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Low carbon solutions for drinking water provision to low purchasing power people

A study on solutions for improving drinking water provision to underprivileged communities in urban slums

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- Master thesis -

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Abstract

The processes of water procurement, treatment and distribution are associated with high energy use. Low carbon energy solutions for the provision of drinking water are not only important in the context of environmental impact, but also for economic considerations.

In this study, technologies for water intake, treatment and distribution were compared in terms of energy use. It was found that some of the technologies identified as most energy-efficient are currently not widely used because of financial constraints. These technologies need to be developed further in order to become cost-effective.

A case study on Safeda Wali Jhugi in East Delhi was performed in order to illustrate how the analysis on energy-efficient technologies can be used for decision-making in practice. Furthermore, this case study and additional research on water-related issues in India and Delhi were used to identify interventions necessary to support implementation of small scale technological solutions. These include social, educational and institutional measures.

This study also illustrates the need for large scale urban level interventions in order to reduce current high water losses and associated energy waste. Despite the proven cost-effectiveness of certain water loss reduction measures, implementation of these measures is often limited, presumably due to institutional constraints. This is related to little transparency from the government on urban water provision. Hence, increased awareness on the importance of water loss reduction measures is necessary, as well as openness of the government regarding energy efficiency of processes related to water provision.

Contents

List of tables

List of figures

Acronyms

AC	Activated Carbon
ARWSP	Accelerated Rural Water Supply Programme
BBMB	Bhakra Beas Management Board
BDL	Below Detection Limit
CPCB	Central Pollution Control Board
CPHEEO	Central Public Health and Environmental Engineering Organisation
DDA	Delhi Development Authority
DJB	Delhi Jal Board
GAC	Granular Activated Carbon
HDI	Human Development Index
IBT	Increased Block Tariff
JJ clusters	Jhuggi Jhompri clusters
lpcd	liters per capita per day
MGD	Million Gallons per Day
MLD	Million Liters per Day
MPD	Master Plan Delhi
MPN	Most Probable Number
NCRPB	National Capital Regional Planning Board
NDWM	National Drinking Water Mission
NTU	Nephelometric Turbidity Units
PAC	Powdered Activated Carbon
RO	Reverse Osmosis
SSF	Slow Sand Filtration
TDS	Total Dissolved Solids
WUA	Water User Association

1. Introduction

Accessibility to clean water is one of the most pressing problems that low income groups in developing countries deal with today. It is estimated that currently about 20% of the world population does not have access to sufficient drinking water (Rudra, 2011). Water scarcity is a growing problem, as it is directly related with increasing world population and an associated increase in industrial and agricultural activities (Flendrig et al., 2009). It is therefore expected that scarcity of drinking water will increase even further in the future (Forstmeier *et al*., 2007; Mehta, 2007; Voelker, 2004).

A large share of world's poor lives in India. Despite the on-going economic progress and a corresponding growth in financial remittances in the country, India is still coping with high poverty rates. Of the 1.2 billion people living in India, about 37.2% lives in poverty (Banik, 2011). Though in the recent years India has shown great economic progress, with GDP growth rates between 7 and 9 % (Homlong and Springler, 2010; Pradhan, 2010), the Human Development Index (HDI) does not show a corresponding improvement (Homlong and Springler, 2010): India currently has the 119th position in the HDI.

Due to lack of financial means, the inaccessibility to potable water is a major and growing concern for low income groups in India (Motoshita *et al*., 2011). The increasing water deficiency in India is not only a result of population growth, but also of the rapidly growing industrial sector, that has moved from the developed countries to emerging industrial nations like China and India (Motoshita *et al*., 2011).

India's problems with drinking water have far-reaching consequences. Water scarcity has been associated with domestic violence (Parmar, 2003), reduced food availability (Banik, 2011), health issues (Banik, 2011; Mara, 2003; Motoshita *et al*., 2011), and environmental problems (Homlong and Springler, 2010). Furthermore, water scarcity has been directly connected to low education levels in low income communities, especially among women. In areas where water it scarce, fetching water can take up to 14 hours a day (Parmar, 2003). As this is traditionally a woman's job, women generally have little time for education. This is one of the reasons why education levels and literacy are very low in India (Banik, 2011).

Water scarcity affects rural communities in India (Johnson *et al*., 2008), as well as people in slums and suburbs of megacities and peri-urban areas. Considering the nation-wide concerns regarding water issues, and the expected population increase with a corresponding further reduction of available drinking water, serious measures are needed to ensure the availability of potable water now and in the future.

One of the United Nations Millennium Goals is to half the inaccessibility of clean, potable water by 2015 (United Nations, 2010). India is an important area of focus regarding the introduction of measures for improvement, as the country has a high population of which a large part lacks sufficient clean water (Banik, 2011).

In the past decades, the Indian government has committed to improving water quality and availability in the country by introducing several new policies. Most of these are aimed specifically at the rural population. In 1986, the government initiated the 'National Drinking Water Mission' (NDWM, later renamed 'Rajiv Gandhi National Drinking Water Mission'). The main objective of this mission is to 'improve the performance and cost effectiveness of the on-going programmes in the field of rural drinking water supply and to ensure the availability of an adequate quantity of drinking water of acceptable quality on a long term basis' (Government of India, Department of Rural Development, 1990). The starting point and focus of this programme has changed over the years. First, the emphasis was on the technological aspect of the issue, whereas later the focus shifted towards a more people-oriented approach, in which community participation played a central role. Thus, the programme shifted from a 'government oriented supply driven approach', to a 'people oriented demand responsive approach' (Water Aid, 2007).

During the past ten years, the improvement of water quality monitoring has become one of the most prominent goals of the government's programme. This goal is supported by the 'National Rural Drinking Water Quality Monitoring and Surveillance Programme', which was introduced in 2006 (Water Aid, 2007). Furthermore, after launching the 'national water policy' in 2002, emphasis was no longer only placed on providing drinking water in rural areas, but also urban areas were now addressed through national policy (Government of India, Ministry of Water Resources, 2002).

Water provision is associated with high energy consumption. Energy is not only required for treatment and use of water, but also for collection of source water (usually in the form of surface or ground water) and distribution of treated water. Especially in urban areas these processes are energy-intensive. Source water is often not available nearby in sufficient amounts. Therefore, in large cities water is often transported over large distances from source to treatment plant. In addition, treated water needs to be transported over large distances within cities. In developing and transition countries, transportation of water through pipeline systems is associated with high water losses, and thus unnecessarily high energy consumption.

Though the Indian government is obliged by their national constitution to provide its citizens with safe drinking water (Panickar, 2007), the case is complex for those people that live in unplanned colonies in the large cities in India. As the inhabitants of those areas are not legally registered, there are limited possibilities on the government level to observe the law dictating every person's right to clean water. Furthermore, it is difficult to implement a centralized solution for drinking water, as the necessary infrastructure for water distribution is often not present and would be too costly to realize. Therefore, decentralized solutions for water purification could be more suitable alternative (Peter, 2010).

This research aims at providing an overview of the success and failure factors of water purification methods suitable for the unauthorised urban slum communities, and makes a comparison of suitable technologies. There will be a focus on differences in energy requirement, while additionally implementation potential, environmental impact and socio-cultural acceptability of these technologies will be addressed. Furthermore, this research aims to give overview of educational, social, institutional and large scale technological measures that are required in order to support the deployment of suitable small scale technological measures and reduce overall urban water loss.

2. Approach and methodology

2.1 Research questions

Main research question

What are the most energy-efficient methods for improving drinking water provision in urban slums and how can these methods be deployed successfully?

Sub-questions

- What technologies are available for implementation in decentralized water treatment systems and how sustainable are these in terms of energy use?
- What is the technical, economic, social, environmental, and resource-related applicability of solutions for potable water provision in urban slum communities?
- What social, educational and institutional measures are needed to facilitate a successful deployment of a suitable technological intervention?
- What large scale, urban level, measures are required in order to reduce urban water losses and improve energy-efficiency of centralized water supply to urban slums?
- How can decentralized solutions be implemented in the existing centralized water provision system, and what improvements are required to improve energy-efficient water provision on a larger scale?

2.2 Research boundaries

This research focuses specifically on urban areas. It is estimated that by 2025 one-third of the world population will live in cities (Vivar *et al*., 2010). Hence, the need for sustainable and feasible water purification methods in urban areas will continue to grow.

Within the urban context, this research focuses on those areas which are characterized by low income levels and a lack of basic amenities, thus primarily urban slums. An urban slum is defined here as an urban colony that has not been authorized by the government and that lacks basic amenities (see Appendix I, Interview DJB[1]). This

[1] Delhi Jal Board (Delhi Water Board)

means that solutions will be focused on small scale, community level improvement of water provision.

In addition, this research focuses on the provision of water for potable purposes, which includes water for drinking and cooking. Provision of water for other purposes is less of an issue because in most places hand pumps or bore wells are present to extract non-potable water from the ground. Therefore, provision of water for non-potable purposes is beyond the scope of this research.

Regarding solutions for drinking water provision, the research is aimed at identifying the most energy-efficient technologies. Other issues related to sustainability, like chemical use, waste production, or land cover are beyond the scope of this research and will therefore not elaborated upon in much detail.

Finally, this research aims at finding low carbon energy solutions which can be introduced in urban areas all over the world. Though this study was mainly built on water-related issues found in the Indian context, with specific attention to Delhi, the analysis on energy-efficient technologies is independent of socio-cultural context and will therefore be useful in other developing and transition countries as well. Access to electricity has not been taken into account in this research, as it is assumed that in urban areas electricity is readily available. The analysis of socio-cultural and institutional interventions, as well as large scale interventions, is predominantly based on the example of Delhi, but forms a good example for improving deployment of water purification systems in other countries.

2.3 Research methods

The research approach was divided into three parts. First, the technological aspects of improving drinking water provision were researched, including technologies for water treatment and distribution. Second, a case study was done on a slum in Delhi. This study serves as a test case for the overall analysis. It shows how specific characteristics of an area necessitate specific interventions, and is therefore not representative for the overall research. The third part of the research focuses on additional measures needed for improving drinking water provision. Figure 1 gives an overview of the methodology used for this research.

2.3.1 Part 1 – Technology

An overview has been made of available water technologies for improving water provision on a community scale. These include technologies both for water quantity and water quality improvement. An assessment has been made on the energy requirement of these technologies.

Furthermore, the technologies have been described in terms of environmental impact besides energy consumption, social acceptability and implementation potential depending on economic viability, technological appropriateness and resource availability. A decision tree has been created to give an overview of the most energy-efficient options for improving drinking water provision in different situations.

2.3.2 Part 2 – Case study

Subsequently, a case study was done on a slum in Delhi. Through interviews with locals, on-site water quality tests and mapping of the area, an overview could be created of the issues and needs in the community. With this information a solution for improvement of drinking water provision could be suggested based on the decision tree made earlier. This part of the research involved a primary selection of six settlements, out of which one settlement was chosen for final research.

Primary settlement selection

For the primary settlement selection the following criteria were used:

- Provision of drinking water needed to be an issue in the area of focus.
- The inhabitants had to show willingness to cooperate with the implementation of a new system.
- A certain level of awareness on drinking water issues needed to be present, in order to ensure cooperation of the community. This awareness could be created through educational projects. However, due to time limits it was chosen for this study to look for a community with an already present level of awareness.
- Inhabitants needed to be willing to pay a reasonable price for improved drinking water provision.

Because the slums in Delhi are continuously developing and changing, it was not sure beforehand if slums that have been mentioned in recent literature in fact still existed. Slums are cleared regularly by the government and make place for the development plan of the city. In addition, some unplanned colonies are granted authorization, after which development of the area is accelerated. Therefore, the final decision on which settlement to visit was only made during the actual survey. The following six colonies were visited:

- New Selampur (East Delhi)
- Geeta Colony, Safeda Wali Jhugi (East Delhi)
- Geeta Colony, Sama Nursery (East Delhi)
- Kalyanpuri, Mahatma Gandhi Camp (East Delhi)
- Vasant Vihar, Kooli Camp (South Delhi)
- Vasant Vihar, Bhawar Singh Camp (South Delhi)

See Appendix II for a detailed description of these colonies.

<u>Final settlement selection</u>

The settlement to be selected for research had to meet a number of criteria, as mentioned earlier. Furthermore, the settlement should preferably be one with piped water supply, as that would give the opportunity to look at possibilities for improving centralized piped water treatment and supply, and for implementing a new system into the existing centralized system.

Two colonies came close to meeting these criteria, namely Geeta Colony, Safeda Wali Jhugi, and Kalyanpuri, Mahatma Gandhi Camp. Both areas are supplied with pipe water. Quality of drinking water is an issue, as piped water is contaminated and no drinking water is supplied through DJB tankers. Furthermore, the people in these colonies were aware of their water issues and would support the implementation of a system that would improve the provision of safe water to their colony. However, in both colonies it was discovered that quantity of supply was also a major issue. Thus, a solution would have to be found for this problem as well.

Geeta Colony, Safeda Wali Jhugi, was finally selected for further research. The major reason for choosing this colony over the colony in Kalyianpuri was the fact that the one in Geeta Colony was of a reasonable size that could be researched within the limited time frame of the research. Kalyanpuri, being a large slum area, would take too much time to survey properly. Furthermore, a smaller community would require less time in finding a solution for limited water quantity, and would thus leave more time for focusing on water quality issues.

2.3.3 Part 3 – Additional required measures

Finally, through literature study, interviews and field work, an overview was created of additional measures which are, besides small scale technological interventions, necessary for supporting the successful implementation of a new system for water provision. These include small scale social, educational and institutional measures, as well as technological and institutional measures on a larger scale.

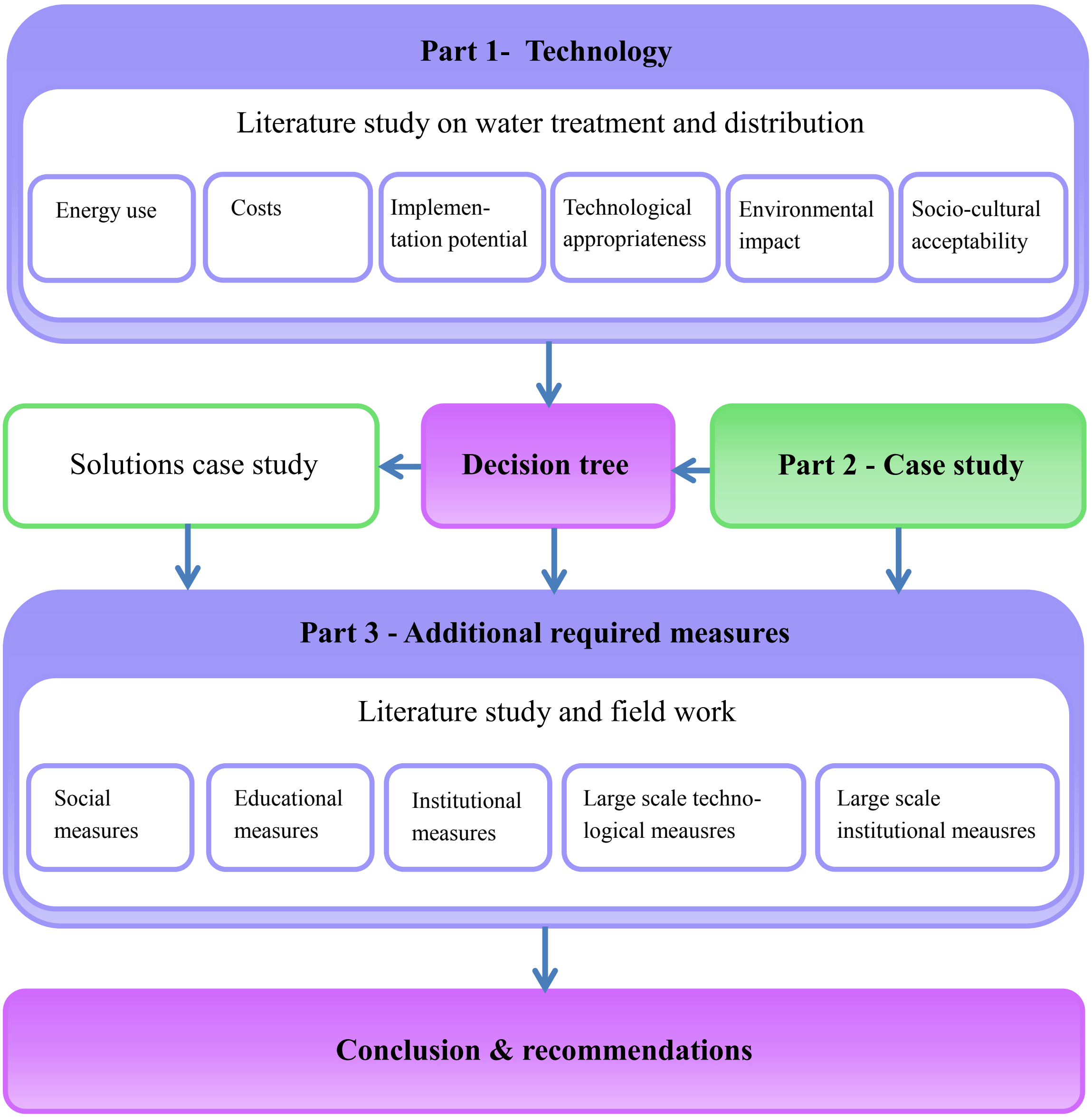

Figure 1: overview of research methodology.

2.4 Thesis overview

The thesis is structured as follows:

- Chapter 3. Background information on water issues in India and Delhi.
- Chapter 4. Analysis of small scale technological interventions regarding success and failure factors and energy use. An overview is given of the most energy-efficient technologies.
- Chapter 5. A case study of an urban slum in Delhi. The choice for technological interventions is based on the specific characteristics of the community and on the analysis of most energy-efficient technologies from Chapter 4.
- Chapter 6. Discussion of additional required interventions, in terms of social, educational and institutional measures. Subsequently, the importance and possibilities for large scale urban interventions is discussed.
- Chapter 7. Discussion on the value-addition of this research in comparison to other case studies.
- Chapter 8. Conclusion on the value of energy-efficient water provision, as well as suggestions for future research on low energy technologies that are not yet cost-effective.

3. Research background

3.1 Water provision and use in India

The densely populated Indian Union holds 16% of the world's population, while it receives only 4% of total available fresh water (Government of India, 2007). Though the influx of fresh water has remained constant over the past decades, the population has increased rapidly. This has led to growing concerns regarding water supply due to increasing water stress (defined by an availability of less than 1700 m^3 water per person) all over the country and cases of water scarcity (defined by an availability of less than 1000 m^3 water per person) in some places (Government of India, 2007).

In 2007, when the 11^{th} 5 Year Plan was launched by the Indian government, the aim was to increase the relative amount of expenditures on health and rural drinking water and sanitation. Though it was aimed to increase the expenditure to 2-3% of GDP, a level of only 1.8% was reached by 2011 (Government of India, 2011). The 12^{th} Year Plan strives for a further increase of these expenditures, hoping to reach 2.5% in 2017 (Government of India, 2011). This offers possibilities for the implementation of measures addressing current water issues.

India's rising water problems are two-fold. First, there is the problem of water stress and water scarcity, which is a growing concern due to the continuous population increase. Another problem is water quality. Pollution of both ground and surface water is rising due to increased use of pesticides in the agricultural sector; an ever developing industrialization with corresponding waste disposal, often ending up in surface waters (Banik, 2011); increased waste production from a growing population.

<u>3.1.1 Water supply</u>

With a growing population, the supply of sufficient amounts of source water has become a problem in many parts of India. Groundwater, though contributing only 0.6% to the world's total water content, is the most important water source in India as well as in many other developing countries (Meenakshi and Maheshwari, 2006). The key advantage of groundwater is its relative purity, which sometimes enables people to use it without prior treatment.

The extent to which quantity is a problem differs between Indian states, and water trading between states is a difficult, politically charged issue. Basically, all states have to ensure their own water provision. In states where ample surface and ground water is available, e.g. Kerala, this is not a problem. However, in the dry, mostly coastal, states, water provision proves an on-going challenge. Examples are cities and towns in the states of Tamil Nadu and Andhra Pradesh (Ministry of Urban Development, 2005).

Not only lack of source water or inability to produce drinking water leads to water supply shortages, the provision of sufficient amounts of water can also be an issue for people living in remote rural communities or in underprivileged (usually unauthorized) urban areas, where water distribution is not or inadequately organized. Both rural communities and unauthorized urban areas of large cities are difficult to reach by pipelines from a centralized water distribution system, as this is in most cases financially impossible.

Rural communities constitute a large part (almost 70%) of India's population, with a total of over 700 million people living in small rural villages (Water aid, 2007). In rural communities most people resort to rainwater harvesting, groundwater pumping, or using river water if available (Peter, 2010). In many cases this water is used untreated, and is therefore a major source of illnesses, epidemics and other health issues (Water aid, 2007). Water pollution is becoming an ever increasing problem, as water availability is declining (rivers and groundwater wells running dry due to the increasing water demand), while pollution is growing due to progressive agricultural and industrial activities. This combination strongly affects water quality.

3.1.2 Water supply issues

When intermittent water supply is available, the communities rely on the precious hours of the day or week in which water is distributed to them. As the timing and period of water availability is often uncertain, poor people who cannot afford a water container spend many hours of their time waiting at water collection points and gathering water in buckets or jerry cans. Usually this task is assigned to women, who consequently have little time left for other household tasks, let alone education or other ways of personal development.

Underprivileged communities in urban areas deal with yet another type of problem. In most of India's cities the availability of ample source water is not an issue. The problem lies in the accessibility of water for the urban poor (Ministry of Urban Development, 2005). A large part of the nation's urban population lives in slums and urban areas, where in most cases access to the centralized water provision system is lacking. In the case of intermittent supply the slum dwellers are able to gather and store water in a far from ideal, time-intensive manner. However, if no intermittent supply is available, people are forced to buy bottled water at a high price.

According to an internationally accepted standard (Interview Vitens, see Appendix I), about 3% of household income is a fair portion to be spent on water. In many developing countries this percentage is lower. However, in the poor communities of developing countries this percentage is much higher, either in time investment (and thus work time loss) or in actual costs of bottled water.

3.1.3 Health issues

The main health problems associated with the use of unsafe water are a consequence of microbial pollution (Peter, 2010). It has been estimated that almost 40 million Indians are affected by waterborne diseases every year, children being at the highest risk (Water Aid, 2007). An estimated 1.5 million children die each year in India as a result of diarrhoea. World-wide, waterborne diseases are still the leading cause of death in many developing countries, as observed by the WHO in 2004 (Peter, 2010).

Besides microbial pollution, naturally occurring chemical pollutants also have major health effects (Peter, 2010). The most common natural chemicals in India, and in many other countries, are arsenides and fluoride (Meenakshi and maheshwari, 2006).

Water contamination is not only an issue for those who use untreated groundwater, but also for people connected to the centralized pipeline systems. Though the water provided through this system is treated, contamination takes place almost always during distribution. This is related to the fact that the existing pipeline systems in large cities in India are often of bad quality. Pipe leakages, in combination with intermittent supply, lead to an influx of contaminants from outside the pipeline system, thus resulting in contamination of the treated water. People who can afford it often have a small treatment system installed in their household, in order to make their water safe to drink. Low income groups, however, cannot afford such an investment and have to drink pipe water untreated, or rely on private vendors who sell bottled water for a much higher price than local governments would (Bell *et al.*, 2009).

3.2 The slums of Delhi

3.2.1 Background

The expansion of Delhi into the metropolitan city that it is today has taken place in a tremendous pace. In 1901, when Kolkata was still India's capital under the British rule, Delhi's population was as low as 0.4 million (Batra, 2005). After Delhi became the nation's capital in 1911, the city started growing rapidly. This growth rate increased after independence in 1948 and the subsequent partition of India and Pakistan. Almost 0.45 million Pakistani refugees found shelter in Delhi, causing an overload of the existing urban services (Singh and Shukla, 2005). This was when Delhi's issues around provision of safe drinking water started, and ever since the city has been unable to keep up with the increasing population pressure, leaving more and more people deprived of drinking water and other basic amenities.

Today, Delhi is home to about 15 million people, and estimates predict a population increase up to 23 million by 2021 (Delhi Development Authority, 2005; Rai, 2011). With the current economic growth in India, mostly concentrating in the urban areas of the country, it is expected that urbanization will continue to grow in the future. Compared to other developed and transitional countries, India currently has a small share of urban population, about 30%. Nevertheless, more than 50% of GDP is ascribed to urban areas. It is no surprise, therefore, that rural low income groups consider migration to a city as an opportunity to benefit from the economic growth and improve their living standards.

Though the living conditions in Delhi have improved significantly over the past decades (Singh and Shukla, 2005), a large part of the city's population is living in subhuman conditions in unplanned settlements. These are settlements that have been built on ground that belongs to either the government or to private parties, and were not intended for residential use. Unplanned settlements are created by immigrants who move to the city hoping to find a better future than the one rural life offers them. Since housing in planned colonies of the city is unaffordable to them, they build new settlements wherever they can find space, for example along railways, on river banks or under bridges. The number of these settlements is growing rapidly due to increasing migration from rural areas (Dutta, 2006). An expected 300,000 migrants move to the city every year (Batra, 2005). The far majority of the newcomers therefore remain in subhuman conditions in slum communities their whole life.

Delhi's unplanned or unauthorized areas have a complex history. For this reason there are many different categories of unplanned settlements. The terminology of Delhi's settlements is rather confusing and literature is often not consistent on this. However, Water Aid (Singh and Shukla, 2005), Batra (2005), and Dutta (2006) give a good overview of the unplanned, or informal, settlements that are present in Delhi. A short description of the different categories of Delhi's unplanned settlements is given in Appendix III.

3.2.2 Current water supply scenario

Despite of the desired water provision to Delhi's settlements as prescribed by the water supply norms, limited supply and distribution facilities render many of Delhi's citizens devoid of drinking water. The actual provision of water to informal settlements is, according to Water Aid (Singh and Shukla, 2005), only an average of 30 lpcd[2]. In Delhi, like in many of India's cities, the supply of source water is not the main issue here. Delhi depends mostly on the rivers Yamuna and Ganges for its supply of source water (Delhi Development Authority, 2005). An additional share of source water is supplied by the Ravi and Beas rivers, through Bhakra Beas Management Board (BBMB) (DJB, undated). A relatively small share of total water demand is covered by groundwater (DJB, undated).

According to Delhi Jal Board, currently about 3840 MLD[3] (845 MGD[4]) of treated water is available for the citizens of Delhi (2010 measurements: DJB, undated). The majority of this supply, 3385 MLD, comes from surface water, while 455 MLD is derived from groundwater. This is still 1070 MLD short of the 4910 MLD demand. This gap is usually filled with groundwater. Notwithstanding the water shortage in Delhi, DJB has calculated that an additional 910 MLD is potentially available from surface waters, as currently only 3385 MLD of the total available 4295 MLD is treated for use (DJB, undated). This leaves possibilities for future improvement of water supply. Furthermore, DJB is taking action to increase the supply of source water in various other ways, in order to overcome the current shortages and meet the expected demand of 6275 MLD in 2021 (DJB, undated).

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[2] Liters per capita per day

[3] Million liters per day

[4] Million gallons per day, Imperial gallons

Though the supply of source water is one of the problems that Delhi is facing, the equal distribution of available water for domestic use is perhaps an even bigger issue. According to DJB, the current per capita domestic water supply is 191 lpcd, which is considerably higher than the aim of a minimum supply of 135 lpcd to all citizens. In 1951 70-80% of the city's population had no access to drinking water. Since then, and taking into account the rapid growth of the city's population, the water supply has improved considerably. Yet despite sufficient central water supply and improved distribution efficiency, still in 2010 almost 30% of the population of Delhi was devoid of a sufficient supply of drinking water (DJB, undated).

More information on water provision in Delhi and the role of the government can be found in Appendix III.

3.2.3. Water access and quality in Delhi's unplanned settlements

Provision of water to Delhi's planned colonies is, though certainly not without some major efficiency issues, covered well by a centralized pipeline system. The largest bottleneck in securing safe drinking water provision to Delhi's unplanned areas is found in limited supply of water to those areas and a lack of treatment and distribution facilities (National Institute of Urban Affairs, 2005; Steps Centre, 2011). Expansion of the city's centralized water network is as yet not an option for these areas, as this would be too costly. Furthermore, connecting slums (often located in the periphery of the city centre) to the central water network would only be feasible when distribution efficiency would be significantly higher than the current level of water supply revenue, which is below 50% (figure of 2010; DJB, undated). Therefore, Delhi's slums often depend on decentralized, local water provision.

Water supply to informal settlements is realized in different ways. Community stand posts[5] are most common in JJ clusters[6] and resettlement colonies[7]. In unauthorised colonies, hand pumps and tankers are used, while urban villages receive part of their water through piped supply and use hand pumps for the remaining water demand (Singh and Shukla, 2005). On average, the availability of water in informal settlements is five

[5] Common water collection points, usually consisting of a pipeline ending with a water tap.

[6] Jhuggi Jhompri clusters: settlements of low income migrant labour groups that have built their residents on government land designed for a different purpose. See Appendix III for a more detailed description.

[7] A group of 44 colonies in Delhi that were designed between the 1960s and 1985. These colonies usually offer better living circumstances than JJ clusters. See Appendix III for more information.

hours a day. In settlements where hand pumps are present, water is available at all times. However, here people have to deal with poor water quality, as groundwater is not treated prior to use (Singh and Shukla, 2005). Furthermore, collecting water is often very time-consuming due to either the distance to a water station or pump, or the unpredictable availability of water.

Though the citizens of Delhi's slums are often able to collect water, be it in time-consuming ways, access to potable water is often non-existent, either due to financial limits or because people do not feel the need to purify their water (TERI, 2007). In case of very poor water quality, measures are taken to purify water before drinking. Commonly used measures are: boiling, sieving with cloth, candle filters, sedimentation, and chlorine tablets (TERI, 2007). In case of illness, boiling is often used as a purification method.

4. Technological solutions for improving drinking water provision

In India the quantity of drinking water that reaches underprivileged communities is usually insufficient, despite the fact that usually enough water is available to supply the entire city (DJB, undated). Because urban slums are unauthorized, provision of drinking water by the municipality is generally either inadequately or not at all organized (Banik, 2011; Batra, 2005). Often people are forced to use hand pump or bore well water or collect water from other neighbourhoods (see Appendix II and III). In addition, if water is supplied through a central pipeline system to a slum, water pressure is often low and in most cases water supply is therefore not sufficient to meet the demand of the community. This low water pressure is caused by pipeline leakages and illegal water abstraction by middle and high income groups who can afford a booster pump for private storage of water.

Besides quantity issues, the quality of water supplied to underprivileged communities often does not meet drinking water standards. Therefore, interventions are needed for treatment of drinking water.

In this chapter, small scale technological interventions will be discussed which can improve the local provision of drinking water in slum communities. They will be described in terms of advantages and disadvantages or limitations, as well as energy use. For the calculation of primary energy use, the Indian average efficiency of electricity production was used, which is 0.308 (IEA, 2010). Furthermore, in the case of electricity use, T&D losses were taken into account (25.39% in 2009-2010 (Central Electricity Authority, 2012)) Table 1 gives an overview of all technologies discussed in this chapter. A decision tree at the end of the chapter shows how to determine the most energy-efficient solution depending on the characteristics of the community.

In order to guarantee a successful implementation of these interventions, they would have to be combined with social, educational and institutional interventions, as well as technological interventions on a larger scale. These will be discussed in Chapter 6.

4.1 Increasing water supply

4.1.1 Extraction of groundwater

The most common solution for overcoming local water shortages is by installing hand pumps or bore wells for groundwater extraction. Though this is an easy way for increasing water supply, extraction of ground water is becoming progressively problematic in large cities in developing countries. Due to high population growth and generally low precipitation rate in these countries, groundwater levels are often declining to disturbing depths (Meenakshi and Maheshwari, 2006). In the past years, the issues around low ground water levels have become more and more clear and conservation of groundwater is therefore becoming an important goal for many urban areas. For this reason, extraction of groundwater is often discouraged or even forbidden by municipalities. However, in those cases where groundwater levels are not at risk, groundwater extraction would be appropriate for increasing water supply.

Advantages:

- Increase of source water supply.
- This measure reduces the dependence on water supply from the government.

Disadvantages / barriers:

- In most cities in India groundwater levels are disturbingly low. In the interests of sustainability, therefore, it is often better to find an alternative way of increasing water supply.
- Groundwater needs to be treated before drinking.

Energy use:

Energy requirement for groundwater extraction is highly site-specific. It depends on characteristics like depth of the groundwater level, water quality, and soil characteristics.

4.1.2 Water tankers

In Delhi, many unplanned colonies receive (part of) their water supply from DJB water tankers. Most of these colonies are not connected to a pipeline network at all, but sometimes communities that receive insufficient pipe water are supplied by water tankers additionally. This water is distributed to the communities directly from the water treatment plant and is therefore of good quality. Water supply by tankers is not a sustainable option in terms of energy use, but can be useful as a short-term solution.

Advantages:

- The supplied water is of good quality.
- Supply of sufficient volumes of water is assured.
- The supply of water is not directly dependent on groundwater level or amount of rainfall, thus continuous water supply is guaranteed.

Disadvantages / barriers:

- This is only a short-term solution. In fact, the problem is only shifted from one place to another and now lies with the municipality. Eventually, the basic water quantity problems need to be addressed, which are related to problems of high water losses in the pipelines and insufficient supply of source water on an urban level.
- Sustainability is an issue, as transporting water over great distances by water tankers is energy consuming.
- Water supply is intermittent.
- Possibly conflicts can arise around an unequal division of the supplied water.
- In India willingness to pay for this water will be low, as it has always been provided for free. Also, ensuring that everybody pays a fair price for their share of water is difficult to realize.

Energy use:

The energy use of water tankers is highly site specific and depends mainly on distribution distance.

4.1.3 Rainwater harvesting

More and more research is being done on the possibility of rainwater harvesting systems. Though such systems are generally more often considered for use in rural areas, this measure can also be profitable in the urban context, as recent studies have shown (e.g. Angrill *et al.*, 2012; Islam *et al.*, 2010; Lange *et al.*, 2011; Srinivasan *et al.*, 2010). Rainwater harvesting systems are usually implemented on a small scale, generally household level. Though rainwater harvesting has proven to be an efficient method for reducing water scarcity on a small scale, it was also found that this method is not always cost-effective (Farreny *et al.*, 2011).

Furthermore, rainwater harvesting requires large surfaces. A study in Delhi has shown that a roof surface of 50 m^2 could harvest 18,330 liters of water yearly (CSE, undated). If for instance water availability in a community would come 1 lpcd short of total requirement, and a population of 2000 people is assumed, this would result in an annual additional water demand of 730,500 l. To harvest such an amount of water, almost 2000 m^2 of roof surface would be needed. This would not be feasible to realise in urban slums on the short term, as it would be too costly to reconstruct the existing buildings and make them fit for rainwater harvesting. However, as a long term solution, and in addition to other water sources, rainwater harvesting is worth considering.

Throughout history, rainwater harvesting has been a widely used method in India (interview Waterkeeper Alliance, Appendix I). Traditional methods were used for building cisterns (so-called bawdi) in which rainwater was harvested, naturally treated and stored. In Delhi, around 1000 of these bawdi used to be operational. Unfortunately, with the arrival of centralized water supply through a pipeline system, the bawdi became unpopular, and after a while these cisterns were completely abandoned. Nowadays, most bawdi are in a state beyond repair or have been used as a foundation for buildings.

The Waterkeeper Alliance tries to bring back this ancient method of water collection by introducing traditional and new methods for rainwater harvesting. Unfortunately, due to high investment costs the feasibility of implementation of this measure is low. For sustainability reasons, however, this method definitely requires further research in order to increase cost-efficiency.

Advantages:

- Low environmental impact, as water does not have to be transported over great distances and ground and river water is preserved.
- This is a long-term solution, as it adds to the amount of source water supplied to the city. Considering the expected population increase in Delhi, this measure can be of significant importance in securing sufficient water supply to the city.
- Rainwater harvesting helps preventing floods during rainy season. Most

rainwater in Delhi falls in about 20-30 days (CSE, undated) during the monsoon. Excess water in the city during this time of the year is a cause of problems. By harvesting part of this water, flooding issues can be reduced (Angrill *et al.*, 2012).

- Increased self-sufficiency: lower dependence on governmental water supply.

Disadvantages / barriers:

- This intervention can only be implemented on a local level; it cannot be used for large scale increase of water supply.
- A large surface is required for this measure. In many areas, especially slums, such space is simply not available.
- There is a considerable risk of contamination of harvested rainwater. Therefore, regular monitoring and additional water treatment is needed.
- Implementation is difficult because of high costs. For the same reason, the technology is not yet widely used. Social acceptance might be low because people are unfamiliar with the technology, but this could be overcome with educational programs.

Energy use:

Centralized energy requirement would reduce significantly by installing rainwater harvesting systems. On average, about 50-80% of total energy requirement of centralized water supply systems is used for intake of source water and distribution of treated water (Goldstein and Smith, 2002; Vince *et al.*, 2008). The remaining share of energy consumption is used for water treatment.

By implementing rainwater harvesting systems, the necessity for importing source water will be reduced, as well as long-distance distribution of treated water. Hence, energy demand is restricted to the treatment process and short-distance distribution, and is therefore significantly reduced in comparison with centralized water supply. Furthermore, as water does not need to be transported over large distances, the risk of water losses will be reduced to a minimum as well.

Energy savings can be calculated as follows: A typical 38 MLD (10 MGD, US gallons) water treatment plant consumes about 15,000 kWh/day (Cohen, 2007). This equals 0.40 kWh/m^3. If 50% of this energy is used for procurement and distribution of water, this would mean that a rainwater harvesting plant could save 3.13 MJ/m^3 primary energy. In addition to that come the energy savings related to reduction of water loss.

4.2 Water treatment

In this section, various water treatment methods will be discussed in terms of purification effects and limitations, implementation potential of the technology, environmental impact, and energy use. Regarding energy use, it was not possible to find all necessary information in literature for calculating energy use of water treatment on a small scale. Therefore, figures of larger treatment plants have been used. Hence, the figures presented here are most likely lower than actual energy use in small scale installations. Still, a comparison of these figures gives a possibility for indicating the most energy-efficient treatment methods.

4.2.1 Slow sand filtration

This method imitates the natural water filtration in rivers and lakes. A slow sand filtration system consists of a container filled with sand in which a bioactive layer of bacteria, protozoa and fungi, a so-called *Schmutzdecke*, is grown naturally which serves to remove suspended solids and micro-organisms (Campos *et al*., 2006). This method removes over 91% of viruses and up to 99.99% of bacteria and protozoa (Peter, 2010). Furthermore, slow sand filtration removes 80-85% of iron. Also, suspended solids are removed up to 99.99% (Willemsen, 2010).

Implementation of this technology is easy and has been done earlier with success (TERI, 2007). The materials used are available and cheap. Regarding sustainability this option is favourable compared to many other filter technologies. No chemicals are needed and electricity use is low. The only environmental constraint of this measure is the need of large land areas. Social acceptance of this measure is expected to be high, as there will be no concern about possible health effects related to the filtration system.

Advantages:

- Relatively low investment and operation and maintenance costs (Campos *et al*., 2006).
- Suspended solids are removed up to 99.99%.
- Sustainable method. Slow sand filtration is low in electricity use as filtration

takes place through gravity, and does not require the use of chemicals (apart from additional disinfection needed). It is therefore one of the most sustainable treatment methods (Vince *et al*., 2008).

Disadvantages / barriers:

- Not all viruses and micro-organisms are eliminated with this method, so additional disinfection is required.
- Effectiveness of the filter is reduced as the *Schmutzdecke* grows. Regular cleaning is needed.
- Not effective in removal of agents like calcium, magnesium, sulphate, chloride, fluoride, and removal of iron.
- Large land area is needed (NDWC, 2000). This system is useful for small communities, but not for larger urban areas.

Energy use:
As water is filtered by means of gravity, the filtration process does not require any energy use. The only energy needed is related to filling the overhead storage tank with piped water. However, since water needs to be stored prior to treatment, pumping source water in an overhead container will most likely be a necessity regardless of which treatment method is used.

4.2.2 Activated carbon filtration

Activated carbon (AC) filters are a common method for removal of organic contaminants from water, as well as chlorine and sediment particles responsible for undesired colour, odour and taste (DeSilva, 2000; TERI, 2007). In this method activated carbon reacts with organic chemicals, metal ions and microbial contaminants present in the water (Al-Qodah and Shawabkah, 2009). Two types of activated carbon are used for water treatment, GAC (granular activated carbon), and PAC (powdered activated carbon). Activated carbon has a high surface area (typically around 1,000 m^2/g (DeSilva, 2000)) in order have an optimal exposure to contaminants. Through physical attraction of the positively charged carbon, negatively charged pollutants are tied to the carbon molecules (Lanouette, 1990).

Implementation is easy as this method is widely used. However, the short lifetime of activated carbon has environmental impacts. Activated carbon is created by subjecting a carbon source to high temperature steam (2300ºF) or an acid bath (Dvorak and Sipton, 2008; Noijuntiraand and Kittisupakorn, 2009). In terms of carbon footprint, AC is comparable to ultrafiltration (Vince *et al.*, 2008) (discussed in Paragraph 4.2.2). Though the treatment process of ultrafiltration is more energy-intensive than AC, the production of AC adds significantly to total GHG emissions.

From the viewpoint of greenhouse implications, therefore, activated carbon has some disadvantages. However, the ease of use and the expected high social acceptance of this measure are plusses. Furthermore, the environmental impact of AC could be reduced by using renewable source material for the production of AC (for instance waste material from agriculture, such as coconut or palm seed shells (Noijuntiraand and Kittisupakorn, 2009)). In addition, if activated carbon could be recycled, this would reduce the need for AC production and thus the associated GHG emissions (Miguel *et al.*, 2001).

Advantages:

- Colour, odour and taste are removed.
- Good performance in removal of specific coliform types (microbial contamination), even at the end of the filter's lifetime (Willemsen, 2010).

Disadvantages / barriers:

- Carbon filters have a short life span (around six months) (Peter, 2010), which impacts the sustainability of the measure.
- No effective treatment when source water is highly turbid.
- Not effective in removal of ions like calcium, magnesium, sulphate, chloride, fluoride, and removal of iron.
- Additional treatment is required for removal of suspended particles and disease causing organisms.
- The technology is associated with relatively high costs, because the filters need to be replaced regularly (Willemsen, 2010).

Energy use:

Dosage of activated carbon is very variable and can range from 1-25 mg/l (Cook *et al.*, 2001). Here, a dosage of 10 mg/l is assumed (10 g/m^3). According to Saffarian (2009), the energy requirement for activated carbon production is 5.76 MJ/kg. At a dosage of 10 g/m^3) treated water, this comes down to an energy requirement of 0.058 MJ/m^3. In addition, energy is required during the purification process with activated carbon filters. This is estimated to be about 0.044 MJ/m^3 (Vince *et al.*, 2008). In total, primary energy use for activated carbon filtration is 0.10 MJ/m^3.

4.2.3 Membrane processes

Ultrafiltration

Ultrafiltration is a recently developed membrane technology and works, similar to reverse osmosis (RO), by the use of a semi-permeable membrane through which source water is led under pressure (Wenten, 1996). Ultrafiltration is still in a stage of development and is not applied on a large scale due to financial constraints (Wenten, 1996). However, due to its far lower energy requirement than reverse osmosis (Peter, 2010; Vince *et al.*, 2008) this method might in terms of energy use become a more attractive option than RO if membrane prices decrease (Wenten, 1996).

The implementation potential of ultrafiltration systems is currently rather low, due to high costs of membranes. However, if membrane price can be reduced with further development of the technology, this method might become a feasible option. In terms of environmental sustainability, however, ultrafiltration has some drawbacks because of chemical production.

Advantages:

- Effective removal of pathogens (Peter, 2010).
- Effective in removal of agents like calcium, magnesium, sulphate, chloride, fluoride.
- Low energy use in comparison with reverse osmosis.
- Suitable for desalination.

Disadvantages / barriers:

- Though energy use is low compared to RO, electricity requirement and overall environmental impact is still significantly higher than slow sand filtration.
- The process of ultrafiltration leads to production of environmentally harmful chemicals (Vince *et al.*, 2008).
- High material cost.

Energy use:

Energy use is calculated by adding energy use for chemicals production and energy use for water treatment. According to Vince *et al*. (2008), the production of chemicals (needed for membrane cleaning) requires about 0.3 kWh/m^3 treated water. Water treatment requires about 0.15 kWh/m^3 treated water. This adds up to a total of 0.45 kWh/m^3, which corresponds to a primary energy use of 7.05 MJ/m^3.

Nanofiltration

Nanofiltration acts through the use of nanoparticles such as nanosilver (nAg) and titanium oxide (TiO_2) which have an antibacterial function (Mahendra *et al*., 2009). The most common nanomaterial used for water purification is nanosilver. Nanotechnology is particularly effective in removing microbial contamination and is usually developed in combination with conventional treatment methods like UV or chlorination. It would add to the effectiveness of UV disinfection since it removes viruses, and it increases the potential of chlorination due to its efficiency in removing chlorine-resistant protozoa (Mahendra *et al*., 2009).

As this technology is not yet widely used, implementation could be difficult. Highly skilled staff is needed for installation of the system, as well as specific materials that might not be easily available. Also the high investment and operation and maintenance costs make this option not attractive at the moment. Furthermore, because people are unfamiliar with the technology, it is not sure if social acceptance will be high (Street *et al*., 2009).

Advantages:

- Nanotechnology effectively removes microbial contamination and has good potential for desalination purposes (Diallo, 2009). Nanofiltration can be used as pre-treatment for desalination processes using reverse osmosis or thermal processes. In the case of reverse osmosis, there is a potential for reduction of energy use, as lower pressure is needed when pre-treatment with nanomaterials has taken place (Mohammad, 2008).
- Effective in removal of ions like calcium, magnesium, sulphate, chloride, fluoride, and removal of iron.
- If combined with a conventional treatment method, nanofiltration increases the reliability of purification.

- No or minimal need for ozonation or chlorination and lower need of maintenance of the pipelines. This is related to the lower potential of microbial activity in the treated water (Liikanen *et al*., 2006). Furthermore, no additional treatment is needed for removing odour and taste, as these are already removed by nanofiltration (Liikanen *et al*., 2006).

Disadvantages / barriers:

- Currently, nanofiltration is still a costly method. Therefore, it will not be economically feasible for small scale use in developing and transition countries. However, with on-going development and improvement of nanotechnology, this method might become an economically viable option in the future (Liikanen *et al*., 2006).
- Environmental impact is high (Liikanen *et al*., 2006; Sombekke *et al*., 1997). Though the need for chemical disinfectants is minimized, the energy requirement, need for regular filter replacement and associated waste production outweigh this advantage (Liikanen *et al*., 2006; Sombekke *et al*., 1997). Furthermore, nanofiltration produces demineralized water, and therefore requires adding environmentally harmful products such as lime and soda (Vince *et al*., 2008). These factors make nanofiltration currently an unattractive option for water treatment in regards of sustainability.
- Because people are unfamiliar with the technology, social acceptance might be low. However, this could be solved through educational projects.
- Difficult implementation due to high material costs and unfamiliar technology.

Energy use:

Energy use for filtration with nanomaterials is very variable. This is probably related to the on-going research on nanomaterials. In theory the energy requirement of nanomembrane filters could be very low (0.04 kWh/m^3, according to Ali *et al*. (2005)). However, according to a report from Liikanen *et al*. (2006), energy use for nanofiltration in practice is currently about 0.29 kWh/m^3, which is equivalent to a primary energy use of 4.54 MJ/m^3.

Reverse osmosis

In reverse osmosis source water is pressurized and led through a selective membrane. This membrane allows small molecules, like H_2O, to pass through while larger molecules, like organic material, suspended solids and natural chemicals are left behind (Mezher *et al*., 2010). The method is generally used in combination with a conventional treatment method (Belkacem *et al*., 2006).

Due to high material and electricity costs in comparison with other treatment methods, the implementation potential of this method is not high. Furthermore, in terms of energy use this method is far from sustainable, since this technology requires high amounts of electricity compared to other technologies (Vince *et al*., 2006). However, the possibility for using photovoltaic power for water treatment with reverse osmosis has recently been studied and found to have potential for use on a small scale (Bilton *et al*., 2011). As energy use forms the largest contribution to overall environmental impact, shifting to renewable energy would significantly decrease the overall environmental impact of this method (Bilton *et al*., 2011).

Advantages:

- Effective removal of microbial contamination, suspended solids and odour and taste.
- Particularly suitable for desalination.
- No harmful by-products are created.
- Social acceptability is expected to be high, as this method comes with minimal health risks.

Disadvantages / barriers:

- High investment and operation and maintenance costs compared to conventional purification methods.
- High energy use (Mezher *et al*., 2010; Vince *et al*., 2006).
- Failure of the treatment system can occur when accumulation of foulant takes place at the surface of the membrane (Belkacem *et al*., 2006).
- Relatively high water loss compared to other treatment methods. RO filters require frequent cleaning and therefore a relative large share of backwash water is created.

Energy use:

Electricity consumption for intake pumping is higher than for other treatment methods because of high water loss. In comparison to ultrafiltration, intake pumping for RO requires about 0.13 kWh/m^3 more (Vince *et al*., 2008). This will be added to total energy requirement. According to Vince *et al*. (2008), the treatment process requires about 3.9 kWh/m^3, while the electricity demand for chemical production is 0.4 kWh/m^3. In total, this adds up to an electricity use of 4.43 kWh/m^3. Primary energy use is 69.40 MJ/m^3.

4.2.4 Disinfection

Chlorine disinfection

Though there are quite a number of chemicals applicable for water disinfection, like chlorine, bromine, iodine, potassium permanganate, and ozone[8] (CPCB, undated), chlorine is by far the most widely used chemical. This chemical is the easiest one in its use, and the cheapest option as well. Chemical disinfection is highly effective in eliminating almost all microbial contamination from water at a cheap rate (Peter, 2010). However, certain cyst-forming protozoa like *Giardia* and *Cryptosporidium* are not affected by chlorine (Mahendra *et al*., 2009). Furthermore, socio-cultural acceptance of this method is low in some places, due to expected odour and taste problems.

On small scale use, chlorine disinfection is, though still inexpensive, more costly than UV irradiation. Only with a treatment of more than 6000 m^3 water per day chemical disinfection with the use of chlorine becomes cheaper (Owen *et al*., 1995).

Implementation is easy and cheap. The technology is well known and available and necessary materials are easy to obtain. However, due to the production of harmful by-products related to chemical disinfection, this method has some disadvantages in terms of health and environmental impacts (Boorman *et al*., 1999).

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[8] Ozone is the second most important chemical disinfectant. However, the implementation of a small scale water treatment system with ozone is difficult. Ozone, being a highly unstable gas, needs to be produced on-site, and an on-site mixing device is required due to low solubility of the product (NDWC, 1999). This will not only complicate implementation, but will also significantly increase capital costs. Hence, the use of ozone as a disinfectant is not advised for small scale installations, and was therefore not discussed in this analysis.

Advantages:

- Easy in use.
- Chemical disinfection with chlorine is relatively cheap in terms of investment and operation and maintenance costs.

Disadvantages / barriers:

- Not all microbial contamination is removed.
- Sometimes there is a low socio-cultural acceptance for the implementation of this measure.
- Chlorine has a short-lived reactivity. Therefore, distribution of water needs to be done shortly after disinfection.
- Chemical disinfectants are associated with health and environmental risks as harmful by-products can be produced during treatment (Mahendra *et al.*, 2009).

Energy use:

Chlorine is used for disinfection in the gaseous form, or as hypochlorous acid or sodium chlorite. The most commonly used form of chlorine is chlorine gas (Cl_2), or elemental chlorine (Solomon *et al.*, 1998). The required chlorine dose depends on the type and amount of pollutants in the source water. In this calculation, a dose of 5 mg/L is used. According to Worrell *et al.* (2000), the primary energy consumption for chlorine production is 51.25 GJ/tonne chlorine. With a chlorine dose of 5 g/m^3 water, the primary energy consumption is 0.26 MJ/m^3.

<u>UV irradiation</u>

This method is effective in removing over 99.9% of water-borne coliform, including two types of chlorine-resistant protozoa (Bell *et al.*, 2009; Peter, 2010). Although investment costs are low for this measure (Bell *et al.*, 2009), operation and maintenance costs are said to be relatively high due to electricity costs and costs for UV lamps (Peter, 2010).

UV irradiation is a commonly used technology and has been used before for small scale water treatment in Delhi's slums (TERI, 2007). Therefore it is expected that this technology should be easily implemented. As the technology requires a regular replacement of UV lamps, the use of materials might be considered as environmentally harmful.

Advantages:

- Removal of over 99.9% of disease causing micro-organisms.
- Low investment costs.

Disadvantages / barriers:

- Relatively high operation and maintenance costs when used on a larger scale.
- In case of high turbidity of source water, the effectiveness of the treatment system is reduced.
- Removal of viruses is limited (Mahendra *et al*., 2009).
- Electricity use and regular replacement of UV lights impacts the environmental sustainability of the method.

Energy use:
Depending on the lamp type used, electricity requirement of UV water treatment is 0.013-0.040 kWh/m^3 (Mackey *et al*., 2001). Primary energy use is 0.20 – 0.63 MJ/m^3.

4.3 Distribution

Management of water distribution will be necessary in the case of water loss related to bad quality of the existing local supply network. There are several ways in which water distribution can be managed:

4.3.1 Single water kiosk

For this measure, water needs to be stored at the place where the main pipeline of the central water supply system enters the community. At this point a water kiosk is placed, where people can collect their water and pay per liter with a prepaid smart card. The kiosk should be operated by someone from the community. A similar project has been executed with good implementation success in a slum in East Delhi by TERI (2007)[9].

A smart card system needs to be installed, as well as a tap point. This will require little material. Furthermore, energy use is also limited compared to the second and third option, as no booster pump needs to be installed to distribute the water to the colony.

[9] Unfortunately, though the project was operating with success for a number of years, conflicts between community members resulted in a stagnation of the project. This should in the future be prevented by putting more emphasis on awareness creation and on a supervisory function of the local government (more on this in Chapter 6).

However, acceptability of this measure might be low due to the increased distance between households and water collection point.

Advantages:

- Equal distribution of water can be managed easily.
- People pay for what they use, so conflicts around possible unfair distribution of water or unfair tariffing are avoided.
- No new pipelines have to be placed, which will save costs.

Disadvantages / barriers:

- Because there is only one point where people can collect water, there might be peak times during the day where people have to wait long for their turn.
- The water collection point is further away for most people than the tapping points they were used to. This might be regarded a disadvantage by the community members.
- Sensitive for social abuse and corruption if not maintained by the right people. However, with awareness creation, involvement of all community members by means of a local association, and a supervisory function of the local government, this risk should be reduced to a minimum. Such measures will be discussed in more detail in Chapter 6.

4.3.2 Pipelines and public stand posts

If community members are used to having public stand posts in the community, a single water kiosk is most likely not a feasible option, as the residents will not approve of the increased distance from household to water source. To enable all residents of the community to have a water collection point nearby, a pipeline system should be constructed (if not already present and in a good state) which supplies to a number of public stand posts spread evenly through the community. Payment should then be done per household per month, the height of the water bill depending on household size.

Implementation is technologically not an issue. Regarding material and energy use this option has a considerably higher environmental burden than the first option, as pipelines and a booster pump are required.

Advantages:

- Water collection points are closer to the houses than would be in the case of a single water kiosk.
- A start of a pipeline system has been made. If central water supply to this area improves (after further development of the area), the local pipeline system can be implemented in the central pipeline system and possible new connections.
- No time is lost on waiting, because each stand post caters to specific households and water supply is continuous.

Disadvantages / barriers:

- It is difficult to keep track of an equal distribution of water.
- Possibly conflicts can arise around inequality of water provision or payment.
- Placing a pipeline system will add to the investment costs.

4.3.3 Pipelines and multiple kiosks

A third option is to construct a pipeline system (if not already present and in a good state) and, instead of installing stand posts, install a number of 'pay and use' water kiosks in the community. The advantage of multiple water kiosks over stand posts is that water collection can be measured precisely and payment can be done per unit of collected watery, like in the case of a single, central water kiosk. A similar system is currently being developed by DJB and is expected to be easy in use and maintenance (IWR, 2012). Community members can buy water by using a smart card.

Implementation of this measure is technologically not complicated. However, this option is more costly and has a higher environmental burden since the water kiosks require more material and slightly more energy. Nevertheless, social acceptance will be high, as this system is similar to what the community members are used to, and a fair payment of water is guaranteed.

Advantages:

- The distance disadvantage from a single water kiosk is addressed, as all community members will have a water kiosk close to their house.
- No time is lost on waiting, because more than one kiosk is available.
- Equal distribution and payment of water is possible.

Disadvantages / barriers:

- A disadvantage of this option is the high investment costs compared to installation of stand posts.

4.3.4 Long term: possibility for individual household connections

In some cases, it might be possible to place individual household connections on the long term, provided that the colony is authorized by the government. If no authorization takes place, individual household connections are not an option as this is a long term and costly intervention. Furthermore, individual connections will only be approved by the government if they are constructed in an authorized colony.

The construction of a pipe system with connections to each household in the area will have to be carried out in cooperation with the community members, in the form of a water user association (the details of this WUA will be described in Chapter 6). This is needed to make sure that the interests of the local residents can be defended at all times. What is important for individual household connections is that the water user association needs to be the mediator between the local residents and the municipality. Though the municipality has to give permission for an extension of the pipeline system, the executive work needs to be carried out by the water user association. Also, the final responsibility for the local pipe network, payment of water, and monitoring should be at this association. The association is accountable to the municipality and in turn receives the funds that the municipality would provide for any community of similar characteristics.

For regulatory reasons, this intervention will be difficult to implement. Only if the colony is authorized the option of individual household connections will become realistic. In addition, a well-organized water user association is required, in combination with a good cooperation with the municipality. Furthermore, the municipality needs to allow the water user association to have part in local decision-making regarding water provision.

Technologically, implementation of this method is only possible if the community estate develops in the future: the buildings need to be fit for individual household connections. Furthermore, material and energy requirement will be high, so financially this measure is only possible if sufficient funding is available. This also illustrates the high environmental burden of this option in comparison to the previously mentioned options. However, social acceptance for this measure will undoubtedly be high.

Advantages:

- This measure will address any inconvenience regarding possible waiting times at a kiosk or stand posts, as well as any distance inconvenience.
- The final responsibility of the local water network is at the water user association, thus alleviating the responsibilities of the municipality and DJB. These authorities are therefore able to focus on the large scale water network or the water treatment plants. If tasks and responsibilities are divided in such a way, it becomes possible for each party to become more specialized and deliver better end results. Furthermore governmental monitoring of different aspects of the water network will become easier if tasks are divided.
- By installing good quality monitors, distribution and payment of water will proceed in a non-discriminatory way.
- As water is stored at the entrance of the community and distributed continuously from there, residents are no longer inclined to illegally install a private booster pump and storage container at their house. This will considerably reduce energy use, as well as water losses due to over-storage and excess of water use.

Disadvantages / barriers:

- Authorization of the colony is essential.
- High investment costs. Large subsidies are needed in order to realise individual household water supply.
- This measure requires approval from and cooperation with the municipality. It is unsure to which extent municipalities are willing to cooperate and change existing regulations.
- Implementation is difficult due to possible institutional constraints.

4.4 Summary and roadmap for decision-making

The previous analysis has shown that significant differences exist between technologies regarding their energy requirement. The results have been summarized in Table 1.

The choice for the most energy-efficient set of technologies depends on the specific needs of a community regarding water requirement, water quality, and preferred distribution system. The decision tree in Figure 2 shows how decisions should be made in order to improve water provision in the most energy efficient way.

Table 1: overview of technological interventions			
Measure	**Advantages**	**Disadvantages / barriers**	**Primary energy use**
Increasing water supply			
Extraction of groundwater	• Increase of source water supply • Reduces dependence on governmental water supply	• Environmental impact of lowering groundwater levels • Treatment necessary	Site-specific
Water tankers	• Good quality water • Sufficient volumes of water supplied • Supply of water not directly dependent on groundwater level or amount of rain water	• Short-term solution, actual problem is not solved • Sustainability issues due to large energy demand • Water supply is intermittent • Possible conflicts around unequal distribution of water • No willingness to pay for water	Site-specific
Rainwater harvesting	• Low environmental impact • Long-term solution, source water supply to the city is increased • Increased self-sufficiency • Helps prevent flooding	• Only small scale use • Large surface required • Risk of contamination of stored water • Difficult implementation due to high costs and unfamiliar technology	Procurement and distribution energy savings of >3.13 MJ/m^3
Water treatment			
Slow sand filtration	• Low investment and O&M costs • Almost complete removal of suspended solids • Sustainable method	• Insufficient removal of microbial contaminants • No effective removal of ions and iron • Effectiveness reduces as biolayer grows • Large land area is needed	-
Activated carbon filtration	• Removes colour and odour • Good performance up to end of lifetime	• Reduced sustainability due to short lifespan of filters • No effective removal of ions and iron • Treatment not effective in highly turbid water • Insufficient removal of organisms and suspended solids • High costs	0.10 MJ/m^3
Ultrafiltration	• Effective removal of pathogens • Effective removal of ions • Low energy use compared to RO • Suitable for desalination	• Relatively high energy use • Production of environmentally harmful chemicals • High material costs	7.05 MJ/m^3

Nanofiltration	• Effective in removal of microbial contamination and desalination • Effective removal of ions and iron • Increased reliability of water purification • Few harmful by-products of water treatment	• Expensive • High environmental impact • Possibly low social acceptance • Difficult implementation due to high material costs and unfamiliar technology	4.54 MJ/m^3
Reverse osmosis	• Removes microbial contamination, suspended solids, odour and taste • Particularly suitable for desalination • No harmful by-products • High social acceptability	• High investment and O&M costs • High energy use • Risk of failure in case of foulant accumulation • High water loss	69.40 MJ/m^3
Chlorine disinfection	• Easy in use • Low investment and O&M costs	• Not all microbial contamination removed • Low socio-cultural acceptance • Short-lived reactivity of chlorine • Health risks due to chemical waste	0.26 MJ/m^3
UV irradiation	• Removal of over 99.9% of disease-causing micro-organisms • Low investment costs	• High O&M costs • Effectiveness reduced in highly turbid water • Electricity and material use impacts sustainability • Removal of viruses is limited	0.20 – 0.63 MJ/m^3
Distribution			
Single water kiosk	• Easy management of fair water distribution • Costs are saved because old pipelines do not need to be replaced • No conflicts around unfair water distribution or tariffing	• Risk of long waiting times • Larger distance from households • Sensitivity for corruption	
New pipelines and public stand posts	• Proximity to households • Possibility to connect new system to central pipeline system • No waiting times	• Difficult to keep track of equal water distribution • Possibly conflicts around unfair water distribution or tariffing • High investment costs	
New pipelines and multiple kiosks	• Proximity to households • No waiting times • No conflicts around unfair water distribution or tariffing	• High investment costs	
Long term: individual household connections	• No waiting times • Less responsibility with DJB • No conflicts around unfair water distribution or tariffing • No installation of individual booster pumps	• High investment costs • Authorization of the colony is essential • Approval from and cooperation with municipality is needed • Implementation is difficult due to possible institutional constraints	

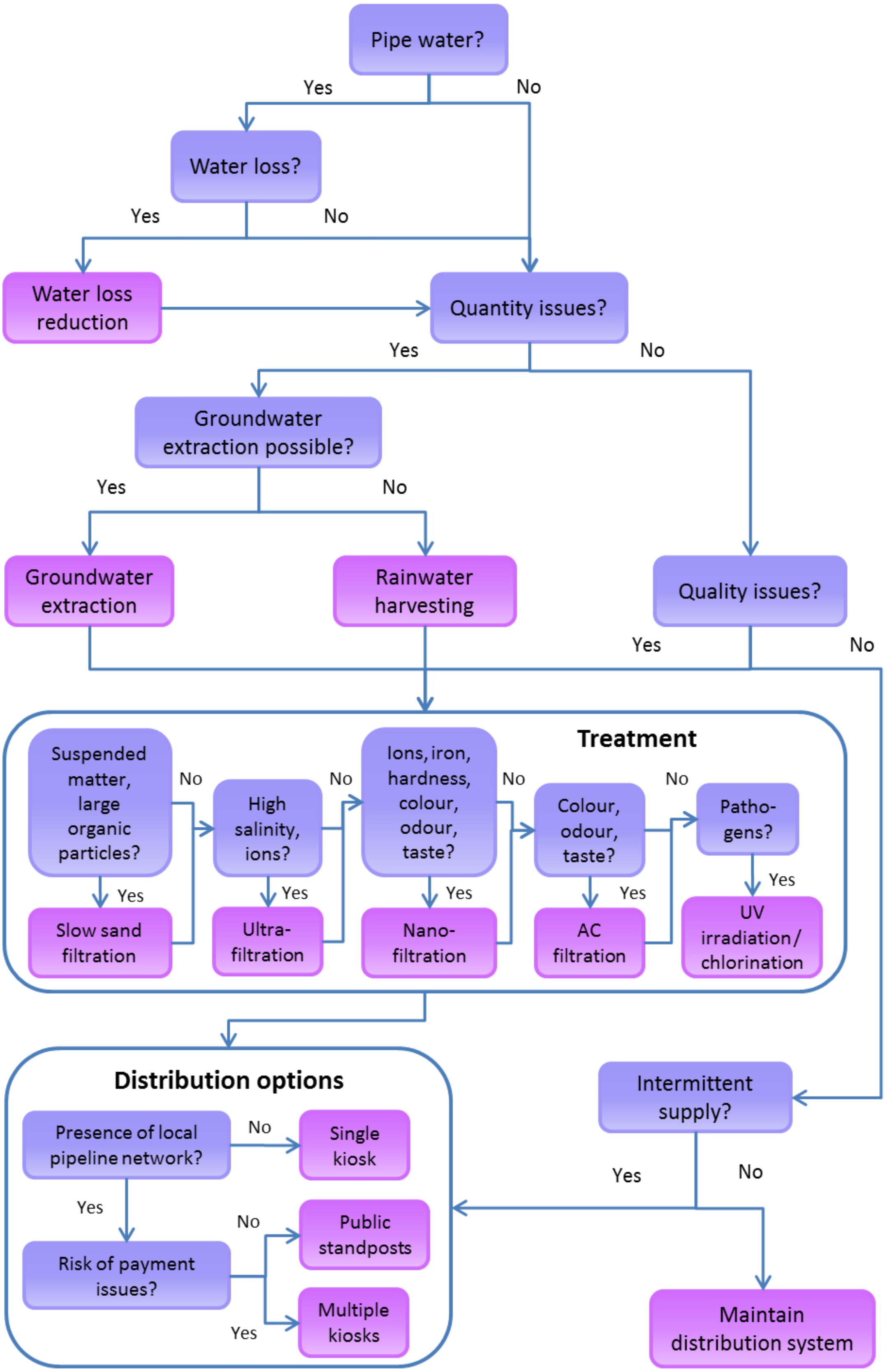

Figure 2: Decision tree for development of energy-efficient and improved water provision system.

5. Case study: Water provision in Safeda Wali Jhugi, East Delhi

5.1 Introduction

In order to test the practical usefulness of the results of the technological analysis, a case study was carried out on water provision in a slum in Delhi. The colony chosen for research was Safeda Wali Jhugi, an unauthorized colony located in the district Geeta Colony in the eastern part of Delhi, east of the Yamuna River. The slum covers about 8000 square meters and contains approximately 300 households[10] (Figure 3).

During four visits to Safeda Wali Jhugi, information of the area was collected by conducting household questionnaires (Appendix IV), mapping the water collection points and sanitation facilities, taking water samples, and interviewing the pradhan, the chief of the community. The results of the questionnaires and water sample tests are found in Appendix V and VI respectively.

A total of 36 households were interviewed during the survey, which equals 12% of the total number of households. The average household size calculated from the data was 5.7. The total population size was estimated to approximately 1700 people.

5.2 General information

5.2.1 Education, occupation and income

The results of the household questionnaires revealed that one-third of the population in Geeta Colony is illiterate (Figure 4). Of the total population, 59% has had basic education, while 8% is above matriculate. The far majority of the population works either as labourer/rickshaw puller, or as a shopkeeper. Monthly income varies between households from Rs.[11] 30,000 to Rs. 96,000. Average annual income is slightly over Rs. 55,000. With a household size of 5.7, this average is just above poverty line as set by the Indian government: in Safeda Wali the monthly per capita consumption is 877 Rs., whereas the poverty line stands at 860 Rs. as per 2012.

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[10] Residents of the area claimed that the jhugi covers between 500 and 1000 households. However, the map on Figure 3 shows that the area is not large enough for this number of households. Therefore the calculations made in this research are based on an assumption of 300 households.

[11] Indian Rupees. Conversion rate: €1 = Rs. 68.1010 (27-07-2012, Reserve Bank of India, http://www.rbi.org.in).

Figure 3: Map of Safeda Wali Jhugi in Geeta Colony. Black lines: borders of the colony. Blue lines: water pipe lines. Red dots: main water collection points. Yellow dots: hand pumps. Yellow square: public toilets. Brown line: Border of area with pipe water supply.

This poverty line has been regularly lowered by the Indian government in the past years, and is therefore highly criticized by international NGO's and media, arguing that actual poverty levels are no longer reflected by the current poverty line (Gill, 2012). When taking into account older Indian poverty lines (for example 2011: 965 Rs.), Safeda Wali Jhugi clearly falls within the category of extremely low income groups.

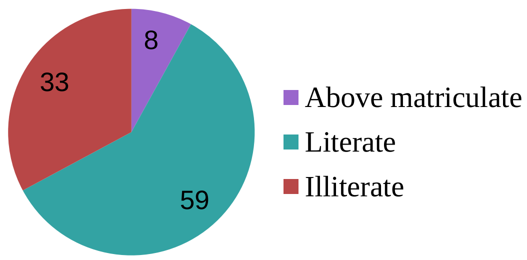

Figure 4: Education level in Safeda Wali Jhugi (Estimated % of population).

5.2.2 Current scenario of water provision

The only source of drinking water in the area is piped water supply from DJB, supplied from Bhagirathi treatment plant in east Delhi. Water is supplied for two hours every day, one hour in the morning (6 am till 7 am) and one hour in the evening (7 pm till 8 pm). This water was originally supplied to 8 public stand posts with water taps. However, over the years additional pipelines have been installed by the residents in order to create more points for collecting water. Furthermore, it was discovered that all taps have been removed from stand posts and pipe endings in a response to continuous low water pressure. Therefore, all tap points in the area consist just of a pipe ending from which water starts pouring as soon as water supply starts.

Picture 1: Discussion on water issues in the community.

Occasionally, additional water is supplied by DJB water tankers, but according to the residents this supply is very irregular and therefore unreliable. The pipe water supplied to the community is used for drinking and cooking. For other purposes hand pump water is used. Both private and public hand pumps are present in the settlement. One public facility is present in the area for bathing, toilet use, and washing. The water in this facility is supplied by a bore well run by DJB.

Water quantity as well as water quality were reported to be an issue in the area (Figures 5 and 6). In general, quantity of water supply was regarded as more problematic than quality. Especially during the summer months the amount of water supplied to the colony was found to be insufficient to meet demand. Issues with water quality were also stated to be more serious during the summer. In winter months, both water quantity and quality are less of an issue, though still prevalent.

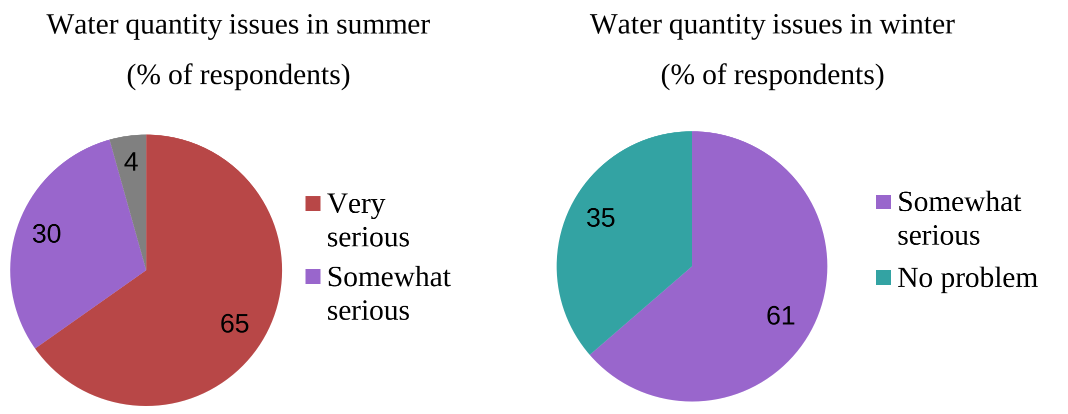

Figure 5: Water quantity issues in summer and winter, as perceived by local residents.

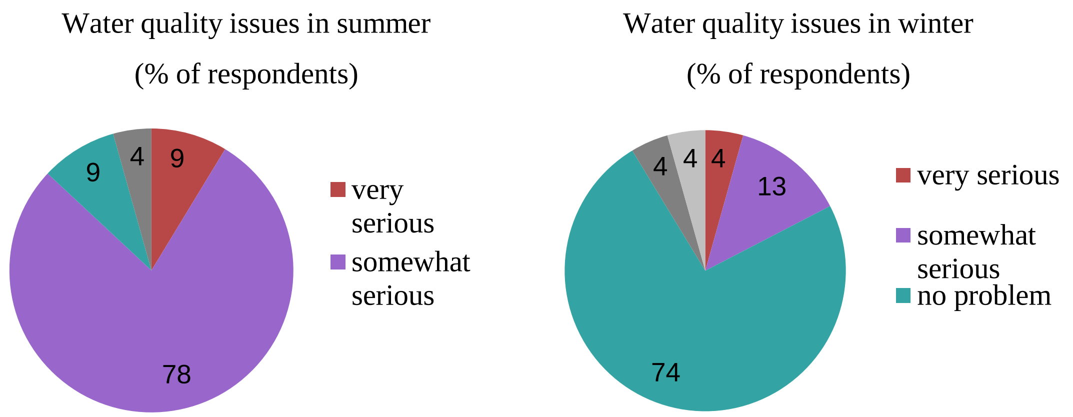

Figure 6: Water quality issues in summer and winter, as perceived by local residents.

On a survey during one of the morning water supply times it was found that water supply started around 6.00 am and ended around 7.15 am. According to the engineers at the local booster pumping station responsible for the supply to Geeta Colony, supply of pipe water takes place every day from 6 am to 7.30 am and from 7 pm to 8.30 pm. However, the pipelines to Geeta Colony are usually already closed about 15 minutes before the official end of supply. The colonies that are the furthest away from the booster pumping station will experience this first. Geeta Colony is one of these colonies, and therefore receives water for only 1 hour and 15 minutes each time water is supplied.

From ten minutes before the start of water supply in the colony queues started forming at public tap points. Water was collected mostly by adults, both men and women.

The most common storage containers used by the residents were plastic 20 liter water bottles as seen in picture 3. Also larger containers up to 40 liter were used, as well as plastic buckets of different sizes. Most of the containers were closed after filling, although many of the buckets remain open during and shortly after transport to the household. During storage, however, the containers were closed. Most of the containers were washed before filling. A few people washed their hands before filling the container, but this did not seem to be common practice.

Some of the water taps were for public use, while others were for private use. A number of people had a tap point inside their house or close to the entrance to their house. At those points water was only collected by the owners of the house. Therefore, at many of those taps water was wasted as the owners were not filling their containers there continuously.

During water collection, it was seen that people use water running from the pipes for bathing and washing utensils. However, this is only done by the people that have an individual household connection or a connection close to their house. After the time of water supply, stored tap water is used almost exclusively for drinking and cooking.

Picture 2: 20l water containers.

It was noticed that many water tap points were located very low to the ground. At many of those places a hose was connected to the tap and used to fill the containers (picture 4). In many cases the end of the hose was hanging in the bottle or bucket, often touching the water. After use the hose was often left on the ground, which leads to contamination.

Picture 3: Water collection with a hose.

Due to construction of additional tap connections by local residents, the flow rate in the pipelines has reduced a great deal and was found to be very variable among tap points. About three of the original eight stand posts were still working reasonably well. One was located at the entrance of the community, and two in one of the main streets there. The other stand posts had quite low flow rates, comparable to that of the individual household connections.

In total there were 11 hand pumps, available for public use. The total number of water taps in the colony was 51. Table 2 gives an overview of the distribution of water taps in the colony. The taps inside the houses (indoor taps) were for private use, while the outdoor taps were for public use.

Table 2: Distribution of water taps

Location	Outdoors, nr of connections	Indoors, nr of connections
First main street	18	5
Second main street	12	6
Side streets	6	4
Total	36	15

A part of the colony, located at the south-west side on the map, does not have access to any stand posts. The last stand post in that direction is located near the temple at the north west side of the colony, but this stand post is not functioning. The households that have no access to the stand posts in the colony go to other places in Geeta Colony to fetch their water. As the water taps are not close by people often take a cargo bike with a number of 20 liter water containers and fill these once a day, usually in the morning. This water is primarily used for drinking and cooking, and occasionally for washing utensils or bathing babies. The people of this part of the colony generally do not take water from the public stand posts inside Safeda Wali Jhugi, as they have to wait for the nearby households to first collect their water before they are allowed to collect water for themselves. Often water supply has already stopped before these people get the chance to fill their containers. Furthermore, no hand pumps are available in this particular area either, so also for non-domestic purposes the inhabitants of this area rely on water from other areas.

5.2.3 Sanitation

A facility with public toilets is located in the north-west corner of the colony and is supplied by groundwater from an independent bore well, running on electricity. Water is pumped from this bore well to an overhead tank and stored there. This facility is used for toilets, washing clothes and bathing. In total there are 13 toilet seats for the men and 11 for the women. Furthermore, there were 3 closed bathrooms for the women and 2 hand wash taps. For the men there was one open bathroom with 5 taps for bathing and 2 hand wash taps.

The water from this bore well is never used for drinking or cooking, as it is very hard according to the residents. Another bore well that used to supply water to the whole community but which has been out of operation for the past years, is located across from the public toilets. A third, also not operating, is located at the parking place next to the entrance of the colony.

A second public toilet facility is located across the street that passes the entrance of Safeda Wali Jhugi. This facility is used by another slum area located there, but also by the residents of Safeda Wali, as this is a rather large colony compared to its neighbour.

According to the residents water supply to the public toilets is of sufficient quantity. However, at times of a power failure, which happens sometimes during the summer, water is not supplied to the toilets and people have to bring their own stored tap water. This problem is not regarded as very serious by the residents.

5.3 Observed water-related issues

5.3.1 Water quantity issues

According to the citizens of the colony, water supply is not sufficient to meet the demand of the community. Though most respondents said that there are no conflicts between users of DJB stand posts, they do acknowledge that there is a 'normal' amount of disturbances during water supply.

Furthermore, the fact that water supply is so limited in terms of quantity adds significantly to the time needed for fetching water. Though every household has a stand post nearby, it takes on average 53 minutes a day to collect water. This has to do with the fact that people have to be at the stand posts early in order to get a share of the water supplied, and sometimes have to go a second time if they were not able to collect water the first time.

It was discovered that a bore well was present near the entrance of the colony and had been operating until a few years ago. From the time that Bhagirathi water treatment plant started supplying to the area; however, the bore well has been shut down on the assumption that enough water would reach the colony through the pipelines of the treatment plant. In addition, closing the bore well was part of a city-wide policy to reduce over-exploitation of groundwater and the related risks of contamination.

It was discovered that quite some water gets wasted during supply hours, probably because some taps were not used for filling water all the time. A lot of water was seen being discharged through the drains at the sides of the streets. This of course also includes the water used for washing utensils, bathing, and washing the containers.

Though people claimed that water never gets wasted at Geeta Colony, practice showed that water wastage is indeed present. This could be one of the factors for the water shortages in the community. Although all people stated they had a shortage of water, they also claimed that the community is very cooperative and allows everyone to collect a necessary amount of water. Thus everyone in the community usually gets to collect water during supply, but in the end the total amount of collected water was reported not to be sufficient for the households.

5.3.2 Water quality issues

Though water quantity issues were regarded as more pressing than water quality issues, almost all respondents expressed their concern about the quality of their drinking water.

The pipe water supplied to the community was reported to be of a yellow colour at the onset of supply, and sometimes muddy or blackish. This would last for about 5-10 minutes before the water became clear. The water that comes out of the taps in the first ten minutes is therefore discharged and not used for potable purposes.

The residents stated they did not know what factors could be responsible for bacteriological contamination of their drinking water. They further said that the yellow water reported to be present during the start of supply, does not occur each time of supply. During the rainy season this yellow water is more common than outside the rainy months, or at times of construction on the water system or leakages. However it occurred regularly that the first tap water would come out slightly coloured (yellow), most often occurring in the evening. This could possibly be block water, accumulated during non-supply.

Hygiene is maintained by regularly cleaning the drains and removing garbage from around the stand posts. Nevertheless, a survey revealed that the drains and surroundings of stand posts were still very much below a desired hygiene level. This was also acknowledged by the residents of the community. Water containers were often washed before filling them with water.

More than two-thirds (69%) of the residents collect water from their household container by dipping with a small container without handle, which comes with high contamination risks. The other 31 % used a container with tap.

Several water samples have been tested in order to get an idea of the contamination factors. Water samples were taken from the tap points during water supply, water storage containers, a hand pump and the bore well. For the results of these tests, see Appendix VI. It was found that all water samples stay within the permissible limit of all tested factors except bacteriological contamination. The hand pump water exceeds the desirable limits for TDS[12], total hardness, calcium, magnesium, and chloride, but stays within the

Picture 4: Cleaning of water containers.

[12] Total Dissolved Solids

permissible limits of these parameters. Similarly, the bore well water exceeds the desirable limits for TDS and calcium, but stays with all non-coliform parameters within the permissible limits.

Among the tap water samples the highest bacteriological contamination was found in water from a tap point collected at the onset of supply. Here total coliform was as high as 1000 MPN[13]/100ml. This indicates that the water supplied from Bhagirathi treatment plant is contaminated during distribution, presumably due to leakages in the pipelines. These could be leakages in the main pipelines, but might very well also be leakages in the illegal and low quality individual pipelines that have been constructed by the residents of Safeda Wali Jhugi themselves.

At a later moment during supply, the coliform contamination of this tap water was found to be much lower, 29 MPN/100ml at the same tap point. This could be explained by the fact that water supply is intermittent. Hence, when water supply is stopped, contaminants add up in the pipelines due to low water pressure. Upon supply of water, this build-up of contaminants leaves the pipelines first, after which cleaner (but clearly still contaminated) water follows.

Stored water from the same tapping point was found to have a bacteriological contamination of 400 MPN/100ml, and thus much higher than the 29 MPN/100ml found at the timing of supply. It could be that this water was collected at the beginning of supply. This is, however, unlikely since the residents are aware of the higher contamination during onset of supply, and therefore wait with water collection until the water is cleaner. Therefore, it is assumed that this contamination has taken place during collection or storage of the water.

Picture 5: Water sampling.

Despite the observed contamination, water-related illnesses were found to be not frequently occurring in the area (Figure 7). Only a small part of the money spent on doctor's fees is related to diseases like diarrhoea or skin diseases (only 3% of total monthly medical expenses; see Table 3). Nevertheless, though water-borne

[13] Most Probable Number

illnesses do not seem to occur much in the area, the residents were quite concerned about their health and expressed their wish to have clean water and reduce the risk of diseases. Furthermore, all respondents stated to be willing to pay for the provision of clean drinking water to their colony (Figure 8).

Table 3: Medical costs	
Type of costs	**Amount/percentage**
Total average monthly medical costs (costs per household per month)	Rs. 514
Average monthly medical costs for water-related illnesses (costs per household per month)	Rs. 17
Costs for water related illnesses / total costs	3.31 %

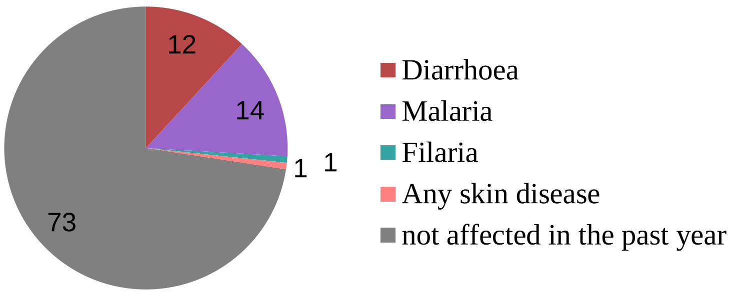

Figure 7: Occurrence of water related illnesses (% of population affected in the past year).

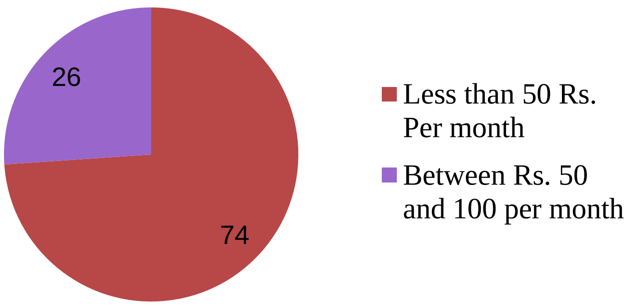

Figure 8: Willingness to pay for the provision of drinking water (% of households).

5.4 Suggested interventions for Safeda Wali Jhugi

5.4.1 Summary of drinking water related issues in Safeda Wali

Concluding from the previously discussed scenario in Safeda Wali Jhugi, the main water-related issues in the community are as follows:

1. ***Shortage of water supply***

Insufficient availability of water, mainly a consequence of significant losses during supply, was considered by the community as the most pressing problem in the area. According to the Indian Standard for water supply (Bhavan, 1993), communities that are supplied by public stand posts should receive 8 lpcd for drinking and cooking. However, it was found that the people in Safeda Wali Jhugi receive on average only 5.8 lpcd. Thus, there is a shortage of supply of 2.2 lpcd.

2. ***Insufficient water quality***

Water quality does not meet the Indian standards for drinking water, due to bacteriological contamination (ranging from 29 MPN/100ml to 1000 MPN/100ml) and regular occurrence of colour and mud in pipe water supply. Thus, treatment is required prior to distribution to the community.

3. ***Inconvenience of intermittent supply***

Intermittent supply increases the waiting times during collection of water. Furthermore, people are forced to stay at home during specific times of the day, which reduces their mobility. This problem can easily be addressed by managing water distribution.

4. ***Insufficient hygiene practiced during water collection, use and storage***

Though the community members are aware of the importance of preventing contamination of water and are trying to ensure that water stays clean, there is still a lot of improvement possible for reducing contamination risks during collection, use and storage of water. For example, the use of hoses for collection from the tap points and dipping water from household storage containers are both associated with high contamination risks. Educational measures are needed to improve hygiene practices.

To address these issues, several measures need to be taken in terms of technological interventions, but also social, educational and institutional measures are required. In this paragraph, the most suitable technological interventions will be identified, based on the decision tree of Chapter 4. Chapter 6 discusses the additional interventions that are required in order to ensure the support of the community and achieve a successful deployment of the suggested water provision system.

5.4.2 Suggestions for improved water treatment and distribution

The choice for a water treatment method depends on type and level of water contamination. The water supplied to Safeda Wali Jhugi was found to show coliform contamination, as well as regular occurrence of mud and yellow colour. In order to make disinfection effective, large (organic) particles and colour need to be removed first. Slow sand filtration would be the most energy-efficient, step for removal of organic particles. Subsequently, removal of colour and coliform could be done through nanofiltration or a combination of activated carbon filtration and a disinfectant. The technological analysis has shown that nanofiltration, if only used for removing microbial contamination and colour and odour, is currently not a realistic option due to high costs and energy use. Therefore, a combination of AC and a disinfectant is a better option in this case. Removal of colour and microbial contamination can be done through a combination of activated carbon filtration and chlorination (0.36 MJ/m^3) or carbon filtration and UV irradiation (0.30 – 0.73 MJ/m^3).

From an energy perspective, the use of UV irradiation is preferred over chlorination here, as it allows the possibility for achieving the lowest possible energy requirement for water treatment (0.30 MJ/m^3). Furthermore, the use of UV irradiation allows the possibility of using renewable energy on-site in the form of for example solar panels. In the case of chlorination this is not possible since the energy requirement for this method is related to chlorine production. Thus, no on-site energy improvements can be achieved. Furthermore, the use of solar energy for UV irradiation would make this option attractive in terms of greenhouse gas implications. If UV lamps could be powered by solar panels, the only greenhouse gas emissions from this method would be related to the production of the lamps and the solar panels. In addition, primary energy requirement would be reduced significantly when using local solar panels, as there would be no conversion and transmission and distribution losses. Primary energy requirement would thus be between 0.013 and 0.040 MJ/m^3.

In addition its benefit of achieving low energy requirement, UV disinfection does not have the negative side effects of producing harmful chemicals associated with chlorine disinfection. Whereas an excessive use of chlorine could injure health and environment, this risk is absent in UV irradiation.

The acceptance of UV irradiation as a treatment method is expected to be high in this community. UV irradiation is a well-known technology and has been successfully implemented in another slum in Delhi, with approval and cooperation of the local residents (TERI, 2007).

After treatment of water, the most energy efficient method for distribution would be a kiosk. This method would not require energy for distributing water through pipelines. However, since the residents are already used to having water tapping points close by, they will most likely not approve of this measure. Therefore, in the case of Safeda Wali Jhugi, stand posts or pay-and-use water kiosks would be preferable. Since pay-and-use water kiosks have the advantage of fair water pricing and guaranteed payment of water, this option is preferred over stand posts.

An overview of the most suitable and energy efficient solutions regarding water provision in Safeda Wali Jhugi is given in Figure 9.

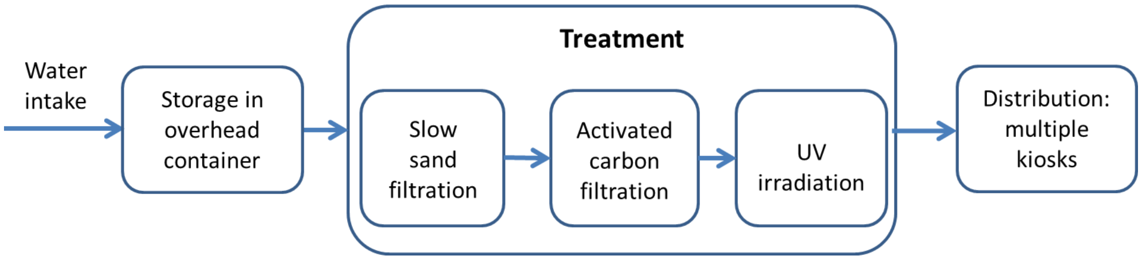

Figure 9: Overview of suggested interventions for Safeda Wali Jhugi.

The pipelines should supply to a sufficient number of kiosks that each cater to a certain share of the community. If one kiosk is placed for every 30 households, 10 kiosks would be required in total. As the community now officially only has 8 public stand posts, it is assumed that 10 kiosks will be sufficient for the community. Though some people are now used to individual supply, it is assumed that they will prefer the suggested intervention of water kiosks, as the continuous supply it ensures is a great advantage.

To make sure that the surroundings of the kiosks remain clean, they should be placed on an elevated platform and cleaned regularly by someone assigned for this job by the water user association. Furthermore, all stand posts will have a tap that will regularly be checked, in order to make sure it is functioning well and is not being removed. Furthermore, the pipelines need to be checked regularly to prevent the construction of illegal individual connections.

The suggested water provision system addresses three of the four issues identified in Safeda Wali. Water provision is increased by the construction of a new distribution system. If this would remain insufficient to meet the demand of 8 lpcd, additional water requirements could be met by supplying water with DJB tankers, and on the long term by installing rainwater harvesting systems. Water quality issues are addressed by treatment. In addition, this system allows for continuous supply because water is stored prior to treatment. The last issue of insufficient hygiene practices needs to be solved through educational measures, which will be discussed in the next chapter.

6. Additional required interventions

The interventions suggested in the previous chapters would theoretically be suitable for improving provision of drinking water in urban slums. However, it needs to be stressed that the support of the community stands at the basis of all possible interventions. Community members need to be willing to participate in any intervention and be aware of the importance of the interventions that are proposed. Therefore, additional interventions are necessary that will increase awareness among locals and their participation in decision-making on implementing technological solutions. A summary of the proposed interventions is given in Table 4.

Furthermore, all interventions discussed so far are interventions on a community level. However, in the context of the large scale issues around water provision in urban areas, decentralized water provision only offers a small contribution to improvement. Centralized water supply, generally associated with disturbingly high water losses in developing and transition countries, remains untouched with these measures. Therefore, additional interventions are required in order to improve the efficiency of centralized water supply. Most of these interventions will be focused on reducing water loss, which could result in significant energy savings. A summary of the proposed interventions is given in Table 5.

The interventions suggested in this chapter have been based on the findings from the field research at Safeda Wali Jhugi, interviews with experts (Vitens, DHV, DJB, see Appendix I), as well as literature review of similar case studies (Bell *et al.*, 2009; Development Alternatives, 2005; Ryan *et al.*, 2006; Singh and Shukla, 2005; TERI, 2007; Velleman, 2009).

6.1 Interventions on a local level

6.1.1 Increased awareness through education

A program aiming at increasing awareness on water and health is essential for reducing the risks of water contamination during collection and storage of water. Furthermore, such a program will make people more aware of the water quantity issues in their community, and of the need for better water management. There are several ways in which education on water issues can be given:

- Public lectures in the community on water issues and possibilities for solving these issues, and on their rights regarding provision of safe drinking water

- Workshops aimed at increasing awareness and at active involvement of the community members. These workshops should leave room for feedback and group discussions. Furthermore, workshops at the health centres of the community will serve as means in which people can actively increase awareness on the link between water and health and the importance of hygiene.
- Education for children in school or at the community by using methods that interest them, e.g. through street plays or board games designed around water-related issues, or by showing films related to the topic.

Effects:

- Awareness is increased on community members' rights regarding water provision.
- Knowledge on water and health issues is increased, and therewith the awareness on the importance of clean water.
- Through education from a young age, future generations will be more inclined to work towards making water provision clean, efficient, and sustainable. This will have long term benefits.

Limitations:

- The actual effects of awareness raising projects will depend upon the cooperation of the community. If there is little willingness to cooperate by way of changing behaviour in order to increase hygiene, and to pay for the water provision, it will be difficult to make progress on the long-term.

6.1.2 Water user association

A water user association (WUA) is necessary to stand at the basis of any intervention that is implemented in the area. This association will be appointing the people responsible for the operation and management of a newly introduced system, and will ensure that any issues related to water or to the new intervention are properly addressed. This WUA is necessary in order to ensure that local residents become involved in the new water provision system. In addition, the WUA cooperates with local NGOs which will have a function in additional water related or social projects in the area. The WUA, in combination with local NGOs will also function as a source of information regarding water related topics. Furthermore, the WUA is responsible for collecting the fees that are paid by the consumers.

The water user association includes a number of staff members, preferably all coming from the community. Each staff member has specific responsibilities:

- Chairman: Holds final responsibility for all decisions made in the WUA. All other staff members are accountable to the chairman and need approval from the chairman for any measures taken. Furthermore, the chairman is responsible for maintaining contact with (potential) funders, DJB and other government agencies that are involved in water provision. Finally, the chairman is responsible for maintaining relations with the community members.
- Plant operator: Is responsible for operation and maintenance of the water storage and treatment plant, as well as for the distribution system. Supervises proper use of water taps if stand posts are installed, and proper use of the pipelines. Any disturbance of the system (e.g. removal of taps or construction of illegal pipes) should be solved and reported to the chairman or DJB if judicial measures are needed.

Furthermore, an accountant would have to be employed for the financial administration of the water provision system. This person keeps track of payment of all costs related to water provision in the community, including costs made for educational projects related to water and any other cost made by the water user association. Additionally, the accountant is responsible for keeping track of payment by consumers. This job should be performed by someone from the municipality or from local water works (like DJB in Delhi).

The involvement of the local government or local water works is crucial for a long term success of the WUA. Not only is the municipality in this way able to keep track of what happens in the community, as an outside monitoring agent it also has a regulatory function in the case of inherent conflicts or reduced confidence of the community members. In addition, the involvement of the municipality is needed in order to maintain the connection with centralized water supply. Therefore, it would also be preferable if the municipality would be responsible for the primary investment of the local water supply system and would thus become the owner. All revenue from drinking water supply would then also go to the municipality, while the WUA receives a share for their effort and labour hours. The WUA would then in a way be hired by the municipality. The advantage of this is that on the long term it would be easier for the municipality to switch to water supply on a household level, since it owns the facilities that are there already. In addition, if the municipality becomes aware of the financial benefits of improving and tariffing water provision on a local level, this might give an incentive for investments in improving drinking water provision in other areas as well.

Of course it is very likely that a municipality is not willing to provide the investment costs for a new water provision system. In that case, investments would have to be done by an NGO or other interested organization. In any case, the local residents will most likely not be willing to provide the capital costs for installing a new water provision system, first because they simply don't have the financial means, and second because this would result in high risk of inherent conflicts over costs and benefits (Development Alternatives, 2005).

In the case of Safeda Wali Jhugi and similar small communities, all these positions would be part-time functions, since the intervention required there is only a small one. Depending on the responsibilities and working hours, the staff members should receive a generous wage, in order to make sure their work is taken seriously and performed with care (Bell *et al.*, 2009).

The work of all staff members of the WUA needs to be verified by the municipality or someone from the municipality, in order to make sure that tasks are performed properly and an honest working attitude is maintained.

Effects:

- A voice is given to the community members. They will become more involved in solving their community's water-related issues and as they will feel responsibility towards their community they will be more inclined to really make an effort for improvement.
- Direct measures can be taken when needed, adapted to the specific needs in the community. Though the municipality will still have an overall controlling function, the executive work and local decision-making is done by the WUA, which will reduce time loss due to bureaucratic burdens.
- The implementation of a new water provision system can be monitored closely. Hence, potential problems will be noticed immediately.

Limitations:

- Cooperation of the municipality and local water works is needed. It is not sure if they will allow a WUA in this form, as government may be of the opinion that too much bureaucratic freedom is given to the community. However, if the municipality maintains an overall controlling function over the WUA, the WUA actually becomes part of the local government and can thus be seen as a government agency.
- Cooperation and trust of the community members is needed. If the community has no confidence in the WUA, the organization will never be successful. Therefore, the staff members of the WUA need to be well respected and reliable people from the community. Furthermore, their actions also need to be closely monitored by someone from outside the community, such as Water Works or the municipality.

6.1.3 Fee for provision of clean water

A small fee is asked from the consumers for the clean water that will be provided with the implementation of a novel system. The method of payment depends on the type of system that is installed. In the case of kiosks, water use is easy to monitor, and people can pay by the amount of water they use, for instance by means of a smart card. If stand posts are installed, it is not possible to monitor water use. In that case payment is done monthly per household, the tariff depending on household size. A fair fee would be around 30-60 Rs. monthly per household (Bell *et al*., 2009; TERI, 2007). The questionnaires have shown that the people of Safeda Wali Jhugi are willing to pay this amount of money if they are ensured with a continuous supply of safe water for drinking and cooking (see Figure 6 and Appendix V).

Effects:

- A fee charged for the provision of clean water in the community can cover the operation and maintenance costs of the implemented interventions, as has been shown by several similar projects carried out (Bell *et al*., 2009: TERI, 2007). If possible, this fee could pay back the initial investment costs as well (Bell *et al*., 2009).
- Charging a fee will increase people's awareness on the importance of clean water. Since water treatment takes place in their immediate environment, they

can see the difference a water treatment facility makes, understand the costs that are related to it, and, upon using the treated water, value the benefits of the new treatment facility. This will help them to understand the importance of making a small financial contribution to water supply.

- Furthermore, it is expected that when the residents start paying for their water, they will become more careful about their water supply system because by paying they will have a stronger feeling of partial ownership of the supply system, and hence a stronger feeling of responsibility for maintenance of the system. Thus, the residents will be more inclined to keep pipelines and stand posts clean and intact. Because people pay for their water, social control on the maintenance of the water supply system will be increased and placement of individual connections will no longer be tolerated by the community.

Limitations:

- The whole community needs to support the decision to implement a new water provision system that will require a fee from the consumers. After the installation of a new system people will no longer have the option to receive free water from DJB, as all water is stored and treated. In the case of Safeda Wali Jhugi this is not an issue, as the results of the household questionnaires have shown that everybody in the community is willing to pay a fee. Yet, if there would be any doubts among the community members, it is expected that a well-organized education program will convince the residents of the importance to pay for water.

6.1.4 Summary

Table 4: overview of local level additional interventions			
Measure	**Tools**	**Effects**	**Limitations**
Education	Public lectures, workshops, child education	• Increased awareness on human rights • Increased awareness on the health benefits of clean water • Long-term benefits of educating the young	• Cooperation of the community members is needed
Water user association	Established by community members	• Responsibility with community • Direct measures can be taken • Close monitoring is possible	• Cooperation of DJB is needed • Cooperation and trust of community is needed
Fee for water provision	Fixed monthly contribution or pay per liter. Possibly IBT	• O&M costs are covered • Increased awareness • Increased social control	• Support of the whole community is needed

6.2 Interventions on a larger scale

The interventions suggested in the preceding paragraphs and chapters all focus on small scale solutions. However, to address the larger water-related issues of Delhi, some large scale interventions are of crucial importance. Eventually, if these large scale measures are not taken, the actual problem of urban water loss will not be solved and, in terms of both quantity and quality issues, the effect of the small scale solutions will remain limited. If central pipelines will remain to be of low quality, this will not only result on significant water losses, but also in unnecessary water contamination. With the prospect of an ever growing population in Delhi, water collection, treatment and distribution need to improve significantly in order to ensure a provision of sufficient volumes of clean water in the future. Currently a large share of the water supplied to Delhi is lost. According to DJB, 50% of all water that leaves the treatment plants is lost in terms of revenue, either in the form of physical leakages (accounting for 20-30%), or non-revenue loss due to illegal tapping and water supplied for free to slum areas (accounting for 20-30%) (Interview DJB, Appendix I). By monitoring water use and loss, tariffing water and renovating the pipe system physical water loss can be reduced significantly, and revenue can be increased a great deal due to a reduction of non-revenue water.

6.2.1 Monitoring of water use and loss

Currently, most water meters that are installed are not functioning properly. Therefore, water is often not paid for and leaks or illegal taps go unnoticed. By installing proper functioning water meters in the water network as well as in all households, both water use and loss can be monitored.

Effects:

- Water loss is reduced because leaks and illegal taps can be located.
- With proper household water meters, water use can be measured and be paid for. This will increase the income from water sales.

Disadvantages / barriers:

- Implementation difficulties due to bureaucratic constraints.
- Because of its proportional connection to payment, water meters can be subject to deliberate damaging and manipulation. However, good supervision and a financial sanctioning system should minimize this risk.

Implementation potential and environmental burden:

The implementation potential of this measure is currently very low, due to reluctance of the government to install water meters. The general thought is that installing water meters is a costly measure, which is furthermore associated with infrastructural constraints due to the necessity of uncovering underground pipeline networks. However, a recent study by the Centre for Civil Society (CCS, 2003) has shown that this option might well be far more realistic than has always been assumed. Installing water meters is not only a cheap measure when viewed in the light of DJB revenue from drinking water, it is also a very effective measure for increasing revenue from drinking water and reducing water loss in an efficient way. Placing water meters enables the possibility of a targeted approach towards pipeline leakages. Thus, instead of the need of replacing an entire pipeline network, replacements can be restricted to those locations where leakages have been found.

For the same reasons, this measure will on the long term have a positive effect in terms of environmental burden. Though material and energy is required for placing water meters, the resulting reduction in physical water loss and the possibility for effective, site-directed improvement of the pipeline network will reduce the long term environmental burden of the current pipeline network (see also paragraph 6.3).

6.2.2 Tariffing all distributed water

To make sure water provision is taken seriously and done in a proper manner by the government, the costs recovered from provision of drinking water need to cover the costs made by the government. Therefore, consumers need to pay a fee for the water provided to them. This will also make sure that consumers become more aware of their rights and are more inclined to protest when water supply is not efficient in terms of quantity and quality (they can 'demand' good quantity and quality of water since they pay for it). Though ideally this would require individual household connections (with well-functioning water meters), this is not possible for the unauthorized areas, as DJB is not capable of increasing the water supply system with the same rate as the current rate of the city's expansion. However, several non-governmental projects have shown that local water supply points, for example a water kiosk (TERI, 2007), can be an effective method for supplying sufficient volumes of clean water against a small fee, which covers investment and operation and maintenance costs. Furthermore, the preliminary field study in six slums in Delhi and the case study of Safeda Wali Jhugi have shown that people living in the peri-urban areas of large cities are willing to pay for their water. Other studies from literature have found the same results (Bell *et al*., 2009; TERI, 2007; Velleman, 2010). Thus, there is a potential to increase the government's cost recovery from water supply.

Effects:

- By using an increased block tariff[14], operation and maintenance costs of the water network can be covered.
- As was explained before, charging a fee will increase people's awareness on the importance of clean water, as well as make them more careful about their water supply system.
- More monetary means will be available for investing in new methods of water provision, for example rainwater harvesting.

[14] A tariff structure in which a basic volume of water is provided for a very low tariff, or for free, and additional water requirement becomes increasingly costly. In this way investment and O&M costs can be recovered, water supply remains affordable for all citizens and excessive water use is discouraged. See for more information Appendix III.

Disadvantages / barriers:

- A well working water monitoring system needs to be installed, which is costly.
- Socio-cultural acceptability of this measure is low, as many people are used to not paying for their water. Educational programs are needed in order to increase awareness on the benefits of water tariffing.

6.2.3 Replacement and maintenance of pipelines

Safeda Wali Jhugi receives its water from Bhagirathi treatment plant in East Delhi. This plant was built in 1983, and the pipeline network still dates back to this year. Also, most of the treatment facilities and the water pumps have not been renewed since the treatment plant was built. As the pipelines are almost 30 years old, there is a possibility that the contamination of water supplied to Safeda Wali Jhugi is caused by leaks in the pipe system. Unfortunately, since no water meters are present, these leaks cannot be detected. Thus, the actual state of the pipeline network needs to be investigated further. If leakages would be found, the best long term solution for Safeda Wali Jhugi, as well as all other regions that Bhagirathi supplies to, would be to replace all old pipes with new pipes of a better and more durable material. This would not only result in better water quality, but it would also significantly reduce water losses through leakages.

The same goes for the entire pipeline network in Delhi. Serious reduction of water losses can only be achieved when leaks are detected and broken pipelines replaced.

Effects:

- Water loss is reduced significantly.
- Long term solution. In the light of increasing urban population and associated increase of water demand, it will become essential to reduce water losses to a minimum in the future.

Disadvantages / barriers:

- High costs. Large scale replacement of pipelines requires huge investment costs (Sultan, 2012). In addition, to trace leakages water meters need to be installed. This adds to investment costs as well, though compared to total investment costs the share for water meters is very low (CCS, 2003).

6.2.4 Renovation of old treatment plants

As Bhagirathi treatment plant, including its pumps and treatment facilities, dates back to 1983, it is very well possible that, in terms of energy use, considerable improvement can be made. Since the pumps are almost 30 years old, their energy efficiency is likely to be lower than is desired. Installing new pumps would increase the energy efficiency of the plant and reduce energy use and costs. The same applies for other treatment plants in the city.

Unfortunately, as officials from the treatment plant were not willing to provide quantitative data on the functioning of the plant, it is not possible to give an indication of the extent to which improvements are possible. More research, as well as openness from the treatment plant officials is needed.

Effects:

- Reduction of energy use.
- Possibly reduction of water loss.

Disadvantages / barriers:

- High investment costs.

6.2.5 Recycling water

Eventually, improved water management is needed in order to cope with the increasing water demand of the city. With the high growth rates of the city, recycling water will become unavoidable in the future. There is a great potential here as water recycling is currently minimal.

Advantages:

- Ground and surface waters are left unaffected
- Contaminated water does not end up in nature, but is treated directly after use.
- Low energy use for transportation in comparison with conventional water collection methods: water can be recycled within the city walls and therefore no transport over large distances is needed. Furthermore, treatment of recycled water requires less energy than treatment of raw water (Friedrich *et al.*, 2007).
- Water availability in the city will be increased.

Disadvantages / barriers:

- Low socio-cultural acceptability. Water recycling is currently not cheered at by Indian consumers, due to prejudices about impaired water quality. Educational programs are needed to change this view on recycled water.

6.2.6 Continuous water supply

In India, and many other developing countries, intermittent water supply is common. This method of supply is chosen because it is generally expected that intermittent supply will make consumers more careful with their water and thus will result in water saving.

However, it has been found during this research in Delhi, and observed by experts as well (interview Vitens, Appendix I) that in fact intermittent supply does not lead to water savings. On the contrary, this form of water supply is a major factor in water loss and contamination. Water loss is related to two factors. First, people who can afford it will install storage containers on the roofs of their houses and use water pumps in order to collect large volumes of water during supply times. The excess water pumped up after the water tank is filled, is being discharged without use. Because these people always have enough water available, they have no incentive to be careful with water.

Low income groups, on the other hand, are not only forced to use their water with great care, but also receive less water than planned because of the excess water collected by their wealthier neighbours.

In addition, intermittent supply results in changing water pressures in the pipe lines. Because of this, contaminated ground water and air can enter the pipeline system, which not only leads to contamination of the water, but also results in a quicker deterioration of the pipelines. This in turn results in higher physical water losses and higher costs for maintenance of the pipelines.

In the interest of energy efficiency and efficiency of water treatment and distribution, continuous water supply would be a much better option than intermittent supply. However, proper monitoring and tariffing are essential to restrict outrageous water use.

Advantages:

- People are no longer inclined to install individual water pumps, which are associated with high energy consumption.
- No water loss due to excess of water storage.

- Reduced water contamination due to constant pressure in the pipe lines
- Reduced deterioration rate of the pipeline system.

Disadvantages / barriers:

- Proper monitoring and water tariffing is essential.
- Regulatory and technological constraints. Shifting to continuous supply requires drastic changes in the existing governmental policies, as well as changes in the water supply systems (more booster pumps are required, and pipeline leakages need to be fixed).

6.2.7 Summary

Table 5: overview of large scale interventions

Measure	Tools	Effects	Disadvantages / barriers
Monitoring water use and loss	Water meters	• Water lost can be reduced • Increased income from water sales	• Difficult implementation • Risk of deliberate damaging or manipulation of meters
Tariffing all distributed water	Pay per liter on the basis of an increased block tariff	• O&M costs are covered • Increased awareness • More money available for implementation of new technologies	• Water meters are needed, but expensive • Low socio-cultural acceptability
Maintenance of pipelines	Executed by DJB and WUA	• Water loss reduced • Long term solution	• High investment costs
Renovation of treatment plants	Executed and monitored by DJB	• Reduction of energy use • Reduction of water loss	• High investment costs
Recycling water	Executed by DJB and possibly WUA	• Ground and surface waters unaffected • Direct treatment of contaminated water • Low energy requirement • Total water availability is increased	• Low social acceptance
Continuous water supply	Executed by central/local government	• No longer an incentive for individual booster pumps • Reduced water loss • Reduced water contamination • Reduced deterioration rate of pipeline system	• Proper monitoring and tariffing essential • Regulatory and technological constraints.

6.3 Environmental and financial benefits of large scale measures for water loss reduction

According to Pilcher *et al*. (2008), water losses could reasonably be reduced to 15% physical loss and 5% non-revenue loss. If physical water loss could be reduced to 15%, this would mean that the efficiency of water supply would increase from 75% to 85%. Thus, water supply would increase with a factor 1.13. This means that to achieve current volumes of water supply to the city, 13% less energy would be required per unit of supplied water if water loss would be reduced from 25% to 15%.

A study of the Centre for Civil Society (CCS, 2003) in India has revealed that about Rs. 350 million (approximately € 5 million) is needed to install meters in the city of Delhi to check leakage and theft. In comparison, DJB's monthly income from water sales is Rs. 187.5 million (€ 2.6 million). If these water meters would be installed and DJB would start tariffing all distributed water, economic losses through non-revenue water could be reduced to 5% (Pilcher *et al*., 2008). As non-revenue water currently accounts for 25% of total water supply, a reduction to 5% would mean a saving of 20 percentage points. Thus, the share of revenue water would increase from 75% to 95%. This means that water sales could increase with a factor 1.27. DJB's monthly income could thus be increased from Rs. 187.5 million to Rs. 237.5 million (€ 3.3 million). Thus, the costs for installing water meters could be recovered in 7 months.

Thus, taking into consideration the financial benefits of installing water meters, the investment costs are small. Of course, installing meters does not directly lead to a reduction of physical and non-revenue water loss. Actual renovation of pipelines adds considerably to investment costs. However, when meters are installed, locating leaks and illegal pipeline connections can be done with much more precision. Replacement of pipelines can be limited to those places where problems occur, and replacement of entire pipeline networks will not be necessary.

Currently, a large project is being developed in which two of the oldest treatment plants in Delhi (Chandrawal, operating since 1937, and Wazirabad, operating since the 1960s) are being renovated. In addition, all pipelines these treatment plants distribute to are planned to be replaced (Sultan, 2012). The costs of these measures are huge and add up to a total of Rs. 30 billion, or € 417 million. If, instead of replacing the entire pipeline network, pipeline replacement would be restricted to those places where water loss occurs, this would significantly reduce costs, as well as environmental impact.

7. Discussion: comparison with other case studies

The study done here differs from similar case studies on improving local drinking water provision in a number of ways. Generally, projects on drinking water provision in developing countries focus on the mainstream, readily available technologies, such as groundwater extraction, slow sand filtration, activated carbon filtration, chlorination and UV irradiation. (for instance, the Slum Water Program in slums in Mumbai (Bell *et al*. 2009); a TERI project in Kalandar Colony, a slum in Delhi (TERI, 2007)).

The Slum Water Program focused on water provision in various slums in Mumbai, most of which did not have piped water supply. Like in Safeda Wali Jhugi, both quantity and quality of water supply were an issue in these slums. It was chosen to supplement municipal water supply with locally extracted groundwater. Water treatment was done by UV irradiation. Distribution was done largely with so-called water taxis, auto rickshaws with water tankers. Though this system is financially very attractive according to the developers, it has some drawbacks in terms of environmental impact and long term potential. First, increasing groundwater extraction in Mumbai, the largest city in India, can lead to a reduction of groundwater levels to a disturbingly low level and a deterioration of groundwater quality. For this reason, the present study argues that rainwater harvesting is a better option, especially when taking into account population growth.

Distribution with auto rickshaws is an easy solution for local water provision on the short term. However, on the long term this solution offers no possibility for connecting with a central water supply system, and thus offers little potential for improvement of the water provision system on the long term.

The project of TERI in Kalandar Colony is very similar to the case study of Safeda Wali Jhugi. Both slums have piped water supply and water quality issues. Kalandar colony, however, did not need additional water supply. For this colony it was chosen to treat pipe water with a system of sand filtration, an AC filtration and UV irradiation. Thus, the interventions suggested for this colony are similar to those suggested for Safeda Wali Jhugi. However, TERIs study on Kalandar colony does not discuss technological possibilities for different situations and is therefore not useful on a large scale.

The Slum Water Program and the project in Kalandar Colony both give solutions for technological interventions, as well as interventions on a social, educational and institutional level. The latter have been used, among others, for defining the non-technological interventions in the present study. In other studies, however, the technological part does not seem to have received much attention at all, and the focus has mainly been on social, educational and regulatory measures (Ryan *et al*., 2006; Velleman, 2009).

Though the present study also discusses well known technologies as well as necessary non-technological measures, it furthermore includes technologies that are not widely used in small scale drinking water provision systems in developing countries, but which could have a great potential in terms of low energy use or environmental impact. These are for example rainwater harvesting, water recycling, nanofiltration and ultrafiltration. The importance of these technologies should not be underestimated. With the increasing world population and correspondingly growing drinking water demand, efficiency of energy and material use, and water use, re-use and collection becomes increasingly important. It is therefore necessary to look further than the technologies that have been common in the past decades. Instead, development work should open up to considering technologies that have a large potential for low energy use and environmental impact, even if these are currently not widely used.

In addition to broadening the view on technological options, this study places decentralized solutions in a larger context by suggesting possibilities for improvement of centralized water provision systems in the future, and indicating how decentralized systems can be incorporated in a centralized system. In the interest of water use efficiency, energy efficiency and efficiency of material use, it is essential to tackle water provision issues at the basis. The study at Safeda Wali Jhugi has shown that water quality problems most likely already start in the main pipeline system. Installing a local treatment facility solves the local problems. However, for the majority of the areas that the central pipeline system supplies to, water quality still remains to be an issue. In order to be really effective with improving water quality, the central distribution system ought to be improved. This would not only improve water quality for a larger number of people, but would also reduce the necessity of placing local, decentralized systems.

The same goes for quantity issues. Local water supply can be increased for instance through rainwater harvesting or groundwater extraction. However, if the central water supply system would be improved to such an extent that physical water losses would be minimized, the local need for increasing source water supply would reduce considerably.

Though many articles are available on implementation of measures for improving drinking water provision in developing countries all over the world, it was found that research on the actual success of implemented solutions is not common. Though solutions might be effective on the short term, their success on the long run is not known, or at least not documented. This is a major disadvantage for future projects, as it is not possible to learn from documented difficulties regarding long term success of water provision systems. The only way to find such information now is to talk with NGO's and research institutes that have experience in the field.

8. Conclusion and recommendations

The aim of this research was to provide an overview of the success and failure factors of water purification methods suitable for unauthorised urban slum communities. A comparison of suitable technologies regarding their energy requirement showed that considerable differences exist between technologies. In contrast with other studies, this research included technologies that are currently not commonly used on a small scale in developing countries. Furthermore, this study views local water provision in a broader context of urban water provision in general.

It was found that rainwater harvesting is an energy-efficient method for increasing source water supply. Though this method can only be used on a small scale and will contribute little to overall urban water requirement, rainwater harvesting is expected to become essential in the future, when surface water and ground water no longer suffice for meeting the demand of urban populations.

Regarding water purification, ultrafiltration and nanofiltration offer great potential for low energy use water purification, but are currently not widely used in developing countries since they are not yet cost-effective. In order to make these treatment methods more attractive, further development of the technologies is necessary, particularly regarding their use in small scale water treatment systems.

Besides technological interventions, additional measures on a social, educational and institutional level have been suggested to support the successful deployment of a technology. In addition, this research stressed the importance of large scale technological and institutional interventions.

This research included a case study on Safeda Wali Jhugi, a slum in East Delhi, and a comparison with similar case studies. Unfortunately, it was found that impact assessments of water provision projects are not common. This is a major impairment for future water provision projects. Hence, research is needed on the long-term success of measures that have been implemented in the past. This is essential for further optimization of decision-making regarding small scale water treatment in urban areas.

In this research it was also found that little information is available on energy use in small scale water treatment. Therefore, this research focused on energy use in larger scale water treatment. In order to make a more precise comparison of decentralized water provision technologies, further research is needed on the energy use of small scale water treatment systems.

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Appendix I – Interviews

Interview Gerard Soppe, Vitens, 12-01-2012

Subject: water purification in urban areas in India

Background Vitens: Vitens is specialized in the technological aspects of procurement, treatment and distribution of drinking water in The Netherlands and a number of developing countries (www.vitens.nl). Together with Water for Life (www.waterforlife.nl) Vitens carries out project in developing countries in Africa and Azia. Although Vitens is currently not active in India, they are planning to start projects in this country this year.

What (kinds of) water purification technologies are currently most suitable for deployment in developing countries?

That depends on the water source. There is an important difference between groundwater and surface water. Groundwater is relatively easy to purify. Often treatment takes place through aeration (using a filter or by pumping ear through the source water). India holds relatively large amounts of groundwater. Therefore the water scarcity there is not as serious as is often suggested.

Surface water is more difficult to purify, since it is generally more contaminated than groundwater and it contains more dissolved solids. Purification of surface water generally takes place in the following way:

2 to 10 days storage in a reservoir, where sedimentation of large particles takes place → subsequently, water is pumped in a next reservoir where alum is added. This triggers flocculation → After this process sedimentation takes place in a next basin. The upper (clean) layer of water in this basin is pumped to the next basin → here the water is purified in a sand filter → subsequently disinfection takes place with the use of chlorine, ozone or UV technology (which is fairly new).

Depending on the presence of manganese, iron or acid additional treatment methods are needed. These usually take place earlier in the treatment process. In the case of acidity for example, calciumcarbonate is added in order to raise pH level. After treatment water is distributed to the consumer.

At the moment water enters the treatment plant, it usually has a turbidity of about 20 NTU[15] (this is an average in India. Turbidity is much higher in some places, and could be up to 600 NTU). The WHO aims to reduce this turbidity to 2 NTU. In comparison to The Netherlands: In The Netherlands source water has a turbidity level of 0.3-0.5 NTU when it enters the treatment plant. During treatment this is reduced to 0.2 NTU.

What (cultural/social/governmental) issues could interfere with the implementation of new water purification technologies?

An important problem is the social structure in the country and the major difference between rich and poor. Related to that is the reluctance of the upper class to contribute financially to water provision to the lower class. In India the caste system (though officially abolished) still present: the last name indicates the caste. People from higher castes are often not willing to financially support people from lower castes. Low income groups pay relatively more for water provision than the higher income groups, because the wealthier can afford methods for water storage (for example an overhead water container). Poorer people, on the other hand, need to stay at home to collect water during the time that it's available (usually a few hours per day or a few days per week).

The government has an important task in solving this issue. The municipality is responsible for the provision of clean drinking water. Currently, municipalities have a lot of trouble realizing the provision of water to all citizens. Therefore there is now more private sector involvement, in which municipality decides on the policy, but implementation is done by a commercial company.

In what way do energy-related questions play a role in the implementation of water purification systems?

Energy is needed for distribution, to get the water into the network: often pumps are needed. But if the tariff is full cost recovery, this is not a problem. The best option is to install generators at the production site, in order to save costs.

Another important feature of drinking water in terms of sustainability: drinking water is so essential that it provides a great deal of working force if the provision of drinking water is well arranged (because of good health). However, this fact is

[15] Nephelometric Turbidity Units

difficult to measure and therefore difficult to sell to governments or companies.

The people in India are used to intermittent supply. A disadvantage of this is the quality of the water: often there is no pressure on the pipeline network, which results in contaminated water from outside to enter the network. Also, there is a risk of air entering the system when pressure drops. Because there is a lot of iron present in the Indian water network, the pipelines will start corroding after contact with air. This results in a reduced quality of the pipeline network, more leakages and higher costs. In addition, storage of water on a household level is less hygienic than a continuous water supply.

In short, intermittent supply is more expensive and leads to higher water losses than continuous supply. However, it is difficult to shift to a system with continuous supply. The new 5 year plan of the Indian government aims to provide continuous water supply in several areas in the country.

Another method to guarantee sustainability is to add a minimum amount of chemicals to the water. The use of chemicals and energy needs to be minimal. An effective way to realize this is by making sure that the quality of the source water is already high when it enters the treatment plant. By storing the water in a good quality reservoir prior to treatment, the treatment plant itself can remain smaller and will require fewer chemicals. Energy use for distribution depends on the location of the treatment plant: drinking water production on a higher location means less energy requirement for distribution (gravity does a large part of the work). Little energy is required in the treatment plant itself. The larger part of the energy requirement is in distribution, which has to be done under pressure.

In what ways can the implementation of new water purification technologies be financed?

One way is to leave water supply to commercial companies, possibly from abroad. The fact remains that eventually water needs to be paid for. This can be done through the municipality (taxes, perhaps higher taxes for the wealthier people), the client (tariff is full cost recovery), subsidies (by lowering the tariff for low income groups, or by offering general subsidies for households with low income, when they are registered). A policy for commercial companies can also offer solutions: e.g by implementing a target that for every 50,000 connections for high income households, 20,000 connections have to be installed for low income households.

It is important that municipalities get a hold on the water system. Through an incentive low purchasing power people should get access to (drinking) water.

The general norm is that not more than 3% of the household income should be spent on drinking water. For the low income groups in India this percentage is currently much higher. In The Netherlands this percentage is lower.

The advantage of India is that it is an emerging economy. There is much more money available than in other developing countries, and therefore also more possibilities.

In what way should the current policy in India be revised in order to improve the implementation of water purification technologies (in urban areas)?

The current policy is very much focused on the private sector. However, the private sector aims for profit, which can be harmful for the consumer. There already exists a drinking water company which belongs to the Indian government, but this one functions inadequately. However, if water treatment would be given out to the commercial sector, the government will lose their knowledge of the water supply system. This knowledge ends up with the private sector. Such a contract between government and commercial companies generally lasts for about 25 years. When that period has past, the knowledge with the government is lost. Therefore, the government is forced to enter into another contract with the commercial companies and thus becomes dependent on the private sector. This is detrimental for the government and consumers: consumers pay on average 10% more for their water when it is supplied by commercial companies.

In general there are three types of drinking water systems: French, English, and Dutch. In France the system of governmental cooperation with the private sector functions well: every municipality requires the involvement of a private operator, but still has quite some influence.

In the Dutch model provinces are the owners of the drinking water systems. Companies are responsible for the executive work, but are not allowed to make profit.

The English system is completely outsourced to the private sector. Everyone wants to sell water, but nobody wants to invest in the network that is already there en is being used by all companies. This results in a deterioration of the water network. This system is comparable to the system that is possibly being implemented in India. Regarding the experience in England, the effectiveness of this new policy is questionable.

<u>Interview Gert Uittenbogaard, DHV, 26-01-2012</u>

Subject: sustainable methods for water purification in urban areas in India.

Background DHV: DHV is a consultancy and engineering company that focuses on solving complex problems, predominantly in the area of infrastructure and mobility, water and environment, space and property and industry (www.dhv.nl). In the field of water purification in developing countries, DHV plays a role in consulting on the possibilities for developing suitable water purification methods, after which implementation of a selected technology is executed by other companies (DHV cooperates with Vitens, among others).

What is the current situation in India regarding drinking water?

Currently a reasonably large amount of the Indian population (about 90%) has access to drinking water. The current drinking water systems are, however, far from sufficient for making drinking water available for the entire population. Sanitation (sewerage) forms yet a larger problem, since only 50-60% of the population is connected to a sewerage network. At the moment there is a lot of research on improving waste water treatment, among others by the UN and WHO.

Regarding the slums: these are often not registered. Slums are generally located in areas where occupation is officially forbidden, for example in river beds. Therefore, drinking water provision is difficult to establish in those places. It is better to focus research on drinking water provision on local solutions for low income areas that are registered with the government.

What are the most important sources of drinking water for the urban areas in India?

Groundwater is an important source for drinking water (contributing about 40%), but the share of groundwater use varies between cities. In cities water is often stored in small reservoirs on the roofs of houses. Furthermore, it often happens that people have installed water pumps in their back yards, or that public pumping stations have been installed on certain points.

Water provision differs considerably between states. Especially the coastal areas generally have access to little water. One example is Madras: this city is located at the coast in the southeast of the country. There is a lot of salt water that cannot be used, while fresh water is scarce because there are no rivers in the area. Moreover, because of the water scarcity in the country it is difficult to receive water from neighbouring states.

Supply of water to cities takes place in several ways: supply from outside the city, or local supply: rainwater harvesting on top of a roof, or groundwater. Cities should not be dependent on supply from outside. However, groundwater cannot be pumped up in too large volumes, as the groundwater level is declining.

What solutions could improve drinking water provision in urban areas?

First start with investigating the water chain. If the water chain has been mapped, the problems in the slum area need to be determined. Find out what the reasons are behind the reduced availability of drinking water win the area. For example: residents are not connected to the drinking water network, or there is simply no water available; political problems (see next question) (it is good to first name all the reasons why the government sometimes cannot do anything for the slum areas). The consequence of the absence of drinking water provision in slums is that water often needs to be purchased for a high price from private vendors.

After the first analysis, determine what exactly you want to investigate. Then you will be able to find a great deal of information on that topic. Subsequently, look for a case study on internet to focus on. Take a look at for instance Indian NGOs.

It is of essential importance to determine the factors that limit the implementation of solutions for drinking water provision. Think of restricted availability of land area (sedimentation basins require a lot of space), energy costs, labour costs, maintenance, life cycle. The problems that arise in a slum area first need to be analysed well. Then it becomes possible to create and compare a number of methodologies, where you need to take into account the difference in costs, method of purification (in supply and/or drainage?) and possibilities for recycling.

The solution then needs to be found in decentralized, energy friendly systems: the best option is to select a number of specific cases of a city in India and to do research on the most suitable solutions for those cases.

Regarding methods for water purification: look at sustainable possibilities for water purification for low income people in urban areas. What requirements does such a system need to meet? The choice for a water purification system depends on the water quality and type of pollution. This differs between areas. For instance, for organic material sand filters could be used. Also look at indicators for energy use, use of chemicals, use of ground area, and compare these parameters to find out which solution is the most suitable one. Compare sources from literature and compare a number of decentralized solutions.

Furthermore, the use of drinking water needs to be restricted (sustainable water use) and solutions need to be local. Monitoring and water tariffing are important here: in India many people don’t pay for their water. This mentality needs to change. The method of distribution could play a role here: if water is not 24 hours per day available and needs to be collected at specific distribution points (e.g. a water pump), people are more careful with their water.

Recycling is an important method for water and energy savings. By using simple sedimentation techniques used water can be treated and re-used. Another sustainable solution is storage of rainwater. In the process of pumping up groundwater, the possibilities for recharge should be considered.

A possible method should be implemented as cheap and sustainable as possible, for example by involving the local population in the construction of a water purification and distribution system. Also, the implemented methods need to be easy to understand and easy in use.

What (cultural/social/governmental) problems arise with the implementation of new water purification methods?

Slum residents are at the bottom of the social ladder and live on places where they are not allowed to live, so often there is not much that the government can do for them. Moreover, these people are not organized, they have no political power and are therefore not able to stand up for their rights.

To what extent does the government or municipality play a role in improving drinking water quality?

India supports the Millennium Development goals: the political will is present. The problem with slums is that they are located in areas where habitation is officially forbidden. For that reason it is better to look at solutions for areas where people can legally stay.

To what extent do energy questions play a role in the implementation of water purification systems?

There are two types of water purification: drinking water and sanitation (waste water treatment). Look at what is the most urgent one to investigate. The energy costs for operation and maintenance of a drinking water system are often about 60-70% of total costs. In this area energy savings are possible. One example of a sustainable water purification system in The Netherlands is an open water system with reed which purifies water in a natural way. This system is only suitable for treatment of waste water.

How can sustainability be guaranteed with the implementation of new water purification systems? What factors should be taken into account?

70% of the usable water in India is used in agriculture. It is generally assumed that the efficiency of this water use is remarkably low, around 40%. Water savings should therefore primarily take place in this sector. Re-use of drainage water is a necessity in dry or urban areas. Furthermore, centralized drinking water distribution through water pipelines is extremely inefficient: 30-40% losses (because water use is not monitored, people do not pay for their water, leakage due to bad maintenance of the pipelines). A much more efficient use of India's water sources is possible, and would reduce water loss considerably. Think of which water sources could best be used for guaranteeing sustainability as much as possible.

Interview Radheyshyam Tyagi, Delhi Jal Board, 20-3-2012

Subject: water supply and demand in Delhi's planned and unplanned colonies, and Geeta Colony in specific

Definition of 'slum'

Important for this research is first to have a clear idea of what type of area you would define as a slum. In general, an area is considered a slum if it has not been recognised by the government, and is deprived of basic amenities because the government has limited possibilities for improving the living standards in the area. These areas have no parks, no proper corridor for laying services like a water pipe line system or sewerage. Therefore water supply or sanitation is hard to provide.

All JJ clusters fall within this category. Most unauthorized colonies can be categorized as slums as well, though there are also many unauthorized colonies that are equipped with all the necessary amenities.

What is the water supply and demand scenario of Delhi?

Currently there are no shortages of water supply. DJB is supplying 850 MGD (3864 MLD) to the city, which has a population of about 17 million people. This means an average of 200 lpcd is supplied.

However, there are local differences in water supply, with especially the unplanned colonies receiving lower per capita amounts of water. Local solutions in these areas should make water supply more rational.

In what ways is DJB anticipating on increasing water demand in the future?

In the future Delhi will face a water crisis. According to the master plan 2021, 1380 MGD (6274 MLD) will be required in the future. This gap cannot be matched solely by increasing source water inlet, as not enough source water is available. The solution is water management, especially through reducing water waste trough leakages.

Furthermore, 3 sources of raw water have been identified: the Lakhvar, Vyasi, and Kishau water dams. Together these should account for an addition of 500 MGD (2273 MLD) of raw water. However, time is needed for this project. All three dams still need to be constructed.

Another option was the Renuka dam for storage of rain and melt water. The original idea was that the electricity produced by the dam would be retained by the organization operating the dam, and the water would go to Delhi. However, this project has not started yet and will most likely not be exercised, as it involves a lot of tree cutting, which will not be approved of by environmental agencies

How is water supply and waste water sewerage realized in unplanned colonies?

Three methods are used by DJB:

-Water supply through pipelines from a planned colony or water treatment plant to the slum area. However, often there is no space for laying the water supply system.

-discrete water supply system: If it is not possible to direct water from existing supply systems to the slum, a decentralized supply is implemented by means of a bore well supplying to community stand posts

-water tanker supplying regularly

Regarding sewerage, there are no proper systems for this in slum areas. Sewerage flows directly into the drains, then into bigger drains and ends up in the river. No treatment facilities are present. In planned colonies, however, a well working sewerage system is present, and waste and sewerage water is treated before drainage.

Which treatment plants in Delhi distribute potable water to the city?

There are 7 treatment plants supplying potable water to the city. Together they have a capacity of 750 MGD (3410 MLD). 60% of this water is supplied to east Delhi, the other 40% to south Delhi. The entire northwest of Delhi is catered by a 100 MGD (455 MLD) groundwater supply, treated with disinfectant.

Which treatment plant distributes water to Geeta Colony?

Sonia Vihar treatment plant[16]. This is a new treatment plant supplying both to east and south Delhi.

Why is the bore well at Geeta Colony not operating at the moment?

Before Sonia Vihar started operating, Geeta Colony was struggling with water deficiency. Now water scarcity is not an issue anymore, as Sonia Vihar supplies enough water to the area. Furthermore, the groundwater form the bore well was contaminated

[16] Note of the author: it was discovered later that it is not Sonia Vihar, but Bhagirathi treatment plant which supplies to Geeta Colony.

by the Yamuna river and was not suited for drinking water purposes. When the bore well was still operating, the water was only used for non-potable purposes.

What is done with the waste water produced during water treatment?

4 recycling plants have been built in the past years to recycle 45 MGD (205 MLD) of waste water from the treatment plants.

What are the average losses of treated water during distribution?

Total water losses are about 50% (around 1932 MLD). These include technical losses (20-30 %, due to leakages), and commercial loss (20-30%, this includes water theft and water that is supplied for free to slum areas). 1932 MLD of water is supplied to paying consumers.

How is DJB monitoring water quality, water supply and water consumption in planned and unplanned settlements?

Quantifying how much production is there. Raw water quality is checked every hour. Also an online water quality monitoring system is being introduced in the near future to make monitoring of water quality easier and more organized.

Water consumption cannot be measured. Household water meters are often not correct, and are not everywhere installed. But progress is made in this field. It will take about 2 to 3 years before every paying household has correct water meters. By that time also metering of water leakages is planned to be improved significantly, in order to reduce water losses through leakages. The aim is to reduce leakages to 15-20%, which is an acceptable limit.

<u>Interview Ms. M. Krippendorf, Child Health Clinic, and Minakshi Arora and Siraj Kesar, Waterkeeper Alliance, 28-3-2012</u>

Subject: Water and health issues in India

Background Child Health Clinic: Ms. Krippendorf is a doctor specialized in child health care, and is consultant at the Child Health Clinic in Delhi. Furthermore, she is involved in a project focusing on 'early enrichment' of children in rural areas at the ages of 0-7. Enrichment of young children is promoted by using playful methods in which children develop a variety of skills that function as a basis for their education starting at the age of 7. The concept of the method is easy to implement in an existing health care project. As education is of crucial importance for improving health care in an area, the method is based on interlinking health care and education. This includes that health care workers are payed by the organization to dedicate 10% of their job description to early enrichment. If all health care workers are included in a project, a highly skilled mix of experts is created, that can educate children on a large variety of topics.

Background Waterkeeper Alliance: Ms. Arora and Mr. Kesar are experts on water quality and supply issues in India. Their work for Waterkeeper Alliance is done on a voluntary basis (see website: www.waterkeeper.org, and for India Water Portal: www.indiawaterportal.org). The organization is independent of any funding or government aid and works solely with volunteers. The aim of the organization is to preserve rivers all over the world. In India, Waterkeeper Alliance runs projects on educating rural and urban communities to increase awareness on the water issues in the country. Waterkeeper Alliance aims to create awareness from a young age, and therefore has created methods for educating children on water issues in a way that appeals to them, e.g. by playing games. Also, water quality tests are carried out throughout the country, and research is done on sustainable ways of water harvesting and treatment.

What are the current most pressing water quality and quantity problems in India?

Arsenic contamination is a serious and increasing problem in the country. Especially in the areas Punjab, eastern Uttar Pradesh, Balia, and Gazipur, health issues as a result of arsenic contamination are disturbingly high. Arsenic ends up in groundwater due to over-exploitation of groundwater resources. As groundwater levels are declining continuously, boreholes have to be drilled more deeply, increasing the risk of drilling into arsenic containing rock. Once such rock types have been reached by the bore wells, arsenic dissolves into the water. This chemical being very injurious to health, it increases health issues in the affected areas to a disturbing level, as it can cause cancer immediately after exposure. The acceptable limit for arsenic in groundwater is 10 ppm. However, in some regions, this level is much higher, ranging from 200 to 3000 ppm. In the regions affected by arsenic contamination skin and stomach cancer are highly prevalent. Especially children are at risk.

In Delhi, arsenic contamination is a problem in some parts of the city, due to arsenic contamination of the Yamuna river. This contamination is not caused by arsenic containing rocks, but by the presence of certain arsenic containing coal plants on the river bed.

In India the problems regarding arsenic contamination in groundwater are not addressed accordingly, and are often even denied by local populations and the government. This contrasts the situation in nearby countries like Bangladesh, where arsenic contamination of groundwater is regarded as a serious problem, and measures are taken on a government level to reduce the risks of contamination and increase awareness.

Another upcoming issue related to groundwater harvesting is uranium contamination, which also results from over-exploitation of groundwater resources and the resulting necessity of boring deeper wells. In some cases tube wells have hit uranium containing rocks, which caused uranium to dissolve into the water. In Bhatinda, a rural area in Punjab, uranium contamination of groundwater has led to a sharp increase of the proportion of mentally retarded children in the area. Furthermore, pesticides and fertilizers are used in abundance in this area (and in many other rural areas as well), which contribute to the severe health issues here, mainly affecting children.

The case of Punjab is an interesting one as in theory it is very easy to solve the water-related problems here. The people that live in Punjab have generally good incomes and could afford to improve their drinking water provision. Furthermore, Punjab has a large network of canals. Hence, much surface water is available, which could easily be treated for potable purposes. Nevertheless, the people of this region stick to using bore well water, due to unawareness of the health issues related to this water, as well as their conservative attitude regarding drinking water provision.

What are the possibilities for solving current water issues in India?

Rainwater harvesting is a sustainable and effective solution. In contrast to using bore wells, rainwater harvesting avoids the risk of over-exploitation of groundwater resources and the related issues regarding contamination with uranium, arsenic, and other heavy metals. In historical times, rainwater harvesting was a widely used method for ensuring drinking water provision in India. In so-called 'bawdi' (a type of cistern), rain water was harvested and purified in a natural way. Delhi alone used to have around 1000 of these bawdi. However, nowadays, these are not in use anymore. Many have been closed off or have been used as a foundation for buildings. It is believed that currently only about 70-80 of the 1000 bawdi are in a sufficient condition for renovation and reuse as rainwater harvesting facilities. Though they only contribute a little to the total water requirement, it would be profitable to restore these bawdi.

There are several methods to increase the potential of rainwater harvesting. For example through rooftop rainwater harvesting, or surface rainwater harvesting. In Rajasthan the latter method has been used for a long time, where rainwater is stored in a so-called 'tanka', a surface rain water storage facility. This system has through history proven to be very efficient.

<u>Interview Vikas Zadoo, Sonia Vihar water treatment plant, 27-3-2012</u>

Subject: Operation of Sonia Vihar treatment plant. Vikas Zadoo is manager of the online monitoring system at the treatment plant

When did this treatment plant start operating?

2006

How much water is sourced to the treatment plant and where does this water come from?

142 MGD (646 MLD), the plant has a capacity of sourcing 662 MLD (which equals 146 MGD). Source water comes from the Tehri dam in the Ganga river. Water is taken from Mural Nagar, which is at a 30 km distance from the plant.

To where does this treatment plant distribute?

East Delhi: Sastripark and Tahirpur

South Delhi

What is the range of supply of Sonia Vihar? Are there differences between summer and wither months?

Supply is always the same, but the quality of the source water differs with season. Before the monsoon, water is very contaminated and a lot of chemicals are needed for purification. During monsoon water has high turbidity.

How much water is distributed?

140 MGD (636 MLD)

How much waste (backwash) water is created? What is done with the backwash water of this treatment plant?

1.5 MGD (6.8 MLD), all of this is recycled

What other waste water discharges are there? (sludge disposal?)

There is a total of 0.6-0.7% of actual water loss which is being discharged. In the context of sustainability, sludge is used for a vegetable garden at the plant.

What methods for water treatment are used?

Conventional methods: aeration, pre-chlorination, pre-settler (in case of high turbidity during monsoon), treatment with poly aluminum chloride (PAC), pulsator by use of vacuum chamber, sand filter, chlorination.

What chemicals are used for treatment and how much?

PAC and chloride, amount is not known

What is the share of water leakage during distribution from Sonia Vihar?

This is known by DJB, as DJB is responsible for actual distribution of the treated water.

Regarding leakage within the plant, if leakage exceeds 1.5%, a penalty is given by DJB. The same goes for power consumption. If this exceeds 232 kWh/Ml, the plant needs to pay a fine. Currently, power consumption is around 211-212 kWh/Ml.

How is leakage monitored? What are future plans to improve monitoring?

Information available at DJB

How is water quality monitored?

Information available at DJB

How old are the pipe lines that Sonia Vihar supplies to?

All pipelines date from the time of construction of the plant, thus from around 2006. Sonia Vihar does not supply to older plants.

How many pumps are used in the treatment facility?

8 pumps for raw water (of which 4 stand by)
6 pumps for distribution to South Delhi (of which 2 stand by)
3 pumps for distribution to Tahirpur (of which 1 stand by)
2 pumps for distribution to Shastri Park (of which 1 stand by)

How much energy is consumed in the entire water procurement and distribution process?

This is known by DJB, as DJB pays for the electricity bill.

What is the installed capacity of the pumps?

pumps for raw water: each pump has a capacity of 6896 m3/h

pumps for distribution to South Delhi: each pump has a capacity of 4300 m3/h

pumps for distribution to Tahirpur: each pump has a capacity of 3000 m3/h

pumps for distribution to Shastri Park: each pump has a capacity of 2700 m3/h

What is the actual discharge capacity?

The efficiency of the pumps is around 85-86%

What are the costs for procuring water, chemicals, electricity, salary (how many people are operating the plant)?

This information cannot be given

How are the costs covered for water that is distributed for free? Increased block tariff?

Information available at DJB

Appendix II – Settlement survey

1. Settlements visited

Six areas were visited in total, of which four were located in east Delhi and two in south Delhi. The choice of the areas was based upon presence of slum characteristics, and proximity. For reachability considerations it was decided to stay within the urban centre of Delhi. Thus, the outskirts of the city, that include urbanized and rural villages, were not included in the survey. First, the areas in east Delhi were surveyed, followed by a survey of two areas in south Delhi, in order to get a complete picture of the variety of settlements present in Delhi. All six areas visited are JJ clusters. Each of the areas was surveyed regarding characteristics like population size, quantity and quality of water supply and presence of water borne illnesses, as well as willingness of the population to cooperate with the implementation of a new system for drinking water provision.

New Selampur (East Delhi)

Quantity of water provision was reasonable in this area. Supply was facilitated through pipelines, DJB tankers, and complemented by hand pumps. The quality of the pipe water and groundwater was insufficient for drinking, and was therefore only used for non-domestic purposes. Drinking water was provided by DJB tankers, which occurred twice a day, one hour in the morning and one hour in the evening. Piped supply was poor in terms of both quantity and quality, due to extremely low water pressure. Frequently piped supply was not available at all, and if available it was often coloured. Also odour problems were reported. Groundwater was reported to have a bad smell and taste and to be yellow in colour. Other issues in the area were connected to lack of toilet facilities, and lack of cleanliness and proper drainage. The community showed to be very cooperative and willing to pay for better water provision.

Picture 1: Women and children in New Selampur collecting water supplied by a DJB tank.

Geeta Colony, Safeda Wali Jhugi (East Delhi)

Water provision to this area in Geeta Colony was found to be poor in terms of both quantity and quality. Piped water is the main source of water supply. However, this was said to be of low quality and quantity due to low pressure. Hand pumps were used to fill the additional water need. This could however not be used for potable purposes as the groundwater was too contaminated. Additionally, it was stated that sometimes water would be supplied by DJB tankers, but this supply was very irregular. Furthermore, a bore well was present in the area and provided water to the colony until a few years ago. This facility had been closed as soon as piped water supply had been extended to the area. Water quality is an issue in the area. Water borne illnesses like diarrhoea were reported to be common. Other issues were cleanliness of the area, drainage and lack of sufficient toilet facilities. The community seemed willing to cooperate with initiatives for improvement and to pay for better water provision.

Picture 2: Woman washing utensils with hand pump water at Safeda Wali Jhugi.

Geeta Colony, Sama Nursery (East Delhi)

The colony at Sama Nursery is a small community of approximately 150 house-holds, struggling continuously with limited water supply. As the settlement is built in an area that will be required for other purposes in the future, no piped water supply or bore well has been installed in the area. Ground water was available through hand pumps, though only a few hand pumps were present in the area. One public hand pump was found at the entrance of the settlement. The

Picture 3: Hand pump at Sama Nursery.

quality of the groundwater is however not suitable for potable purposes, as issues have been reported regarding smell, bad taste and yellow colour. Potable water was provided by DJB tankers twice a day, one hour in the morning and one hour in the evening. Additional water requirement was fulfilled by fetching water in other communities. Drinking water quality is not a very big problem as the water provided by DJB meets the standards. Instead the largest problem regarding drinking water is related to quantity. Other issues in the area are absence of public toilets, cleanliness of the area and drainage. The community seemed willing to cooperate and to pay for better water supply. However, the area is quite small, and therefore there is no incentive from the government side to improve the area. Rather, there is a good chance that the area will be cleared in the near future.

Kalyanpuri, Mahatma Gandhi Camp (East Delhi)

Near Sanjay Lake in Kalyanpuri a large slum community is situated. Due to its size, the area has been subdivided into five smaller clusters. These are: Mahatma Gandhi Camp, Jawar Mohalla, Sastri Mohalla, Pandit Ram Prasad Bilmill Camp, and Khoka Patri Camp. Water is supplied to the area by DJB through piped supply two hours a day, one hour in the morning and one hour in the evening. According to the residents, the volume of water supplied is not enough to meet the demand of the population. Some private hand pumps have been installed to supplement DJB water supply. However, this water is not fit for drinking due to groundwater contamination. Though pipe water quality has been reported to be insufficient for drinking as well, it is still being used for domestic purposes, being the best source for drinking water available in the area. Other issues in the area are absence of toilets, cleanliness of the area (a large open dumping was found close to the entrance of the settlement), and drainage. The community is willing to cooperate with any initiative that will lead to improvement of drinking water provision, as well as to pay a fee for safe drinking water.

Picture 4: An open dumping near the entrance of Mahatma Gandhi Camp.

Vasant Vihar, Kooli Camp (South Delhi)

This is a small slum colony of about 250 households, located in the rich neighborhood Vasant Vihar. The colony is supplied with bore well water, which is used for both domestic and non-domestic purposes. According to the residents, they receive sufficient volumes of water and it is suitable for drinking. However, a sign at the entrance of the colony states that the bore well water is not safe for drinking. Other issues in the area are related to absence of toilets, cleanliness of the area, and drainage. Though the community stated to be satisfied with the current drinking water provision, they expressed willingness to cooperate with research in the area, and would be prepared to pay a financial contribution to the supply of drinking water if a system was introduced that would improve drinking water quality.

Picture 5: A sigh at Kooli Camp warning that bore well water is not safe for drinking.

Vasant Vihar, Bhawar Singh Camp (South Delhi)

Like Kooli Camp, this colony is supplied with bore well water. However, Bhawar Singh Camp is much larger than the aforementioned, comprising approximately 4000 households. Water is supplied for four hours per day, two hours in the morning and two hours in the evening. The residents of the colony have stated that the volume of water supplied to the area is not sufficient to meet the needs of the community, and they say a second bore well is needed to solve water quantity problems. Furthermore, complaints regarding water quality were reported, as well as health issues in relation to bad water quality. Other issues in the area are

Picture 6: Children in one of the main streets of Bhawar Singh Camp.

related to cleanliness of the area, and drainage. The community has stated to be prepared to cooperate with initiatives for improving drinking water provision, as well as to pay a fee.

2. Other results from the survey

Some of the colonies initially selected for preliminary research turned out to have been quite well developed in the past few years. An important observation from the field research was that the dynamics of Delhi's development are enormous, with the development of slum areas takes place in a very rapid pace. An example is Sangham Vihar (South Delhi), one of the areas that was initially selected for survey, but turned out to have been fully developed in the past two years. This colony had been coping with severe water supply and drinking water quality issues only two years ago. Now the area is well developed, with wide streets, shops, and ample water supply. This makes it difficult to keep track of the existing slum areas, as the city is changing continuously.

Though this rapid development seems to indicate good progress, there is a dark edge around the development of Delhi's slum areas, as it usually involves the resettlement of the existing slum population to the outskirts of the city. In most cases these people lose the few possessions they have – most importantly, their house – and have to start from scratch in an area deprived of all basic amenities. Though the urban centre of Delhi seems to be getting wealthier and developed, the larger part of the city, the peri-urban areas, consists mostly of unplanned colonies where people live in subhuman conditions. These areas are growing continuously.

During the survey in the six JJ clusters, it was found that there is much willingness within communities to cooperate with the introduction of a new drinking water supply system. All questioned communities were also willing to contribute financially to the provision of potable water. Furthermore, all communities complained about issues regarding cleanliness of the area and drainage. Also, almost all communities stated that the absence of toilet facilities was a problem.

Appendix III – Water in Delhi

1. Delhi's unplanned colonies

The development of Delhi's unplanned or unauthorized areas is a complex one, due to changing regulations over the years. Currently, there are many different categories of unplanned settlements. The terminology of Delhi's settlements is rather confusing and literature is often not consistent on this. However, Water Aid (Singh and Shukla, 2005), Batra (2005), and Dutta (2006) do give a good overview of the unplanned, or informal, settlements that are present in Delhi. Based on these studies, a short description of the different categories of Delhi's unplanned settlements is given here.

Designated slum areas

Designated slum areas are areas that have been notified under the Slum Areas (Improvement & Clearance) Act of 1956 as being unfit for occupation due to bad housing conditions (Batra, 2005). Designation of slum areas took place until about three decades ago. Therefore this category comprises some of the oldest acknowledged informal settlements in Delhi, mostly situated within the city walls. Most of these slum areas, after having been designated, were either upgraded or cleared (Batra, 2005).

Unauthorised colonies

Unauthorized colonies are colonies that have been built on either private or government property that was not designated for residential use (Batra, 2005). The living conditions in these colonies are very diverse. Many colonies are inhabited by middle or high income groups, who have bought their land from rural landowners (Singh and Shukla, 2005), and thus have a legal right to their residential area. However, by building private dwellings, they are interfering with the government's plans for the city's expansion, and have therefore limited access to basic amenities (Singh and Shukla, 2005). Though middle and high income residents of unauthorised colonies are often able to find a means to gain access to basic amenities, this is far more difficult for the low income groups residing in those areas.

Regularised unauthorised colonies

Regularised unauthorised colonies are colonies that have been approved by government agencies, a political decision that often has implications for the further use of the area (Batra, 2005).

Jhuggi Jhompri (JJ) clusters or squatter settlements

JJ clusters are settlements of low income migrant labour groups that have built their residents on government land. This land was initially designed for a different purpose, like a park or open space (Singh and Shukla, 2005). The dwellings placed at JJ clusters are variable, varying from tents and huts made out of plastic or tin sheets, to brick constructions.

JJ relocation colonies

JJ relocation colonies are JJ colonies that have been relocated after the owner of the land on which the colonies were settled required the use of the land (Batra, 2005). This type of colony should not be confused with so-called resettlement colonies, which comprises a group of 44 colonies that were designed between the 1960s and 1985. Some of these colonies have the same standards as planned colonies, and usually offer better living circumstances than JJ clusters or JJ relocation colonies (Batra, 2005).

Urban or urbanized villages

Urban or urbanized are villages that have been incorporated in the city due to the city's expansion (Batra, 2005). When villages are notified as urban villages, they become part of the macro development plan of Delhi.

2. Water supply norms and current situation in Delhi

The municipality of Delhi has an aim and obligation to provide sufficient water to all Delhi's residents, which is defined in a set of water supply norms. The recommended supply water norms for metropolitan cities vary between government agencies. The supply norm of the Central Public Health and Environmental Engineering Organisation (CPHEEO) is widely used. This norm was originally set at 150 lpcd for metropolitan cities (National Institute of Urban Affairs, 2005), but has been raised by a loss count of 15% to 172 lpcd (Batra, 2005). The National Capital Regional Planning Board

(NCRPB) handles a different, more variable, norm of 150-225 lpcd (Batra, 2005).

These are general norms advised for metropolitan cities. Though the state aims to set reasonable standards for water provision for every type of settlement in Delhi, the norms are currently still varying considerably between settlement types (Delhi Development Authority, 2005). In practice, this means that a lower per capita amount of water is assigned to unplanned colonies in comparison to planned colonies (Delhi Development Authority, 2005). The norms that have been set on a micro level range from 40 to 200 lpcd, as proposed by the Indian government (Batra, 2005). A norm of 40-70 lpcd has been advised for clusters where no piped supply is available, thus this applies to JJ clusters, unauthorised colonies and designated slum areas. This amount of water should be provided for by building one community stand post for every 150 persons (Singh and Shukla, 2005). An amount of 150 lpcd is provided for resettlement colonies, which is the same as the amount provided for rural villages. Regularised colonies and urban villages should receive 168 lpcd, while the norm for planned colonies has been set at 200 lpcd.

A similar scheme has been presented by Delhi Jal Board: 225-270 lpcd in planned colonies and urban villages, 131.75-154 lpcd for regularised unauthorised colonies and rural villages, and 42.5-50 lpcd to JJ clusters, unauthorised colonies, and designated slum areas (Batra, 2005). However, the draft MPD[17] 2021 provides more promising objectives, by emphasising that 135 lpcd should be made available for all residential areas. This amount could be split up in a potable and a non-potable share, though the provision of potable water to all areas should be ensured (Delhi Development Authority, 2005). Furthermore, the draft MPD 2021 advises the supply of 225 lpcd to planned colonies (Delhi Development Authority, 2005).

Though access to sufficient volumes of safe water is crucial for human health, the WHO currently does not state a clear norm of per capita minimum drinking water requirement (WHO, 2011). However, in their latest 'guidelines for drinking water quality' the WHO does state that a volume of 7.5 lpcd is sufficient for 'hydration and incorporation into food for most people under most conditions' (WHO, 2011). An additional volume of water is needed for food preparation, laundry and hygiene. Though a total minimum volume of water needed to secure healthy and hygienic living conditions is not given, the WHO states that a total volume of 20 lpcd is not sufficient,

[17] Master Plan Delhi

while 50 lpcd is enough to meet the demand (WHO, 2011). Of this 50 lpcd, the WHO advises that 20 lpcd should be treated for potable use, while the other 30 lpcd can be used for non-potable purposes (Bell *et al.*, 2009). Other advised supply volumes of potable water range from 20 lpcd (Bell *et al.*, 2009; Peter, 2010) to 40 lpcd (Government of India, 2010). The ARWSP[18] applies a minimum standard of 40 lpcd (Government of India, 2010).

These two numbers fall within the earlier mentioned range of water supply norms as stated for unplanned settlements. Though in some settlement this norm is met, there is still a large number of settlements that do not have access to the minimum per capita requirement of water. Furthermore, the quality of the water provided to unplanned settlements is often below minimum standards, and is therefore associated with major health issues (TERI, 2007).

3. Water pricing

Water is a valuable commodity. Nevertheless, many people in India regard water as something that should be freely available. Water pricing is therefore a sensitive issue. Especially in the domestic sector this becomes clear, as here water provision is generally under-priced. For industry however, water prices are higher (Vishwanath, 2006). This ambiguity is cause for conflicted interests of water providers and a preference of water supply to industry over domestic supply (Mathur and Thakur, 2003). Furthermore, because on average the profits of water provision are more than 20% lower than operation and maintenance costs, there is little incentive to invest in improvement of existing water supply systems and installing new systems (Mathur and Thakur, 2003).

The current situation regarding water provision in India is therefore far from ideal. It has become clear in the past decades that water pricing needs to become reasonable in order to ensure safe water provision. A real and fair price for water is however difficult to determine, as it is dependent on many different factors, like availability of source water, water demand, purification requirements, and willingness to pay. Ideally, the price of clean water should be the same for everyone, but this is impossible to realize with decentralized solutions. Therefore, when looking at water provision on a community level, the pricing of water needs to be based on the specific requirements in

[18] Accelerated Rural Water Supply Programme

that area and the associated costs, as well as on the locals' ability and willingness to pay.

A fair system that enables access to clean water for all levels of society and that is widely used throughout India is the system of 'increased block tariff', where a basic volume of water is provided at low cost, and additional water requirements are being offered at an increasing tariff (Vishwanath, 2006). In this way, the higher water tariffs subsidise the low water tariff of basic water requirement. This system works very well in urban areas, although there is still much improvement of the system possible regarding fairness of water distribution and water preservation (Vishwanath, 2006). Such an 'increased block tariff' has shown to be quite efficient in the middle and high income regions of cities. It is not sure if such a system would also work in unplanned colonies, as people would probably only use basic amounts of clean water. However, there might be variability in this between settlements. Thus block tariffing could be something to look into, especially if development of the area in the future leads to increased water use or if pipeline systems expand into the area, which will also result in increased water use. Current water tariffs applied by DJB for pipeline supply to the domestic sector are as follows (DJB, 2009):

Table 1: Water tariffs used by DJB

Monthly consumption (kilolitre)	Service charge (Rs. per month)	Volumetric charge (Rs. per month per kilolitre)
0 – 10	50	2
10 – 20	100	3
20 – 30	150	15
> 30	200	25

The profits of this water supply are not sufficient for DJB to cover investment and operation and maintenance costs for water treatment and supply. This is the case in most of India's metropolitan cities, which has led to significant financial losses for local governments over the past years (Vishwanath, 2006). Therefore, the prices as specified by DJB do not represent realistic and fair water prices. Though consumers are now used to these low water prices, and thus the procedure of increasing water prices to a reasonable level is complicated, the awareness of water issues seems to be increasing, and thus the readiness to pay higher bills for drinking water (Bell *et al*., 2009; Dutta, 2006; TERI, 2007).

In unplanned colonies, the willingness to pay for clean water plays an important role in water pricing. Several studies have shown that many people in the underprivileged colonies of Delhi and other large cities are willing to pay a reasonable price for improvement of drinking water provision to their communities (Bell *et al*., 2009; Dutta, 2006; TERI, 2007). Furthermore, many people in those communities are aware of the hidden costs they pay for intermittent and unreliable water supply. According to Dutta (2006) these indirect costs are on average 4.6 times the average monthly amount that is paid for water. Furthermore, if hidden costs are included in the total water bill, it turns out that the poor spend between 5 and 10 % of their income (Rai, 2011). This share is much higher than the 3% that is advised by the WHO and the 1-3% that lower and middle class citizens of industrialized countries spend on water (Rai, 2011). According to a research by Dutta (2006) residents of unplanned colonies are prepared to pay almost 3 times the price of their current water bill, if this ensures reliable supply of safe drinking water (In 2005 this was Rs 101 on top of the average monthly water bill of Rs 56: Dutta, 2006). If this would result in time savings and reduced costs for health care, this would eventually effectuate financial benefits.

Appendix IV – Questionnaires

<u>General Information</u>

Study Area:

Name of respondent:

Contact number:

Total nr of households:

Total population:

Major occupational pattern of the community:

Availability of power in the area:

Causes of variation in quantity of water in water sources:

Type of water supply in the area:

Source of piped water supply:

Ground water source:

Location of ground water source:

Type(s) of water supply system present:

Capacity of the existing OHT:

Number of household connections:

Present water supply duration:

Sufficiency of water supply:

House connection water charges:

Sufficiency of water quality (regarding colour, odour etc.):

Presence of landfill area, open dumping, nearby toilets:

Health issues related to water quality:

Community support for a new drinking water system:

Willingness to pay tariff:

Willingness to pay partial contribution:

Main issues:

Our findings:

Household Questionnaire

Area Name:	**Serial number:**
Date of survey:	**Name of respondent:**

General Information

1	**Name of house owner**	
3	**Members in family**	Male: Female: **Total:**
4	**Occupation**	
5	**Main source of income**	*(Pl specify)*:
6	**Education level**	*Above Matriculate (Nos.):* *Illiterate (Nos.):*
7	**Total Annual Income**	**(Rs.)**

Water

S. No.	*Issues*	*Outcome*
1	**Sources of drinking water for household**	**1. Open Well** **2. Tube well** **3. Public Tap** **4. Hand pump** **5. Any Other** *(Pl specify)*
2	**How far is the water source from your house?**	1. Inside the house 2. Within 100 meters 3. Between 100-500 meters 4. More than 500 meters
3	**How much time is spent in collection of water from sources outside the house?**	…… ………………………...*(minutes/day)*
4	**In case of piped water supply or public tap**	a. What is the duration and timing of supply? b. Water supply pressure *(Pl tick):* High. ......, Medium……., Low………..
5	**Do you store water in the house?**	Yes No What is the period of storage?
6	**Amount of water used for households purposes** *(based upon assessment by households)* *(Liters/day)*	see table below

Usage	**Amount used** *(liters/day)*
a. Drinking	
b. Bathing	
c. Cooking	
d. Washing of cloths	
e. Sanitation (Toilet)	
f. Other use *(if any, please specify)*	
Total	

<table>
<tr><td>7</td><td>In which of the following usage water quantity is not sufficient? (please tick as appropriate)
What is the quantity of water required? (Mentions in liters/day against applicable usage heads)</td><td>
<table>
<tr><th rowspan="2">Usage</th><th rowspan="2">Pl tick if not sufficient</th><th colspan="2">Required quantity (liters/day)</th></tr>
<tr><th>During Summer</th><th>During Winters</th></tr>
<tr><td>a. Drinking</td><td></td><td></td><td></td></tr>
<tr><td>b. Bathing</td><td></td><td></td><td></td></tr>
<tr><td>c. Cooking</td><td></td><td></td><td></td></tr>
<tr><td>d. Washing of cloths</td><td></td><td></td><td></td></tr>
<tr><td>e. Sanitation (Toilet)</td><td></td><td></td><td></td></tr>
<tr><td>f. Other use (if any, please specify)</td><td></td><td></td><td></td></tr>
<tr><td>Total</td><td></td><td></td><td></td></tr>
</table>
</td></tr>
<tr><td>8</td><td>What do you feel about quality of your drinking water?</td><td>a. Odour : Yes No
b. Colour: Clear………Muddy………Blackish……..Other………………
c. Taste: Sweet ……… Salty……….Other………………………
d. Any other …….. ………………</td></tr>
</table>

<table>
<tr><td>9</td><td>Do you clean your water container?</td><td>Yes No
If Yes, specify the frequency of cleaning
a. Once a day
b. More than once a day
c. Once in two days
d. Others…………..</td></tr>
<tr><td>10</td><td>Do you keep your drinking water covered?</td><td>Yes No</td></tr>
<tr><td>11</td><td>Do you treat your water before drinking?</td><td>Yes No
If Yes, Then specify the method of treatment
I. Boiling
II. Use filter, ZeroB, Aquaguard etc.,
III. Sieving with Cloth/Alum etc.,
IV. Sedimentation
V. Chlorination
VI. Any other…………</td></tr>
<tr><td>12</td><td>How much do you spend on doctor’s fee and medicines in a month?</td><td>Rs.</td></tr>
</table>

<table>
<tr><td>13</td><td>What are the frequent illnesses in your family and who is most affected (past 6 months)?</td><td>

Diseases	No. of family members affected	Reason perceived	How much cost incurred for treatment
Diarrhoea			
Malaria			
Filaria			
Any Skin disease			
Others specify			

</td></tr>
<tr><td>14</td><td>With respect to potable water, rate the problem of availability and quality using the following codes:
Very serious …………… 1
Somewhat serious…….. 2
No problem…………….. 3
Don't know……………… 4</td><td>

	Availability	Quality
In summer		
In Winter		
Overall		

</td></tr>
<tr><td>15</td><td>Do you pay any water charges?</td><td>Yes No
If Yes,
a. please specify the amount paid monthly:
Or the amount paid per unit of water (e.g. Rs./liter or Rs./ten liters):
b. To whom do you pay water charges?
c. Do you incur any separate charges for drinking water procurement? (If yes, how much per month?):</td></tr>
<tr><td>16</td><td>Is potable water a problem in your area?</td><td>Yes No</td></tr>
<tr><td>17</td><td>Do you feel any initiative for solving the drinking water problem can work in your area?</td><td>Yes No</td></tr>
<tr><td>18</td><td>Does everyone have rights to access water from the available sources?</td><td>Yes No</td></tr>
<tr><td>19</td><td>Any water users' associations? Since when?</td><td>Yes No</td></tr>
<tr><td>20</td><td>Any water rationing? Quotas/quantity allocation</td><td>Yes No</td></tr>
</table>

21	**Any conflicts between these users?**	Yes No
22	**Willingness to partially contribute for an intervention applied to your area.**	Yes No
23	**Willingness to pay tariff for interventions on drinking water supply/provision**	Yes No *If Yes,* a. What is the amount you can afford to pay per month? *(please tick)* – *Less Rs. 50/-* – *Between Rs. 51 to 100* – *Between Rs. 101 to150* – *More than Rs. 150*
24	**Any other comments or suggestions**	

Appendix V – Results household questionnaires

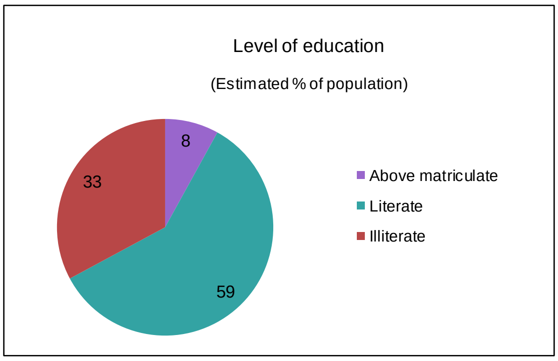
General information

Demographic characteristics (1)	1st day of interviews	2nd day of interviews
total nr of households	23	13
total nr of men	78	
total nr of women	57	
Total nr of people	135	69
share of households surveyed (%)		12.0

Demographic characteristics (2)	
Average household size (nr of people)	5.7
estimated total nr of households	300
estimated total population size (nr of people)	1700
sex ratio (nr women per 1000 men)	731

Education

Level of education	nr. of people questioned	Estimated % of population
Above matriculate	11	8
Literate	81	59
Illiterate	45	33

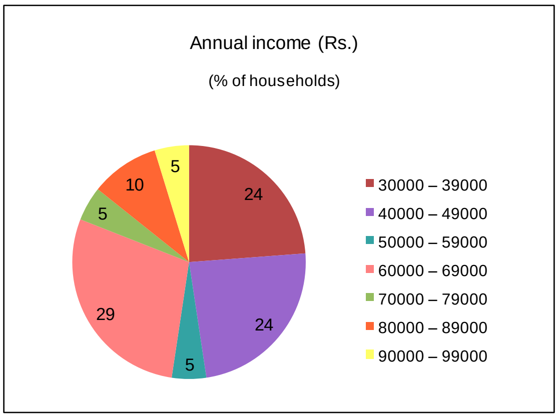


Occupation and income

Occupation	nr. of households
Labour/rikshaw puller	10
Shopkeeper	7
Other	3
no answer	1

Income

Annual income (Rs.)	nr. of households	% of households
30000 – 39000	5	24
40000 – 49000	5	24
50000 – 59000	1	5
60000 – 69000	6	29
70000 – 79000	1	5
80000 – 89000	2	10
90000 – 99000	1	5
Average annual income (Rs.)		55238

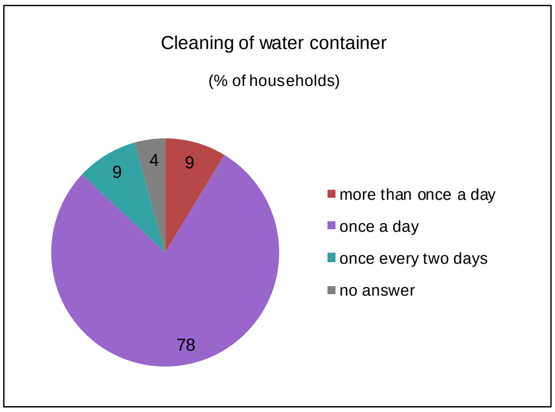


Water

Average time spent on collecting water (min/day)	53

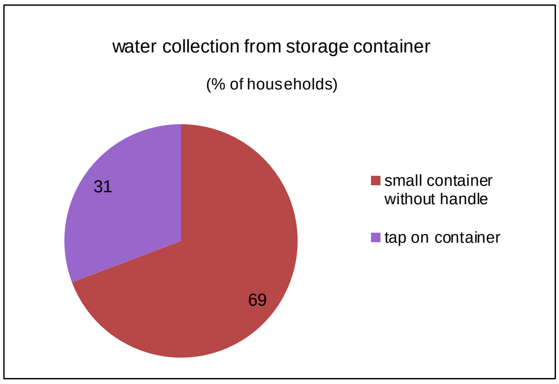
Period of water storage	nr. of households
1 day	15
2 days	5.5
3 days	1.5
no answer	1

potable water use and requirement	average (liter per capita per day)
Use of water for drinking	2.6
Requirement of water for drinking (WHO)	7.5
Shortage of drinking water (according to WHO)	-4.9
Use of water for drinking and cooking	5.8
Requirement of water for drinking and cooking (Indian Standard)	8.0
Shortage of water for drinking and cooking (Indian Standard)	-2.2



Cleaning of water container	nr. of households	% of households
more than once a day	2	9
once a day	18	78
once every two days	2	9
no answer	1	4

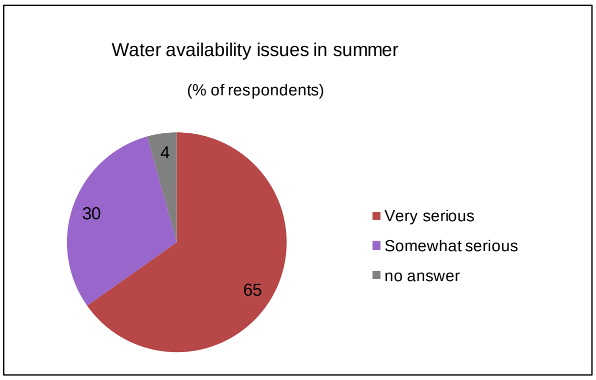
Water collection from storage container	nr. of households	% of households
small container without handl	9	69
tap on container	4	31

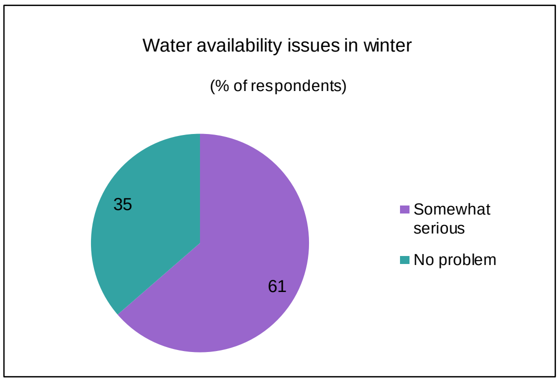


Water availability issues

Water availability issues in summer	nr. of respondents	% of respondents
Very serious	15	65
Somewhat serious	7	30
no answer	1	4
total nr of respondents	23	100

Water availability issues in winter	nr. of respondents	% of respondents
Somewhat serious	14	61
No problem	8	35

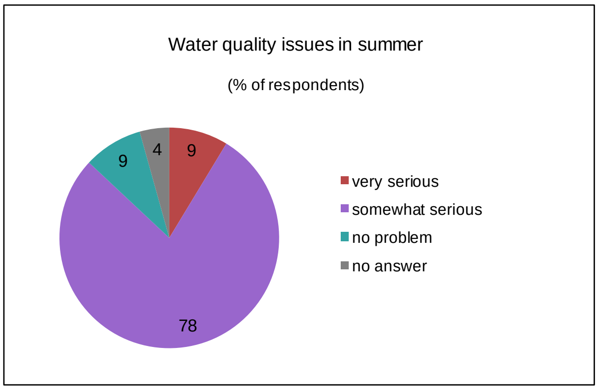


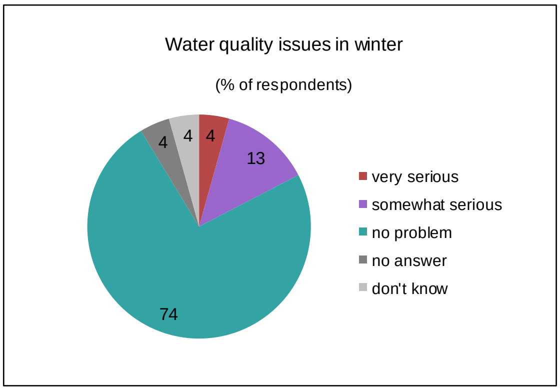


Water quality issues

Water quality issues in summer	nr. of respondents	% of respondents
very serious	2	9
somewhat serious	18	78
no problem	2	9
no answer	1	4
total nr of respondents	23	100

Water quality issues in winter	nr. of respondents	% of respondents
very serious	1	4
somewhat serious	3	13
no problem	17	74
no answer	1	4
don't know	1	4



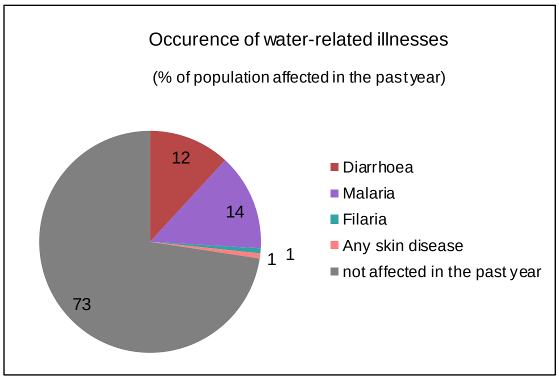


Health

Total average monthly medical costs (Rs. per household)		514

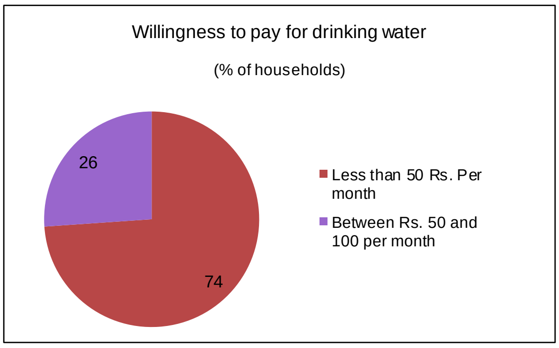
Occurence of water-related illnesses	**% of households affected in the past year**	**% of population affected in the past year**
Diarrhoea	39	12
Malaria	57	14
Filaria	4	1
Any skin disease	4	1
not affected in the past year	8	73

Average yearly medical costs for water-related illnesses (Rs. per household)		204



Payment for drinking water

Willingness to pay for drinking water	**nr of households**	**% of households**
Less than 50 Rs. Per month	17	74
Between Rs. 50 and 100 per month	6	26



Appendix VI – Results water quality tests

Guidelines followed: Indian Standard of 1993 (see references: Bhavan, 1993)
BDL = below detection limit
TDS = total dissolved solids

Date: 27-03-2012

Sample Description: Two samples of water were collected by TERI team from Safeda wali jhugi, Geeta colony on 13/03/2012.

	Parameters	Results		Minimum	Limits	
		From house hold container, (Public tap water), near entrance of the jhugi (S1)	Hand pump, near temple at the entrance of Jhugi (S2)		Desirable Limit	Permissible Limit
1	pH	7.5	8.0	1.0	6.5 to 8.5	No relaxation
2	TDS; mg/l	221	1098	10	Max. 500	Max. 2000
3	Total Hardness (as CaCo3); mg/l	48	392	2	Max. 300	Max. 600
4	Calcium (as Ca); mg/l	12	96	2	Max. 75	Max. 200
5	Magnesium (as Mg); mg/l	4	37	2	Max. 30	Max. 100
6	Chloride (as Cl); mg/l	8	274	2	Max. 250	Max. 1000
7	Fluoride (as F); mg/l	0.3	0.4	0.05	Max. 1.0	Max. 1.5
8	Sulphate (as So4); mg/l	29	113	1	Max. 200	Max. 400
9	Nitrate; mg/l	BDL	1.2	1	Max. 45	No relaxation
10	Iron (as Fe); mg/l	0.15	BDL	0.05	Max. 0.3	Max. 1.0
Bacteriological						
11	Total Coliform (MPN/100 ml)	73	133	0	-	-
12	Fecal Coliform (MPN/100 ml)	Nil	Nil	0	-	-

Date: 03-04-2012

Sample description: Safeda wali jhugi, Geeta Colony

Location	Tap water, at the entrance of the jhugi, corner shop, safeda wali jhugi, opposite to 9 block gate, Geeta colony.	Bore well water, Community toilet at the end of the jhugi	Tap Water, from Dr. Balram yadav clinic, inside the jhugi	Tap water, at the entrance of the jhugi, corner shop, safeda wali jhugi, opposite to 9 block gate, Geeta colony. (2nd sample from S1)	Stored water from tap-S1 ,House near shiv vairo mandir at the main road	Stored water from tap, from house no. 161, inside the jhugi	Stored water from tap, hotel at the entrance of the jhugi, adjacent to location no. S1 (shop)	**Limits**	
								Desirable Limit	**Permissible Limit**
Sample Code	**S1**	**S2**	**S3**	**S4**	**S5**	**S6**	**S7**		
Parameter									
pH	7.0	7.5	7.0	7.0	7.0	-	-	6.5 to 8.5	No relaxation
TDS (mg/l)	119	525	117	106	112	-	-	Max. 500	Max. 2000
Chloride (mg/l)	11	118	9	11	9	-	-	Max. 250	Max. 1000
Total Hardness (mg/l)	84	222	88	74	72	-	-	Max. 300	Max. 600
Calcium (mg/l)	9	95	7	9	7	-	-	Max. 75	Max. 200
Magnesium (mg/l)	4	20	6	5	5	-	-	Max. 30	Max. 100
Sulphate (mg/l)	29	37	26	27	26	-	-	Max. 200	Max. 400
Nitrate (mg/l)	BDL	2.3	BDL	BDL	BDL	-	-	Max. 45	No relaxation
Fluoride (mg/l)	0.3	0.5	0.2	0.2	0.2	-	-	Max. 1.0	Max. 1.5
Iron (mg/l)	BDL	BDL	BDL	BDL	BDL	-	-	Max. 0.3	Max. 1.0
Bacteriological									
Total coliform (MPN/100 ml)	1000	Not done	180	29	400	94	-	-	-
Fecal coliform (MPN/100 ml)	Nil	Not done	Nil	Nil	Nil	Nil	-	-	-
H_2S vial Test	Positive	Positive	Negative	Negative	Negative	Negative	Negative	-	-