What long term solutions for compensative groundwater use are available for people of all levels of income in semi humid areas?

FLORIAN GIESLER

A case study about Bangalore

BACHELOR THESIS IN DELTA MANAGEMENT STUDIES

What long term solutions for compensative groundwater use are available for people of all levels of income in semi humid areas?

FLORIAN GIESLER

Student ID 61817
Supervisor: Liliane Geerling
Delta Management
30th Juli 2015
This Bachelor Dissertation is submitted in fulfilment of the requirements for the degree of Bachelor of Delta Management in Delta Management studies at the HZ University of Applied Sciences by Florian Giesler

Supervisor: Liliane Geerling

30.07.2015
DEFINITION OF TERMS

**Borewell**
A pipe that is put into a hole that has been bored in the ground, and used with a pump in order to get water from under the ground (Indian English). (Online Dictionary, 2015)

**Aquifer**
A layer of rock or soil that can absorb and hold water. On its lower end its bordered by a bedrock with a low conductivity that holds the water. Aquifers have a natural slow flow toward low lying water bodies and can be used as freshwater source. (Online Dictionary, 2015)

**Lower Aquifer (Vadose Zone)**
The top layer of rock or soil that can easy absorb and hold water. On its lower end its bordered by a bedrock with a low conductivity that holds the water and separates it from the deeper Aquifers. It is easy accessible by wells and mainly used as freshwater source. It can refill fast and has fluctuation with rain seasons. (USGS, 2015)

**Groundwater Recharge**
Groundwater recharge or deep drainage or deep percolation is a hydrologic process where water moves downward from surface to groundwater. This process usually occurs in the vadose zone below plant roots and is often expressed as a flux to the water table surface. Recharge occurs both naturally (through the water cycle) and through anthropogenic processes (i.e., "artificial groundwater recharge"), where rainwater and or reclaimed water is routed to the subsurface. (Glendonning, 2010)

**Rainwater Harvesting**
Rainwater harvesting is the accumulation and deposition of rainwater for reuse on-site, rather than allowing it to run off. Its uses include water for garden, water for livestock, water for irrigation, water for domestic use with proper treatment, and indoor heating for houses etc. In many places the water collected is just redirected to a deep pit with percolation. The harvested water can be used as drinking water as well as for storage and other purpose like irrigation. (Reddy, 2006)

**Storage Tank**
A rain water tank that is used for storing rain water runoff, typically from rooftops via rain gutters. There are various kinds from open barrels to big water tanks above and underground. They can be made of concrete or steel. (Online Dictionary, 2015)
Filtration

In this case Filtration means the filtration of rainwater through different kind of layers of rock and clay. The water is seeking slowly though bedrocks in water tanks. These filters needs to exchanged or refresh after every year. (Masagi, 2014)

Monsoon

The rainy season from June to December with every day rainfall. Almost all precipitation is occurring during these months. After the monsoon season a dry season is following with very low precipitation. (Mudde, 2007)

Drainage Pits

A drainage pit, also called a dry well, is used where water drainage is poor is a usually 1 meter deep pit that is filled with gravel that leads rainwater water to a storage tank. (Online Dictionary, 2015)

Urban

An urban area is a location characterized by high human density and vast human-built features in comparison to the areas surrounding it. (Online Dictionary, 2015)

Rural

In general, a rural area is a geographic area that is located outside cities and towns. (Online Dictionary, 2015)

Percolation

The slow infiltration of water into the ground with the force of gravity. (Online Dictionary, 2015)

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>RWH</td>
<td>Rainwater harvesting</td>
</tr>
<tr>
<td>WLF</td>
<td>Water literacy foundation</td>
</tr>
<tr>
<td>mm</td>
<td>Millimetre in precipitation per year</td>
</tr>
<tr>
<td>MCA</td>
<td>Multi Criteria Analysis</td>
</tr>
<tr>
<td>BWSSB</td>
<td>Bangalore Water Supply and Sewage Board</td>
</tr>
</tbody>
</table>
This Bachelor thesis was written by Florian Giesler as part of the graduation process for the final semester of Delta Management to obtain the title Bachelor of Delta Management. This research was done during an Internship at the Water Literacy Foundation in Bangalore, India. The objective of this research is to provide information about the groundwater usage of Bangalore, India and to explore options for a compensative groundwater use. For the research the official code of conduct from the European Science Foundation was followed which includes:

Researchers, public and private research organizations, universities and funding organizations must observe and promote the principles of integrity in scientific and scholarly research. These principles include:

• Honesty in communication;
• Reliability in performing research;
• Objectivity;
• Impartiality and independence;
• Openness and accessibility;
• Duty of care;
• Fairness in providing references and giving credit
• Responsibility for the scientists and researchers of the future.

The full explanation can be found at: http://www.esf.org
ABSTRACT

This research is analyzing Bangalore’s situation regarding water management. It analyzes RWH techniques with the result that they can raise the groundwater significantly and can help to improve the situation especially for the low income population. Its major drawback are the implementation costs, usually the systems pay off within two years after the implementation but need to find investors that are willing to finance the project.

Borewell recharging units offer the best solution for urban areas because of their resilience against pollution and high efficiency. Other states like Goa and Rajasthan are already implementing solutions on a bigger scale but Bangalore has not started yet to create effective policies to manage their scarce water sources more efficient.

The fact that Bangalore is lying on a plateau of 400 meter height makes pumping water from the Cauvery River to the city is very energy demanding and on long-term not very cost effective in the long run.

The solutions provided by the WLF will help to catch and store the rainwater cost effective. The lack of reliable public sources makes water to a precious good and the installations become fast cost effective for people that can afford them in the first place. For people that can’t afford these services an own fund is created that pay for projects of the low income people in Bangalore and other areas in Karnataka.

RWH can help to reduce the pressure but will never be able to fully serve the whole freshwater demand. The city will always depend on expensive water on the Cauvery River but needs to decrease their demand. RWH is easy to implement and should become as usual as it is already in other states of India like Rajasthan.

Never the less RWH cannot be the only solution for the future demand rather it can only help to improve the situation. Bangalore needs to renew its infrastructure and implement more polices that reduce the overall demand. The lakes are unlikely to come back in a city with such a rapid growth and less space available each year.
# CONTENTS

1. Introduction 1
   1.1 Gap of Knowledge ............................................................... 2
   1.2 Objective and Research Question ........................................ 3
   1.3 Background ........................................................................ 4

2. Theoretical Framework 6
   2.1 Pre-Condition ...................................................................... 6
   2.2 Scope and Limitations of Research ....................................... 6
   2.3 Problems of Groundwater usage in developing countries ........... 7
   2.4 Literature ........................................................................... 9
      2.4.1 Lake Type Borewell Recharging Unit 9
      2.4.2 Groundwater, self-supply and poor urban dwellers 9
      2.5.3 National Seminar on Rainwater Harvesting and Water Management papers 10
      2.5.4 Draft Master Plan– 2015 Towards a Vibrant International City 11
      2.5.5 Man-made drought and the looming water crisis 12
   2.5 Method .............................................................................. 12
      2.5.1 Evaluation of projects 13
      2.5.2 Choice of sources 13
      2.5.3 Data Handling and Processing 13
      2.5.4 Creating a MCA 15

3. Analysis/results 16
   3.1 Bangalore ......................................................................... 17
      3.1.1 Hydro geological setup 17
      3.1.2 Geological setup 17
      3.1.3 Precipitation and recharge 17
      3.1.4 Aquifers 17
      3.1.5 Water Resources 18
      3.1.6 Scope of Groundwater augmentation through artificial recharge 18
   3.2 Problem analysis ................................................................ 19
      3.2.1 Disappearance of Lakes 19
      3.2.2 How much groundwater is currently used in Bangalore and what is the predicted amount of water needed for the future? 0
      3.2.3 Surface water sources of Bangalore 0
      3.2.4 Predicted water usage 2
4.2.1 Costs
4.2.2 Amount of water harvested and efficiency factor
4.2.3 Imitability
4.2.4 Resilience to external factors
4.3 GOA .......................................................... 2
4.3.1 Background
4.3.2 Problem
4.3.3 Open cast mining in Goa
4.3.4 Case Goa University in Taleigao
4.4 Conclusion .......................................................... 5
4.4.1 Costs
4.4.2 Amount of water harvested and efficiency factor
4.4.3 Imitability
4.4.4 Resilience to external factors
4.4.5 Resilience to climate shifts
5. Multi Criteria Analysis .......................................... 6
5.1 Decision context ................................................ 6
5.2 Options ......................................................... 6
IMITABILITY .......................................................... 7
5.3 Results .......................................................... 8
5.3.1 Bangalore
5.3.2 Rajasthan
5.3.3 Goa
5.4 Conclusion ....................................................... 11
6. What long term solutions for compensative groundwater use are available for people of all levels of income in semi humid areas? 12
Discussion
Works Cited
1. INTRODUCTION

This bachelor thesis sets out to what extend compensative groundwater recharging in semi-arid areas might be possible. To analyze this madder a borewell recharging unit build by the WLF in Bangalore is used for a case study. First the conditions in Bangalore are explained regarding its history of water management and the cause of the problems.

In the following chapter a closer look to the Borewell recharging unit made with explanation about the functioning and price with the goal to indicate its feasibility for the low income population. For reaching this target group special planning approaches need to be made. To analyze this matter a standard problem planning template used by the WLF was analyzed to find out what stages need to be changed if the costumer does not pay for the project himself. With the goal to improve projects financed by third party to improve the water management in the slums.

In the end 2 other cases with similar problems in other states of India are analyzed regarding factors like their efficiency, resilience and if it’s possible to duplicate them other projects. A multi criteria analyses will help to indicate its strong and weak points in comparison with Bangalore.
1.1 GAP OF KNOWLEDGE

The water shortage of Bangalore just recently became a problem. In the past there was plenty of water due to the two very humid rainy seasons and the high amount of lakes distributed all over the city. The most research papers that are available are from the early 2000s till today. The idea of using rainwater for groundwater recharge is something that is already known since more than a century but the knowledge got lost during the Industrialization. Watershed management is known to be an important factor in efficient water management for semi-humid areas. (J. W. Kijne, 2003). Furthermore all techniques mentioned are natural like, land smoothing, drain construction, the introduction of BBF system, use of bullock-drawn agriculturist, summer cultivations, dry seeding, etc. and work slowly through natural processes. This makes it unsuitable for urban areas since they need a lot of space with unsealed surfaces (J. W. Kijne, 2003).

Other regions of India with a longer history of water shortage already came up with artificial groundwater recharging techniques. Arid areas like Rajasthan area already very experienced with rainwater harvesting since they have already have a long history of water shortage. They have a high diversity in all kinds of approaches (Glendenning, 2010). Nevertheless it is not known if these techniques also work in southern India with a much higher annual precipitation and silt and clay soils (Resources, 2011). It was not possible for me to find any recent case study about artificial groundwater recharge in the metropolitan area of Bangalore. This can be seen as a predictor for a gap knowledge in the south of Karnataka including Bangalore.

Figure 2 Dry Pump
1.2 OBJECTIVE AND RESEARCH QUESTION

India is one of the most divergent countries in the world. While Bangalore is becoming the “silicon valley” of India 70% of its population have no access to computers and have troubles to meet their basic needs of food, water and shelter. While big companies and rich people can satisfy their need for freshwater water by drilling deeper and deeper bore wells or buy it from water tanks, the population is depending on public sources or affordable borewells. (Times of India, 2011).

Borewells are reliable sources for drinking water for the lower income population because they are free of charge and can meet the individual needs. The problem in Bangalore is that rainwater cannot percolate in the ground due the clayey soils in the rainy season and borewells cannot recharge during the rainy season the groundwater that is extracted in the dry season. This results in dried up bore wells which are not reliable enough for industries or agriculture (Jacob, 2012).

The objective of this research is to create a balance of discharge and recharge for borewells in Bangalore. This will result in a sustainable groundwater use that is affordable for the whole population.

This objective is translated in a main research question which is subsequently translated in sub questions.

The main question of this research is:

What long term solutions for compensative groundwater use are available for people of all levels of income in semi humid areas?

A case study of groundwater water recharging units in Bangalore.

- How much groundwater is currently used in Bangalore and what is the predicted amount of water needed for the future?
- What are the problems of extensive groundwater usage in Bangalore?
- What is the current state of freshwater management in other states of India and how could it be relevant to Bangalore?
- What is a groundwater recharging unit and how does it work?
- What planning and finance approaches makes groundwater available for people with a low income?
1.3 BACKGROUND

Bangalore is becoming the technology hub in India, with companies like Cisco and Microsoft already settled, it is known as the next Silicon Valley. Soon it might become a true alternative to the established American factories and software developers due to low labor costs with sufficient knowledge (Jenny T. Grönwall, 2010).

The increased welfare lures people from all over India to Bangalore seeking for business opportunities. The population has a steady increase of 3.5% annually (Authority, 2015) (Jenny T. Grönwall, 2010). The increased welfare of a growing minority combined with the steady growth of the total population lead to an accelerating freshwater demand. Other water-related problems come from an over-exploitation of groundwater and poor recharge of aquifers during the rainy season and usurpation of lakes by real estate development. (Jenny T. Grönwall, 2010)

Approximately three quarters of the freshwater is coming from the Cauvery River. The River is dammed with reservoirs in the north of the city, build by the official governmental water company. Most of the poor population is using borewells as their main water sources because it is freely available. It is estimated that there are 312.000 public owned and 105.500 private owned borewells. The Department of Mines and Geology estimates that annually 124.510.000m³ water are exploited through unregistered while only 32.900.000m³come from0078 that are registered (G.V. Hedge, 2012). This imbalance water discharge and recharge leads to a lowering groundwater table which leads again to deeper borewells in the long run it creates a positive feedback that will end in a serious water crisis for the poor population Bangalore (see figure 3).

Dug wells in urban environments are usually shallow and placed in areas were groundwater can be found lower than 15 meters. They give the possibility for the poorest people to have a potable water supply because of their low implementation costs.

Annual data of the Indian Water Portal show that there is an annual rainfall of about ~ 859mm regarding the Köppen classification, Bangalore is defined as a semi-tropical region (Heinrich & Herg, 1994). Karnataka is one of the most humid regions in India and the only places facing water problems are the southern municipalities around Bangalore which also have the highest population density of the province (Shivakumar, 2007). This indicates that the problem does not occur naturally and is manmade.

90% of Bangalore surface coverage consists of red laterite and red fine loamy and clayey soils. Their fine texture are the reason for the low infiltration capacities and hence the recharge of groundwater during the rainy season and increase the runoff. Most aquifers can be found in depths of 100-110m after the monsoon the groundwater level can rise up to 1.77 meters and 12.02 meters below ground level. (Masagi, 2014)

Most of the problems occur during the long dry seasons from December to June followed by heavy monsoon rainfalls from June to September and a small secondary rainy season from November to December (Mudde, 2007). The rainwater can’t infiltrate in the ground fast enough during the rainy season and runs off or

---

Figure 3 Circle of destructionSource: WLF
evaporates due to high temperatures and low humidity. The water accumulates usually in lakes which are nowadays becoming rare. They are filled up for retail development and replaced by impervious surfaces due to urbanization. Bad management of the already scarce resource worsens the situation artificially. Much water is uncontrolled pumped from the ground and because it’s free of charge it’s handled lavishly. Never less observations of rainfall patterns in the last century show that the precipitation can vary between 100mm and 10.000mm per year with increasing fluctuations due climate change (Jenny T. Grönwall, 2010).

Since the British colonization the Cauvery River was a water source for the city but already in 1882 first thoughts were given if the river would be able for the long-term as a safe water supply for the population and British military at that time (Gupta G., 2012). Now with population crossing the 10 million border within the next 10 years (Authority, 2015) the worries seem to become serious enough to look for a new water source for the future. Right now about ~8.1 billion liters of water per day are pumped from the river to the city. With additional dams and channels the amount will increase to 13.1 billion liters of water per day. Experts say that a further increase of the water outtake is unlikely to happen and soon the river can’t cope with the demand of the city water use (Gupta G., 2012).
2. THEORETICAL FRAMEWORK

2.1 PRE-CONDITION

There are various case studies from other project sites around the world and in India treating the problem of a decreasing groundwater level. During the research the conductor had access, to all data from monitoring and project planning made by the Water Literacy Foundation, this data lacks most of the time scientific reliability because it consist often of estimations rather than measurements. The usual way plan a project is rather context first than science first.

Never the less some basic data about the project sites like tank size, pumped water, annual precipitation and costs can be used because the numbers are easy to evaluate. The need for some real research is quite urgent, most people working for the WLF are engineers that focus just on the realization of the projects and not the science behind it. A case study will be useful for the WLF but also for other studies that tackle the water shortage in Bangalore.

2.2 SCOPE AND LIMITATIONS OF RESEARCH

Due the short time and the limited available information there will be clear limits of what can be accomplished during the research. At first the project area will be limited to some project sites from the WLF in Bangalore. The case study will focus on one system of rainwater harvesting applied by the WLF and two projects in less detailed for a comparison. This results in a spatial limitation to the project site. There many different ways to successful recharge groundwater in urban areas, during the research it will be focused on techniques applied by the WLF.

The point that the research was done in India will add more limits to the dissertation. There are boundaries in language and differences in culture and working attitude that will have an effect on the Thesis. Sometimes it is not possible to get reliable information about important factors or the sources are not possible to find out. It was always tried to find the most reliable source and it will be mentioned if not scientific methods were used to conduct the research.
2.3 PROBLEMS OF GROUNDWATER USAGE IN DEVELOPING COUNTRIES

Self-supply

The ground water is mostly used by the low income households. Most all their water comes from one source and is not mixed with water from other borewells. It is sometimes directly delivered to the households or to public wells and shared by a community. Every person that owns a small part of land is allowed to use the groundwater underneath it with no limits in discharge. If the borewell has a high yield the water may be sold to water tankers and is an additional source of income. Because of the self-supply it is nearly impossible to say how much groundwater is actually used. (Grönwall, Mulenga, & McGranahan, 2010)

Indirect use of groundwater

Indirect use of groundwater is provided through pipes by a public and centralized water system. The water comes from controlled sources mixed and distributed by the government. The amounts of water that are drained are monitored and frequent quality checks are done. Disturbances in the yield of borewells can be seen easily. This system can be often ineffective because of an over aged distribution system, with lacks that wastes a lot of water. The government charges money for the use of this service. (Grönwall, Mulenga, & McGranahan, 2010)

Sometimes it’s hard to differentiate the two systems because most households use both sources. Public systems in developing countries often don’t work the whole time so people look for alternative sources during the down times. (Grönwall, Mulenga, & McGranahan, 2010)

Also 20% of Bangalore population live in “slum-like” dwellings with no water supply at all. They need to get their water from alternative sources or use public wells close by. It is almost impossible to provide water to the whole population from public sources so the city depends on the self-supply of the population for its fast development. The task of the government should be to refill the aquifers by groundwater recharging during the rainy season. This saves money on short term because no distribution network is needed. Contrary the government need to monitor the groundwater level and include rainwater harvesting techniques for all its public spaces where it’s possible. Also it is important to reduce the groundwater pollution by protecting surface waters and manage the sewage. The following figure defines the exact strengths and limitations of groundwater usage and actions needed to be made by the government. (Grönwall, Mulenga, & McGranahan, 2010)
<table>
<thead>
<tr>
<th>To prevent depletion of groundwater</th>
<th>Strengths</th>
<th>Limitations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conduct hydrological assessment of aquifers</td>
<td>Improves knowledge; enables informed decisions</td>
<td>Lack of skilled manpower &amp; equipment; costly</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>To increase well water quantity</th>
<th>Strengths</th>
<th>Limitations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Introduce rainwater harvesting and other artificial means of recharge</td>
<td>Increases recharge to wells &amp; aquifers; balances withdrawals</td>
<td>Needs regulatory framework &amp; control; costly. Dry periods restraints</td>
</tr>
<tr>
<td>Increase number of wells</td>
<td>Increases volumes withdrawn &amp; number of access points</td>
<td>Risk of sinking water table. Lack of skilled manpower &amp; equipment; costly</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>To reduce groundwater contamination</th>
<th>Strengths</th>
<th>Limitations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reduce open defecation and usage of pit latrines, especially unlined</td>
<td>Reduces risk of pathogens percolating into wells and aquifers</td>
<td>Necessitates alternative solutions; costly. Lack of space.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>To improve well water quality at point-of-collection</th>
<th>Strengths</th>
<th>Limitations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Improve unprotected, dug wells by inner lining, platform and cover</td>
<td>Reduces contamination, seepage &amp; risk of pathogens flushing into well</td>
<td>Lack of skilled manpower &amp; equipment; costly. Does not protect deep aquifers</td>
</tr>
<tr>
<td>Practise hygienic well use</td>
<td>Reduces risks of pathogens spreading</td>
<td>Needs normative framework &amp; control. Cont over</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>To improve water quality at point-of-use</th>
<th>Strengths</th>
<th>Limitations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chemical water treatment (chlorine, etc.)</td>
<td>Kills bacteria /viruses</td>
<td>Costly; time constrains. Needs info/education. Changes smell/ taste.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>To improve groundwater distribution</th>
<th>Strengths</th>
<th>Limitations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Install hand- or electric pumps</td>
<td>Increases quantities. Reduces contamination from buckets</td>
<td>Costly; lack of skilled manpower &amp; equipment. Risks over-extraction</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>To integrate urban well/groundwater into water resource management</th>
<th>Strengths</th>
<th>Limitations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Identify appropriate selection of measures (from above and others)</td>
<td>Facilitates contextualised &amp; customised measures</td>
<td>Lack of baseline data. Lack of skilled manpower; costly</td>
</tr>
</tbody>
</table>

Figure 4 (Grönwall, Mulenga, & McGranahan, 2010)
2.4 LITERATURE

2.4.1 LAKE TYPE BOREWELL RECHARGING UNIT

WLF is on a war path in constructing more and more lakes. In this direction, Mr. Ayyappa Masagi as an individual and through his organization has constructed over 500 lakes. This has brought him an entry of his name into the Limca Book of Records for the highest number of Lakes constructed in India. The WLF has also done extensively research about Lakes in detail, their importance and reasons for their decline. The results showed that keeping lakes exposed would result in evaporation and contamination by human activities. People have forgotten the lakes after river water supply and borewell systems came in place. The modern perception of lakes is that they are dumping yards for sewage and refuse. The WLF is on a critical mission to prove that it is not enough to only harvest rain water in lakes but also protect them from evaporation as well as contamination. To achieve this, Mr. Ayyappa Masagi has innovated Lake Type Borewell Recharging Unit.

Lake Type Borewell Recharging unit is a system where water is naturally filtered and 20% of annual rainfall volume is percolated through Earth soil layers while around 80% of the annual rainfall volume is injected into the borewell directly. The rain water is stored in Sub-soil water table and eventually percolates further to rejuvenate underground water table. The following images show first the ground water flow under the natural condition and then the influence of a borewell. (Source: Internal documents of the WLF)

2.4.2 GROUNDWATER, SELF-SUPPLY AND POOR URBAN DWELLERS A REVIEW WITH CASE STUDIES OF BANGALORE AND LUSAKA WRITTEN BY JENNY T. GRÖNWALL MARTIN MULENGA GORDON MCGRANAHAN.

This report includes several case studies about groundwater management in Bangalore. The paper was published in 2010 this means it is 5 years old at this point. Ms Grönwald studied in Sweden is an expert in ecosystem services, resilience and equity aspects of urban poor people, and articles on Indian water law and the right to sanitation under Swedish law.
Mr Mulenga is studied in Great Britain and published papers about Sanitation Urban sanitation in Zambia and South Africa.

Mr. Mc Granhan is working for th International for Environment and Development. His research interests include poverty, urban transitions and environmental justice.

All three authors have a Ph. D. and have a good reputation in their research fields. It must be mentioned that none of them is Indian what can be a disadvantage in the local problems but also offers the possibility of a very objective research. They are all experts in the problems of developing countries.

The paper handles the topic of water management and can help for the choice of methods. It includes references to the international millennium goals. The main focus is not on groundwater recharging but more on the strategic and efficient use of the limited availability. The research includes the social factor of the poor people which are the main user of the groundwater since it is for free and modern techniques allow cheap usage of it. Furthermore the challenges of climate change are well handled in this paper.

There are 2 case studies included. One about Bangalore and one about Lusaka in Zambia. In both cases the water groundwater is the main source from the low income population both cities have similar soil structures.

The objectives of this review are:
• To explore the extent to which urban dwellers, and especially those living in low income areas, depend directly and indirectly on groundwater
• To explore the difficulties they face as a result
• To raise awareness of and emphasize the need for better integration of groundwater in the planning and management of urban water resources.

This paper will mostly help to formulate the methods and to bring facts about the international perspective of groundwater use and limited information about recharging. While it won’t be a problem during the research to get data about groundwater recharging in Bangalore since the research was conducted at a company that is specialized on this topic. It will help me to create a good outline and the case study about Zambia can help to make references to the other case.

2.5.3 NATIONAL SEMINAR ON RAINWATER HARVESTING AND WATER MANAGEMENT PAPERS

This document consists of 24 short research papers all aiming at Rainwater harvesting and water Management in different places in India written by more than 40 different authors. They all focus on different areas and different problems and include several case studies. When they are used there will be a reference to each exact paper of this collection but in this literature review they will be handled as a bulk because it would be too complex to describe each in detail. Overall it can be said that they include specialized knowledge about the problems of rainwater harvesting in India.

The content of this research paper are several descriptions of different rainwater harvesting methods, some of them also include groundwater recharging, it offers a very good description of the problems groundwater shortage is causing at the moment. It offers numbers about changes in precipitation with tables for Bangalore and other for the last 20 years (till the publication 2006). It includes an overview of the Limitations and the response to droughts in different places in India. Also it discusses the need for water tankers, when they are useful and when they are hindering the development of sustainable groundwater management. It is good have an overview due to the problems of Indian research data that is discussed in the Portfolio.

The bad side of this collection is its age, it was used as handout for the National Seminar on Rainwater harvesting and Water Management in 2006 within the last 10 years a lot has changed in this field and demand has increased rapidly.
2.5.4 DRAFT MASTER PLAN – 2015 TOWARDS A VIBRANT INTERNATIONAL CITY

The master plan is made by the Bangalore Development Authority. The master plan is offering all basic information about population growth, the functions of the different parts as a city and a roadmap for future development. Furthermore it defines the Vision of the city planners of Bangalore for the next decade. It is alarming that most of it concentrates on the economic development of Bangalore and exclude its water shortage for most parts. Also it is just a draft version of 8 pages and gives limited information to each topic and the final version was never made or at least not accessible for the public.

Even the limited information that is provided in this paper can be very useful because it is the official data and shows the focus of the urban planners of Bangalore.

Figure 6 Population growth in Bangalore
2.5.5 MAN-MADE DROUGHT AND THE LOOMING WATER CRISIS

This report is written by B.P. Radhakrishna. Wikipedia says that he is known as the doyen if Indian Geology. When the paper was published in 2006 he was already 88 years old. He is a professional of Bangalore. He created the Banglolian society of geology which had the goal of improving the quality of research about geology in India. He has a very good reputation and is one of the most experienced research about Bangalore’s geology and hydrology.

The paper focusses on the causes of Bangalore’s freshwater shortage. It explains to causes and also offers ideas for solutions. He highly recommends using rainwater to refill the aquifers. His expertise helps to understand the long term development of Bangalore’s groundwater shortage. Resource availability for water supply to Bangalore City, Karnataka

This report is written by G. V. Hegde and K. C. Subhash Chandra, there can be no information found about the two authors but this paper just includes basic data about Bangalore geological conditions and there reliability is not that important in this case. This paper will just be used for basic knowledge about the geology.

2.5 METHOD

1. Research Phase
   It begins like most research with library and internet research about the current state of other researches to this topic. The research question should answer questions that don’t have valid answers yet.
   Other sources of knowledge are Interviews with other people that have knowledge about the situation.

2. Analysis Phase
   In the end of phase 1 the writer ends up with a large amount of information from various source. The next logical step is to make a well-structured analysis. It begins with choosing the important information of the collected bulk. During this phase the writer have to make clear why he chose those information over other he excluded.
   Another step is to write down information about all people and organizations that are important to the case. Charts and diagrams can help to give an overview about all included stakeholders to the project.
   The Result of phase two is a collection of organized and relevant information to the research question, Information about all relevant experts and stakeholders and finally the research question with relevant sub-questions which should answer the main question not more or less.

3. Writing the case study
   The case study should start with a question the situation is explained and the problem that will be answered is pointed out in an obvious manner. In this stage it is as important to rise the interest of the reader as giving first relevant information about the background. The organization should be as follow
      a. Introduction
      b. Background of the problem
      c. Costumers
      d. Governmental Policies
      e. Success stories
      f. Potential improvements
      g. Management problems/opportunities
      h. Conclusion
   It is important to keep write down all information so that is also useful for other cases in other countries.

4. Writing a MCA
   To achieve the highest possible quality of research it is necessary to use a variety of different sources but also to have expert conservations about the topic. Furthermore it is important to use also external opinions from farmers, and other organizations. I will visit project sites and speak the owners of the borewells. Through the NGO Leave Ur Mark It there
is the possibility to speak to different organizations fighting the water scarcity in India with different methods.

A case study have to more than a description, it explains to the reader what problems the writer was facing in the beginning and puts him in the same situation he was facing in the beginning. It leads the reader through the problem analysis and feeds him with information until the research questions is answered or the statement disproved.

After the case study is finished it needs to be rated to compare it to other ways of groundwater recharging methods from other areas. Since it is the goal of this research to find out the best suitable method for Bangalore first the right criteria for successful groundwater recharging projects have to be found. Afterwards the projects will be evaluated due to this criteria and different projects will be compared with a Multi Criteria Analysis.

The exact steps about how to write a case study can be found in the appendix.

2.5.1 EVALUATION OF PROJECTS
For a reliable result the criteria for a successful project need to be defined in advance. The criteria from the WLF were chosen as a basis. The WLF is exchanging with their costumers about the results constantly and a lot of experience in the field of RWH. The researcher personally added costs to it compare with other techniques.

For measuring the efficiency of different rainwater harvesting methods following factors are used for compartments

- Costs
- Improvement in borewell water quality and quantity
- Replicability
- Resilience to external factors
- Adaption of climate shifts

2.5.2 Choice of sources
The literature review will be based on the previous studies of the WLF, researched papers that are validated by the institute and the books written by Ayyappa Masagi.

All collected data about rainwater harvesting methods will be measured by the staff of the WLF or personally. The official project plans are used to analyze the project management of the WLF.

Internet research

Internet research will be limited in this project due the lack of information about the Water Literacy Foundation methods. Never the less the internet provides a wide range data regarding climate estimations and information about India and Bangalore. The data will be from official governmental website or data that is vilified by WLF.

Case Studies

Case studies will be the core of the research paper, information will be gathered from project plans, personal interviews, and visits of as much project sites as possible.

MCA

The final results will be compared in an MCA to other cases in Goa and Rajasthan. The exact procedure will be described in the next chapter.

2.5.3 DATA HANDLING AND PROCESSING
All data will be stored on the personal computer of the author and in the “One Drive” cloud from Microsoft as a backup. Microsoft Word is used for text editing and the Acrobat Reader for opening research papers. MS Excel will be used to create tables about costs and check rooftop rainwater harvesting and borewell recharging installations while it will be possible be active involved in the latest project on the factory ground.

For measuring the efficiency of different rainwater harvesting methods following factors
are used for compartments. These factors will be compared in a Multi Criteria Analysis to compare them between different projects.

**Costs**

The Costs are easy to figure out since the WLF is carrying out all constructions or pays other parties to so if specialists are needed.

**Amount of water harvested**

To calculate the recharge an average rainfall of 780mm is estimated the catchment area can be found in the project description. The formula catchment area in m² (A) times annual precipitation in m³ (R) times an efficiency of 70% (E).

\[ A \times R \times E = \text{Annual harvest} \]

**Efficiency factor**

After knowing the costs the efficiency can be calculated with the formula. Costs in rupees/annual recharge in m³.

**Imitability**

It is important to find a solution that can be used for all places without big changes, only this way it can be kept cheap and easy to maintain. The way evaluate the Replicability is to count external factors that have influence to the project, like soil type slope or special features of the landscape. The result will be a value between 1 and 10 while 10 is the highest.

**Resilience to external factors**

Bangalore has a steady population growth of 3.25% this means projects should include an increase in demand for future. Also the use of areas very dynamic since urban planning is uncommonly for most areas of the city. This should be included in the project to make it resilient to future changes of the urban landscape. The result will be a value between 1 and 10 while 10 is the highest.

**Resilience to climate shifts**

Since all evidence looks like the world climate will have some drastic shifts in the next decades the systems should be able to work properly in weather extremes. Factors that indicate resilience to climate shifts are:

Annual consumption / Annual harvest

The goal is to have number of one or higher here, if there is at least two times as much water harvested than used years of drought are not problem as long as they occur not regularly.

**Changes in time**

For the last century the rainy season started during the first week of June and ended at the end during the weeks of January. These seasons might change with and occasional heavy rainfalls during the dry season happen more frequent in the last years. The system should be able to deal with this changes and use this water effectively.
2.5.4 CREATING A MCA

1. **Establish the decision context**
   a. Establish aims of the MCDA, and identity decision makers and other key players
   b. Design the socio technical system for conducting the MCDA
   c. Consider the context of the appraisal

2. **Identify the options to be appraised**

3. **Identify objectives and criteria**
   a. Identify criteria for assessing the consequences of each option
   b. Organize the criteria by clustering them under high-level and lower-level objectives in a hierarchy

4. **‘Scoring’. Asses the expected performance of each option against the criteria. Then assess the value associated with the consequences of each option for each criterion.**
   a. Describe the consequences of the options
   b. Score the options on the criteria
   c. Check the consistency of the scores on each criterion

5. **‘Weighing’. Assign weights for each of the criterion to reflect their relative importance to the decision.**

6. **Combine the weights and Scores for each level in the hierarchy**
   a. Calculate overall weighted scores at each level of hierarchy
   b. Calculate overall weighted scores

7. **Examine the results**

8. **Sensitivity analysis**

   a. Conduct a sensitivity analysis: do other preferences or weights affect the overall ordering of the options?
   b. Look at the advantage and disadvantages of selected options, and compare pairs of options
   c. Create possible new options that might be better than those originally considered
   d. Repeat above steps until a ‘requisite’ model is obtained

(Government, 2008)
3. ANALYSIS/RESULTS

Figure 7 Borewell recharging unit under construction
3.1 BANGALORE

3.1.1 HYDRO GEOLOGICAL SETUP
The City of Bangalore covers an area of around 830 m² of which around ~50% fall during the monsoon season from June to September it lies on a plateau 920 meter above NAP. The area was formerly the catchment area for the Arka-vati River to the west and the Ponnaiyar River to the south east. Nearly of 560 m² of its area is sealed surface the rest are parks, lakes, or recreation facilities like golf clubs and race courses. The climate is semi-arid with around 800mm precipitation annually falling in monsoon months. (Bhavan, 2012)

3.1.2 GEOLOGICAL SETUP
The plateau the city is covering is part of the gneissic complex with Migmatites, Granodiorites and intrusive granites to an average depth of 15 m by loamy to gravelly soils of varying thickness. In the eastern part of Bangalore 60m thick saprolite formation covered by 2-5 m lateric soil can be found. The saprolite and lateritic soul are clayey and form an impermeable layer above the aquifers. The soil results during the monsoon in a rapid surface run-off while the sealed surface from buildings are also having a positive effect to the runoff. The impermeable layer created the right conditions for 100’s of lakes spread through over the city of which most were filled up due urban development in the 80’s. (Bhavan, 2012)

3.1.3 PRECIPITATION AND RECHARGE
The average rainfall in Bangalore is 937 mm 50.37% of it falls during the monsoon between June and September with its peak in last week the monsoon months. 937mm of rainfall times 830 km² (937x830.000) results in 777,710,000 liters of annual rainfall. Due lack of data it can’t be told how much of this water results in runoff and how much is able to infiltrate the ground for this reason estimation based on Parkers Formula. It consists 2 calculations for the paved and unpaved area. The paved area is estimated to have a runoff of 85% will it is estimated that the open spaces have a runoff 50% due the clayey soils and the strong monsoon rains over short periods. (Bhavan, 2012)

For the sealed surfaces the calculation is 560,000 m² x 937mm x 0.85 = 446,012,000l runoff or 560,000 m² x 937mm x 0,15 = 78,708,000l infiltration. For the unsealed surfaces the calculation is 270,000 m² x 937mm x 0.5 = 126,495,000l runoff and infiltration (the formula is the same since coefficient is 50%).

The end result is a total runoff of 572,507,000l and 205,203,000l infiltration

3.1.4 AQUIFERS
Due High drainage of groundwater there can be no base flow measured. The water level is kept below the channel base so no groundwater is leaving the system through regular flow. Because of the Monsoon climate the groundwater water level from Mai till November is significant higher than during the rest of the year. The depth varies through the city from 4m to up to 85m according to data from Ministry of Water. Newspaper articles from worried citizens write that in some parts there can no water be found above 200 meter. It is also known that there is a drastically decline in the groundwater due an increase extraction combined
with sealing of the surface. Also and filling up of the old lakes that were once an important part of Bangalorian landscape has a negative impact on the aquifers. (Bhavan, 2012)

3.1.5 WATER RESOURCES
It is estimated that there is an annual groundwater recharge of 3290 ha³. The water comes for 2125 ha³ from rainwater infiltration and 905 ha³ from 96 perennial tanks (water basins). Additionally there is a 263ha³ recharge from sewage which is about 1% of the annual produced capacity. A study 2011 said that 30% of the borewells have a depth of 100m, 54% between 200 and 300m and 0,56% are deeper than 300m. The total annual demand is accounted for 48.600 ha³ but there can be just 37,374 ha³ supplied by surface and groundwater resources. The shortage of 11.226 ha³ means that it can be estimated that 2,2mio people face water scarcity. With 9.161 ha³ more groundwater being extracted than recharged 2.38mio more people will badly affected.

This concludes that 7.6 mio are endangered to suffer from water scarcity in the near future. (Bhavan, 2012). Since its rapid increase of population Bangalore already faced several major water crises, like in 1974 with the result water tankers were send to nearby lakes like the Ulsoor lake and people relocated to the metropolitan area with higher groundwater tables. Pumping costs are already the reason for 75% the municipal energy use. (Bhavan, 2012)

3.1.6 SCOPE OF GROUNDWATER AUGMENTATION THROUGH ARTIFICIAL RECHARGE
The decreasing groundwater level leaves waste amounts of space for artificial recharge. Since the water level is decreasing since 1970’s without a chance of refilling. The clayey soils protected the land from subsiding in the short term but the increase load of buildings of its surface could cause problems in future.

The government saw the potential of rain water harvesting and groundwater recharging already in 2009 and wrote the ground water harvesting regulations. It says that every owner or occupier of a building site bigger than 2400 ft² (~720 m²) shall provide rain water harvesting structures. This policy that the Indian government stands behind groundwater recharging projects. (Bhavan, 2012)
3.2 PROBLEM ANALYSIS

3.2.1 DISAPPEARANCE OF LAKES

The main cause for Bangalore’s actual water crises are along with its rapid increase in size and its mismanagement of resources is the disappearance of its lakes. Those were the reason to establish the city at this location in the first place in the 15th century. The water tanks harvested the rain during the monsoon reason and made it available during the dry season, furthermore it refilled the groundwater level continually. (Thippaiah, 2009)

After the city was able to fund the distribution of water from the Cauvery River in the 70’s it seemed that there was no need for these water tanks anymore and their depletion began. From 1973 to 1996 about 34% of all lakes disappeared and became sealed surfaces for industry and dwellings. Low building regulations combined with corruption made it easy for constructors to buy unoccupied land in the city core and use it for major real estate development. The lakes that are still there are often used for dumping untreated sewage and become unavailable as additionally they became one the major contributors to the groundwater pollution. (Thippaiah, 2009)

Bangalore has three different lake systems that are interconnected but work independently. The lake systems take place in the three different valleys of Bangalore, Koramangalachallaghatta, Vrishabhavathi and Hebbal. The drainage zones are called the, Varthur lake series, the Puttenahalli lake series, Hulimavu Lake series. (Thippaiah, 2009)

Even if there are low legal boundaries to stop the disappearance of lakes, the population become more aware of the situation and start to take action against the drainage of lakes since the 90’s. Petitions and demonstrations are now always hindering the construction of new real estate in places that were formerly used for lakes. The latest development is giving away leasing rights of lakes to hotels that use them for different recreation purposes like a floating park. Even the leasing contract includes that the leaser is responsible for the cleanup of the lakes after usage, environmentalists are worried that due to corruption and the lack of governmental restrictions the lakes will be in big danger. The public sectors argues that there are almost 3000 lakes in Bangalore and it is impossible to pay for their clean up without involvement of the private sectors. In March 2011, the high court of Bangalore accepted a legal framework that aims “to carry out the restoration work and indicates the extent to which the lakes have been encroached, polluted and protected”. (Radhakrishna, 2004) (Thippaiah, 2009)
3.2.2 HOW MUCH GROUNDWATER IS CURRENTLY USED IN BANGALORE AND WHAT IS THE PREDICTED AMOUNT OF WATER NEEDED FOR THE FUTURE?

Fore future water scenarios of Bangalore the domestic water demand needs to be discussed at this point. An increase of welfare brings an increase of water usage by the population India (V. & C., 2012). Bangalore, known as the silicon valley of India, has a strong focus on industrial development and less on agricultural development. The table below shows that the increase of water usage for agriculture will be very low while the usage for industrial usage is fourfold at the same time. For Bangalore this means that the needed water will increase much more than in other Indian cities that focus on less water extensive economic fields. (Narain, 2012)

Bangalore's estimated population growth until 2025 will be 60% of its current population. This information comes from an international program focusing on the fastest growing cities in the world. In this ranking Bangalore is named as the 3rd fastest growing city behind Lagos and Kinshasa. The Master plan of Bangalore predicts an annual growth of 5.5% and confirms studies from other research institutes. This will increase the pressure on the system already reached its limit after the growth of about 800% since 1941. (Grönwall, Mulenga, & McGranahan, 2010) (Krishna, 2013)

The water scarcity hits the poorest people most. Bangalore has the highest water prices in India. The distribution of water happens very unequal for many reasons. First the location plays a major part, the Cauvery river enters the city from the south-west people living there have best access and can get water almost all day long. The city core has a water pipe coverage of 100% while the coverage in the outer skirts decreases down to 10%, the piped network is often over aged (up to 100 years old) and has the danger of contamination. The old pipes are one of the major reasons for the 40% distribution loss in the city. (Grönwall, Mulenga, & McGranahan, 2010)

Slums have no direct access to the public water system and need to get it from public sources like open wells outside their living area. Those slums make up 14% of the city’s population. Most parts of Bangalore get their water during scheduled times that can vary between 3-6 hours daily, during the dry season the distribution can drop down to 2 hours daily. Overall the distribution of water is still in governmental hands but since the value of water is increasing the private sectors gets more power and the population shows worries about the future prices for water. (Grönwall, Mulenga, & McGranahan, 2010)

3.2.3 SURFACE WATER SOURCES OF BANGALORE

Bangalore is built in an arid region of the normally very wet state of Karnataka. The only close by rivers are the Arkavathi River to its west and the Kumudvathi River southwest. Both of them are seasonal rivers that only deliver water during the rainy season and are dried out for the rest of the year. During the past the main water came from its abundant lakes that covered as much as 4 percent of its area, all connected by creeks that offered an easy accessible water source.

Even more important these lakes were rising the groundwater and made it possible to access it easily from shallow wells. Already in the 1915 the lakes could not cope with the risen water demand. Water shortages resulted in the plan to build the first water reservoir at the Arkavathi in a distance 20km to the city. The reservoir could fill up during the rainy season and supply water for the whole year. (Narain, 2012)

Other projects followed that used the two close by rivers for the construction of reservoirs that could store water thought the whole year. Their usage was always limited by their small size and the flat land around Bangalore made it not possible to build reservoirs that are big enough to store enough water for the whole year. After another decade the big Cauvery River came to center of attention as a
freshwater source. The main problems were the 100km distance to the city and the fact that its riverbed lies 490m below the average city. In 1969 the first constructions started that are known today as the first stage of the “Cauvery Water Supply Scheme (CCWSS)” After the Cauvery river was successfully used as a freshwater source the project was fast expended over the next decades CWSS stages 2, 3 and 4 followed, always with the goal to bring more water from the river to the city. The last stage was finished in 2015 and delivers around 810 million liters water daily to Bangalore. The pumping requires 50 Megawatts of energy and makes the water supply very costly. (Narain, 2012)

During the distribution 40% of the water is lost through lacks in the pipes or evaporation. This means that almost half the water after it is pumped 500 meter upwards and 100km far will be lost without any use. In addition there are no alternative sources for the increasing water demand and plans are already in progress to increase the pumped water from the Cauvery River further. Its total limits are estimated at around 1470 MLD (million liters daily) but farmers from downstream say already that their share is taken for the goods of cities and industries. (Krishna, 2013)
3.2.4 PREDICTED WATER USAGE

Predicting the future is very hard for a country that is so fast developing. It can be said that India’s development lies around 10 years behind that of China. Knowing this it can help to take a look at the Chinese development in the last 10 years since they have equal consumption patterns. The capitalistic economy offers more possibilities for faster growth. There are several studies focusing on India’s fast growth that offer predictions for the future. These can be used to take a look on the overall position of Bangalore within India. Bangalore is already known of city with a high developing potential and information can be found in many papers about mega cities that also include the use of resources like water.

Most of India’s water demand comes from its food production. Its grain production has risen by 207 million metric tons in the last three decades, while its demand has been decreasing in recent years. India is one of the biggest grain exporters in the world. In the last decades a shift from the production of grain products to non-grain products like oil crops, roots and tubers and vegetable, fruits, sugar and cotton can be measured. Total share of grain products has lowered to 36% in 2005 (Gupta S., 2001).

Research papers assume a steady increase of the per capita income until 2050 of 5.5% annually. The share of the industrial sector to the overall economic growth will increase to 40% due to the continuous industrialization of the country. Also a big share of the agricultural production is still done with pre industrial methods like the use of buffalos instead of tractors. Another factor could be the change from crops with higher yields or some that fit better to the soil.

With these economic trends the consumption patterns will change. Non-grain products will become a more important part of the food intake. Their share will increase from 36% in 2005 to 54% in 2050. These products are known for a higher water demand in their production. With the growth of food demand the water demand will grow with same patterns. Total crop area will grow by increasing the area of non-rain feed areas by using more groundwater for irrigation.

The Government knows about the difficult future of Bangalore’s water supply and is already looking for new sources that could quench Bangalore’s thirst. New sources for the rising fresh water demand might come from the Netravathi River or from Dakinshina Kannada. Both sources are far away from the city and it would need big amounts of energy to pump it to the high lying Bangalore. Another costly alternative would be a desalination plan next to Mangalore (Grönwall, Mulenga, & McGranahan, 2010).

The city is working on reducing its 40% freshwater loss but to build new pipes is estimated to costs around 20 million rupees per km (~300000 euros) and the city is already struggling on extending its current network and reach its fast growing suburbs. A cheaper alternative might be to use the water underneath the city and help the groundwater to recharge again. Policies were made that said every build up area bigger than 2400 feet shall install rainwater harvesting measures. But it is unclear how the implementation should be ensured. (Gupta S., 2001).

Value of crop production and demand and production surpluses or deficits of India.

![Figure 11 Increase of water usage (Narain, 2012)](image)

The sewage which is now polluting the precious lakes in the city could be another source for freshwater. There are very insufficient sewage recycling capacities and almost more around one third of water entering the city is leaving it as untreated sewage at the moment. The implementation of new sewage plants could reduce pollution and bring water at the time, also...
it has the advantage that the water is already in the city and needs to be transported from other sources far away. (Gupta S., 2001).

3.2.5 GROUNDWATER USAGE

BWSSB (Bangalore Water Supply and Sewage Board) maintains more than 7000 official borewells in Bangalore which have a pumping capacity of about 70 MLD but these borewells are just a small share compared to the unknown number of private borewells with an estimated capacity of 282 MLD. The capacity of private bore wells are a big discussion and there are no concrete numbers. Calculations of the estimated water usage and supply say that around 30% of Bangalore’s freshwater comes from private bore wells. Numbers of bore well constructors say that around 6500 new bore wells are drilled annually. Most of them are replacing dried up borewells. Just from 2001 to 2006 60% of the used borewells dried up. It is estimated that the groundwater usage increases annually by around 7%. The water level has declined from 10 -12 meters in 1990 to 75 – 90 meters in 2010. The reasons for the decline is the rapid increase of groundwater usage with a lower groundwater recharging at the same time. (Radhakrishna, 2004)

While water is getting scarce the business with water tankers is increasing at the same time. These tankers get there water to 50% from private water bodies and tankers is known that freshwater has the highest value of whole India, reasons for this is the scarcity of reliable sources but also the good economy that make it possible to charge high prices for water. (Krishna, 2013)

3.2.6 WHAT ARE THE PROBLEMS OF EXTENSIVE GROUNDWATER USAGE IN BANGALORE?

The first problem starts with an increase of population and with it an increase the freshwater demand. The ever growing city of Bangalore needs more space for offices industry and housing. After all available space was occupied by housing and industry the lakes got into focus and got developed to construction sites. The lakes played an important role in refilling the groundwater with the rainwater stored during the monsoon season. Since the water cannot accumulate anymore in surface water bodies it is now discharged as runoff that has no chance to infiltrate the clay soils the city is built on. After a lake is once developed there is almost no way in turning it back to its natural state. Most of the time the now big open space is used by single big complexes that could not be Squeezed in the central area before. This means that traditional RWH do not work anymore because it usually include big water basins that are able to store water. This can be used as directly as a freshwater source or hold water long enough until it percolates slowly in the ground and recharge the aquifers in an amount that compensates the water that is depleted by borewells.

The three boxes in the upper right corner visualize the “circle of destruction” which is very simple and consist of 3 factors.

Because there is more groundwater used than recharged the groundwater level decreases. The result is dried out borewells that can’t be used anymore. To make the aquifer accessible again deeper borewells are drilled to use water from deeper sources which are not depleted
yet, from the deeper aquifers more water is used than recharged again and the circle starts from the beginning. This fact can be monitored by statistics that show the depth of new drilled borewells every year. Deeper borewells have a clear relation to higher costs for construction and a higher consumption of energy to pump the water to the surface. While bigger companies and the richer people are most of the time able to pay the higher price for water, the need for deeper borewells is a massive problem for the population that relies on cheap water from self-dug borewells as their main water source. It has to be mentioned that the “circle of destruction” is the main reason for the water crisis but does not include its motivation.

The result is the problem of water shortage that will end one day if it is not handled in a major water crisis. This takes Bangalore as its state as the technique hub of India at risk. Technology businesses need a good reliable infrastructure that will let them able to grow for the future. People working in this businesses usually earn enough money to have a high living standard and want to live in a city that can satisfy their needs. Other cities like Chennai are already on the rise and are looking for opportunities to become more attractive for businesses.
3.2.7 WHAT ARE SOLUTIONS FOR A STABLE GROUNDWATER TABLE?
A stable groundwater level must be created by different measures that on the one hand increase the groundwater recharge and on the other hand decrease the discharge. On possibility of decreasing the discharge is roof rainwater harvesting, the technique aims at collecting the rainwater from the roofs during the rainy season and use it directly. The disadvantage is that the natural filtering capacities from the soil layers are unused and need to be replaced by artificial filters. Rainwater in cities is mostly contaminated from air pollution and fine dust that settled on the roof before the rain.

Roof rainwater harvesting is a simple solution to collect rainwater that meets the freshwater supply in Bangalore for about 6-8 month (Masagi, 2014). The amount of water that can be harvested can be calculated the formula.

Rain Fall Harvest = Area x Amount of Rain x Efficiency

Like mentioned before the annual rainfall of Bangalore is ~800mm per year and an average rooftop size of 96m². The efficiency in Bangalore can be set to 80% (Masagi, 2014). This gives a result of 61,440 litre per year. Regarding the human development report from 2006 the average water consumption of an Indian 135 litres per day (Radhakrishna, 2004)

3.2.8 CONCLUSION
India is facing major water crisis for the future. Because it is known as the technique hub of India Bangalore one of the cities that benefit most of India’s fast economic growth. This leads to a rapid increase of people and welfare in the city. The century old water system was not able to grow sustainable with the demand of the city. The Cauvery River which seemed to be a source for freshwater that will solve the problems the city was facing in the 70s is very inefficient. Its big distance to city and it elevation that is 500 meter lower than the city brings the need of excessive pumping to bring the water to height of the city. Also there will be soon higher demand for water than the river can offer. Other plans like the desalination plans next to Hyderabad would be even more energy consuming because it would be even further away and still 500 meter below the city level.

The groundwater levels are decreasing in an alarming rate because the low income population already cannot afford the expensive Cauvery River water. Additionally the suburbs around the city which are not connected to the city’s public water network depend of the groundwater as their main freshwater source. RWH can help to improve their situation but it needs to be implemented more consequent.

Still the city needs to find ways to decrease its demand, use the water from the Cauvery river more efficient (means that the infrastructure needs to be replaced to decrease the loss by

<table>
<thead>
<tr>
<th>Sector</th>
<th>2000</th>
<th>2025</th>
<th>2050</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total</td>
<td>% from</td>
<td>Total</td>
</tr>
<tr>
<td></td>
<td>BCM</td>
<td>groundwater</td>
<td>BCM</td>
</tr>
<tr>
<td>Irrigation</td>
<td>605</td>
<td>45%</td>
<td>675</td>
</tr>
<tr>
<td>Domestic</td>
<td>34</td>
<td>50%</td>
<td>66</td>
</tr>
<tr>
<td>Industrial</td>
<td>42</td>
<td>30%</td>
<td>92</td>
</tr>
<tr>
<td>Total</td>
<td>680</td>
<td>44%</td>
<td>833</td>
</tr>
</tbody>
</table>

Notes: a) Domestic withdrawals include those for livestock water demand
b) Industrial withdrawals include cooling needs for power generation
leaks) and connect the suburbs to the public water network.

RWH has a good chance to be act as sustainable freshwater source and decreases the pressure on the aquifer drastically, nevertheless there will always be a need for surface water to quench the cities future thirst.
The Problems are visualized schematically in the figure 14. The problem starts with an increase of population and with it an increase the freshwater demand. The ever growing city of Bangalore needs more space for offices industry and housing. After all space available space was occupied the abundant lakes fast got into focus (See the disappearance of lakes in the appendix) and got developed to construction sites. The lakes played an important role in re-filling the groundwater with rainwater stored during the monsoon season through the whole year. Since the water cannot accumulate anymore in surface water bodies it is now discharged runoff that has no chance to infiltrate the clay soils the city is built on. After a lake is once developed there is almost no way in turning it back to its natural state. Most of the time the now big open space is used by single big complexes that could be squeezed in the central area before. This means that traditional RWH do not work anymore because they include always big water basins that are able to store either the freshwater demand directly as a freshwater source or hold enough water to recharge the aquifers in an amount that compensates the water that is depleted by borewells.

In the upper right corner the “circle of destruction” can be seen which is very simple and consist of 3 factors. Because there is more groundwater used than recharged the groundwater level decreases, the result is that borewells dry out can’t be used anymore. To make the aquifer accessible again deeper borewells are drilled to use water from deeper sources which
are not depleted yet, from the deeper aquifers more water is used than recharged and the circle starts again. This fact can be monitored by statistics that show the depth of new drilled borewells every year. Deeper borewells have a clear relation to higher costs for construction and the needed energy to pump the water to the surface. While bigger companies and the richer people are most of the time able to pay the higher price for water the need for deeper borewells is a massive problem for the population that relies on cheap water from self-dug borewells as their main water source. It has to be mentioned that the “circle of destruction” is the main reason for the water crisis but does not include its motivation.

The result is the problem of water shortage that will end one day if it is not handled in a major water crisis. This takes Bangalore as its function as the technique hub of India at risk. Technology businesses need a good reliable infrastructure that will let them able to grow for the future. Other cities like Chennai are already on the rise and are looking for other opportunities to become more attractive for businesses.
3.4 WHAT IS A BOREWELL RECHARGING UNIT AND HOW DOES IT WORK

There are 2 different kinds of borewell recharging units, direct and indirect borewell recharging. The main difference between those is the way the water infiltrates the ground and if it needs to be filtered before or not.

3.4.1 INDIRECT RECHARGING
Artificial Ground Water Table Recharging boosts percolation of rain water into the earth layers with naturally processes. However, most of the water experts and rain water harvesting professionals adopt small lakes, agri-ponds, soak pits, rain water pits, percolation tanks, etc. They all are different systems to hold water long enough to allow a slow percolation of water into the earth. This technique is called Indirect Recharging and is considerably slow in recharging and sustaining the ground water table. The water has to pass through thick earth layers before reaching the water table. The advantage of this technique is that the water don’t need to be filtered since the soil layers have enough time to filter it naturally like it would does anyway naturally. Anyway this method can cause problems in monsoon seasons because the storage tanks tempt to overflow during heavy and long rains. Bangalore has a monsoon climate and almost all its rain happens in the four monsoon months, installations letting the water percolating naturally to the ground needs either a lot of surface area or a lot of time.

The construction of big lakes in Bangalore seems to be impossible at the current state since it is already hard enough to keep constructors from removing the last existing lakes in the city.

![Figure 15 Natural groundwater recharging](Image)

Most of the RWH experts in India either, filter and store roof rain water in the storage tanks
(Fig-1) or use it for recharge purpose using Rain water pit.

In both the cases, the storage capacity is too limited and they overflow during back to back rains or during heavy rains.
3.4.2 DIRECT BORE WELL RECHARGING

This concept is about collecting, filtering and storing rainwater in sub-soil and ground water aquifers to recharge and sustain bore wells. Unlike the lakes and traditional rain water pit systems, where rain water passes through hundreds of feet of earthen layers before reaching the sub-soil and ground water aquifers, in this concept, rain water is thoroughly filtered and injected into the borewell directly to send the rain water to the aquifers from where your borewell is extracting water out. Results are much quicker compared with indirect recharging.

The following image depicts the concept of direct borewell recharging:

![Borewell Recharging Unit Image]

Figure 16 Borewell Recharging Unit

3.4.3 DIRECT RECHARGING VS. INDIRECT RECHARGING

Indirect recharging is very slow and has problems with the monsoon rainfall patterns but uses natural processes for filtering infiltration. The water is infiltrating the ground slowly by the force of gravity. By removing the upper layer of clay the water can infiltrate the ground much faster usually.

An old Indian belief said that for every 100 acres there should be a lake to collect enough rainwater and ensure a sufficient soil moisture groundwater recharge. This method was practiced for the last centuries until borewells made it possible to replace groundwater recharging by extracting water from deeper aquifers which were not accessible before. The population density increased in some areas and space became too valuable for leaving big areas of open space. The process of indirect recharging can be compared to the old situation of Bangalore with its big amounts of lakes in the city, so it can be considered to be a more natural way that tries to recreate the old situation of Bangalore. On the other side the situation of Bangalore’s fresh water usage can be compared to the former times when lakes and groundwater usage were enough to bring water for the whole city. The old system was
changed because the natural surface waters were insufficient for the increased need of freshwater. This situation has got worsened and it would not be possible to get enough water just from precipitation that infiltrated the ground slowly during the dry season. Indirect recharging is also very vulnerable to the pollution of water bodies. Most of Bangalore's surface waters are heavily polluted from trash and sewage. The new created lakes would need to be protected by new laws that ensure the water quality. Due the high corruption in most parts of India, including Bangalore, it is very hard to enforce laws for companies that would have a big economic benefit by breaking them. This means that there is no reliable way to protect big water bodies in the city and its suburbs. Solutions need to be found.

Indirect recharging might be a solution for all the storage problems. It is a technological solution to the low amount of space within the city. The storage tanks can be small enough to put them underground and protect them by solution from other sources. It is a very centralized solution that could be applied in many places in the city center.

The water needs to be filtered since it won’t percolates naturally though all the earth layers. The filters need to be replaced after ~ 10 years, for this the recharging units needs to be dig out and constructions needs to be done. The whole process is still very cheap because it needs no heavy machinery and all work can be done by unskilled human labor, what can be considered to be ample in India. The old filters need to be dumped in save place, a sustainable solution need to be found for this. The used materials are different kind of gravels and silt which can be found in abundance in Bangalore. The used pumps are a slightly modified bore well which are a very common technology in India, there are enough skilled experts to fix and maintain them very cost efficient within the city. The efficiency is much higher than using indirect recharging since all water that comes after the “first flush” (The valves will stay closed during the first rain and all the dust from the rooftops and parking lots is washed away, afterwards they are opened and all water can reach the catchment) will directly into the catchment tank and can where its protected from evaporation and all water that gets lost will still slowly infiltrate the ground.
The differences between direct and indirect recharging can be summarized as follows:

<table>
<thead>
<tr>
<th>Case</th>
<th>Indirect Recharging</th>
<th>Direct Borewell Recharging</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rain water movement</td>
<td>The rain water movement is slow through the earth’s soil layers, all movement happens by the power of gravity</td>
<td>Filtered rain water is directly injected into the borewell it needs energy to be pumped down, the speed can be controlled with the pump</td>
</tr>
<tr>
<td>Storage capacity</td>
<td>Storage capacity is limited due to space and financial constraints</td>
<td>Sub-soil and Ground water aquifers offer big capacities for storage</td>
</tr>
<tr>
<td>Costs</td>
<td>Indirect recharging can be considered to be very cost efficient, also almost no maintenance costs can be expected</td>
<td>Direct bore well recharging needs the same installation as indirect recharging units but also filters and pumps. Filters needs to be cleaned every 10 years and electricity for pumping is needed</td>
</tr>
<tr>
<td>Heavy rainfall</td>
<td>Rain water pits overflow due to limited storage capacity</td>
<td>No overflow except during the heaviest rainfall of the year</td>
</tr>
<tr>
<td>Back to back rainfall</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
3.4.4 DIRECT BOREWELL RECHARGING UNIT

Direct borewell recharging is very space efficient because most of the structure is located underneath the ground. As described before because of Bangalore’s monsoon climate storage tanks would need to store all water from the rainy season for the dry season to make it available through the whole year. This would need enormous storage tanks. For example the average roof is which was described earlier as 83m² would need to be able to store be able to store 6640 liters (800mm per centime times 100 for square meters times 83 for the housing site) if a tank this size would be built as cube it have a length of a side of 25m. This could be only acquired with lakes, the history of Bangalore shows that there is no space anymore for lakes and other solutions need to be found.

The geology of Bangalore brings another problem. The clay layer does water percolate very slowly into the ground and the drained groundwater cannot be easily compensated with big surface waters.

The following texts will show how direct borewell recharging units can solve these problems.

Situation before the construction

It is known that the top soil layer is not capable of storing enough rainwater to provide sufficient soil moisture through the whole year. Furthermore the sporadic rains don’t give enough time for rain water to percolate and enable the sub-soil to hold more water.

3.4.5 TECHNICAL DETAILS

A bore well recharging unit consists of three basic parts.

1. The Collection / percolation Tank

Internal sources says that percolation tank should be able to store the from a heavy rain of 30mm for till the next rain after 24 hours so the pump and filters have enough time to store it underground. Even the direct borewell recharging technic can be considered to be very efficient we assume a loss of 10% due imperfect pipe system, small spills and evaporation before the collection tank is reached.

This adds up to the formula:

Catchment area in m² x 0.30l rainfall x 0.9 efficiency= storage in liters.

For a simple example we assume to have a housing site of 1 acre.

10,000m² x 0.30mm x 0.9 (90%) =2,700l

A typical collection tank to harvest rainwater from one acre could be 9m x 10m wide and 3 meters deep.

2. The gallery

Since the rainwater will be injected directly to the ground without any filtration through earth layers it needs to be filtered through the gallery. The filter system consists of three parts. The Gallery is the first part of it and it can be described as follows. First a stone wall with some rough gravel that slows the water down and let it infiltrate slowly in the filtration system.

After the stone wall, a layer of sand comes to filter out coarse particles from the rainwater.
In the end there comes a mixture of different jellies and clay sands. Mr. Masagi has his own patented mixture which consists of a jelly made of charcoal, and different kinds of silts. The gallery has a low height.

### 3. The recharging unit

The recharging unit is the technical part of the construction. It consists of several stages and several elements. First there is the tube itself. It is filled at the bottom with several elements for filtering the water, a big borewell shaft with the actual borewell tube itself which reaches several hundred feed into the ground. The water flow can be described as following.

Gravitational forces do not work at this point anymore and water movement comes from pressure created by the borewell pump. The first stage is the concrete box which also acts as a border for the filtration unit. It acts as a second filter consisting of similar elements to the first stage by definition, sand and Mr. Masagies jelly mixture. The water reaches the gallery through the box. Afterwards the water is soaked up the borewell shaft by the borewell pump in a tube.

In the shaft it can infiltrate the borewell tube through small holes. The tube itself is filled with fine mesh that is finally filtering the smallest particles from the rainwater and acts as last stage for the filtering system. The tube also includes the borewell pump which injects the water finally into the ground through the long borewell tube. The tube has again small holes in the end and allows the water the infiltrate the ground over an area of several meter.

---

**Figure 18 Recharging Method**

Structure design forces water to pass sideways and upwards through the filter media for effective filtering & avoids silt blockage.

Height difference creates water pressure and forces water to flow into the pit & well through filter media.
The three level filter ensures that all water is clean when it reaches the aquifer and has no can be pumped and used later with the same treatment like it would have come from indirect recharging.

**ITS LIMITS**

Bangalore’s urban area is approximately 741 km² big. The total considering an annual precipitation of 850mm there are falling 629,850,000,000 liter rain annually within the city limits.

The BWSSB is providing around 328,500,000,000 million liters annually to the city. As mentioned before it is estimated that only 60% of the used water is provided through the public network. All in all this adds up to an annual water consumption of 459,900,000,000. This would mean that 75% all rain would be needed to terminate the dependency on the Cauvery River. These numbers are very rough estimations but should be able to visualize the problem. To plan that 75% of the cities surface is covered by RWH structures that use the water with an efficiency of 100% is utopian. The Cauvery River will always play an important role in water management.

But RWH is a way to avoid the water crisis that will occur when all deep aquifers will be depleted. But is not a silver bullet solution for all water management in Bangalore. There is a need to reduce the demand on the one hand and find ways to compensate the water groundwater which is pumped through borewells every year. It also a possibility to act with sole responsibility to the future problems and farm their own water when public networks become unreliable.
3.5 EXAMPLE FOR COST CALCULATIONS

This chapter will show an example the cost calculations. It will help to indicate the financial feasibility and answer the question if the concept is also affordable for the low income population. The tables in the beginning show the properties of a project afterwards it will be explained if this example would be feasible for the low income population.

3.5.1 EXAMPLE SITE

**Collecting & Storing Rain water**: The roof rain water would be channelized through pipes, filtered and stored in the existing sump.

**Underground water table recharging**: The overflow rain water from existing sump would be used to recharge the underground water table.

<table>
<thead>
<tr>
<th>Sl No</th>
<th>Observations</th>
<th>Answer</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Company site area</td>
<td>2000 m²</td>
</tr>
<tr>
<td>2.</td>
<td>Built up area</td>
<td>1600 m²</td>
</tr>
<tr>
<td>3.</td>
<td>Number of borewells</td>
<td>2</td>
</tr>
<tr>
<td>4.</td>
<td>Number of Water sumps</td>
<td>1 of 20000 liters. There is another sump that has been damaged beyond repair due to tree growth. Earlier we had planned to use it has collection tank.</td>
</tr>
<tr>
<td>5.</td>
<td>Company water source</td>
<td>Borewell and Water tankers</td>
</tr>
<tr>
<td>6.</td>
<td>Any rain water harvesting attempts</td>
<td>Yes but not meeting the expectations</td>
</tr>
<tr>
<td>7.</td>
<td>Objective of RWH</td>
<td>Enhance the existing RWH system and sustain borewells</td>
</tr>
<tr>
<td>8.</td>
<td>Annual rain water that can be harvested based on the Company area considering Bangalore’s average rain fall of 1000 mm</td>
<td>1,600,000 liters</td>
</tr>
</tbody>
</table>
Installations

<table>
<thead>
<tr>
<th>Location</th>
<th>Solution(s)</th>
<th>Water source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Existing sump</td>
<td>Gallery Type Filtration Unit</td>
<td>Roof rain water from DPP1 and Canteen</td>
</tr>
<tr>
<td>Around existing borewell</td>
<td>SMT Type Borewell Recharging Unit</td>
<td>Overflow rain water from the existing sump</td>
</tr>
</tbody>
</table>

### 3.5.2 RAIN WATER HARVESTING & BOREWELL RECHARGING ESTIMATION

The following table visualizes the estimated costs in a GANT chart. All Costs and Benefits are included in this table. The revenues are estimated by giving 3000 liters recharged water the value of 300 rupees because this is the price for water bought from a water tanker on average (it fluctuates through the year with the seasons).

<table>
<thead>
<tr>
<th>Appartments</th>
<th>Building costs / m² GFA</th>
<th>Building costs total</th>
<th>WLF Charge</th>
<th>Honorary Discount</th>
<th>total per excl. ground</th>
<th>total invest. costs excl. ground</th>
<th>Revenues from saved water tankers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gallery</td>
<td>1.00</td>
<td>46.50</td>
<td>46.50</td>
<td>4.650</td>
<td>1.860</td>
<td>53.010</td>
<td>53.010</td>
</tr>
<tr>
<td>Pipelining</td>
<td>600,00</td>
<td>110</td>
<td>66.000</td>
<td>6.600</td>
<td>2.640</td>
<td>125</td>
<td>75.240</td>
</tr>
<tr>
<td>Trench</td>
<td>100,00</td>
<td>30</td>
<td>3.000</td>
<td>300</td>
<td>120</td>
<td>34</td>
<td>3.420</td>
</tr>
<tr>
<td>Digging</td>
<td>1,00</td>
<td>39.80</td>
<td>39.80</td>
<td>3.980</td>
<td>1.592</td>
<td>45.372</td>
<td>45.372</td>
</tr>
<tr>
<td>Borewell recharging unit</td>
<td>30,00</td>
<td>175</td>
<td>5.250</td>
<td>525</td>
<td>210</td>
<td>200</td>
<td>5.985</td>
</tr>
<tr>
<td>Total</td>
<td>732,00</td>
<td>155.30</td>
<td>15.530</td>
<td>6.212</td>
<td></td>
<td></td>
<td>177.042</td>
</tr>
</tbody>
</table>

All prices are in rupees the exchange rate at the point of the survey during March 2015 was 67 rupees equals to 1€.

The estimated recharged amount for this 1,600,000 liters the estimated costs for this amount delivered by water tankers would be 160,000 rupees compared to the 183,027 rupees installation costs the project would pay off within the second year. Afterwards this money can be counted as profits.

The revenue, like mentioned before comes from money saved by not needing water tankers and using rain as water source. The payoff for this case will happen after 1.1 years or 13.5 month. This does not include the positive environmental effects of having a neutral or positive groundwater balance.
3.5.3 CONCLUSION
The high investment costs are a big obstacle for the implementation of a direct borewell recharging unit. After it was once financed the money that is saved on being not depended anymore on water tankers will soon be higher than the money spent for construction. Seeing it from another point of view this indicates that the project only makes sense if there is no possibility for other water sources than borewells or water tankers. When there is access to the public water system it will take longer until the investment reaches a breakeven point.

Often people would need to find a way to finance the project in the beginning with money from third parties. Foundations can help for the implementation to improve the living situation for people living in slums drastically by financing RWH techniques like the direct borewell recharging unit.
3.6 RESULT

3.6.1 COSTS
The Costs for this project are 177,042 ₹ (~2500€) including the harvesting and recharging facilities. As mentioned before there will be constant revenue from water that is now available for free which would have need to be bought before.
For Indian standards this is a lot of money and the solution focusses rather on the upper class and or companies. Unlike for indirect recharging methods many of the costs also cant composed with cheap physical labour from relatives or benefited because modified pumps need to be bought and a new borewell need to be drilled.
Another drawback comes from the patented filter system used by the WLF what makes it impossible to replace them by yourself.
For this reasons the system might be too costly for a typical single household.

3.6.2 AMOUNT OF WATER HARVESTED AND EFFICIENCY FACTOR
1,600,000 liters were harvested from 1600m² of catchment area. The total harvested amount divided by the catchment area shows that 1000 liters per year per square meter can be harvested. The direct borewell recharge is known for its high efficiency because after the water is cached it is stored in covered tanks and after a short time directly pumped into the aquifer.

3.6.3IMITABILITY
The system can be implemented near almost every sealed surface a rooftop. The infiltration unit needs a low amount of space for the storage of water and the tank. This makes it suitable for urban areas.

Specialists are needed to build the system. The filters need to be replaced after around 10 years and again a specialized company is needed to do this. This has bad influence on the Immitability because it is not technique that can be easily copied by other companies or even done by the people themselves.

3.6.4 RESILIENCE TO EXTERNAL FACTORS
The water is reaching the aquifers not naturally all natural filter processes that would happen normally are replaced by a faster systems. The filters have a maximum filter capacity to particles. They are designed for the common street dust and the usual amount of dirt that occurs on the cities of Bangalore. Heavy chemical pollution by industries might cause problems because the filters are not designed to break them down and the groundwater could get polluted what could cause irreparable damage to humans and nature.
The advantage comes that the water is entering a closed system as soon as its cached by the drainage pipes that are leading to the storage tanks from there it is filtered and pumped into the aquifers. There are no possibilities for the water to become soiled by trash or sewage.

3.6.5 RESILIENCE TO CLIMATE SHIFTS
This system is built to harvest much rainwater over a short period, lower precipitation results in less water that is available for recharging. When too much rain is falling and that water can’t percolate through the filter fast enough. The basin will overflow and water is discharged through drainage pipes which part of the design for the collection tanks.
3.7 CONCLUSION

The rainwater harvesting methods used by the WLF have several advantages which makes them suitable for the specific needs for the urban area in Bangalore.

They use simple technology that is already familiar to the user; the construction includes water basins which can be made of any kind of non-permeable material like house walls, to ensure its non-permeability concrete can be used to seal the surface. They are sealed with a cap made of concrete that can be bought at a standard construction store in the city. Next to the basins a borewell needs to be dug in the same kind as it’s done for the usual pumps that exploit the groundwater. People that want to recharge their groundwater should be already familiar with borewell pumps because they are also needed to access the stored rainwater during the dry season. For owners of a borewell in India the working mechanism of borewell pump is crucial and knowledge how to fix common pumping engines is common. Enclosing the borewell there is a ring of concrete in the same kind as it is used for sewage systems. The only special knowledge is needed is the one regarding the composition of the filtering earths and gravels. The filters are supposed to be exchanged by the WLF but there are many companies rising in Bangalore which have expertise in filtering systems. When the rainy season starts the pump is running continuously the only effort that need to be made is turn the borewell pump on as soon as the monsoon starts.

The simplicity of the technology is also the reason the reason for the cost effectiveness. Borewell pumps can be bought for less than 100€ (Pumpkart, 2015). The digging is usually done simple manpower of construction worker because it is cheaper than renting an excavator, construction workers are already used to work with concrete what means that there is no need for specialized workers. The WLF itself is buying all the materials they need at the Samipidge Road Market which offers everything that is needed for constructions to fair prices.

![Ayyappa Masagi at store in the Sampidge Road Market](image)

Including the fact that building borewell recharging unit usually allows to use the old facilities that were used before for pumping ground water that are but dried out and could not be used before the money that is saved for not constructing a new, deeper borewell is only slightly higher.

A direct borewell recharging unit is also designed to address another problem of the RWH in Bangalore. It is very effective in using space, usually the whole construction does not take more than 20² and the space can even be used for other needs as long as there are not permanent constructions build on top because they need to be accessed sometimes for repairs to the pumps and replacement of the filters. The filters are efficient enough to use water from the roads what makes every sealed are on the roof or ground a potential source for RWH.
3.8 WHAT PLANNING AND FINANCE APPROACHES MAKE GROUNDWATER AVAILABLE FOR PEOPLE WITH A LOW INCOME

As a help to organize the planning of the WLF a template for planning was made during the research. It is supposed improve the process of project implementation. Before the project plans included only on the budgeted and technical drawings (See the example in the Appendix I). This step was necessary to improve the stakeholder involvement and to give costumers deeper insights in the problems, actions, goals, limits, results and monitoring.

The normal procedure is written in standard writing. After each chapter the text added in blue italic explains how the standard should be adapted to include people that usually cannot afford the project but would benefit from it.

BACKGROUND

With this background for all projects in Bangalore, the main focus on this section is on:

- Water scarcity
- Water quality and water borne diseases
- Water mismanagement/ water illiteracy
- Flooding / Water logging
- Why it is necessary to address the problem / issue;
- Analysis of the root causes of the issue and impact of the issue
- Who all will benefit by the project? How there is a win – win for different stakeholders
- Process of formulating the current project proposal (any study, observation, analysis)
- Potential partners in implementation

- Why do these people cannot afford it if it is done by regular financing
- How many people could benefit from it
- How could RWH improve the image of an institution of company
- Which communication channels will be used to outreach for investors that could help to finance this project

3.8.1 ORGANIZATIONAL COMPETENCE

In this chapter it will be explained what the WLF can do for costumer. Key partners are mentioned and the vision, objectives and goals are listed. The tasks for the stakeholders mentioned in the last chapter are explained in detail. Furthermore responsibilities are shown before so the costumer knows what will be his task and where the responsibilities of the WLF are beginning and ending. Finally it includes which stakeholders can improve the value of the project by bringing in their expertise.

It will be explained how NGO’s or public institutes can be included in the project that can carry out parts of the project without needed to be paid. It is written down which rights or privileges stakeholders gain that help to finance the project (e.g. When a company pays for the groundwater recharge and wants to help nearby living people). When the project aims at improving the situation for a community, legal partners (who is the actual costumer?) need to be defined.

Background of the implementing organization

- Vision / mission and key programs / focal areas of operations
- Outreach and achievements
- Key project partners
- Responsibilities
- Expertise and Competency in addressing the identified issue

- Which NGO’s or private partner need to be involved for financing
- Who pays what?
- Who will own the RWH system after its built
- Who is the legal costumer of the project

3.8.2 PROJECT OUTREACH, OUTCOMES AND IMPACTS:

This section is supped to explain how RWH will improve the present situation. It indicates at which problems the project is aiming. Also first prognoses regarding the desired changes in the hydrology of the area are made and how it will improve the situation for people which are living in the area.

This section is focusing on the process itself and needs just little adjustment if the project is focused on the low income population. The main difference in this chapter is that it will include also which exactly target group can have benefits of this project and why they need help from third parties to improve their situation.

- Outreach / coverage of the project over the project duration (at least quarterly, if not monthly)
- Expected outcomes of the project: how will the problem situation change?
  What changes are expected to take place at different project intervals?
  What are the indicators on which these can be measured?
- Expected impacts: In the long run how the project will benefit the community, local institution / area / any other specific stakeholders and the Company
- Water literate community, Community would know what to do when they have excess water and what to do when they face water issues.

- Increase in ground water table static level, quantity and quality
- What additional benefits are gained that could be not accomplished without external help,
- Which persons are the benefited

3.8.3 PROPOSED PROJECT STRATEGY AND ACTIVITIES

The overall strategy is shown. It is explained which RWH techniques are suitable for the project. First estimations are made how the project will pay off for costumer in the future. It is explained in a logical casual manner how the actions are improving each of the problems explained in the first chapter. The goal of the chapter is to point out what the customer is paying for in detail.

For project that are financed by others here the focus is more on the benefits of people, it will explained how many people can improve their situation. Sustainable projects that will improve the living situation for long term it is important to teach the community how they can use the RWH after the project is finished and avoid to fall back in old manners when the WLF finished the project and put the system in the hands of the new owner.

- List of key interventions / activities
- Feasibility survey of the target areas
- Preparation of neighboring community, local NGOs and by capacity building through proper awareness, Training and exposure for participation during implementation, ownership development for operation and maintenance after the project period.
- How participants / area will be selected and engaged in transformative process, who will be involved in imple-
mentation etc. Will there be any contribution / resource sharing by any stakeholder
- Ensure transparency and accountability in project implementation through meetings and media use
- Scale and sequencing of the activities
- If possible attach map of the area indicating activity coverage
- How will be ensured that the project creates a long term improvement in the availability of freshwater

3.8.4 PROJECT IMPLEMENTATION STRUCTURE AND OPERATIONS OF THE WLF:

After it is explained which actors are involved and what are their responsibilities this chapter focusses only on the WLF. What will be done by the WLF and for which tasks personnel from the outside is hired. It is explained in detail how many working hours of work will be outsourced by the organization.

When the project is financed by third party the costumer has a high chance to be not able to pay for future maintains. Because of this someone needs to be taught about the basic functions of a RWH system so the people are able to maintain the systems by themselves.

- How can the benefited be involve
- Which tasks do they need to learn to maintain the RWH structure

3.8.5 PROJECT MONITORING AND REPORTING

It is necessary to organize the communication in before the project starts to ensure good working feedback channels. Here the communication channels will be explained and which facts will be important for the costumer. How often will he get feedback and who will be the first contact partner for questions or feedback. This includes the WLF but also how the communication to third parties can be ensured.

It is important to show the people that helped to finance the project with donations what they accomplished with their money. When people get a positive feedback after they donated money it will engage them to get involved in more projects in the future. Social media can help to share permanently the development and share small accomplishments frequently.

- Framework /design; what records will be kept by whom? Will any date base created?
- What will be the content of the monthly / quarterly and annual report?
- Who will be responsible for monitoring and reporting?
- What will be the feedback mechanisms for involved stakeholders?
- Any plan of third party / social audit be included?
3.8.6 PROJECT BUDGET

Budget for the entire project period (3 to 5 – whatever is proposed) year on year
Detailed monthly budget up to Mar 2015 – breaking it down in capex / non-recurring and opex/ recurring costs, including operational costs; with references for each unit cost included
Working out cost per unit of result – like cost of educating one girl child, cost of planting and surviving one tree, cost of setting up one learning facility etc,
If possible give a rough estimate of Social Return on Investment through this project; by spending CSR budget what will the corporate get back? Risk mitigation, savings on wastages? Brand image, improved stakeholder relation, etc.

*When the WLF is acting as an NGO it is important to show where all the money is going and that there are no profits that are kept by the WLF foundation. Detailed public accessible finance approaches are important. In Annual reports there are detailed lists of the money that was donated and what it was used for.*
4. WHAT IS THE CURRENT STATE OF FRESHWATER MANAGEMENT IN OTHER STATES OF INDIA AND HOW COULD IT BE RELEVANT TO BANGALORE?

4.1 RAJASTHAN

Rajasthan is located in the north of India and has a similar monsoon climate to Bangalore but has a much lower average in precipitation of 400mm, almost all rain fall is occurring during the monsoon months from June to September (Suutari & Marten, 2005). In their history the population learned to use their groundwater organized and efficiently by small associations that could be called water boards. Archeologists found rainwater catchments which are dated back to 1500 B.C the old rulers of the state were always aware of the importance of vegetation for refilling the groundwater, the common RWH structure was a Johad, a crescent shaped dam built to block rainfall runoff. This structures would create a small pond in front which was used during the monsoon directly to get water for irrigation, but even more important the blocked rainwater was able to infiltrate the ground and recharge the aquifers. (Suutari & Marten, 2005) These structures were typically made by a group of farmers that would all benefit from them and inveigle the farmers to and organize they water resources together. (Gupta S., 2001)

In the 1950 the villagers began to drill borewells and were able to gain their water more efficiently without further constructions from deeper aquifers. With the implementation of those diesel powered pump the Johads became obsolete for the moment and the “cycle of destruction” began in detail; a lower groundwater level followed by deeper borewells that lowered the groundwater level again. (Padre, 2000)

Another factors was worsen the situation, after India became a republic the government was focusing on boosting their economy. With the removal of the former kings and princes that were ruling the state for centuries their old

Figure 22 Johad; Source “SUSTAINABLE URBAN ENVIRONMENTS Sustainable Placemaking” (www.sue.bdp.net)
practices also got lost. In the past the forests were owned by the monarchs and the population was only allowed to cut down strictly regulated amounts of trees for fire wood. After the monarchs were removed the forests were owned by the young state who was not able to implement fast laws and controls regarding deforestation. (Gupta S., 2001) The result was a fast deforestation of many major forests in Rajasthan and the ground was let uncovered and prone to erosion. The uncovered soil resulted in a high runoff and the added up to the problem of a lowering ground water level. (Suutari & Marten, 2005)

4.1.1 BRINGING BACK THE JOHADS

In the mid of the 80s the problems got so bad that even farmers that owned fields of 600 acres in size still had problem to earn enough money to sustain their extended family. Most of the population needed to mitigate to wetter areas near Himalaya or to big cities.

Maybe out of depression or for other unknown reasons the first farmers in the district of Alwar started to renew again the silted up Johads. After the next monsoon it could be seen that the groundwater level for his own field but also for the neighboring farmers were raised again and borewells were filled with water again.

The results were so impressive that many people copied his efforts and were renewing their old Johads or were building new ones. Since the Johads were built and financed by the farmers themselves there was also a higher motivation to maintain them without any governmental pressure. By the mid of the 90s a whole movement regarding bringing back the Johads has been established. (Gupta S., 2001)

This table shows the rise in groundwater level in Village Buja within 9 years (before and after constructing a Johad). It shows a substantial increase of the groundwater level. Many wells al-

<table>
<thead>
<tr>
<th>No.</th>
<th>Total depth of well (m)</th>
<th>Depth of water level in 1985 before construction of Johad (m)</th>
<th>Depth of water level in 1994 after construction of Johad (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>24.68</td>
<td>Dry</td>
<td>11.12</td>
</tr>
<tr>
<td>2</td>
<td>22.25</td>
<td>Dry</td>
<td>10.98</td>
</tr>
<tr>
<td>3</td>
<td>20.4</td>
<td>19.4</td>
<td>8.05</td>
</tr>
<tr>
<td>4</td>
<td>17.0</td>
<td>15.7 (mostly dry)</td>
<td>8.8</td>
</tr>
<tr>
<td>5</td>
<td>24.68</td>
<td>21.68</td>
<td>4.57</td>
</tr>
<tr>
<td>6</td>
<td>21.0</td>
<td>15.0</td>
<td>5.76</td>
</tr>
<tr>
<td>7</td>
<td>13.10</td>
<td>8.5</td>
<td>2.44</td>
</tr>
<tr>
<td>8</td>
<td>25.30</td>
<td>19.3</td>
<td>7.63</td>
</tr>
<tr>
<td>9</td>
<td>24.50</td>
<td>19.0</td>
<td>7.75</td>
</tr>
<tr>
<td>10</td>
<td>20.25</td>
<td>Dry</td>
<td>12.63</td>
</tr>
</tbody>
</table>

Figure 25 Borewell Depths in Alwar

![Figure 24 Function of a Johad Source gwadi.org](Image)

that the groundwater level for his own field but also for the neighboring farmers were raised again and borewells were filled with water again.

The results were so impressive that many people copied his efforts and were renewing their old Johads or were building new ones. Since the Johads were built and financed by the farmers themselves there was also a higher motivation to maintain them without any governmental pressure. By the mid of the 90s a whole movement regarding bringing back the Johads has been established. (Gupta S., 2001)

This table shows the rise in groundwater level in Village Buja within 9 years (before and after constructing a Johad). It shows a substantial increase of the groundwater level. Many wells al-
4.1.2 CRITICS
The reasons to bring back the Johads was simple. They were an ancient technology that was used in the past of Rajasthan to harvest the monsoon rain for the dry season. This technique was replaced during the modernization of farming with the new borewell that pump water more efficient from deeper aquifers. The disappearance of the dams led to a water crisis, so it makes sense to bring old techniques back and restore the old water balance. Sceptics say that the past is easily romanticised and these solutions were only possible due very low labour wages for maintaining these structures. The farmers that have the biggest advantages are those who are already wealthy and can afford massively groundwater extraction during the dry season while the people that bring the labour to rebuild and maintain these traditional methods. Wealthy farmers on the other hand should build new and more efficient concentrate structures to harvest rainwater and make their systems more efficient. (Gupta S., 2001)

4.2 CONCLUSION

4.2.1 COSTS
The costs can be kept very low because there is almost no need to materials, most work can be done with physical labor which is cheap in rural India (for not skilled workers 1000 rupees per month [15€]) (Bouyamourn, 2015). Overall a Johad can be dug within 2 Month by 10 people, this adds up to costs of around 300€. These costs fluctuate as much as the shape and size of a Johad be very different from one case to another.

4.2.2 AMOUNT OF WATER HARVESTED AND EFFICIENCY FACTOR
It is hard to get down to straight numbers on how much water was percolating the ground which would have been run off. The groundwater increased in the case study about 13 meters with low investments.

4.2.3 Imitability
Johads are a well-known rainwater harvesting technique that is used since many centuries. Its simplicity makes it very easy to copy. In rural areas just a slope and free space is needed to build a Johad.

For Bangalore this solution is not suitable because it is built on a very flat plateau and there is almost not free area in the city. Other solutions that occupy less space with a very high efficiency are needed.

4.2.4 RESILIENCE TO EXTERNAL FACTORS
Since this solution is designed for unpopulated rural areas there are usually not many threats from pollution. The major problem is the dam which needs to the subject of maintenance for every dry period.

RESILIENCE TO CLIMATE SHIFTS
When rainfall becomes unreliable due climate shifts. The Johads help to use the scarce water more efficiently by storing it under the ground. The groundwater can be usually considered as reliable source for potable freshwater. If the rainfall increases, the Johad will overflow and the water will be spoiled as runoff to the next surface water. A danger from too heavy rainfalls comes when the dam will break and causes flooding, this puts the fields and villages nearby in danger.
4.3 GOA

4.3.1 BACKGROUND
Goa can be considered as a high rainfall area with heavy rainfalls from June till September. Rain clouds come during this time from the Arabian ocean and are blocked by the mountains in the hinterland. This circumstances results in a precipitation of 2500mm per annum along the coast and rockets up to 4000m in the forests in front of the mountains, the total rainfall averages to 3200mm over the whole country. (Pasi, Matto, & Jainer, 2014). The monsoon climate is similar to Bangalore but the precipitation is more than three times higher. Because of this fact it has the similar problems regarding storage of harvested rainwater like Bangalore. The ground also has high levels of clay and let’s water percolate only slowly into the ground.

The problems are also man made with the difference that most of the ground water is not extracted by the households but from the mining companies of Goa as described later.

4.3.2 PROBLEM
Even with this high rainfall which average is at least 3 times higher than in Bangalore the state is facing a manmade water crisis for several reasons that come through mining, increase of population and increase of welfare for its population. Even Goa is the smallest state in size in India it has the second highest GDP per capita which makes it to a big player and it is seen as a role model for a fast growing and good working economy. (Mohan, 2008)

Overall 33% of Goa’s water supply comes from groundwater sources are constantly monitored by governmental organizations like the department for agriculture and is considered to be safe. The increase of usage results in lowering groundwater levels in the past years which don’t causes problems yet but shows a trend that should be observed for the future and solutions should be found before there will be a crisis. (Pasi, Matto, & Jainer, 2014)

Thinking about Goa the first thing that comes to mind will be its well-known beaches that make it to a tourist hotspot. But for the industry the 90 open casts mines might be more important, which are responsible for about 50% of the iron ore exports of India. Due to disastrous impacts to the environment named: changes in the groundwater and sedimentations flow of the rivers. (Technology, 2012)

Politicians like to point out the economic importance of iron ore mining that already started in 1947 and have been an important employer in the past. But the mining industry had always problems with massive corruption issues. Mining companies mine more ore than is shown on the paper, places with high ecological value are used for mining (At least 33 big mines are located in the less than 1.5 km away from natural preserved area that is takes places in the whole eastern part of Goa) and the contribution of the industry to the actual welfare of the people is questionable because most revenues disappear to the owners and politicians. This is also a reason why reports show massive fluctuation in the importance of mining and its share of the GDP fluctuates with the sources from 5% up to 30%. What can be said that there are very low tax revenues from the mining industry and that it has immense effects of the eco system because of deforestation and sedimentation of the water systems. (Newsome, 2013) (Naqshbandi, 2011)

Good access to the natural harbor of Marmugao and a number of channels leading to the
coast made the exploitation very profitable. The iron belt stretches from north to south and can be divided in four Talukas (administrative divisions), Bicholim in the north and Salcete, Sanguem and Quepem in the southern district (Technology, 2012). Due to a rise of the international iron prices the production rocketed during the last century with disastrous effects on the landscape, ecology and the surface and groundwater sources till it came to a halt due new efforts in the government to restrict mining.

4.3.3 OPEN CAST MINING IN GOA

Open cast mining in Goa has a long history the first known mining operations already started in early 1900’s but it took till the 1940’s when the Portuguese government started giving consitions to private companies and mining became a major economic factors for Goa.

The majority of Goa’s iron ore located in its lateritic plateaus. These plateaus consist of a lateritic cover with a layer of various types of clay underneath. In their core powdery iron ore with concentration between 25-30%. (Chachadi, 2006) It is estimated that around 1400 Million tons could be exploited within the next 20 years. (M.K. Chkaraborty, 2001)

For mining the iron ore the lateritic clay cover needs to be removed by dozing and ripping, sometimes drilling and blasting is used in hard and compact latrine. Afterwards the lumpy and powdery ore zone can be mined. Afterwards the ore needs to be processed to reach the required cut-off rate of about 60% for exports. Most of its exports is done by ships from the Mormugao and go to China. (BanOnMining)

The mining starts on the top of the hill by cutting systematic benches of 7 to 10 meter height and slope of >30° (Technology, 2012). After the laterite clay is removed groundwater the excavations passed the groundwater level and water needs to be constantly pumped out. Further effects on the environment are: Deforestation, Land degradation, Groundwater pollution, Surface water pollution, Dust pollution and damage to the tourist beaches of Goa.

Almost all mines are owned on of the 3 governmental mining companies, Fomento, Salgaocar and Sesa Goa. All companies are under the critics for having close ties with politicians and influencing regulation for mining in Goa. (GoaMiningCollapse)
4.3.4 CASE GOA UNIVERSITY IN TALEIGAO

The Goa University has a stuff and student population of around 1500 people and uses 450000 liters per day of which 50% come through 12 borewells spread over the campus. The RWH system was installed in 2007 and funded in a public private partnership from Sociedade de Fomento Industrial Pvt Ltd, Bhagavathi Ana Labs Ltd; Timblo Pvt Ltd, V M Salgaocar & Bro Pvt Ltd, Vasco (Goa) and Mineral Engineering Services and Coca Cola Ltd (Pasi, Matto, & Jainer, 2014).

The Aquifers depths varies between 65 to 110m below ground (fluctuating with the seasons). The installed system consists is direct harvesting water from a rooftop and the not covered natural area, including a pond. The natural area belongs to the university plot and is free of soil ing by urban pollutants like trash or road dirt (Pasi, Matto, & Jainer, 2014).

The RWH harvest water from around 1.5 hectares. It leads the rainwater through a deep trench of 20mx 10m x2m to a sand filter with the dimensions of 3m x 3m x 3m. From there it enters the main recharge trench which is one meter below the sand and coal filter. Additional to the filter system the first 15 minutes of rain after the dry season are spoiled through the first flush valves in the way the dust accumulated on the rooftop can be discharged without the need to filter it (Pasi, Matto, & Jainer, 2014). The recharging well is drilled to a depth of 89 and has is percolation holes starting at 65 meters. The storage tank has a capacity of 100.000 liters (Pasi, Matto, & Jainer, 2014).

<table>
<thead>
<tr>
<th>Salient features of the RWH system at Goa University</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Parameters</strong></td>
</tr>
<tr>
<td>Total catchment area</td>
</tr>
<tr>
<td>RWH structure</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Total volume of recharge (in year 2010)</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Cost of system (in Rs)</td>
</tr>
<tr>
<td>Savings per annum (in Rs)</td>
</tr>
</tbody>
</table>
4.4 CONCLUSION

4.4.1 COSTS
The costs of the project were 160,000 rupees (~2300€) for this large scale project. It is estimated that there 4,400,000 rupees are saved because water from the borewell can now be used through the whole year and during summer there is no need any more for the expensive water tankers. Water tankers needed to be ordered during the dry season when the groundwater level was and the public network was also delivering less than 50% of the time water. All these expenses added up to a substantial amount that now can be used for other purposes.

4.4.2 AMOUNT OF WATER HARVESTED AND EFFICIENCY FACTOR
The total amount of harvested rainwater is approximately 39 mio liter of rainwater this makes 243 liter per rupee or 16,800 liter per euro. The efficiency factors is set at 70% this is 10% than the system in Bangalore and comes through the lower amount of sealed surfaces and longer ways from the point the water hits the ground to the collection pond. All drainage system are uncovered.

4.4.3 IMITABILITY
First of all this project was combined with the education from the university. Students helped to plan and organize it with the goal that they are prepared to do the same of projects in the future by themselves. The educational factors is very important for having a long-term solution for whole India, the knowledge needs to be spread.

4.4.4 RESILIENCE TO EXTERNAL FACTORS
This system can be used wherever borewells are used. The amount of space needed can be used to make it more efficient but in this case there was no need focus on a small are because the used spaced was not intend to use for other purposes in the near future anyway.

But RWH structure was especially designed for the university. Slopes of the hill were used to catch rain the structures could have built smaller. This means that the actual project cannot be copied easily even when the process of designing can be used for other projects.

4.4.5 RESILIENCE TO CLIMATE SHIFTS
All systems are designed to take no damage if overflow occurs, this means there is a maximum for the amount that can be recharged. If it rains less there is less water that will be recharged but on the other hand the scarce water will be used more efficient than before.
5. MULTI CRITERIA ANALYSIS

5.1 DECISION CONTEXT

To find out “What long term solutions for compensative groundwater use are available for people of all levels of income in semi humid areas?”

First it’s important to find a cheap solution that can be implemented in many situations to gather information about these topics the Costs and Imitability need to be analysed.

For a compensative groundwater usage the efficiency should be high enough to recharge at least as much water as is pumped from the aquifer.

For long term solutions the system needs to be resilient to external factors and to climate shifts. Only in that case it can be insured that the RWH technique will work in the future even when the situation worsens, regarding weather and pollution.

The solutions are graded from 1-10 in which 1 stands for the worst rating and 10 for the highest. This scale gives enough room for a precise rating.

5.2 OPTIONS

Costs

The Costs are easy to figure out since the WLF is carrying out all constructions ore pays other parties to so if specialists are needed. A 1 in costs means that is only affordable for the richest share of the population while a 10 means that who owns a borewell pump should be able to afford it.

Amount of water harvested

To calculate the recharge an average rainfall of 780mm is estimated the catchment area can be found in the project description. The formula catchment area in m² (A) times annual precipitation in m³(R) times an efficiency (E). A*R*E= Annual harvest. For this study it was chosen that a 5 means that just enough water is harvested to compensate the water drained by the borewell through an average year of rainfall. An 1 means that there not enough water harvested to make a difference at all and a 10 means that there is more water harvested than could ever be used.

Efficiency factor

After knowing the costs the efficiency can be calculated with the formula. Costs in rupees/annual recharge in m².

Imitability

It is important to find a solution that can be used for all places without big changes, only this way it can be kept cheap and easy to maintain. The way evaluate the imitability is to count external factors that have influence to the project, like soil type slope or special features of the landscape. The result will be a value between 1 and 10 in which 10 is the highest. A one means that a design needs to be changed fundamentally for every time it is built a 10 would show that the exact same structure could be copied to any other place without any changes.

Resilience to external factors

Bangalore has a steady population growth of 3.25% this means projects should include an increase in demand for future. Also the use of areas very dynamic since urban planning is uncommonly for most areas of the city. This
should be included in the project to make it resilient to future changes of the urban landscape. Additionally it is important that all is resilient to pollution because this on of the main problems for potable water in urban landscapes. The result will be a value between 1 and 10 while 10 is the highest.

**Resilience to climate shifts**

Since all evidence looks like the world climate will have some drastic shifts in the next decades the systems should be able to work properly in weather extremes. Factors that indicate resilience to climate shifts are:

- Annual consumption / Annual harvest
- Changes in time

The result will be a value between 1 and 10 while 10 is the highest. The score is for one half related to the amount of water harvested and for the second half should deal with climate variations.

**Table**

<table>
<thead>
<tr>
<th>COSTS</th>
<th>EFFICIENCY FACTOR</th>
<th>IMITABILITY</th>
<th>RESILIENCE TO EXTERNAL FACTORS</th>
<th>RESILIENCE TO CLIMATE SHIFTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>BANGALORE</td>
<td>6</td>
<td>7</td>
<td>9</td>
<td>9</td>
</tr>
<tr>
<td>RAJASTHAN</td>
<td>10</td>
<td>10</td>
<td>6</td>
<td>3</td>
</tr>
<tr>
<td>GOA</td>
<td>7</td>
<td>10</td>
<td>7</td>
<td>6</td>
</tr>
</tbody>
</table>

Changes in time

For the last century the rainy season started during the first week of June and ended at the end during the weeks of January. These seasons might change with and occasional heavy rainfalls during the dry season happen more frequent in the last years. The system should be able to deal with this changes and use this water effectively.
5.3 RESULTS

5.3.1 BANGALORE

Costs
The high costs for water in general help the case of Bangalore to be very cost efficient, projects that are implemented usually pay off after one or two monsoon seasons. People that can afford a borewell should also be able to afford a borewell recharging unit, especially because money can be saved because borewells do not need to be so deep energy can be saved.

What was a back draw for these techniques is that special filters are used that need to be replaced continuously. These replaced should be done by the WLF foundation to guarantee that there will be no contamination because if the patent mixture used by the WLF. This means it is rather expensive structure that needs an investment in the beginning which takes time to pay off for this reasons the case gets 6.

Efficiency factor
The whole design of the RWH structures is focused on having a very high efficiency factor which is up to 90%. The formula discussed in the options leads to the following number: 1,600,000 liters / 177,042 rupees = 9.03. This means that theoretically 9 liters of water are recharged for every rupee that was spent. The efficiency is set 7 because it is very efficient for small projects because it has a percentage of efficiency. But the costs are high and shows a lower harvested water / cost ratio.

Imitability
The imitability got a high rate for several reasons. Named there is that the borewell recharging unit does not occupy much space. Almost all of it under the ground and its top can be used for other purposes as long as there are no permanent structures on top so it can be accessed for maintenance. Never the less the basic unit can resized and reshaped but most of the time fits as a standard block into almost every environment. It is more useful in urban areas than in rural areas because it saves the smaller area that is needed with a higher price than for example indirect recharging methods. Also it can be used for almost every kind of soil because it skips the percolation process by electric pumps. This makes it suitable for almost every situation but the special filters give a reduction of one point results in 9.

Resilience to external factors
Natural filtering processes are not working anymore and even the filters can filter out all particles and bacteria they cannot clean chemical pollution.

The advantage comes that the water is entering a closed system as soon as it’s cached by the drainage pipes which are leading to the storage tanks. From there it is filtered and pumped into the aquifers. There are no possibilities for the water to become soiled by trash or sewage. Pumps can be replaced with stronger models if their performance is not sufficient anymore.

Overall there is a high resilience to all factors that could occur in urban landscapes with the possibility to increase their demand.

Because of these factors the system is very resilient to almost all external factors except chemical pollution and gets 9 points.

Resilience to climate shifts
This system is built to harvest much rainwater over a short period, lower precipitation results in less water that is available for recharging. When too much rain is falling and that water can’t percolate through the filter fast enough. The basin will overflow and water is discharged through drainage pipes which part of the de-
sign for the collection tanks. Pumps can be replaced with stronger models if their performance is not sufficient enough anymore. This gives it a high resilience for climate and external factors, gets a 9 on the score.
5.3.2 RAJASTHAN

Costs
The costs can be lowered to zero if there is a availability of free labour by families or future users of the structure. This makes it affordable for everyone and gets the highest result possible.

Efficiency factor
The efficiency is not possible to measure reliable but the fact that the water is almost the whole time prawn to evaporation and the percolation have to happen naturally it can be considered to be much lower than the direct recharging system of the two other cases. Since the exact price could be zero and the amount of harvested cannot be measured exactly the formula does not work in this case. But due its big size for catchment areas and the costs of close to zero it makes sense to give the highest mark 10.

Imitability
The working methods about Johad is widespread and easy to copy.

They are not useful for urban areas because they occupy a lot of space. They also need a slope to collect the water in a pit this would be in Bangalore for example a problem because the city is built on a plane plateau.

The need for a special topography decreases its imitability drastically. Because it is still easy to build when the right topography it gets 6 points.

Resilience to external factors
It is hard to increase a Johad in size because they are fitted to the topography of the environment. The recharging lake that is produced in front of the dike is vulnerable to pollution and often can be directly used for freshwater supply. This all makes it very vulnerable for external factors and gets 3 points. The reason why it is not getting two or less points is that the water will still be naturally filtered percolating to the ground even when it polluted on the ground.

Resilience to climate shifts
When rainfall becomes unreliable due climate shifts. The Johads help to use the scarce water more efficiently by storing it under the ground. The groundwater can be usually considered as reliable source for potable freshwater. If the rainfall increases, the Johad will overflow and the water will be spoiled as runoff to the next surface water. A danger from too heavy rainfalls comes when the dam will break and causes flooding, this puts the fields and villages nearby in danger. This all gives it bad score climate shifts, but it have to be said that the overall resilience to climate shifts improves with a Johad.

5.3.3 GOA

Costs
In Goa there is a lower price for water than in Bangalore but there is a higher precipitation what allows to harvest more harvest with the same RWH structures. The case study showed that the RWH already paid off multiple times after the first year. The filters need to be replaced but no special techniques are used what means that the works can be done by the companies that offers the best price. The costs are basically the same as for the case study in Bangalore but don’t need a special filter this is why they scored one point higher.

Efficiency factor
The efficiency is set at 70% what is an average percentage for direct borewell recharging units. The formula explained before looks in this case as following 39,000,000 liters / 160,000 rupees = 243 liters harvested per rupee that was spent. This results in more water that could ever be used and will increase the groundwater level for nature and the surrounding area. For these reasons it gets the highest score of 10.

Imitability
The RWH a design especially made for this one case. It can’t be easily copied and placed to other sites because it takes into account the topographies and occupies spice that can be used
for other purposes because the water could get soiled. For those reasons the score is set to 6.

**Resilience to external factors**

The RWH used in this case is an open system where all water is all the time uncovered till it is pumped to the aquifer. This makes its prone to pollution of the surface.

It can be easily increased in its size by building more pumps on other locations. Or replacing the pumps with a stronger models. The fact that the water could easily get polluted drags the score down to a 6.

**Resilience to climate shifts**

All systems are designed to take no damage if overflow occurs, this means there is a maximum for the amount that can be recharged. If it rains less there is less water that will be recharged but on the other hand the scarce water will be used more efficient than before. Since the recharging system is similar to the one of Bangalore they also got the same score (9 points).

### 5.4 CONCLUSION

The case of Bangalore is very efficient and is design to withstand the problems of pollution from big cities. The drawback are the costs, this is why the system only makes sense if the water prices are high enough to make economic sense. Another strength of the project comes from design that unit design that makes it easy to copy it all over the city as a decentralized network. The solution focusses more on small scale harvesting rather than big scale projects but its scale could also be increased to harvest big areas with several recharging units that work as a collective.

The case study about Goa used a similar technique but not as a closed system especially designed for this one project. This decreased its price but makes it more vulnerable external factors like pollution from trash and sewage. The high score for its efficiency can be explained that it is built in much more humid region than the other two cases.

The example of Rajasthan represents a method in which with almost no investments a structure is build that is feasible for everyone and helps to create a compensative groundwater management. It needs a lot of open space and is only suitable for rural areas.

Overall it can be said that the case study of Bangalore is useful for urban center were efficiency is more important than costs. They are designed to deal with all urban problems. The Goa case is a good example for a solution for suburban areas at the edge of a city. They can harvest big amounts and are very cost effective. The case study from Rajasthan is a solution that can be implemented by farmers to deal with the ever decreasing groundwater level. It is a easy solution that might bring the possibility to harvest one more crop cycle because they are able to irrigate their plans during the dry season.
6. WHAT LONG TERM SOLUTIONS FOR COMPENSATIVE GROUNDWATER USE ARE AVAILABLE FOR PEOPLE OF ALL LEVELS OF INCOME IN SEMI HUMID AREAS?

Conclusion

There is no perfect solution available that fits all needs. For rural sub urban and urban areas area each different solutions available. While rural areas with agriculture can allow to use a lot of space for the creation of recharging lakes where the water can accumulate through the rainy season and slowly percolate over the whole year to raise the groundwater level. The new lake is not potable but can be used for irrigation while the water that percolated through the ground can be pumped up as a freshwater sources for the farmers. This solution is very cheap and every farmer how knows in which direction the water runs off his fields should be able to find the best spot for the pond without any help by third parties.

The research has shown that the best solution for rain water harvesting in urban areas up to now is the direct borewell recharging method. It has the advantage that the groundwater level is raised at the same point where it is extracted.

It is very space efficient because it does not need basins to store water for a longer period. Almost endless amounts can be stored in the ground without the need for big storage tanks.

Because it is a closed system it is protected against the major pollutants in India, trash and sewage. The filters allow to recharge water from highways and major roads that are usually kept free of trash. The high efficiency this makes it suitable for very arid regions. Another advantage comes through its imitability. There is no need for natural percolation and the soil tape is no matter for the implementation of the system. The functioning of a borewell pump is common knowledge in India and there are many repair services available. The major disadvantage comes with its price. To make it available for low income a way to finance the construction is needed. Even the projects usually pay off after two years the low income population cannot afford the installation in the first place and rather pay every month more price per liter but in smaller sums.
very efficient systems or if not possible by subsidies.

The Goa example has shown that those two techniques can be also combined. The clean water from rooftops can be used for direct recharging while the water that runs off the ground can be stored in lakes and percolate slowly into the ground. This decreases the price of the installation and is suitable for big open areas in cities like park or public buildings. This would decrease the pressure on the water system and help to reduce the overall water usage of a city.
DISCUSSION

During this research it was clear that Bangalore is facing a difficult future in sustaining its freshwater supply for the fast developing city. The water crisis will first hit the poorest people that can afford the raising water prices in the city. The lowering groundwater level will make it at one point impossible to use self-services like private borewells to get affordable water.

But not just the low income population is endangered also Bangalore’s economy will need feasible and reliable water sources. The fast increasing welfare of a small share of Bangalore’s population will increase the pressure on the water system even further. The land use planning focuses just on the economic centers of Bangalore which can be named as the Old City Centre and the Electronic City. The suburbs act mostly self-organized and the implementation land use plans that include areas for surface water and big Rainwater harvesting projects will be very difficult.

The fact that Bangalore is lying on a plateau of 400 meter height makes pumping water from the Cauvery River to the city is very energy demanding and on long-term not very cost effective. Also plans to pump water from other rivers further away or the creation of a desalination plan on the coast will cause a further increase of water prices.

A cheaper solution will be to use the water that falls on the city during the monsoon season. There is enough precipitation serve the water demand for the next decades without much energy. The groundwater pumping facilities are already there and could be easily further extended.

The solutions provided by the WLF will help to catch and store the rainwater cost effective. The lack of reliable public sources makes water to a precious good and the installations become fast cost effective for people that can afford them in the first place.

For people that can’t afford these services an own fund is created that pay for projects of the low income people in Bangalore and other areas in Karnataka.

RWH can help to reduce the pressure but will never be able to fully serve the whole freshwater demand. The city will always depend on expensive water on the Cauvery River but needs to decrease their demand. RWH is easy to implement and should become as usual as it is already in other states of India like Rajasthan.

Never the less RWH cannot be the only solution for the future demand rather it can only help to improve the situation. Bangalore needs to renew its Infrastructure and implement more policies that reduce the overall demand. The lakes are unlikely to come back in a city with such a rapid growth and less space available each year.


*Times of India*. (2011, 12 07). Retrieved from India’s income inequality has doubled in 20 years: http://timesofindia.indiatimes.com/india/Indias-income-inequality-has-doubled-in-20-years/articleshow/11012855.cms

Appendix

1. Establish the decision context
   a. Establish aims of the MCDA, and identity decision makers and other key players
   b. Design the socio technical system for conducting the MCDA
   c. Consider the context of the appraisal

2. Identify the options to be appraised

3. Identify objectives and criteria
   a. Identify criteria for assessing the consequences of each option
   b. Organize the criteria by clustering them under high-level and lower-level objectives in a hierarchy

4. ‘Scoring’. Asses the expected performance of each option against the criteria. Then assess the value associated with the consequences of each option for each criterion.
   a. Describe the consequences of the options
   b. Score the options on the criteria
   c. Check the consistency of the scores on each criterion

5. ‘Weighing’. Assign weights for each of the criterion to reflect their relative importance to the decision.

6. Combine the weights and Scores for each level in the hierarchy
   a. Calculate overall weighted scores at each level of hierarchy
   b. Calculate overall weighted scores

7. Examine the results

8. Sensitivity analysis
   a. Conduct a sensitivity analysis: do other preferences or weights affect the overall ordering of the options?
   b. Look at the advantage and disadvantages of selected options, and compare pairs of options
   c. Create possible new options that might be better than those originally considered
   d. Repeat above steps unit a ‘requisite’ model is obtained