 21.2 (2020) and $33.8{\cdot}10^9m^3yr^{-1}$ (2030) of the available water in the basin, depending on development and climatic scenario. It can be concluded here that non-agricultural water use, currently relatively low, could take a considerable fraction of the water available in the basin in the future, especially in the accelerated growth scenario and in dry years.

4.7 FINAL COMMENTS

This chapter presented the findings for the Hyderabad case study. The mix or research tools applied to Hyderabad, has gained much insight into the urban water system, its physical processes and management. Also, the influence that the city's water use has on a larger area, beyond the urban boundaries, has been analysed.

A fast rise in urban water demand spurred by population growth, forced major expansion in water supply in response. The city is water-stressed, with intermittent water supply and a rationing scheme in place for years. Hyderabad's thirst for water has been notable for over half a century now; since the 1960's, additional water is being pumped from outside the local catchment. While local water sources were exhausted, the city has virtually created a new water source, to the benefit of thousands of farmers downstream the city. While the Musi River, flowing through Hyderabad, was damned upstream of the city, downstream of the city a growing mix of industrial and domestic wastewater and stormwater is disposed of into the Musi River has created a new river. With population growth and boosts in urban water supply, likewise did the generated volume of wastewater increase. The analysis confirmed that concerns exist for human health associated to the use of wastewater in irrigated agriculture. Elevated risks of infections with helminth, hookworm and *E. coli* exist for farmers using water from the Musi River (Ensink 2010, Ensink 2008, Ensink 2006). Nevertheless, wastewater reuse has become a widespread practice, with clear benefits for farmers' livelihoods and urban food security.

Hyderabad represents a clear example of urban development and expansion influencing the water cycle in and beyond the local catchment. In the case of sustained fast urban growth, urban water demand may take up to 35% of basin water availability in dry years by 2030. This may conflict with other users in the basin, most notably its biggest water user; agriculture. Also environmental flow requirements could potentially be affected.

The results are further discussed in the general discussion chapter (Chapter 7). The discussion chapter also compares the results from Hyderabad with the results from the Accra and Addis Ababa case studies. The discussion is followed by the final chapter (Chapter 8), in which conclusions are drawn.

5. CASE: ACCRA

This chapter will discuss the case of Accra, presenting the results that answer research questions numbers 1-5 presented in chapter 1. Followed by general introduction to Accra, the institutional setting is outlined together with a discussion of the prevailing water issues in Accra.

Accra could be classified as a mid-size million plus city when compared to the largest cities on the African continent. Recent data suggest that Accra would rank as the 19th largest urban centre in Africa and 7th in the West African region in 2010 (UN-Habitat 2008b). Accra is one of the many West African capitals located along the coast, and the coastal areas have been the major centres for industrial development; except for Cameroun, all capital cities are located along the coast.

5.1 CHAPTER INTRODUCTION

This section gives a general introduction to the city of Accra, one of the three focal cities where the fieldwork for this research was carried out. Accra is the capital of Ghana, located along the coast at the Gulf of Guinea to the South. Accra is the country's economic and political centre. It is the largest city in the country, with an official population of 3.3 million based on the latest census carried out in 2000 (GSS 2005). Ghana's stable political situation in the last few decades has made Accra a particularly favourable location for multi-national companies to settle ground as well as hosting many international events. The smooth transfer after 8 years of leadership of one party, to the major opposition party in early 2009 was broadly considered as an example of good governance and democracy for fellow African nations. The previous government had pursued a strong policy of stimulating private investments as part of a free-market economy. As a result, the construction of taller buildings in various parts of the city is creating a fast visual transformation. The urban area of Accra more than doubled in a time span of 17 years, from 216 km^2 (1985) to 555 km^2 in 2002. Estimations of urban area plus area in transition indicate a total urban area of 750 km^2 in 2002 (Yankson *et al.* 2004), which could fairly represent the situation as it was in 2008. Accra's fast urban growth and spatial expansion is still on-going. The lack of urban planning and stringent regulations for housing development have created unregulated urban sprawl. This type of urban growth and expansion undermine sustainable development (Amuzu and Letmann 1994; Grant and Yankson 2003). Urban water pollution and poor sanitation and water shortage can be considered as negative side effects of fast urban sprawl.

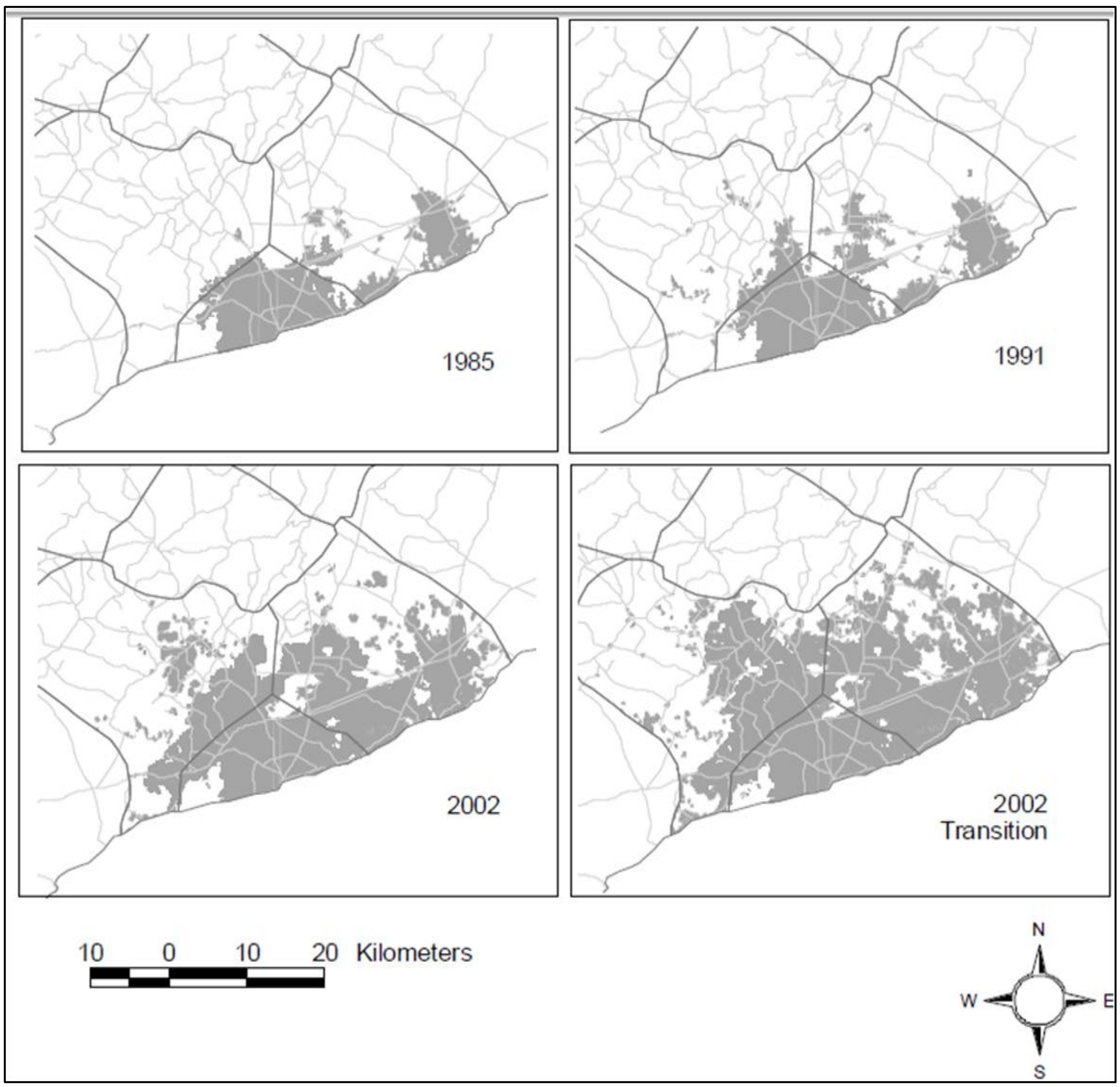

Figure 19. Spatial urban expansion of Accra during 1985-2002.

Source: Yankson et al. **(2004)**. Urban area was identified using texture-based classification of Landsat (E)TM satellite images. The image labelled '2002 Transition' shows the urban area for 2002 plus adjacent areas that were (in 2002) in transition to becoming urban.

In this respect it is important to distinguish between the differently defined urban areas that are all referred to as Accra in documents. There is a large difference in both surface area and population. From comparing the politically defined surface area with the measured built-up area of Accra, it can be concluded that about half of the ATMA and not more than 20% of the GAR are actually built-up. Comparison of the population figures reveal that most of the population residing in Accra live in the Accra Metropolitan Area, which is also more densely populated than ATMA or GAR. In this thesis, the urban agglomeration of Accra that includes several districts is referred to as Accra. Many institutional challenges arise when cities grow outside the municipal area. Purely rural programmes do not offer appropriate services when rural settlements develop urban characteristics. At the same time, urban authorities lack the mandate, capacities and skills to adequately serve them. As a consequence, these residential areas located in the per-urban fringe are often faced with a poor provision of water and sanitation services, much worse than in the inner city (Norström et al. 2008; Norström et al. 2009). People residing in the urban fringe are often not covered by the piped supply network and rely on water from wells, boreholes, tanker supply or remote standpipes. In Accra, water costs, and reliability and quality of these alternative sources of water differ significantly from water from the conventional water supply system.

Table 11. Surface area and population of Accra urban area according to political and physical delineations.

	Surface area (km^2)	Population (millions)	Source
Politically delineated area			
Greater Accra Region (GAR)	3,245	2,9	(GSS 2005)
Accra Tema Metropolitan Area (ATMA)[4]	1,261	2,7	(Twumasi and Asomani-Boateng 2002)
Accra Metropolitan Area (AMA)	200	1,8	www.ama.ghanadistricts.gov.gh

[4] ATMA is sometimes also referred to as 'Mega Accra'

Physically built-up area[5]			
Urban area	751	-	(Yankson et al. 2004)
Urban area	422	-	(Natcho 2006)

Accra's spreading urbanisation influences the quality of the water in the watersheds within which the urban areas are located. The two largest and perennial water bodies of concern are the Odaw-Korle and the Densu rivers, and their numerous feeder streams. A temporal analysis of water quality in these water bodies shows a continuous change for the worse over time for both Densu (Ansa-Asare 2001; Karikari and Ansa-Asare 2006) and Odaw-Korle Catchments (Boadi and Kuitunen 2002; Karikari *et al.* 2006). The main sources of pollution identified are liquid and solid wastes from settlements upstream in the river catchments. The development and enforcement of pollution-control policies and governmental accountability are still in a primary phase. Also, in discussions with policy advisers it was made clear that public environmental awareness is still in its infancy. In spite of its economic growth, the majority of the population have survival on their minds, rather than keeping the environment clean. Furthermore, polluting behaviour is influenced by the quality of the water. Since people's perception is that waterways are polluted, it encourages further negative behavioural patterns, leading to a vicious circle which only strict enforcement might break (Abraham 2009).

In Accra, many water-related issues prevail, some of which are more visible than others. Very few of primarily the low-income households have direct access to tap water, resulting in higher prices paid for water from secondary sources (van Rooijen *et al.* 2008). The absence of large-scale domestic wastewater treatment in the city is polluting lagoons and the ocean (Karikari *et al.* 2006; van Rooijen and Drechsel 2008). Open gutters that carry a mix of stormwater and domestic wastewater are a human health risk factor (Lunani 2007). Gutters and drains are under-designed, poorly maintained and blocked with garbage and solid waste. Their poor functioning as stormwater drainage systems contributes to more frequent flood events, especially in the low-lying, low-income and high-density residential areas (Jafaru 2008).

[5] Based upon satellite images.

The perennial streams are used to source water (Obuobie *et al.* 2006). However, they are now polluted, due to expanding urbanisation. Therefore, the impact of water pollution on urban agriculture in Accra and surrounding areas is substantial (Suleiman 2007; Amoah; Drechsel et al. 2008). Inadequate sanitation and waste disposal are causing risk to consumers of the produce. Industrial effluents and untreated sewage have degraded the urban aquatic environment which has extended from within cities into the marine ecosystem (Louassi and Biney 1999). The MDG targets for improved water supply and safe sanitation must be achieved under the above-described environmental, economic and social conditions.

5.1.1 Institutional setting of the water sector in Ghana and Accra

Water provision to urban and rural areas is under the authority of different institutions. Rural water supply is governed by the Ghana Water and Sewerage Corporation (GWSC) while urban water supply, including Accra, is under the authority of the Ghana Water Company (GWCL).[6] Regulation of environmental management, water tariffs and water resources management become institutionalised with the setting up of regulatory bodies, the Environmental Protection Agency (EPA), Public Utilities Regulatory Commission (PURC) and the Water Resources Commission (WRC), respectively. Stormwater drainage and maintenance of the major drains are under the authority of the Urban Roads Department of AMA.

Sanitation and wastewater disposal are under the management of the various district assemblies in the urban region. According to the National Environmental Sanitation Policy (Republic of Ghana 1999), sanitary disposal of wastes, including solid wastes, liquid wastes and excreta shall be carried out by the respective waste management departments within the assemblies. They may provide the services either directly or indirectly through private contractors or franchisees.

[6] The boundaries used by GWC/AVRL are not the same as the administrative boundaries. Hence, they do not have the same view on what is considered urban and what is rural.

The management of urban water in Ghana has a history of ten years of attempts for Private Sector Participation (PSP) and organised resistance from civil society, which entailed a high level of public interest and much debate (Edig *et al.* 2003; Bohman 2007; Fuest and Haffner 2007; Drechsel and van Rooijen 2008; Bohman 2010). At the end of 2005, a contract was signed between Aqua Vitens Rand Limited (AVRL) and the Government of Ghana, to operate and maintain the urban water supply systems, initially for five years. AVRL has set targets to expand water supply coverage, reduce non-revenue water (physical losses and illegal connections), and improve the efficiency of the GWCL. At this moment in time, it is likely that GWCL will become fully in charge of urban water management, after AVRL's contract is finished by 2011. The Ghanaian staff is said to be ready to take over operations from AVRL.[7]

[7] http://www.ghanabusinessnews.com/2009/08/24/ghanaian-staff-say-they-are-ready-to-take-over-from-avrl/

5.2 TEMPORAL DEVELOPMENT OF WATER SUPPLY AND SANITATION IN ACCRA

5.2.1 Water supply development in Accra

Piped water in Accra originates from two main sources, located respectively 5 and 60 km away from the city centre, namely the Weija and Volta Reservoirs They both currently provide over 98% of the city water supply, in equal proportions (Figure 20). The balance is added from groundwater from the *Dodowa Well Field System*, located about 10 km north of the Accra City Centre. Throughout the 20th century, water treatment capacities were upgraded from Weija and additionally from the Volta (*Kpong* head works), in a response to rising water demands. Development of water treatment and supply from both surface water sources has followed a stepwise increase over this period, which is discussed below.

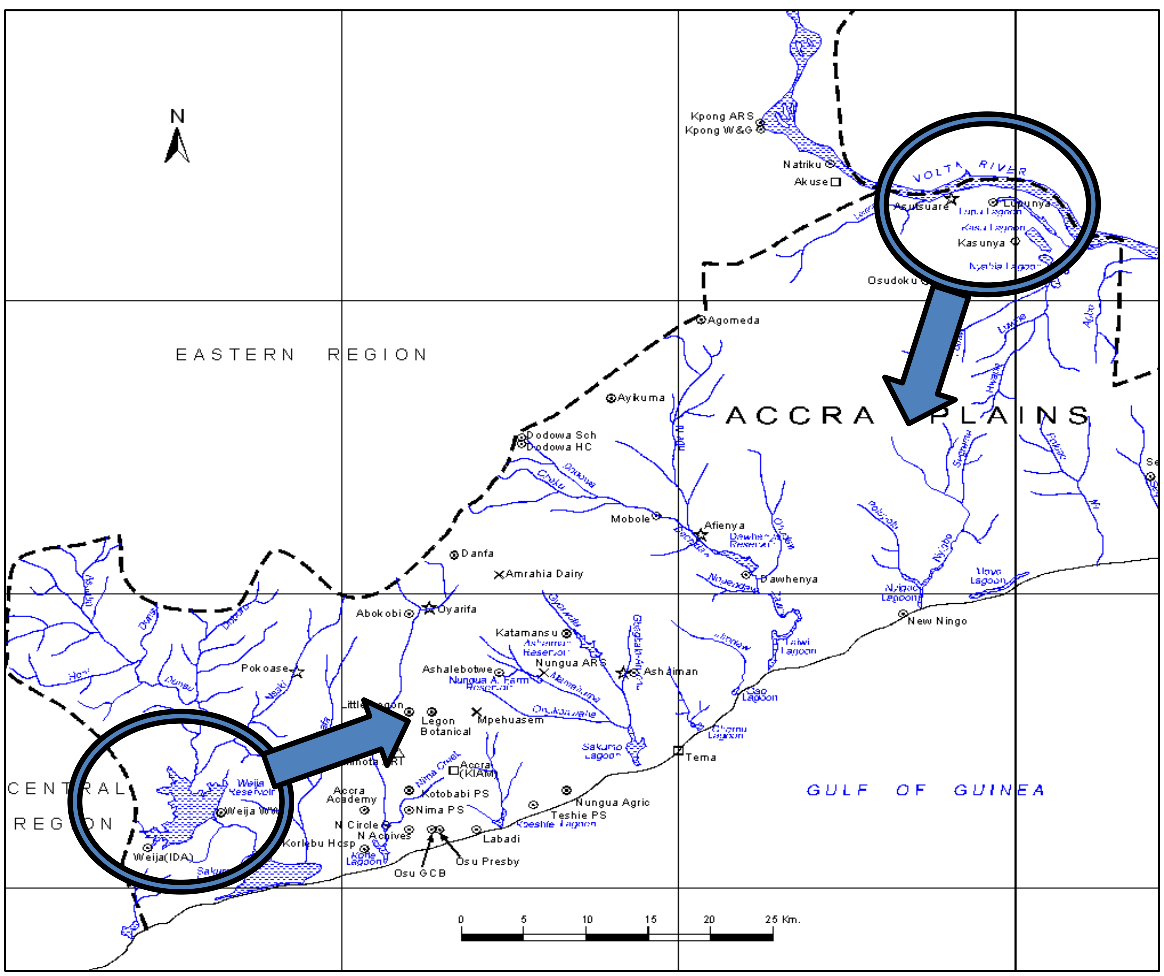

Figure 20. Sources of water supply to Accra. Source: WRI.

Prior to 1928, Accra had no organised form of water withdrawal and supply existed in the sense that we know it nowadays. Water was taken by people themselves from streams, wells and dug holes within the city whose water quality had hardly been disturbed yet by human activities. The first water treatment and pipe-borne supply system for Accra was constructed in 1928, to process water from the Densu River (Amuakwa 2007), with a daily treatment capacity of 909,000 litres to a city population about to reach half a million. Water was being withdrawn straight from the Densu River and supplied to the city through a constructed piped network. This created a big shift from dependency on groundwater to surface water, even though many people still relied on water sources inside the city and close to their homes. By 1950, an estimated 65% of water consumed originated from local groundwater sources.

In 1948, construction of the Weija Dam was completed, that prevented the Densu River from flowing naturally into the ocean (Figure 20). The purpose of the created reservoir was to store water for agricultural and domestic use in an agreed ratio of respectively 65 and 35%. Plans were developed to supply water for irrigation in the western part of the Accra Plains. In 1953, water supply to Accra increased after the first treatment plant (*Candy*) was commissioned, further away from the city than Weija, at Kpong. A treatment capacity of 23,000 m^3d^{-1} was thereby added to the existing 909 m^3d^{-1} at Weija; increasing installed treatment capacity 25 times. In 1961, the Government of Ghana found it necessary to upgrade the existing water treatment facilities to meet the water demand of a fast-growing population. Ten years after the last major investment in water-supply infrastructure, in 1963, treatment capacity at Kpong was increased with another 23,000 m^3d^{-1} when the newly constructed Bamag plant was commissioned. Two years later, the treatment plant at Kpong was expanded with the construction of a new treatment plant (*Kpong new*), adding 182,000 m^3d^{-1} to the 46,000 m^3d^{-1} of existing installed treatment capacity. This extra treated water was intended to supply the rapidly expanding industrial hub in the Tema zone, East of Accra. The new treatment plant was accompanied with the installation of a booster station and reservoir to bridge the distance between Kpong and Tema. In the period between 1966 and 1984, for almost 20 years, no major infrastructural expansion works were done, mainly due to the politically turbulent era that Ghana was going through. Meanwhile, the population of Accra did not stop growing, and existing supplies were under increasing pressure due to steeply rising urban water demands. By the year 2000, supply from groundwater had already reduced to 0.5%. This is likely due to deterioration of groundwater sources, especially in the densely populated areas of Accra. To meet a growing water demand, in 1984, the installed water treatment capacity at Weija was increased with 68,000 m^3d^{-1} when the Adam Clarke treatment plant started its operations.

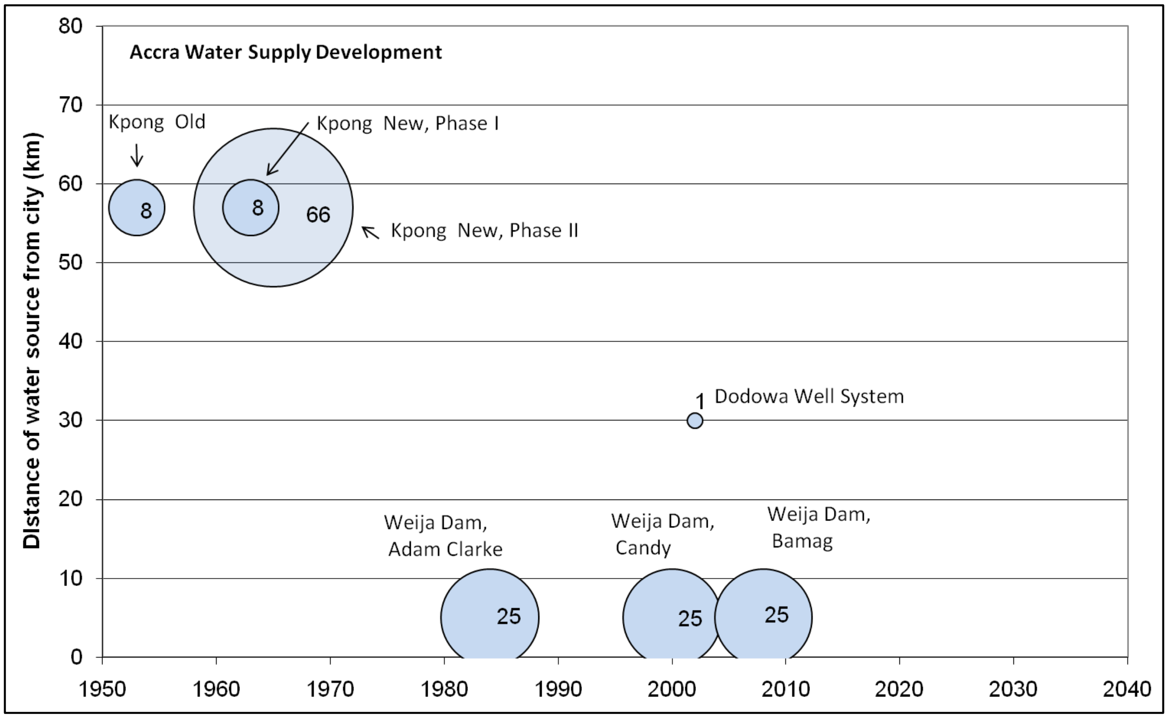

Figure 21. **Water supply development to Accra during 1950-2040.**

Source of data: AVRL (2006 #28) and *Amuakwa (2007 #385)*

In 2000 and 2008, an extra 68,000 m^3d^{-1} were added to the installed water treatment capacity at Weija. For the future, it is planned to expand treatment capacity at Weija with another 68,000 m^3d^{-1}. At that new level, the environmental limit is said to be reached (Amuakwa 2008). After this, meeting larger future water demand will have to be met by additional water from the Volta Lake. Besides this, a project is being prepared to extract groundwater with a capacity of 200,000 m^3d^{-1} (or about $80{\cdot}10^6 m^3yr^{-1}$). Exploration is planned to start early in 2010 and production before mid-year, to be produced incrementally over about 3 years (Allisson 2009). However, the likeliness that this plan will be carried is uncertain. If Accra continues to rely on the Weija and Volta Reservoir, groundwater use will remain marginal at 0.4% in 2030.

In the historical timeline of water supply to Accra, it is observed that there were two periods, each of over 10 years in which no expansion of the water supply infrastructure was undertaken, namely in the periods 1965-1978 and 1984-2000. In both these periods, the population of Accra increased by more than 50%.

Table 12. Development of formal water supply and water treatment for Accra between 1928 and the present.

Year	Event	Comments	Installed treatment capacity (cumulative, m^3d^{-1})
1928	First water treatment plant in Accra at Weija	Slow sand filtration. Capacity of 909 m^3d^{-1}.	909
1948	Weija Dam constructed	Commissioned in 1951, for irrigation and urban water supply	-
1951	Start construction Candy TP First conventional WTP at Weija	Commissioned in 1953, Cap. 23,000 m^3d^{-1}. 16 sediment tanks, 6 filters	24,000
1963	Bamag Plant commissioned at Kpong (construction started in 1961)	Treatment capacity of 23,000 m^3d^{-1}	46,000
1965	New WTP constructed at Kpong	Treatment capacity of 182,000 m^3d^{-1}, for supply Tema industries	228,000
1968	Weija Dam collapsed	Due to heavy rainfall	-
1978	New Weija Dam commissioned	construction started in 1974	-
1984	Adam Clarke WTP commissioned (construction started in 1983)	Additional installed capacity of 68,000 m^3d^{-1}	296,000
2000	Increase of installed treatment capacity with 68,000 $m^3\,d^{-1}$ at Weija		365,000
2008	Increase of installed treatment capacity with 68,000 $m^3\,d^{-1}$ MGD at Weija		433,000

Source: AVRL (2006 #28)and Amuakwa (2008 #368)

In spite of increased supplies, Accra's rapid population growth over the last century has resulted in only 60% of the demand being met currently (2005). Demand is estimated at 105 lpcd, based on target figures from the water utility (Adom 1997). Even though water supply has increased by about 20% in the period 1986-2006, per capita availability has gone down by almost half, which can simply be attributed to urban population growth (Figure 22).

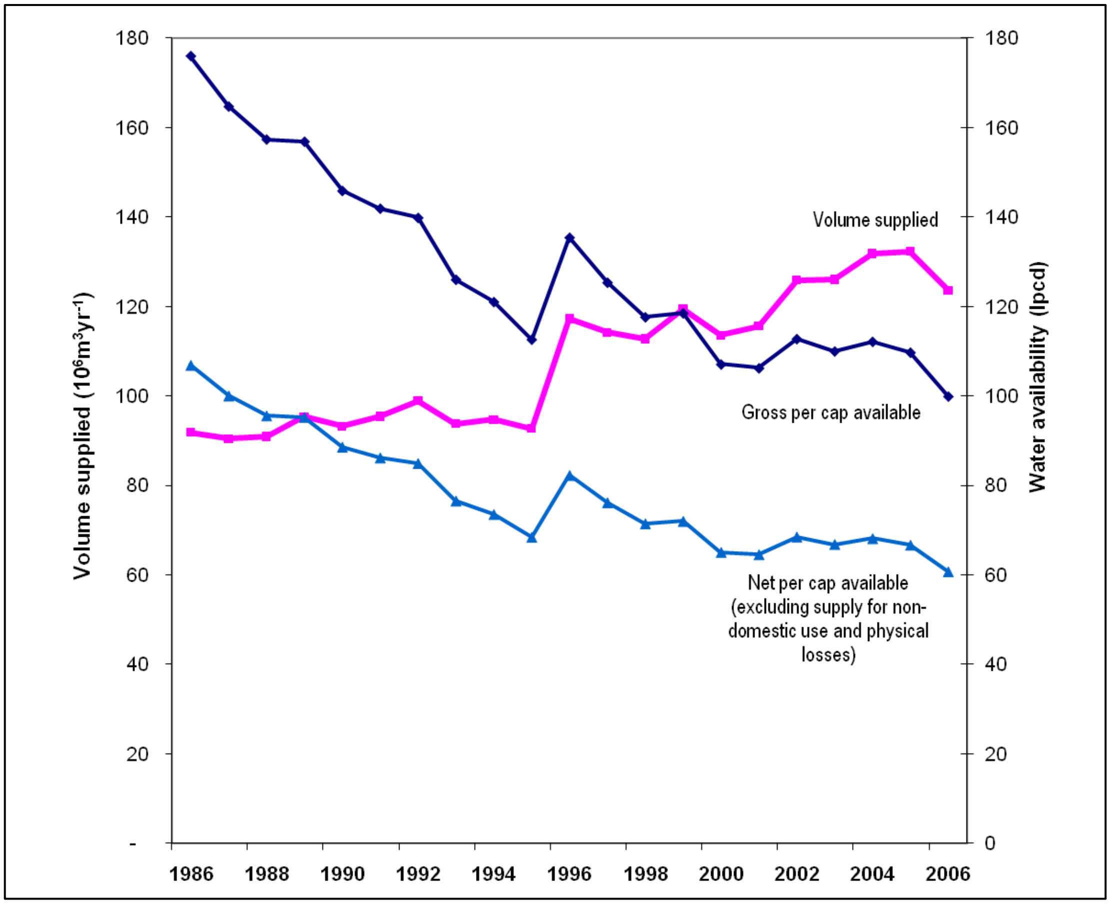

Figure 22. Water volume supplied to Accra versus gross and net per capita water availability.

'Gross Per Cap Available' was calculated by dividing 'volume supplied' over the population. Net per cap Av = Gross – 0.3Gross (physical losses) times 0.8 (20% that goes to the non-domestic sector).

Source: Modified from AVRL (2006 #28)

The supply demand gap, currently 55%, is calculated from average water supply (55 lpcd) and estimations for water demand (100 lpcd). Within the city, access to piped supply is generally less in the urban fringe areas and low income areas. In spite of an extensive coverage of the piped network, due to the limited water availability, in some areas a rotational supply system is followed and water flows only sporadically, or not at all. Evidence for the negative causal relationship between access to water and price paid for water has been found by various authors (Sarpong and Abrampah 2006 Van Rooijen et al., 2008; Nyarko et al. 2008). Structural water shortage in Accra has made water vending a lucrative business, providing a source of income for probably thousands of people. These businesses range from sachet vendors to tanker truck drivers to small cart operators, to individual neighbourhood and household selling points. Although there is plenty of theoretical knowledge of the link between the per capita volume of daily water used and human health, it is not known to what extent current water use patterns in Accra are affecting human health.

5.2.2 Sanitation services and wastewater disposal infrastructure

Revealing descriptions of the sanitary conditions in Accra and attempts to improve sanitation in the colonial period have been noted by McPhee in 1926; "*Pigs rooted among all the garbage that covered the streets of the town along which no purifying sea breeze blew. The sea, the wells, the ponds and the very air were polluted with unwholesome matter (. . . .) Gutters were uncut, and the drainage was non-existent.. The "pure water" reservoirs soon became popular with natives as bathing places. A vigorous sanitation policy was set on foot in 1885. The pig nuisance was abolished, a public reservoir and four large water tanks, ... and a large drain was constructed*" (McPhee 1926 cited in Acquah (1958). Soon after, the Accra Town Council set up standing committees, for water, sanitation, and open spaces among others, in order to improve governance of basic infrastructure and services in the city. This was regarded as one of the foundations for municipal governance to improve sanitary services (Acquah 1958).

A survey by Acquah done at 9,663 houses[8] in 1954 showed that 68% of the population were in houses without latrines. However, the municipality had 107 public latrines for males and 107 latrines for females, which were said to be cleaned daily by sanitary labourers paid by the Municipal Council. From all the private latrines in place, 12% were water-closets (Acquah 1958).

More developments were initiated by the government. The authorities are gradually replacing public pan latrines with septic tanks, and wherever possible, acquiring new sites for the erection of additional blocks of latrines'. On the drainage system: "The majority of drains run

[8] Each house was said to accommodate one household.

along the sides of the main roads. As they are open, all sorts of things are thrown in them, and they become very offensive places. Some people, and especially children, use them instead of public latrines" (Acquah 1958). The Medical Officer of Health in Accra was clearly aware of the cumulative health risks associated with poor sanitation and poor drainage in the city, as stated in his annual report for the year 1953: "*The remedy for the poor drainage and sanitary services lay in putting into effect a major engineering project involving two distinct problems. (a) a water-borne sewerage scheme, and (b) the construction of foul waste-water and stormwater systems. The municipal authority lacks the funds for such a project, and it is considered that a grant will be made in the future from Central Government funds for the works to be executed*". Of the existing state of affairs, he said: "*The developed areas are now riddled with cesspits, septic tanks and soak ways which create a fouled sub-soil through which the water mains pass. Improvement in night soil is being achieved by decreasing the risk of contaminating the water-supply. It must be stressed that Accra is long past the stage when measures of camp sanitation, which now exist, will suffice. The town has reached the point where modern methods of sewage disposal and drainage are necessary*" (Acquah 1958). The sewerage system that he suggested in 1953 was built two decades later, in the early seventies.

Table 13. Key events in the development of wastewater disposal and treatment for Accra and Tema between 1950 and the present.

Year	Event	Comments
n.d.	Construction of Tema Sewerage System (TSS)	Capacity: 20,000 m^3d^{-1}
1972	Construction of sewerage system in Accra Central	Capacity for 1,500 connections
n.d.	Korle Gonno faecal plant/Polate sewerage plant	Design capacity: 50 m^3d^{-1}
1988	Achimota faecal plant	Design capacity: 250 m^3d^{-1}
1995	Teshie-Nungua faecal plant	Design capacity: 80 m^3d^{-1}
2002	Completion of James Town UASB	Design capacity: 16,120 m^3d^{-1}

"*The sanitary conditions in Accra were indeed awesome and deplorable. Accra is badly congested, with poor housing*" (Patterson 1979). A visiting observer from the Liverpool School of Tropical Medicine gave an interesting description of the sanitary situation of the "native town": "*A complete absence of any system of drainage completes what to a European eye is nothing more than a noisome and a pestilential district*" (Fielding-Ould (1900), cited in Patterson (1979). Patterson (1979) mentioned population growth, financial incapacity and climate as the main factors for the human health issues, between 1900 and 1940, by stating that "*health problems resulted from rapid urbanization in a poor tropical country*".

In the history of Accra, only a few major civil engineering projects were carried out in the public sanitation sector (Table 13). In 1972, a sewerage system was constructed in the central part of Accra and a separate one in Tema, built a few years later. For a long time, the bucket was the common way in which people in Accra practised sanitation. The bucket was used in both private and public toilet places (Acquah 1958). The faecal waste was carried away on carts and dumped into the Ocean, west of the sea outfall of the Korle Lagoon, which is now known as *Lavendel Hill*. Open defecation is still practised, most notably and visibly on the beach. Until now, most residents have made use of public toilets. Improvement of sanitation facilities in Accra, as part of sanitation target of the Millennium Development Goals (MDG) has generally been regarded as slow (WHO/UNICEF 2006; Gustafsson and Koku 2007). With 51%, Ghana (both urban and rural) has by far the highest fraction of people using a shared facility and, with just 10%, the lowest fraction of people using an improved sanitation facility (WHO/UNICEF 2008). However, after recent discussions on the 'quality' of public toilets and the reliability of coverage data (Bostoen and Evans 2008), this large group is now being regarded as 'improved', from a perspective of hygiene (GSS 2006). The poor water quality and environmental state of the Korle Lagoon was the reason for initiating the development of the Korle Lagoon Ecological Restoration Project (KLERP) at the start of the new millennium. In 2003, a dam, with a so-called interceptor, was constructed to prevent further inflow of water from the main stormwater drains into the lagoon. This water is now being pumped through a 1.2 m (inner diameter) pipe with an outflow 930 m offshore with a maximum pump capacity of $2 m^3 s^{-1}$. During periods of peak run-off from rainfall events the floodgate is opened, to allow flushing of excess water through the spillway. This civil engineering project aims to clean the *Korle Lagoon* and reduce pollution of the coastal waters near Accra.[9] The above analysis has made clear that the existing sanitation systems in place in Accra have a lot of room for improvement.

[9] Source: www.KLERP.com website.

5.3 THE URBAN WATER BALANCE OF ACCRA

This sub-chapter contributes to the second research question objective (1.3.2), on the urban water balance.

5.3.1 Major water flow components of the urban water balance of Accra

A water balance of Accra has been composed using the boundaries of the urban area as the physical delineation (Figure 23). The surface area of Mega Accra was estimated at 422 km^2, using remote sensing imaging (Natcho 2006). The main water flows that enter and leave the city are considered. The dimensions of lateral groundwater flows are complex and considered as trivial because interaction with the urban area through groundwater extraction and recharge levels is low compared to the other urban water flows. Therefore, interaction of the urban area with groundwater was not included in this assessment. The main water flows are treated in the following paragraphs. Every flow or component was given a symbol as in Figure 23.

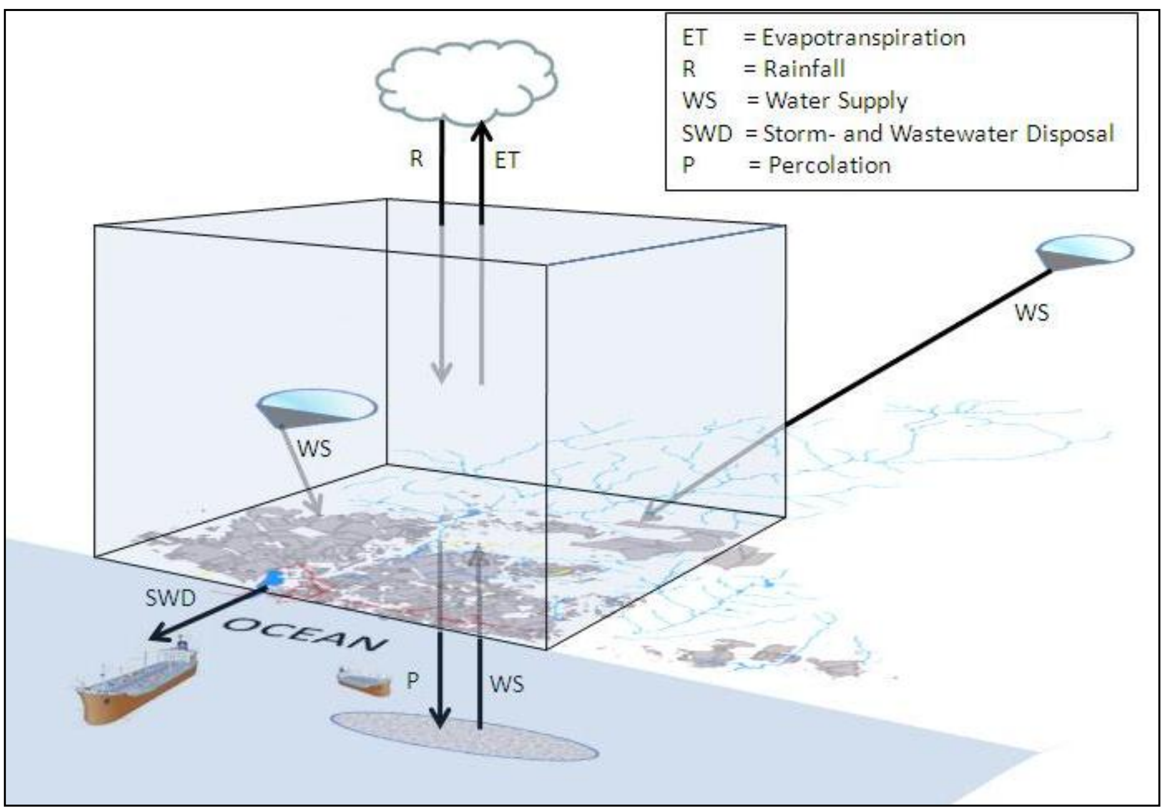

Figure 23. Visual representation of the urban water balance for Accra.

5.3.2 Rainfall and evapotranspiration

Daily time series over the period 1970-2005 for rainfall and 1961-2004 for potential evapotranspiration were used to assess the climate and its input in the water balance. The annual rainfall pattern consists of two rainy seasons, the heaviest in April-May-June (56% of annual rainfall) and the other one in the September-October (15% of annual rainfall). Average annual rainfall and potential evapotranspiration are respectively 742 and 1,100 mm. The volume of water from rainfall that falls on the urban area (422 km^2) is $313 \cdot 10^6 m^3$. The volume lost through evapotranspiration is estimated from the difference between rainfall and the sum of run-off (see 5.3.4) and infiltration (see 5.3.6), which comes to $62 \cdot 10^6 m^3$. An additional but unknown volume of water originating from piped supply is lost to the atmosphere through human transpiration (sweating) and crop evaporation. The fraction of the evapotranspiration (originating from rainfall) that is previously used in the household, such as for gardening, is unknown and not specified in the water balance.

5.3.3 Water supply

The volume of water produced and supplied to the city of Accra was 140 $\cdot 10^6 m^3 yr^{-1}$ in 2008 (AVRL 2006). This value represents the total gross volume of water produced at the treatment plants including the volume of physical water supply and distribution losses that occur after the water treatment process. Around 65 $\cdot 10^6 m^3 yr^{-1}$ of water is produced at Weija (taken from the Densu River) while 75 $\cdot 10^6 m^3 yr^{-1}$ is supplied from the Volta Lake at Kpong treatment works. Monthly time series over the period 1996-2006 from the GWCL provide an overview of the monthly variation in the past decade. Annual production increased in this period roughly from 100 to $140 \cdot 10^6 m^3$. Roughly one quarter of the produced volume is lost through physical losses in the piped network which is included as infiltration.

An unknown volume is withdrawn directly from Weija Lake by tanker trucks and used for construction work (Amuakwa 2007). A fraction of this water may also be delivered to households for domestic use.

5.3.4 Stormwater run-off and wastewater disposal

These two types of run-off from the city eventually find their way to the ocean. Water that enters the ocean originates from two distinct sources. The first is through the two major lagoons that Accra has: Korle and Kpeshie. This water consists of a mix of wastewater and stormwater the proportions of which are dependent on the weather conditions. Run-off was estimated using an urban run-off coefficient which is assumed to be typical for highly paved urban areas, 65% (Maidment 1993). Accra is considered to have similar conditions. Annual run-off from rainfall (stormwater run-off) is therefore estimated at $204 \cdot 10^6 m^3$. The second source is faecal sludge from septic tanks that is being disposed directly into the ocean. During the day, on average, two or three tanker trucks empty their cargo at a beach site, where the wastewater flows directly into the ocean. Currently, more than half the volume of collected faecal sludge is dumped into the ocean (Obuobie *et al.* 2006). The volume of wastewater from septic tanks and wastewater disposed off in gutters that enters the ocean is estimated at 84,000 m^3 annually. This practice is tolerated by the AMA which apparently has no better alternative at hand. The annual volume of water leaving the city through surface run-off and disposal in the ocean is estimated at $288 \cdot 10^6 m^3$.

5.3.5 River run-off into the urban area

River water enters and flows through the urban area through two major rivers systems, the Densu and Odaw rivers (Figure 25). Since the impoundment of the Densu River in 1948, its outflow into the lagoon was dramatically reduced in volume. River run-off has not been consistently monitored. Annual run-off of the Densu River is around $140 \cdot 10^6 m^3$, based upon monthly mean run-off records for 1967-1980 (Figure 24). A considerable part of this volume, $65 \cdot 10^6 m^3 yr^{-1}$, is withdrawn at Weija Dam for treatment and subsequent water supply to Accra. The effective Densu River run-off entering the urban area is estimated at $75 \cdot 10^6 m^3 yr^{-1}$.

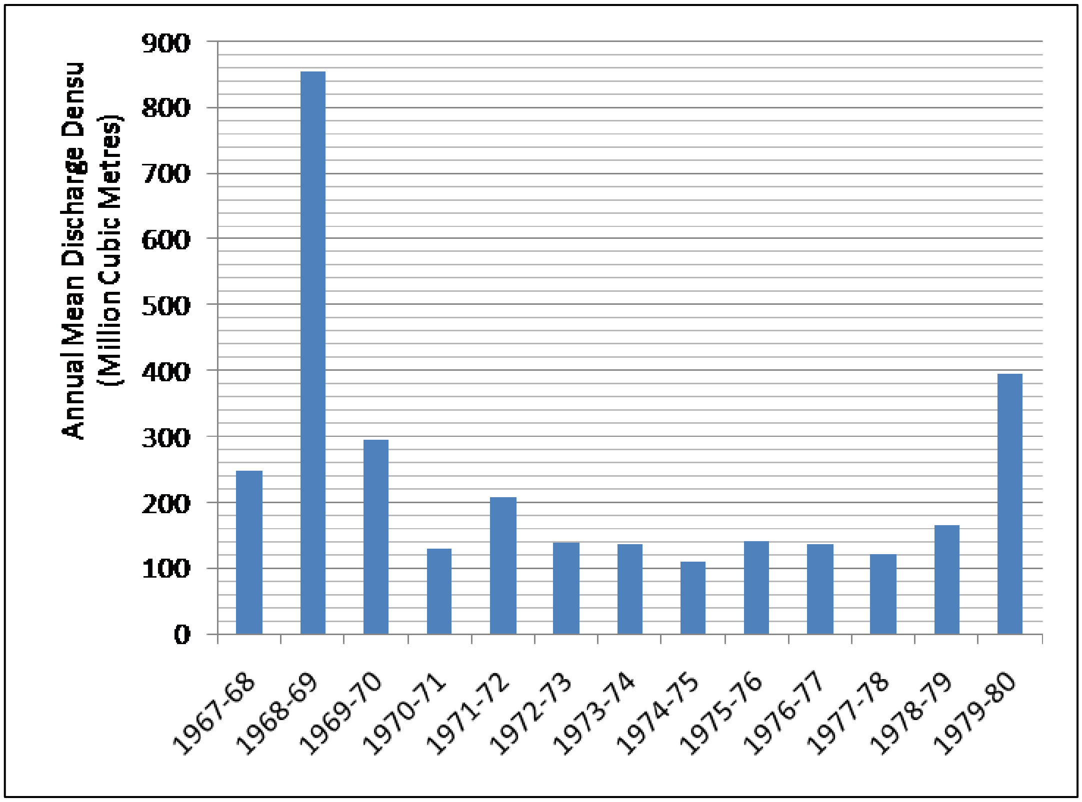

Figure 24. Densu River run-off during 1967-1980, measured at Nsawam.

Source: WRI **(2009 #387)**

The Odaw River drains the northern and central parts of Accra. This part of the Odaw Catchment accounts for an estimated 60% of the Accra Metrolopolitan Area and accommodates 80% of the industries in Accra (Amuzu 1997). The river shows a clear transition when followed from its source, about 30 km from the town centre at Aburi, to the Korle Lagoon at the coast. The land use changes from agricultural to peri-urban, to heavily urbanised. Within the urban area, most of the river sections have been lined with concrete beds, which have basically converted the river into a drainage network for untreated wastewater and stormwater. Due to uncontrolled waste disposal, the parts located in the urban area have turned into open sewers. Since 1995, river discharge monitoring has ceased due to logistical and developmental issues within the basin and existing historical flow data could not be found. Since an estimated 80% of the Odaw catchment is urban area, the volume of water entering the urban area through surface flow is considered low. The main lagoons within the Accra urban area are from West to East; Sakuro, Korle, and Kpeshie lagoons.

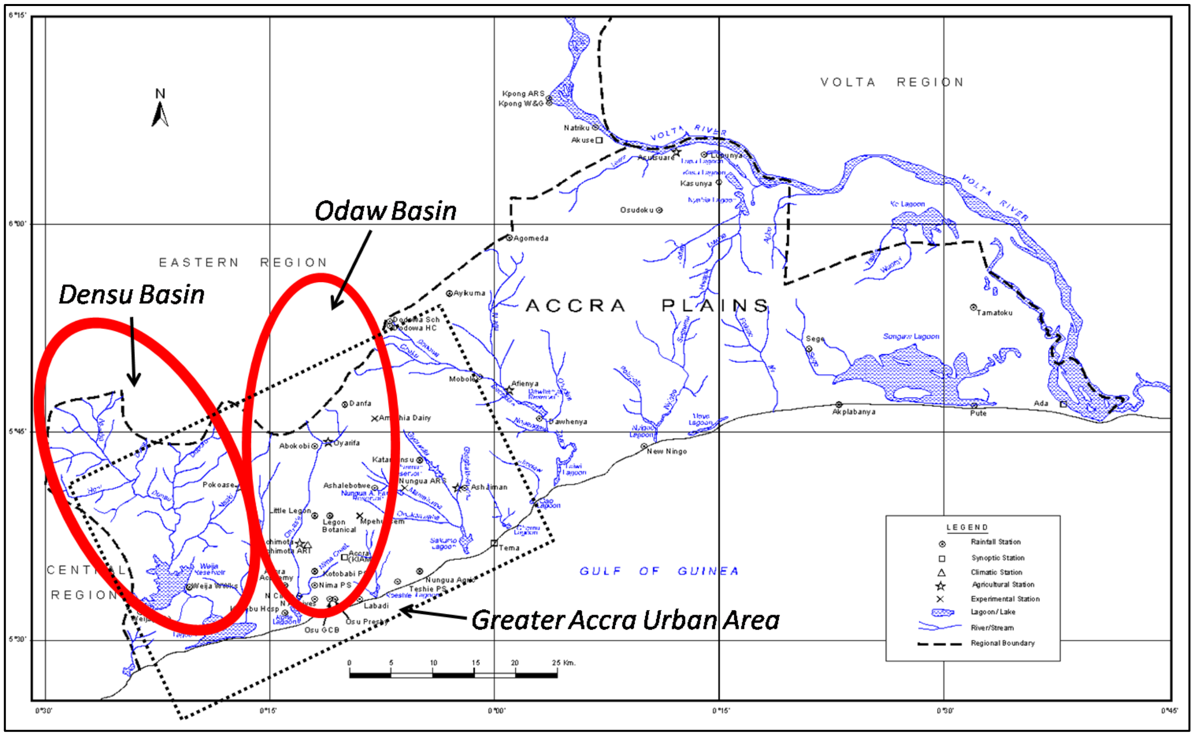

Figure 25. **River drainage network of the Greater Accra Region.**

Source: Modified from (WRI 2007)

5.3.6 Groundwater abstraction and percolation

In the GAR region, groundwater is extracted through privately owned wells and boreholes, estimated at $5 \cdot 10^6 m^3 yr^{-1}$. This abstraction is mainly for rural domestic water supply while a small percentage is used for livestock watering, small-scale irrigation, construction work and industrial purposes (Kortatsi 1994). Besides this informal and rather scattered form of groundwater, GWCL is taking water from wells (at Dodowa) at $0.6 \cdot 10^6 m^3 yr^{-1}$ (Al Hassan 2007). This volume is marginal compared to the volume drawn from surface water bodies (around $140 \cdot 10^6 m^3\ yr^{-1}$). The Dodowa wells are located in the Accra plains, about 30 km northeast of the urban centre, outside the urban area. This water is imported into the urban area through the piped water supply network. Water from Dodowa only supplies the areas in Northern Mega Accra (Amuakwa 2007). According to GSS, some households within the AMA area have boreholes (0.3%) and wells (4.4%) as their main source of water (GSS 2005). This volume of water could be in the range of $1\text{-}2 \cdot 10^6 m^3\ yr^{-1}$ (roughly 5% of pop times 3 million person times 30 lpcd). A large portion of the groundwater below Accra has high salinity levels and therefore inappropriate for domestic use. Overall, urban groundwater is likely to be contaminated to some extent with percolated wastewater. In particular, the quality of shallow groundwater has been declining and many boreholes and dug wells have been abandoned due to increased salinity levels (Kortatsi 1994; Zuppi 2005).

Infiltration and percolation of surface water to the groundwater is considered as a water flow leaving the urban unit. Water infiltrates the soil in the permeable areas like surface water, and green spaces like gardens and cemeteries. Infiltration rates are relatively low due to the clayish texture of the soil (Kortatsi 1994; WRI 2007). It is assumed that a significant fraction of the water flowing through gutters and retaining in clogged gutters is leaking to the soils through numerous cracks in the gutter profiles. It is assumed that all the infiltrated water percolates down to the groundwater. The annual volume of groundwater recharge through percolation is estimated at $47 \cdot 10^6 m^3$. This applies when using a fraction of permeable area (15%). Also, it is assumed here that all rainfall on the permeable area subsequently infiltrates and percolates, and all rainfall on paved areas turns into run-off.

5.3.7 Infiltration and percolation through physical losses in the piped water supply network

A considerable fraction of water produced for urban uses is lost through leakage in the piped water supply and distribution system (25%). This volume is assumed to be proportional to the variations in daily supplied volume. Annually, the amount of water leaving the urban unit to the groundwater through losses comes roughly to $35 \cdot 10^6 m^3$. Currently, AVRL, which acts as the operator of the water supply management, has committed itself to reducing the fraction of physical losses by 5% per year.

5.3.8 Water balance summarised

The following table shows all water flows that were considered in the assessment.

Table 14. Components and annual volumes of the Accra water balance.

IN			OUT		
Component	Symbol	Volume ($10^6 m^3 yr^{-1}$)	Component	Symbol	Volume ($10^6 m^3 yr^{-1}$)
Rainfall	R	313	Evaporation and transpiration	ET	62
Water supply	WS	140	Percolation	P	82
River run-off	RR	75	Physical losses in piped network	P2	35
			Natural percolation	P1	47
			Stormwater run-off	SWR	204
			Wastewater disposal	WWR	84
			River run-off	RR	14
Total		528	Total		528

In summary, the *in*-side of the water balance consists of three components; rainfall, water supply and river run-off. Rainfall takes the highest proportion of total inflow and is unevenly distributed in time. Water supply and river run-off have a fairly equal volume, taking the balance of the total water volume of $453 \cdot 10^6 m^3$ that enters the urban area in a year. The *outside* of the water balance shows four main components, namely; evapotranspiration, natural percolation, stormwater run-off and wastewater disposal.

5.4 PROJECTIONS FOR URBAN WATER DEMAND

The previous section discussed the temporal development and overall situation of water and sanitation infrastructure and services. This section discusses possible scenarios for water demand against water supply to Greater Accra. The main factors that steer water demand are population growth, economic growth and water savings made at the utility and end-use level. In order to make plausible projections for the future water situation of Accra, it is important to understand these factors. The projections for urban water demand are based on assumptions for urban population growth rates and changes in per capita water demand. Water savings are accounted for in the water savings scenario. Adom (1997) gives numbers for per capita water demand in Accra, being 85 (in 1985), 100 (2005) and 120 lpcd (2020). His estimations include non-domestic demand and losses in the water supply and distribution network.

Estimations of current water demand for Greater Accra range between 364 and 475 $\cdot 10^3 m^3 d^{-1}$ or 133-173 $\cdot$ $10^6 m^3 yr^{-1}$ (Table 15). Plausible projections are presented for water demand in Accra (Figure 26).

Table 15. Estimations for current urban water demand in Accra.

Water demand		Year of estimation	Source
10^3 m^3d^{-1}	10^6 m^3yr^{-1}		
475	173	2007	(AfDB 2005)
456	166	2007	(Kessie 2007)
409	149	2007	(Lievers 2007)
364	133	2005	(AVRL 2006)

Projections for per capita water demand are labelled as general urban development scenarios and presented in (Table 16). The *business-as-usual* scenario incorporates a per capita water demand projection based on Adom 1997, and shows a linear annual growth rate of 0.9% during 2010-2030. The *water savings* scenario shows a stagnation of per capita water demand. This assumes that water savings are being made at the end use and utility level, which would therefore result in no further increase in per capita water demand. The *accelerated growth* scenario represents a further increase of the growth rate of per capita water demand in the future. A linear annual growth rate of 1.7% was chosen, which is based on actual growth rates recorded during 1965-1985 in Accra (Adom 1997).

Table 16. Projected growth rates for population and per capita water demand in Accra during 2010-2030.

Scenarios	Projected annual population growth rate (%)	Projected annual growth rate of per capita water demand (%)
Business-as-usual	4.4	0.9
Water savings	4.4	0.0
Accelerated growth	5.4	1.7

Population growth projections are labelled as general urban development scenarios, similar to the projections for per capita water demand (Table 8). The *business-as-usual* scenario and water savings scenarios (the latter not affected by population growth) uses a linear annual population growth rate growth rate of 4.4% during 2010-2030, which is based on the present estimated growth rate for Accra. The *water savings* scenario shows an overall stagnation of per capita water demand. This would be the effect of water demand management options being implemented by the water utility and at the end-use level. In the case of Accra, where water demand is suppressed by supply, it is assumed that any water saved at any level will be re-distributed and used in the city anyway. The *accelerated growth* scenario represents a higher increase of the population growth rate, namely 5.4% per year.

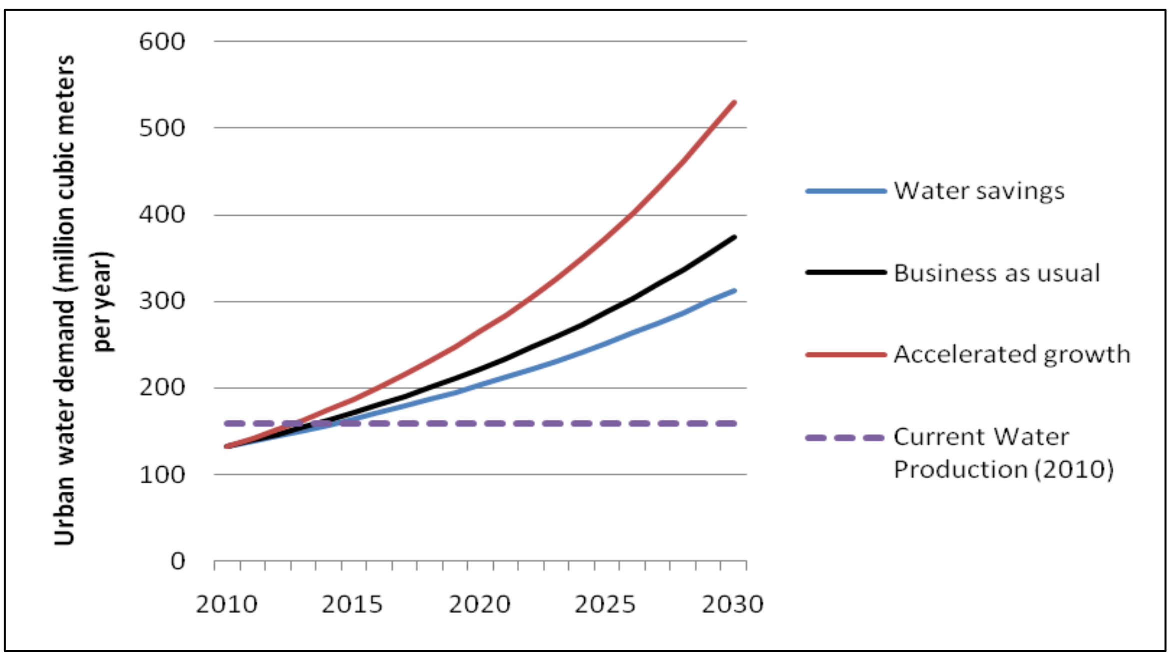

Figure 26. Scenarios for gross urban water demand in Accra

It has become clear that in any of the investigated scenarios, urban water demand will be severely constrained by supply in the future. Even if water would be saved and the current increase in per capita water use would stagnate, steady population growth alone will demand more water, as can be seen in the *water savings* scenario (Figure 26). The *accelerated growth* and *business-as-usual* scenarios show a larger gap between supply and demand projected until the year 2030. In any event, current water production will need to be doubled in order to meet projected water demand by 2030.

5.5 WASTEWATER USE IN AGRICULTURE

5.5.1 Current situation

As in many cities of developing countries, open space urban and peri-urban agriculture is part of the city fabric in Accra. Untenanted land, open spaces belonging to institutional entities, buffer zones and other types of land reservations, particularly along streams and drains, are the common areas for this type of farming activity (Obuobie *et al.* 2006). Open space farming is a dynamic viable and largely sustainable livelihood strategy for over a thousand farmers in Accra (but the number is in constant flux), and for this reason, spatio-temporal analyses will show that its dynamics are linked to the changing pattern of urbanisation. As open spaces are lost to settlements and urban infrastructure, the spreading city boundaries provide similar marketing opportunities, and allows for newer areas to be farmed, still within the city.

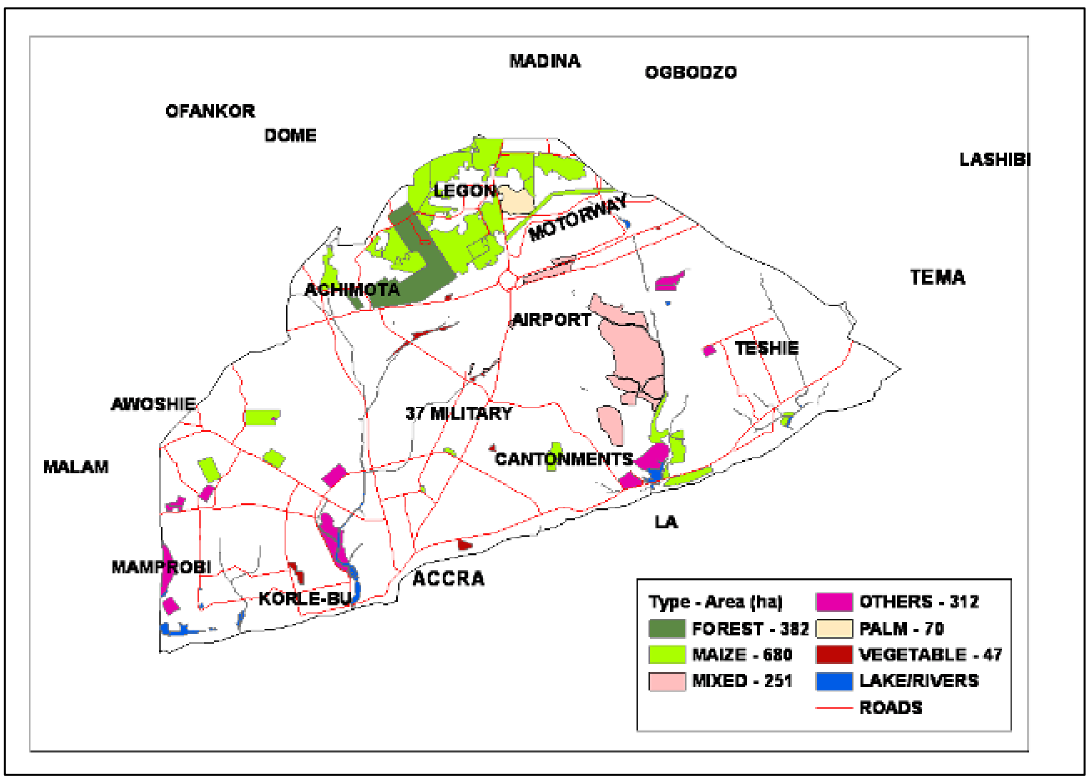

Figure 27. Open spaces within the Accra Metropolitan Area, including those in use for urban agriculture.

Source: Obuobie **(2006 #19)**

A study on the changing landscape in Accra ground truthing[10] in 2009 in the La area indicated that the cultivated area has reduced from 122 ha in 2001 to 87 ha in 2007, due to sale of land for housing purposes (IWMI, *unpublished data*). However new agricultural areas have opened up in Adenta, Ga South and Tema, on the outskirts of the rapidly expanding urban area. These original agricultural areas have lost out to urbanisation but still maintain plots of cultivation, presumably due to the demand for these activities.

Along the tributaries of the Odaw River and other streams, extensive urban farming takes place on any unoccupied open spaces. About 680 ha are under maize cultivation (which is not irrigated), 47 ha are exclusively under vegetables and 251 ha are under mixed cereal-vegetable systems, resulting in an average area of 100 ha of irrigated urban vegetable production (Figure 27). Some of the sites have been in use for more than 50 years. There are about 800-1,000 market-oriented vegetable farmers of whom 60% produce exotic and 40% indigenous local or traditional vegetables, with only the latter using parts of their production for home consumption. Farming areas in the city range between 1 and 30 ha; with plots around 0.05 ha per farmer. Although the total area appears to be small, farmers crop up to 8 times per year and supply 60-90% of the perishable vegetables consumed in the city (Obuobie *et al.* 2006). Most sites belong to government institutions or private developers who have not yet started constructing. Most farmers have only informal land use agreements with the landowner or his caretaker. Vegetable farming is done on raised beds each of which covers an average area of 3-8 m^2. Water fetching and irrigation are manual, usually with watering cans. In some cases motor pumps are used to fill small intermediate ponds. Where the topography allows it, gravity is used to support furrow irrigation. Compared to Addis Ababa the climate is much hotter and the irrigation frequency higher. For example, lettuce is irrigated thrice a week in Addis Ababa but twice a day in Accra.

[10] Ground Truthing is the process of sending technicians to gather data in the field that either complements or disputes airborne remote sensing data.

5.5.2 Urban agriculture in relation to urban development scenarios

As made clear in the foregoing section, urban agriculture in Accra contributes to water and nutrient recycling, urban food security and the preserving of open green space in the city. These benefits are starting to get attention by local governments and policy makers. Better regulations and putting a higher value to it could greatly enhance those benefits. However, urban population growth and the processes of physical expansion and densification of urban areas have so far proven to be difficult to control by the authorities in Accra (Otoo, 2006 #44; Yeboah, 2003 #372).

Based on water demand projections calculated for the three urban development scenarios, resulting wastewater flows have been calculated (see table 7). A further densification of the urban area is likely to push urban agriculture further to the margins of land use. On the other hand, all three urban development scenarios entail increases in water supply to answer rising water demand. This will result in more wastewater being generated in the urban area, which in turn could benefit agriculture for the advantages mentioned earlier.

Table 17. Projections for wastewater volumes based on urban development scenarios for Accra, for 2010, 2020 and 2030

Year	Projected wastewater volume by urban development scenario (MCM yr^{-1})		
	Business-as-usual	Water savings	Accelerated growth
2010	106	106	106
2020	178	163	212
2030	299	250	424

All the three urban development scenarios described here show substantial increases in the volume of wastewater that will be generated as a result of increases in water supply to the city. Within the investigated time frame of 20 years, wastewater volumes are expected to roughly double, triple and quadruple in respectively the water savings, business-as-usual and accelerated-growth scenario (see Table 17).

The extent to which opportunities for reuse of larger wastewater volumes will actually be taken depends on developments in wastewater treatment and -disposal (-infrastructure), the policy environment and availability of (nearby) land. These are important factors when expansion of actual reuse in agriculture should be realised. Based on the availability of infrastructural plans, a major change in the current wastewater disposal infrastructure is not to be expected in the near future. The policy environment in Accra has turn more in favour of wastewater reuse, leaving behind the previous stigma that wastewater reuse is inappropriate and illegal. Although open spaces exist throughout the Accra urban area, its coastal location unfortunately does not allow for much area downstream of the city where wastewater can be reused for crop irrigation.

5.6 BASIN-LEVEL INFLUENCES OF URBAN WATER USE

As described earlier in paragraph 5.2.1, Accra's residents are provided with water that originates from three sources; surface water from two sources; the Volta and Weija reservoirs, and a much smaller fraction from groundwater (Figure 20). This paragraph addresses the question as to what extent urban water use has an impact on the basin water balance. The Volta and Weija reservoirs receive all excessive rainwater generated in the Volta and Densu basins. The characteristics of these two basins are drastically different: the Densu Basin covers 2,500 km^2 of densely inhabited land (240 persons km^{-2}) whereas the Volta Basin covers around 400,000 km^2. A large fraction of the active population in both basins is engaged in agriculture. The population density in the Densu Basin is much higher than in the Volta Basin; 387 against 79 person km^{-2}, due to a large part of the capital located in the Densu Basin (GSS, 2005 #20). This could also explain why anthropogenic water pollution is much more prevalent in the Densu river system. Due to the complexity associated with assessing groundwater behaviour and availability and the low level of extraction and use, groundwater is left out of this section. To answer this question, current urban water withdrawals and scenarios for urban water demand in 2020 and 2030 are compared with basin water availability (Figure 28).

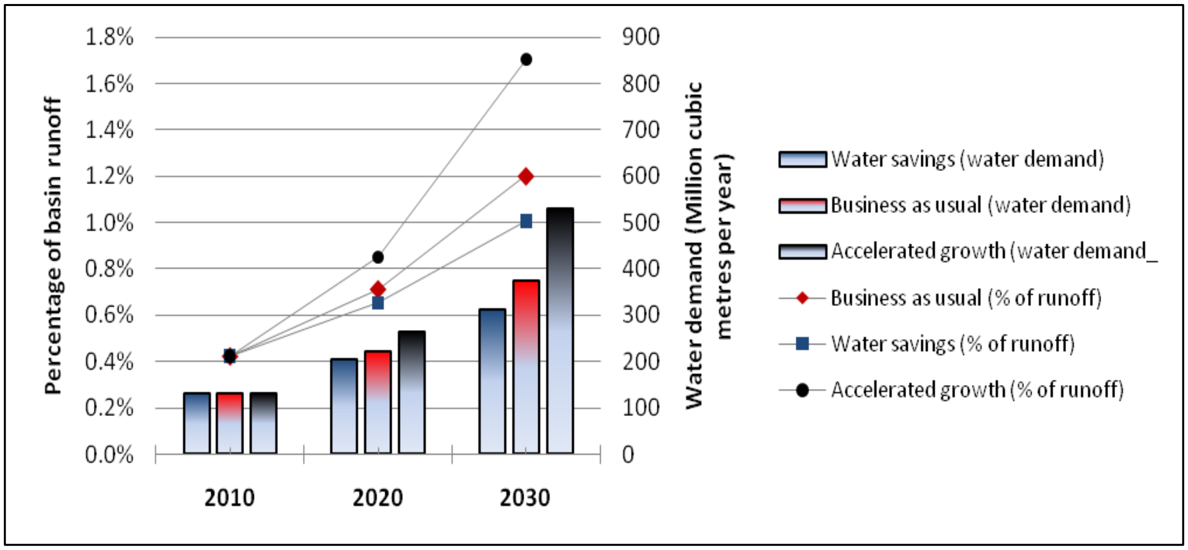

Figure 28. Scenarios for Accra water demand expressed in volume and percentage of basin runoff.

Source: Calculated based on data from ***(Andreini et al. 2000; Giesen et al. 2001; AVRL 2006; WRI 2009).***

Current water demand of 132 $\cdot 10^6$ m^3yr^{-1} accounts for 0.4% of combined average run-off in the Volta and Densu Basin. Depending on urban development scenario, current water demand is expected rise to 222-265 $\cdot 10^6$ m^3yr^{-1} in 2020 and 313-530 in 2030. These volumes account for 0.7-0.9 (2020) and 1.0-1.7% (2030) of combined average runoff in the Volta and Densu Basin. These fractions are minor compared to average basin run-off, however water availability is largely contributed by the Volta basin. The Volta Basin accounts for 99.6 of the average basin runoff of the Volta and Densu Basin combined, the 0.4% balance originates from the Densu.

Table 18. Comparison of current water use and scenarios for water availability in the Volta and Densu basins.

Water source*	River run-off (10^6m^3)		Current urban withdrawal		
			Volume	Percentage of run-off (%)	
	50% dependable flow	75% dependable flow	(10^6m^3)	50% dependable flow	75% dependable flow

Volta Basin (1966-1998)	31,000	20,000	75	0.24	0.38
Densu Basin (1967-1980)	141.8	136.9	84	59.2	61.4

*recorded time series

Urban water withdrawal accounts for 0.24 and 0.38% of respectively 50% and 75% dependable flow in the Volta Basin. The share of water abstraction in the Densu basin is much higher, at 59.2 and 61.4 of respectively 50% and 75% dependable flow. Current water abstractions seem to be minor compared to basin availability in the Volta, but extreme climate change scenarios may cause much lower levels of water availability. Also, other water uses in the basin now and in the future may show more significance within the basin water balance. So the question that remains is to what exact extent, developments in the basin may influence urban water supply. The following two sections discuss urban water use in the Volta and Densu Basin in more detail.

5.6.1 Urban water use from the Densu Basin

The Densu Basin passes through three regions of Ghana and falls under ten district administrations. The basin is of great socio-economic importance for water supply for irrigation and urban use (Accra Consensus). Land use changes have resulted in a general decline of vegetative land cover, causing more intense flooding, erosion and subsequent siltation in parts of the river, most notably the Weija Reservoir (Kusimi 2008).

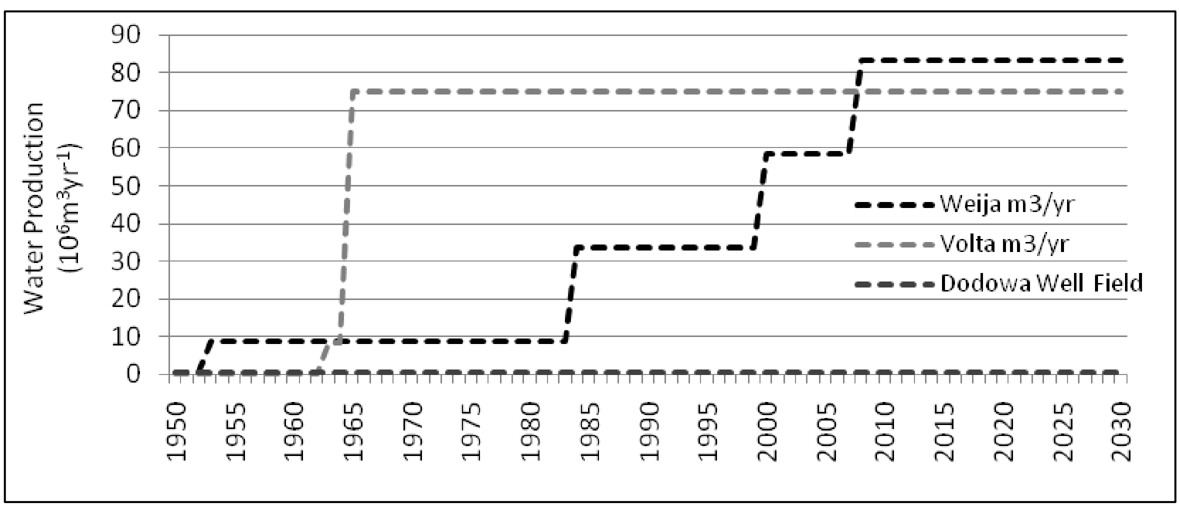

Figure 29. Gross water production for supply to Accra urban area, by source, for 1950-2030.

Water supply from the Densu River started in 1928 and has, since then, seen a step-wise increase in water treatment capacity and subsequent gross water production (Figure 29). Due to the absence of data for river run-off from Densu since 1980, it is becomes difficult to assess the current fraction of water that Accra is using from the Densu Basin. Based on run-off records for the period 1967-1980, urban withdrawal accounted for 6% of median run-off. When assuming a similar scale of run-off at present, water use takes a large fraction, about 60%, of Densu run-off. However, further expansion of treatment capacity and subsequent water production from Weija Lake could be hindered more by deterioration of water quality rather than decreased run-off generated from the Densu Basin (Karikari, 2006 #337; Amuakwa, 2007 #385). "*Weija has no natural limit, it is a big lake. The withdrawal limit is the quota set by the water company. We have calculated that the water level would drop 1.5 metres due to the increased withdrawal for urban water supply*" (Kootstra 2009). The real fraction may be higher due to decreases in annual run-off combined with increases in water extraction in the catchment of the Densu River. This is supported by evidence of reported increases in water use, as well as of pollution with untreated domestic wastewater and agricultural drainage water (Ansa-Asare 2001). Also, evaporation from the reservoir (surface area 310ha) possibly causes significant losses, thereby reducing water availability.

5.6.2 Urban water use from the Volta Basin

The Volta Basin is one of the largest river basins in Africa and extends over six countries in West Africa. In 1964, the lower reach of the river was dammed to generate hydropower, primarily to supply the mining sector with power. The impoundment of the Volta River created a huge reservoir, the largest artificial lake in the world by area, with a surface area of 8,500 km^2. An estimated 7.5% of the river flow is lost through evaporation from the lake's surface (Andreini *et al.* 2000). The damming of the Volta River has caused environmental effects downstream of the dam. The reduced outflow into the ocean may have enhanced saltwater intrusion into the coastal area around the estuary.

Since the erection of the dam, two major periods of droughts, in the early eighties and late nineties, brought the lake level below the minimum level needed to sustain power generation from the turbines. In contrast to power security, the security of water supply has not been affected by fluctuations of the lake level. However, frequent power outages do affect water treatment rates and subsequent supply, since the pumps at Weija and Kpong need time to restart and get back to operation. "*Lately, power cuts have happened more often. The problem is that if there is lights-off*[11] *for five minutes, it takes 25 minutes to start all the pumps again. In normal years, we have one-two power cuts per week, sometimes no power cuts for even 25 days, which results in reduced water production in those days"* (Amuakwa 2007). The huge size of the Volta Reservoir does not give reason to suggest that any future climatic scenario or withdrawal by other water users will constrain the current use and future expansion of urban water supply to Accra. However, a trend of reducing reservoir inflows has been observed (Gyua-Boakye and Tumbulto 2000; Giesen *et al.* 2001). The primary cause is a reduction in mean annual rainfall in the catchment. Also, many new boreholes have been drilled in the upstream catchment with the potential to induce recharge from rivers and streams in the Volta Basin. The third probable cause of reduced stream flows of the Volta may be land use development (such as expansion of irrigated area) (Giesen *et al.* 2001). The influence of additional boreholes and irrigation development on reservoir inflows should be investigated in order to make statements with sufficient confidence.

5.7 FINAL COMMENTS

This chapter presented results for the Accra case study. The historic analysis has shown that the urban area has expanded as a result of fast population growth. Since 1950, about every decade investments were made in instalment or upgrading of water supply plants to boost per capita water availability (figure 3). Even though water supply increased, per capita water availability decreased during 1986-2006, which can be attributed to population growth (Figure 4). Less attention was given to wastewater treatment, resulting in large volumes of wastewater leaving the city to date, degrading the most notably the Korle Lagoon and the marine environment of shore. The current situation of polluted water bodies and human health risks due to exposure to water polluted with faecal waste shows much similarity with the situation

[11] 'Lights off'` is a common local term used for 'power outage'

described by McPhee in 1926. Wastewater has not been properly management due to insufficient institutional and financial capacities at the municipal level and insufficient priority given to it. The conversion of green and permeable areas into paved areas in combination with slow enlargement of the urban drains has worsened flood events that occur every rainy season in the city.

The urban water balance has provided insight into scale of the major water flows that enter, run through and leave the urban area of Accra. Roughly two-third of the rainfall is converted into run-off while 60% of the water supplied returns as wastewater. Another major component in the water balance is river run-off entering the urban area. Smaller components are evapotranspiration, percolation and physical losses from the piped supply network.

The scenario analysis provided insight into the impact of three urban development scenarios on water demand, wastewater flows and -reuse, and comparison of city water use with basin water availability. In all scenarios investigated, urban water demand will continue to be severely suppressed by water supply. Official plans to upgrade water supply facilities were not found for Accra. Although, this makes it difficult to speculate about future scenarios, it can be assumed that water supply will increase in an effort to meet water demand. All three urban development scenarios show substantial increases in the wastewater volumes that will be generated as a result of likely increases in water supply to the city. A projected doubling, tripling and quadrupling of wastewater volumes during 2010-2030 in respectively the water savings, business-as-usual and accelerated-growth scenario has major implications for the management of wastewater disposal and treatment. The potential for reuse depends largely on land availability and the policy environment.

Accra is expected to have little influence on basin water availability and vice versa. Annual urban water use, currently at 0.4% of total basin water availability (Volta and Densu Basins), is expected to increase to 1.0-1.7%, depending on scenarios for urban development. Future scenarios for basin water availability was considered by using 50% and 75% probabilities of occurrence, based on historic run-off records. The impact that water use has on water availability for agriculture in the Volta Basin remains low, with less than 5% withdrawal in all urban development and water availability scenarios that were investigated. Current urban abstraction from the Densu Basin is already high with about 60% of run-off pumped to the city. This fraction however is not expected to increase much further due to a further deteriorating water quality in the Weija Reservoir, expected to hinder expansion of water supply capacity.

The findings on Accra discussed in this chapter were derived based on the research design as outlined in the methodology chapter (chapter 3). The set of tools developed and applied to investigate the research questions was found to be effective and appropriate for application in the Accra case study.

6. CASE: ADDIS ABABA

This chapter discusses the results for the Addis Ababa case study. The urban water balance is only discussed briefly for Addis. Instead, the sections on wastewater irrigated agriculture (6.5) and the basin impact of urban water use (6.6) are discussed in greater detail.

6.1 CHAPTER INTRODUCTION

Ethiopia is often called the roof of Africa due to its generally high elevation. The country is one of the East African countries located in the Horn of Africa. Addis Ababa is the capital of Ethiopia. The city is located fairly central in the country (Figure 5), on the southern foothills of the Entoto Mountains in the Awash Basin. The urban area extends over a sloping area that ranges in elevation between 2,400 and 1,800 m, making it the third highest capital in the world. The city is the nation's economic and political centre and is host to many international organizations such as the African Union. Of all industrial companies in the country, 65% are located in the capital.

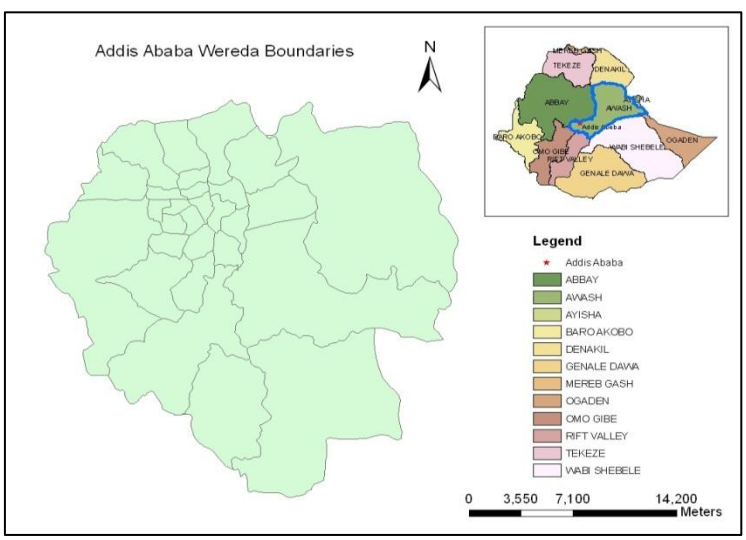

Figure 30. Satellite image of Addis Ababa.

The urban area of Addis Ababa has expanded dramatically over the past decades (Melesse 2005; Tessema 2005; UN-Habitat 2007; UN-Habitat 2008a). Despite this finding, no reliable data were found on the actual change of the built-up area of Addis over any time period.

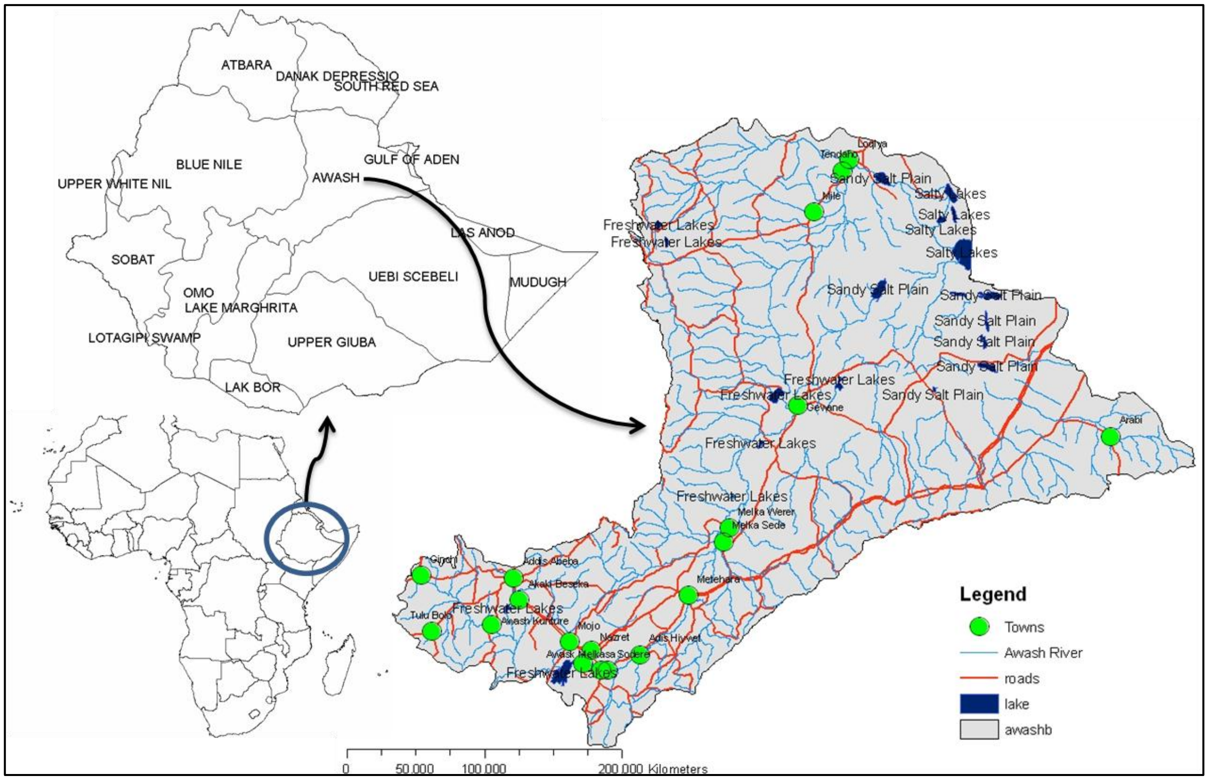

Figure 31. Location of Addis Ababa in the Awash Basin, Ethiopia.

In terms of population size, Addis Ababa stands out as the only million plus city in an otherwise primarily rural country. In 2006, 16% of its population was living in urban areas, of which 25% were residing in Addis Ababa (MoFED 2007). Urbanisation has started only recently, so *the city* is a relatively new phenomenon. It has been argued that this urban youthfulness partly explains why the management of many services by the city authorities has shown a generally poor performance (Ayenew 1999). Like in many cities in low-income countries, it is difficult to determine the exact population of Addis Ababa. Official statistics for the urban population are likely to be underestimated (UN-Habitat 2007). This is because information on the number of people living in informal settlements is not included in the statistics. Secondly; there may be a considerable number of people living in the urban fringe areas that have so far not been classified as part of the urban agglomeration of Addis Ababa.

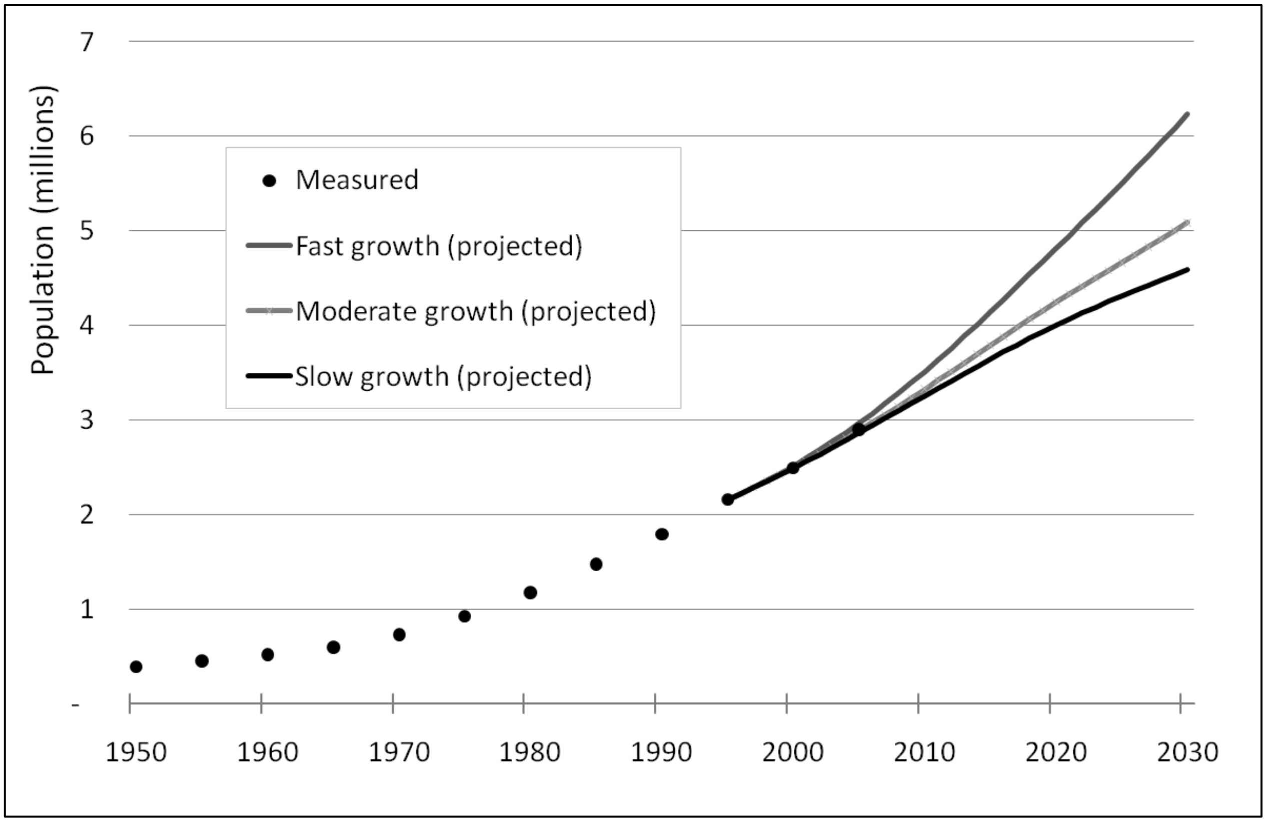

Figure 32. Measured and projected population of Addis Ababa during 1950-*2030.*

Sources: (CSA 2006; UNESCO 2006)

The Addis Ababa case illustrates an example of a city where many of today's urban water issues have emerged, at multiple scales and across sectors. The research questions are answered within the main research themes of urban water supply, sanitation, wastewater irrigation and basin water management.

Institutional setting of the water sector in Addis Ababa

The management of the water supply and sewerage system is the responsibility of the Addis Ababa Water Supply and Sewerage Authority (AAWSA), set up in 1972 and formerly known as the Water Services Section under the Addis Ababa Municipality. Regarding sanitation services, the municipalities in Ethiopia are responsible for ensuring the collection, transportation and disposal of septic sludge. This responsibility has so far not been high on the agenda of the urban authorities; there is a lack of clarity on roles and responsibilities. Also, there is simply a structural lack of funds for almost any public service in Addis Ababa, and then sewage is considered a non-priority issue (Gebre 2008; Zelalem 2008). As a result, sanitation and disposal of wastewater are poorly managed in Addis Ababa (Van Rooijen and Taddesse 2009).

One issue related to management capacity is the fact that within AAWSA many old staff have been replaced by younger personnel: "*Too many senior staff, having 10-20 years of experience, left the organization in a short time span. Instead younger people have come, they are good people but they lack experience (…) there is an urgent need for local technical capacity building and knowledge should be transferred*" (Rosenberg 2008). This citation indicates that as in many other organisations, there may be poor institutional memory: records are not adequately kept, indicating that knowledge of senior staff was largely in their heads and some of this knowledge may not have been transferred to new staff.

6.2 TEMPORAL DEVELOPMENT OF WATER SUPPLY AND SANITATION IN ADDIS ABABA

This section sets out the history of urban water supply and sanitation services in Addis Ababa. The results presented here aim at contributing to the first research objective (section 1.3).

6.2.1 Water supply development in Addis Ababa

Until around 1900, the residents of Addis Ababa were using water from hand-dug wells and springs on the slopes of the Entoto Mountain range. The first known form of organised water supply in Addis Ababa was realised in 1901 during the reign of Emperor Menelik II. A cement canal conveyed water from a number of springs located at the foot of the Entoto Mountains to a reservoir in the city, under gravity. From there it was pumped to several parts in the city through pipes (AAWSA (1957) cited in Kebbede (2004)). Addis Ababa did not experience water shortages in this period. Enough springs and wells were available in and around the city that provided enough water year-round. In 1919, a period of relatively low rainfall caused the first recorded period of water shortage in the city. As a response to the shortage of water, people began digging wells close to the river in order to extract from groundwater. The government responded to the situation by tapping additional water from one of the streams originating from a mountain slope (Kebbede 2004). Until 1950, groundwater remained the dominant source of water, accounting for an estimated 80% of total water use.

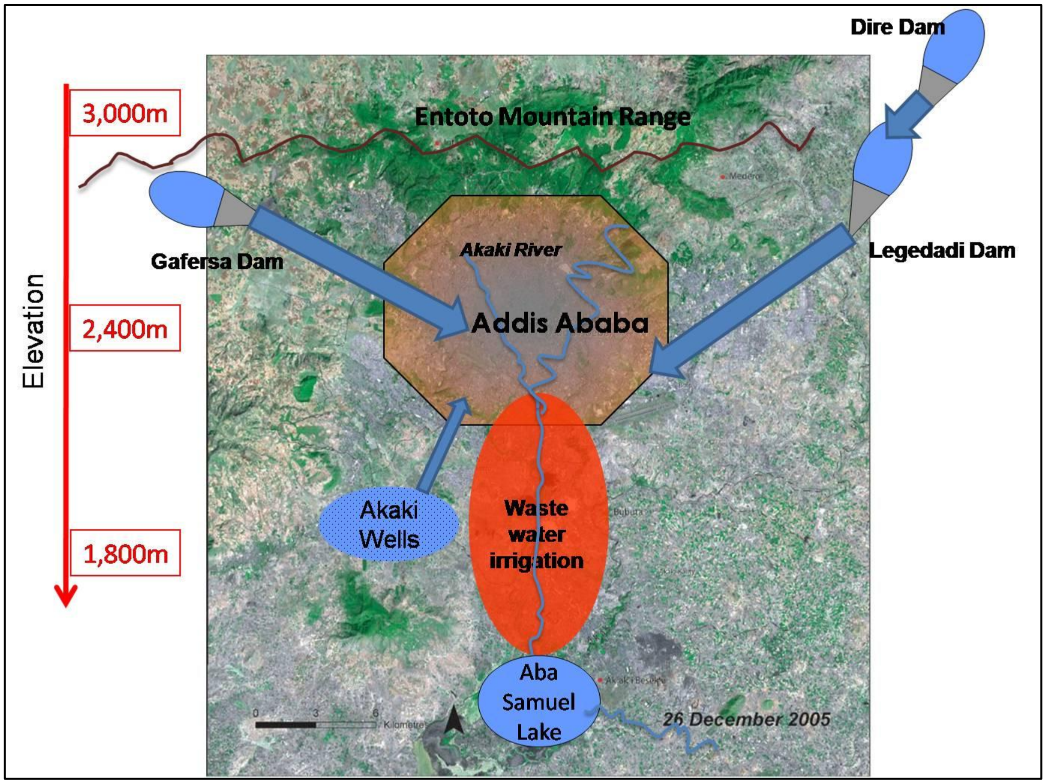

Figure 33. Sketch of water supply to Addis Ababa and wastewater irrigation downstream of the urban area.

Source of map: UNEP-GRID.

Since the late 1960s, the population of Addis Ababa increased rapidly, with annual growth rates averaging between 3% and 4%. Consequently, water demand rose rapidly as well. Addis Ababa has seen a series of major water-supply expansion projects that lifted water supply capacity to higher levels (Figure 34). The Gefersa Dam, completed in 1943, was the first major infrastructural work designed to supply water to the city (see Figure 33). Much later in 1960, a treatment plant was built at Gafersa. In the 1960s, many springs were abandoned due to their deteriorating water quality (Fissha 2006). In 1970, water supply was expanded again with the commissioning of the Legadadi treatment plant at the newly built Legadadi reservoir. During the 1980s, both treatment plants were upgraded and equipped with larger pumps and transmission lines which allowed for water production to increase. By then it was argued that the upgraded water treatment capacity would be sufficient at least until the early 1990s (Sime 1998). Before the turn of the century, the first organised supply from groundwater was established, with the Akaki Groundwater Development Project. The productive Akaki Well field system, located 30 km south of the city centre, currently supplies 55,000 m^3d^{-1}. Together with other springs, groundwater accounts for 24% of total water supply to Addis Ababa (Table 19).

Table 19. Characteristics of present sources for water supply to Addis Ababa.

Water source	Volume (10^6m^3)	Catchment area (km^2)	Production ($m^3\ d^{-1}$)	% of total	Year of construction	Location relative to city
Surface water						
Legadadi*	44	20	168,000		1970	33 km N-East
Dire*	19	7			1995-1999	33 km N-East
Gefersa	8	5	23,000		1942-1943	18 km N-West
Sub-total	71	33	191,000	76		
Groundwater	No. wells					
Akaki well field	29	-	55,000		1995-2001	10 km South
Other wells and springs	32	-	13,800		1995-present	varies
Sub-total	61	-	58,800	24		
Total			249,000			

Source: (AAWSA 2008)*Legadadi and Dire reservoir are connected and provide one single supply line, hence a single production figure is given.

At present, the water utility in Addis Ababa uses five different sources of water, of which two are groundwater sources and three are surface water sources (Table 19). In terms of volume, 3/4th of water is withdrawn from the surface water and the balance is taken from groundwater sources.

When urban water supply is plotted in time, the enormous expansion of supply becomes visible (Figure 34). Current water supply to Addis Ababa is just below 100 Million m^3yr^{-1}. However, this is expected to increase threefold if the planned expansion would be realised.

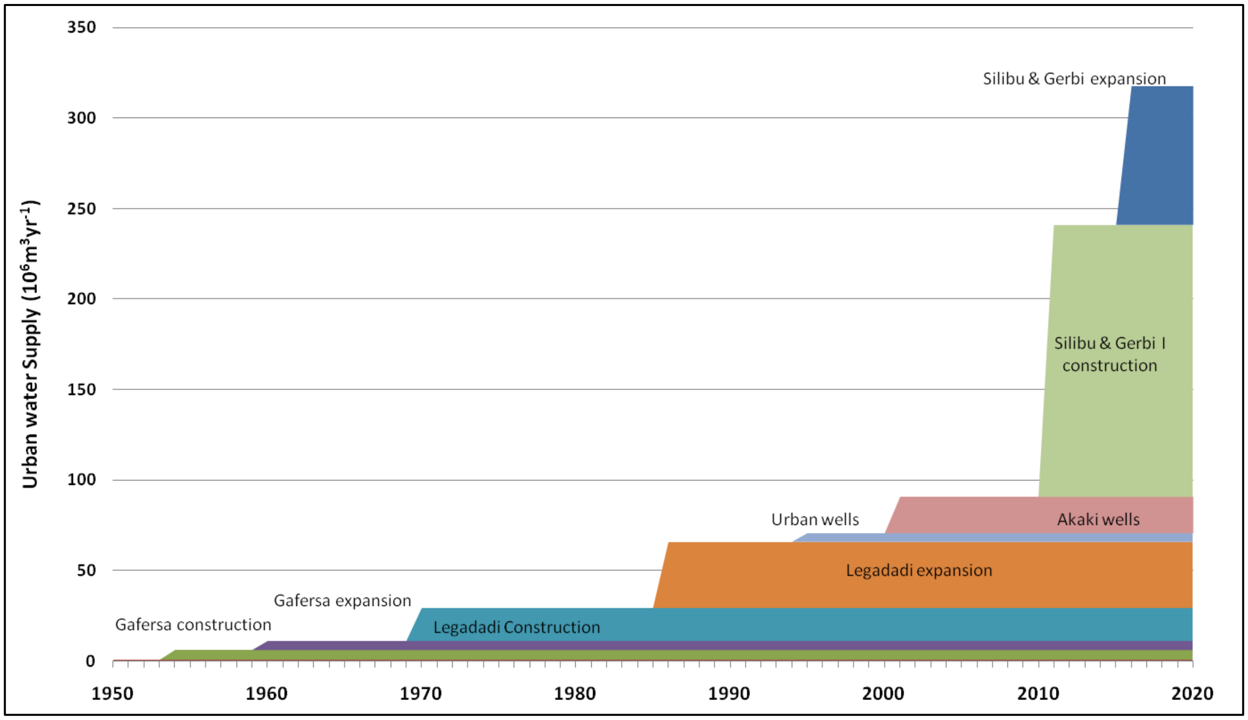

Figure 34. Gross water supply to Addis Ababa during 1950-2020.

Sources: (Tahal 2005; AAWSA 2008)

Current water use

In 2003, water supply was $80{\cdot}10^6m^3yr^{-1}$. Up to 2009 this increased to $91{\cdot}10^6m^3$ with the exploitation of additional borewells (Tahal 2005). When current supply is divided over the current population of 3.3 million (in 2009), this brings a gross per capita water availability of 76 lpcd. When accounting for 35% of physical water and distribution losses, per capita availability is reduced to 49 lpcd. When abstracting water for non-domestic (accounting for 50% of total) (AAWSA 2008; NEDECO 2002; Rosenberg 2008), a mere 25 lpcd becomes the average water availability for domestic consumers. This figure seems unrealistically low, however was not contested by staff from the water supply company (Tekle 2008). In addition, similar findings were reported in a study by NEDECO that found average domestic consumption amounting 22 lpcd, whoever the figure is based on data from the year 2000. The same study showed that a very small part of the population has an in-house piped tap (about 4% of the population) and uses on average between 80 -100 lpcd. The remaining population (94%) are served by own or neighbour's yard connections and uses between 15 and 30 lpcd. This rate is relatively low for urban areas and it is low when compared to the proposed minimum standard of 50 lpcd (Gleick 1996). It should however be noted that the figure given for average per capita consumption should be interpreted with caution for inacuracies. Informal water use (from springs, wells etc.) is not accounted for in the calculation of average per capita consumption. Accounting for this would raise the figure to an unknown extent. Furthermore, data on population number may be overestimated which would give underestimated lower consumption figures.

Based on the available data it can be said that access to urban water supply has potential for improvement. A far majority of the urban population does not have a tap connection the house or on the compound (94%), and instead relies on a standpipe or tap in the neighbourhood. When observing urban water supply during 1998-2004, a declining trend can be observed for per capita domestic consumption, despite substantial increases in gross water production (Figure 35). The physical water loss fraction has remained constant in the same period. The widening gap between gross and net per capita availability indicates that the fraction of non-domestic consumption has increased over the years.

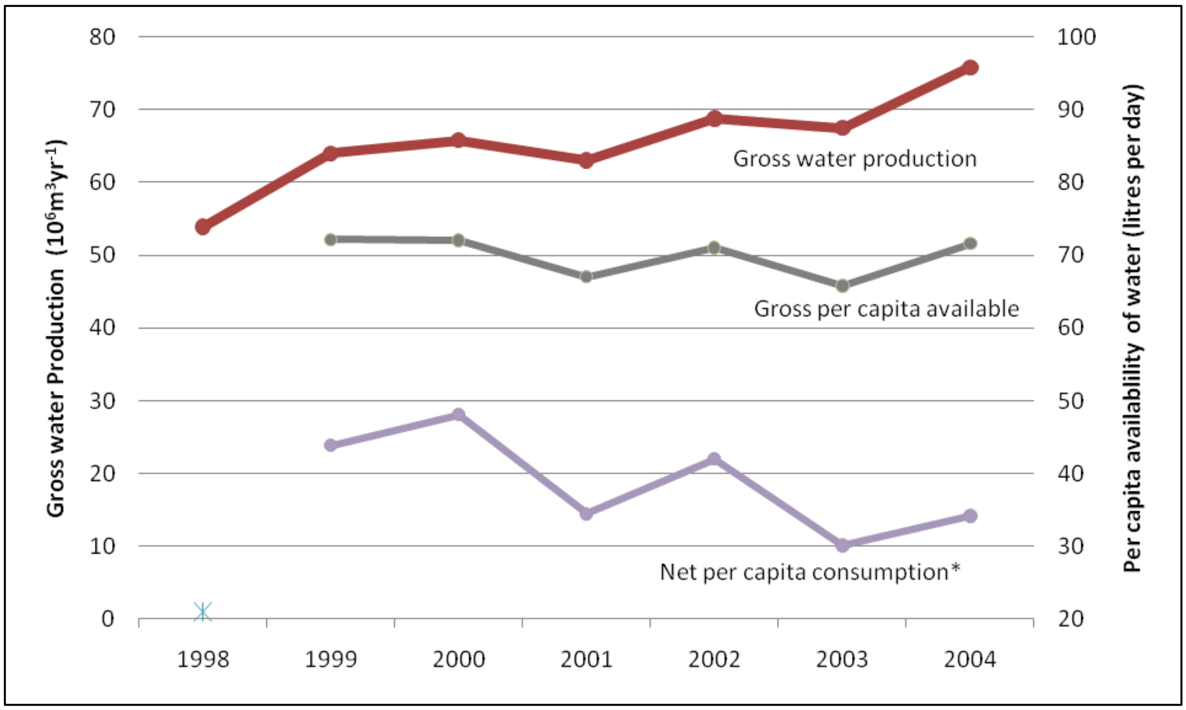

Figure 35. **Gross water production, gross per capita water availability and actual per capita consumption in Addis Ababa during 1998-2004.**

*Excluding physical losses and non-domestic uses.

Source: **(AAWSA 2008) and UN-Habitat (2007)**

6.2.2 Future plans

"*The water sources upstream Addis Ababa within Awash seem to be fully utilized and exploited. Then, downstream there is plenty of water, but taking this water would give very high pumping costs. Downstream is not suitable for dam construction and is also too costly. So we need to go behind the mountains*" (Waltenigus 2008). This is an illustrative quotation of the acting head of the water production and distribution department at AAWSA. The data suggest that the water sources currently in use for urban water supply have been exhausted. In order to meet future demands, new sources will have to be exploited. The low per capita water use suggests that there is not much scope for water savings at the domestic level.

High sediment loads are causing siltation, which is reducing the live storage volume of the Gafersa and Legadadi reservoirs. Increased turbidity levels were observed in water entering the treatment plants. This has led to increasing treatment costs and subsequent costs of water supply from these reservoirs (UNESCO 2006; Gessese and Yonas 2008). During the 1980s and 1990s, experts anticipated that a big boost in water supply from new sources was needed for Addis Ababa in order to meet increasing demand. In 2002, AAWSA advertised for the design of urban water supply expansion. The international bid was won by Tahal, that subsequently prepared an ambitious plan to take water from behind the Entoto Mountains (Tahal 2005). The project encompasses the construction of two new dams in the Gerbi and Sibilu rivers, transmission lines, a treatment plant and a tunnel of 4.7 km to be drilled through the Entoto Mountains. The Gerbu and Sibulu rivers are located in the neighbouring Abbay Basin which is also known as the Blue Nile Basin. The planned project is technically very complex and requires extensive technical expertise for carrying it out. "*Compared to the planned supply strategy, the current supply is very simple*" (Rosenberg 2008). The water supply expansion project has not yet found funding (Zenebe 2007; Waltenigus 2008).

Water supply development is constrained due to a few factors that will be discussed here. One of the problems is lack of information needed for water demand planning. There is not much demographic data available which is needed to make projections for water demand. The current projections for water demand show large variations due to a wide range of population growth scenarios. Furthermore, the different altitudes across the urban area make it relatively unfavourable for water distribution. Currently, there are 30 different pressure zones and 60 reservoirs in the city (for storage and distribution) while there is a difference in altitude of 1.9-

3.0 km to be overcome with pumps (Rosenberg 2008). While currently the number of borewells from the Akaki well field system is being extended, this source alone does not seem to be enough to satisfy additional water needs in the future. It is estimated that the new boreholes will give a yield of 3,000-5,000 m^3d^{-1}. To reach a similar scale as water supply from surface water sources, hundreds new wells would need to be exploited. The number and dispersed character of the borewells make it very difficult to exploit and manage them. In this situation, it is expected that supply from groundwater will reduce from 27% in 2000 to 8% of total supply by the year 2030.

Based on the analyses, the increase in urban water demand is being anticipated by the water utility, with the development of studies and plans to expand water production to Addis Ababa. However, the future of urban water supply expansion is greatly determined by the financial environment and more specifically the likeliness of acquiring external funding to carry out water supply expansion projects.

6.3 Sanitation and wastewater disposal in Addis Ababa

6.3.1 Household sanitation facilities

The most recent city-level data for Addis Ababa give the fraction of people using a pit latrine in the range of 70-75%, while the fraction of flush toilet users is 11-17% (Figure 36). Most flush toilets have a septic tank installed, and a few are connected to the sewerage system. The rest of the population, between 10-15%, use a household item (e.g., pan, bucket) or have no facility at all (CSA 2001; UN-Habitat 2004; CSA 2005b). In some low-income neighbourhoods, public toilet and shower facilities exist. The pit latrines have common problems such as overflowing with stormwater and blocking of the suction pipes of vacuum trucks with solid waste thrown into the pits (Worku and Adam 1999).

Less than 10% of the urban area is covered by a sewerage system that measured just 150 km in total length. The AAWSA is currently extending the network in two areas. However, it is being noted that in absolute terms, the expansion of the urban area is going much faster than the expansion of the sewered area (NEDECO 2002b; Zelalem 2008). This brings in the question as to whether expanding the sewerage system is the best way of improving wastewater disposal infrastructure at the city level. This issue will be further discussed at the end of this chapter and in the general discussion chapter.

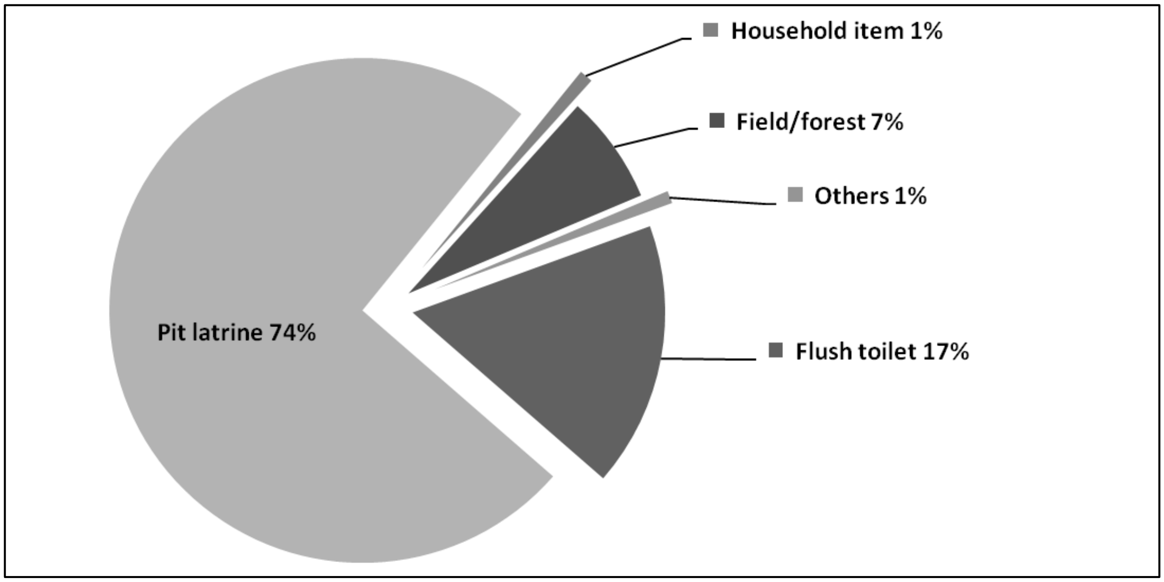

Figure 36. Breakdown of sanitation facilities in use in Addis Ababa.

Source: (CSA 2005a)

6.3.2 Wastewater disposal and treatment

The current principal sources of wastewater are the households and institutions. Wastewater produced by institutional facilities is essentially domestic in nature. Other important sources of wastewater include commercial facilities and recreational areas. Domestic wastewater in Addis Ababa is characterised by low discharge rates due to a relatively low living standard of most of its population and a low fraction of the population connected to the sewerage system (NEDECO 2002b; Zelalem 2008). Most wastewater from industries is not being treated and instead is disposed of straight into nearby urban water bodies (EPA 2005; Teku 2006; Gebre 2008) (see section 6.5).

Wastewater treatment occurs at two locations, namely, Kaliti on the south and Kotebe on the west side of the city. The Kality treatment plant has a series of wastewater stabilisation ponds and drying beds. The stabilisation pond system consists of eight ponds lined up in series in a large U-shape, and receives wastewater and stormwater from the sewerage system with a retention time of 30 days. The effluent flows out into the adjacent Akaki River. With an average treatment of 5,200 m^3d^{-1} it runs under the design capacity of 7,600 m^3d^{-1} (Alemayehu 2008). The origin of the sewage can be assumed to be mainly domestic as the final pond is containing a cage with fish (*own observation*) that is part of an experiment being conducted by students of Addis Ababa University (AAWSA and AAU). Fish would likely not survive in the final pond of a simple wastewater treatment if it would receive large influents of industrial wastewater. Eight drying pools are used for disposal of septic sludge from pit latrines and septic tanks. The wastewater is transported to the plant by vacuum trucks with a frequency of over 100 trucks a day (Alemayehu 2008). The Kotebe treatment plant receives only sludge from vacuum trucks that empty septic tanks and pit latrines, with an estimated annual treated volume of 85,000 m^3 (NEDECO 2002b). The sludge treatment at Kotebe is similar to the Kality plant in design, which consists of a series of drying beds. After the sludge has dried and turned into compost, it is dumped on a nearby open space without any known further use. Approximately 60% of the total generated sludge is collected by trucks from AAWSA while the balance is collected by private operators. The sludge treatment process employed in Addis Ababa is considered appropriate and effective; it does not require much expertise or maintenance and the drying process is fast in the dry season of Addis Ababa, which is eight months per year.

When observed over time, sanitation development[12] is perceived to be slow (van Rooijen and Tadesse 2009). The proportion of urban dwellers covered by improved sanitation at the country level has remained constant at 58% during 1990-2000 (WHO 2000). A Demographic and Health Survey (DHS) carried out in 2005 give 52% of the urban population in Ethiopia using an improved sanitation facility. To date, a more recent survey does not exist (WHO/UNICEF 2010). This means that at the country level, improved sanitation coverage has declined. Given the high population growth rate in Addis Ababa and the negative impact of population growth on sanitation coverage, it can be assumed that a similar decline is the case for Addis Ababa. Household sanitation facilities and wastewater disposal infrastructure at the

[12] With the term *sanitation development* is meant here: the development of sanitation infrastructure at the individual or household level (toilet facilities and wastewater disposal and treatment systems)

country and city level are generally considered as being in a poor state (World Bank 1997; NEDECO 2002b; Mekonnen 2008, Mafuta et al 2011).

6.4 SCENARIOS FOR URBAN WATER DEMAND

This section presents scenarios for the demand of water that are likely to be expected in the future for Addis Ababa. The results contribute to research objective three (section 1.3.2); to predict water demand for the three different urban development scenarios that have been tested in the other case studies as well. No data were found on historical trends in water demand for the period 1950-2011. The change in water demand in that period was based an assumed 1.5% annual growth rate and a present (2010) baseline gross demand of 161 lpcd. This results in a gross water demand of 25 lpcd for 1950, which is considered reasonable (Tekle 2008). Current and future water demand has been estimated by various authors (Table 20). Domestic water demand is currently in the range of 70-100 lpcd. Gross water demand is around 150 lpcd. The difference between the two figures is composed by non-domestic water demand and physical losses. Non-domestic water demand is about half of total demand, based on consumption records (NEDECO 2002b), while the physical loss fraction is approximately 37% (AAWSA 2008).

Table 20. Per capita water demand estimations for Addis Ababa.

Per capita water demand (lpcd)					Source
2002	2011	2015	2020	2025	
75					(NEDECO 2002a)*
103					(Shewaye and Adam 1999)
	77 (161)	102 (192)	128 (229)		(Tahal 2005)
	(152)	(171)	(198)		(Sime 1998)
	(161)		(192)	(229)	(AAWSA 2008)

* The gross or total water demand including non-domestic water demand and physical losses is given within brackets.

Average water demand of people residing in high income areas ranges between 80 and 130 lpcd. Actual use depends on the sanitation facilities installed and the availability of storage tanks to overcome shortages in water supply (NEDECO 2002b). Water demand in Addis

Ababa is expected to further increase due to population growth, rising per capita domestic water demand and non-domestic water demand (NEDECO 2002b; Tahal 2005; Medhim 2008; Rosenberg 2008; Tekle 2008; Tessema 2008). Projections of future water demand are presented here for the business-as-usual, accelerated growth, and water savings scenarios. These scenarios are based on a combination of projections for population growth given by (CSA 2006) and various projections for future per capita water demand based on (Tahal 2005), as presented in Table 21.

Table 21. Projected growth rates for population and per capita water demand in Addis Ababa during 2010-2030.

Scenarios	Projected annual population growth rate (%)[1]	Projected annual growth rate of per capita water demand (%)[2]
Business-as-usual	2.64	1.75
Water savings	2.64	0.90
Accelerated growth	3.87	2.50

1 Based on scenarios in CSA 2006
2 Based on scenarios in Tahal 2005

The per capita water demand projections has incorporated water for non-domestic use and physical losses. Water demand, currently around $200{\cdot}10^6 m^3$ per year, is expected to rise to roughly 450, 500 and $580{\cdot}10^6 m^3$ in 2030, in the water savings, business-as-usual and accelerated-growth scenarios, respectively (Figure 37).

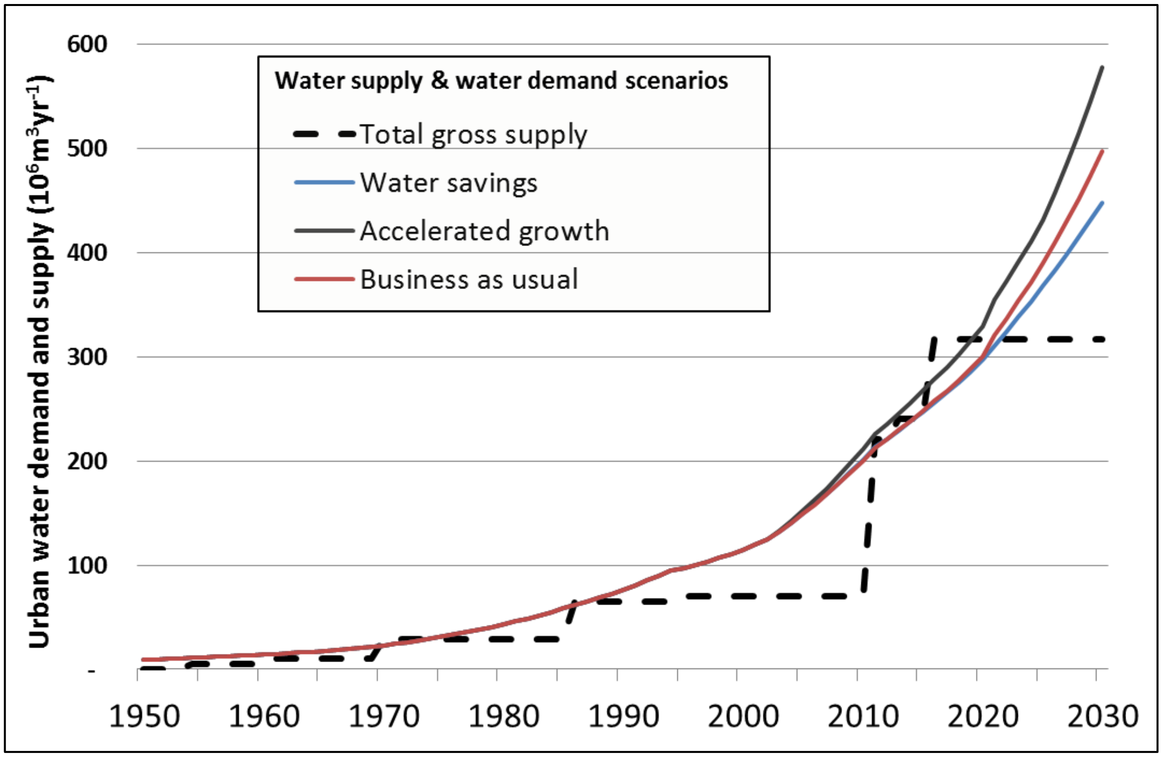

Figure 37. Water demand and supply for Addis Ababa during 1950-2030. Historical water demand and projected scenarios are given for 2000-2030.

Sources: Modified from (Tahal 2005; CSA 2006).

The current gap between water supply and demand is estimated at 69% based on equation [3], in section. This can be observed as an important indicator for chronic water stress occurring in the city of Addis Ababa. When observing future planned supply versus water demand in Addis, it can be noticed that water-stress is likely to prevail to a considerable extent.

6.5 SCENARIOS FOR WASTEWATER USE IN AGRICULTURE

This section discussed the use of urban water in urban and peri-urban agriculture in Addis Ababa, which aims to contribute to answering the fourth research question. A description of the current situation will be followed by an analysis of future scenarios set out for Addis Ababa.

6.5.1 Current situation

Due to a combination of poor sanitation facilities and undulating topography, 65% of the wastewater generated in the city (EPA 2005) ends up directly in surface water. This wastewater finds its way through a dense network of surface drains and streams and finally drains into the Akaki River. This river originates in the Entoto Mountains in the north and flows southwards via two main branches, Little and Great Akaki rivers, eventually feeding into the Aba Samuel Lake (Figure 38). Effluent of the small fraction of wastewater that undergoes treatment is discharged into the same Akaki River. In addition, solid waste, most visibly plastics, are actively disposed of into urban streams or are flushed into the river during times of rainfall.

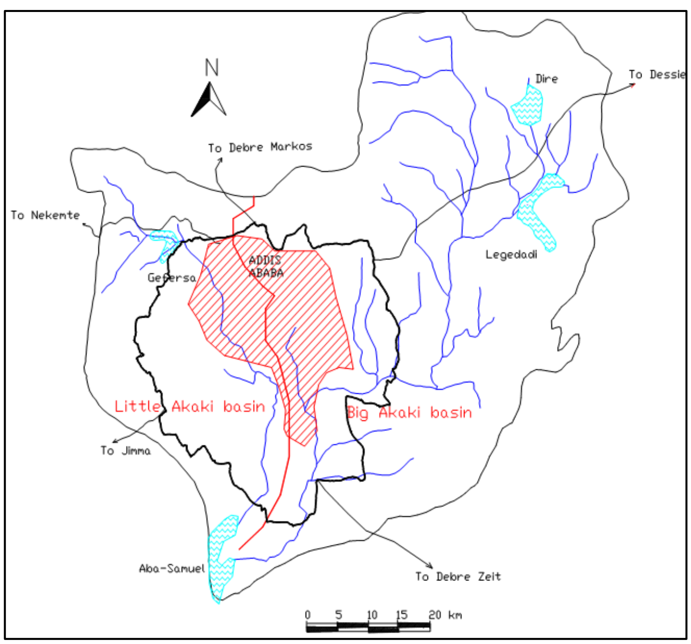

Figure 38. **Akaki River Basin and location of Addis Ababa.**

The striped shape represents the built-up area of Addis Ababa. The surrounding thin grey line represents the borders of the Little and Big Akaki basins. The inner quasi ring-shaped thick black line represents the political boundary of the city.

Source: (Alemayehu et al. 2008).

Since the 1940s, a variety of vegetables have been produced within and around the city, mainly using water from the Akaki River. Outside the rainy season these crops require irrigation, which is done informally by smallholders without any ‘modern’ irrigation infrastructure, such as weirs and lined canals. Farmers often take advantage of gravity by blocking waterways upstream and allowing a proportion of the water to flow through conventional earthen channels into a larger system of furrows. Further downstream, pumps are also used to flood fields (van Rooijen *et al.* 2010). Irrigation of vegetables takes place along the river banks on an estimated area of 400 ha, producing over $11 \cdot 10^3$ tonnes of more than 14 different vegetables each year (Kebede 2008). Irrigated farming is also done in backyards, although no estimations exist on its scale. Farmers are organized into 11 vegetable producers and marketing cooperatives. There are also many independent vegetable farmers, bringing the total number to around 1,300. There is no legislation that prohibits or permits the use of stream water for crop production in the study area, although campaigns try to alert people to the health risks associated to the use of this water.

Urban farmers do not pay for the water they use. However there is an annual tax in place for their farmland. The vegetables they produce are for both market and home consumption, in the ratio of approximately three to one. They provide about 60% of the vegetables to the cities’ vegetable markets. Urban farming is their main source of household income (Weldesilassie 2008).

6.5.2 Urban agriculture in relation to urban development scenarios

The previous section made clear that wastewater and stormwater generated in Addis Ababa is being reused informally, though organised, in irrigated agriculture, providing a source of livelihoods for many farming households. The sustainability of this practice clearly depends on the availability of water for irrigation. Future water availability, in turn, depends on demographic and infrastructural developments in the city, which are not entirely predictable. “*The wastewater master plan serves as a road map for us. Only, there is no money to carry out* *the proposed projects. The budget needed to carry out the project is 250 million Euros*" (NEDECO 2002b; Zelalem 2008). Future scenarios for irrigation with marginal water in Addis Ababa depend strongly upon the quality and patterns of availability of the wastewater (Mekonnen 2007; Adebaw 2008). The quality of the wastewater will depend strongly on industrial development, pollution control and future developments in infrastructure for domestic wastewater disposal and –treatment. Heavy metals such as iron, copper, zinc, manganese, nickel, lead and arsenic have been found in levels, exceeding the natural values (Itanna 2002; Itanna and Olsson 2004; EPA 2005). A UNEP-lead project is underway that aims to clean up the Akaki River and rehabilitate its original eco-system functions (EPA 2008). The future availability and quality of urban water will depend on developments of sanitation facilities in the city. Efforts to improve sanitation in the city should also help reduce the pollution load into the river.

Based on water demand projections calculated for the three urban development scenarios (section 6.4), resulting wastewater flows have been calculated (Table 22). Water supply is likely to increase in order to meet expected increases in water demand, in all three scenarios. As a result, more wastewater will be generated in the urban area, which in turn could benefit famers within and downstream off the city.

Table 22. Projections for wastewater volumes based on urban development scenarios for Addis Ababa, for 2010, 2020 and 2030

Year	Projected wastewater volume by urban development scenario (MCM yr^{-1})		
	Business-as-usual	Water savings	Accelerated growth
2010	160	161	169
2020	240	238	263
2030	398	359	462

The above table makes clear that from present, substantial increases in the volume of wastewater will be generated as a result of increases in water supply to the city to be expected. Within the investigated time frame of 20 years, wastewater volumes are likely to at least double in all the scenarios, up to 398, 359 and 462 $10^6 m^3 yr^{-1}$ in respectively the business-as-usual, water savings and accelerated-growth scenario (Table 22). In time, the growing variation in wastewater volume between the scenarios reflects the effect of different continuous growth rates for both urban population number and per capita water demand.

Similar to findings for Accra and Hyderabad, the actual scale of future wastewater reuse will depend largely on developments in wastewater treatment and -disposal infrastructure, the policy environment and the land availability. In addition, the level of contamination of soils and crops may also pose restrictions to irrigated agriculture. However, this will depend on crop quality monitoring systems, and society's response to these potential health risks.

6.6 BASIN-LEVEL INFLUENCES OF URBAN WATER USE

This section analyses to what extent the urban water balance of Addis Ababa influences the availability of water resources at the basin level. The findings contribute to answering the fifth research objective; to assess the impact of future urban water use on water availability for agriculture. The assessment focuses on two main areas of impact: downstream and upstream of the city. The two areas are discussed separately below, followed by a generic section.

6.6.1 Upstream impacts of the urban water balance

In this assessment, urban withdrawal is compared with basin water availability and non-urban withdrawals. As discussed earlier, water is currently supplied to Addis Ababa from three surface water sources and one groundwater source, all located in the Awash Basin (Figure 31). Current annual withdrawal for urban use stands at $90 \cdot 10^6 m^3$, which is nearly 2% of annual run-off generated in the Awash Basin (Table 23).

As discussed earlier in section 6.5.2, future water supply from two new reservoirs (Gerbi and Sibulu reservoirs) in the neighbouring Abbay Basin will be realised if funding is found. The planned withdrawal from the Abbay Basin is impressive in terms of scale since it amounts to more than double the current volume supplied to Addis Ababa. However, with 0.46%, the fraction of urban water can still be considered marginal compared to average run-off generated in the Ethiopian part of the Abbay Basin (Table 23).

Table 23. Comparison of urban water use with basin water availability and irrigation potential.

Basin	Annual basin run-off	Urban use		Irrigation potential
	$10^6 m^3 yr^{-1}$	$10^6 m^3 yr^{-1}$	% of Run-off	ha

Awash	4,900	90	1.84	134,121
Abbay	54,800	250 (planned)	0.46	815,581

Sources: (MoWR 1998); (Awulachew et al. 2007); (AAWSA 2008).

Both the Awash and Abbay basins hold a large potential for irrigation development (Awulachew *et al.* 2007). In that regard, it is not known yet what the future irrigation water requirement would be in any irrigation development scenario. The findings drawn from the comparison of urban water supply values, basin run-off and estimates for irrigation potential are only indicative.

The three scenarios for urban water demand (presented in section 6.4) were compared with total basin runoff in the Awash and the Ethiopian part of the Abbay Basin (Figure 39). Water demand remains marginal in all three demand scenarios, accounting for 0.5% and 0.6-0.8% of basin runoff, respectively by the year 2020 and 2030.

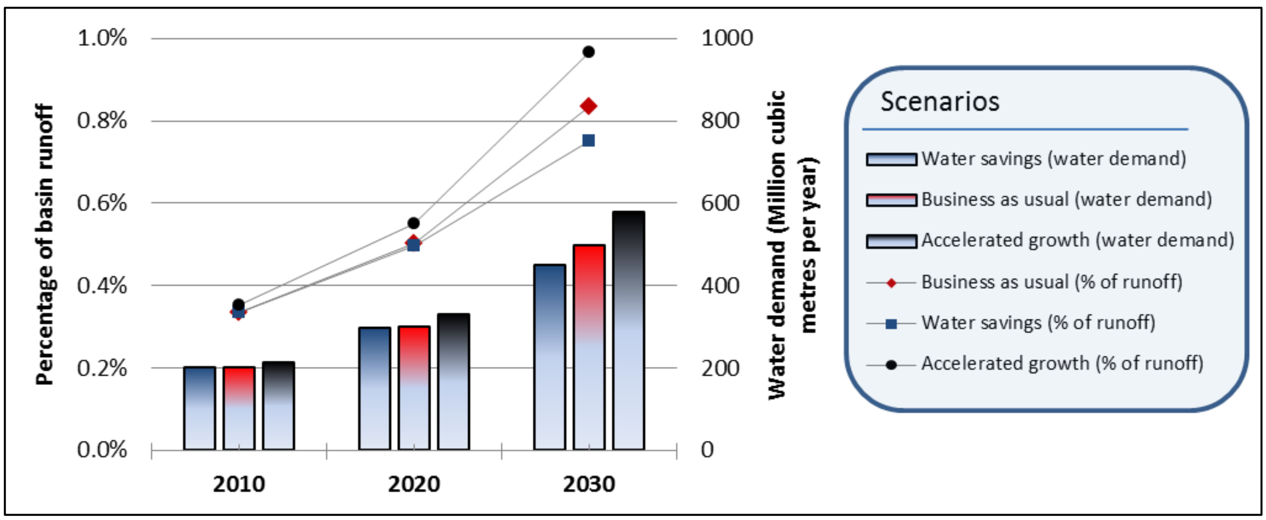

Figure 39. Scenarios for Addis Ababa water demand versus combined basin runoff, expressed in volume and percentage of basin runoff.

Runoff is combined runoff from Awash Basin and the Ethiopian part of the Abbay Basin.

It should be emphasized that many factors have not been considered here, such as the impact of for climate change scenarios, industrial water use scenarios (affecting water quality) and an assessment of current and future agricultural water use. However, based on this analysis, it can be concluded with some level of certainty that urban water use in Addis Ababa is likely to continue to have little influence on water resources upstream located upstream of the city.

The most prominent impact that the urban water balance of Addis Ababa has on the area downstream of the city, is alterations to the water quality of the natural water bodies. This will be discussed in the section below.

Human activities within the urban area of Addis Ababa have led to gradual deterioration of the water bodies within and downstream of the city. The sources of pollution are categorised into wastewater originating from households and industries. In addition, solid wastes such as plastic, are polluting the water ways. The disposal of industrial wastewater into streams in Addis Ababa is widespread, and has caused a general deterioration of all water bodies found in Addis Ababa (EPA 2005; Alemayehu *et al.* 2006; Demlie and Wohnlich 2006; Melaku *et al.* 2007). There are over 2,000 registered industries in Addis Ababa that account for 65% of the total number of industries registered in Ethiopia. Many of them are located along the Akaki River and release their effluents into it without any form of treatment (Figure 40) (Mohammed 2002; EPA 2005; Tolla 2006; Adebaw 2008; EPA 2008; Gebre 2008; Mkandla 2008).

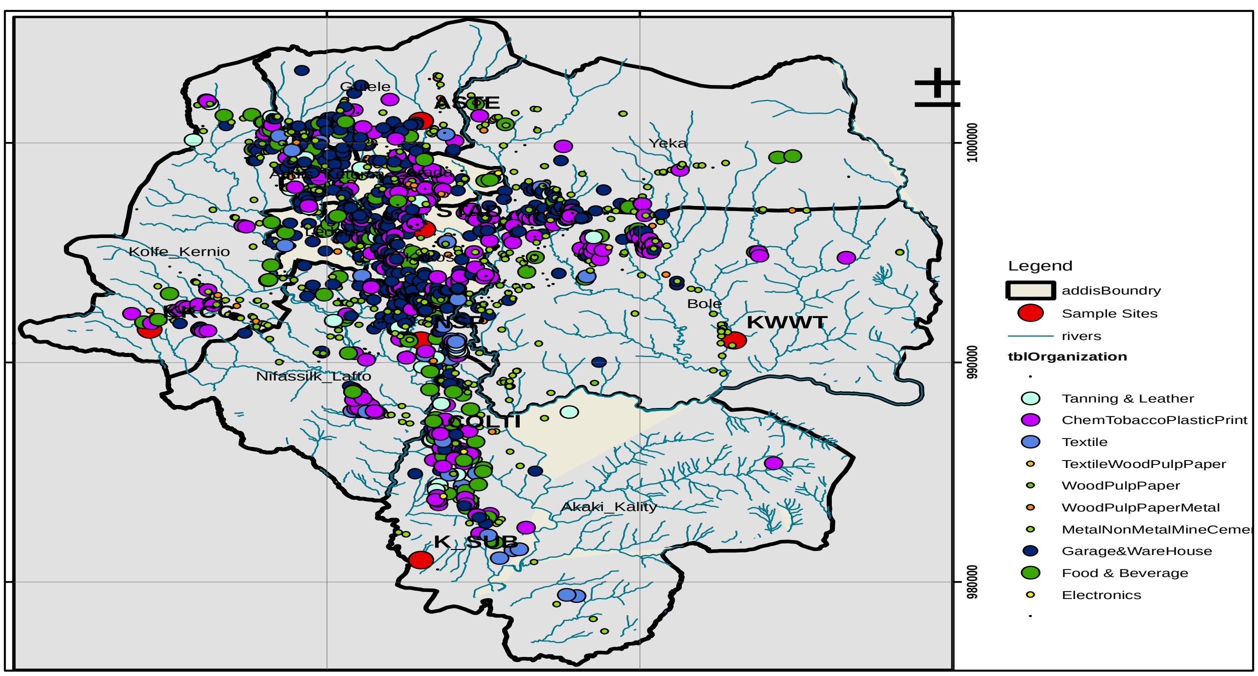

Figure 40. Location of industries in Addis Ababa.

Source: EPA unpublished.

According to the Addis Ababa Environmental Pollution Authority (EPA), 90% of all industries lack facilities to some degree of on-site treatment plant, and subsequently discharge any effluents into adjacent streams (EPA 2005). The lack of separation between industries and residential areas adds to increased exposure to pollutants that could affect human health (Teku 2006). According to the Sanitation Beautification and Parks Development Agency (SBPDA), altogether 2,256 m^3 or 851 tonnes of solid waste are being generated daily of which 65% is collected and disposed into a dump site. Another 10% of the waste is composted and recycled while the remaining 25% is dumped into open spaces, ditches and water bodies (Chekole 2006). In addition to solid waste, domestic wastewater is a major contributor to water pollution in Addis Ababa. The final impact of pollution is manifested in an increased health risk due to exposure of humans and animals to polluted waters, soils and crops. For Addis Ababa, it is difficult to quantify the impact of water pollution on human health. Health risks for consumers of wastewater irrigated crops would still be low since the individual amount of vegetable intake is still low. However, dietary habits of the urban community are said to have changed in recent years (Itanna 2002). This, in turn could change the burden of health risks associated with the consumption of these vegetables.

Further downstream, the Akaki River flows into the Aba Samuel Lake, approximately 30 km from the city centre (Figure 33). Kebede (2008) argues that this lake functions as a natural treatment plant where organic pollutants are broken down and heavy metals settle down and accumulate on the bottom of the lake. Another impact is the degradation of wetlands downstream of Addis Ababa. Some small wetlands have decreased in size due to the construction of dams for power generation. The most visible sign of wetland degradation is changing land use due to the expansion of agricultural lands (Taddesse *et al.* 2006). The above described alterations are likely to continue with further growth and expansion of Addis Ababa. Stronger institutional capacities and a more stringent and effective regulations regarding pollution control could minimize a further degradation of the environment.

6.7 FINAL COMMENTS

Addis Ababa represents a case where many of today's urban water issues emerge. The city is water stressed, and shows typical related symptoms, such as low average per capita water availability (25 lpcd for households) and a large chronic gap between formal supply and demand (69%). The historical analysis showed that in some periods in history, water availability was probably better. In time, the number of sources of water supply has increased and water supply has increase more than tenfold since 1950. When Addis Ababa was founded, shallow hand-dug wells and springs provided sufficient and clean water to its small population. Nowadays, water is supplied from three large reservoirs and a well field system located tents of kilometres away from the city centre. Ambitious plans have been made, to tap additional water from the neighbouring Abbay basin, which reflects both that supply needs a major boost and that local sources have been exhausted.

While the city's population is growing fast, the water supply authority is in need of expanding current supply. While many project proposals have been developed, funding is an issue. The financial structure is not strong enough to execute large scale infrastructural projects without external support. The analysis of water demand has shown that supply will need to be increased greatly in order to meet any scenario for water demand. The basin level analysis indicated that current city water use and future scenarios for urban water use do not significantly impact water availability or agricultural water use in the Abbay and Awash basins.

Downstream of the city, other issues have emerged as a consequence of Addis' expansion and growing water consumption. While most industries dispose of their effluents into nearby drains flowing into the Akaki Rivers, the same water is reused in irrigated agriculture quite extensively. Besides general environment degradation, this type of urban agriculture has entailed health risks to both farmers and consumers of vegetables grown with wastewater.

7. DISCUSSION

This chapter discusses the results of the three cases studies by cross-comparison and evaluates the different research tools applied. The main similarities and differences found between Accra, Addis Ababa and Hyderabad will be discussed in greater detail here. Particular reference will be made to the identified drivers to urban development. This chapter focuses on to the main research objective; to develop and validate a mix of effective research tools that investigates the urban water balance of fast growing water-stressed cities in developing countries.

7.1 INTRODUCTION

The cities presented in the case studies share a number of characteristics that are common for urban water systems in water stressed cities in non-industrialised countries. The management of the urban water system and physical environment in which cities are embedded were found to be detrimental both to the current state and to likely future development paths of the cities. The financial and institutional aspects of urban water management are also areas with critical limitations. From a physical environment perspective, challenges exist in dealing with rapid demographic growth coupled with the availability and vulnerability of water resources for urban water supply. These findings will be discussed further throughout this discussion chapter.

Even though the cities are located in very different geographic regions of the world, they do share a few features that are typical for fast-growing water-stressed cities in non-industrialized countries. All three cities can be considered metropolises that are experiencing fast population growth and physical urban expansion caused by natural growth and migration from rural areas. The cities are impressive by way of size of population, but also the rapid spatial expansion (currently ranging between 540-750 km^2 for the 3 cities). The historical analysis has shown that population growth is one of the key drivers to urban development in the cities. The cities' urban water systems are supply-driven and, in relation to this, there are structural shortcomings to meet rising urban water demand which can be considered another driver to urban development. Typical high fractions of unaccounted-for-water (35-55%), which undermines the financial capacities of the water supply companies. The stormwater drainage system is poorly equipped to deal with stormwater flows, and severe floods strike parts of the cities during events of intense rainfall. Sanitation facilities are generally poor, with a low fraction of wastewater treatment (7-30%) and subsequent large-scale disposal of untreated wastewater into urban water bodies. Low levels of sanitation standards and treatment capacities have been identified as additional drivers to urban development in the cities. Another common feature is peri-urban agriculture, providing a source of income to a significant number of urban households, but introducing additional human-health risks associated with exposure to polluted water used for crop irrigation.

Table 24. Comparative contextual factors for Accra, Addis Ababa and Hyderabad (2005).

Indicators		Accra	Addis Ababa	Hyderabad
Population	No. (millions)	2.9	3.4	6.8
	Growth rate (% yr^{-1})	4.5	3.5	5.0
Built-up area	km^2	750	540	600
Location	-	Coastal	Inland	Inland
Average rainfall	mm yr^{-1}	807	1,055	805
Supply-demand gap	%	55	69	56
Actual domestic water use	l cap^{-1} d^{-1}	55	35	80
Unaccounted for water	%	55	35	40
Wastewater treatment capacity	% of volume generated	7	30	23

Sources: based on data presented scattered throughout the results chapters; chapter 4 for Hyderabad, chapter 5 for Accra, and chapter 6 for Addis Ababa.

The geographical location of the city in the water basin is found to be an important factor which influences the way water flows are managed within and downstream of the cities. In this respect, coastal Accra differs from inland Hyderabad and Addis Ababa. The ocean south of Accra is polluted by large-scale disposal of wastewater and outflows of several polluted lagoons; a common phenomenon for coastal cities in the West African region (Scheren et al. 2002). While in Accra, the outflows from inland waterways are discharged into the sea, in

Addis and Hyderabad, they serve the purpose of agriculture downstream of the cities due to availability of land. Another consequence of Accra's coastal position is that much of the groundwater, especially in low-lying parts of the city, is too saline and therefore not appropriate for domestic use. With reference to water availability for urban extraction, differences exist in the level to which water resources are both available and vulnerable (section 7.6).

As noted earlier, the cities also reflect similar characteristics for the way urban water is being managed. Planning is generally poor and there is a chronic financial gap in funding for improvement and up-scaling of water supply and distribution as well as wastewater treatment infrastructure.

Analysis of post-1950 growth patterns of the three cities shows fast population growth due to migration from rural areas in addition to natural growth, which is confirming general international reports (UN 2004; UNFPA 2009). While Hyderabad hit the million-mark around 1950, it took Addis Ababa and Accra another 25 and 35 years, respectively, to reach this number (Figure 41). Accra and Addis Ababa have projected growth rates that are considerably higher than their historical rates. While Hyderabad's population is expected to triple in the 40-year period from 1985 to 2025, Accra's population is expected to triple in a 15 year shorter period, during the 25-year period spanning 2000-2025. In that same period, Addis Ababa's population is expected to double. It is anticipated that Accra's population number is projected to overtake Addis Ababa's population around the year 2015. This is due to Accra's higher projected growth rate projected up to the year 2030. The projected annual growth rate for Accra is 5.5% versus 3.8% for Addis Ababa during the period 2005-2010, and respectively 4.8 and 3.1 during 2010-2015 (UN-Habitat 2008c). It is emphasised here that the population numbers presented in Figure 41 should be interpreted with caution, due to the inaccuracies entering these estimations because of the unclear definitions of urban boundaries (see section 2.2.3).

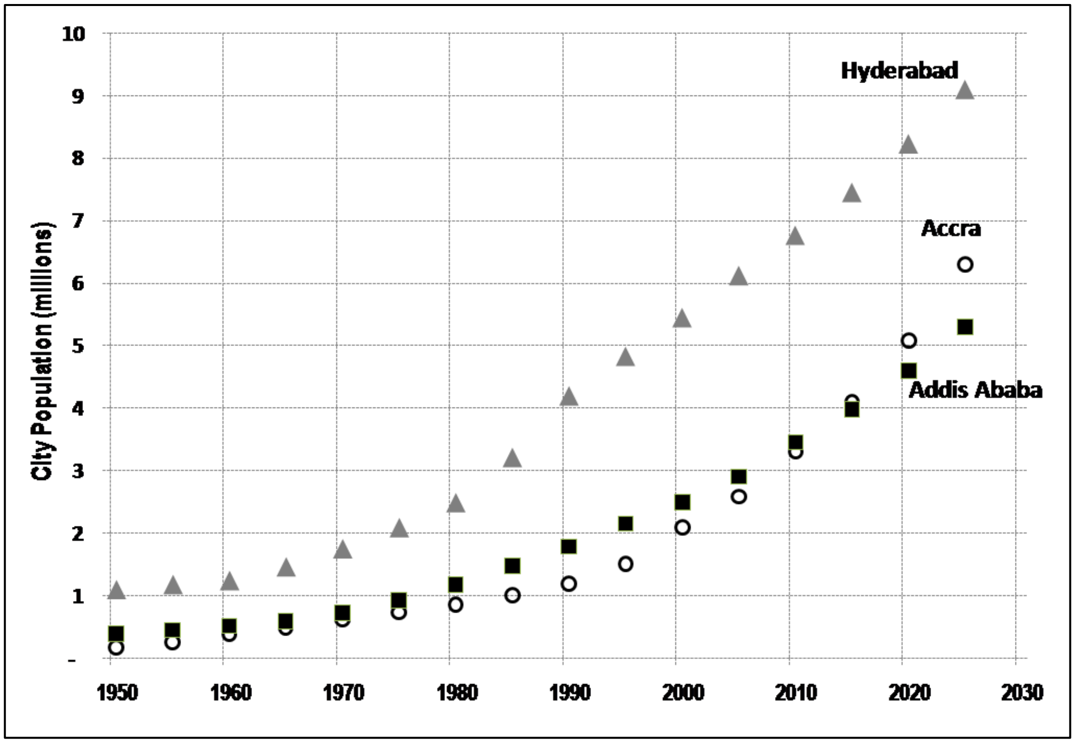

Figure 41. **City population of Accra, Addis Ababa and Hyderabad during 1950-2025.**

Source: **(UN-Habitat 2008c)**

All cities can be considered economic engines of the country [Accra and Addis Ababa] and state [Hyderabad], which can partly explain rapid population growth experienced in the 3 cities. Economic growth has attracted population from rural areas to settle in the cities. Economic growth also contributed to a change in individual demands as a result of an average rise in standards of living, as illustrated for example, by rising per capita water demands. Economic growth would also in theory bring increased tax revenue for investments in water supply and wastewater infrastructure.

7.2 TEMPORAL DEVELOPMENT OF URBAN WATER SUPPLY AND SANITATION

This section analyses the development patterns of urban water supply and sanitation infrastructure as observed in the cities. The discussion corresponds to the first research objective, outlined in the introduction and methodology chapters.

Over the past 60 year period of investigation, all cities show a similar temporal pattern of a supply-driven system for both water supply and sanitation services. Water supply capacity was upgraded and expanded at least every ten years, in order to keep up with rising urban water demands. Improvement of sanitation infrastructure and services occurred at a much slower pace. The reason for this slower pace is the inability on the part of the respective authorities, to give priority to the sanitation issue, which confirms findings in literature (Bahri 2009, Lane 2008, UN-Habitat 2008).

Little data was available to quantify the full scale of groundwater withdrawal and it was therefore difficult to estimate the quantities and consequent share of groundwater in total city water supply. Nevertheless, when observing official data, it can be concluded that urban water supply to Accra and Addis Ababa shows a tendancy towards less dependency on groundwater versus surface water. Accra and Addis Ababa showed a reduction in groundwater share from respectively 65 and 80% (in 1950) to 0.5 and 27% (in 2000) of total supply to the cities. For Hyderabad, reliance on groundwater went up in that same period from 6 to 14% but is expected to reduce to 9% in 2030 because of their reliance on surface water sources which have always been the dominant source of water supply to Hyderabad. This is partly due to the evident large availability of surface water sources, compared to groundwater. Literature indicates that water supply to all three cities shows a shift in the use from groundwater to surface water sources (Patterson 1979; Chettri and Bowonder 1983; Kebbede 2004; Bohman 2010). Water sources for the urban dwellers also moved from individual and informal groundwater sources (springs, wells) to organised supply from surface water sources (Table 25). The steep reduction of water supply from groundwater in Accra can be explained by a general deterioration of its quality, especially in the more densely populated parts of the city. In Addis, reliance on groundwater reduced as well, however this is due to the successful exploitation of new surface water sources, rather than a deterioration of the water quality of its groundwater as is the case in Accra.

Table 25. Share of groundwater sources in urban water supply.

Year	Accra	Addis Ababa	Hyderabad
1950	65	80	6
2000	0.5	27	14
2030	0.4	8	9

***Sources*: calculated, based on time series for water supply (see appendix D-F)**

It can be observed that wastewater treatment capacities for urban water supply in the three cities have not been upgraded in parallel with growing wastewater volumes generated (Figure 42). This pattern is reflected in both the growing volumes of untreated wastewater volume and the relatively small gains in expansion of wastewater treatment capacity in the cities. When analysing expansion of the sewerage system, it is being noted that during the past 60 years, a relatively small fraction of the urban area was sewered as a result of just a few sewerage expansion projects carried out in the 3 cities. On-going urban expansion has kept the sewered fraction of the urban area small in the 2 African cities (5-10%) and substantial in Hyderabad (41%). Grey water generated in kitchens and bathrooms is mostly disposed of into gutters and stormwater drains where a part is lost through infiltration or evaporation unless it enters large canals or streams. Black water from toilets either flows away from the site (through sewerage or stormwater systems) or remains on site (in pits or septic tanks). Wastewater that remains on-site infiltrates into the soil and evaporates or is eventually removed when septic tanks are emptied. In Addis Ababa and Hyderabad, septic sludge is disposed of in corresponding treatment plants, where most of the water evaporates, while in Accra nearly all is officially dumped into the ocean.

Wastewater treatment is currently limited compared to the volume of wastewater generated. It can be concluded that even if existing plans for expansion of wastewater treatment are realised, there will not be enough capacity for full treatment in 2020 (Table 26; Figure 42). There is a substantial increase expected in the generated wastewater volume (due to planned increases in water supply), but only a modest increase in the potential treated fraction. The untreated wastewater volume will actually increase in Addis Ababa and Accra. In contrast to the African cities, untreated wastewater volume will reduce by half in Hyderabad. However, a reduction of the volume of untreated wastewater can only be accomplished if the authorities in all the cities are able to meet targets for planned expansion of wastewater treatment. This is an important lesson to take into account for the planning and management of the urban water system. It should also stimulate local planners and policy makers to rethink strategies on how best to deal with residual water flows in their cities.

Table 26. Wastewater generation and treatment in Accra, Addis Ababa and Hyderabad for 2008 and 2030 (within brackets – planned)*

		Accra	Addis Ababa	Hyderabad	Source
Wastewater generation	$1,000\ m^3d^{-1}$	225 (307)	130 (453)	585 (807)	Section 3.3.4, equation 5
Installed treatment capacity	$1,000\ m^3d^{-1}$	16 (29)	39 (238)	133 (590)	(NEDECO 2002b; AfDB 2005; GHMC 2005)
Wastewater treatment fraction	%	7 (9)	30 (53)	23 (73)	Section 3.3.4, equation 6
Untreated wastewater volume	$1,000\ m^3d^{-1}$	209 (278)	91 (215)	452 (217)	Section 3.3.4, equation 7

**Figures are calculated based on current and planned urban water supply.*

Compared to no treatment in the past, the gradual increments in wastewater treatment capacity as a result of several expansion projects can be considered as a good achievement. However, when wastewater treatment is expressed as a percentage of the volume of generated wastewater, it is not impressive. In Accra, the one Sewerage Treatment Plant (STP) built in early 2000 was able to treat 3% of the wastewater generated at that time. The proposed expansion of capacity beyond 2020 is likely to treat up to 9% of the wastewater volume to be expected by then. As can be observed in Table 26, the situation is more positive for Addis Ababa and Hyderabad where respectively 50% and 70% of the wastewater can be treated in 2030, compared to 30% and 20% currently. The reason for these lower figures for Accra could be the lack of political will and insufficient priority given to the upgrading of existing wastewater treatment facilities.

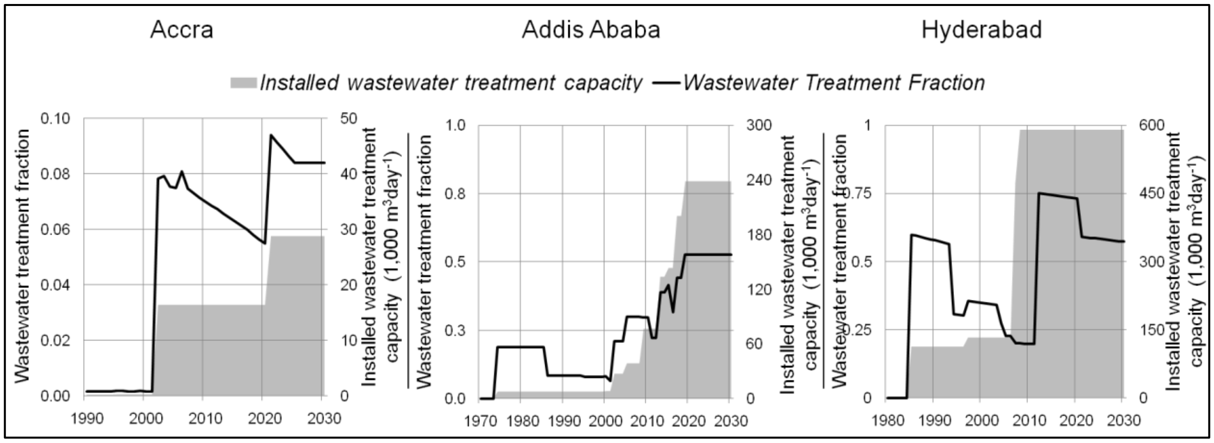

Figure 42. Installed treatment capacity and wastewater treatment fraction for Accra, Addis Ababa and Hyderabad, during 1950-2030.

Source: results are derived from (NEDECO 2002b; AfDB 2005; GHMC 2005) for installed wastewater treatment capacity, and equation 6 (section 3.3.4) for wastewater treatment fraction.

The decline in treatment fraction in Hyderabad during 1985-2005 was mainly driven by the increase of the wastewater volume (as a result of increasing water supply), while the installed treatment capacity only increased slightly. When interpreting **Figure 42**, it should be noted that the 'Installed wastewater treatment capacity' does not represent actual treatment. Based on own observations and expert opinion, it can be said that some wastewater treatment facilities are no longer in operation. Some of the reported reasons for this are the lack of spare parts to fix facilities with breakdowns, insufficient wastewater inflow to run the plant, and intermittent power supply.

Typical environments of scarce and poor historical records were encountered during data collection in Accra, Addis Ababa and Hyderabad. The main tools applied to reach the first research objectives were historical analysis together with semi-structured interviews. The assessment of published and grey literature was cross-checked with information provided from field experts through the interviews. In cases where literature was found to be unreliable or unavailable, information from experts was considered as complementary. Especially the combination of tools was found to be extremely effective for this type of research. Experience in using the various tools is discussed at the end of this chapter.

7.3 URBAN WATER DEMAND SCENARIOS

The case study results point out that future urban water demand is mainly driven by population growth and changes in per capita domestic water demand. On-going industrialisation in the cities and its impact on city water demand is largely unknown. However, it is likely to push urban water demand further up. In cities that are already water stressed, a growth in industrial activity may threaten water supply to households, since priority by water supply companies is often given to industries (Molle and Berkoff 2006, UNDP 2006) . "*In many developing countries, industry is effectively taking advantage of weak local water governance; passing liability for demand-side considerations either to already overburdened local utilities or to local communities and water users"* (UNESCO 2003)

The analysis confirms for all three cities that water demand is constrained by supply which is a good indicator of city level water stress. Currently just 55, 69 and 56% of demand, in Accra, Addis Abba, and Hyderabad respectively, is met by supply. In the low-income section of the population, water-demand management options do not seem feasible since water consumption is low and water is already being used wisely (van Rooijen *et al.* 2008). The high-income section of the urban population could reduce water usage to some extent, through a change in consumption behaviour. Furthermore, the rotational system of supplying water, limits the supply to the richer areas of the city as well, and limited storage volumes impose economic water use even in these areas.

It is clear that water supply will need to be expanded more regularly and drastically, particularly for Accra, to address the widening gap between supply and demand. In the case of Accra, this will depend on external donor assistance to carrying out these expansions. However, what happens in Addis Ababa and Accra in case water supply flattens out in the coming years? Would economic development in the cities be affected by water scarcity? On the other hand, a further escalation of water stress and its impact on society and the environment may urge authorities and donors to give more priority to investments in the urban water sector.

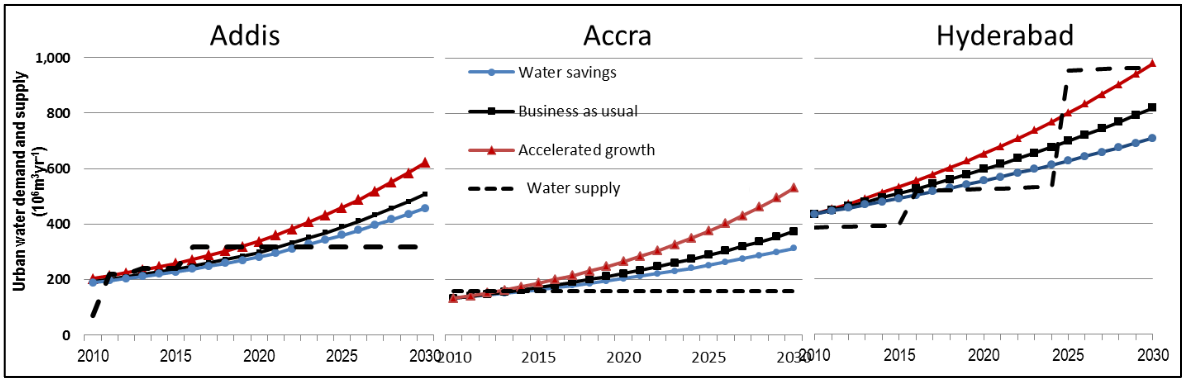

Figure 43. Water supply and projections for water demand for Accra, Addis Ababa and Hyderabad during 2010-2030.

The three curved lines in all three cities represent projections for water demand, based on the three generic scenarios for urban development. The dashed line in each chart represents planned water supply except for Accra where only current water supply is shown as a horizontal dashed line.

Sources: collected data; respective data are found in appendix D-F.

Indeed, will the major water supply expansion projects planned for Addis Ababa and Hyderabad still be inadequate to meet demand beyond the time frame of investigation, if the cities continue to grow further at similar rates? There is also scope for demand management at the utility level (Kayaga and Smout 2006; van der Steen and Howe 2009). Reducing physical losses and illegal connections has been mentioned by the water utilities of the cities as a good strategy to reduce urban water stress. However, it can be questioned whether such measures will effectively reduce or even control the persistent and widening gap between urban water demand and supply in the investigated cities.

The assessment of the water balance and prediction of water demand in the cities was carried out using a combination of three research tools as was originally designed (Figure 6). The applied tools are; semi-structured interviews, scenario development and urban water balance modelling. The semi-structured interviews supplemented and completed information generated from the scenario development and urban water balance modelling. The combination of quantitative and qualitative research methodology applied in the city case studies, proved to be very appropriate to gain a good understanding of the scenarios for urban development and their influence on future water demand.

7.4 WASTEWATER USE IN AGRICULTURE

This section discusses the results on the use of wastewater in irrigated agriculture presented earlier in this thesis for Hyderabad (section 4.5), Accra (section 5.5) and Addis Ababa (section 6.5). The discussion is centred around the potential of wastewater reuse in the cities, with reference to the identified drivers to urban development.

Irrigated agriculture in the cities is practised informally on plots of 1.5 ha or less, with marginal water that is generated in the urban area (Table 27). Hundreds of farm households within and downstream of the city (except for Accra in the latter case) grow mostly vegetables with this water discharged by the city and its residents. These areas of crop production along drains and rivers receiving wastewater, contribute to the open spaces in cities where built-up areas with impermeable surfaces are rapidly expanding.

Table 27. Characteristics of irrigated urban agriculture with wastewater in Accra, Addis Ababa and Hyderabad.

Irrigation characteristics	Accra	Addis Ababa	Hyderabad
Crop types cultivated	Vegetables	Vegetables	Paragrass, rice, vegetables
Common irrigation method	Watering can, seldom furrow irrigation	Flood and furrow irrigation	Flood and furrow irrigation
Average plot size (ha)	0.05	1.0	1.5
Irrigation schemes	None (hand-made high beds)	Hand-made channels and furrows	Partly; pumping stations, channels, tanks
Water storage facilities	Dug-outs, sand-bag dams	Small ponds, self-made dams	Check dams in river, large ponds (tanks)
Sources of water	Drains, streams, river	River, streams and drains	River, tanks
No. of irrigating farm households	800-1,000	1,300	Not determined
Irrigated area (ha)	100 (in the city)	1,240	100-500 (in city), 8,000 (downstream)
Vegetables on city markets from these areas (%)	60-90% of easily perishables	90% of easily perishable, 60% of others	< 5% of all

Source: The data are presented in the result chapters; section 5.5 for Accra, 6.5 for Addis Ababa and 4.5 for Hyderabad. A similar table was published in van Rooijen et al. (2010).

In the case of Hyderabad, the large irrigation schemes downstream of the city actually contribute towards improvement of water quality (Ensink *et al.* 2010) (Figure 17). This urban and peri-urban farming provides many households with their main source of income and accounts for the major part of vegetables sold on the urban markets in Accra and Addis. Findings from literature on all cities confirm that urban farming is an important source of livelihood to portions of the population in the cities, and contributes substantially to the urban food market (Scott *et al.* 2004b; Drechsel *et al.* 2010).

Irrigation water from drains and rivers contains a mix of stormwater, grey and black wastewater and groundwater. The year-round nature of wastewater disposal in cities provides farmers with a dependable water source and allows for multiple cropping seasons. However, a large fraction of the wastewater generated in cities, which is a potential water source for agriculture and other uses, still remains unused. An estimated 13 and 20% of the annual volume is being used in agriculture in Accra and Addis Ababa, respectively. In Hyderabad, the fraction is much higher with an estimated 90% of water disposed of in the city being used for irrigation (Table 28).

Table 28. Wastewater production and use in Accra, Addis Ababa and Hyderabad for 2005.

		Accra	Addis Ababa	Hyderabad
Total wastewater generation	10^6 m3yr^{-1}	80	49	213
Industrial wastewater	10^6 m3yr^{-1}	9	4	37
Wastewater use in agriculture	10^6 m3yr^{-1}	10	9	192
	% of total generated	13	20	90

Sources: total wastewater generation calculated with equation [5] (section 3.4). Time series for water supply derived from AVRL (2006) for Accra, Kebede (2008) and Asfaw (2007) for Addis and HMWSSB (Unpublished) for Hyderabad. Figures for industrial wastewater were derived from volumes of water used by industries from records from the respective water utility, using a water return fraction of 0.8 for all cities based on Tchobaoglous and Schroeder (1985). Figures for wastewater use in agriculture were derived from Lydecker and Drechsel (2010), for Accra, Adebaw (2008), for Addis Ababa, and van Rooijen et al. (2005) for Hyderabad.

The future of irrigated agriculture in and around the focal cities is influenced by various factors, most notably availability of land, water and the influence of industrial effluents on this water sources used in irrigated agriculture. In the case of water, both the availability and the quality are important. In a fictitious future scenario where all wastewater generated is being collected *in situ* in septic tanks or a sewerage system, there would be significantly less water available for farming in central areas of the city while urban fringe areas may benefit from their vicinity to new locations for wastewater disposal. On an annual basis there would be much less water flowing in the rivers and streams serving as irrigation sources, and hardly any water in the dry season. Van Rooijen et al (2005) calculated for Hyderabad that the annual volume of wastewater has the same order of magnitude as the volume of stormwater generated in the city. In Accra wastewater is less than half of stormwater run-off. The water balance was not done for Addis Ababa. Based on the analysis of sanitation infrastructure development in the cities, a major change in the current pathways of wastewater disposal is not to be expected in the coming decades.

The second factor of major importance to wastewater reuse in agriculture is the availability of land. Urban agriculture is a dynamic process that seems to be driven by urban development and land use change in growing cities. It can be observed that urban agriculture is practised mostly in the urban fringe areas and, therefore, moving away from the city centre as the urban area is expanding and otherwise open or unbuilt land is converted (Buechler and Mekala 2005; Cofie and Drechsel 2007).

A third factor is the development of industries and industrial activities of those industries that consume water and dispose of wastewater in the cities. When observing current water consumption, all cities have a low share of industrial water use, resulting in marginal volumes of wastewater relative to the urban water balance. In all cities urban wastewater is mainly of domestic origin (Table 28). However, the city cases also brought to attention that certain levels of toxic components in untreated industrial effluents may entail harmful levels of contamination of the environment. Therefore, the sustainability of farming will depend on the laws and regulations with respect to the control of industrial pollution and quality of the agricultural products, and more importantly the extent to which these are being enforced. Finally, much will depend on the legal status that will be given to urban farming in future municipal land use plans and policies.

The holding of semi-structured interviews in conjunction with field visits provided a very good understanding of the current state of wastewater irrigated agriculture in relation to the urban water balance. Based on findings from interviews and own observations scenarios could be developed with inputs from the urban water balance modelling. The modelling enabled quantification to some extent, of the potential scale of wastewater irrigated agriculture. The qualitative part provided information on the issues around it in the areas of human health, environment, policy, public perception and farmer livelihoods.

7.5 BASIN-LEVEL INFLUENCES OF URBAN WATER USE

This section discusses the general findings for the cities in relation to basin water availability and contributes to the fifth research objective. The city case studies confirm a general pattern of increasing influence of the urban water balance, upstream and downstream of the urban area in terms of water quantity and water quality. This main finding will be discussed in relation to existing literature.

Upstream impacts of urban water use

The city's level of dependency on the basin was assessed by examining the location of the water sources relative to the city and assessing their contribution to total water supply to the city. The figures on water supply development presented for each city in the results chapters were modified and merged into a single chart (Figure 44). Figure 44 has merely been designed to give an indication of the city's changing geographical dependency on water sources. In this figure the average distance from water source was weighted by the volume withdrawn from each source in order to have the size of withdrawals incorporated (equation 8, section 3.3.4). The results show an interesting difference between Hyderabad on one hand and Accra and Addis Ababa on the other hand. From the year 2000 onwards, Hyderabad shows an extension of its water supply to sources much further away, from an average distance of 20km during 1950-2000, to 140km beyond the year 2020. This trend is not visible for Accra or Addis Ababa, which maintain an average distance of water sources to city of up to 60 and 35km respectively, during 1950-2030.

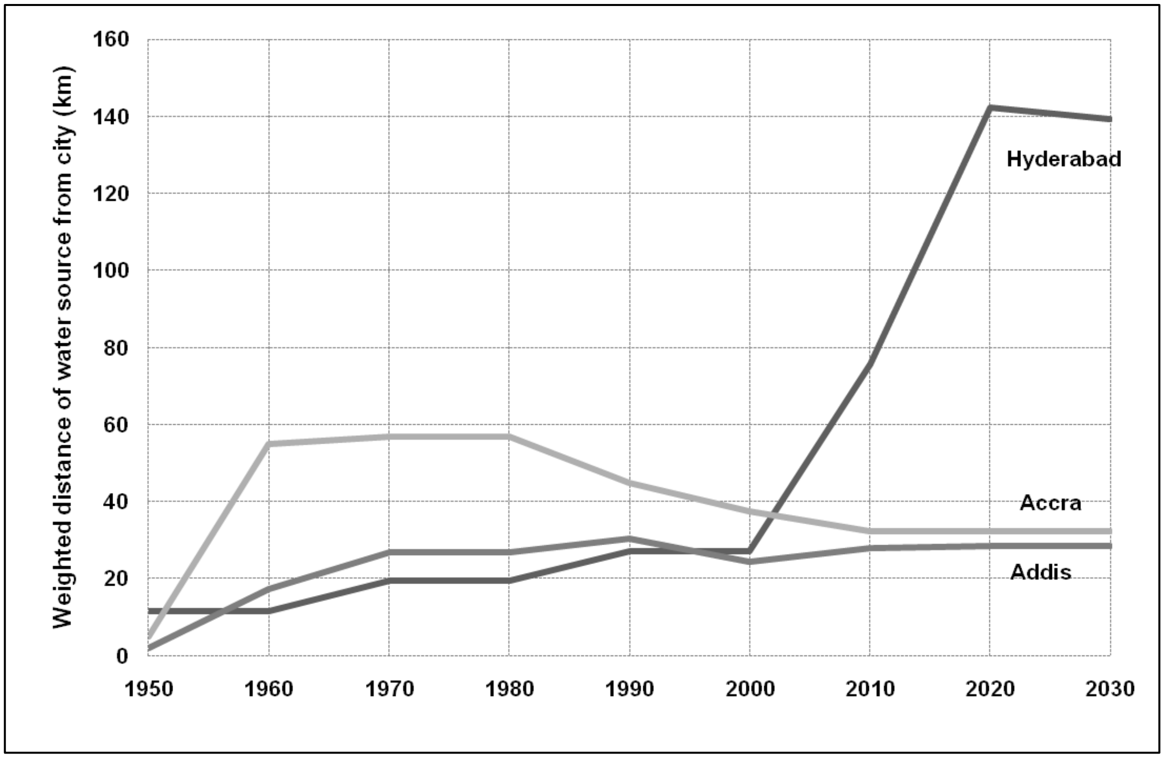

Figure 44. Weighted distance of water source to the city for Hyderabad, Accra and Addis Ababa, during 1950-2030.

Sources: calculated from time series for water supply (see appendix D-F) and equation [8]

The size of water sources in use at a given instant dictates how soon and how far a city will have to source its additional water, as the needs expand. On the one hand, Accra started water supply from the Volta Lake in 1960, which can potentially provide all of Accra's water needs, given its dimensions. It is therefore not expected that water will be sourced from elsewhere. Addis Ababa never needed to go beyond the 30 km distance in search of new water sources. This is due to its favourable location close to the water-generating Entoto Mountains and the adjacent Abbay Basin. In contrast, Hyderabad shows a clear temporal and spatial pattern of divergence further away from the city (Van Rooijen 2005). The huge jump away from the city is caused by the massive expansion projects to supply water from Krishna and Manjira rivers. With rising water demand, the increasing dependence of cities on water sources further away has also been termed as the *urban water gradient* (Scott 2010). The results confirm findings of Molle and Berkof (2006) and Showers (2002) that the geographical expansion of urban water sources is determined by the geography of the basin, climate and financial capacity of the water supply authority. It may be difficult to compare the weight of each of these determinants. The development trajectories of cities in relation to their water sources will be further discussed in section **Error! Reference source not found.**, taking into account the vailability and vulnerability of urban water resources.

The impact that urban water use has on agriculture is different downstream of the city compared to its upstream area. Upstream changes in inter-sectoral water allocation to the benefit of cities can affect agriculture. However, none of the city case studies have shown any such indication. This is because the water sources in use by the cities are not yet fully allocated due to their large size. However, changing land uses upstream of the cities and climate change are drivers that may put the sustainability of all water uses in the basin at risk.

The city case studies show no evidence of large-scale impact on irrigated agriculture where water sources are being shared. The urban water balance modelling has proven to be a useful tool to investigate cities influence on upstream water resources

Downstream impacts of urban water use

In the literature review (chapter 2), downstream impact was defined as any impact the urban water balance has on downstream water users and the environment. The findings of this research confirm that the downstream impacts of the cities studied are centred mostly on the pollution aspect. Pollution has led to increasing human health risks and environmental degradation. This process is on-going in all cities.

The results of the case studies point out that a significant group of farmers is benefitting from the secure water flows leaving the city by storing and using it as a source of irrigation water for growing crops for the local food market. It is being debated whether this practice should be promoted or forbidden, since urban agriculture also holds health risks when polluted water is used. The reality is that irrigated agriculture with marginal water in and around cities is a widespread practice in developing countries providing income to large numbers of households (Scott *et al.* 2004a; Raschid-Sally and Jayakody 2008). However, health risks can be mitigated with simple and low-cost risk-reduction measures at the farm, market and household stages (WHO 2006; Drechsel *et al.* 2010).

In Addis Ababa and Hyderabad, the area downstream of the city was already used for irrigated agriculture since the 1960's, before the cities had even started their growth spurt. At present, farmers in the vicinity of the city are confronted with changes in the availability and quality of water for irrigation. Farmers benefit from secure year-round run-off due its high input of urban wastewater. In all cities the present wastewater generated in the cities is mainly of domestic origin and largely contains organic compounds. Coastal Accra has raised pathogen levels in the water on some beaches with local damage to the marine environment (Lunani *et al.* 2008). Differences also exist between Hyderabad and Addis Ababa. Hyderabad has a large-scale irrigated area with irrigation infrastructure in place, downstream of the city. This irrigated area has been growing in parallel with, and in response to, growing wastewater volumes generated in the city. Addis Ababa has less-extensive farming areas than Hyderabad but it is nevertheless significant in scale. In both cities it had been observed that there are alterations in water quality due to the disposal of urban effluents, up to 40 km downstream of the city.

The downside of large volumes of untreated wastewater being available in cities is a health risk due to exposure to (fairly unknown) levels of chemicals (in particular for Addis Ababa) and exposure to pathogens (for all cities) present in the water.

A key factor that determines the sustainability of irrigated agriculture in and around cities is the level of industrial pollution control. Industrial pollution cannot be controlled by the farmers and poses a serious threat to the sustainability of irrigated agriculture. Control means proper treatment in situ, done by the respective industries that generate the effluent. It also means keeping industrial effluents separate from the main sources in use by the farmers. In the case of Hyderabad, a large industrial area named Patancheru is currently disposing its industrial wastewater into a separate and isolated catchment (Shivkumar and Biksham 1995). In the future, it is possible that industrial effluents from this area will be connected to the Musi Basin. The industrial area at Patancheru has been named one of the most polluted places on earth (Crosette 1991). The environmental concern of pollution of urban water bodies in association with reuse has been raised by authors for all cities (Mensah *et al.* 2001; Gerwe 2004; Melaku *et al.* 2004). However, not much research has been done on the contamination of soils and crops.

It can be summarised that a general pattern exists for the urban water balance creating a growing downstream footprint when the city is located inland. This process has been termed the *inverse implication of the urban water gradient* (Scott 2010). The tools of urban water balance modelling and scenario development has proven to be a powerful methodology to gain insight into general patterns and scales of wastewater flows generated from cities.

7.6 WATER DEVELOPMENT FRAMEWORK FOR FAST-GROWING CITIES IN DEVELOPING COUNTRIES

This section explores a translation of the case study findings into a generic framework for water and sanitation development trajectories for cities and their impact on basin water resources.

The presented case studies have revealed patterns of the cities interaction with their upstream and downstream areas mainly through urban water withdrawals, disposal of wastewater and stormwater drainage. The analysis has made clear that both demographic and climatic drivers are detrimental for this interaction. The sketch below (Figure 45), visualises the interaction that the urban unit has with the areas upstream and downstream of the city. The city is dependent on water sources that are usually located upstream of the city, such as a river, groundwater (wells), and reservoirs. Within the urban area, the water supply and distribution, and stormwater drainage infrastructure determine how wastewater is leaving the urban unit. Downstream of the city, the urban wastewater eventually ends up in other water bodies with a certain fraction being reused in agriculture (Figure 45). A similar conceptualization was introduced by Lundqvist et al. (2003), who labelled the three areas in Figure 45 (upstream, city, downstream), the three dimensions of water use.

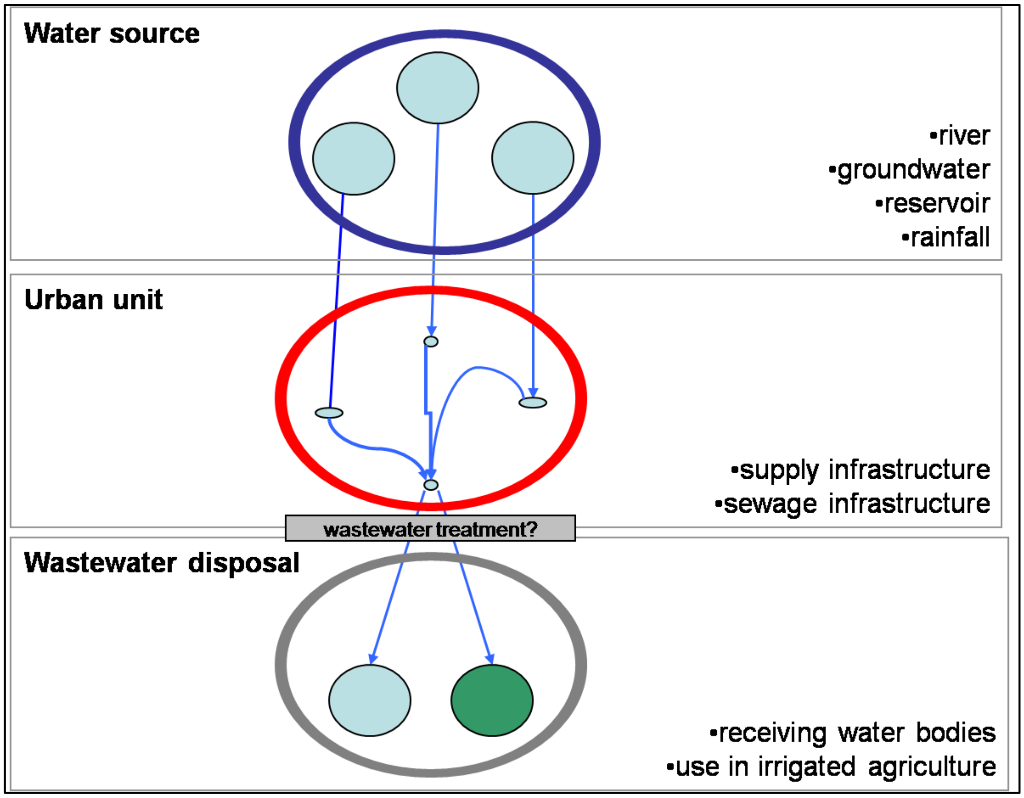

Figure 45. Schematization of the upstream and downstream impact of urban growth on water supply and wastewater generation.

Source: van Rooijen et al. (2010)

As discussed earlier in this chapter, the institutional environment and state of water resources are considered as key factors in the future development of water supply and sanitation to the cities. Relative to each other, the cities seem to be at different levels of institutional development. However, this type of assessment was not explored in depth in this PhD study, being beyond the original scope.

The state of water resources for urban water supply can be placed in different positions relative to each other, using the 2 indicators; resource vulnerability and resource availability (Figure 46). Water resource vulnerability in this context is the relative level to which the available water resources are vulnerable to a deterioration of its water quality and/or a reduction in availability, for example due to competition with other water users or the impacts of climate change. Water resource availability is defined here as the relative level of availability of water resources, without considering technical or economic constrains to extraction from these sources.

The positions of the cities in Figure 46 are not to scale, but are merely shown to give their position relative to each other. The current state corresponds with the year 2010. The arrows shown reflect a time-trace of the pathway of the cities from the past (1950) to the present (2010), to a likely future state (2030). The time-trace is based on the findings of the case studies. Figure 46 serves as a framework to understand the current state of water resources and builds further upon conceptualization of cities in a basin, as done by Molden and Sakthivadivel (1999) and Molle (2003). The framework helps explaining why the cities investigated experience the described urban water issues, such as chronic water shortage.

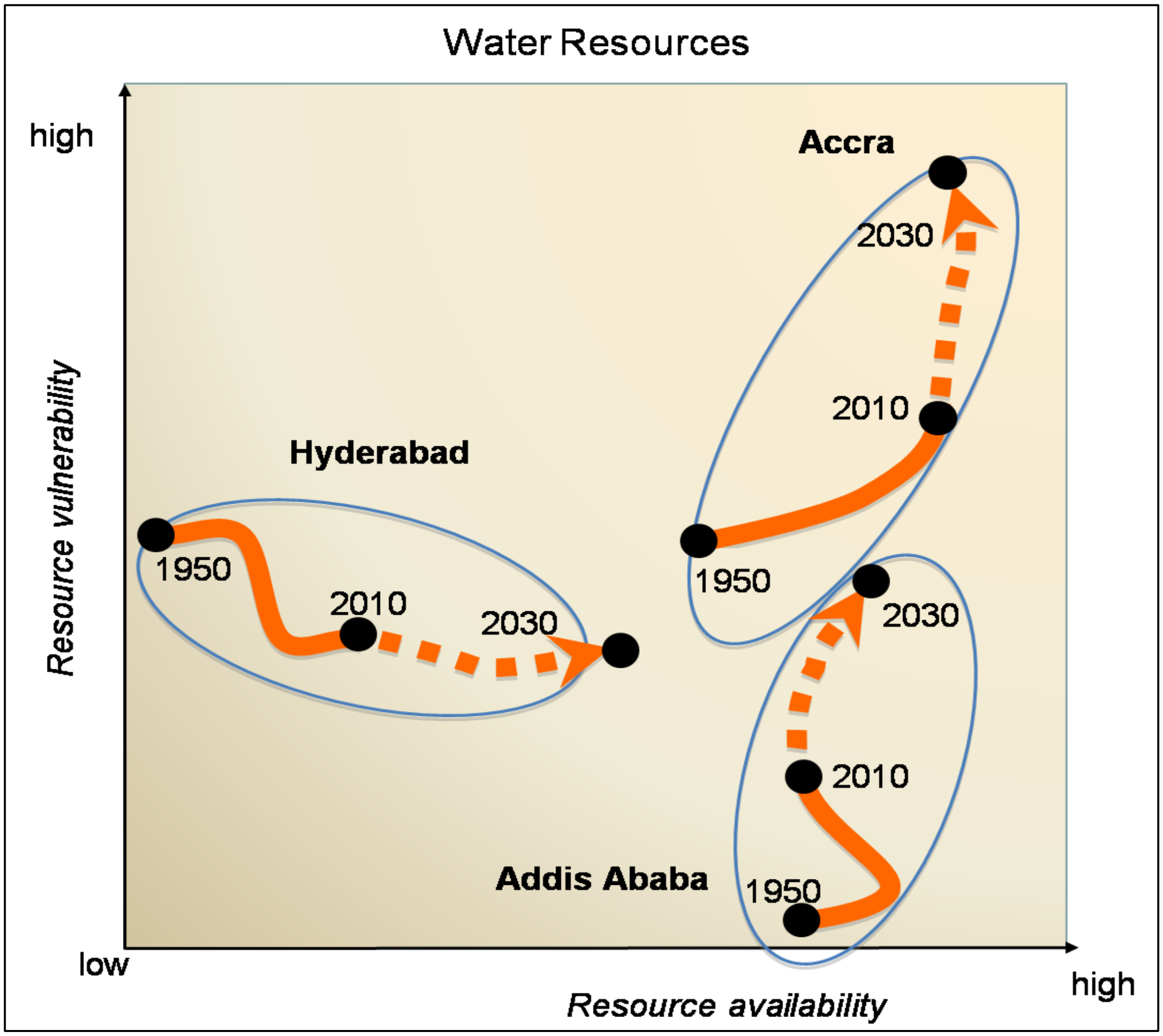

Figure 46. Visual representation of the development pathways of water resources of Accra, Addis Ababa and Hyderabad, during 1950-2030.

The state of water resources is compared for the indicators, resource vulnerability vs. resource availability. The charts are meant to show the state of the cities for the mentioned indicators, relative to each other.

With reference to Figure 46, the state of urban water resources is described first for resource vulnerability and then for resource availability. Regarding resources vulnerability, Addis Ababa currently has the lowest level of vulnerability of water resources however; this has increased since 1950 and will increase further. This is due to upstream catchment development and the impact of siltation on resource vulnerability. Hyderabad has a medium level of resource vulnerability, which is reduced since 1950 and is expected to remain at medium level. Lastly, Accra, like Hyderabad, had a medium level of resource vulnerability in the past (1950), however, vulnerability has increased up to present and is likely to further increase in the future.

Regarding water resources availability, Addis Ababa has a medium level of resource availability which has fluctuated since 1950 and is predicted to remain the same in the future (when additional water resources are tapped into). During 1950-2010, Hyderabad has increased availability of its water resources by tapping into new and larger reservoirs through major infrastructural development that is likely to continue with economic growth. Water resource availability for Accra increased over the past with the tapping from the voluminous Volta Reservoir in the early 1960s. This gave a spurt to water availability. Future water availability for Accra is uncertain; periods of low rainfall and increasing water use may reduce water availability especially in the Densu Basin that drains into the Weija Reservoir.

Climate change is still a largely unknown driver that may affect water availability and vulnerability. The institutional environment of the cities, with respect to urban water management, has not been assessed in enough detail to draw conclusions with sufficient confidence. Based on the results of this PhD, it is recommended that an institutional assessment is carried out, in order to better assess current developments in urban water management in the cities.

Consequences of the urban water cycle: Drivers and impacts

The prevailing water issues in the cities studied can be viewed as part of a cause-consequence-impact diagram (Figure 47) which is the result of a combination of physical constraints and institutional limitations related to the water cycle, described similarly by Niemczynowicz (2000).

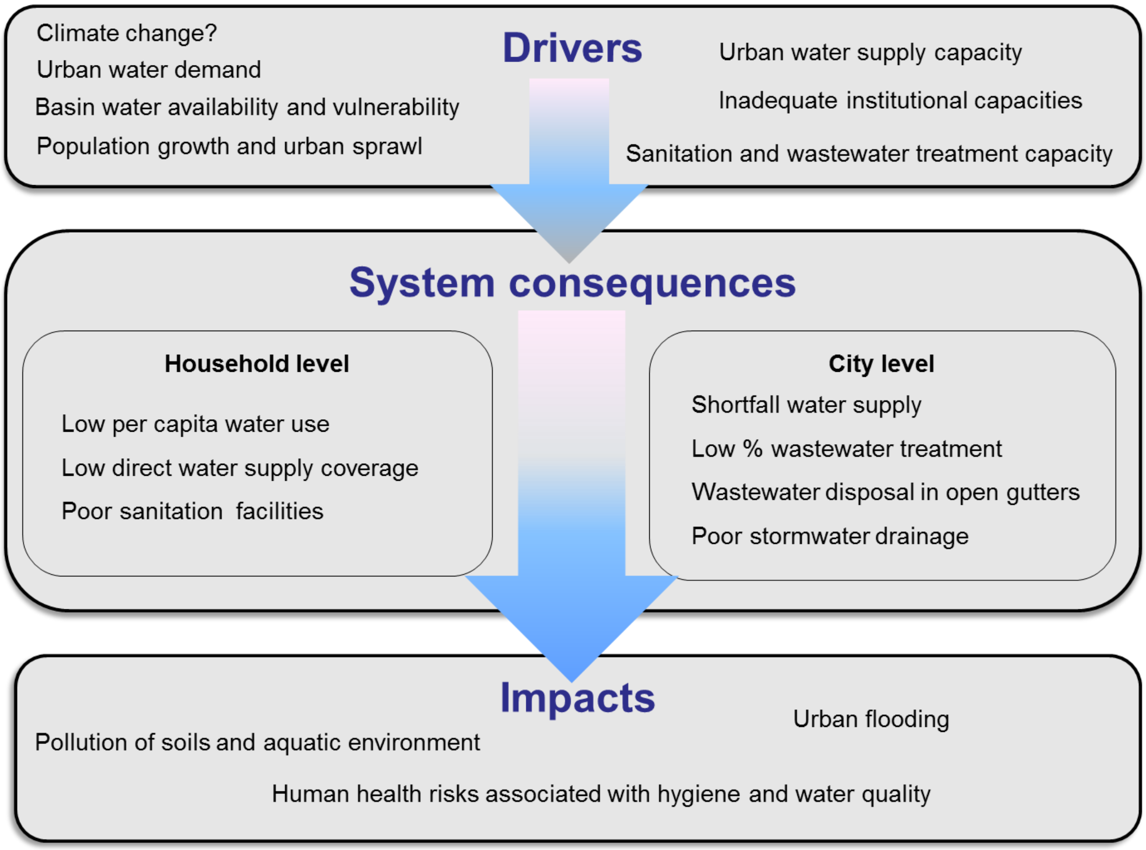

Figure 47. Cause-consequence-impact diagram of water issues in the cities studied.

The driver 'inadequate institutional capacities' goes with the others as interlinked "embedded" processes.

Drivers may or may not originate outside the boundaries of the urban area, both physically and institutionally, and the impacts of these drivers may extend beyond the boundaries of the urban area. For the cities studied, the identified drivers are *urban water demand*, *population growth* combined with *unregulated urban sprawl*, *insufficient institutional capacities*, *and urban water supply capacity*, *sanitation and wastewater treatment capacity and basin water availability and vulnerability*. In addition, climate change is a driver; however, the extent of its impact on urban water management is largely unknown. These identified drivers correspond largely with those drivers identified to generate scenarios for urban development (section 3.3.4). Basin water availability and vulnerability includes climate change as an underlying driving force.

The drivers identified determine the functioning of the urban water system as a whole. As a consequence, water issues are manifested at the household level (*low amount of water supply (lpcd), low water supply coverage (%), intermittent supply, poor sanitation facility*) and at the city level (*shortfall in water supply, low fraction of wastewater treatment (%), wastewater disposal in open gutters, poor state of stormwater drainage system*). These water issues are often being used as indicators to assess the state of the urban water system (see section 2.2). Impacts of these system consequences are reflected at the level of human health and the environment. Human health risks are associated with *poor hygiene and water quality*, *recurring urban flood events*, and *pollution of soils and the aquatic environment*. From an environmental perspective, the aquatic environment (rivers, streams, ocean, etc.) is impacted due to pollution from domestic wastewater. As pointed out earlier in section 7.5, increasing pollution with industrial effluents, currently observed to be low in the cities, may create an additional burden on human health and the environment.

Section 7.5 concluded that the cities show a pattern of a growing water footprint at both ends of the urban water cycle. This pattern can be illustrated in a simplified sketch that reflects the temporal and spatial dimensions of growing cities in a basin (Figure 48). The sketch illustrates the growing interaction of cities with upstream and downstream water resources. Upstream of the city, the number of sources in use for water supply is usually expanded. Over time, water sources are not necessarily located further away from the city. Sometimes, water sources located outside the local catchment are brought online. This largely depends on specific geographical and climatic conditions. The expanding area downstream of the city, simplified as grey area (Figure 48), illustrates the growing impact that cities may have.

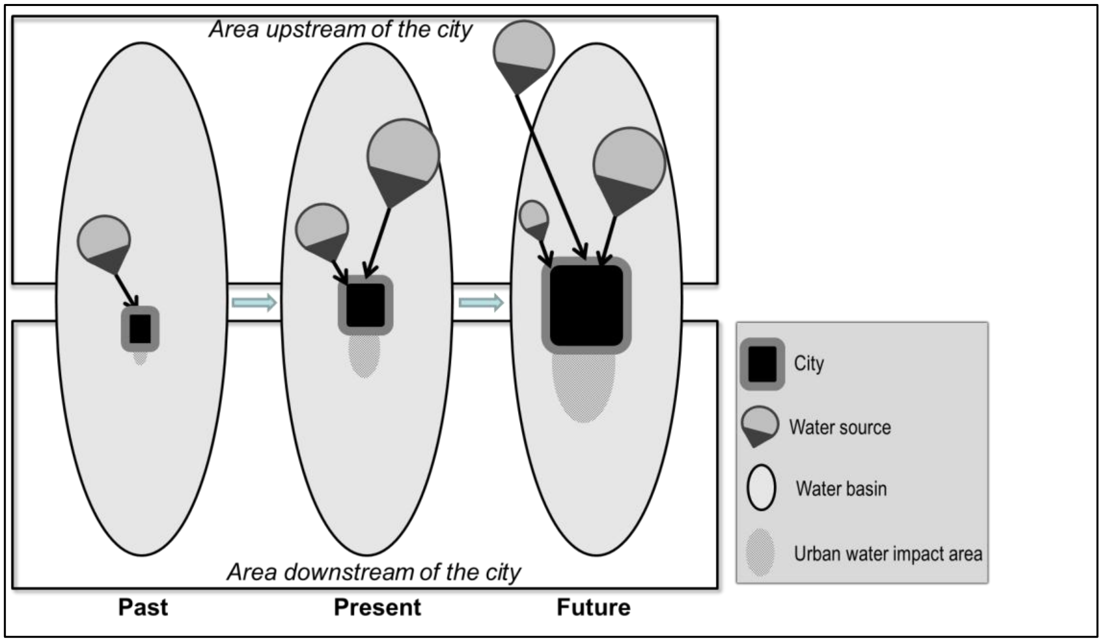

Figure 48. Sketch of the growing impact of urban water use on the upstream and downstream areas.

This section, section 7.6, discussed the results of the combined case studies in order to reach generic findings and to develop a framework for cities in a similar environment and development context. The various tools applied in this research formed the basis for this synthesis and the development of these findings. It was found that cities show clear interaction with areas up- and downstream of the urban area, through water supplies and demands that constitute the urban water balance (Figure 48). Insights were gained on the future scales and impacts of water flows that will result from further growth and development of the cities. The analysis and cross-comparison revealed some general development patterns (Figure 46) and causal processes (Figure 47) that exist for water-stressed cities in a similar context.

7.7 EVALUATION OF THE RESEARCH TOOLS

A combination of tools were applied to investigate the research questions centred around growth and development of water-stressed cities and the implications for water demand, wastewater generation and reuse. As presented in section 3.3, the tools that were applied are:

1. Historical analysis

2. Semi-structured interviews
3. Urban water balance modelling
4. Scenario development
5. Comparative analysis

These five tools were used to contribute to one or multiple research objectives (see Figure 6).

The research design as described in the methodology chapter provided the justification for employing the research tools. The importance of this mix of research tools in order to effectively address the research questions has been highlighted throughout the thesis. While the sub-objectives were derived from actual gaps in research, the main objective is seated on testing an innovative set of research tools. Each tool is evaluated separately in this final section of the discussion.

7.7.1 Evaluation of the historical analysis

The historical analysis carried out in the case studies contributed to gaining a solid understanding of the historical growth and development that cities experienced from 1950 up to its present. Complementary information was sought on the way management of urban water supply and sanitation was done. Findings from the historical analysis, together with information from the semi-structured interviews were found to be extremely useful for understanding the water issues prevailing in the cities of focus. A combination of local and international literature sources cross-checked with results from interviews was used. The historical analysis contributed to answering mainly research question one, however its findings were found beneficial for addressing the other research questions as well.

Two types of difficulties were encountered with this tool. Firstly, local literature was not always availability and of sufficient quality. Secondly, the accessing or obtaining certain literature was found to be difficult at times. Local literature was not always readily available. Often it appeared that documents were only available in hard copy. Sometimes individuals at local organisations who held these documents were not eager to share this information. Data documented in literature sources were often found incomplete, unreliable and inaccurate.

Issues of quality of the data in gathered documents were dealt with by cross-checking information with individuals and international literature. In some cases data or findings from the other case studies were used to verify the quality of data.

Difficulties in obtaining specific local literature from certain locations were overcome by establishing a relationship of trust with the consulted individuals. Often it helped when individuals were met more often. This was accomplished by inviting them to my own office, making new appointments, or through spontaneous meetings at events, such as workshops and conferences. In a single case in Addis Ababa, unpublished data were finally shared after opportunities of co-publishing material were offered. The fact that I was based in the cities for several months up to several years contributed to building formal and informal relationships with target individuals. This, in turn, provided a sufficient level of understanding and trust and enhanced willingness to share data. I found that being based in the city of focus for a prolonged period of time, continuous networking and investing in professional and informal relationships were essential factors for the successful collection of information from local literature. A longer period of fieldwork in the cities would probably have deepened historical analysis

7.7.2 Semi-structured interviews

One component of the data collection during the fieldwork was the holding of semi-structured interviews. The target group for the interviews were individuals who are regarded as professional experts and/or very experienced with water management in the city of the case study. Their information can be considered essential for helping to understand the urban water system and its management. In addition, this helped to contribute to gaining the historical perspective with carrying out the historical analysis.

The semi-structured interviews provided information needed for carrying out the historical analysis, modelling, and scenario development. As discussed in the previous sub-paragraph, individuals were not always eager to share information. The fact of being a student sometimes received less interest to some individuals to share time for an interview. Interviewees were sometimes too busy to meet, which resulted in mere conversations with their secretaries.

The above difficulties encountered with carrying out the interviews were dealt with in several ways. Most of all, using the strategy of dogged persistence proved successful. Also, a soft and informal approach when taking the interviews often brought a more relaxed atmosphere during the interviews, which enhanced willingness to share insights, data and other types of information. Holding more and more extensive interviews may have resulted in more information and subsequently, a broader evidence base for obtaining the results presented in this thesis.

7.7.3 Urban water balance modelling

The urban water balance modelling was done to predict outcomes of scenarios for water demand (objective 3), assess scenarios for wastewater reuse (objective 4) and to assess the impact of future urban water use on water for agriculture at the basin level (objective 5). The modelling was done after composing the main components of the water balance. The data needed for the modelling were derived from data collection, through the historical analysis and semi-structured interviews. For the modelling, the VENSIM software was chosen and applied.

The VENSIM model proved to be very useful to gain insight into the scale and pathways of the major water flows that constitute the water balance. The simplicity of the model and relatively modest data requirements were found very suitable for prediction of scenarios and assessment of wastewater reuse potential and impact of the water urban water balance. The model was found very easy to work with, because it was built and designed for the purpose of this research. Furthermore, the fact that I had already built a similar version of the model before starting this research, proved to be an advantage. Errors encountered during the modelling were dealt with by consulting the comprehensive software manual and by method of trial and error.

Limitations of the model tool were the fact that the model has not yet been applied elsewhere in an urban water balance context. Therefore the performance of the model itself and the quality of the model results could not be compared and verified. However, model outputs were compared and verified with local data and international literature. Based on comparison with literature, the model outputs are found to be reliable. This way of quality control was found to be sufficient. Since the purpose of the modelling was not to get accurate numbers but instead indications of scales, the accuracy of the results is considered of acceptable standard.

The model was found to be an effective tool for research in a context of low data availability. Urban water balance modelling with VENSIM can complement qualitative research very well.

7.7.4 Scenario development

Scenario development is one of the tools that was applied in this research and contributed to objective 3, 4, and 5. Results from the historical analysis and semi-structured were used to compose and analyse the scenarios. Scenario development was an important component of the modelling and was therefore done in conjunction with the modelling.

The two main factors that constitute the urban development scenarios, projections for urban population and water demand, were found difficult to assess. This is due to wide ranges found in various literature sources and a general low level of reliability and accuracy of these sources. This difficulty was overcome to some extent by comparison of these sources and selecting the most realistic projections. However, in spite of these issues of reliability and accuracy, the aim of the scenario analysis was to generate indicative figures for the likely range of scale for urban water demand and wastewater generation. This is considered to be well accomplished.

One of the main limitations of the scenario analysis is the lack of data for estimation of a few indicators that are considered relevant. For example, informal water use and non-domestic water demand were only rarely found. A further assessment of these indicators would enhance the results gained with this tool.

7.7.5 Comparative analysis

The fifth and final tool, comparative analysis, consisted of the comparison of results from the three city case studies; Hyderabad, Accra and Addis Ababa. This tool was used to cross-check data collected for the cities and compare results gained with the other tools. In addition, this tool was an important instrument to address the fifth and final research objective.

It was found relatively easy to apply comparative analysis in this research, since all three case studies used the same type of data and employed the same methodology. All three case studies used the same tools, indicators, drivers and scenarios. Results from the comparison have given some interesting information that was found very useful towards conceptualisation of the water balance of fast growing in water stressed cities.

One of the limitations of the comparative analysis carried out here, is the absence of any tools employed for statistical comparison. The lack of reliable data is the main reason why such an assessment has not been carried out. More comprehensive and reliable databases for the cities are needed to carry out a more profound comparison. Another limitation is the number of cases that were compared. Comparison with results from other cases that applied a similar methodology would enhance the credibility of the tool.

7.7.6 Final remarks

For researchers, the combination of tools applied in this research is found to be an appropriate and effective methodology to investigate the urban water balance of fast growing water-stressed cities in developing countries. As a means to verify findings derived from using individual tools, these findings were compared with results from other tools. This method is believed to have improved the strength of analysis. For local urban water planners and managers the complete set of tools may not be appropriate, since the process involved in this methodology is time consuming. The water balance modelling tool however is regarded as an excellent tool for application by local water planners and managers, such as the respective urban water supply authority and ministry of water resources. It is considered relatively easy to master the model; to build and adjust it according to the location-specific situation and to model specific scenarios. Those who are involved in urban water planning and management in their daily work will also have an advantage in accessing data, compared to external researchers. The VENSIM urban water balance model has shown interest by researchers from

Addis Ababa University. In August 2010, students and staff from the water supply company were trained in the use of the model, as part of the URAdapt research project[13].

[13] http://uradapt.iwmi.org/events.aspx

8. CONCLUSION AND IMPLICATIONS

8.1 CHAPTER INTRODUCTION

This last chapter draws the conclusions, based on the results from this research. The conclusions follow the order of the 5 research objectives as listed in section 1.3.The aim of this research was;

To develop and validate a mix of effective research tools for investigating the urban water balance of fast growing water-stressed cities in developing countries with limited data available.

After discussing the 5 research objectives, the aim of this research is evaluated. This is followed by a discussion of implications of the research for policy, practice and theory, and limitations of the research. This chapter closes with suggestions for further research.

8.2 TEMPORAL DEVELOPMENT OF URBAN WATER SUPPLY AND SANITATION

This section addresses the first research question, which is:

How did urban water supply and sanitation develop in the cities, as they relate to demographic growth?

This research found a general pattern failure to keep urban supply and sanitation in pace with growth and expansion of the city. Fast population growth has been one of the major factors. Poor coverage of water and sanitation services as well as other prevailing water-related issues do not stand alone, but are part of a cause-consequence-impact, shown in the diagram (Figure 47). It is the result of a combination of physical constraints and institutional limitations related to the water cycle. It was found that the driving forces and impacts of water issues extend beyond the boundaries of the urban area.

The cities of the case studies share a number of similar characteristics that are detrimental for the current state of the water system and likely future development paths. Urban water supply development and expansion have always been more closely related to supply infrastructure than to demand. Water use has been constrained by insufficient supplies due to insufficient water production. In the case of Accra and Addis Ababa, per capita water availability actually reduced due to supply expansion not keeping pace with city water demand.

The cities have seen slow progress in improvement of sanitation facilities to move up the sanitation ladder. Wastewater treatment is low compared to the wastewater volume generated, now and in the future. Though a substantial increase is expected in wastewater volume generated at least in Hyderabad and Addis Ababa (due to increases in water supply) there will only be a modest increase in the potential treatment fraction. The untreated wastewater volume will actually increase in Addis Ababa and Accra, while it will reduce by half in Hyderabad. The sustainability of the conventional way of expansion of wastewater treatment should be reconsidered for cities in a similar environment. What is meant by conventional way here is increasing installed capacity of wastewater treatment plants that require a relatively high level of expertise for maintenance and that do not consider reuse in its design.

The historical analysis in combination with the holding of semi-structured interviews has proven to be effective in analysing historical growth and development of the cities. Application of these tools gained sufficient insight into and understanding of the urban water system and its management. Both tools have provided essential information needed to address the main research objective.

8.3 THE URBAN WATER BALANCE

This section provides conclusions for the second research question, discussed in the first chapter, which is:

What are the most important urban water flows that compose the urban water balance?

In all three cities, the urban water balance is driven by two main sources of water; water supply and rainfall. As described above, the water supply flows depend on water supply infrastructure and its development. The stormwater drainage infrastructure is under-dimensioned and incapable of dealing with events of intense rainfall, leading to serious flooding of sub-areas in the cities. The on-going reduction of permeable areas due to construction, and expansion of the urban area are contributing to a worsening of the flood impact. The urban water balance is a good method to gain insight into the scales of water flows in the urban area. Urban water balance modelling is useful for gaining insight into future scales of water flows according to scenarios for urban development and water availability.

The integration of sanitation into water supply and general city development plans is advisable, in order to reach a more sustainable urban water system. The urban water system should be managed more holistically and with better planning, in order to deal with the interrelated water issues that prevail in the cities under study.

The composition of the urban water balance has proven to be useful and effective in analysing the main pathways and scales of water flows, flowing into, through and out of the urban areas of the investigated cities. Application of the urban water balance gained much insight into the urban water system. The urban water balance tool has proven to be useful and effective for contributing to the main research objective.

8.4 WATER DEMAND SCENARIOS

This section provides conclusions for the third research question of this research, which is:

What are the scenarios for water demand, based on different scenarios of demographic growth and change in living standards?

In the cities studied, changes in in-house water supply facilities and equipment in existing urban areas may change individual water demands. Also, a possible trend of rising standards of living is likely to contribute to increases in urban water demand. The annual added city population due to fast population growth is pushing up water demands as well. For all cities studied, one unknown factor is how the industrial sector will develop and expand, and the claims it will make on available urban water sources.

Large investments are needed in both the water supply and sanitation/wastewater treatment infrastructure to combat the current water-related challenges that prevail in the cities studied.

In this research, urban water balance modelling was applied as one of the tools to investigate scenarios for urban water demand. The software used for the modelling (VENSIM) has proven to be very appropriate and effective in order to investigate the related research objective. Scenario development and semi-structured interviews are the other tools that were applied to answer this specific research questions. These two tools are considered essential instruments, which allowed the modelling exersize to be carried out with a sufficient level confidence and accuracy.

8.5 URBAN DEVELOPMENT, CONSEQUENT WASTEWATER FLOWS AND WASTEWATER IRRIGATION

This section provides conclusions for the fourth research question, discussed in the first chapter, which is:

What are the implications of different urban development scenarios and the consequent wastewater flows, for wastewater irrigation potential and risks?

All three cities have significant areas in the urban fringes of the city where crops are grown for household use and sale on local markets. Wastewater volumes generated in cities are likely to increase parallel to water supply increases. Despite planned expansion of installed treatment capacity in all cities, the untreated volume will increase in Addis Ababa and Accra, while it will reduce by half in Hyderabad, by 2020. It is expected that, given the benefits to farmers from wastewater irrigation, the irrigated areas downstream of Hyderabad and Addis Ababa will further expand. In Accra, there may be possibilities for expansion in the open-space areas. However, due to Accra's coastal location, an increase in disposal of wastewater into the marine environment can be expected.

In order to answer this research question, the tools scenario development, urban water balance modelling, and semi-structured interviews were applied. The set of tools has proven to be useful and effective in order to investigate scenarios for wastewater flows and wastewater irrigation potential and risks.

8.6 BASIN IMPACT OF URBAN WATER USE

This section provides conclusions for the fifth research question, discussed in the introduction chapter, which is:

What is the impact of future urban water use scenarios on water availability for agriculture at the basin level?

The presented case-studies have shown that the city is interacting with the upstream and downstream areas through urban water supply and disposal of wastewater and stormwater. The analysis has made clear that both demographic and climatic developments are detrimental for this interaction. The institutional environment and state of water resources are considered as being detrimental to the cities in the future development of water supply and sanitation. The case studies confirm a general pattern of increasing influence of the urban water balance of the basin both upstream and downstream of the cities.

The downstream impact of urban water use is a direct result of the infrastructure currently in place for the disposal of wastewater and stormwater that is generated. With the successful exploitation of larger water sources in larger basins, water supply seems to be secured for the next decades. However, the rising water demands may occur in those basins leading to possible over-allocation in periods of low water availability. A possible increase in the variability of seasonal rainfall due to climate change may reduce basin water availability for water use sectors in dry years.

Based on the findings of the research, it is concluded that the cities reflect a general pattern of growing impact on water and users and the environment, especially downstream of the city. The impact is alterations in water availability and water quality of groundwater and surface water sources. This impact has potential implications for water reuse, which is manifested in large scale wastewater reuse in agriculture. To date, upstream impacts have been minor. However, catchment development and climate change may create stress on the existing water sources. Increasing competition with irrigated agriculture that shares the same water source may appear as the cities grow further. In Hyderabad the city has already taken water out of agriculture and farmers have adapted to the new circumstances (Celio 2008; Celio et al. 2010).

Relatively simple modelling and calculations carried out through the scenario development and urban water balance modelling have proven to be very appropriate to investigate the impact of future urban water demand on water availability for agriculture at the basin level.

8.7 CONCLUSIONS WITH REFERENCE TO THE RESEARCH AIM

The aim of the research was: *to develop and validate a mix of effective research tools for investigating the urban water balance of fast growing water-stressed cities in developing countries with limited data available*.

The composition of the urban water balance and modelling are suitable tools for local planners. The results that can be derived from applying these tools, as demonstrated in this thesis, can support decision making in the area of urban water resources management. The generation and testing of urban development scenarios and its impact on the water balance is considered a very useful tool for local water planners. As demonstrated in this thesis, the tool scenario development does not necessarily need complex computer software. A potential issue that needs to be overcome is that for data collection and scenario development specifically and integrated assessments in general, the potential user will need to collaborate with other stakeholders, such as various municipal departments. If collaboration is traditionally not much done, it will require some additional efforts and a certain level of pragmatism.

Overall, it is concluded that the mix of tools that was applied in this research is found to be an appropriate and effective methodology for this type of research.

8.8 IMPLICATIONS FOR POLICY, PRACTICE AND THEORY

8.8.1 Implications for policy and practice

Based on the findings of the research, a few implications for policy makers and managers of services in the urban water sector are discussed here. Furthermore, the suitability of the various tools for application by local practitioners and decision makers is being discussed.

It has become clear from the findings that policy makers and practitioners should be heading towards a more integrated management of urban water resources. For example, the publication of a national water policy, as done in Ghana, is a good first step. Policy makers and practitioners in urban sanitation should bear in mind that improvement of sanitation facilities should include water sensitive design. Facilities that use large quantities of water, most notably large-flush toilets, are simply not feasible in cities that are chronically water-stressed. A solution may be the introduction of poor-flush toilets on the market, tailored to the high income section of the urban population that uses most domestic water per capita

Institutional capacities should be increased in order to better combat the described challenges that the water utilities are confronted with. Findings in this thesis made clear that the multi-sectoral nature of water uses in and around the cities requires a more holistic and multi-sectoral approach, to be adopted by local planners and policy makers. The spatial dimension of urban water use should be better addressed by reducing adverse impacts that urban water use has on water users and the environment, upstream and downstream of the city.

Water supply expansion plans should be linked to wastewater disposal plans, and should include a section that anticipates the increase in wastewater generated from the urban area. The thesis has demonstrated that a set of relatively simple calculations on water accounting is a good method for doing so. A reduction of the volume of untreated wastewater discharged to the environment can only be accomplished if the authorities in all the cities are able to meet targets for planned expansion of wastewater treatment. Plans for expansion of treatment plans should be better adapted to the local circumstances in the cities and should pay attention to opportunities for water re-use.

Urban agriculture is taking place at significant scale in and around the cities studied. This practice can be made more sustainable if water quality concerns and land use security are adopted in the city development plans. This can only be accomplished when local planners and policy makers are convinced of the importance of urban agriculture to urban food security and livelihoods in their cities. Further studies on wastewater treatment and reuse are recommended for the sake of resource recovery and protection of human health and the environment. Also, possible problems from industrial effluents mixing with the urban streams used for agriculture should be further investigated.

Industrial pollution control is essential in order to reduce the impact of industrial effluents on water users downstream and the environment. Institutional capacities in the cities will need to be increased in order to enforce legislation for treatment of industrial effluents. Industries should be encouraged to make their production processes more environmentally friendly.

Poor solid waste disposal is an issue that is interlinked with water pollution and stormwater drainage in the cities studied. Proper collection of solid waste from households is needed. This means that at the institutional level solid waste collection should be given more priority and allocation of funds. A reduction of solid waste disposal into the urban environment will reduce clogging of drains and subsequent flooding, and prevent a further degradation of the environment.

Learning from experiences in other cities can also be a good way for local planners, decision makers and policy makers to improve urban water management in their cities. The comparative analysis has demonstrated that the cities can have similar patterns of development and have similar processes and interactions between components of the urban water balance. Historical analysis is considered less useful as historical knowledge is already available within the organisations. As made clear in the methodology, the carrying out of semi-structured interviews was applied as a tool to gain additional insight into the urban water system in the case studies. Getting insight into system is also recommended for local planners and decision makers. A more appropriate way of achieving this is by organising regular meetings with representatives from relevant institutions that are involved in urban water management.

8.8.2 Implications for theory

The findings from this research add more evidence to the existing body of literature on the impact of water-stressed cities on the basin in South Asia and sub-Saharan Africa. Evidence for increasing dependence of cities on water sources located in rural areas further away from the city (Mumford 1956; Chene 1996; Showers 2002; Molle 2003; Molle and Berkoff 2006), was only found for Hyderabad, and not for Accra and Addis Ababa. Fast growing cities do not by definition show a pattern of increasing dependence on water resources further away. The physical water resources environment, in which the cities are located, is one of the determining factors for this dependence.

The *inverse implication of the urban gradient* (Scott 2010), was confirmed for all cities. The findings from all three cities confirm a growing impact downstream of cities, as a result of urban growth and development in combination with poor wastewater disposal and wastewater treatment.

The findings also confirm earlier studies by (Eiswirth et al. 2000; Fane et al. 2005; Schertenleib 2005) that conventional centralised wastewater treatment systems have failed in the past and are not suitable in the present and future, to adequately deal with the fast growing wastewater volume generated in cities in a similar context.

Findings from this research contributed to a further conceptualization of the interlinked set of water issues that prevail in water stressed cities in South Asia and sub-Saharan Africa.

8.9 LIMITATIONS OF THE RESEARCH

The availability and quality of the collected data limited the quality of analysis. It has proven difficult to obtain the desired data. The data factor is a major limitation for research of this type in developing countries. The lack of transparency and bureaucracy encountered at the institutions visited, are accountable for this. The lack of ownership may have resulted in the experts feeling reluctant to share data. A research project in which the local institutions are partner is likely to give a better climate of data-sharing. On the other hand, one of the contributions of this research is the compilation of data from a range of sources in three countries in three different world regions. The triangulation method that could be applied to the data from the three cities is believed to have improved the strength of analysis.

Further data collection could improve analysis and establish a broader support of the findings drawn from this research. In particular the generation of specific GIS maps for land cover would strengthen the database used for this analysis.

As far as is known, the city-level urban water balance model has never before been applied to compose an urban water balance model in cities in a context of data scarcity. Whilst this work was pioneering in that sense, the lack of other similar work has limited the scope for comparison of model outputs. Due to the non-availability of data, the model outputs could not be verified with empirical data.

8.10 Suggestions for further research

Alternative options for wastewater disposal and treatment should be researched. In particular, decentralized wastewater treatment that is designed for reuse could be very appropriate in the context of the cities studied. Sanitation infrastructure design should be oriented to reuse. The research of options that incorporate the design for service planning approach is recommended here (Murray and Buckley 2010).

The potential of water demand management options such as water harvesting from rooftops should be investigated in all cities. This could reduce water stress in the cities; however the extent of any benefit is largely unknown. Research on water demand management options for Accra using the VENSIM software found that stormwater reuse, shower retrofits and reducing non-revenue water are the most cost-effective measures that can be taken, to reduce water stress (van Rooijen et al, 2011).

The vulnerability of water resources to a reduction in water availability due to climate change was not addressed in this research. This type of research is suggested in order to better support the water utilities in adjusting their water supply plans to any likely impact as a result of climate change.

A more thorough analysis of the institutional environment within which management of the urban water cycle takes place would shed light on how to make improvements and would help to better understand the context of the cases studied. The institutional performance of the cities could be placed in a comparative conceptual diagram using indicators by using method similar to the water resources context (Figure 43).

Similar case study research in other cities would broaden the evidence base for reaching conclusions in this area of research.

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