Sveriges lantbruksuniversitet
Swedish University of Agricultural Sciences

Department of Economics

With a few liters of clean drinking water

A Cost Benefit Analysis of the socio-economic effects from implementing new clean drinking water technologies in rural India

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A Cost Benefit Analysis of the socio-economic effects from implementing new clean drinking water technologies in rural India

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"Water is essential for all dimensions of life. Over the past few decades, use of water has increased, and in many places water availability is falling to crisis levels. More than eighty countries, with forty percent of the world's population, are already facing water shortages, while by year 2020 the world's population will double. The costs of water infrastructure have risen dramatically. The quality of water in rivers and underground has deteriorated, due to pollution by waste and contaminants from cities, industry and agriculture. Ecosystems are being destroyed, sometimes permanently. Over one billion people lack safe water, and three billion lack sanitation; eighty per cent of infectious diseases are waterborne, killing millions of children each year."

World Bank Institue
WATER POLICY REFORM PROGRAM - Nov. 1999

Abstract

In 2010, Airwatergreen AB started testing their new technology, the Airwaterwell, an atmospherical water generator of their own design that is running on solar heat, with a production capacity of three litres of water per day and m^2. The purpose was to focus on foreign aid organizations as main purchasers for project investments towards rural communities in developing countries that suffer from lack of, or compromised quality of drinking water. In order to further understand if this technology would bring a positive impact in the developing countries, the company contacted the Swedish University of Agriculture for a socio-economic study of the Airwaterwells' potential.

The authors elected Cost benefit analysis as the appropriate method for conducting the study and India became the study region because of its many problems with water related issues such as diseases as well as insufficient water supply for households. The regions that this study is based on are Gujarat, Haryana and Uttar Pradesh given their differences in income, health situation and poverty rate. A model was constructed to estimate the primary benefits such as health related benefits and benefits from time saved from fetching water in these regions.

To diversify the study, two other project alternatives was included. A representative heat pump, Electrolux Oxy-3, theoretically converted to an Air-water generator was added as a project alternative, capable of producing 2,1 litres per day. Also the already established solar-disinfection field is represented by the 10 litre Solvatten unit, has been included. The Solvatten disinfection bottle addresses all the variables problems formulated in the model except for the time to fetch water.

In order to study the impact of the implementation of the project alternatives, the benefits for providing households with clean drinking water was measured. After benefits and costs have been added, Net Social Revenue for the project alternatives was compared. In order to address the inherent uncertainty of a multi-variable model, a thorough sensitivity analysis was performed. Lastly, the necessary cost-level for a future implementation of the Airwaterwell was analysed and discussed, given the cost-levels of the other project alternatives.

In the analysis, it was found that Uttar Pradesh was the best region for investment, where Airwaterwell yielded a return on investment of 4,66 (0,87-19,0) times the initial amount. At current cost level, it was not able to match the performance of the Solvatten unit, but out-performed the more technologically related Electrolux Oxy-3 heatpump. With the model constructed in this analysis, the return on investment is higher in regions with a higher proportion of children. Conversely, if Airwarerwell units are distributed to children only, return on investment is increased to 8,4 times the initial amount.

Sammanfattning

Under 2010 började Airwatergreen AB testa sin nya teknologi, Airwaterwell, en atmosfärisk vattengenerator efter egen design som drivs av solvärme, och vars produktionskapacitet är uppskattad till tre liter vatten per dag. Målmarknaden var biståndsorganisationer och marknadsnischen fattigdomsbekämpning via rent vatten. För att ytterligare utvärdera om denna teknik skulle ge en positiv inverkan i utvecklingsländer, kontaktade företaget Sveriges Lantbruksuniversitet för en socio-ekonomisk studie av ett Airwaterwellprojekt.

Författarna valde att använda Cost-benefit analysis som metod för att genomföra studien och Indien utsågs till studieregion på grund av dess många problem med vattenrelaterade frågor såsom sjukdomar samt otillräckligt vattenförsörjning för hushåll. Tidigare Cost-benefit analyser inom detta område har ofta varit kontinentala i sin omfattning, avgränsade till exempelvis sydostasien. Mer regionalt avgränsande analyser har också gjort, men de har ofta fokuserat på avgränsade kategorier, såsom grundvattenföroreningar. Målet med denna studie är att genomföra en regionalt begränsad studie, som omfattar alla områden där samhällsnyttan kan öka av att tillhandahålla rent vatten till indiska hushåll.

Regionerna Gujarat, Haryana och uttar Pradesh ansågs som bra testregioner då de hade tydlig variation i inkomst, hälsosituation och fattigdomstal. Med denna uppdelning kan man studera specifika effekter när variabler som inkomst, sjuktal, spädbarnsdödlighet och vattentillgång varierar. En modell konstruerades för att uppskatta de primära förmåner som förväntas uppstå om hushåll förses med atmosfäriska vattengeneratorer såsom Airwaterwell, eller vattenrenare inom SODIS-fältet (soldisinfektionsflaskor). Utöver Airwaterwell utgörs projektalternativen av en representativ värmepump, Electrolux Oxy-3 som drivs av solceller, samt Solvattens 10 liters enhet (en teknologi inom SODIS-metoden).

Kostnaderna för denna analys består av produktpriser, pga svårigheter att uppskatta installationskostnader, samt så har inga av projektalternativen några löpande kostnader. Samhällsnyttan antas kunna genereras primärt från; minskad tid lagd på att hämta vatten, minskad sjukfrånvaro både för vuxna och barn, minskad dödlighet bland barn under fem och minskad arsenikförgiftning (i berörd region). Samhällsnyttan periodiseras per år under projektalternativens livslägd, och diskonteras till dagens värde (2011 US dollar).

Empirin till analysen hämtades primärt från nationella hälsoundersökningar, där datan redovisas regionsvis samt uppdelad i urbana och rurala kategorier. Dessa undersökningar gjordes under åren 2004-06. Från dessa dataset kommer även inkomstuppgifterna, som räknades upp med hjälp av Indiens löneutveckling och justerades för köpkraft gentemot den amerikanska dollarn. Detta för att simulera ett utländskt biståndsprojekt. Uppskattningar för minskad förekomst av diarré baserades på tidigare fältundersökningar, som använts av andra forskare för liknande analyser. Där regionala data saknas har andra källor använts, i första hand nationella Indiska undersökningar.

För att analysera och tydliggöra den osäkerhet som finns när en multi-variabel modell har konstruerats, genomfördes en omfattande känslighetsanalys. De variabler som inkluderades var de som kunde väntas ha störst påverkan på det slutgiltiga resultatet. I analysen visade det sig att Uttar Pradesh var den bästa regionen för investeringar där Airwaterwell gav en avkastning på 4,66 (0,87-19,0) gånger det initialt investerade beloppet. Detta berodde primärt på de högre fertilitetstalen (i kombination med den större minskning av diarre bland barn), vilket övervägde effekten av högre inkomster i Haryana. För de hushåll som utrustades med Solvatten-enheter genererades samhällsnytta motsvarandes 14,48 (35,57-3,36) gånger det initialt investerade beloppet. E-Oxy-3 visade bara positiva resultat i den bästa regionen, där resultatet uppmättes till 1,10 (4,49-0,10).

Från känslighetsanalysen konstaterades att statistiska värdet av ett liv, sjukdomsminskning bland barn, tid lagd på att hämta vatten och sociala diskonteringsräntan var de variabler med störst påverkan på det slutgiltiga resultatet. Mindre signifikant roll spelade hälsokostnader, sjukdomsminskning bland vuxna och graden av arsenikföroreningar. Ett antal specialfall analyserades, det första gällande en distribution av projektalternativen enbart till hushållens barn, vilket hade en positiv effekt på samhällsnyttan. Eftersom det statistiska värdet av ett liv är både en teoretisk konstruktion och ett kontroversiellt ämne, analyserades resultatet med denna variabel struken. Det minskade samhällsnyttan, med den största minskningen i den bästa regionen Uttar Pradesh. Slutligen redovisades resultat utan köpkraftsjustering, för att simulera ett inhemskt finansierat projekt. Samhällsnyttan minskade, men förblev positiv för Airwaterwell och Solvatten.

När resultaten analyserats konstaterades att samhällsnyttan maximerades (givet projektalternativen) när investeringarna skedde i regioner med högre fertilitetstal, och speciellt när enheterna distruberades enbart till barnen. Med samhällsnyttan beräknad är det relativt enkelt att beräkna ett monetärt värde av rent vatten, vilket uppskattas till två till tre amerikanska cent per liter vatten, beroende på regionen (14-21 öre). Detta är i linje med de högre uppskattningarna från tidigare WTP-studier, i urbana Kalkutta.

I sista avsnittet diskuteras de osäkerheter som finns i modellens konstruktion, samt de variabler som utelämnats. Resultaten konkretiseras även, och potentialen för investering debatteras. Generellt sett kan det konstateras att Airwaterwell är det projektalternativ som genererar högst total samhällsnytta. En beslutsfattare utan specifika budgetrestriktioner bör alltså överväga det projektalternativet. Solvattenprojektet är dock det altermativet med högst generad vinst per investerad krona. När budgetrestriktioner är satta, eller antalet hjälpta hushåll ska maximeras, är Solvatten det gymnsammaste alternativet. Det bör noteras att Airwaterwell har potentialen att löna sig enbart från minskad tid lagd på att hämta vatten, om projektet lanseras i områden där avstånden till vattenkällor är längre. Detta är ett nyttområde som enbart skapas av de atmosfäriska vattengeneratorerma, eftersom Solvatten bara operererar på de befintliga vattenresurserna.

Abbreviatons

AWG – Atmospherical Water Generator
AWW – Airwaterwell
BS - Base Supply
CBA - Cost Benefit Analysis
DRR – Disease Reduction Rate
E-oxy 3 - Electrolux Oxy 3 heat-pump
GDP – Gross Domestic Product
HH - Household
HC - Healthcare
IFAD - International Fund for Agricultural Development
MDG - Millennium Developmental Goal
NGO – Non-governmental organization
NPV - Net Present Value
NSR – Net Social Revenue
PPP – Purchasing Power Parity
POU – Point-of-use
POUWT – Point-Of-Use Water Treatment
ROI - Return On investment
SDR - Social Discount Rate
SODIS – Solar-Disinfection
SV - Solvatten
SVL - Statistical Value of Life
WTP – Willingness To Pay

Table of Contents

1. INTRODUCTION **1**

1.1 PROBLEM BACKGROUND 2
1.2 OBJECTIVE 4
1.3 LITERATURE REVIEW 5
1.4 OUTLINE OF THE THESIS 7

2. METHOD **9**

2.1 COST-BENEFIT ANALYSIS 9
3.1.1 Critique against Cost-benefit Analysis *9*
3.1.2 Theory of Pareto-efficiency *10*
2.2 METHODS USED WITHIN THE COST BENEFIT ANALYSIS 11
2.2.1 The social discount rate *11*
2.2.2 Statistical value of life *12*
2.2.3 Purchasing Power Parity *12*
2.4 ALTERNATIVE METHODS 12
2.4.1 Water pricing *12*
2.4.2 Willingness to pay *13*

3. EMPIRICAL MODEL **14**

3.1 PROJECT ALTERNATIVES 14
3.1.1 Atmospherical water generators *15*
3.1.2 Solar water disinfection *16*
3.2 STANDING 16
3.3 IMPACT AREAS 17
3.4 COSTS AND CURRENCY CONSIDERATIONS 17
3.5 BENEFITS OF PROJECT IMPLEMENTATION 18
3.5.1 Benefits from time saved collecting water *18*
3.5.2 Health-related benefits *18*

4. EMPIRICS **22**

4.1 SELECTION OF STUDY REGIONS 22
4.2 EMPIRICAL DATA 23
4.3 COSTS 24
4.4 HEALTH RELATED STATISTICS 24
4.5 TIME SPENT FETCHING WATER 26

5. RESULTS **28**

5.1 BENEFITS FROM TIME SAVED 28
5.2 SUMMARY OF BENEFITS AND NET SOCIAL REVENUE 29
5.3 SENSITIVITY ANALYSIS 31
5.4 RESULTS FROM SENSITIVITY ANALYSIS 33

6. ANALYSIS **37**

7. CONCLUSIONS **39**

8. DISCUSSION **40**

BIBLIOGRAPHY **43**

Literature and publications *43*
Internet *45*
Personal messages *46*
Datasets & Reports *46*

APPENDIX **47**

1. Introduction

In National Geographic magazine from 2010, a story focused on a New Dehli woman out on the streets searching for clean drinking water for her family is being told (National Geographic, 2010). This family spends most of their day on a quest for gathering water, when they could have worked and sent their children to school. This of course is not a story of just one household, but the life of thousands and thousands of people in India who`s main daily problem is water-related. It describes a harsh everyday struggle to find water, which may be contaminated and cause diseases such as diarrhea. A case of diarrhea can incapacitate an adult for up to five days, making the struggle for financial security and sufficient nutritional intake even harder (HDI, 2006). For children in developing countries, repeated cases of diarrhea results in loss of education, stunted growth and, worst case scenario, death (UNICEF, 2012).

To put it into proper context, UNESCO has deemed access to water and the quality of water to be essential in the struggle against poverty throughout the world (UNESCO, 2009). Much of the poverty can be found specifically in rural communities. This holds true for South Asia and India especially where the rural poverty hasn`t declined in any remarkable rate since the 1990`s (globalissues, 2011). According to the Millennium developmental Goals set by the World Health Organization, the extreme poverty and hunger should be eradicated, universal primary education achieved, gender equality promoted and women empowered, maternal health improved and child mortality reduced, all this achieved by year 2015 (UN, 2012).

Fulfilling these goals are critical particularly in India, where it has been estimated that almost 700 million Indians are afflicted by waterborne diseases annually, resulting in the deaths of 1,5 million children (Khurana *et al*, 2008). This is caused in part due to a large and increasing population, periods of water scarcity and dubious health-coverage. The situation is further worsened due to the lack of clear, coherent government regulation over water policies. In an Asian Developmental Bank report from 2007, it has become clear that the result of these water policies has become an inefficient government regulated water scheme, where the water is provided through public taps, water-pricing nonexistent and the lack of control over water quality has become a major problem.

The lack of clean water has an impending effect on sanitary conditions and health in many developing countries (UNESCO, 2009). Even for those communities with access to water, the logistic of gathering drinking-water can be extremely time-consuming which diminishes potential work-force efficiency. This represents a societal loss for the communities who suffer from the logistical efforts to find water. Can innovation and new technologies, if not solve this problem, at least help alleviate it?

1.1 Problem background

To understand the general problem of access of water and how it affects society, there is a need to understand the definition of water as a resource. How does water as a resource function when used by society? To further understand why this becomes a problem, there is a need to understand how bad water quality arises which the will be discussed from a perspective of sustainable development. Finally this chapter will summarize how bad water quality affects societal inequality.

Defining the water problem

The general problem with water supply is that even though the world is covered by 70,8% of water, it's still a resource that can be exhausted. Since roughly 97 % of the water is found in the oceans, this leaves three percent that exists on the landmass, and out of these three percent, only 0,3 percent is freshwater held up in rivers, lakes and reservoirs. The rest can be found in glaciers, permanent snow and groundwater reservoirs (Piamental *et al*, 2008).

Approximately 30 percent of the freshwater supply can be found in the ground. This water has been accumulated over millions of years in vast aquifers beneath the ground. This is still by definition a renewable resource, since it's replenished from rainwater, though replenishment is slow, at an average of 0,1 to 3 percent per year. An extended extraction of groundwater aquifers will cause groundwater levels to decrease over time. To put into larger context, this extended extraction causes major problems for the agricultural and rural communities that are dependent on groundwater for irrigation and other needs. Also if these groundwater aquifers are exhausted, the surface soil is prone to sink, which decreases the ability for the aquifer to replenish (Piamental *et al*, 2008).

Given the nature of water resources, and since the flow of water into underground aquifers can`t be measured, it is taken for granted that unlimited extraction can be done. In economic theory, these underground aquafiers are defined as ”common property resources” (Nafziger, 1997). The problem with these kinds of resources is that they stimulate a negative overuse of the water source from one of those using it, which affects everyone dependent on the water source. This is known as "The tragedy of the commons"- example.

The over-usage could be spurred because of a general lack of knowledge of the status of the resource (Nafziger, 1997). It could also be spurred how the problem is prioritized in society. Given a growing society where high poverty levels exists, the first societal priority is to solve the issues of poverty as fast as possible before poverty rates reaches critical levels, while the well-being of the environmental systems are lowly prioritized. This example can be seen at many places throughout the world and the combination could lead towards break-down in the environmental system in the future, as the problem of grinding poverty manifests itself in the desperation of the people within the society, as they strive for immediate gain, forgetting of long-term social sustainability. This leads the society to degrade and to destroy their immediate environment, through over-usage, without regards for future generations. This development could be halted by re-investing in the health of the resource and its regeneration.

This is exemplified in a study from the International Water management Institute, conducted in northern parts of India and Pakistan (Molden *et al,* 2001). The test sites within the study showed clearly that people using the water resources had limited consequence-thinking regarding inflow and outflow of the water basins that were tested. For example, the people took no regards for their actions, concerning their neighbors downstream. This is one example of how bad water quality arises. The main issue with water distribution in India is the way that people perceive water, as a common good where the government supply water almost free of charge (Asian development bank, 2007). Given this, there is no incentive to care about the return flow of water, which promotes the spread of negative externalities such as waterborne diseases and water pollution (Rogers *et al,* 1998, & Panayotou, 1993). Solution to this kind of problem would be to eliminate market distortions that spur overuse of common property resources, but it can also be argued that financial market solutions would require better water-infrastructure, which many developing nations lacks.

Social consequences of the water problem

It should also be noted that poverty is today considered to be more of a rural problem, which can be seen throughout the developing countries today (globalissues, 2011). In studies conducted by International Fund for Agricultural Development (IFAD), it can be noted that the South Asian areas in particular have only a small decline in rural poverty. As of 2008 there were still almost 80 percent of the population in this area living in poverty are living in rural areas South Asia. Its estimated that 500 million of the rural population are affected by extreme poverty, that is, living on less then 1,25 US$/day which is internationally recognized as the extreme poverty limit.

This can also be seen out of gender perspective, where the IFAD study also pointed out that women tend to do more work for less payment each day, and are the primary care-givers for their families in almost all rural societies, yet they are barely featured in recognitions or policies (globalissues, 2011). This can be linked closely to the water situation, were women tends to be the responsible part for household services. For example, they take the active role of caring for their children in times of sickness.

Whenever there is a household with longer distances to water sources, the women and children are commonly assigned the duty of collecting the water (wateraid, 2009). Amongst the children, the girls are often chosen for this task. For women this becomes a drain on their ability to find employment and provide their families with an additional or increased income. For children, this affects their education with low presence in elementary school, severely hampering their ability to get a proper education. In addition, a lack of proper sanitary facilities in schools, have also been proven to be a factor preventing children to go to school.

It has been confirmed through studies that interventions for improved sanitation and water facilities increases societal welfare (wateraid, 2009). First, these interventions diverts focus from water-fetching towards work, and results in higher income which can be used to pay for school fees. Secondly, since children do not have to work for the family each day to find water, they can now attend school. Also a large part can attend simply because the lack of water related illnesses. The higher participation in school could also improve the general attitude towards education, furthering the advancement of the society as a whole.

The frontier of new technology

There are new emerging technologies that would address these problems and produce clean drinking water, for example solar-driven atmospheric water generators, solar disinfection and heat-water pumps. This has been the focus of attention for the Uppsala-based company Airwatergreen AB, with their new technology, the Airwaterwell (AWW). The Airwaterwell is a portable heat-pump classified as an Atmospherical Water Generator (AWG) which produces drinking-water from airborne moisture. The machine itself is powered by solar-generated heat, making it a technology with no byproducts and small running costs for producing a fixed amount of water per day. The water can be produced in the household or its vicinity, which would save time.

To study the socio-economic effects of a future implementation of the AWW technology, an economic model has to be constructed since the AWW is still in prototype stage. The areas that would benefit most from implementation have been generally characterized as being landlocked, rural communities in developing countries that has limited supply of water due to water related diseases or distance to the water source, or both.

The model that has been used, is a model constructed from Cost-benefit analysis method, which will be further discussed in the following chapter. India has been chosen as the area of study due to its complex water situation, and wide-spread water-related problems, especially in the rural areas. In order to provide an unbiased study, three different states, Gujarat, Uttar Pradesh and Haryana, with different sets of income, poverty rate and presence of water-related diseases have been chosen as study-areas for this thesis.

In order to diversify this study, it will include other technologies within the field of clean drinking water. These technologies are the solarcell driven Electrolux Oxy-3 heat-pump, an atmospherical water generator, which is similar in technology to the Airwaterwell and could be used to a similar purpose. Also included is the solar water disinfection plastic bottle (SODIS), a common water-treatment unit against microbes, already applied in developing countries today. It's important to realize that heat-pumps produce a fixed amount of atmospherical water each day, while the SODIS technology purify the existing water resources available in the region.

Airwatergreen AB have for the AWW technology, specifically targeted the market of project investors in regional development within developing countries or external financiers such as foreign aid investors, which clarifies the delimitations of this thesis, where the stakeholders are the investor and the average household. Further details of delimitation of this study will be brought up in chapter 3.

1.2 Objective

The overlaying goal of this thesis is to understand the socio-economic impact an investment in the emerging technologies in the field of water purification would have for rural households in the developing world. For this analysis the three regions mentioned in the problem background has been chosen. To perform this task, an economic model based upon the "Cost-benefit analysis"-method will be constructed.

The foundation of this study is the measurement of how clean drinking water can provide socio-economic development, by providing less water related diseases, and decrease time spent fetching water. Applying the study on different regions will evaluate whether different variables such as income and household composition affects the outcome, and if so to what end. Given that at a different price-levels and different type of performances from each technology included in the study, the technologies will generate different sets of benefits and by extension different net-social revenue. By answering this question, project alternatives will be ranked. Uncertainty and impact of single variables are evaluated through a sensitivity analysis.

As of today, the Airwaterwell only exists as a prototype, and therefore no final product price exists. For the model, a best estimate provided by Airwatergreen AB will be used. An additional benefit of the analysis will be to establish a viable the price-range, i.e. between the break-even point (net social revenue equals cost) and the point where the cost makes the other project alternatives more viable.

1.3 Literature Review

In this review, some of the studies that have been used to gain a deeper understanding of the water problem are presented and briefly summarized. The aim is to show how previous researchers have viewed the water situation, and how water quality has been valued. These studies are important to mention as they have influenced this thesis, and identified a research gap which this study will attempt to fill.

Published in 2009 by United Nations, the third World Water development report assesses the global situation and tracks the progress of the Millennium Developmental goals (MDGs). In broad strokes, the report describes an increased awareness of the problems caused by, and surrounding, the issue of drinking water (UN, 2009). It also notes that while intentions in many parts of the worlds are good, the global economic development can provide conflicting incentives. While fulfilling the seventh MDG in southern Asia is still feasible, it will fail in sub-Saharan Africa and the poorer Middle-eastern countries. The report also highlights the connection between water issues such as scarcity and pollution, and extreme poverty.

In a study presented in the World Health Organization journal of water and health, a global cost-benefit analysis on implementation of a universal basic water supply, basic water sanitation and purification by 2015 in developing countries in South America, the Middle-east, Africa and Southeast Asia is conducted (Hutton *et al*, 2007). The study assumed that the people who do not have access to a safe water supply would be halved. The reduction of cases of diarrhea was derived from the expected amount of people to gain access to clean water. The analysis took investment and running cost into account of the sanitation and clean water supplies. The analysis evaluates the effects for each region of the world, and their sensitivity analysis shows that in developing countries, this sort of investment would always have benefits that outweigh the costs. For project alternatives, the study uses a wide variety of coverage in terms of sanitary measures and ways to provide clean drinking water. Worth noting is that the study concluded that improved water and sanitation would indeed generate benefits, but it points out that these benefits are not always financial benefits. These benefits could be measured in time-savings, such as higher presence in school instead of being sick and less time collecting water. Of the studies reviewed, Hutton et al (2007) has performed the broadest analysis in terms of impact areas, as well as project alternatives. In is worth nothing that, for this study, costs for the different project alternatives were considered the most uncertain estimate, mostly due to variation of prices for labour and materials, as well as infrastructural considerations.

Similar methods have been used in previous studies published by the journal of water and health. In a 2007 study the cost-effectiveness analysis (CEA) method were utilized on solar disinfection, chlorination, filtration and disinfection on the same developing regions that were included in the Hutton *et al* study (Clasen *et al*, 2007). Specific setting in this study was that they only tested against low-technology water supply, such as dug-wells and communal water supplies. In the study, population-models were used for the entire South-Asian region, to account for externalities and spill-over effects generated from improved health status. CEA method is a similar method to CBA but measures and compares cost of the implementation given a specific level of benefits. In this case it’s a measure of how much lower the implementation costs will be per technology, considering a set of health costs that needs to be reached. This leaves out the components of eventual social benefits that could be accounted for. Although positive results were shown for each of the methods applied into the CEA.

The studies done by Hutton *et al* and Clasen *et al* could be deemed as hypothetical studies since they are in fact measuring a large portion of the globe. This general theory of how clean water could make economic impact is in line of how the problem is formulated in this thesis, and will therefore return to adress these issues. Quantifying such a large population is therefore to be considered theoretical. In the Hutton *et al* study, the authors themselves admit and points out, that regionally based studies has to be conducted for higher reliability, and so far less of those kind of studies has been conducted.

Other studies, performed at national perspectives outlines more specific situations, and specific problems, and the costs of water related diseases, for instance, a study conducted of the costs of Mexico’s water supply in March 2009, where it is believed that 60 percent of diarrhea cases is derived from unsafe food and water (Maran˜o´n-Pimentel, 2009). The study used a wider perspective and looked at the countries costs of water-borne diseases. The conclusion drawn from this paper is that there is different type of costs to society. First of all, primary costs for the disease, such as hospital costs. Benefits derived from opportunity costs, such as lost working time are classified as secondary. The estimation concluded that households bear twice the costs from unsanitary conditions, in comparison to the state level.

Similar studies have been done, for example, a study in South Africa, telling that there are several types of costs related to water-related illness and draws similar conclusions as the Mexican study (Pegram *et al,* 1998). Both studies take statistics into account how water-related diseases affect people. A study on water situation in Bolivia on the other hand has given an approximation that a clean drinking-water source within the household would decrease sick-leaves with 44 percent (Quick *et al,* 1999). This is the same information used by Hutton *et al* in their global study.

There has been a handful willingness to pay (WTP)-estimations of the price of clean water in Indian regions, for example Roy *et al* (2002) who performed a household survey in Calcutta. From 250 household of various income, an estimated price of $4,7*10^{-5}$ US$/liters clean water to 0,023 US$/liters. The wide range is explained by the author because water behaves as a luxury good, i.e. poor household are willing to pay very little for clean drinking water, whereas wealthier household are willing to pay exponentially higher.

This is contradictory towards both intuition and economic theory, since water is usually defined as a necessity good, where you'd expect WTP to increase as income increases, but not proportionally or higher than the income increase. Roy *et al*'s findings are supported by smaller case studies, for example Sighn *et al* (2004) who found that regionally in Uttar Pradesh, the monthly WTP is at least twice as high as the actual, regional fee. Guha (2007) performs a similar analysis of an urban population and found a lower WTP for purified water than Roy *et al*, but still above the actual fee. This is addressed in a survey performed by Marie Zerah (2002), which concludes that the majority of the Indian high-income population regards water as a cheap or free resource. What they are willing to pay for is an increased quality of water. Jalan *et al* (2004) proposes that this disparity is partly an issue brought on by lack of information. When informed about possible fecal contamination, the chances of purifying the water supply within the next week increased with 11%.

In addition, there have been narrower studies, calculating WTP for drinking water clean of arsenic contamination. An example of this is a World Bank study, in Bangladesh used contingent valuation among households to conclude their awareness of arsenic poisoning in their water (Ahmad *et al,* 2003). The households questioned were informed of solutions to the problem and their willingness to pay for any of these solutions. This targets a specific water problem that so far today has no clear solution. In this case contingent valuation and willingness to pay methods can be utilized as to give a measurement of the appropriate price of any given solution to the problem. Similar studies has been done, as for example a more broader study analyzed the demand for higher water quality in West Bengal by J. Roy, asking about the willingness to pay for improved water quality, given educational background and buying power of the household as leading independent variables in similar fashion as the Ahmad *et al* study (J. Roy*,* 2008). The Roy study will be addressed further on.

Table 1.1: Impact areas for the previous researchers.

Impact areas	Hutton & Haller, 2004	Clasen *et al*, 2007	Ahmad *et al*, 2003	J. Roy, 2008	Maran˜o´n-Pimentel, 2009	Quick *et al*, 1999
Costs:						
Investment costs	X	X	-	-	-	-
Running costs	-	-	-	-	-	-
Benefits from reduction of:						
Caregiver abseente from labor	X	-	-	-	X	-
Decreased logistics	X	-	-	-	-	-
Ground-water pollutions	-	-	X	X	-	-
Medical expenses	X	-	-	-	X	-
Mortality	-	X	-	-	-	-
Diarrhea	X	X	-	-	X	X
Unsanitary conditions	X	-	-	-	-	-
Workdays lost	X	-	-	-	X	X
Scope						
- Continental	X	X	-	-	-	-
- National	-	-	-	-	X	-
- regional	-	-	X	X	-	X

None of the papers presented estimates an actual valuation of water value for a specific region except for "willingness to pay"-studies. The mentioning of WTP in this regard is to acknowledge that it is the most commonly used study-method for regional studies. This will be further commented on in the method chapter, but its sufficient to say at this point that the WTP-studies shows a correlation between the participant and a given problem/solution and how he/she valuates this problem. But the water problem is a large problem affecting the society in a way that could be measured through statistics as what have been done in the Hutton *et al* study. Together, these studies illustrate the effects in terms of socioeconomic benefits from investing into improved water quality and sanitary measures.

The measure of how the solution to water problem has consequences on society on smaller scales such as villages and communities is yet to be done. This could be viewed as important area of focus since foreign aid organizations such as the Swedish International Development Cooperation Agency (SIDA) for example, under (minister for development cooperation) Gunilla Carlsson has declared that focus should be moved away from budget support towards aiding specific projects (svd, 2012). This new line of foreign aid policies within Sweden further motivates why this sort of studies in aiding regarding developing countries should look at regional development and project aid. This also calls for the necessity to understand how different conditions in different regions calls for specific project investments. A good way to analyze these types of problems is by applying them to the cost benefit analysis method.

1.4 Outline of the thesis

The outline of this thesis will be divided into five major sections, where each section will be built up to follow each step of the cost benefit analysis conducted. Chapter two will approach the cost benefit analysis as a method, and provides a brief explanation of how cost benefit analysis is conducted. To broaden the picture, the potential flaws of CBA, and its major criticism is presented and addressed as well as the alternative methods that has been excluded and the reasons why to exclude them.

The third chapter will be devoted to the model which this thesis is based upon. This chapter will take the reader through, step by step, on how this study has utilized cost benefit analysis. It will further explain what properties these different technologies attains, what kind of benefits has been deemed relevant and the different equations set up in the model to give a mathematical interpretation of these benefits. These equations have been formed to fit the necessary data and statistics.

The fourth chapter will introduce the reader to the study-areas of Gujarat, Haryana and Uttar Pradesh in terms of brief summary of each of the Indian states. It will also introduce the state specific data collected for this study, where the use of household, health and income specific statistics will be explained. Also costs of the different technologies will be explained.

The fifth chapter will give us the results. The benefits from the different projects will be calculated and the Net Social Revenue for each project alternative will be explained. This section also includes a sensitivity report, which is crucial to understand how these different project alternatives respond to variable changes.

Finally the sixth, seventh and eight chapters will be the analysis, conclusions and the discussion-sections respectively. In the sixth chapter the findings will be brought into the light and certain topics will be given a deeper analysis. The sixth chapter will be on answering the questions from the objective section and conclusions will be drawn. The eight chapter and provide a general discussion on what this thesis has accomplished well, but also the consequences there is for including and excluding certain areas and topics from the study, and what could have been made different in retrospect.

2. Method

In this section, the necessary tools and methods needed for understanding the water situation will be discussed, going through the broad perspective of what defines water as a resource, and how it can be put in an economic perspective. To understand the problematic at hand, we must discuss out of the perspective of how this research study will be conducted, namely through a Cost-benefit analysis which will be explained in the first subchapter, as well as critique against it. The other sub-chapters will be devoted to closer examine relevant tools used in this study, for example how the discount rate function, and how the measurement of the value of a statistical life. Lastly, the reader will be briefly guided through alternative methods considered for this kind of study but has been rejected.

2.1 Cost-benefit Analysis

Cost-benefit was founded as a method in the 19th century for budgeting purposes, and was established as method in 1936 when the US Flood act was being established. (encyclopedia brittannica, 2011). It was used to evaluate whether the benefits from flooding prevention out-weighted the costs of the projects, and since that point forward has been an established method within the field of economics. The idea of a Cost-benefit analysis is to create a monetized system for the benefits, i.e. the output of a project (Boardman *et al*, 2011). These benefits are aggregated and then weighed against the aggregated costs, to see if there is any positive Net Social Revenue (NSR). Any Cost-Benefit Analysis has the objective to find a resource allocation where benefits are maximized in regards to costs, given pre-specified alternatives. Since a society is made up of multiple individuals, aggregating those costs and benefits requires many considerations and choices made in regards to methods. It should be pointed out that CBA doesn't maximize a society's marginal utility, only ranks the projects after the objectives or pre-requisites. The study itself can be conducted before a project initiation, called *Ex Ante* study. This kind of study can contribute with forecasting for future time-periods. It is commonly used to assist the decision-making process when the government has to decide if they are to direct funds towards a certain project, elsewhere or not at all. Thus it's contributing in a direct way towards public policy decision-making.

The accuracy of a Cost-Benefit study is at its greatest with an *Ex Post* study and the *Ex Ante* is the one being less accurate. Usually, an *Ex Ante* study will attempt to address the uncertainty by performing a sensitivity analysis, in which the importance of single variables, and their effects on the outcome, is shown. Analysts can also rely on previous work on similar projects, or use accepted settings, such as plug-in variables.

Most commonly, a Cost Benefit Analysis is set out with a specific goal, and listed below are nine steps to take before reaching the conclusion of the study: (Boardman *et al*, 2011). Most CBA follows a similar approach, even if the terminology may differ.

1. *Specification of existing alternatives:* Given a certain objective, which alternatives exist for reaching that goal?
2. *Make a decision in regards to who's costs and benefits has a standing.* Those with standing are the stakeholders in the analysis. For example, is the scope of the analysis to be local, national or global?
3. *Identify impact areas*, i.e. from where are the costs and benefits derived.
4. *Quantify*: In this step, calculate costs and benefits in all the impact areas using an appropriate valuation method.
5. *Monetize*: Translate the social costs and benefits into a currency of choice.
6. *Discount*: If the streams of benefits and costs are divided over time, use discounting to calculate net present value.
7. *Summarize*: Add up costs and benefits
8. *Perform a sensitivity analysis:* With respect to uncertain variables, attempt to calculate intervals for errors.
9. *Make a recommendation:* Based on your findings, make a recommendation.

3.1.1 Critique against Cost-benefit Analysis

CBA is an accepted method for evaluating the potential of a specific project, or compare alternatives in order to rank them. Moreover, it has a long history with water-related evaluations, which suggest it should be a good fit for this analysis. As with most methods however, CBA is not without criticisms and controversy.

The main aspect of critique against CBA concerns its accuracy. CBA remains an estimation of reality, at best performed at the top of the researcher's ability. In reality however, budget and time for a CBA analysis is often a constraint (Boardman *et al,* 2011). Even if time and resources are not a limitation, there are indications that researches tend to systematically undervalue costs and overvalue benefits in regards to implementing larger projects (Flyjvberg *et al* 2002, p.). It is argued in their paper that the systematical distortion is in fact not due to an error in knowledge or calculations, but rather systematic in nature. These findings are supported by the assumptions of behavior, in which regional administrators would see some of the costs associated with a project as benefits, mainly through the jobs created (Boardman *et al* 2011). These finding are also supported outside the literature on CBA-analysis, as shown by Lovallo & Kahneman (2003). According to them, failure strikes approximately 75% of new projects. Blame for this is assigned to anchoring, failure to draw on past experiences and organizational pressure to produce optimistic forecasts. This suggest that tendencies for optimistic forecasts regarding cost and benefits are not exclusive to CBA-analysis, but rather lies in human psychology, market structures and governmental incentives. As done by Flyjvberg et al, the best way to evaluate the accuracy of CBA-analysis is to perform an *Ex-Post* analysis on the same project. Needless to say, this can be problematic on the projects with a longer lifetime, let alone an intra-generational project.

One other large uncertainty rests on the selection of the social discount rate. Especially over longer projects, varying the discount rate can affect the policy-decision. One partial solution to this is to include multiple alternatives in the analysis. If their timetable for delivery of benefits is reasonably similar, potential bias from selecting a faulty SDR is avoided. The problem of accuracy when comparing against status quo, or the counterfactual still remains, but with a positive value for net social revenue, the best alternative should surface as the recommendation.

An argument of different nature can be made against the CBA method of monetizing all the impact areas. A commonly used example is the value of a human life, actualized when planning projects like road-improvements or disease-alleviation. Estimations of this are commonly made based on average salaries and life-expectancy. But the argument could easily be made that those estimations are not exact, since you cannot know what a deceased individual would do with his or her life. And the stronger argument, that a person’s life is not determined by his or hers predicted future earnings, especially since this oftentimes becomes a question of GDI/capita. Another impact area that can be hard to estimate is animal life, or biodiversity. Outside the agricultural field, the recommended methods to estimate this would be a willingness-to-pay survey or the travel-distance method, as part of a CBA. However, this relies heavily on a public interest in the impact area, which is not always prevalent.

Several measures will be taken to address some of these problems in the CBA performed here. As part of the sensitivity analysis, NSR will be calculated and presented without the SVL variable. The SDR will be varied quite a lot, to account the uncertainty brought on by the method. WTP will not be used except in the impact area where no better alternative could be found. Bias in the analysis itself is harder to counteract. The strategy employed here has been to clearly present all equations and data, as well as state and explain all methodical choices taken. Generally speaking, throughout the construction of the model, efforts will be made to keep estimation of benefits sensible.

3.1.2 Theory of Pareto-efficiency

When discussing welfare economics and Cost-benefit analysis, one has to approach the subject of Pareto efficiency which is fundamental. The general theorem of Pareto efficiency is *“An allocation of goods is Pareto efficient if no alternative can make at least one person better off without making anyone else worse off”* (Boardman *et al*, 2011). On this basis welfare economics and cost-benefit analysis has its foundations. If two agents on a market are sharing a single resource and from their points of consumption, there can be improvements made, this position is known as a *status quo*. The potential *Pareto Improvement* for one of the agents is when the agent is consuming the resource over the status quo point, without affecting the other agent´s consumption. The market share that can be consumed without the other agent being worse off is known as *Pareto Frontier.*

Basic fundamentals of CBA analysis regarding any project is the net social benefits, which always need to be positive for a project to be Pareto efficient. That is benefits outweigh the costs for a project for any market agent. To understand this, it's needed to understand how a agent values any project initialised on the market. The fundamentals of this study are the *Opportunity Costs,* which is what the input spent for a given project could, otherwise be used for. By definition *“The Opportunity Costs of using an input implement a project is its value of best alternative use”*, and if the alternative use would generate a higher net benefit, the project would be rejected.

However, using the theory of Pareto efficiency for decision making is difficult. Pareto efficiency always strives towards an optimal resource allocation, which is that after everyone has been compensated, everyone wins on a given project. Using Pareto efficiency can be difficult when providing a Cost-benefit analysis, since it has to take the four factors into account. First, any researcher needs to aggregate costs and benefits for all agents on the market, as well as regarding individual costs and benefits for each agent. Secondly, even if this gathering of information was achieved, the administrative costs to make transfers for each government project could be high. Third, it would be hard to operate a system for the compensation payments for a project, which did not distort the behaviours of individual agents. And fourth, that everyone would be fully compensated would make agents overestimate costs and underestimate benefits for any given project.

Instead of Pareto efficiency, Cost-Benefit Analysis rely on *Potential Pareto efficiency*, which states that anyone who gains on a projects implementation has to compensate those who would lose on it, and still acquire a positive net benefit. In practice, the question of implementing a project is whether there are sufficient net benefits for those who gains on the project, to fully compensate those who would lose on its implementation. This is known as *Potential Pareto Improvements.* The potential Pareto efficiency is based on the net benefits criterion; *"adopt only projects that have positive net benefits"*. There are four statements in favour of potential Pareto efficiency; First, in theory it says that choosing projects with positive net benefits, society will maximize aggregate wealth. And in richer societies, there is a capability to help their poorest members, and if redistribution of wealth is a normal good that everyone aspires, the richest members of a society will have a higher willingness to help. Second, depending on the different type of project implemented, it will hold a different set of benefits and costs on individuals of a society, which makes evaluating more complex for larger projects. But it is likely that the effects of all projects will average out over all individuals, and that everyone will realize positive net benefits from all projects. Third, potential Pareto efficiency weighs in benefits and costs for all individuals in the society that's being studied, and does not hold any bias against any groups. Therefore it is likely that adopting Pareto-inefficient projects will be reduced. Fourth; if equal income or wealth is a goal of society, there are potential to address the goal through transfers, after all efficiency-enhancing projects have been implemented.

2.2 Methods used within the Cost benefit analysis

This section is devoted to the different methods of valuation that has been used within the thesis. It`s necessary to describe the logic behind these methods early on since these have played a major part in building of the model, in order to get appropriate results.

2.2.1 The social discount rate

When a project is expected to generate cost and or benefits over a longer period of time, analysts adhere to the rule that financial post further into the future are worth less than a similar post today. The main reason for this is the fact that investors always have the option to invest their resources somewhere else and accumulate a larger amount, over time. When investing now, they face an alternative cost generated from interest. Benefits and cost are therefore discounted into net present value (NPV) by assigning weights;

$$NPV = \sum_{t=0}^{T} w_t D \qquad (1)$$

Where W_t is the corresponding weight denoting the time-period between 0 and T in years.

$$w_t = \frac{1}{(1+i)^t} \qquad (2)$$

The right hand term in *equation 1* consist of the assigned weight w_t (depending on the time-period t and the discount rate) and the term D which denotes a recurring financial post in the project. A longer project lifetime means that further importance is placed on the selection of the social discount rate (SDR).

Several considerations can be made in regards to the choice of SDR. The simplest way to describe SDR is an approximation of the value-incrassation stakeholders would require to wait for a future benefit. The simplest approximation would be to equal the SDR with the average rate for private savings accessible to the public. People have very different preferences, and even though many are comfortable saving at a low rate, many of those borrow funds at the same time, at a higher rate. It can easily be argued that return on private savings does not represent the true value of future benefits or costs. Other options should be considered. The first alternative is to consider for an uncertain future by adding a premium for risk on discount rate. Boardman *et al* (2011) recommends that those considerations should be accounted for in the sensitivity analysis instead. Another common method used is to utilize the marginal return on private investment as an approximation of SDR. The argument for this, as presented by Harbenger (1969), is that before a government takes funds out of private ownership, it should at least demonstrate an ability to produce greater or equal to returns that the funds otherwise would have. This method is not unchallenged. As pointed out Arrow & Lind (1997), most private sector loans include a small risk-premium, which wouldn't apply to a government. SDR could also be derived from the borrowing rate of long-term government bonds (adjusted for inflation), thereby using the closest approximation of the actual cost of the projects, assuming it's government-implemented. There exist alternatives, as opposed to derive the SDR from financial markets. Analysts can use the shadow-price of capital, i.e. the consumption equivalents of capital. Many researchers advocate their own SDR, derived in many different ways but usually from economic growth observed over longer periods.

In the model outlined in the following chapter, the discount-rate has been set at 3,5 % in accordance with recommendations outlined for projects of intra-generational lifetimes (Boardman *et al*, 2011). Further description of how the SDR will be used, is further described in the beginning of *chapter 3, Empirical model*. The inherent insecurity of selecting a specific discount rate will be addressed in *chapter 5.3 Sensitivity analysis*.

2.2.2 Statistical value of life

When evaluating the social benefits of providing clean drinking water, you cannot overlook what intuitively too many people would be the largest possible benefits of all the categories, namely the lives saved. In India, the under-five mortality rate has been steadily declining, but the national average remain above 60 deaths per 1000 births, with some regions showing numbers above 100 deaths (NFHS-3, 2005). Needless to say, while the development may be seen as cause for optimism, the fact remains that one in 16 children born in India does not live to reach his or hers fifth birthday. WHO (2010) estimates that between 13 and 18% of these deaths are caused by diarrhea, and that above 90% of all deaths due to diarrhea happen before the age of five. Since the disease is almost exclusively spread by contaminated water, it's certainly justifiable to include decreased under-five mortality as an impact area in any analysis evaluating the benefits of clean drinking water.

The statistical value of life is a term used by economists and analysts as an approximation of the value of a human life (Mankiv, 2012). The most common method of approximation is the aggregated marginal value of a small increase in risk by occupation, in other words the amount a worker require as a wage-increase for a small increase in risk. SVL is still a widely debated analytical tool, in no small part due to the ethical considerations. A country with lower wages would generally mean a lower SVL, which in turn means that developing countries have lower SVL than developed ones. One interpretation of this would be that developed countries are willing to pay substantially more to avoid deaths than developing countries. If this mindset is transferred to global considerations, it would effectively mean that a life in the OECD-countries are worth more than a life elsewhere, something that can be argued against ethically.

Due to lack of data, SVL estimations are far more uncommon in developing countries than in the OECD region (Madheswaran, 2006). According to the Madheswaran, this is attributed to the lack of consistent data in the occupational field.

2.2.3 Purchasing Power Parity

Purchasing Power Parity (PPP) is a currency conversion rate that both converts currencies to a common currency and equalize the purchasing power of currencies in different countries. They means of the method is to eliminate the differences in price levels between countries in the process of conversion (OECD, 2012). The standard currency is often US dollars, and therefore used in this study, and the PPP-conversion is used to properly reflect the value of benefits between a two countries.

2.4 Alternative methods

For this thesis, two methods were considered. First, it was considered using the method of water pricing given that the study would address the problem of economic value of water. How to value water could also be done by the contingent valuation study, in this brief chapter both methods will be discussed and be given a reason to why they were excluded.

2.4.1 Water pricing

It is clearly pointed out that even if water is not often treated as an economic good, it has been viewed more and more as an economic good. However, it would be necessary for all sources of water to be integrated into the pricing mechanism, where all effects are considered (Rogers *et al*, 1998). The basic principles of water pricing are that value of water and the cost of water should balance out.

The value of water is represented by the economic value of water plus intrinsic values. Economic values could be summarized as the value for the user but also the values for secondary users of the same water source. Intrinsic values in this case represent externalities such as house pricing would be affected by a change of quality in water supply.

The opposite costs works similarly, with the full cost of water being the economic cost and economic externalities for secondary users, and also mentions the environmental externalities. This could be used as for analyzing river basins as well as underground aquifers. However, this study given the literature review and the conclusion is that health-diseases are the major externality. This externality could easier be analyzed by contingent valuation methods.

2.4.2 Willingness to pay

Contingent valuation studies are the most common when examining economic value on non-market goods. Willingness to pay (WTP) is a valuation method used to get benefits from non-market goods expressed in monetary terms, or market goods with its externalities valued (Boardman *et al*, 2011). The usual way of eliciting the monetary value is through a survey, or interviews. It is a commonly used method to price an environmental good, or gauge a price from a distorted market. Since these characteristics (distorted market, presence of externalities) have been identified in India, a WTP study with the aim of evaluating the benefits from clean drinking water could certainly be justified.

As seen in the literature review, such studies have indeed been undertaken by previous researchers. However, due to the combination of low market prices and a close connection between income and WTP for clean water, utilizing willingness to pay analysis to merit investment into water purification becomes problematic. The risk becomes apparent that areas where the net social revenue (NSR) would be highest from providing clean drinking water, the WTP would also be the lowest and therefore merit the same investments in some other region. In order to ascertain a more sensitive WTP without necessarily a close connection to income levels, or such a broad interval (high value being almost 500 times the low value), the population would probably need to be educated or informed to a higher degree. However, any researcher attempting to inform the participants in the survey will face the risk of directing the respondents towards a specific decision.

With the factors discussed above in mind, it has been decided that measuring alternative costs is a viable approach for this study, given that it will present a more fact-based result based on statistics and previous research. However, specific results of the Roy *et al* study will be used as plugin values to identify the benefits of decreased arsenic poisoning for this study.

3. Empirical model

In order to understand how this study utilizes the Cost-benefit Analysis, this chapter will describe how the study is performed. The model that has been constructed in Microsoft Excel will be explained in order to understand the results and discussion that will follow this chapter, and what statistics and plug-in values has been used. It is necessary to point out that this model has been created for the purpose of being easily adaptable to any given region given availability of statistics and datasets.

To evaluate the potential for the technologies Airwaterwell, Solvatten and a representative Heat-pump, a cost benefit analysis (CBA) was chosen. A CBA study allows for an evaluation of the monetary value associated with the benefits from having access to a Point-of-use water treatment unit (POUWT). The aim is to calculate a consumer surplus, known as the net social revenue (NSR) by subtracting socio-economic costs from socio-economic benefits (*equation 2)*. CBA was the method elected to perform the task with the reasoning outlined in the previous sections.

$$NSR = \sum_{t=0}^{T=20} w_t B_t - C_0 \qquad (3)$$

Net social revenue equals benefits minus costs, over the lifetime of the projects.

Where;
T= Number of years for the expected lifetime of the projects.
B = Benefits each year from the projects.
C_0 = Costs from installing POUWT-units at time-period 0.
w_t = discounting weight for each time-period

The CBA-analysis will be performed after the nine basic steps, outlined in the method section. When benefits have been summarized, this information can also be used to calculate a value for water and Return on Investment (calculated by dividing Net Present Value of Benefits by total costs).

Since the costs for the project alternatives consists of the installation costs and purchase prizes, with no running costs, the cost of the technological alternatives are therefore not discounted since they are made at time-period zero. The exception is the Solvatten SODIS bottle, which requires re-investment during the time-frame set for this study, this will be described further in chapter 3.1.2. The discounting is then only applied towards the periodic benefits and the statistical value of life (see *equation 11*). These are discounted by applying weights, as described as seen in *equation 3*.

Benefits are discounted over the life-span of the project which is set to 20 years, given that two of the three project alternatives have an operating time of 20 years. Since none of the alternatives by definition are considered inter-generational, it is not necessary to consider a diminishing discount-rate, or take other measures to account for appropriate weight on future generations.

Given an installation of a project alternative with running costs, the cost-structure of *equation 3* would simply be altered to add yearly running costs in similar fashion as the benefit-structure is constructed.

3.1 Project alternatives

For further understanding of the project alternatives, this section will provide a brief explanation of the alternatives as well as their technological fields. Given the aim to alleviate poverty and foster economic development, the objective is to provide hypothetical rural Indian households with clean drinking water. The first alternative here, in accordance with the standardized method is to abide the status quo, in other words do nothing in this village and invest the resources for poverty alleviation somewhere else. Second to fourth alternative all consist of supplying the rural household with either of three technologies, all of which provide the clean drinking water.

The number of units needed for each project should also be clarified. The Atmospherical Water Generator projects (Airwaterwell and the representative Heat-pump, E-oxy-3) are determined by the need to supply all individuals in the Household with the required minimum amount of drinking water. The size of the Solar disinfection alternative (Solvatten technology) is dependent on purifying the entire household supply of water, to achieve a higher reduction of diseases. The technological properties of the project alternatives are further elaborated in the next section.

The aim of the analysis itself is to compare Airwaterwell with other recent innovations in the field of water purifying and production. For limitations, the selected technologies are all Point-of-Use systems, allowing for quick delivery and utilization. POU-water treatment systems are also independent of infrastructure and geographical conditions.

Table 3.1: List of alternatives for the Cost-Benefit Analysis

Alternatives	Technology
Status Quo (counterfactual)	None
Airwaterwell	Air-water Generator (AWG)
Solvatten	Solar disinfection (SODIS)
Heatpump	Air-water Generator (AWG)

For Status Quo, the counterfactual, benefits and costs are both assumed to be zero. No investments are made, and subsequently no gains are made. With this assumption, a positive result for return of investment for any project alternative becomes a "passing grade", which means it should at the very least be considered for investment.

3.1.1 Atmospherical water generators

An atmospherical water generator is a device that extracts humidity from air and transforms it into water which can be condensed for drinking purposes (Wahlgren, 2000). The size and production capacities vary amongst the machines, but they are divided into three classes. They either work by cooling a surface below the point of dew-formation, or focus vapour through a desiccant of solid or liquid kind, or induce convection in a solid structure.
AWG units are aimed at small scale, household solutions for water-scarce areas, or areas where water is polluted. The process gathers only water molecules, which makes the end product distilled water. To produce one liter of water, on average two kWh of energy is required. Clean water such as this removes any concerns of pollutants and pathogens remaining, although there are other smaller concerns before the product is ready for consumption, such a maintaining a proper salt-balance when consuming distilled water.

The Airwaterwell

Airwaterwell, at the time this analysis is performed, is an AWG-technology at the prototype stage. It is expected to produce three liters of water per day, with a surface requirement of one square meter (pers. mess. Fredrik Edström, 2011). It utilizes a small amount of solar-generated electricity to operate a light fan, forcing humid air through contained desiccants. The main body of the AWW-unit is solar panels for generating heat, which drives the captured moisture out from the desiccant, producing distilled water ready for consumption. AWW is then tapped by the consumer once or twice per day. Considering the relative simplicity of the construction, AWW is expected to have a long lifetime with very little service or replacement of parts required.

AWW will utilize the Solarus Thermal system, CPC-T-1500W, which at 100 degrees Celsius will operate at a 22% efficiency (Solarus, 2012). With an average solar radiation of 7kWh per day in India, AWW would be able to produce 3,08 liters of water per day and m^2. A single AWW-unit is estimated to have a lifespan of 20 years ($T = 20$).

The Electrolux oxy-3

Electrolux oxy-3 is a heatpump that could be utilized as an AWG with little modification (Electrolux, 2012).In this analysis, it is seen as a representative AWG-unit, based on an existing Heat-pump. It could run either on solar generated electricity, or on an external power source. E-oxy-3 would operate with a efficiency between 13,2 and 16,7%, utilizing the Solarus PV system, which would yield an average production of 2,1 liter per day and m^2 (Solarus, 2012). The Electrolux Oxy-3 with the Solarus PV system is estimated to function for 20 years, similar to the AWW. This heath-pump could also run with a simple electrical socket as an external power source with production-capacities at significantly higher rates, but this option has been ruled out.

The utilizing of the electrical power grid for the Electrolux Oxy-3 is because in rural areas the Indian electrical grid is quite unreliable, with only 54 percent of rural India having any electricity supply as of 2010 (Sargyan *et al*, 2010). But most decisive for ruling out using the electrical socket is the running costs being introduced. At a national price of 6,38 INR/kWh, producing one liter of clean drinking would yield running cost of 0,064$ per produced liter (World Energy Outlook, 2007). Since this is unlikely to be cost-effective within the foreseeable future, this alternative has been excluded from the analysis.

In other words, AWW and E-Oxy-3 are Point-of-use water generators which produce completely clean drinking water in addition to the normal household supply. Other methods such as boiling or filtering may be used at the rest of the water required for preparing food, hygiene measures and other assorted household needs, but this has not been included in the analysis.

3.1.2 Solar water disinfection

Solar water disinfection, also called SODIS, is the combined method of heat and ultra-violet radiation applied on water (www, SODIS, 2012). The method can be performed with as little equipment as a PET-bottle and a surface area of metal subjected to sunlight, making it an ideal technology to implement in many developing countries (eawag, 2011). UV-radiation has been shown to negatively affect both a pathogens ability to perform cellular respiration and its ability to generate ATP for reproduction (Bosshard *et al,* 2010). This effect was substantial in testing, even after one hour of being subjected to sunlight. Even if pathogens remain in the water, with the ability to reproduce diminished, their adverse effects on humans are lessened. The Swiss Federal Institute of Aquatic Sciences and Technology (2011) has produced and distributed brochures on the SODIS method, available in multiple languages. Following their guidelines, a user can safely produce clean drinking water with relative ease by avoiding some common pitfalls (high turbidity, wrong material in the bottle etc).

Solvatten

The Swedish company Solvatten AB has launched its own portable unit, fitted with a measuring stick that indicates the level of microbes in the water at any given time (Solvatten, 2011). For the analysis, this product has been chosen to represent the SODIS technology, since the microbe-measuring stick makes it safe to utilize, without the risk of mistakes in regards to the degree of purification of the water.
The patented Solvatten bottle is a 10 liter unit, with an operating time between two and six hours for each use. Water would be gathered in other containers, brought home and poured into the Solvatten units. Because of the relatively high difference in time-requirement, it is not possible to estimate exactly how many units of Solvatten-bottles will be necessary for each household. This will be addressed in the sensitivity report. Solvatten has a lifespan of at least five years, by managerial account, making T = 5 in that case. Since this study This means that Solvatten is evaluated with benefits under a period of 20 years, with re-investment done at years 5, 10 and 15.

$$NSR_{SV} = \sum_{t=0}^{20} w_t B_t - C_0 - w_5 C_5 - w_{10} C_{10} - w_{15} C_{15} \qquad (4)$$

The Net Social Revenue for Solvatten given the requirement of re-investment each 5th year

In summary, the Solvatten alternative is a POUWT-unit that disinfects the entire household supply, but do not increase it. In these respects, it's a different measure than the AWG alternatives.

3.2 Standing

Determining the groups with standing in this analysis is straightforward. An organization of inexplicit origin is supplying the POUWT-units to the households. Since the technologies evaluated are limited in size and will not produce any waste, motivates the limitation of groups with standing. While costs are carried solely by the supplying organization, benefits are generated both directly by the households and indirectly in form of societal benefits. No difference is made between these categories, save in the discussion section where this decision is evaluated.

In this model, the financers are thought to be an OECD aid organization, but by adjusting the purchasing power parity factor on the benefits, the origin and type of this organization can be easily changed. This issue will also be further addressed in the sensitivity analysis in chapter five.

3.3 Impact Areas

From the literature review, the impact areas have been identified as follows;

Table 3.2: Primary impact areas for this analysis.

Area of impact	Costs	Benefits
Financing of project	X	
Decreased time spent fetching water		X
Decreased sick-leave, adults		X
Decreased sick-leave, children		X
Decreased under-five mortality		X
Decreased arsenic poisoning		X

In order to parameterize the impact areas, equations are defined for all of them. If not stated otherwise, the equations hold for all the technological alternatives. The costs for all the project alternatives can be summarized by purchasing costs of the POUWT-units

$$C_0 = nC_p \quad (5)$$

C_p = Price per unit of POU water treatment units.
n = Number of POUWT-units installed per household.

From this, costs are summarized for the first period as C_0 (*equation 5*). For all the following periods, only the running costs multiplied by the number of POUWT-units are added. As previously mentioned, the Solvatten project alternative has to be re-invested in each 5th year during the projects life-span of 20 years.

Total benefits from the first period are summarized in *equation 6*. B_a denotes benefits derived from decreased sick-leave from adults, B_c benefits from decreased sick-leave for children and B_l benefits from decreased logistic burden of gathering water. B_d signifies benefits from lives saved with access to clean drinking water and B_g benefits from decreased exposure to groundwater pollutants. The total number of POUWT-units designated to provide adults with drinking-water are referred to by n_a, POUWT-units intended for children designated by n_c. All benefits are calculated per POUWT-unit and year.

$$B = n_aB_a + n_c(B_c + B_d) + n(B_l + B_g) \quad (6)$$

Benefits from project alternatives first period, 2011 US$

Where;
$n = n_a + n_c$

3.4 Costs and currency considerations

In this step, the considerations and calculations with regards to costs and currency are explained.

The first step is to quantify the costs for the organization supplying the POUWT-units, which is relatively straightforward. An initial cost such as installation cost, education of the consumers such as brochures etc. have not been included in the analysis. Estimating this would at best carry a very large uncertainty. Costs for the projects are then composed of purchasing price times the required number of units. The number of POUWT-units is determined by the basic household need in terms of drinking water (relevant for the AWG-alternatives) and the household supply of water (used for Solvatten). Since running costs such as maintenance and replacement of spare parts is as an uncertain estimation as installation costs, it has also been excluded from the analysis. The representative Heat-pump, E-Oxy-3, has the option of being powered by electricity taken from an external power source as well, such as an electrical socket. As an option, this has been excluded from the analysis given the reasons described in the project alternatives section 3.1.1.

Since many of the datasets, reports and articles upon which this analysis is based upon were authored in different years, benefits need to be re-calculated to a common year and currency. The US dollars has been adopted as the currency since it`s generally a accepted international currency, and it coincides with the currency choice in similar works done by previous authors. 2011 was chosen as the base-year, given that it`s the year when this project was started. When converting income, the values are converted to US$ with the average exchange rate of the concerned year, taken from XE services website, 2011 (xe, 2011). These incomes are then calculated towards 2011's value adjusting for GDP growth, adjusted for inflation (IMF, 2011). The assumption here is that wages will have grown at the same pace as GDP in India.

Since the scenario evaluated is that of foreign aid, i.e. a donor organization from an OECD country supplying Indian households with POUWT-units, a PPP-index of conversion for the year 2011 has been used (tradingeconomics, 2012).

3.5 Benefits of project implementation

This section will take us through the various components that form the benefits as seen in *equation 5*. Before moving further into the model, explaining the various components of the benefits. Following through almost each benefit-section in the model is the l_w variable, standing for the quota of total production for an AWG unit per day. This variable, when analyzing the SODIS method will be replaced with number of Solvatten-units needed to fulfill a adult persons daily needs.

3.5.1 Benefits from time saved collecting water

Research has indicated that in rural India, it is generally the women's lot to carry water (ref needed). Benefits are thereby quantified by analyzing how much time is saved when providing a household with AWG-units, given the spatial availability. Benefits are then derived as time saved, per POUWT-unit and year. To monetize this benefit, opportunity cost such as the average wage for a female worker (which could be earned during these hours) is used. To summarize benefits from time saved (*equation 7*), the following variables are used;

y = Time spent per day gathering water, hours
w_h = Hourly wage for a rural female worker in Indian region, 2011 US$.
l_w = Production capacity of one AWG-unit, liters.
l_{tot} = Total quantity of water carried per day and person.
σ = Number of days fetching water, per year.

The hours spent fetching are multiplied by the hourly wage. The (l_w/l_{tot}) quota allows for calculation of how much time a single AWG-unit saves. Since fetching water is assumed to be a year-round chore, it needs to be multiplied by the number of days this duty is performed. Benefits from time saved are only derived from the AWG-technologies, which increase the household supply, and will not be calculated for the Solvatten (SODIS) technology.

$$B_l = y\, w_h\, \sigma \left(\frac{l_w}{l_{tot}}\right) \qquad (7)$$

Benefits from decreased time spent gathering water, 2011 US$ per POUWT-unit & year.

3.5.2 Health-related benefits

To properly present the health-related benefits, a brief outline of the health-concerns used in this analysis is included. Three of the four impact areas of health-related benefits are due to reduction of diarrheal cases.

Diarrhea

Diarrhea as a disease is defined by the WHO (2012) as the passing of three loose or liquid stools per day. While the disease is both treatable and preventable, it remains the second largest cause of death for children worldwide. The cause of death is not the disease itself, but rather the dehydrating effect that can leave an individual without the water and salt it needs for survival. Worldwide, diarrhea is most commonly caused by superficially contaminated food and water. It is caused by large groups of parasitical organisms, bacteria or viral infections. The bacteria Escherichia coli and Rotavirus are the most common causes. Diarrhea itself is usually divided into three classes, acute watery diarrhea (Includes cholera), acute bloody diarrhea (otherwise known as Dysentery) and persistent diarrhea (lasts longer than two weeks. Preventable measures include clean drinking-water and hygiene measures, after the fact treatment includes rehydration and Zinc-supplements.

In India, diarrhea alone causes the loss of 73 million workdays and the death of 1,5 million children annually (Wateraid, 2008). Both studies by Hutton *et al* (2004 & 2007) and Clasen *et al* (2007) use diarrhea as the only waterborne disease for their valuation of benefits, in part because of the good empirical basis, but also in order to provide a safe, low estimate of the actual benefits. In accordance with the previous researchers, this model has been constructed with diarrhea as the only waterborne disease for which a water-project will yield a reduction in occurring cases. The following benefits sections is therefore based upon the reduction of diarrhea cases. Apart from water related diseases, another aspect when analyzing drinking water is eventual groundwater pollution by heavy metal, for example Arsenic which will be mentioned further later in this chapter.

Benefits from decreased sick-leave, adults

Benefits from decreased sick-leave are calculated by estimating the number of sick-days per inhabitant amongst the population caused by unsanitary drinking-water. The benefits are estimated by the opportunity cost, the wage that could have been earned during those days. Benefits from decreased sick-leave for adults, B_a, is calculated (*equation 8*) by using the following variables;

S_a = Number of sick-days per year, adult.
l_a = Amount of water required per day and adult, liters.
w_d = Daily wage, combined male and female average, 2011 US$.
e_a = Average health-care expenditure per sick-day, 2011 US$.
d_a = Degree to which clean drinking water would decrease diarrhea for an adult, as estimated in the case-study performed by Quick *et al* (2000).

Benefits from decreased sick-leave for adults, per POUWT-unit and year can then be monetized as;

$$B_a = d_a S_a \left(\frac{l_w}{l_a}\right)(w_d + e_a) \qquad (8)$$

Benefits from decreased sick-leave for adults, 2011 US$ per POUWT-unit and year.

For all the health-related benefits, the decreasing factors d_a and d_c are used. Those are taken from field-studies, for AWW and Heat-pump they are derived from studies which have evaluated point-of-use disinfection of drinking water. For Solvatten, this analysis relies on field-studies testing the SODIS method. The proportion with which diarrhea can be expected to decrease are multiplied with the number of sick days, which again is multiplied by the daily wage (combined male-female average) plus health-expenditure. This is in turn multiplied by the quota from AWW or Heat-pump production, divided by the minimum drinking-water requirement for an adult. To calculate B_a for Solvatten, this l_w/l_a quota is replaced with the number of units assigned to fulfill the needs of an adult

Benefits from decreased sick-leave, children

To estimate the benefits from decreased sick-leave for children, the percentage of school-children suffering diarrhea is used. Based on this, the average number of sick-days per child and year are calculated. In order to monetize benefits from decreased sick-leave for children (*equation 9*), the assumption is that the expenditure per student and day is wasted when a child sick. The same expenditure becomes a benefit when a project-alternative allows the child to attend school instead.

To monetize this impact area, the following variables are used;

l_c = Amount of water required per day and child, liters.
s_C = Sick-days per year & child.
e_C = Average spending per day & student public and private, 2011 US$.
d_C = Degree to which clean drinking water would decrease diarrhea for a child, as estimated in the case-study performed by Quick et al (2000).
$\boldsymbol{\partial}$ = Proportion of a workday spent on a sick child, by primary care-giver

For calculating B_c, Hutton *et al* (2004) estimation is utilized, it means that each sick-day for a child results in half a workday lost by the primary care-giver. Otherwise the calculations are the same as *Equation 8*, with decreasing factor for a child and a child's minimum requirement of drinking water. Benefits from the decreased sick-leave for children, per POUWT-unit and year can be summarized as;

$$B_c = d_c S_c \left(\frac{l_w}{l_c}\right)(\partial w_d + e_c) \qquad (9)$$

Benefits from decreased sick-leave for children, US$ 2011 per POUWT-unit and year

Benefits from decreased under-five mortality

This benefit (B_d) rate is based on decreased risk of death and the statistical value of life. For this analysis, the focus has been placed on under five-mortality since the majority of deaths due to water-related illnesses occurs before the age of five. B_d is calculated (*equation 10*) using the following additional variables;

δ = Proportion of children in the under-five age group
p_d = Risk of dying before the age of 5.
v_l = Statistical value of a child's life, 2011 US$.
d_d = Percentage of deaths due to diarrhea.
z = Four years (the amount of years a child need clean drinking water before reaching the age of five)

Benefits from this impact area are based on risk of dying before the age of five, and the proportion of this caused by diarrhea as well as relevant disease reduction rate and the value of a child's life. In order to calculate the benefits per POUWT-unit and year, the value of a child's life need to be multiplied by δ (proportion of children in the under-five age group) and further divided by z (the number of years a child needs drinking water before the age of five). By doing this, benefits from a child surviving to the age of five are designated down to a single year, in line with the benefits from other impact areas. Further, the l_w/l_c quota assigns the benefits to a single POUWT-unit. The variable z is chosen as four years rather than the more intuitive amount of five years. This rests on the fact that a newborn child requires very little drinking water during its first year, and should instead rely on breast-milk until 6-12 months of age (babycenter, 2012). In a study conducted in India, it has also been confirmed that mothers who chose to breastfeed during almost the entire infant period, reduced infant morbidity (Rao *et al,* 1992).

$$B_d = \frac{\delta d_c p_d d_d v_l \left(\frac{l_w}{l_c}\right)}{z} \qquad (10)$$

Benefits from decreased unde- five mortality, US$ 2011 per POUWT-unit and year

Statistical value of life for a child in India is calculated based is based on the statistical value of life. In the interest of providing a safe estimate for benefits, for this analysis a cost for the years before adulthood is subtracted from the SVL.

$$v_l = \frac{1}{(1+r)^{13}} \sum_{1}^{45} SVL - a_r^{13} \rho \frac{i_h}{\varphi} \qquad (11)$$

Value of a child's life.

Where;
SVL = Statistical value of life, India
r = Social Discount rate.
ρ = Proportion of household income devoted to raising children.
I_h = Household income.
φ = Regional fertility levels (determines household size).

The SVL equation depends on that child survives past the critical age of five where the risk of child mortality is most significant. In order to provide a low, sensible estimate for the value of a child's life, the SVL has been discounted as a periodic income starting 13 years into the future when the child reaches adulthood at age 18, and ending by the expected lifetime of an Indian citizen, which is 63 years of age, hence the summation of 45. In addition to this, a cost has been assigned to raise a child to this point. For the base-line analysis, this has been chosen as a proportion (75%) of the total household income divided by the number of children in the household. This assumes that the household spends a fixed amount of resources on its children, something that will be addressed in the sensitivity-analysis.

Benefits from decreased arsenic poisoning

Arsenic contamination of groundwater is caused by naturally occurring mineralic arsenic (Smedley & Kinniburgh, 2002). It is most commonly transmitted to humans through the implementation of deep tube wells. At present time, arsenic poisoning has been detected in several countries spanning four different continents. The groundwater contaminations of arsenic threatening the largest populations are those in Bangladesh and West Bengal, India (J. Roy, 2008).

Arsenic is a shiny metalloid that dissolves in water and is impossible to detect without the aid of chemical indicators (J. Roy, 2008). When contaminated water is consumed, arsenic poisoning has been linked to numerous health-conditions, such as skin, bladder and cardiovascular cancer. There are also instances of birth defects and degenerative effects on the reproductive systems.

Several studies have analyzed the occurrence and health effects of arsenic contamination in multiple South-Asians regions, meaning there is ample datasets for economic analysis. One such study estimated the Willingness to Pay for arsenic-free water in Bangladesh (2003). The household WTP in that region, for arsenic free water, was estimated as 0,3 percent of the household income, drawn from a survey of the population. The author comments that this is a rather low estimate, which is attributed to limited awareness of the effects of arsenic contamination, and the long incubation period of the illnesses.

For this study, benefits from decreased arsenic poisoning are calculated from a willingness to pay study performed in West Bengal, India, which evaluates the social benefits of decreasing Arsenic levels under 50 µg/liter (Roy, J., 2008). It should be noted that the labeling choice made by J. Roy may be somewhat misleading, since his study is based on evaluating health-statistics as well. However designated, the WTP value in this study is estimated between 0,59-1,04 INR per month, household and ug reduced above 50 ug/liter. To calculate benefits from decreased arsenic poisoning, the following variables are used.

WTP_a = Willingness to pay per decreased µg Arsenic and liter drinking water, per year and household.
a_r = Rate of arsenic contamination above 50 µg/liter.
n = Number of AWG units per household.

$$B_g = \frac{(WTP_a a_r)}{n} \qquad (12)$$

Benefits from decreased arsenic poisoning, US$ 2011 per AWG-unit and year

This category of benefits are only assigned to the AWG methods of producing water, the Solvatten-units do not purify water of arsenic. There are ways to treat drinking-water contaminated with arsenic, but this analysis is limited to three specified alternatives. This category of benefits is also specific in terms of region, since only a few states in India have groundwater contaminated by arsenic.

Summarizing cost and benefits for each technology
In the beginning of this chapter, each impact-area was summarized and categorized into specific costs and benefits *(table 3.1)*. Too easier comprehend how each project alternative affects this analysis the following table is being presented.

Table 3.3 Index of impact areas for both types of technologies

	SODIS technology	AWG-technology
Costs		
Installation costs	X	X
Running costs		
Re-investment costs	X	
Benefits		
Decreased time spent fetching water		X
Decreased sick-leave, adults	X	X
Decreased sick-leave, children	X	X
Decreased under-five mortality	X	X
Decreased arsenic poisoning		X

In table 3.3 each technology group has been categorized to each benefit tested in the study. This will be elaborated on further in the upcoming chapters. The including of running cost in the table is to affirm that if other technologies that includes these costs should be used in a future study with similar delimitations, this model should suffice with an extension of the cost structure of the model.

4. Empirics

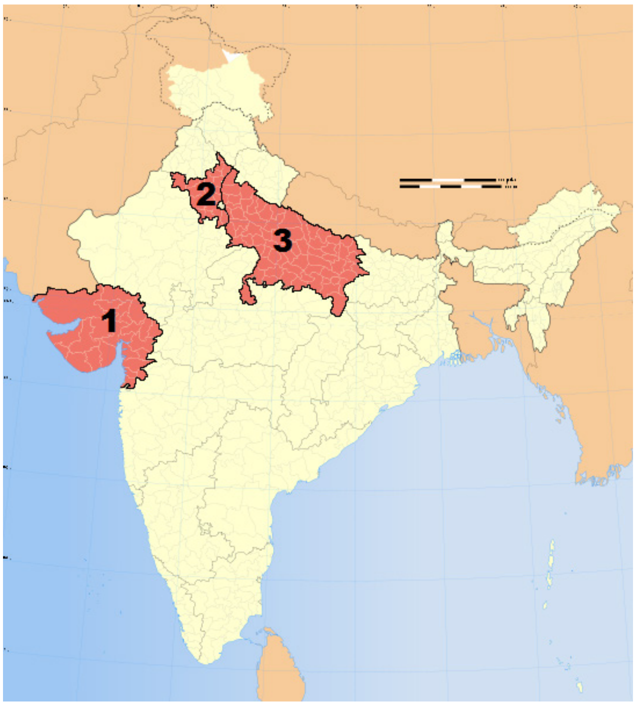
This chapter of the thesis is initiated by the regional statistics which the state-selection was based on. A short presentation of the selected states Gujarat, Haryana and Uttar Pradesh follows. The second part of the empirical section is devoted to the statistics, region-specific and national, that are used for the analysis itself.

4.1 Selection of study regions

Given the availability of empirical data, three different regions in India were elected to perform the analysis on. To test the robustness of the model, we strived for a disparity regards to income, poverty, and health status. In order to more easily comprehend the study, the project alternatives have been applied to the average rural household in each state. Dispersing the effects over three study region gives the study a more objective standpoint, and provides a good perspective of what project alternative works in different type of circumstances.

Table 4.1: Statistics from the selected Indian states

Region	Household income, US$ 2011	Poverty rate	Arsenic contamination
Gujarat	931	13,1%	No
Haryana	1550	11,3%	No
Uttar Pradesh	745	33,2%	Yes



Picture 5.1: Study-regions (wikipedia.org, 2012)

Region 1: Gujarat

Gujarat is thought to represent an average province, and it's the ninth richest state of India. It has a poverty rate of 13 percent, which is the 15th lowest amongst the Indian states. The under-five mortality rate is 52 per thousand births, which is then ninth lowest in India. Gujarat is not one of the states suffering from heavy metal ground-water pollution, which means that no benefits from this have to be taken into account for the CBA. Gujarat has a population of 50 million people.

Region 2: Haryana

Haryana is one of the wealthier provinces per capita in India, located in the northern part of the country. For average income, it places at fourth place of all the Indian states. It still has a relatively high under-five mortality rate at 39 per 1000 births, ranked as the fourth lowest. Haryana's groundwater is polluted to some degree by arsenic, but not enough to make avoidance of this a beneficial post in the CBA as of today. Haryana has a population of 21 million inhabitants.

Region 3: Uttar Pradesh

Uttar Pradesh is one of the poorer states in India, with a poverty percentage of 33,2 and an income-rank as the fifth lowest amongst all Indian states. In Uttar Pradesh, the under-five mortality rate is estimated at 116 deaths per 1000 births, by far the highest in the country. Groundwater pollution by arsenic is prevalent enough in this region. The population in Uttar Pradesh is estimated at 200 million people at the latest census.

4.2 Empirical data

Empirical data was gathered from a wide variety of sources, since no single, suitable dataset was found which matched the criteria's for the model. The Indian survey, NFHS-3, implemented in 2005 and presented in 2006, serves as the base for this analysis. This study focuses on economic, social and health-statuses of households in all regions of India, and was performed by the Ministry of health and family welfare. All aspects are surveyed for two categories of people, those who live in rural areas and those who live in urban areas. It is the third in a series of survey, with the fourth underway as this paper is being written. Over 3000 households participated in this study. NFHS-3 however, does not detail income as monetary value, but rather chooses to utilize a five grade health index, which takes in to account housing, possessions and access to transportation.

Income-details are obtained from the Human developmental index, a study performed by Oxford University in 2004 and 2005, published in 2010. It lists many of the same categories as the NFHS-3 study, allowing for verification of variables and data. This analysis rely heavily on their surveying of income, presenting divided categories such as rural and urban dwellers, male and female, total household income. All data is presented by state as well as national average, and some such as income is presented divided into quintiles. Salary data regarding causal work and permanent work are also made available. Health-care costs are also taken from this survey.

In regards to the estimated decreasing-factors for diarrhea, this analysis relies on case-studies carried out by previous researchers. For the AWG technologies (AWW and the Oxy-3), this analysis utilizes decreasing-factors from a field-study performed by Quick *et al* (1998) in Bolivia, focusing on point-of-use drinking water treatment. The decreasing factors formulated in this study are used in previous work in CBA-analysis's, such as Hutton *et al* (2007) and Clasen *et al* (2007). For the Solvatten-technology, this analysis utilizes a decreasing-factor from field studies of the SODIS method (Fewtrell *et al*, 2005). From those, the one with the best grade in a meta-study were elected for this analysis.

Table 4.2: Non region-specific variables used in the analysis

Variable	Notation	Value	Source
Disease reduction rate, adults	d_a	0,223	**Quick et al, 2000**
Disease reduction rate, children	d_C	0,55	**Quick et al, 2000**
Proportion of mortality caused by diarrhea	d_d	0,18	**WHO, 2006**

Finding data for regional expenses per student and year proved to be difficult. A country report issued in 2006 shows data only for Haryana and Gujarat, values which are very similar and close to the national average (Global march against child labour, 2006). No data was found for Uttar Pradesh. In addition, this study estimates that the rural population in these states spends an additional 50% in private expenses on students. Given these findings, and the lack of additional data to compare with, the estimate used for expenditure per student and year are based on GDP/capita 2011, and allocation of governmental budget 2006, since no later data has been found available. The uncertainty in regards to Uttar Pradesh is addressed in the sensitivity report.

Prices for the respective projects are taken from the company's manufacturing the POUWT-technologies. AWW prices, cost and installation costs were estimated by the inventors and company founders (pers. mess. Fredrik Edström, 2011). Solvatten AB does not list prices publically, only shipping possibilities. Prices were taken from a public interview (P. Solberg, 2010). For the Electrolux produced heat-pump E-oxy-3 EXH09HXI, prices were taken from a performed google search (whiteway, 2012).

4.3 Costs

The costs for the various projects are estimated from company information in regards to the different projects. Prices are calculated to 2011 US$.

Table 4.3: Costs for the different suggested projects, 2011 US$.

Project	Cost/unit
Airwaterwell	**288,6**
SODIS	**77,0**
E-Oxy-3	**856,6**

The scope of the project depends on the required number of POUWT-units per household. For the AWG technologies, this depends on required minimum amount of drinking water, and for the SV technology, the estimated household supply.

Table 4.4: Household water data, liters.

Variable	Notation	Estimation	Source
Liters water req. per day, adult	l_a	5	P. Gleick, 1996
Liters water req. per day, child	L_c	2,5	P. Gleick, 1996
HH consumption of water (total)	l_{tot}	80	Motiram & Osberg, 2006

In addition, household composition is the second part that determines the household requirements are the fertility rates, which determines the number of children used in the representative household.

Table 4.5: Household sizes by state (HDI-04/05) and POU-WT units required.

State	Rural HH size	AWW per HH	SV per HH	E-Oxy-3 per HH
Gujarat	4,8	5,67	2,67	8,10
Haryana	4,9	5,75	2,67	8,21
Uttar Pradesh	6,1	6,75	2,67	9,64

These estimations in *table 4.5* are based on drinking water requirements for adults and children. It is assumed that a standard household contains two parents and their children. For AWW, it would be required to have 1,67 units per adult, and 0,83 units per child. For SV this corresponds to 0,67 units per adult and 0,33 units per child. The Oxy-3 requires the highest number of units, 2,38 per adult, and 1,19 per child.

As per technological recommendations from Solvatten AB, the technology has a recommended usage-time of two to six hours to guarantee the entire household supply of water. This makes the minimum amount required for a household somewhat hard to pinpoint, which will have to addressed in the sensitivity report. For the base-line calculation, it has been elected to assume that the average time-span of four hours will be used.

4.4 Health related statistics

The 2005-2006 NFHS-3 survey presents detailed information of cases of diarrhea amongst rural children in all Indian regions. Data for the adult population were taken from the HDI-3 survey, which also lists the number of sick-days per case of diarrhea. Wages and health-expenditure were also drawn from this survey. Unless stated otherwise, all empirics concern the rural population.

Table 4.6: Diarrhea statistics (HDI-04/05) by state (children aged five years and over). healthcare expenditures in 2011 US$.

State	Cases/year & Child	Days sick/case, Child	Cases/year & Adult	Days sick/case, Adult	HC expenditure / sick-day
Gujarat	3,38	4,1	0,79	5,3	0,74
Haryana	2,60	4,6	0,87	5,3	0,77
Uttar Pradesh	2,08	4,6	1,55	5,3	0,42

The NFHS-surveys also list children mortality among the rural population. Benefits from this were derived from averted cases of under-five mortality. Since the survey do not list state-by-state burden of diseases in regards to under-five mortality, this is assumed to follow the national average of 18% being assigned to diarrhea.

Table 4.7: Under-five mortality rate, per 1000 births, from NFHS-3.

State	Under-five mortality rate	Under-five mortality due to diarrhea
Gujarat	71,5	12,87
Haryana	61,2	11,02
Uttar Pradesh	100,0	18,00

Airwaterwell is a new technology that has not yet been field-tested. Since no study of an AWW-project has been implemented, the effects on illnesses-reduction from clean water must be taken from another study. The best data available are summarized by Fewtrell *et al* (2005) in a meta-study that compiles the results from over 60 case-studies of sanitation, hygiene and water-quality improvements. For this analysis, the results of interest are those from point-of-use disinfection of water. For their analysis, Hutton *et al* (2004) relies on a study on reduction of diarrhea performed by Quick *et al* (1999). This study reported a decrease in cases of diarrhea amongst adults by 22%, and among children by 55% due to point-of-use disinfection of drinking water.

Table 4.8: Recent estimates of SVL in India, in Indian Rupees.

Author	SVL (RS)	Low (RS)	High (RS)	Year
Madheswaran	15 000 000			2006
Simon et al		6 400 000	15 000 000	1999
Shanmugam's		14 000 000	19 000 000	2001
Miller	2 240 000	1 920 000	22 400 000	2000

Presented in the table 4.8 above, is a list of some of the peer-reviewed estimations done by analyzing the Indian labour market through compensating variation. The studies shown above differ, but center around roughly the same amount. It's worth noting that all studies generate a higher SVL-amount than what the workers would earn in their lifetimes. This is not uncommon for studies like this however, regardless of whether the study takes place in an OECD or a developing country. The exception is T. Miller (2000) who presents a lower estimate (with a broader range) than the contemporary research which is the one that will be used for this study.

Income for the categories of people needed for the analysis are was taken from the HDI-04/05. The data is generated from a sample of over 18 thousand respondents. Income data is also reported in Indian Rupees, which was calculated to US$ of 2011. Of interest for this analysis are the different sub-categories of the rural population, presented in the table below. In table 5.9, additional statistics used for the model are presented.

Table 4.9: Income levels for various sub-categories of the rural population, by state, in 2011 US$ (HDI-04/05).

State	Female av. Income/day	Male av. Income/day	Household av. Income year
Gujarat	1,44	1,96	651,7
Haryana	2,23	3,60	1365,4
Uttar Pradesh	1,18	2,08	637,5

Expenditure per student and year are used as an estimation for "wasted days" when students are suffering from diarrhea and facilities, teachers etc are under-utilized. Since state-specific data has proven to be unavailable, one estimate has been used for all three regions (trading economics, 2012). This estimate should hold for Gujarat and Haryana, but more uncertainty is this estimate when regarding Uttar Pradesh. This is addressed in the sensitivity analysis.

Table 4.10: Educational statistics, all India.

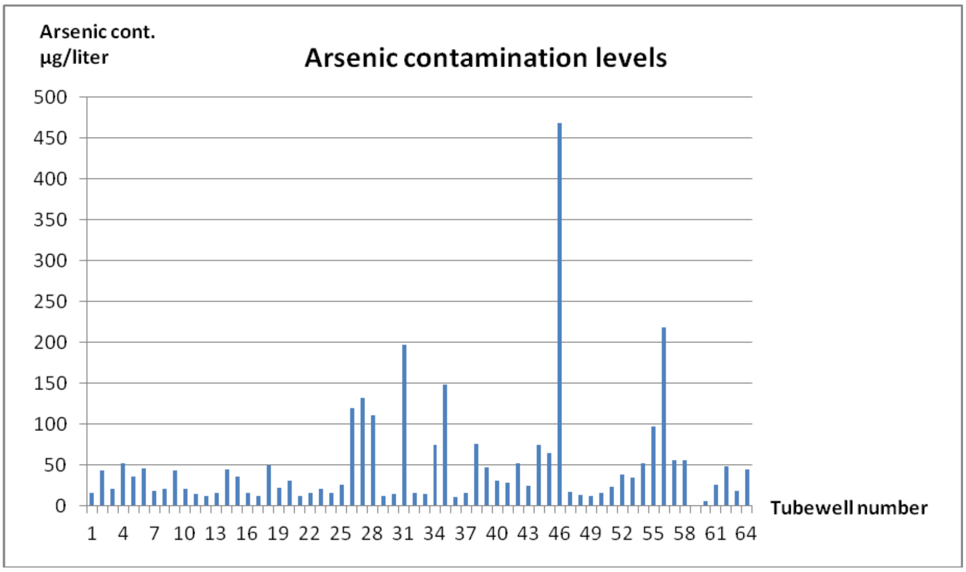
	% student exp. Of GDP/capita	% Private expenditure on education of GDP/capita	GDP/capita 2011 ($), PPP adjusted
India	8,6	4,3	3608

The benefits from decreasing arsenic poisoning are calculated by utilizing the WTP from the study done by J. Roy (2008). In this study, it is estimated between 0,13-0,26 US$ per year and per decreased µg Arsenic per liter water. This value was estimated utilizing cost derived from the health-effects caused by the contaminated groundwater. Arsenic levels in tested tube-wells in the state of Uttar Pradesh are taken from a study performed by Chauhan *et al* in 2009 on 65 wells, tested thrice over a year. The value of decreased arsenic will be calculated according to the limit set by the Indian health agency (less than 50µg/liter) and not the limit set by WHO (10µg/liter). For this analysis, it has been assumed that the project would be implemented in a location among the 50% worst off regions in Uttar Pradesh. This will be addressed with alternatives in the sensitivity analysis.

Table 4.11: Degree of arsenic contamination above government limit, µg/litre water.

State	Arsenic level, average	Arsenic level, highest 50%	Arsenic level, highest 25%
Uttar Pradesh	0	32,75	74,83

Just to clarify, the following diagram from J. Roy`s study from 2008 has been included. The following diagram shows how arsenic contamination levels vary over the sampled wells.



Graph 4.1: Degree of arsenic contamination in Uttar Pradesh sample.(J.Roy, 2008)

4.5 Time spent fetching water

Data in regards to time spent fetching water is severely lacking. A study performed by Motiram & Osberg (2006) estimates the average time spent gathering water at 47 minutes for the woman and 40 minutes for men (those men who perform this duty), in rural India for people with need to fetch water. Of the total time spent, for those with no access to tap-water, close to 87% of it was done by women. This study was performed with data gathered in the year 1999.

In the same study, it is shown that five percent of the rural households spend more than two hours each day gathering water. There are several sources of anecdotal evidence suggesting a higher disparity, both in time per household and allocation of the time between genders. There is no doubt that there exist households, and groups of them, where one adult spends almost their entire day fetching water. This makes the levels chosen for the variable of time spent fetching water somewhat problematic for this analysis. An analysis focused on a project of national scale would use a national average as a variable. A project of the scale proposed in this analysis can take a more targeted approach, and would logically be located to the areas where it generates the highest NSR. For the base case of this analysis, it has been elected to use two hours as the time spent fetching water per household.

To monetize the benefits, income that could be earned during the hours saved were used. The income data is taken from the HDI-3 report. For this analysis, a key assumption is made; Because of the social norms in India, it is assumed that the majority of the freed time will be female time (B. Upadhyay, 2004). Women's wage is therefore used as the opportunity cost that would be gained from the time saved.

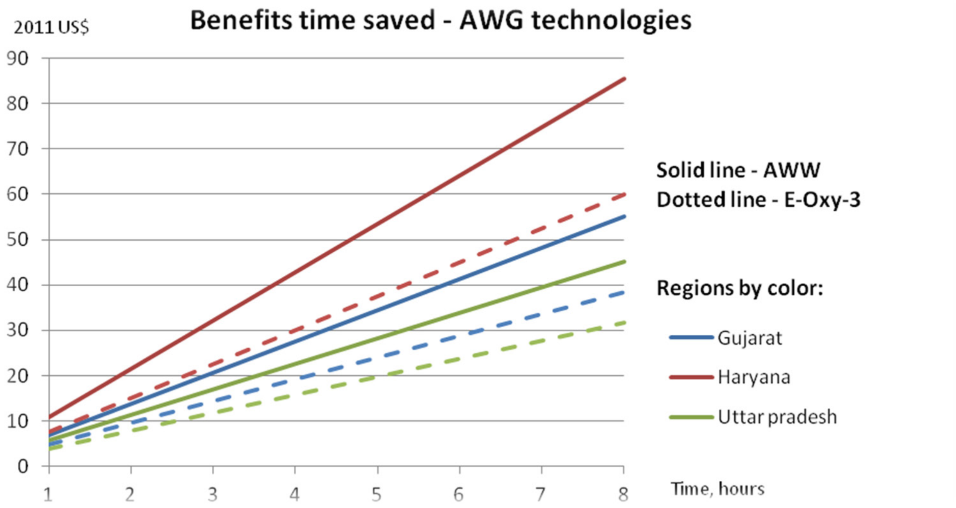
A major concern when performing an analysis this way is of course whether there are available work to replace those hours previously spent gathering water. While there is no way to prove that this is actually the case, most economists take the perspective that, in the long run the unemployment-rate will remain unchanged. This should hold especially true for this kind of model, which simulates a small scale project, affecting around 1000 people. So while there is no guarantee that the time saved will generate additional income in the short run, there is no reason to believe that it wouldn't in the long run.

5. Results

In this section, the results from the CBA analysis is presented, step by step and later summarized. In the first section, the household requirements in regards to the number of POUWT-units are shown, dependent on the levels of fertility in the different regions. Following this, the benefits from the impact areas are presented. All Benefits are presented as PPP adjusted 2011 US$, if not explicitly stated otherwise. The results are further elaborated in the following sensitivity analysis.

5.1 Benefits from time saved

The AWG technology, as mentioned, allows water production at household level. Since reliable and recent data describing time allocated to fetching water has been difficult to come by, it has been elected to illustrate the benefits B_l from a wide array of situations. Graph 5.1 shows the benefits gained from not having to fetch as much water, as a function of total time spent, daily. As benefits are derived from wages as the opportunity cost, B_l is by far the largest in Haryana.



Graph 5.1: Benefits from decreased time spent fetching water, as a function of total time. Benefits in 2011 US$ per AWG-unit and year.

5.2 Summary of Benefits and Net Social Revenue

Lastly, benefits are listed and summarized. With this, NSR and return on investment are calculated. All values are presented per household. NSR are calculated by subtracting the total cost from the NPV of the total benefits (*Equation 2*). ROI are calculated by dividing the NPV of the total benefits by total costs.

Table 5.1: Summary of results for Gujarat region, 2011 US$ per household

Summary	**AWW**	**SV**	**E-Oxy-3**
Costs			
Unit costs	1635	205	6934
NPV costs	1635	205	6934
Benefits			
B Time spent fetching water	78	0	78
B Decreased sick-leave, adults	13	37	13
B Decreased sick-leave, children	92	84	92
B Decreased under-five mortality	210	257	210
B Decreased Arsenic poisoning	0	0	0
B Total	393	378	393
NPV Benefits	5592	5372	5592
Net Social Revenue	**3956**	**4727**	**-1342**
ROI, per $1 invested	**3,42**	**8,32**	**0,81**

In Gujarat, an AWW project generates the largest NPV of benefits, but Solvatten generates the largest return on investment and net social revenue. The representative Heat-pump E-Oxy-3 does not generate positive NSR, and should therefore not be considered for investment in this region.

Table 5.2: Summary of results for Haryana region, 2011 US$ per household

Summary	**AWW**	**SV**	**E-Oxy-3**
Costs			
Unit costs	1659	205	7033
NPV costs	1659	205	7033
Benefits			
B Time spent fetching water	123	0	123
B Decreased sick-leave, adults	21	63	21
B Decreased sick-leave, children	93	90	93
B Decreased under-five mortality	181	218	181
B Decreased Arsenic poisoning	0	0	0
B Total	418	371	418
NPV Benefits	5934	5273	5934
Net Social revenue	**4274**	**4268**	**-1099**
ROI, per $1 invested	**3,58**	**8,15**	**0,84**

In Haryana, the relations between the technological alternatives are altered. The largest NPV of benefits are still generated by AWW, and NSR are almost identical between AWW and Solvatten. The AWG-alternatives generate a slightly higher NSR and ROI, and the Solvatten alternative slightly lower in both categories. E-Oxy-3 do not generate positive NSR, which means that this project should not be considered for investment in Haryana either.

Table 5.3: Summary of results for Uttar Pradesh region, 2011 US$ per household

Summary	**AWW**	**SV**	**E-Oxy-3**
Costs			
Unit costs	1948	205	8260
NPV costs	1948	205	8260
Benefits			
B Time spent fetching water	76	0	76
B Decreased sick-leave, adults	19	66	19
B Decreased sick-leave, children	76	67	76
B Decreased under-five mortality	435	525	435
B Decreased Arsenic poisoning	32	0	32
B Total	639	658	639
NPV Benefits	9083	9352	9083
Net Social revenue	**7135**	**8706**	**823**
ROI, per $1 invested	**4,66**	**14,48**	**1,10**

In Uttar Pradesh, the greatest NSR are generated for all technologies. However, the relations between them are unchanged. The AWW and Solvatten project alternatives generate their highest NSR and ROI, and E-Oxy-3's ROI is positive when evaluated in the Uttar Pradesh region, meaning it could be considered for investment.

In order for AWW to generate equal ROI as the Solvatten alternative in Uttar Pradesh, its product price would have to be put at $95. If price is set to be comparable with the representative Heat-pump, it can be put as high as $1200.

With all the benefits calculated and summarized, the results can be presented as a monetary value on a liter of water. While this has no real impact on the selection of the societal optimal project alternative, it can still serve as a measurement to evaluate whether the market price of clean drinking water is set high or low. The estimation of the monetary value of one liter of clean water is calculated by dividing the sum of the benefits per POUWT-unit and year with the total production from that unit, during one year. Since the price is an estimate of what water could be valued at in India, these calculations are made without PPP-adjustment.

Table 5.4: Monetary value of 1 liter of clean drinking water, 2011 US$.

Region	**AWG technology**
Gujarat	**0,0227**
Haryana	**0,0237**
Uttar Pradesh	**0,0309**

The socioeconomic benefits of having access to one liter of clean water is estimated between 2,27 and 3,09 US cents, depending on the region.

5.3 Sensitivity analysis

A multi-impact analysis of several projects, spanning over multiple years faces a lot of uncertainty. To account for this, a sensitivity analysis is performed. In accordance with the literature, the aim is to provide intervals for the calculations which provide a general idea of how accurate the final estimations are. The impact areas of significant importance are presented in *table 5.5*, in no order of importance. Following this, a justification for each included impact area, and its considerations, is presented. The notations in table 5.5 are based on the variables effect on the benefits, not the variables themselves. In other words, a variable is placed in the minimum category if it is thought to decrease benefits and in the maximum category if benefits are expected to increase.

The aim of the sensitivity analysis is threefold. The first aim is to illustrate to the analysts, and the readers, which variables are of special significance for the results. Secondly, the results are presented with one variable changed at a time, with both high and low estimations. Thirdly and lastly, the sensitivity analysis allows a presentation of the pessimistic case and the optimistic case. The pessimistic case is the NSR calculated with all variables as the minimum estimates, and in the optimistic case with all the variables with the high estimates. The pessimistic case can be seen as the absolute lowest expectations one could place on the projects, and the optimistic case as the highest.

Table 5.5: Impact areas on which the sensitivity analysis is performed

Impact area		Minimum	Base case	Maximum
Base supply drinking water, adult	**(liters)**	3,75	5	6,25
Base supply drinking water, child	**(liters)**	1,88	2,5	3,13
Disease reduction rate, adults		0,16	0,22	0,34
Disease reduction rate, children		0,39	0,55	0,84
SODIS disease reduction rate		0,50	0,66	0,87
SVL	**($)**	50 000	60 000	700 000
Time spent fetching water per day	**(h)**	0,9	2	8
Expenditure children, proportion of HHI		0,5	0,75	1
Degree of arsenic contamination		Av.	> 50%	> 75%
Solvatten purification rate	**(liters/day)**	15	30	45
Social discount rate	**(percent)**	2	3,5	6
AWG project lifetimes	**(Years)**	10	20	30
Distribution of POUWT-units		N/A	HH	Only child.
Expenditure per student & year, Uttar Pradesh (PPP adj. $)		233	465	N/A
Purchasing power parity		Not used	Used	Used

For the sensitivity analysis, a utilized 95% confidence-intervals where used whenever available in the data-sets. When such data was not available, the best estimations have been used. Justifications for those estimations follow in this section.

Minimum required amount of drinking water, children and adults. This variable mainly affects the number of AWG or Solvatten-units per household, based on the objective of providing clean drinking water. Needless to say, how much water an individual requires depend on a lot of factors, such as climate, occupation, age and diet, to name a few. For this analysis, the variable has been chosen more due to the generally academic accepted amount used in other similar work, rather than a physiological evaluation of a human body's biological need. For the sensitivity analysis, this variable was allowed to vary with 25%. Of course, it can certainly be expected that the water requirement to vary more than this over the course of a calendar year, due to the shift in temperature. However, all the projects need to fulfill the minimum requirement for the vast majority of the year, otherwise the objectives are not fulfilled and it could not be expected to decrease the cases of diarrhea to the degree that has been specified in the model. The high and low values here should rather be seen as potential variation in body mass and occupation.

Disease reduction rate, adults and children: The rates to which diarrhoea are estimated to decrease are estimated by relevant case studies. When available, the sensitivity utilizes the values estimated by a 95% KI, with the mean value as the base-case.

Statistical value of life, India: The statistical value of life are taken from a meta-study performed by T. Miller (1999), which evaluates the income elasticity of the SVL in 30 countries. The studies that base the SVL for India are wage-risk studies that have been peer-reviewed. For the sensitivity analysis, the high and low estimates are used. An additional scenario is presented without this impact area, which allows for evaluation of benefits without the controversial variable.

Time spent fetching water; is by far the most controversial and complicated variable for this model. Not in the least because no comprehensible, regional data-set from the desired time-period could be found. The benefits from time saved become a linear function of time spent fetching water, which makes any estimation of this problematic in itself. As shown in the empirics-section, the one comprehensive survey that has been used, suggests that around 20% of India's households spends on average 54 minutes daily fetching water. In the same survey, it was shown that out of those households, one in 20 spent more than two hours each day fetching water. Since this model simulates a small-scale investment, two hours of water-fetching per day seemed appropriate as the base-case for the time spent fetching water variable. While this might seem excessive, it is based on the notion that small-scale projects would first be targeted in areas where the access to water is problematic. For the low value of the sensitivity analysis, 0,9 hours (54 minutes) has been chosen for the low value, indicating that this would be the benefits of placing the projects in any area irrespective of distance to water-sources. For the high value, it has been set as eight hours per day, the full Indian work-day. As an estimation, this might again seem excessive, and this number is not supported in the ITUS 98-99. But there are plenty of anecdotal evidence such as interviews, single village case-studies etc which suggests that eight hours each day is a reality for a sizeable part of the population. It could also be seen as adjusting the model for bad years, years in which precipitation is low, power shortages are frequent or water-deliveries are infrequent.

Expenditure per child, as proportion of household income: This variable was introduced to assign a cost to the SVL, to acknowledge the fact that while children have a great emotional value to parents and communities, they do not yield physical products or services until later in life. With this, it is not intended to point out that a person is only of value when that person is producing something, and there is no attempt in making a ethical statement by including this. The variable was included to acknowledge that while a child's death is tragic independent of the child's age, the societal losses will be greater if a 15 year old was to perish than a two year old, simply because more resources will have been invested in the older child. For the base-case, it has been assumed that 75% of the household income is spent on the children. As a high estimate, this is altered to 100%, and for the low estimate, 50%.

Degree of Arsenic contamination: For this analysis, it is assumed that the project would be implemented in the regions that are worst off in regards to arsenic contamination. For the base case, this means that the average of the 50% highest contamination levels is used. For the minimum benefits, the actual average of the contamination levels in the Uttar Pradesh region is utilized, and for the high value the average of the 25% highest contaminations are used. The minimum scenario therefore simulates locating the project without consideration towards arsenic levels. The base-case and the high scenario signifies to which degree the project can encompass

Solvatten purification rate: In order to achieve the disease-reduction rate estimated in the SODIS-case studies for the Solvatten technology, the household supply of water needs to be treated. Since the estimated time for purifying one charge of the 10 litre bottle varies between two and six hours, this would equate a difference in capacity between 20 and litres per day and unit. For the base case, 30 litres has been selected. This particular issue could merit further discussion. It could be argued that

Social discount rate: The social discount rate determines how much weight should be placed on benefits in the future, rather than the alternatives available now. Not many analysts express absolute confidence in their chosen SDR, and in agreement with the recommendations it has been included in this sensitivity analysis. For the base case, the optimal growth rate method has been employed, which places the SDR as 3,5 percent. The high and low values are six and two percent, respectively. Neither of the project alternatives have expected lifetimes which merit a declining discount-rate.

AWG project lifetimes: Due to the uncertainty of as of yet not launched technology, the lifetime of the POUWT-units are allowed to vary with 50%. The lower value for this variable should be seen as a minimum estimation of the functional lifetime of the units, the higher as a very optimistic scenario.

Distribution of POUWT-units, children and adults: During the evaluation of the results, it became apparent that with the variables chosen for the base-case, distributing the POUWT-units among children will result in a higher

NSR than supplying the entire household. In light of this the sensitivity analysis has been extended with a scenario of only supplying POUWT-units to children, evaluated with other variables as base-case.

Expenditure per student & year, Uttar Pradesh: Reliable data for this variable was missing from Uttar Pradesh. It was decided to use the same estimate for the base-case as the other regions, since according to the India state report, there is no real difference between rural Gujarat and rural Haryana. While there are not much difference in income between rural Gujarat and rural Uttar Pradesh, it was decided to acknowledge the uncertainty in the sensitivity report by reducing the expenditure by 50%.

Purchasing power parity: Benefits are calculated with to purchasing power parity US$, in order to properly reflect the value. NSR will be presented with a normal exchange rate as well, to account for the scenario of a domestic investment.

5.4 Results from sensitivity analysis

In this section, the results from the sensitivity analysis are presented. The base-case NSR are altered with the selected variables altered one at a time. Results in *table 5.6* are calculated from Uttar Pradesh, the region which showed the greatest returns per investment (for sensitivity report for Gujarat and Haryana, see appendix). NSR from the base case for each project alternative is shown in the first row. If one variable isn't relevant for one or more technologies (such as SODIS-purification rate on the AWG technologies) the denotation N/A is used, short for not analyzed. In this section, the NSR generated by Solvatten is calculated using 5 years (the lifetime of the units, rather than the project lifetime) It will not alter the ROI or percentual change.

Table 5.6: NSR per household from sensitivity analysis, Uttar Pradesh, all project alternatives, 2011 US$.

	Base AWW		Base SV		Base Oxy3	
NSR	4796		1860		591	
By variable	**High AWW**	**Low AWW**	**High SV**	**Low SV**	**High Oxy3**	**Low Oxy3**
Time f. Water	6979	4395	N/A	N/A	2774	191
SVL, India	50526	4081	19293	1587	46321	-124
Degree Ars. Cont.	5185	4492	N/A	N/A	981	287
SV purification Rate	N/A	N/A	1906	1722	N/A	N/A
Social Discount Rate	6730	2709	2300	1325	2535	-1507
% HH expenditure ch.	4838	4753	1874	1846	621	561
SODIS DRR	N/A	N/A	2495	1376	N/A	N/A
AWG DRR children	7148	3498	N/A	N/A	2963	-718
AWG DRR adults	4894	4742	N/A	N/A	689	537
BS Water children	4869	4721	N/A	N/A	1196	-25
BS Water adults	4867	4724	N/A	N/A	1186	-5
Exp. Per Year & Student	N/A	4583	N/A	1814	N/A	378
Project lifetime (AWG)	6591	2263	N/A	N/A	2397	-1957

In *table 5.7*, the percentage impact on NSR by varying each variable is shown. Presented like this, it is easy to follow the impact of each variable on the outcome of the analysis. Since the NSR of the E-oxy-3 technology is relatively low, the percentage changes may appear disproportional, as seen in column six and seven, in compared to the other project alternatives. While an esthetical problem of presentation, this does not affect the individual ranking of the variables overall importance.

Table 5.7: Percentage change of NSR from sensitivity analysis, Uttar Pradesh, AWG and SV.

Percentage change						
By variable	**High AWW**	**Low AWW**	**High SV**	**Low SV**	**High Oxy3**	**Low Oxy3**
Time f. Water	45,5	-8,3	N/A	N/A	369,5	-67,7
SVL, India	953,6	-14,9	937,4	-14,6	7741,3	-121,0
Degree Ars. Cont.	8,1	-6,3	N/A	N/A	66,0	-51,4
SV purification Rate	N/A	N/A	2,5	-7,4	N/A	N/A
Social Discount Rate	40,3	-43,5	23,7	-28,8	329,2	-355,1
% HH expenditure ch.	0,9	-0,9	0,8	-0,8	5,1	-5,1
SODIS DRR	N/A	N/A	34,2	-26,0	N/A	N/A
AWG DRR children	49,1	-27,1	N/A	N/A	401,6	-221,6
AWG DRR adults	2,0	-1,1	N/A	N/A	16,6	-9,2
BS Water children	1,5	-1,5	N/A	N/A	102,5	-104,2
BS Water adults	1,5	-1,5	N/A	N/A	100,8	-100,8
Exp. Per Year & Student	N/A	-4,4	N/A	-2,5	N/A	-36,0
Project lifetime (AWG)	37	-53	N/A	N/A	306	-431

As seen in the two tables above, utilizing the high estimate of Indian SVL has a disproportionate effect on the overall outcome, changing NSR with over 900% for the AWW and SV project alternatives. For the following cases, the high estimate for SVL has been excluded from the sensitivity analysis. This means that the optimistic scenarios utilize the same SVL variable as the base case.

Table 5.8 – 5.9 presents the same percentage change from single variables in Haryana and Gujarat. Following these analyses, the special cases will be presented.

Table 5.8: Percentage change of NSR from sensitivity analysis, Haryana, AWG and SV.

Percentage change						
By variable	**High AWW**	**Low AWW**	**High SV**	**Low SV**	**High Oxy3**	**Low Oxy3**
Time f. Water	122,6	-22,5	N/A	N/A	475,5	-87,2
SVL, India	689,1	-10,8	764,8	-11,9	2671,4	-41,7
Degree Ars. Cont.	0,0	0,0	N/A	N/A	0,0	0,0
SV purification Rate	N/A	N/A	4,7	-14,0	N/A	N/A
Social Discount Rate	35,9	-40,2	20,2	-24,9	139,2	-155,8
% HH expenditure ch.	1,5	-1,5	1,5	-1,5	5,7	-5,7
SODIS DRR	N/A	N/A	36,3	-27,6	N/A	N/A
AWG DRR children	41,0	-22,6	N/A	N/A	159,1	-87,8
AWG DRR adults	3,7	-2,0	N/A	N/A	14,4	-7,9
BS Water children	-0,2	0,2	N/A	N/A	50,0	-50,8
BS Water adults	-0,3	0,3	N/A	N/A	69,5	-69,5
Exp. Per Year & Student	N/A	N/A	N/A	N/A	N/A	N/A
Project lifetime (AWG)	40,8	-57,6	N/A	N/A	158,3	-223,3

Table 5.9: Percentage change of NSR from sensitivity analysis, Gujarat, AWG and SV.

Percentage change

By variable	High AWW	Low AWW	High SV	Low SV	High Oxy3	Low Oxy3
Time f. Water	84,2	-15,4	N/A	N/A	-248,0	45,5
SVL, India	831,0	-13,0	833,7	-13,0	-2449,1	38,3
Degree Ars. Cont.	0,0	0,0	N/A	N/A	0,0	0,0
SV purification Rate	N/A	N/A	4,6	-13,7	N/A	N/A
Social Discount Rate	39,7	-43,8	22,0	-27,0	-117,0	129,0
% HH expenditure ch.	0,8	-0,8	0,3	-0,3	-2,4	2,4
SODIS DRR	N/A	N/A	36,2	-27,6	N/A	N/A
AWG DRR children	47,9	-26,4	N/A	N/A	-141,2	77,9
AWG DRR adults	2,4	-1,3	N/A	N/A	-7,2	4,0
BS Water children	1,4	-1,4	N/A	N/A	-44,3	45,0
BS Water adults	2,0	-2,0	N/A	N/A	-63,8	63,8
Exp. Per Year & Student	N/A	N/A	N/A	N/A	N/A	N/A
Project lifetime (AWG)	41,6	-58,6	N/A	N/A	-122,5	172,8

Optimistic and pessimistic scenarios

In *table 5.10*, the optimistic and pessimistic scenarios are evaluated. Return on investment is presented for each project alternative and region, given all variables set on their high and low estimates, respectively. One notable finding from performing this analysis is the fact that given the pessimistic case, ROI and NSR are no longer positive for the AWW alternative. Also, it is apparent that when NSR are lower, Uttar Pradesh ceases to be the optimal province for investment, in favor of Haryana.

Table 5.10: Return on investment for optimistic and pessimistic scenarios, all project alternatives.

Return On Investment

Region	AWW, opt.	AWW, pess.	SV, opt.	SV, pess.	Oxy3, opt.	Oxy3, pess.
Uttar Pradesh	19,02	0,87	35,17	3,36	4,49	0,21
Haryana	14,03	0,90	19,22	2,16	9,82	0,63
Gujarat	12,12	0,88	19,69	2,40	8,49	0,61

Special case: Distribution amongst children only

When constructing the model and reviewing the results, it was apparent that returns from the project alternatives increases in the region where fertility levels are higher. In short, it is more favorable to provide children with AWG or Solvatten units, given the model specification and set-up. With this in mind, another special scenario was included, where the distribution of POU-WT-units are targeted to children only. In *table 5.11,* return on investment for this scenario is presented. For all regions, this yielded a higher NSR Uttar Pradesh remained the best region for investment, but Gujarat became a more viable alternative than Haryana, since the effects of income are lessened. Since the SODIS disease reduction derived from the case studies are dependent on purifying the entire household supply, this scenario was not evaluated for the Solvatten technology.

Table 5.11: Return on investment when distributing AWG-units to household children only.

Return On Investment

Region	AWW	E-Oxy-3
Uttar Pradesh	8,39	1,99
Haryana	6,63	4,64
Gujarat	7,06	4,94

Special case: Excluding Statistical Value of Life

In this analysis, SVL has been used to put a monetary value on decreased under-five mortality. As part of the sensitivity analysis, SVL has been excluded and NSR calculated without the impact area of under-five mortality. This allows readers uncomfortable with this choice of method, for any reason, to evaluate the project alternatives without it. As seen in *table 5.12*, ROI are decreased for all project alternatives. Without the SVL-variable included and nothing else different, the decrease of ROI are largest in the region with the highest under-five mortality rate. Haryana becomes the best region for investment for AWW and SV, and the representative Heat-pump doesn't break even in Uttar Pradesh anymore.

Table 5.12: Return on investment when benefits from under-five mortality has been excluded

Return On Investment			
Region	**AWW**	**SV**	**E-Oxy-3**
Uttar Pradesh	1,49	2,94	0,35
Haryana	2,03	3,35	0,48
Gujarat	1,59	2,66	0,38

Special case: Domestically funded projects

When performing this study, PPP-adjustments have been made between US dollars and the Indian Rupee. This was done to simulate an OECD aid organization purchasing the POU-WT units and distributing it amongst the Indian households. In interest of completeness, the ROI is presented without the PPP-adjustments, thereby simulating a case where the POU-WT units are purchased domestically. As shown in *table 5.13*, calculating benefits like this decreases return on investment. E-Oxy-3 are not a viable investment anywhere, but the internal order between the other alternatives and regions doesn't change.

Table 5.13: Return on investment without PPP-adjustment (Project alternatives funded domestically)

Return On Investment			
Region	**AWW**	**SV**	**E-Oxy-3**
Uttar Pradesh	1,88	5,59	0,44
Haryana	1,49	3,28	0,35
Gujarat	1,50	3,40	0,35

In the sensitivity analysis performed in this section, the importance of single variables, and their respective impacts on the results, has been clarified. Three special cases has also been included, the first to evaluate a potential alternative distribution of resources, the second to show the results without the controversial variable of SVL, and the third to simulate a domestic investment in the project alternatives.

6. Analysis

In this section, the results are analysed and put into context.

All projects alternatives yield positive values for Net Social Revenue, which means that they all should be considered for investment. The representative Heat-pump, E-Oxy-3 only yields positive NSR in the most promising region, Uttar Pradesh. Given no budget limitations, the project which yields the highest NSR could potentially be chosen, which is the Solvatten technology except in the Gujarat region. Additionally, if an investor desires to maximize returns on investment, Solvatten technology is the optimal choice.

Given the foreign aid scenario, i.e. an OECD country chooses to invest in an AWW project of the magnitude described in the analysis, the base-case generates returns between 3,4 and 4,7 US$ per 1 invested US$. The best returns on investment are generated in Uttar Pradesh, with the lowest benefits generated in Gujarat. These returns are within the ranges usually estimated when performing analysis's of this kind. Some project estimations, such as these done by Hutton *et al* and Clasen *et al*, present higher results than calculated in this thesis. Some other water and sanitation related projects have estimations on return in terms of thirty times the investment cost. In part, this is because those analyses include positive externalities and spill-over effects (such as an overall lessened burden of disease). For the analysis performed in this paper, efforts have been made to use estimations without externalities, thereby simulating a true small-scale project. A project of the magnitude analysed here will naturally lack the economies of scale associated with projects on national scale, or even regional. While this could make an AWW-project seem like an inferior alternative, three things should be pointed out.

First of all, this analysis has been performed with the core idea of providing a base value when estimating benefits. By using only health-effects from decreased diarrhoea and arsenic poisoning (when relevant), decrease of other illnesses and other groundwater contaminants become a bonus. Secondly, the model allows for regional evaluation which highlights differences in investment potential. Thirdly, the model constructed in this thesis allows for easy comparisons with other technologies or other regions as well. If interest exists, use this model with other technological alternatives included, in these regions or others.

Income levels and fertility

A general finding evident in the results is that NSR increases in the regions where fertility levels are higher. This is linked to the fact that the average child requires less drinking water than an adult, and that findings indicate a higher reduction in disease rates when it comes to diarrhoea. This suggests that poorer regions are better suited for investments irrespective of the fact that many benefits are derived from opportunity costs such as wages and income, as long as the average household has more children. These findings also indicate that, should the total number of POUWT-units be too limited to provide adequate coverage for the entire household, children's needs should be met first. This is further confirmed in the sensitivity analysis, where it's found that ROI increases to over eight times the initial invested amount, when POUWT-units are distributed amongst children only. While this distribution might be intuitive parental instinct, the higher benefits may not be reflected in the household income, since the benefits from healthier children are derived from more efficient education and the somewhat arbitrary statistical value of life. Whether this will affect HH decision-making or not remains to be seen. When distributing POUWT-units only to children, NSR increases by 80%, AWW's increase being the second highest.

A long-standing concern when performing CBA studies in developing countries have been the fact that low wages tend to undervalue actual benefits. In this study, the poorest province Uttar Pradesh shows the best results in regards to return on investment, simply because the health-impacts are larger in a province with higher disease-rates and under-five mortality. Admittedly, this finding hinges on the inclusion of SVL as a variable, as shown in the sensitivity analysis's special case (see *table 5.12*). Without it, the higher rural income in Haryana outweighs the larger disease-reductions in the other regions.

Statistical Value of Life

The statistical value of life is a controversial topic in itself, something that has not been discussed thoroughly in this thesis. A decreased under-five mortality would be a great achievement, and large emphasis must be placed on this. Since children under five neither work nor attend schools, SVL were chosen as a variable. To account for the fact that the vast majority of the deaths due to diarrhoea are children under five, a cost were assign for a period until the benefits start, when the child reaches adulthood. While this may give the indication that children are viewed as a cost until the age of eighteen, and then start to generate benefits, that has not been the intention of this study. Rather, the strive have been to restrict the SVL in order not to allow it to dominate the analysis. In addition to this purpose, results of the CBA have also been presented without SVL. This allows readers who view SVL as a questionable variable to evaluate the results without it.

Without the SVL variable included, NSR for AWW decrease by 45-60%, depending on the region, with the higher loss from the previously most profitable region of Uttar Pradesh. Haryana is now optimal location for investment, since the higher income amongst adults plays a larger part amongst total benefits. The Solvatten project alternative suffers the highest percentage loss of NSR, and the representative Heat-pump E-Oxy-3 can no longer be considered a potential investment alternative anywhere.

Value of water
From this model, one litre of clean drinking water is valued between 0,022 and 0,031 US$ in Gujarat and Uttar Pradesh, respectively. When estimating this, benefits were not calculated using PPP, since this is a valuation of a market commodity. These estimations are in line with the higher values estimated in previous studies, such as Roy *et al* (2002), and higher than the actual market price. As initially suspected, this indicates the existence of some form of market-distortion or in-efficiency. In the model, the highest value of water is calculated in Uttar Pradesh, for the reasons discussed earlier in this section. This lends some credence to the initial idea for this thesis that a WTP study would direct the decision-maker towards the wealthier regions, whereas the model constructed here will do the opposite.

Sensitivity analysis
The variables with largest impact on the outcome are SVL, children's disease reduction rate (AWG), time spent fetching water, social discount rate and SODIS disease reduction rate. Health care expenditure, adult disease reduction rate (for the AWG alternatives) and degree of arsenic contamination affect the outcome less. These outcomes are not unexpected, since this model shows the greatest gains from reducing diarrhoea amongst children. Also expected was the effect on NSR of the high estimate from SVL. Utilizing this, NSR is increased by over 950%. Since this single variable makes the rest of the model almost arbitrary, the base-case estimate of SVL was used for the optimistic case, even though all other variables were set on their high estimate. It is worth noting here that the high estimate for SVL derived from the T. Miller study isn't that much higher than those taken from contemporary studies (as seen in the method chapter 2).

Since the impact areas are fewer for the Solvatten project alternative, the difference between the optimistic and pessimistic cases are a little lesser than the difference between those cases for the AWW alternative. Another finding from the sensitivity analysis is the surprisingly small impact when varying the amount of drinking water needed. Since this is the variable that determines the scope of the investment, intuitively, it would play a larger role than it does. The reason for this is the fact that while the drinking water for both children and adults was allowed to vary with 25%, the total supply of water (per household) was kept constant. This means that, while a lower requirement of drinking water means less POUWT-units per household and thereby less costs, it also means less time saved from fetching water, which in turn decreases NSR slightly.

Another important finding from the sensitivity analysis concerns the potential of time saved, when not having to fetch as much water. In a high-wage region like Haryana, an AWW investment could pay itself off solely from this impact area in as little as four years, and a little over seven years in a region like Gujarat, provided the projects where implemented in areas where inhabitants spent upwards of eight hours each day fetching water.

7. Conclusions

As for a start, this thesis had an objective to study the socio economic impact of clean water into the household. With an estimated value of water at 0,022 and 0,031 US$ in Gujarat and Uttar Pradesh it can be confirmed that clean water is in fact a market commodity, which points out the problem in India where no coherent water prices currently exists. This has been measured through the benefits that comes, in order of magnitude; Decreased mortality amongst children, less sick-leave from school, benefits from time saved fetching water, reduced arsenic contamination (where present in groundwater) and lessened sick-leave amongst adults. But to make a fair assessment a larger study would be required to see the socio-economic impact, and it would require more than just an economic perspective. For a study like this, it is satisfying to know, given that clean drinking water is provided, that the society have potential to advance further, which justify the purpose of this study.

Concerning how these project alternatives will generate Net Social Revenue clearly points out that the Airwaterwell at its present projected cost of 1635 US$ to 1948 US$ per household depending on region, is a valid option when investing towards the aim of poverty alleviation, but a decision-maker would ultimately favour the Solvatten technology when offered these alternatives. This is due to the carrying capacity of Solvatten technology, and the cost of only 77 US$. This should be put into context of the benefits where the Airwaterwell generates a return on investment of 3,42 - 4,46 US$ per invested dollar, while Solvatten generates 8,15 - 14,48 US$, where the highest values is found in the Uttar Pradesh region. Since Solvatten costs less and generates higher profits with current Airwaterwell cost projection, it's an obvious choice. However, while Airwaterwell have not been able to match the performance of Solvatten in the regions tested, it has outperformed the representative Electrolux Oxy-3 Heat-pump in every way. Partly, this is because of the superior rate of efficiency, but also due to the lower estimated product price.

Airwaterwell and Electrolux Oxy-3 generates additional benefits in comparison to Solvatten, namely from less time fetching water and reduced Arsenic poisoning. At the base case of the analysis, these additional impact areas are not large enough to match Solvatten's overall performance. In the sensitivity analysis, it is shown that if the air-water generators project alternatives are located in areas where the time spent fetching water is set on the high estimate, return on investment are close to equalized between Airwaterwell and Solvatten in Haryana and Gujarat.

Given that the Airwaterwell is yet not in production, and the cost of production is yet just a projection, if Airwatergreen AB were able to decrease product price per unit down to approximately $95, the company would be able to match the estimated return on investment of Solvatten in Uttar Pradesh. Disregarding component-prices, this would be seen as an absolute lower limit for pricing, provided the company were in possession of some degree of market power. Conceivably, an air-water generator unit should not be priced to produce higher return on investment than a solar disinfection-unit, because of the difference between the technologies. There exists ways to raise the return on investment from the Airwaterwell even higher without altering the price, as seen in the sensitivity analysis. When distributing Air-water generator units only to children, return on investment is increased to 6,6-8,9 for Airwaterwell and 2,0-4,9 for Electrolux Oxy-3. With this scenario, Haryana becomes the least viable alternative for investment, due to the better health-conditions amongst children. If the aim is a market position where return on investment is comparable with the Electrolux Oxy-3 or other air-water generators only, the price could be pushed to $1200.

8. Discussion

Generally speaking, the aim of this analysis has been to keep estimations of the variables sensible. This is partly in order to avoid an overestimation of NSR, but also to account for the fact that the suggested projects are small-scale in nature. In other words, none of the projects are likely to generate the positive externalities that could emerge from a project on a national scale. In such projects as those estimated by Hutton, diseases may be reduced further that suggested in the field-studies, since the overall person-to-person transmission will be lessened. The major intended underestimation of benefits in this analysis was to base the model only diarrhoea as the only water-related disease. This choice has been made by several previous studies

A PPP-rate was used to monetize benefits in this analysis. This scenario assumes a foreign aid style delivery of the projects, i.e. an organisation from a country with a higher purchasing power supplied the technology to Indian consumers. If this analysis was performed for a specific potential investor, the PPP-rate would have to be adjusted. The price of water is calculated without the PPP-rate, simply because that kind of analysis is more in line with a market analysis. Production and packaging would have to take place in India, the primary customers would be Indian household and the price would be set after those conditions.

Concerns with this study

The largest generators of benefits are the impact areas of decreased under-five mortality and decreased sick-leave for children. Potentially, some concerns could be raised in conjunction with this. The largest impact areas for benefits are those who generate socio-economic benefits for society at large, rather than direct household benefits. Since smaller direct benefits are generated for the adults, the actual decision-makers in the household, faith in the project could come into doubt. In the worst-case scenario, this could lead to under-utilization or mismanagement of the POUWT-units. AWW and the E-Oxy-3 are constructed to require a minimum of attendance, and even with waning trust in the full scope of their benefits, an adult should be expected to keep tapping the containers and make sure the solar-lenses are reasonably clean. Solvatten might be more of a concern, since their units require refilling and tapping more often, and some degree of monitoring. But since the field-studies performed on the SODIS-method already have accounted for this (i.e. the results found in those studies include some degree of negligence), no reasons for unduly worry can be found.

In hindsight, the selection of Gujarat as the average Indian state may have been misfortunate. While the state in regards to income is indeed very close to the average in India, further inspection of the data revealed that the rural income is considerably lower. If this analysis were to be repeated, perhaps a more suitable region could be found .In the analysis, it is clear that Gujarat is the least desirable state for investment, which is not in itself surprising, given the combination of reasonable health-status and low rural wages.

Most troubling with this analysis is the fact that reliable data in regards to time spent fetching water could not be found given the timeframe allotted to the analysts. In conjunction with a potential launch of an AWW project, efforts should be made to find suitable datasets, or perform studies in this field. Identifying regions with severe losses due to hours spent fetching water would increase NSR considerably, as seen in the sensitivity analysis. Finding better datasets would also allow for a better estimation of this benefit category as well. In this analysis, benefits from decreased time spent fetching water is approximated as a linear function of the total time designated to this chore. In reality, the benefits would likely take more the shape of a step function (discontinuous function), where you save one or two trips to the water-source, rather than a percentage of total time spent. This analysis could have been done using distance to water sources as a base for estimation instead. Two problems arise from this, however. The first being that households can fetch water from more than one source, and the second being the possibility of queuing at the source, which increases the time but cannot be glanced from distance-related data. Secondly, some water-sources are tap-operated, which also increases delays if they are not operating at all times. Based on this, it is clear that a proper survey of household's time allocation could improve this analysis. To partly account for this problem, it has been attempted to show how benefits vary over the range of time that could be allocated to fetching water.

On a more optimistic note, the sensitivity analysis has shown the potential for the AWW based solely on benefits from less time spent fetching water. Optimal project-sites would be the combination of high-wage regions like Haryana, and locations where households travel long distances to fetch water. In such hypothetical place, AWW could be justified as an investment based solely on time saved. If AWW, or any other AWG technology, should be considered as a foreign aid project based primarily on this, relatively wealthier developing countries facing water scarcity would be prime targets. In the near future, AWW may even be considered as a product for private consumption, if wages continue to increase in regions like India, while demand for water increases further.

Excluded impact areas
With all the benefits within the model, this study should encompass all the major impact areas for projects such as those evaluated in the analysis. Mortality due to diarrhoea amongst older children and adults have not been included. The decision was made simply because the vast majority of the deaths occur in the first years. Benefits from decreased under-five mortality then becomes a minimum estimation, a base-line which is very hard to argue against. Another impact area that could be included in a future analysis is that of stunted growth amongst children. It is heavily documented in the datasets, but the problem is assigning a monetary value to it. Decreasing the stunted growth, for this analysis, has to be seen as an excluded impact area for this analysis, but lends credence to the fact statement made that benefits from decreased under-five mortality should be seen as a low estimate. In addition, there are other impact areas that could not only add to the NSR, but also increase the difference in total benefits between Solvatten and the AWG technologies. One such pollutant is iron, which can build up excessively in the human body and cause harmful effects. But the health-effects, while potentially serious, are still lesser than those caused by arsenic-contamination, it was decided not to include it. Iron-levels are also more problematic because of the fact that they vary considerably over the season, making data-overview difficult.

In itself, the analysis is based on a variety of sources. The datasets themselves are all from the concerned regions, with the population divided into rural and urban categories. As an exception, the lack of suitable data in regards to time spent fetching water can seem glaring. To compensate for this, it has been shown how benefits vary over the time allocated to fetching water from 54 minutes to eight hours. When regional Indian data hasn't been available, the second choice has been national data, preferably specified in regards to the rural population. In some cases, with variables such as decreasing-factors for diarrhoea, the analysis has had to rely on case-studies performed outside India. In these instances, the study has relied on previous researchers or meta-studies to assess the most accepted estimates for this kind of analyses. One clear benefit from using previous researchers and their results is that comparisons between the model in this study and others are made easier.

Perhaps the largest potential beneficial impact area that has been left out is the security provided by the AWG-units. In possession of them, a household can feel reasonably secure in the fact that they will always have bare minimum in terms of drinking water requirement. As a beneficial impact area, it could have been formulated as avoided fatalities during a water-related crisis, quantified by multiplying with the annual chance the crisis occurring. A calculation like this seemed to include too many variables with uncertainty, such as severity of crisis and its resulting health-impacts (the datasets would need to be taken from a number of years, during which societal stages of development would be vastly different). If another researcher has a suggestion on how to estimate this, it is easy enough to add it to the model.

Above, possible concerns and flaws in the model have been discussed, as well as variable estimation and data. Are there any reasons to believe the opposite, namely the possibility that the model is too modest in its estimation? It has been properly addressed in the sensitivity analysis, and in the optimistic case (*Table 5.16*). Since AWW is still a relatively expensive option when discussing water purification, it seems unlikely that it would produce ROI above twenty times the initial investment. The structure of the model itself, and how it fits with India's future development, should be briefly discussed. Since benefits are primarily based on income, a relatively low discount-rate are justified since wages could be expected to follow the economic development. This is the standard approach, and should be used unless having access to trustworthy prognoses dictating otherwise. In India, there are some indications that another approach for discounting may be used. In recent years, wages in India have increased above the annual growth of GDP. A growing rural economy, coupled with increased water scarcity due to industrial use, population growth and climate change could very well increase benefits from technologies that increase the supply of drinking water without tapping groundwater reserves. If so, having access to AWG-units ten years from now may bring considerably larger benefits to the household than shown in this model. The inherent uncertainty in such a simulation makes a sensitivity analysis of this kind at best questionable. An undertaking such as this would also require more time, and access to further datasets.

Technological comparisons
Airwaterwell, E-oxy-3 and Solvatten are similar methods of providing the same service, clean drinking water. Where they differ in output is that Solvatten purifies the entire household supply, but cannot purify some contaminants. The AWG technologies produces completely distilled water, in addition to the household supply. One could argue that these alternatives should be kept separate, since the product, or in the Solvatten case, service they produce are different. The view taken in this thesis is that Solvatten is a very solid product, easy to use, affordable and a very good alternative for this kind of small-scale investment. That Solvatten would generate a higher return on investment was not surprising, given the construction of this model. Also

unsurprising was the fact that AWW would produce a higher NSR than its competitor in the AWG-field. Neither of these rankings of the alternatives are set in stone, however. AWW does not, as of yet, exists a ready-to-purchase product. What this means is that the price is yet to be set, and when production reaches that point, the price can be set based on a number of premises. If you disregard technical and physical limitations for price-setting, this analysis has provided a minimum and maximum price for market entrance. If AWW are priced above the AWG competitor, it will have a hard time becoming a viable investment, both as a foreign aid alternative (evaluated here) or a product for private consumption. If the AWW yields a return on investment close to that of Solvatten units, based on its product price, it will enable a very good market position.

Statistical Value of Life
As seen in the sensitivity analysis, using the high estimate for SVL makes the model itself almost redundant. Statistical estimations of the value of a human life usually end up larger than what the country-specific worker would earn during his or hers lifetime. When the estimate of SVL becomes too large, it will undoubtedly dominate a model like this. Some analysts and readers might then proceed to question the entire model, by association. While this is far from desirable, it remains our personal belief that an analysis like this cannot be accurate without assigning a monetary value of some sort on the under-five mortality rate. In this analysis, efforts have been made (such as discounting the SVL-value, and assigning parental costs) to keep this value sensible. In the model, this makes children into a different category than adults. Hopefully, this should not be seen as a statement about adult life being worth more than a child's. The justification for this structure is simply to acknowledge the fact that more resources, both parental and societal, have been put into a young adult in comparison to an infant. If future researchers don't agree with this formulation of the impact area, it is a small matter to remove the cost-structure.

Formulas for Benefits from decreased under-five mortality were constructed with the idea in mind that it should not be allowed to dominate the model. The cost-structure assigned to the raising of children is, to the best of our knowledge, a unique construction for this study. When everything's been summarized, it seems that the goal have been at least partially achieved, without compromising the structure of the model, or its datasets. For the AWG technologies, benefits from decreased under-five mortality consist of less than 50% of total benefits. The analysis for Solvatten may be a little more problematic, where the rate is between 75 and 90% of total benefits. As expected, the fewer impact areas, the more dependent on benefits from decreased under-five mortality, and by association SVL.

Final words
From the analysis, there are clear indications that Airwaterwell and Solvatten are both viable investment towards poverty alleviation. Airwaterwell produces clean drinking water with a higher efficiency than the technologically related example chosen in this analysis. In the literature review and the empirics section, it has been demonstrated that unsanitary water conditions and distance to water sources cause health-problems and societal losses. In the analysis, it has been proven that the Airwaterwell and Solvatten are cost-efficient methods of alleviating some of that burden, in the regions specified.

With the model constructed for this thesis, a study method has been provided that can be utilized in any desired region, given access to health-related empirics. Limiting it to diarrhoea as the only infectious disease, and arsenic as the only inorganic contamination, this model will provide a reliable estimate of benefits from water-related investment in future studies, regardless of what technology included in the study.

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Appendix

Table 5.12: NSR per household from sensitivity analysis, Haryana, all project alternatives, 2011 US$.

	Base AWW		Base SV		Base Oxy3	
NSR	4274		1468		-1102	
By variable	**High AWW**	**Low AWW**	**High SV**	**Low SV**	**High Oxy3**	**Low Oxy3**
Time f. Water	9516	3313	N/A	N/A	4140	-2064
SVL, India	33727	3814	12696	1293	28350	-1563
Degree Ars. Cont.	4274	4274	N/A	N/A	-1102	-1102
SV purification Rate	N/A	N/A	1537	1263	N/A	N/A
Social Discount Rate	5809	2556	1764	1103	432	-2820
% HH expenditure ch.	4337	4211	1491	1446	-1039	-1166
SODIS DRR	N/A	N/A	2001	1062	N/A	N/A
AWG DRR children	6028	3307	N/A	N/A	652	-2070
AWG DRR adults	4433	4187	N/A	N/A	-944	-1190
BS Water children	4265	4284	N/A	N/A	-551	-1663
BS Water adults	4262	4287	N/A	N/A	-336	-1869
Exp. Per Year & Student	N/A	N/A	N/A	N/A	N/A	N/A
Project lifetime (AWG)	6019	1813	N/A	N/A	643	-3564

Table 5.14: NSR per household from sensitivity analysis, Gujarat, all project alternatives, 2011 US$.

	Base AWW		Base SV		Base Oxy3	
NSR	3956		1503		-1342	
Time f. Water	7286	3346	N/A	N/A	1987	-1953
SVL, India	36835	3443	14037	1308	31536	-1856
Degree Ars. Cont.	3956	3956	N/A	N/A	-1342	-1342
SV purification Rate	N/A	N/A	1572	1298	N/A	N/A
Social Discount Rate	5528	2225	1833	1098	229	-3074
% HH expenditure ch.	3989	3924	1508	1499	-1310	-1375
SODIS DRR	N/A	N/A	2047	1089	N/A	N/A
AWG DRR children	5852	2910	N/A	N/A	553	-2389
AWG DRR adults	4053	3903	N/A	N/A	-1246	-1396
BS Water children	4010	3902	N/A	N/A	-748	-1947
BS Water adults	4034	3879	N/A	N/A	-486	-2199
Exp. Per Year & Student	N/A	N/A	N/A	N/A	N/A	N/A
Project lifetime (AWG)	5601	1637	N/A	N/A	302	-3662