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A review of selected drinking water treatment plants delivered by Naandi Foundation in Andhra Pradesh, India.

En gjennomgang av utvalgte drikkevannsrenseanledd levert av Naandi i Andhra Pradesh, India

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Ås, fall 2010

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Preface/Acknowledgements

The fieldwork for this master thesis started with a stay in Hyderabad, the regional capital of Andhra Pradesh, India. During the first three weeks in Hyderabad, we visited several drinking water treatment plants and were informed about Naandis work in India. Most of the following work and observation were carried out at Naandis office in Vijayawada, Andhra Pradesh, from the start of July to the end of August 2010. The thesis was written as a part of our Master of Science degree in Water and Environmental Technology, at the Department of Mathematical Sciences and Technology, at the University of Life Sciences (UMB), Ås, Norway. This study was made possible through cooperation between Malthe Winje AS in Norway and Naandi foundation in India, where the objective is to get a better collaboration between the organizations. The background for choosing the thesis was a desire to learn about small-scale drinking water treatment plants and learn how to provide safe drinking water in developing countries. The project is co-financed by the University of Life Sciences, Ås.

We would like to thank the University for financial support that made this study possible. We would also like to express our sincere appreciation to the following people and organization for their help and supervision during the whole process:

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Summary

This report is based on experiences from fieldtrips carried out in the period 25.06.10 – 24.08.10 in Andhra Pradesh, India. Together with Naandi foundation, several villages were visited to assess small-scale drinking water purification plants raised under the auspices of "Naandis safe drinking water program". The purpose was to make a review of the observed plants and see if there was any potential improvements or challenges. In this context Naandi expressed a wish that two themes was examined more carefully: The plants' problems and challenges with focus on water quality, water source and pre surveys done before the installation and how the concentrate from the drinking water treatment plants can be handled, with focus on fluoride emission.

A literature review that describes water sources, water quality parameters and membrane filtration technology used by Naandi was written to provide a better understanding of Naandis drinking water purification plants.

The results from the observations shows that nearly all the drinking water treatment plants visited ensured enough clean and safe water to the people in the villages. According to this, Naandis safe drinking water program works perfectly. However, there were observed challenges connected to the plants that affect the costs, operation and maintenance and the water source. These challenges were borewells with water shortage, damaged membranes caused by fouling, plants with high maintenance costs as a result of inefficient pretreatment, low recovery rate of the raw water and absent reject water handling.

The quality and quantity of water in the raw water source played a main role in all the observed challenges and problems. There is suggested, based on the observed challenges, that Naandi should do a more thorough survey of the water source in terms of water quality and capacity before the plant is buildt and monitore this further during the operation of the plant. This can prevent dry borewells, broken membranes and high maintenance cost and lead to a more efficient operation of the plant.

There is considered several methods to remove fluoride from the reject water but most of them has been considered to be too expensive and therefore not possible to implement. The best solution is believed to be lime stone filter, because of low costs and simplicity.

Sammendrag

Denne rapporten er basert på erfaringer gjort under feltarbeid i perioden 25.06.10 – 24.08.10 i Andhra Pradesh, India. Landsbyer med småskala renseanlegg for drikkevann bygget i regi av Naandis program for trygt drikkevann, ble besøkt i samarbeid med Naandi. Formålet var å lage en oppsummering av anleggene og se på utfordringer og mulig forbedringspotensiale. Naandi ønsket at det ble rettet ekstra fokus mot to temaer: anleggenes utfordringer med tanke på vannkvalitet, vannkilde og forundersøkelser før installasjon og hvordan konsentratet fra vannrensetrinnet med tanke på fluorutslipp kan behandles.

Det ble gjort en litteraturgjennomgang av vannkilder, vannkvalitetsparametre og membranfiltrering som brukes av Naandi, for å gi en bedre forståelse av Naandis drikkevannsanlegg.

Observasjonene som ble gjort viste at de fleste anleggene leverte tilstrekkelig med rent vann til landsbyene der anleggene er installert. Med dette i mente, fungerte Naandis program for trygt drikkevann godt. Det ble derimot observert utfordringer og problemer som påvirket anleggets kostnader, drift, vedlikehold og vannkilde. Disse utfordringene var som følger: brønner som ble pumpet tomme, ødelagte membraner forårsaket fouling, anlegg med høye driftkostnader som forårsaket ineffektiv forbehandling av råvannet, lav utnyttelsesgrad av råvannet og manglene håndtering av konsentratet fra renseanlegget.

Alle de observerte problemene og utfordringene kan relateres til kvaliteten og kvantiteten av vannet i vannkilden. Basert på dette, er det foreslått at Naandi gjør en bedre forundersøkelse av vannkilden med tanke på kvalitet og kvantitet, og fortsetter og overvåke dette under drift av anlegget. Dette kan forhindre tomme brønner, ødelagte membraner og høye driftskostnader, og lede til mer effektiv drift av anleggene.

Det er gjennomgått flere metoder for å fjerne fluor fra konsentratet fra vannrensetrinnet, men de fleste viste seg å bli for dyre å installere. Kalksteinfilter ble ansett som den beste metoden på grunn av lave kostnader og enkel oppbygning.

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Part 1: Introduction

1.1 The water situation in India today

India has 4 per cent of the world's fresh water resources and 15 per cent of the world's population. The average annual rainfall for India is 1160 mm, which is the highest average anywhere in the world for a country of comparable size. The rainfall however, fluctuates widely. While some regions have recorded 11690 mm precipitation per year, others have received barely 150 mm. Though the average rainfall in India is adequate to provide sufficient water for everybody, nearly ¾ of the rain pours down in less than 120 days, from June to September. This results that some areas experiencing both drought and flood in the same year. *(Kumara et al., 2005)*.

India has made good progress towards providing safe drinking water for their population. Nevertheless, only 7 out of 28 states in India have achieved full coverage with providing a protected water source for their villages *(Naandi Foundation, 2010).*

Quality of drinking water is a continues concern, and it is reflected by the fact that about 21 per cent of communicable diseases are water born and 75 per cent of water related deaths are that of children below five years *(Naandi Foundation, 2010).* Endemic flurorosis also remains a big challenge. In 1999, 17 out of 28 states in India have areas where it has been reported high natural level of fluoride in the groundwater *(Fawell et al., 2006)*. The most affected areas are Andhra Pradesh, Punjab, Haryana, Rajasthan, Gujarat, Tamil Nagu and Utta Pradesh. Within these states, 10 to 25 per cent of the rural population are considered to be at risk of getting health problems as a result of fluoride intake. A total of 60-70 million people can be at risk, just in India *(Fawell et al., 2006).*

1.2 Naandi foundation

Naandi foundation was founded in 1998, as a non-governmental organisation (NGO) by Dr. K. Anji Reddy and Anand Mahindra. Today Naandi foundation is one of the largest and fastest growing social sector organisations in India.

Naandi is a not-for-profit organisation, which means that Naandi Foundation will not make any economical benefits from any of the projects they are involved in. Every dollar that runs into the Naandi system will be used to enhance the quality of life for the less privileged in the society. Naandis focus is on basic needs like food, quality education, safe drinking water and livelihood opportunities. These challenges affect millions of Indians every day. Every Naandi-project is based on an ideology that says they will build sustainable models within the social sector that deliver critical services efficiently to the communities.

Together with the government, corporates, civil society and communities, Naandi works for solutions that make the most efficient and equitable use of the money spent on the projects, and solve the poverty-related issues in India.

Naandi works within different projects like; provide safe drinking water to villages in rural areas, help farmers to create sustainable livelihoods, midday meal programme for school children and education.

India is divided into 28 states. So far Naandi operate in nine of them. The states where they have projects are: Andhra Pradesh, Rajasthan, Madhya Pradesh, Chhattisgarh, Orissa, Nagaland, Punjab, Haryana and Maharashtra.

Naandi need financial help to implement the different projects. The projects are therefore financed by different actors like the state government, local NGO´s in associations with the government department, NRI´s (Non resident Indians) who have faith in the project, founding agencies like (Frank water (UK), global giving (USA)) and local businessmen who have affiliation to the project site. (*Naandi Foundation*, 2010).

1.3 Naandi safe drinking water program

Population in rural areas in India suffer from bad water quality due to lack of water treatment. High amounts of fluoride and arsenic in the water together with pathogenic microorganisms as cholera, diarrhoea and typhoid, are typically problems that the people suffer from. The safe drinking water programme is created to provide safe drinking water to the villages where this is a concern.

The safe drinking water programme operates in four states in India: Rajasthan, Hariyana, Punjab and Andhra Pradesh. With this programme Naandi has developed a solution that is workable under the given conditions and will ensure villages safe drinking water.

Villages suffering from bad water quality will be contacted and asked if they want to be part of the safe drinking water programme by Naandi. It is important to mention that Naandi will not have any economic advantage of this programme. All components are delivered and assembled from separate partners. Naandi´s work is to do a socio-economic survey, and together with the client decide what kind of technology that is preferable for that particular water source to provide safe water. Naandi will also use their expertise to calculate the need of water in the village, and take care of the operation to build and maintain the drinking water treatment plant for five years. After five years, the plan is that the village has gained enough experience to maintain and operate the water purification plant without help. Naandi could then hand over the responsibility for the drinking water treatment plant to the village. This model gives Naandi opportunity to offer the safe drinking water programme to villages that suffer from bad water quality, and the village will get a water purification plant that ensures access to safe and clean water.

Before Naandi start the project to build a water purification plant, they need a confirmation from the Gram panchayath(village governor) that he will provide a location, a raw water source and electricity to the plant. He also has to confirm that the village is able to collect and pay a percentage of the building cost. The rest of the recourses will be raised from philanthropist, external agencies like Frank water and Water health or as loans from financial institutions.

After the factors mentioned above are ensured and Naandi has made an agreement with the client regarding building process and maintenance of the water purification plant, the total completion will take 90 days, including recruiting and training a plant operator and a safe water promoter. Both will be recruited from the village. The safe water promoters' job is to create awareness among the villagers about the plant and the need of safe drinking water.

People living in the village have to buy a membership from Naandi before they use the plant. The membership costs 150 INR (3,25 USD), and this includes a 20-litre water can. After signing the membership, a monthly fee of 60 – 90 INR has to be paid (depending on the cost of running the plant), to get a membership card with 30 slots. One slot will be marked off for every 20-litre jug that is filled. These charges will cover operational costs as salary of the staff, electricity, washing and antiscaling chemicals and filters that have to be replaced.

The plants product water are analysed every month. The result is published on the plant to let people know the quality of the water they buy. Naandi will also visit and control the operation of the plant monthly.

Naandi has over 400 plants running across the country. To treat the water, Naandi mainly uses membrane filtration together with UV disinfection. At some locations with good raw water quality they only use UV disinfection to ensure that the water not contain any waterborne infection agents.

1.4 Aims and objectives

After a five-year program with Water and Environmental technology at UMB, we feel that we have a broad expertise in water treatment and environmental understanding. Our goal has always been to have a broad approach in our thesis. Therefore, we have chosen a complex task, where there are challenges in several issues. We hope that our work will show the effort Naandi are doing to provide safe drinking water in rural areas in India, and help to solve the challenges they are struggling with.

Naandi foundation presented two themes that needed further research:

- Challenges with installation of drinking water treatment plants in rural areas, with focus on water quality, water source, and collection of necessary conditions for the proper construction of the plant.
- Suggestions for how the concentrate (reject water) from the drinking water treatment plants can be handled with special focus on fluoride emission.

A literature review that includes a description of different water quality and sources will be presented in the thesis. We will further present different membrane filtration technologies, including a description of reverse osmoses (RO). Furthermore, the results from our observation will be presented, and we will explain challenges observed and factors that leading to these challenges. In the last part: 7 and 8, we will discuss the specific findings and present solutions for improvements.

There is a main goal that the discussed solution that can be of benefit both for Naandi and the communities where the plants are located. There is an aim to give both good theoretical and practical solution for the two themes.

1.5 Materials and methods

Several water treatment plants in the Indian state of Andhra Pradesh have been visited. These are further on referred to as plants or treatment plants..

Implementation of the project started by collecting information about the operation of the plants, water sources and how the reject water was handled. The data collection includes water samples, photography's and simple drawings of the area as well as interviews with plant operators.

Literature survey has been conducted on water sources, fluoride and membrane technology to get a better basis.

We have emphasized the use of self-produced material in the thesis, such as photographs, tables and results from the water samples. This material is marked as follows: *(Havig and Holstad, 2010)*. All material obtained from external sources are labelled with references.

1.6 Limitation of the thesis

The water source significance for the treatment plant is something we have emphasized substantially. The focus has been on how the water source affects the operation of the plant, and how the reject water influences the water source.

We have disregarded arsenic as a problem in the groundwater, because it is not present in the observed area. This is an important issue when providing safe drinking water and therefore must be mapped out carefully in the affected areas.

Details' regarding costs of the different solutions has not been handled, but it has still been the basis for decisions we have taken.

A number of technical solutions have been described in general. The technical solutions have to be evaluated more thoroughly before they can be used in for further research.

Part 2: Theory of water quality and water sources

2.1 Drinking water quality

Due to the fact that water is a dissolvent agent, it will normally contain many other substances than just H_2O. Different matters like minerals, gases and organic materials dissolve in the water easily. Water also picks up fine particles wherever it flows, like silt, sand, iron, organics etc. Algae and bacteria can also take place in the water and result in biological growth. Therefore natural water is usually contaminated with numerous dissolved and un-dissolved solids, along with living matters. These contaminates determine the quality of the water, and give a good idea about what kind of treatment processes that are necessary to get drinking water out of the particular source.

The most common contaminants in water are:

Hardness: If the water contains calcium and magnesium salt in considerable amounts, it is termed as hard water. There have not been registered negative health effects due to calcium in drinking water, but there are several user-related problems with hard water. These salts enter the water source through leaching from minerals. Common mineral source of calcium is limestone, while the magnesium typically can come from dolomite.

Colour: The colours in the water are due to dissolved matter. The colour is usually brownish from humus and decayed vegetation, but also metals as iron and manganese can affect the colour of the water.

Dissolved gases: Water normally contains dissolved gases such as free oxygen (O_2) or carbon dioxide (CO_2). High amount of carbon dioxide in the water will make the water more corrosive. The quantities of CO_2 are usually higher in water that does not come in contact with the atmosphere where CO_2 can be released, typically for ground water. Surface water generally contains smaller quantities of CO_2. When water comes in contact with air, oxygen will dissolve in the water until the water is saturated. Surface water may therefore contain oxygen in large quantities, while ground water normally contain oxygen in smaller quantities. Many water sources also contain the gas hydrogen sulphide (H_2S). Hydrogen sulphide is responsible for the well-known “rotten egg” odour noticed in some water supplies. Smell and taste can make the water undesirable to drink.

Suspended matters: Sediments like clay, silt, sand, algae and insoluble iron form visible dirt called suspended matters. In water supplies it is generally classified as turbidity.

Pathogenic microorganisms: Pathogenic microorganisms that are transmitted when water is consumed can cause diseases. Bacteria, virus or protozoa mostly from the intestine of humans or animals, are the main source. Diarrheal diseases related to infected drinking water, accounts for one of the biggest loss of children today in the developing countries (*Fawell et al., 2006*).

Nutrition: All living organisms need nutrients to grow. Nitrate and Phosphor are usually the nutrients that lead to eutrophication in the water source. There are two common sources for the nutrients nitrate and phosphor: point and nonpoint sources. Typical point sources are untreated sewage, wastewater effluent, runoff and leakage from waste disposal. Nonpoint sources can be runoff from agriculture/irrigation, urban runoff areas and general runoff from the ground.

Odour and taste: Water can have bad taste and odour. This can have different origin like algae, fish, different effluent and hydrogen sulphide. These substances can contribute to odour and taste of the water.

Heavy metals: Generic term for metals with density greater than 5 g/cm^3 e.g. Cadmium, zinc, mercury, lead among others. Heavy metals are elements and therefore impossible to break down. Heavy metals will as results of this accumulate in organisms. Some of the heavy metals are necessary for the function of humans' body, but several have toxic biological effect even in very small concentrations. They can lead to damage on the nervous system, kidney, and other metabolic disruptions. Heavy metals may occur naturally in the soil, but can also come from industrial emissions. *(Store Norske leksikon, 2010)*

Fluoride: Fluoride is just one of several substances in water, however it is one of the major challenges in providing safe drinking water in the affected districts. Large doses are regarded as toxic, and lead to health problems like dental fluorsis and skeletal flurosis. Fluoride is a substance that is difficult to derogate from the water and therefore requires more advanced techniques. Naandi express a great concern for the problem with high fluoride intake in drinking water and are working to eliminate this problem.

This is why fluoride is given extra attention in the review.
Fluoride (F^-), is the reduced form of Fluorine (F). It is a common element on the earth as the crust contains about 0.06-0.09 per cent Fluoride. Fluoride is found in different minerals as fluorspar, rock phosphate, cryolite, apatite and others. One of the most common minerals with Fluorine is Fluorite (CaF_2), occurring in both sedimentary and igneous rocks.

Fluoride is found in all natural water sources. Seawater contains an average of 1 mg/l of fluoride, while rivers and lakes usually have low contents of fluoride, typically under 0,5 mg/l. In groundwater the variations are greater, given the properties of minerals in the ground. The main reason for this is that groundwater has greater contact surface and retention time with the surrounding rocks. If the minerals in the ground have a high fluoride level, it is likely that the groundwater also will have a high fluoride level. The concentration of fluoride in the water is determined by the fluorite solubility. The amount of dissolved fluoride is limited by the amount of calcium in the water. This means that the concentration of fluoride can be high if calcium is absent. The same goes for the opposite: if the consecration of calcium in the water is high, there will be low levels of dissolved fluoride in the water *(Fawell et al., 2006).*

Fluoride is an important substance for the function of the human body; it helps bone structure and fights dental decay. For most people this is a good thing and many countries add fluoride in the water to prevent dental decay. However in cases of naturally high fluoride content, the objective will be to lower the fluoride level. On world basis, drinking water is regarded as the largest contributor of daily fluoride intake *(Fawell et al., 2006)*. The average concentration per day is therefore largely given by where we live. With increasing temperature and humidity, the average water consumption will increase. On the basis of variation of where one live, one must consider how much fluoride is an acceptable level in the drinking water. The World Health Organizations' (WHO) expert committee on oral health has concluded that 1.0 mg F/l should be the absolute highest concentration, even in cold climates. 0.5 mg F/l is a recommended lower concentration, this to prevent teeth decay *(W. H. O. Expert Committee on Recent Advances in Oral Health, 1994).*

2.2 Indian drinking water standards

To ensure that the plants provide safe drinking water, Naandi analyzes the water every month. This is to make sure that the plants are working satisfactory and the users can see that the product holds the Indian standard for drinking water.

The Indian standard for drinking water is called IS 10500: 1991. It specifies an upper limit for desirable and permissible drinking water. The drinking water standard is from 1991 and made by the Bureau of Indian Standards. *(Bureau of indian standards, 2003), (Thermax LTD)*

The Indian standard for drinking water contains several different parameters. The parameters listed below are the parameters Naandi use when they analyze the water. These parameters have restrictions regarding the Indian drinking water standard.

Technical terms are explained below:

- *Desirable limits: The desired upper limits of all drinking water in India.*
- *Permissible limits: A legal upper limit in absents of other alternatives.*
- *PPM or mg/l: Parts Per Millions, also the same as milligrams per litre.*
- *NTU: Nephelometric Turbidity Unit, the cloudiness or haziness of the water.*
- *Hazen Units: Spectrophotometric determination of water colour.*

pH: *Desirable limit:* pH 6,5 - 8,5, *Permissible limit:* No pH limits.
pH is a measurement for acidity in water solutions. A neutral solution, like pure water has pH 7. If the pH is below 7 we call the solution acidic, if it above 7 we call it alkalic. Most substances have a pH between 0 and 14.

Colour: *Desirable limit:* 5Hz, *Permissible limit:* 25Hz.
Colour is a measurement of the colour of the water and is given in Hazen. Colour comes from dissolved substances in the water.

Total dissolved solids (TDS): *Desirable limit:* 500mg/l, *Permissible limit:* 2000mg/l.
Total dissolved solids is the total of all mineral solids dissolved in the water.

Turbidity: *Desirable limit:* 5 NTU, *Permissible limit:* 25 NTU.
Turbidity is a measure of the amount of finely divided suspended matters in the water. It

is commonly given in NTU, which is a measure of how much light that is able to pass through the water samples.

Hardness: *Desirable limit:* 300 mg/l, *Permissible limit:* 600mg/l, as total hardness. Hardness is the present of dissolved calcium and magnesium. It is measured as total hardness which contains both temporary and permanent hardness, given as ($CaCO_3$).

Alkalinity: *Desirable limit:* 200mg/l, *Permissible limit:* 600 mg/l, as methyl orange. Alkalinity is the presence of three anions in the water. Carbonates (CO_3), Bicarbonates (HCO_3) and Hydroxyl (OH). The alkalinity is determined by titration of acid solution to the methyl orange, which includes all three anions mention above.

Iron (Fe): *Desirable limit:* 0.3 mg/l, *Permissible limit:* 1.0 mg/l.

Chloride (Cl): *Desirable limit:* 250mg/l, *Permissible limit:* 1000mg/l.

Sulphate (SO_4): *Desirable limit:* 200mg/l, *Permissible limit:* 400mg/l.

Nitrate (NO_3^-): *Desirable limit:* 45mg/l, *Permissible limit:* 100mg/l.

Fluoride (F): *Desirable limit:* 1 mg/l, *Permissible limit:* 1.5 mg/l.

2.3 Water sources

Naandis water purification plants use different raw water sources depending on what is available in the village. The raw water source could be surface water like lakes, ponds and rivers, or groundwater. Groundwater is the most common water source for the villages visited in Andhra Pradesh, but some of the sites also uses river water and water from small lakes and ponds. The different raw water sources will give dissimilar quality depending on the location of the source and external influences. When building a new water purification plant, it is important to take this into consideration.

2.3.1 Shallow lakes and ponds

Shallow lakes and ponds are not normally preferred as water sources because they generally are poor protected against external influences and often very vulnerable to pollutions. Typical pollution sources could be fertilizers used in agriculture, industrial emissions, human waste or infectious agents from humans and animals. *(The Norwegian Institute of Public Health, 2004).*

Fertilizers like phosphorous and nitrogen can be attached to the lake or pond by runoff water from nearby agricultural fields. Phosphorous and nitrogen can cause an increase of organic materials in the water source and lead to eutrophication. Organic matter could damage the lake or pond in the sense of that the microorganisms use free oxygen in the water to break the organic materials down. In a long-term view, the lack of oxygen in the water could damage the ecosystem in the lake or pond and make it useless as a water source. Lack of oxygen could also lead to release of unwanted substances from the water source. *(The Norwegian Institute of Public Health, 2004)*.

Shallow lakes and ponds are vulnerable to pollutions like chemicals and infectious agents because of the limited water volume.
Water sources with limited amount of water has several disadvantages:

- The dilution effect will be less effective in a small water source, which means it will be a bigger chance that the contaminants will reach the consumer.
- A shallow lake or pond will not be able to form a stable temperature layer, which means that a warmer surface layer will cover and protect the underlying colder layer from contamination.
- Because of the short retention time, pollutants will not get broken down properly and absorbed by organisms, nor settled thoroughly, compared to a deeper lake with larger surface area.

Shallow lakes and ponds that are used as water supplies should be protected from external influences to ensure that the water quality does not deteriorate.

2.3.2 Rivers

Rivers are exposed to many of the same influences as shallow lakes and ponds. The water quality and capacity in rivers will often be highly variable. Especially in areas with season-based rain, the quality and capacity will change according to the seasons.

Like the shallow lakes and ponds, the river water could also easily be exposed to accidental contamination. The quick transport of water in a river makes the water intake vulnerable for upstream pollution. The good thing is that acute discharges rapidly will be transported past the intake. A few aspects should be considered before rivers are used as a water source *(The Norwegian Institute of Public Health, 2004)*.

- The water flow in the river should be high and steady over the year.
- Lakes represented in the catchment area, will ensure a more steady quality and flow of water in the river. The lakes will recharge the river if the geology allows it.
- Pollution in the precipitation area could easily reach the river. This will depend on the percolation and the filtering effect of the sediments in the soil.
- If the water quality varies widely during the year, it could make the water purification more complicated.

2.3.3 Groundwater

Groundwater is water located below ground level where all the cracks and pores in the soil or bedrock are completely filled with water. The stability and quality in the groundwater source will depend on many different factors such as permeability, retention time in the ground, filtering properties in the soil, hydrology and geological formation. Generally, groundwater will have better protection against pollution and other external influences compared to surface waters.

The groundwater quality is usually characterized by the chemical composition in the ground. This is why the groundwater generally is less acidic and contains more minerals than surface water, but it could also have negative effect on the odour and taste. Under certain conditions, naturally substances in the ground like flour, arsenic, iron and radon could reduce the quality of the groundwater, or in worst case make it unsuitable as a water source.

Ground water is divided into two main groups after geological formation: groundwater in sediments and groundwater in bedrock

2.3.3.1 Groundwater in sediment

Groundwater in sediments can be fed with water from rivers, lakes, ponds, precipitation, or a combination of this. The groundwater quality will depend on the type of the overlying sediments, depth of the aeration zone, retention time and chemical composition in the ground. Another important element is the sediments filtering effect when the water percolates through the soil *(The Norwegian Institute of Public Health, 2004)*. Normally, groundwater in sediment gives good protection against pollutions. Especially if the aquifer has some size due to the dilution and the grain composition in the sediment is small enough to prevent pollutions from getting through. If the retention time for the groundwater is over 60 days, it is considered to be free from microbes *(The Norwegian Institute of Public Health, 2004).*

Before drilling a borewell it is important to know how the groundwater outtake will affect the ground around the well and the sediments' ability to retain contaminants. Knowledge about the sediment thickness, grain size and the water flow in the ground will give this information. How much water it is possible to take out from the ground, depends on the sediments permeability.

The area around the borewell has to be protected from contamination that may affect the groundwater. Discharge of contaminations such as oil and heavy metals, can make the groundwater unsuitable as water source for years.

2.3.3.2 Groundwater in bedrock

Groundwater can also be present in bedrock. Water will find the way through cracks and spaces. Since the water follows different cracks and openings in the bedrock, it could be transported over a long distance in short time if the well is pumped heavily. This can make it difficult to know where the water comes from in terms of potential pollution sources.

Groundwater from bedrock is often influenced by both surface water and soluble components that come from the bedrock. A layer of sediments such as sand, gravel, clay over the cracks and openings in the bedrock, will often be the main protection against pollution.

Aspects that can affect the ground water in a negative way:

- Free oxygen in the ground will be used in the process to break down organic materials that originates from soil erosion or emissions. This could lead to anaerobic conditions and the carbon dioxide that is formed from this process, will make the water acidic. That again can lead to dissolution of iron, manganese, calcium and magnesium.
- Borewells close to the beach could under some conditions be exposed for salt-water intrusion, if the groundwater level is low. On this point, seawater will be able to feed the aquifer.
- High amounts of some metals could give bad taste.

- Microbial contamination from human activity could affect the groundwater.
- Nitrate and nitrite can be found in the groundwater aquifers that are located in agricultural districts. This is caused by runoff water from the surface of the fertilized area.

Part 3: Theory of membrane filtration technology

3.1 Membrane filtration

Membrane filtration is a wide subject with many different methods and opportunities. In this chapter the focus will mainly be at membrane filtration using reverse osmosis (RO), as RO is the preferred treatment technology used by Naandi.

Membrane filtration is a collective term for several different types of filtering, where a membrane is used to separate contamination from the water. The pore size or the density of the membrane will decide what kind of contamination they are able to reject. This could be everything from particular materials to dissolved solids. The advantage with this type of water treatment is the possibility to decide the water quality of the treated water after the needs at the specific site.

The general principle of membrane filtration could be explained as follows: Water is pushed through a membrane by using a pressure pump. Depending on the pore size of the membrane, different particles in the water will be prevented from getting through because of their size (figure 1). The concentration of contamination will increase on the pressure side of the membrane, and decrease on the other side.

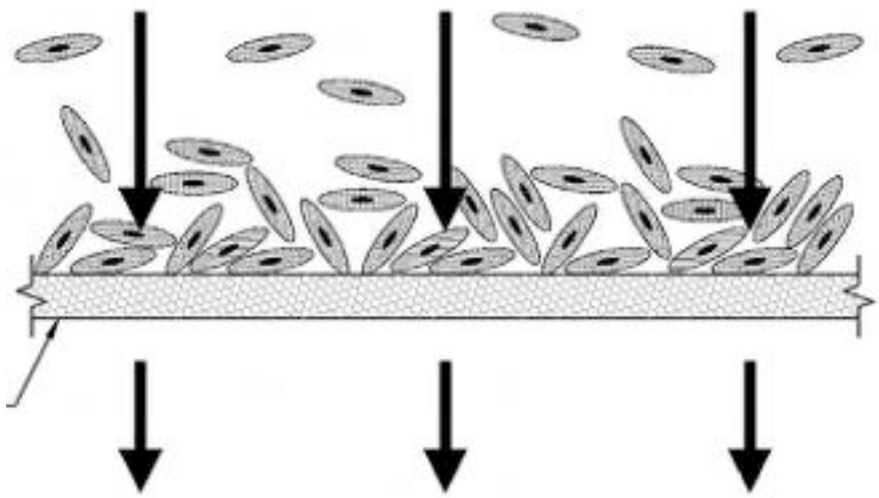

Figure 1: The general principle of membrane filtration. Water flows trough the membrane (in direction of the arrows) and contaminations will be rejected. (United States Environmental Protection Agency Office of Water, 2005).

There are two filtration techniques that are used, “dead end filtration “ and “cross flow filtration” (figure 2). In the “dead end filtration” the water flow will be vertical on the membrane. In the “cross flow filtration” the water flow will follow the membrane surface horizontally, and the pressure will push some of the water through the membrane at the same time.

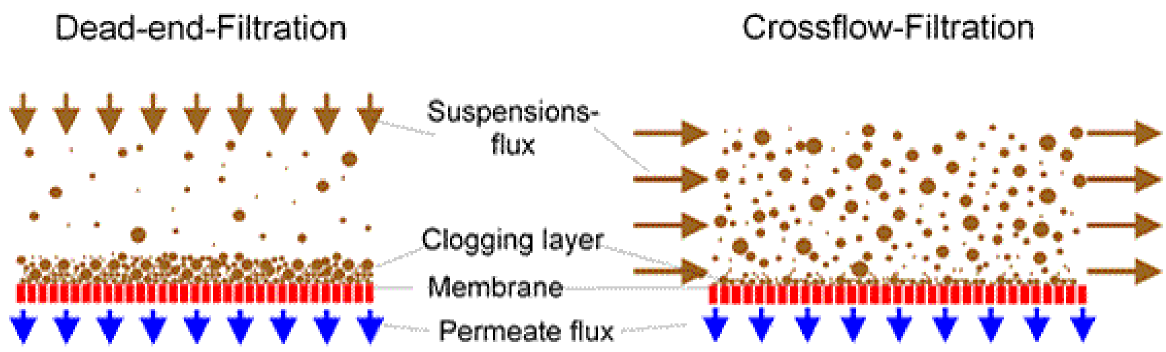

Figure 2: The two main filtration techniques. (Memos membranes modules systems, 2010)

The different membrane filtering processes used in water treatment is categorized after the membranes’ filtering properties or pore size and design. The most common membrane processes used in this purpose are microfiltration (MF), ultrafiltration (UF), nanofiltration (NF) and reverse osmosis (RO).

Micro filtration membranes (MF membranes) have pores with size normally around 0,1 – 0,2 µm, reject large particles and some microorganisms. UF membranes have smaller pores, normally around 0,01 – 0,05 µm, and in addition to what a MF membrane can reject, they also reject bacteria and proteins. NF membranes can be either semi-permeable or porous *(United States Environmental Protection Agency Office of Water, 2005).* A semi-permeable membrane is a membrane where the spaces between the molecules in the membrane material are the only openings. NF membranes’ reject performance is between RO and UF. Membranes used in RO are semi-permeable. RO membranes could reject salt ions, organics and other low molar mass species *(Sagle and Freeman).*

It will be difficult to define exactly pore size in a semi-permeable membrane, therefore molecular weight cutoff (MWCO) is used to describe the filtering properties. MWCO is expressed in Daltons and is the rejection characteristic of a membrane based on atomic weight or mass instead of size. A membrane with a specified MWCO, will hold back >90 percent of the compounds or molecules with a molecular weight exceeding the specified MWCO *(Wagner and B. Sc. Chem., 2001)*. The MWCO level for a RO membrane will typicaly be less than 100 Daltons *(United States Environmental Protection Agency Office of Water, 2005)*.

3.2 Reverse osmosis

To understand the properties of reverse osmosis, the osmosis has to be explained. Osmosis is a naturally phenomenon that occurs when water molecules flow from a solution with low saline concentration through a semi-permeable membrane into a solution with high saline concentration. The two different solutions will try to reach equilibrium with each other. The salt in the solution will not be able to penetrate the membrane; only the water molecules will pass through. They will keep doing this until the solution is in equilibrium or the water level in the column with the high saline concentration has increased so much that the pressure is high enough to force the water molecules back (osmotic pressure). It is the water molecules' ability to flow through a semi-permeable membrane that will give reverse osmosis the opportunity to remove dissolved solids from the water. *(DOW, 2010b)*.

As the name indicates, reverse osmosis is the opposite of osmosis. In a reverse osmosis process, pressure will be added to the column with the high saline concentration. When the pressure is high enough, the water that flows through the membrane will change direction and the natural osmotic process will be reversed. This will increase the concentration of salt in the pressure side of the membrane (feed) and increase the volume of water with low concentration on the opposite side (permeate).

There are several theoretical models that describe solute transport through the RO membranes. The principal models are known as "solution diffusion" and "capillary pore", but it is the solution diffusion model that is the most accepted model to describe the transport through a RO membrane. The solution diffusion model is based on diffusion of molecules in a dense polymer. The pressure, temperature and composition of the fluids on both sides of the membrane will affect this. *(Baker, 2004)*.

3.2.1 RO membranes characteristics

There are generally two main groups of membranes. They are classified after their structure and/or chemical composition, as isotropic membranes or anisotropic membranes. Isotropic membranes are uniform in material and structure across the cross section of the membrane in contrast to anisotropic membranes that are non-uniform in material and structure. To improve the flux the dense separation layer should be as thin as possible, as the transport rate through a membrane is inversely proportional to the thickness of the membrane. In anisotropic membrane, an underlying material that is more porous will support the thin dense layer on top (figure 3). This will make it possible to make the dense layer thin as possible and then improve the flux. Most of the membranes used in RO are anisotropic. *(Baker, 2004)*.

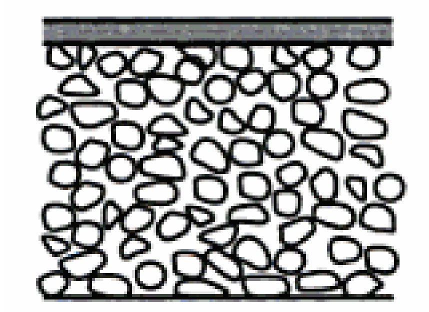

Figure 3: The cross section of a thin film composite anisotropic membrane (Baker, 2004).

Most RO membranes are synthetic and made of organic polymers. Synthetic organic polymers are artificial manufactured and have the advantage of low cost compared to inorganic materials like ceramic or metal. RO membranes are typically either made of cellulose acetate or polysulfone coated with aromatic polyamides. There are advantages and disadvantages with both types. A cellulose-based membrane is stable only in a pH range between 4–6. If the temperature increases, the salt rejection will decrease. The feed water temperature should therefore not exceed 35°C. They are also more susceptible to biodegradation and hydrolyze. The advantage is that the cellulose membrane can tolerate chlorine to a certain extent without taking damage. This could be used to control biodegradation and biofouling. High rejection, flux and stability over a large pH range are advantages of thin film composite membranes (TFC). TFC membranes could also handle higher water temperatures than cellulose-based membranes. The drawback with TFC membranes is their low tolerance against strong oxidants like chlorine. *(Sagle and Freeman)*.

3.3 Spiral-wound modules

Spiral-wound modules are the most common membrane modules designed for RO. The combination of a large membrane surface in a compact module is an advantage and it makes spiral-wound modules generally the preferred choice to remove dissolved solids in the water.

The basic design of a spiral-wound module could be explained as follows: The spiral-wound module contains two membrane sheets that are placed back to back separated by a fabric spacer/permeate collection material (figure 4). Three edges of the membrane will be glued on the fabric spacer (on both sides), together this will constitute a "leaf". The open edge will be sealed to a central tube that is perforated. The central tube, depending on the diameter, often 8 inch, could contain up to 20 "leafs". The "leafs" will be separated by a feed or reject spacer and rolled around the central tube (picture 1), and form a spiral-wound Module.

The feed water will enter at the end of the spiral-wound element, and the water flow will be parallel to the central tube (cross flow filtration). Some of the water will penetrate the semi-permeable membrane on both sides of the leaf and follow the fabric spacer around the membrane layers until it reaches the central tube and flow out as permeate water. The rest of the feed water, dissolved solids and particular contaminants that are rejected by the semi-permeable membranes, will follow the central tube to the end of the membrane module and out of the system.

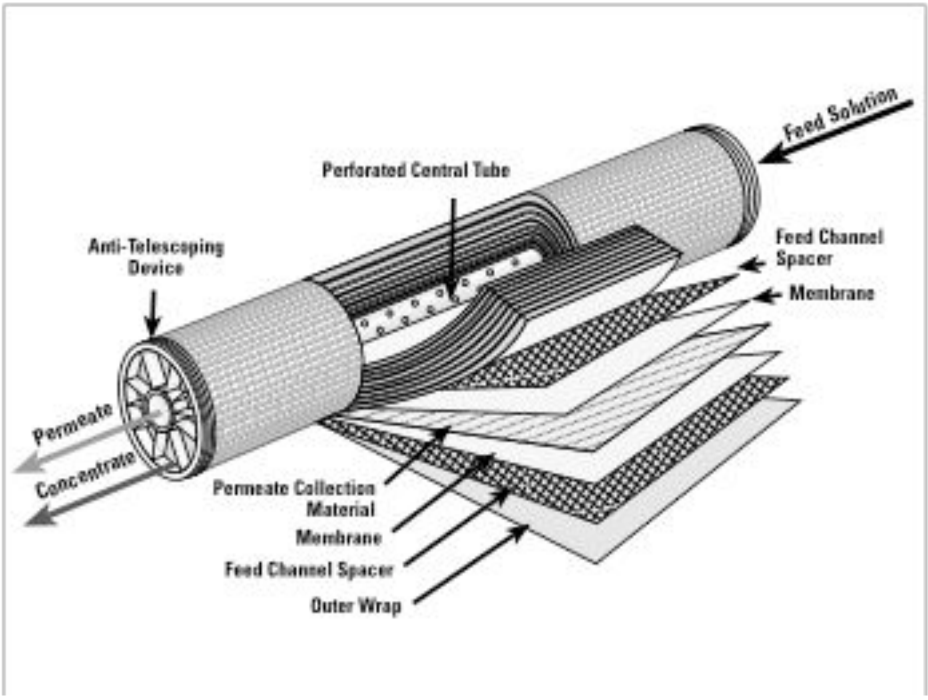

Figure 4: Spiral-wound module (Wagner and B. Sc. Chem., 2001).

Picture 1: The picture shows "leafs" that are connected and rolled around the central tube (Havig and Holstad, 2010).

3.4 Theoretical flux and salt rejection of RO membranes

The most important operating parameters for RO membranes in terms of membrane flux and salt rejection will be: pressure, salt concentration and temperature. The water flux and salt rejection for a RO membrane could be derived, according to *(Baker, 2004)*, as follows:

Water flux:

$J_i = A(\Delta P\text{-}\Delta\pi)$

Where:

J_i = Water flux
A = Constant
ΔP= Pressure difference across the membrane
$\Delta\pi$ = Osmotic pressure difference across the membrane

As the equation shows, the water will flow from the dilute to the concentrated salt solution side of the membrane when $\Delta P<\Delta\pi$ (osmosis). If $\Delta P=\Delta\pi$ will no flow occur and if $\Delta P>\Delta\pi$ will reverse osmosis occur.

Salt flux:

$J_j = B(c_{jo}\text{-}c_{jl})$

Where:

J_j = Salt flux
B = Salt permeably constant
c_{jo} = Salt concentration in the feed water
C_{jl} = salt concentration in the permeate

Since the salt concentration on the permeate side normally is much lower than the concentration on the feed side, the salt flux could be described as:

$J_j = B(c_{jo})$

The two equations above show that the water flux is proportional to the pressure added, unlike the salt flux that is independent of the pressure. This means that the membrane will be more selective when the pressure increases. The selectivity could be measured as the salt rejection coefficient:

$$R = \left[1 - \frac{c_{jl}}{c_{jo}}\right] * 100\%$$

R = salt rejection coefficient

The salt concentration on the permeate side of the membrane could be described as below:

$$c_{jl} = \frac{J_j}{J_i} * \rho_i$$

ρ_i = Density of water (g/cm^3)

The membrane rejection could now be expressed as:

$$R = \left[1 - \frac{\rho_i * B}{A(\Delta P - \Delta \pi)}\right] * 100\%$$

The equations above determine the most important parameters in RO membrane filtration.

- When the feed pressure (ΔP) increases, the water flux will increase linearly and the salt rejection could pass 99 % due to the pressure.
- When the salt concentrations increase, the salt rejection and flux will decrease.
- When the water temperatures increase, the water flux increase and the salt rejection will decrease.

Part 4: Assessment of the drinking water treatment plants

4.1 Plant surveys

To get a systematic overview of what we saw when we visited plants a checklist was created. Our main objective was to observe how the water source affected the system, how the plant was operated and maintained and how the reject water from the plant was handled. It was important to visit the plant personally to get correct answers, and evaluate the situation on site. The checklist was as followed:

- Number of users
- Hours of operation per day
- How long has the plant been in operation
- What is the water source
- Has there been any problem with the water source
- Observe the water source
    - Ground soil
    - Are there some high parameters in the raw water
    - Are there water scarcity
    - Are there some pollution in the area
- How has it been operated and maintained
- Has there been any problems with the equipment
- Which tests were carried out before installing this plant
- Are the users satisfied
- How much electric power does the plant use
- Pressure on the RO membrane
- Differential between inflow and outflow
- How is the plant built up, producer, type of elements and capacity
- How is the reject water handled
- Take picture of the area and the latest test report of the purified water
- Draw a simple sketch of the area
- Take water samples of reject water and raw water

Since Naandi regularly takes samples of the treated water, we decided to copy their latest water sample results instead of take our own. At sites where we could not get a raw water sample, we copied Naandis water samples taken before the plant was built. The water samples presented in part 5.1 will therefore be from different times of the year, and from different years.

The answers we got came from the operators of the plants, maintenance personnel and our own observations. Reports from the plants are found in attachment 1.

4.2 The water sources

When Naandi builds a plant at a new site, it is the clients' responsibility to provide a suitable water source. The client will either be the village or the government.

In some villages the RO plant water supply is solved easily with placing the plant next to the local water tower. The plant can then be connected into the same borewell that already is used to supply the water tower. On sites where this is not possible, the most common option is to drill a new borewell or use a nearby surface source. Usually a local well driller will be hired in to locate a suitable location and drill a borewell. He will have the advantage of being well known in the area and probably have the necessary experience and right techniques to locate a borewell that is suitable as water supply. Before the building of the plant starts, information about the water source will be sent as a part of the primary information report to Naandi. Naandi will then take a water sample of the source to document the water quality. This test gives information about physical and chemical parameters in the raw water that could be important for the operation of the RO plant. *(Pankajan, 2010)* The parameters are listed below:

- pH
- Colour
- Electrical Conductivity
- Turbidity
- Total dissolved solids
- Total hardness as $CaCO_3$
- Non Carbonate hardness as $CaCO_3$
- Calcium hardness as $CaCO_3$
- Alkalinity to Phenolphthalein as $CaCO_3$
- Alkalinity to Methyl orange as $CaCO_3$
- Calcium as Ca
- Magnesium as Mg
- Sodium as Na
- Potassium as K
- Silica as SiO_2
- Iron as Fe
- Chloride as Cl
- Sulphates as SO_4
- Nitrates as NO_3
- Fluoride as F

The plants visited used different water sources as shown in table 1. All the plants except the plant in Kothapeta are RO plants. Eight of the plants are placed near the villages' water tower and use the same borewell as the tower. Four plants have their own borewell nearby the plant. One plant uses a pond and the last one uses a borewell placed on a riverbank.

Table 1: The table showing the water sources for RO plants visited in Andhra Pradesh. The names listed are names of the villages where the plants are located.

Borewell that supply both the village and the RO plant	**Borewell that only supply the plant**	**Pond**	**Borewell in river bank**
Bowrampeta	Kolalapudi	Upputuru	Kothapeta (UV)**
Gagillapur	Remalli		
Mattampalli	Devarapulli*		
Kavuru	Gogulampadu		
Neppalli			
Kacharam			
Nellutla			
Pedhavedu			

* The RO plant in Devarapulli is a Water Health project and has nothing to do with Naandi but is included as an example.

** The plant in Kothapeta is a UV plant based on ultra violet disinfection of the water.

4.3 The different RO-plant setup

Naandi cooperate with several producers of water treatment systems based on RO. Thermax, TATA and Malthe Winje delivered the systems used in the plants visited. The plants setup varies from site to site and between different producers. The different setups used are listed below:

Thermax plant with extra filters. Capacity 1m^3/h.

- Sand filter
- Carbon filter
- Anti scaling and pH dosing
- 10 and 5 micro filter
- High pressure pump
- 2x2 membrane in parallel
- 2x1 membrane in series
- UV
- 5000 litre storage tank, clean water

TATA plant with extra filters. Capacity 1m^3/h

- Sand filter and activated carbon filter in one module
- 10 and 5 micron bag filter
- UV
- 5000 litre storage tank, raw water
- Feed pump
- Anti scaling and pH dosing
- 10 micro filter, 5 micro filter
- High pressure pump
- 2(4) membrane in parallel, and 1 (2) membrane in series
- 5000 litre storage tank, clean water
- UV

TATA plant without extra filters. Capacity 1m^3/h

- Feed pump
- Anti scaling and pH dosing
- 10 micro filter, 5 micro filter
- High pressure pump
- 2(4) membrane in parallel, and 1(2) membrane in series
- 5000 litre storage tank, clean water
- UV

Malthe Winje plant without extra filters. Capacity 1m^3/h

- Feed pump
- Anti scaling and pH dosing
- UV
- 10 micro filter, 5 micro filter
- High pressure pump
- 2(4) membrane in series
- UV
- 5000 litre storage tank, clean water

None of the plants are custom built and adapted the water quality at the specific place. They are based on a general design that can deliver safe water at every site. The extra filters that are delivered with the original treatment module are part of the total treatment package, and not based on the raw water quality.

Picture 2 bellow is a TATA plant with the membranes in the white horizontal tubes, 10 and 5 micro filter in the blue vertical cartridges, high pressure pump to the right and feed pump to the lower left.

Picture 2: Shows a TATA plant with capacity of $1m^3/h$ (Havig and Holstad, 2010).

4.4 Reject water handling

Naandi has not taken on any specific project regarding reject water handling. All reject water is supposed to be lead far away from the site through piping or drainage ditches. Observations showed that this was not followed everywhere. Several plants that where observed sent the reject water out close to the plant or water source. Some practically sent the water back into the water well. Other had led the water away to some bushes or a ditch that could resemble a drainage system.

Table 2: The table shows how the reject water was handed (none of the plants treat the reject water). The names listed are names of the villages where the plants are located.

Reject water lead to a drainage system	**Reject water lead out nearby the borewell or plant**
Upputuru	Mattampalli
Kolalapudi*	Pedhavedu
Nellutla	Remalli
Bowrampeta	Kavuru
Gagillapur	Neppalli
Gogulampadu	Kacharam

* Kollalapudi leads the reject water to a ditch close to the plant, which not necessarily need to be categorised as a drainage system.

4.5 Product water

Water treated by RO normally has good quality. Failure on the membrane module or broken membranes is the main problem related to poor water quality. All the plants visited could confirm good water quality in the monthly water report on the plant. There were some problems with the plant in Upputuru but water samples was not collected from this plant. No plants had any problem with delivering enough water at the time of visit.

Part 5: Observed challenges

5.1 Water samples, results

It was decided to take a sample of raw water and reject water at the visited plants, to get a better understanding of what kind of water quality the various water treatment facilities have, together with an overview of how concentrated the reject water is. These samples would be analyzed for the same parameters as Naandi use in their test reports (table 5). Unfortunately we faced some problems during this work. Several plants were out of power when we visited them, due to this, it was not possible to collect all samples. At some sites, the raw water intake was directly connected to the borewell. It was therefore impossible to take a water sample without disassemble the plants' intake pipe, this was not done.

The water quality will most likely vary over the year, depending on the water source. We have only one water sample for each plant and they are taken at different dates. Due to this, most of the samples can not be compared with each other. The water samples in this report are used as a general description of the water quality and by looking at the specification of substances in the raw water. This will give a better idea of what the RO-systems need to handle.

The examples on the water quality that are shown later in this text is based on the following parameters: total dissolved solids, total hardness and fluoride. The first two parameters will affect the operation of the RO plant and fluoride is important in terms of the users` health. Complete test results of the water samples can be found in attachment 2.

The water samples taken by Naandi are analyzed by Micro testing labs™, Hyderabad, India. Vignana Bharat laboratories in Vijayawada, India, analyze our own water samples.

Table 3: The table shows the 20 parameters used by Naandi to analyse the water together with the drinking water standards IS 10500: 1991. The parameters used in the graphs further in this chapter are marked in red.

CONSTITUENTS	UNITS	STANDARD IS:10500
pH		6,5 - 8,5
Colour	hazen units	<5
Electrical Conductivity (E.C.)	micro mohs	-
Turbidity	NTU	<5
Total dissolved Solids	Mg/l	<500
Total Hardness as **$CaCO_3$**	Mg/l	<300
Non Carbonate Hardness as **$CaCO_3$**	Mg/l	-
Calcium Hardness as **$CaCO_3$**	Mg/l	-
Alkalinity to Phenolphthalein as **$CaCO_3$**	Mg/l	-
Alkalinity to Methyl orange as **$CaCO_3$**	Mg/l	<200
Calcium as **Ca**	Mg/l	<75
Magnesium as **Mg**	Mg/l	<30
Sodium as **Na**	Mg/l	-
Potassium as **K**	Mg/l	-
Silica as **SiO_2**	Mg/l	-
Iron as **Fe**	Mg/l	<0,3
Chloride as **Cl**	Mg/l	<250
Sulphates as **SO_4**	Mg/l	<200
Nitrates as **NO_3**	Mg/l	<45
Fluoride as **F**	Mg/l	<1

5.1.1 Raw water

The water samples used in figure 5, 6 and 7 are collected at different dates. The water samples from Kolalapudi,Ripputuru, Remalli, Neppali are collected in July 2010. The water samples from Kavuru and Kacharam are collected in January and February 2010. Only Upputuru uses a pond as water source, the rest of the plants mentioned use ground water. The average pH for the raw water was 7,3 and the turbidity was below 1 NTU for all the plants.

Figure 5 illustrates that there is differences in the TDS concentration. The plants in Kavuru, Kolapudi, Remalli and Kacharam all have raw water with a TDS concentration above 1200 mg/l. The plant in Kavuru has the highest TDS concentration on 1550 mg/l. Upputuru and Neppali have a TDS concentration on 590- and 580 mg/l. The TDS limit in the drinking water standards is 500 mg/l.

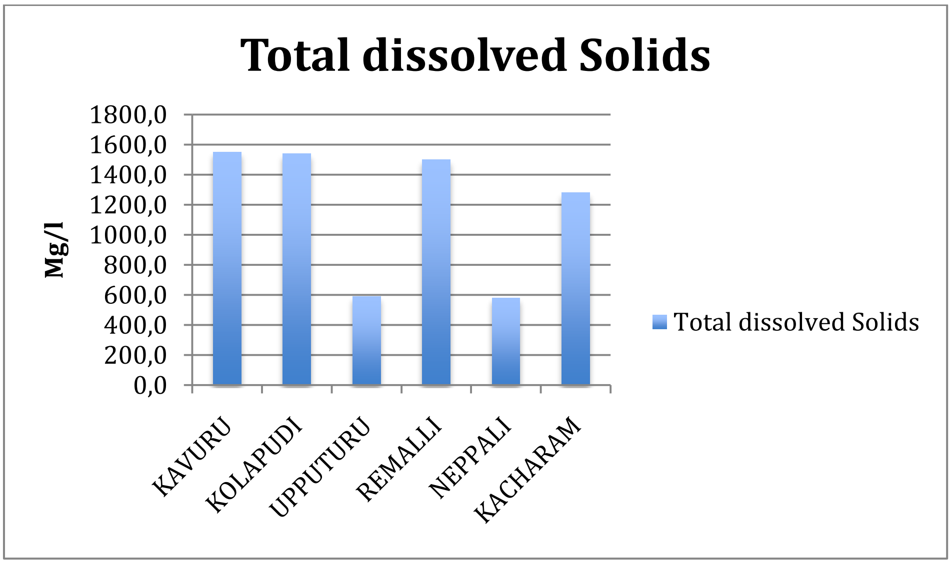

Figure 5: TDS concentration in the RO plants raw water. The water samples are taken by Havig and Holstad (Kolalapudi, Upputuru, Remalli, Neppalli), and Naandi (Kavuru, Kacharam)(2010).

Figure 6 shows that total hardness for the raw water varies from 1112 mg/l (Kavuru) to 130 mg/l (Kolalapudi). In terms of the drinking water standard, the total hardness should be below 300 mg/l. Kolalapudi is below this limit and Neppali close to this limit with a concentration on 330 Mg/l.

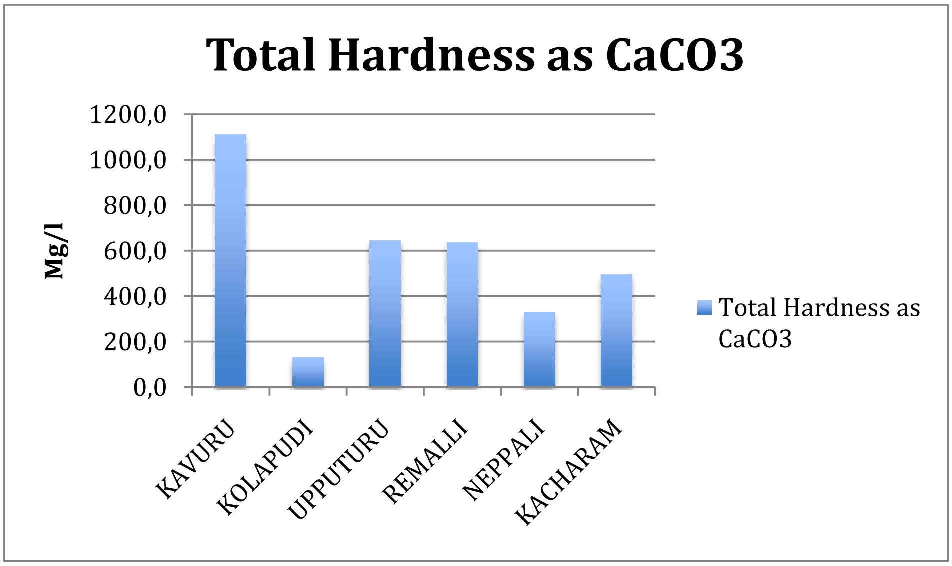

Figure 6: Total hardness as $CaCO_3$ in the RO plants raw water. The water samples are taken by Havig and Holstad (Kolalapudi, Upputuru, Remalli, Neppalli), and Naandi (Kavuru, Kacharam)(2010).

One of the main concerns about the drinking water in rural areas in India is the Fluoride concentration in the water. The recommended concentration in the drinking water standard is below 1 mg/l. Figure 7 shows that Kavuru and Kacharam have a fluoride concentration on 1,1 mg/l and 3,8 mg/l. Rest of the sites has a concentration under 1 mg/l.

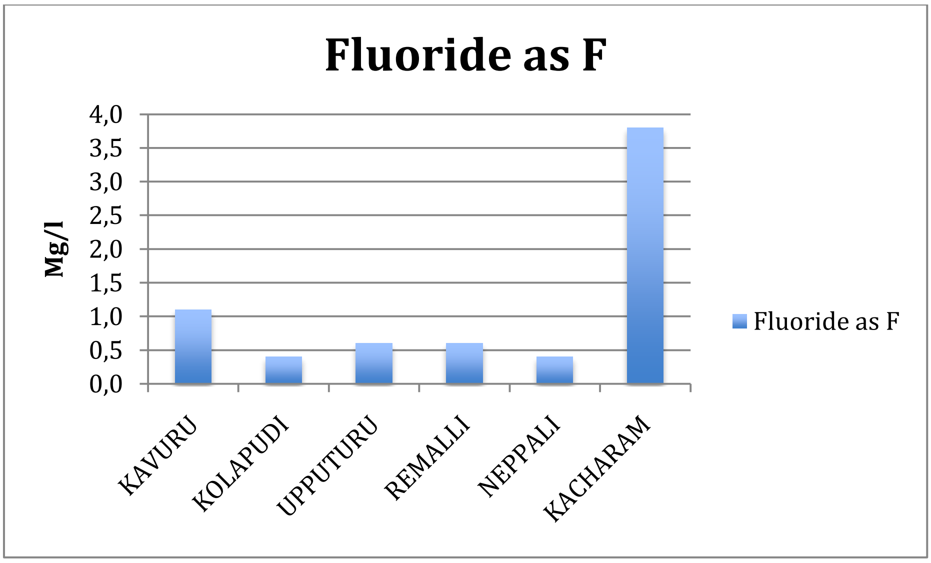

Figure 7: Fluoride as F in the RO plants raw water. The water samples are taken by Havig and Holstad (Kolalapudi, Upputuru, Remalli, Neppalli), and Naandi (Kavuru, Kacharam)(2010).

5.1.2 Reject water

The water samples used in figure 8, 9 and 10 are collected on the same date and therefore possible to compare. The raw water sample is included in the figures to give an impression of the change in water quality after the treatment step. The plant in Upputuru uses a pond as water source, the rest of the plants uses ground water. The average pH and turbidity in the reject water for the four sites was 7,5 and 0,6 NTU.

Figure 8 shows that the water quality decrease due to the TDS concentration. All the plants have less than 50 % recovery, which means that the concentration theoretically should be about twice in the reject water. Upputuru and Neppali are closest to this theory with a TDS concentration that increases by 55 %. Remalli has the lowest change in the TDS concentration with a 40 % increase.

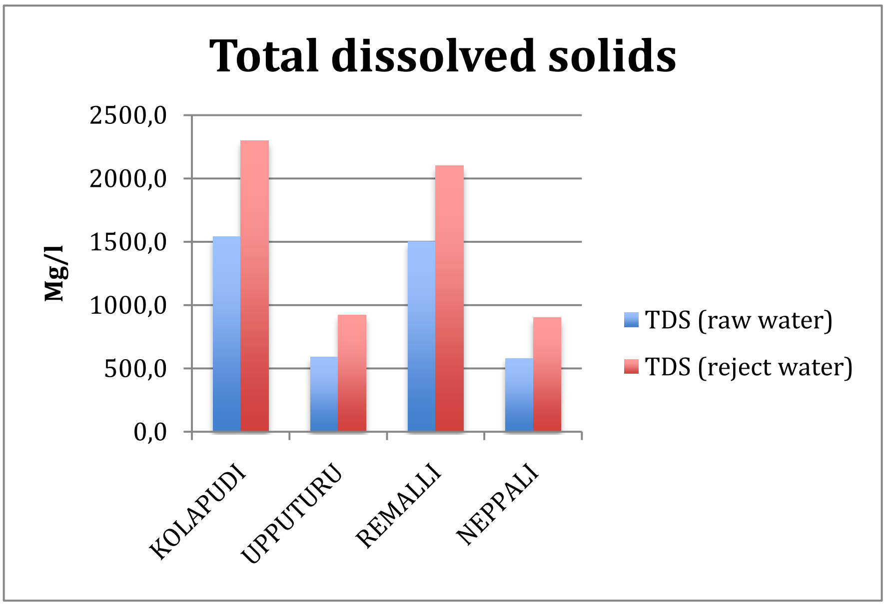

Figure 8: Difference in the TDS concentration between raw water and reject water. The water samples are taken by Havig and Holstad (10.07.10).

Figure 9 show the difference in total hardness between raw water and reject water. Kolalapudi has the highest difference with an increase of the concentration on 420 %. On the contrary, the concentration decreased 220 % in Upputuru.

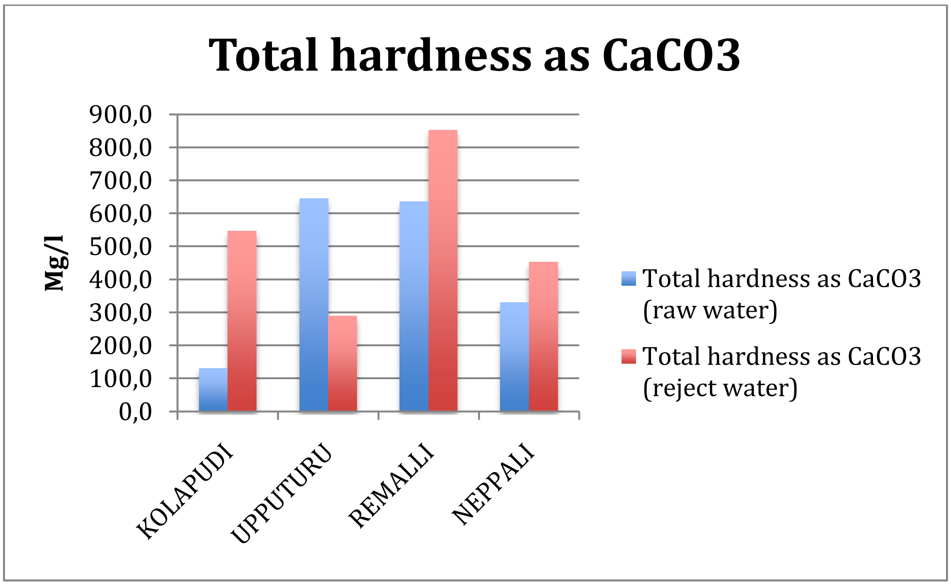

Figure 9: Difference in the total hardness between raw water and reject water. The water samples are taken by Havig and Holstad (10.07.10).

There is no difference in the fluoride concentration for raw water and reject water (figure 10).

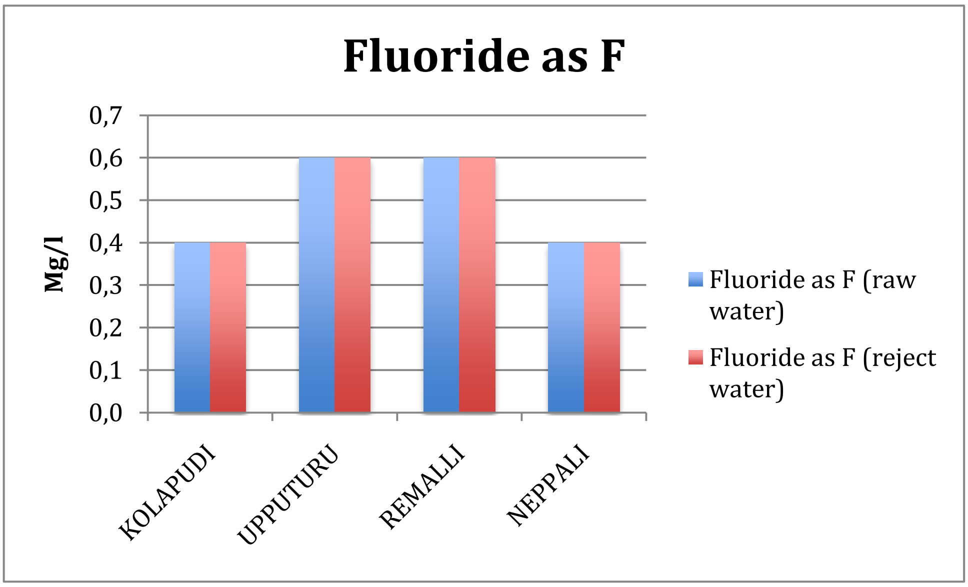

Figure 10: Difference in the fluoride concentration between raw water and reject water. The water samples are taken by Havig and Holstad (10.07.10).

The samples concerning the total hardness and fluoride (figure 9 and 10) shows some abnormally values. The total hardness samples have exceptional large variation between raw water and reject water in Kolapudi and Upputuru. The samples of fluoride also show no difference between raw water and reject water. The reason for this is unknown. There were some communication problems between authors and the laboratory and it was informed later that in subsequent tests the laboratory would need 2 liters of sample water instead of 1 liter as they previously got. The results are therefore highly uncertain.

5.1.3 Treated water

The water samples used in figure 11, 12 and 13 are taken by Naandi at different dates in 2010. All the plants, except the plant in Remalli, delivered product water well within the limits of Indian water standard. The water sample from Remalli shows unexpected values, which indicates that something was wrong with either the water sample or the plant at the time the sample was collected.

Neppali has, as shown in figure 11, the product water with the lowest concentration of TDS (20 mg/l), Remalli has the highest with 1376 mg/l. All the plants (except Remalli) deliver water with a TDS concentration under the 500 mg/l limit which is required by the Indian drinking water standard.

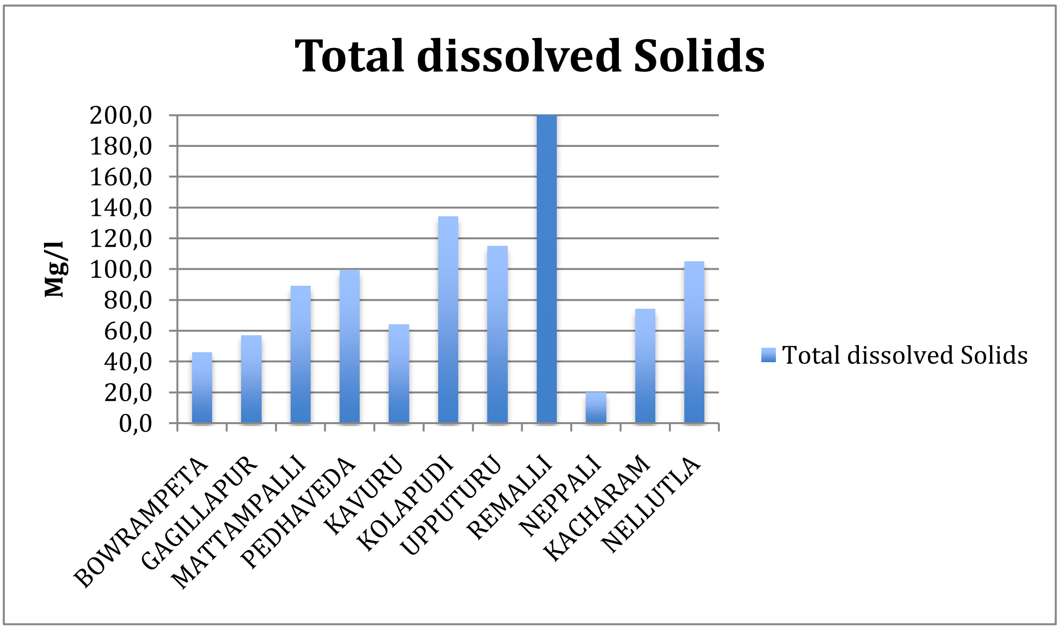

Figure 11: TDS in the water after RO filtration. The value for Remalli is 1376 mg/l. The water samples are taken by Naandi (2010).

Figure 12 shows the total hardness in the product water. Remalli has a concentration of total hardness on 725 mg/l, rest of the plants have concentrations below 36 mg/l. The drinking water standard has set the limit for total hardness to 300 mg/l.

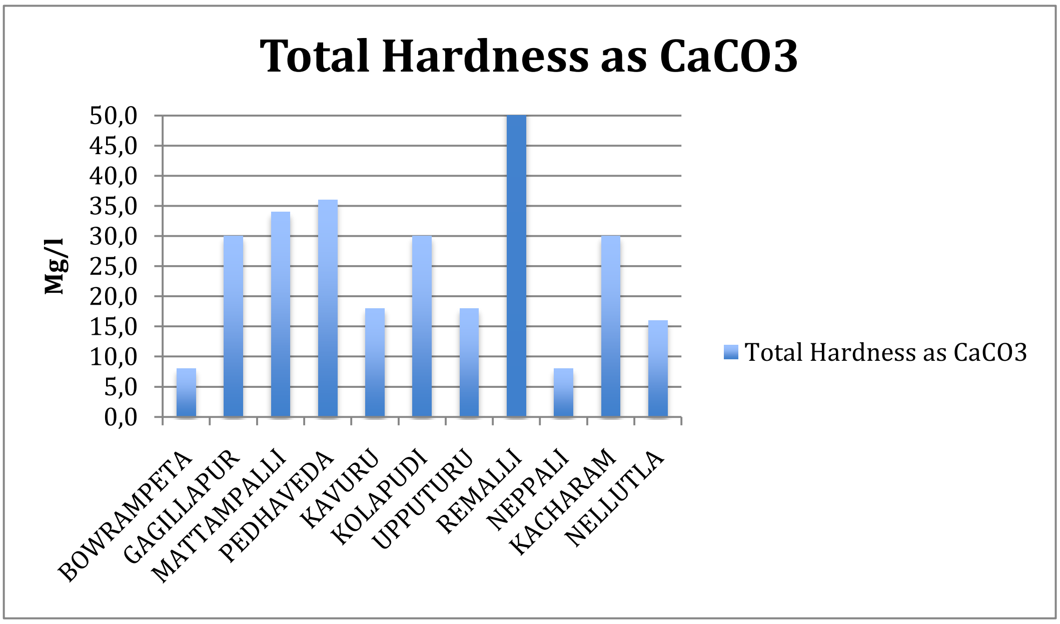

Figure 12: Total hardness as $CaCO_3$ in the water after RO filtration. The value for Remalli is 725 mg/l. The water samples are taken by Naandi (2010).

Figure 13 shows the fluoride level in the product water. Only Remalli (1,3 mg/l) has concentration above the limit set by the drinking water standard. The plants in Bowrampeta and Nellutla have product water without fluoride.

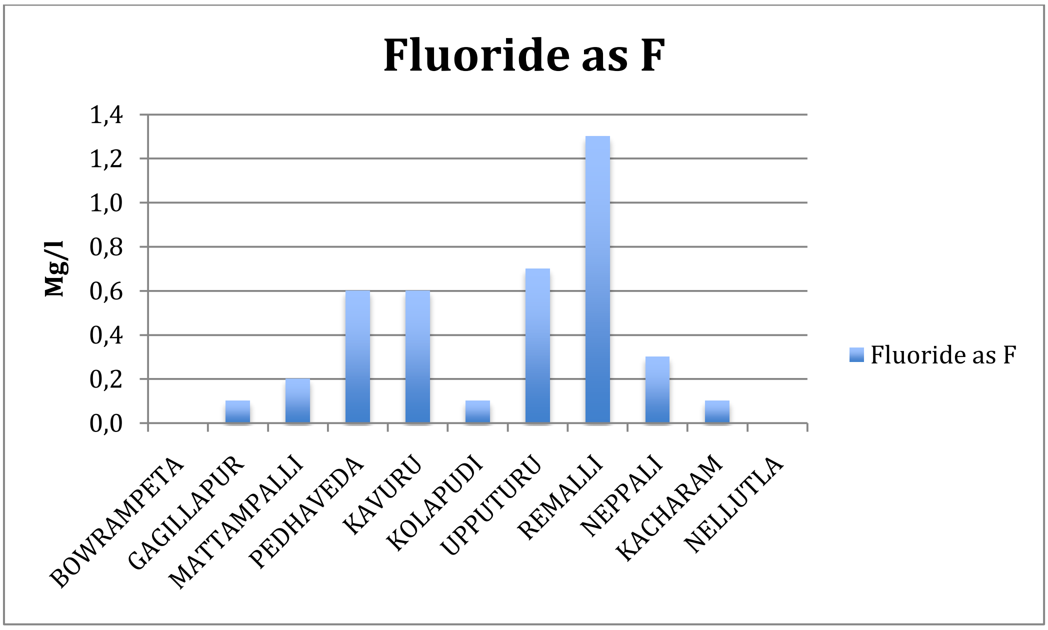

Figure 13: Fluoride as F in the water after RO filtration. The water samples are taken by Naandi (2010).

5.2 The water sources significance for operation of an RO plant

The water source will affect the operation of a RO plant because the water quality determines the efficiency of the plant in terms of cost and utilization. Theoretically the only cost for treating water with RO should be the cost of electric power used to create pressure. In practice the situation is different; the water quality varies and leads to problems if proper precautions are not taken.

5.2.1 Operation problems experienced due to the water source

Some of the plants we visited have had trouble related to the water source in various ways. The problems experienced were borewells that had run empty, RO plants with low permeate rate, RO plants with high maintenance cost, RO plants that contaminated the water source and RO plants with broken membranes. Low permeate rate, high maintenance cost and broken membranes do not necessarily need to be related to the water source, it might have been caused by manufacturing defects or operation and maintenance failure as well. Indication of this were found in only one plant (Upputuru).

The problems and challenges observed at the plants are described below:

- The plants in Kolalapudi and Devarapulli both experienced that their borewell dried up shortly after they started using the plant.
- The plant in Gogulampadu has changed membranes once since the plant was operative. Silt in the raw water deposited on the membranes surface and after a while, the membranes got clogged due to the deposition and had to be replaced.
- We were told that the plant in Upputuru had high maintenance costs due to bad water quality.
- Low permeate rate might not be categorized as a problem, but is mentioned because of the plant's potential to increase the permeate rate.

Table 4: Problems that the plants have experienced. The names listed are names on the villages where the plants are located.

Borewell that dried up	Broken membranes	High maintenance cost	Low permeate rate
Kolalapudi	Gogulampadu	Upputuru	Bowrampeta
Devarapulli*			Mattampalli
			Pedhavedu
			Nellutla

The problems mentioned in table 4 may be related to the water source and the quality of the water. It is therefore important to look at the factors that increase or decrease the water quality and which parameters in the water that could affect the efficiency of the maintenance and operation of the plant in terms of economy and recovery of the raw water.

5.3 Challenges related to the reject water handling

Theoretically, the reject water contains double concentration of contaminations of what is desirable to remove from the raw water with RO. This is assuming the recovery of the plant is 50 %. TDS and Fluoride are examples of two of the substances in the reject that should not be sent back to the water source. All the plants visited face this challenge. It is not a problem preliminary, but it could be. It is therefore important to determine possible solutions of the problem.

Part 6: Factors that leads to the observed challenges

6.1 Changes in water quality

Variations in the water quality during the year will happen because of seasonal changes in the hydrology. The monsoon (which lasts from June to September in Andhra Pradesh) will typically affect the water sources. Because the climate is so dry most of the season, a longer period of heavy rain will increase the water level and change the water quality in the sources. Generally, surface waters like ponds and rivers will be most affected by the seasonal variation in the climate, but also groundwater could be affected in different grade.

Most of the plants visited use a borewell as water source. Examples of factors that could lead to seasonal variability in the ground water quality are variations in recharge quantity and quality and changes in the ground water flow patterns. For surface water, precipitation, evaporation and surface runoff will be important factors *(The Norwegian Institute of Public Health, 2004)*. The depth of the aquifers' water table and the size of the aquifer or the surface water source, will also have impact on the water quality *(Alley, 1993)*. Variation in water quality can also come from consumption and external sources. The use of an RO plant to produce drinking water can lead to two different variations in the water source. One is the use of the source in the form of removing water. The other is the reject water that is sent out again, and contains a much higher level of substances than the original water source.

Three studies *(Subba Rao, 2005)*, *(National Institute of hydrology Jal Vigyan Bhawan, 1999)*,*(National Institute of hydrology Jal Vigyan Bhawan, 2000)* carried out at different sites in Andhra Pradesh (Guntur district, Kakinada town and Krishna delta), showed that the groundwater quality changed over the season. Physical and chemical parameters like pH, total dissolved solids, electrical conductivity, alkalinity, Ca, Mg, Na, and K were monitored over one, three and eight years depending on the study. The changes in the water quality from pre-monsoon (May) to post-monsoon (November) were significant for all three studies, but there seems to be no context between the sites when the water quality improved or decreased within the year. It is therefore natural to believe that the topography, geology and borewell design (deep, shallow) has great influence on the water quality.

The change in the water quality in terms of TDS and fluoride for four water sources connected to Naandis' RO plants in Andhra Pradesh is showed in figure 14 and 15. The water samples are taken in different periods in 2009 – 2010 and are therefore not completely comparative. They are made as an example on variation in the TDS and fluoride concentration but can not be used as basis for further conclusions. However, they show changes in water quality.

The TDS level for Kolalapudi and Remalli shows a difference in the concentration on 401 mg/l and 508 mg/l. Upputuru and Neppali have a difference on the concentration of TDS on 205 mg/l and 104 mg/l.

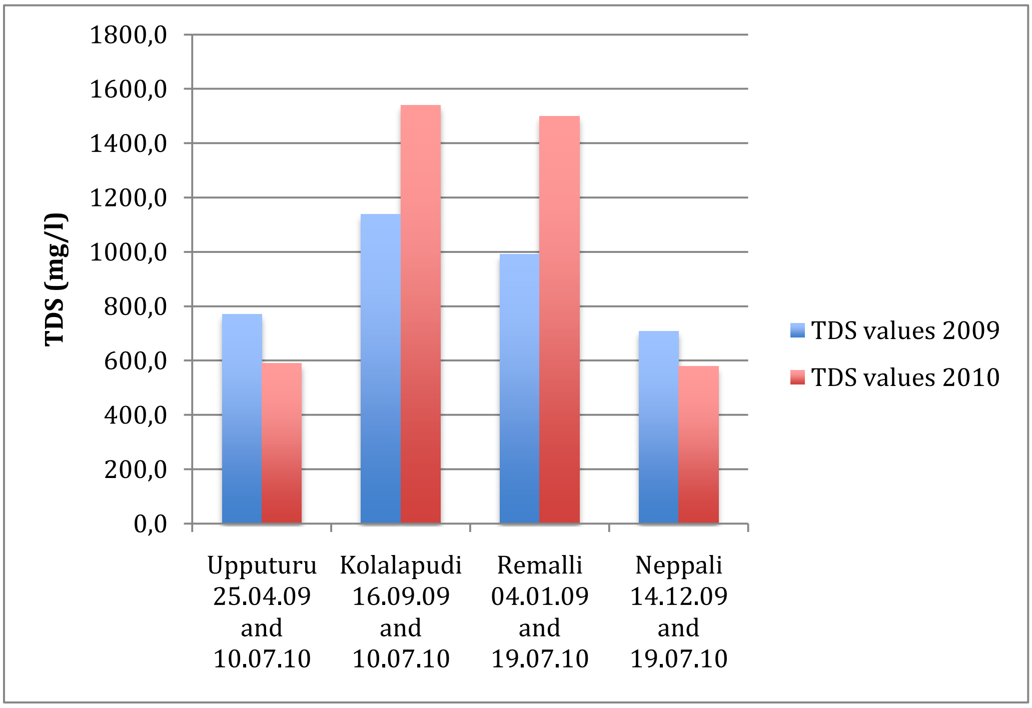

Figure 14: TDS concentration in four different water sources at different periods. Ground water is used as water source for the plants in Kolalapudi, Remalli and Nepalli . In Upputuru are water from a pond used. (The measurements are taken by Naandi (2009) and Havig and Holstad (2010))

Figure 15 shows the Fluorine concentration from the same water samples as used in figure 14. The samples are compared to see if there is difference in the fluorine concentration. Kolalapudi and Remalli have difference in the concentration on 1.4 mg/l and 0.6 mg/l. Upputuru and Neppali have a difference in the concentration on 0.5 mg/l and 0.4 mg/l.

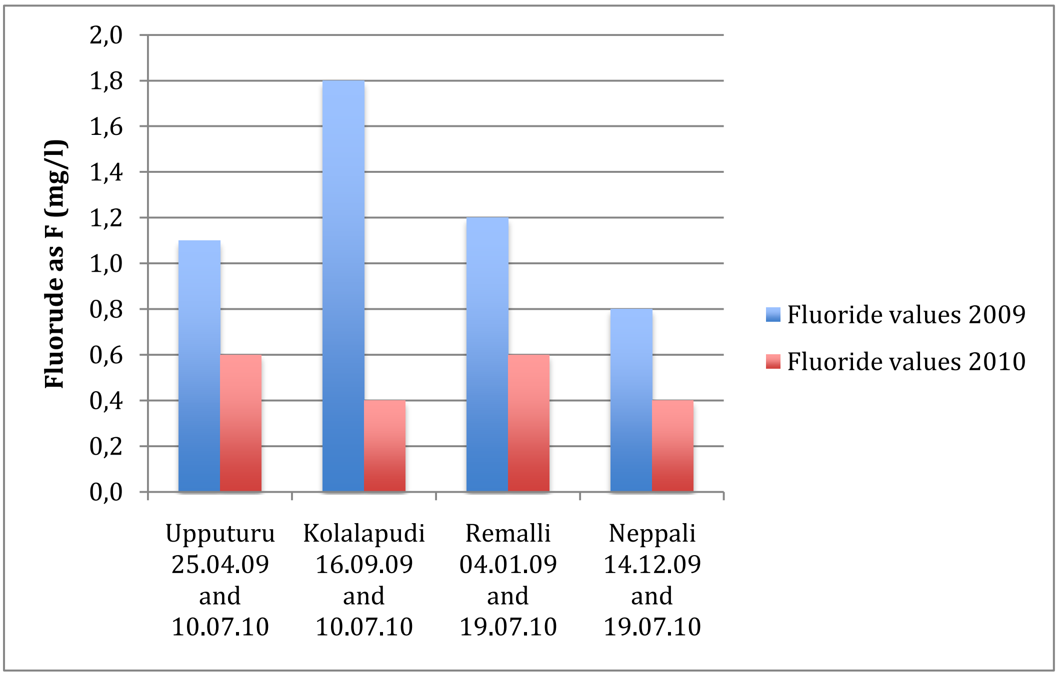

Figure 15: Fluoride concentration in four different water sources at different periods. The plants in Kolalapudi, Remalli and Nepalli use ground water as a water source. In Upputuru are water from a pond used. (The measurements are taken by Naandi (2009) and Havig and Holstad (2010))

6.2 Fouling and fouling sources

Membrane fouling occurs when the feed water contains materials that accumulate, precipitate or grow on the membranes surface and forms a layer that is resistant to permeation. There are several problems related to fouling, in addition to the fact that it is the main reason of permanent flux decline:

- In a spiral wound element, fouling could lead to a higher differential pressure across the spacer and damage the membrane.
- The fouling layer could consist of materials that destroy the membrane and lead to an increase in the salt passage through the membrane.
- The fouling layer can be irreversible and evolve to a level where the flux is so low that the membrane has to be changed.
- Frequent cleaning of the membranes due to fouling will increase the production downtime, workload, energy, chemical use and production of wastewater.

Membrane fouling can, according to, *(Wang et al., 2006)*, be divided into four categories:

- Particulate and colloidal deposition
- Adsorption of organic molecules (organic fouling)
- Sparingly soluble salts (scaling)
- Microbial adhesion and growth (biofouling)

Fouling from particulate and colloidal deposition occurs when particles and macromolecules accumulate on the membranes' surface and forms a layer. Studies have shown that particulate materials under 5 μm contribute to more substantially fouling than particles above this size. Larger particles will often, because of the diffusion mechanisms that work on the membrane surface, be swept away from the membrane surface with the water flow *(Wang et al., 2006)*. The particulate materials and colloids that could cause fouling can be: Clay, silt, organic colloids, iron corrosion products, precipitated iron hydroxide and colloidal silica *(Baker, 2004)*. Pretreatment chemicals could also cause colloidal fouling if they go through the pretreatment system and reach the membrane. These chemicals are typical alum, ferric chloride or cationic polyelectrolytes. Cationic polymers may, together with a negatively charged antiscalant, coprecipitate and foul the membrane *(DOW, 2010a)*.

Organic fouling is caused by chemical or physical adsorption of organic compounds onto the membranes' surface. Adsorption of organic compounds could lead to a cake- or gel layer on the membrane that is detrimental to the permeate flux and could affect the membranes' salt rejection. Organic fouling caused by humic substances is typical for plants using surface water as water source. As the naturally organic matters in the feed water are generally negatively charged, they will be attracted to a positively charged membrane surface. Another aspect is the ability the proteins, polyphenolic compounds and polysaccharides have to bind colloids and particles together. This could increase the fouling and the strength of the fouling layer and make it irreversible under the right conditions. *(Wang et al., 2006)*, *(DOW, 2010c)*.

Scaling is the term of sparingly soluble salts in the water, which precipitate on the membrane surface because of the solubility limit of a salt being exceeded. The precipitation occurs when the concentration of ions in the feed water increase above the solubility limit (supersaturation). The solubility limit depends on the composition of the water and temperature. The scaling is depended on the pH, surface roughness and hydrodynamic conditions on the membrane surface. Calcium carbonate, calcium sulphate, silica complexes, barium sulphate, strontium sulphate and calcium fluoride are the salts that most commonly form scale. The scale layer will tend to increase in amount and strength over time if it is not removed. There are several methods to prevent scaling. The most common methods are the use of anti scalant chemicals and water softening by ion exchange. There are also scalants that are difficult to remove because of the lack of effective anti scalants; e.g. Silica *(Baker, 2004)*, *(Boerlage, 2001)*.

Biological fouling is caused by microbial (bacterial, algal or/and fungal) attachment to the membrane surface. Biological fouling may arise from sulphate reducing and anaerobic bacterias present in the raw water source, algae growth and the presence and growth of microorganisms in the RO module. Biological fouling will be promoted by the existence of assimilable organic compounds (AOC) in the feed water, but also degradation of the membrane material (polymer) will give the microorganisms access to carbon and energy. *(Boerlage, 2001)*. The growth conditions for the microorganisms highly depend on the membrane composition. Cellulose acetate membranes are for example more exposed for bacterial attack than thin film composite membranes. *(Baker, 2004).*

6.2.1 Water sources that are more relevant for fouling

Groundwater has generally a more flattened water quality than surface water *(Alley, 1993)*. Because of the filtering capacity in the soil, organic matter and biological activity will usually not influence the ground water quality to the same extent as for the surface water. Another advantage of ground water is the stable low water temperature compared to surface water. In particular are shallow lakes and ponds in dry areas exposed to temperatures that favour biological activity. It will generally be a greater risk of bio fouling and organic fouling when using surface water as a water source for the RO plant rather than ground water. Nevertheless, membranes using ground water can as mentioned have a greater risk of scaling due to salts. This is because ground water usually has a higher concentration of dissolved minerals.

6.3 Disposal of reject water.

The water treatment plant usually has a central placement in the city. Reject water is therefore at some locations released into the centre of town and close to the water source. When water is pumped up from this source and treated with a RO-system, the reject water theoretically contains almost twice the concentration of substances as for the water in the source. If this is infiltrated back into the source or disposed nearby without precaution, there is a chance that the local water source will deteriorate and the concentration of contaminants will raise. Compared to other treatments techniques, RO-systems do not gather up the waste product, it simply goes straight through and out again. As a result, the unwanted substances in the water are not removed from the sights.

If we look at this in conjunction with fluoride in the water source, this can cause a big problem. Although the test reports cannot prove that fluoride levels increase in the water sources that were visited, there is a risk that it could happen. Naandi has announced concern about this, and therefore this is included as one of the main elements.

In the places where the reject water is lead far away from the water source, there is a chance of overuse of water. This is because the RO-system only utilizes about 50 per cent of the water it takes up, and the rest is lead to another water source or evaporated. If the water source has the necessary capacity to deliver enough water, and gets filled up by naturally infiltration, this will not be a problem. But in areas with water shortage may it be a problem. Also, if the reject water is led away to another water source where fluoride does not occur naturally, this source can be contaminated by fluoride or other substances' in the reject water.

Part 7: Main findings and discussion

7.1 Borewells that dried up

It was experienced two sites where the borewells supplying the plants with water, had dried up short time after the plant was set in operation. The first plant is operated by Naandi and lies in Kolalapudi. The other plant is operated by Water Health and is included in this text only as an example. This plant is in Devarapulli.

The plant in Kolalapudi was completed and ready for operation in January 2009. The treatment step is delivered by Malthe Winje and is based on RO filtration with subsequent UV disinfection. Two cartridge filters (5 and 10 μm), are used as pretreatment. Anti scalant is added to the feed water by a dosage pump to prevent scaling.

The problem with water shortage in the borewell, was in Kolalapudi solved by drilling a new borewell not far from the first one. The ground around the plant consists of rock with an overlaying layer of sand. The capacity of borewells in bedrock will be determined by cracks and openings that lead water. Two borewells at almost the same site can therefore have different capacity depending on which cracks and openings they are connected to. As mentioned before, the village or the government provides the water source and ensures that the quality and capacity is good enough for the plant. In this case the capacity was not good enough in the origin borewell and it was pumped empty. There has not been any trouble related to water shortage in the new borewell.

The plant in Devarapulli is a Water Health plant. The plant was visited because of the interest in the plants' treatment technology based on active aluminium. The treatment process contains a dual media filter, activated carbon filter, active aluminium filter and UV disinfection. The plant was mainly build to remove fluoride from the water, and had a capacity around 1 m^3/day. As in Kolalapudi, water shortage occurred in the originall borewell and a new borewell was drilled nearby. The new borewell had no problems with water shortage, but the fluoride level in the new well was so high that the treatment process did not work satisfactory. It was therefore decided to change the treatment step from active aluminium to RO. This work was under process and was not finished at the time of visit.

These two cases and especially the last one, show the importance of knowing the yield limit in an aquifer before planning a water purification plant. The problem that occurred in Devarapulli with the fluoride will not happen at a Naandi plant, as the RO treatment will handle different concentration of fluoride, but it is an example on a possible disadvantage when changing a water source after the plant is built.

7.2 Broken membranes

The plant in Golgulampadu had a RO module produced by TATA. The plant was built without any pretreatment except from two cartridge filters (5 and 10 μm), and consisted of a RO module with subsequent UV disinfection. The raw water came from a borewell that only supplied the plant.

The problems with the membrane flux started a short time after the plant was operational. The flux decreased slowly and regular washing procedures did not help to reverse this. The flux decreased to a level where the only solution was to replace the membranes with new ones. A dual media filter was installed as pretreatment to try to prevent the decrease of flux, the experience of this was that the dual media filter had no significant effect. It was mentioned that the decrease of flux was caused by silt in the raw water. Silt is small inorganic particles with grain size between 2 – 50 μm and has the second finest sediment fraction after clay. Silt occurs from chemical and physical processes in rock and soil *(Natural Resource Conservation Service, United States Department of Agriculture)*. It was not taken any water sample, so an analysis of the water is not done. The broken membranes were covered with a gray layer that according to *(Driftserfaringer med membranfiltrering, Lars J. Hem og Thor Thorsen)*, substantiated that silt could be the problem.

Membranes are expensive and constitute a large part of the total cost of the plant (it has not been possible to obtain an answer about the precise costs). It was told that the plant in Golgulampadu is in danger of being closed as a result of the high maintenance cost.

7.3 High maintenance cost

The RO module in the plant located in Upputuru is delivered by TATA. The Pretreatment is based on a sand filter, activated carbon filter, 10- and 5 micron bag filter and UV disinfection. Two cartridge filters (5 and 10 μm) is placed on the RO module. Chemicals are added to the feed water to prevent fouling/scaling. The membranes are cleaned with chemicals once per 20 days, and washed for 10 minutes two times every day.

The plant in Upputuru was expensive and demanding to operate, much due to the pretreatment steps that did not work optimally. The washing routines of the equipment in the plant confirm this assumption. The plant in Upputuru had more pretreatment, more chemical usage, and had to wash the membranes more often compared to the other plants' visited. It is unknown if the chemical dosage and the washing routines vary over the season due to variation in the water quality, something that had been interesting to know. The plant did not run optimal and there had been much extra work trying to get the pretreatment steps to work satisfactory. There were some technical problems with the RO module when the plant was visited, but the problem was known and supposed to be rectified within a short time.

The plant use a pond as water source most of the year, but switch to raw water from the river if the pond runs empty. The pond is located close to the village, opposed to the river, which is located about 1 km outside of the village. There seemed to be no regulation for the area around the pond, and the pond lies between the main road and an agricultural area.

The quality of the water in the pond varies. Two water samples taken by Naandi showed a turbidity of 16,2 NTU (30.09.09) and 2,4 NTU (25.04.09). The same samples had a TDS concentration of 568 mg/l (30.09.09) and 770 mg/l (25.04.09). The colour of the water was described as white turbidity for the analysis done 30.09.09 and yellow for the analysis done 25.04.09. The water quality in the river was not documented. When the plants was visited (10.07.10) the raw water had a brownish colour and a turbidity on 0,6 NTU. The raw water sample was collected from the sand filters' reject pipe (used when backwashing the sand filter). The water sample will therefore be unreliable and could give other values if it had been taken directly from the supply pipe.

The high turbidity in the pond can be caused by different factors:

- Surface runoff from the catchment area around the pond could occur under the rain season. As it often rain heavily when it first starts, the rain will wash the ground. Particular matter and other substances on the ground could be transported with the water to the pond.
- Fertilizers used in the agriculture in the catchment area of the pond could be drained to the pond due to the rain. Fertilizers like nitrogen and phosphor could lead to nutrient water and production of a large amount of plant plankton. Growth of organic matter could lead to eutrophication in the water source.
- High oxygen demand as a result of eutrophication in a pond could lead to release of undesirable substances from the bottom sediments.
- The smell of rotten eggs could indicate hydrogen sulphide (H_2S) in the raw water. This can come from organic matter that disintegrates without access to enough oxygen and further create sulphide compounds like H_2S that gives a bad odour.

The turbidity measurement done in September is considerably higher than the measurement done in April. September is in the monsoon period and the surface runoff has probably had impact on the turbidity in the water. April is one of the driest months, this reinforces the theory that the surface runoff has a lot to say for turbidity in the pond. Without further tests, it is difficult to say anything concrete about the water quality and the changes over the season. However, with the turbidity measurements, smell and colour of this water, there is no doubt that the water quality in the pond causes challenges for the RO plant.

Beside the usual maintenance costs, the following factors will affect the increase of cost in Upputuru:

- Pretreatment that not works satisfactory
- Bad raw water quality

Pretreatment that does not work satisfactory and bad raw water quality will affect the amount of chemicals used for anti scaling/fouling, and chemicals used to clean the membranes and the storage tanks. Together with more frequent cleaning of the membranes and the pretreatment filters, this will lead to a demanding and costly RO plant.

7.3.1 Discussion of problems related to borewells that dries up, broken membranes and high maintenance cost

The problems related to dry borewells, broken membranes and bad raw water quality would affect the expenditures and operation of the plant. Both are important for the long-term operation. When a borewell suddenly does not deliver enough water, a new water source must be found. Broken membranes have to be replaced with new membranes, and bad water quality together with a pretreatment step that does not work satisfactory, will lead to high maintenance cost. Common for all these challenges are the unexpected extra costs for the plant. Another problem related to dry borewells, are the water quality in the new water source. The water quality should determine the design of the plant. A new water source can have another water quality than the original borewell. It is then a possibility that the plants' pretreatment step has to be upgraded or changed to handle the quality of the new raw water.

The economy of the project is vulnerable. The salary of the plants' operator and payment on the loan (which is taken to build the plant), shall be covered by the income from the water sale. Unexpected challenges can lead to an increase of the expenditures and this will affect the price of producing the product water. This is especially important after five years when the operation of the plant is handed over to the village. The main goal of "the safe drinking water program" is to provide safe water to the people who need it most to a price they could afford to pay. An increase of the expenditures will make it difficult to operate the plant.

Naandis' reputation is important. A closed plant or a plant with problems will not lead to good public relation for any of the involved parts. The public will lose belonging to the plant, and the plant will lose its credibility as a safe provider of drinking water. There are several NGOs that provide safe drinking water to rural areas in India. Good reputation is important to ensure the public that the "safe drinking water program" is a high-quality and safe option.

7.4 Low recovery rate

The plants in Bowrapeta, Mattampalli, Pedhavedu, Nellutla have all a recovery rate under 41 % (table 5). Low recovery rate does not need to be a disadvantage, but is mentioned because of possible improvements that could be done.

The treatment steps for the plants are produced by TATA and are based on RO with subsequent UV. There are no extra filters in addition to the 5 and 10 µm cartridge filters, and the plants water source is ground water from borewells.

Manometers on the RO module measure the product- and reject rate of the plant. The values in table 5 are based on one measurement done at each of the mentioned plants. As an example of the plants' efficiency in terms of water usage, the plant in Bowrampeta will use almost 2,9 m^3 raw water to produce 1 m^3 of product water.

Table 5: The plants recovery in %.

	Product LPH	Reject LPH	Recovery %
Bowrampeta	900	1700	35
Mattampalli	1100	1750	39
Pedhavedu	1100	1700	39
Nellutla	1000	1500	40

The relation between product water flow and feed water flow determine the recovery rate. The salt concentration, water temperature and feed water pressure are the most important factors in terms of membrane flux, and will therefore affect the recovery rate of the plants. Fouling is the main reason of decrease in membrane flux, and dissolved salts in the feed water are the limited factor for the mentioned plants. To avoid scaling it is important that the concentration of ions at the feed water side of the membrane does not increase above the solubility limit. Therefore is the cross flow along the membrane surface at the feed water side high and the reject water is not recycled.

The disadvantages of a low recovery rate could be:

- Water is/or could be (in the future) a limited resource.
- Treatment of the reject water will be cheaper and often more effective if the amount of reject water is low and the concentration of unwanted substances is high
- Low recovery rate means longer operation time of the plant

- Pretreatment steps as coagulation and flocculation have to handle more water if the recovery rate is low, opposite to high recovery rate.

7.5 Insufficient reject water handling

Reject water handling affect all the plants visited, but in different ways. Some plants has lead the reject water far away from the site/source to reduce the risk of contaminating the water source. Other plants leads it out beside or back of the building. However as several of the plants use a water source some distance away, the effluent water released in proximity to the plant does not necessarily need to affect the used water source. When the reject water is released close to the plant, it leads to muddy and wet environments. This makes the area less hygienic and wears extra on the building.

In Mattampalli and Pedhavedu the reject water was let out close to the plant. The borewells lies nearby in a lowering in the terrain. The reject water flows therefore directly back to the well. This is mainly a problem when the well is located close to the plant, and not placed on a higher position than the reject water outlet. There was not taken any raw water samples from this plant to compare if the water has deteriorated, but one can assume that this will affect the quality of the water source.

Kavuru, Kolalapudi, Remalli, Neppalli, and Kacharam also lead the reject water out close to the plant. However in these cases, the water leads to some bushes or a ditch some distance away from the water source. This makes sure that some of the water gets infiltrated in the proximity of the water source, and may help with recharge, but can also lead to deterioration of the water source. The water samples taken at these sites do not give any clear indication if the water quality suffers from this, due to few samples to compare.

Upputuru, Nellutla, Bowrampeta, Gagillapur and Gogulampadu all lead the reject water away in a drainage system. This is in accordance with the guidelines of Naandi. In Upputuru and Nellutla the reject water was sent in pipes to the water drains along the road. The water drains are open rain and sewage transport systems that run along the side of the road. This water draining system was not present in all the sites observed. Where the water is lead in this drain system is unknown, but they all lead away from the village. This makes sure that the reject water will not infiltrate back into the ground locally. Nevertheless, it can cause lowering of the groundwater level as a result of increased use, as the RO system taken up about twice as much water as what is being exploited, and the remainder is sent away instead of infiltrated back.

The pictures below shows reject water outlets in Mattampalli and Remalli.

Picture 3 and 4. Reject water outlet in Mattampalli (left), and Remalli (right). Water outlet in the left picture is visible behind the bench (Havig and Holstad, 2010).

7.5.1 Discussion of problems related to insufficient reject water handling

Water is a renewable resource, and the local water source in the villages should be able to provide the users with water in the future. It is therefore particularly important to protect the water source from deteriorating. The RO system lets out a concentrate of all the substances beside water, and as mentioned, this can have an effect on the source. Naandi mentioned fluoride rich reject water disposal as one of their challenges that needed extra attention. Fluoride is therefore the substance that is going to be given most attention regarding solution for reject water disposal.

The plants with the highest fluoride concentrations in reject water was Nellutla and Kacharam, with respective concentrations of 2,1 mg/l and 2,2 mg/l. Both of these samples were taken 26.08.2010. Kacharam also had a raw water sample taken 04.02.2010 by Naandi, with fluoride concentration of 3,8 mg/l. Such high concentration of fluoride in Kacharam may come from the fact that the sample is taken during one of the driest months in the region. The other two samples are taken during the monsoon. It indicates that the concentration has not increased in Kacharam, especially with the fact that the first sample is of raw water, and should therefore be significantly lower than the others. However there are uncertainties to how much the rain season has affected the concentration of fluoride in the ground, and there has only been yielded two comparable samples. One must therefore not give these samples to much consideration.

As mention previous, Devarapulli has a serious challenge related to fluoride rich water source. How high the fluoride levels were is uncertain, but several children playing in the area had broken teeth that resembled dental flurorosis. The plant used active alumina to accumulate the fluoride, and dried the wash water and regeneration chemicals in a bed, this to prevent further contamination of the water source. They ended up abandoning this technique due to high fluoride level. If it was the high maintenance costs with frequent change of alumina or the fact that the fluoride level was so high that the treatment step could not deliver properly, is unknown (Have not been able to get answer from Water Health). The idea however is good, with this plant the fluoride is removed from site, and not let out again. With the new RO system that is planned installed, it will be important to get a good solution for handling the reject water.

Although it is not observed any deterioration of the water source with regard to reject water handling, the authors mean it is a valid concern. The RO systems have no problem handling a water source with high fluoride level. However the most important prerequisite for having safe drinking water is to take care of the water source.

Part 8: Suggestions and recommendations

8.1 Water quality monitoring

Because there was no opportunity to observe the installation process for a new plant, the recommendations are based on plants installed by Naandi in the period 2007 – 2010. Naandi has improved their monitoring and testing of the water source since the plants mentioned in this thesis was completed. A fouling test (silt density index) has been implemented in addition to the 20-parameter test at all new sites and in Punjab, water samples of the groundwater are taken regularly to see if the reject water has influenced the water quality.

8.1.1 Water quality monitoring routines

Before the plants were installed, research on possible water sources that could be used was done. This was done as a part of the primary information report and sent to Naandi (Author has not been able to get one of these). When it was decided which water source that would be used at the specific site, a 20-parameter analysis of the raw water was taken by Naandi to document the water quality. The fouling potential in the water source was not measured. Naandi did not test the capacity or monitor the water level in advance, to see if the ground water level was stable and the aquifer could deliver enough water. Naandi have to trust that the provider of the plants' water source has done a proper research of the sources' capacity.

Under operation of the plants, the product water was analyzed monthly to ensure that the treatment step works satisfactory and deliver product water with good quality according to the Indian standards for drinking water. Monitoring the water source or the quality of the raw water was not done at the observed plants.

8.1.2 Recommended monitoring of the water source before and after installation of the plant

The quantity of water in the source will vary over the seasons depending on the hydrology at the site. Areas that are affected by the monsoon are especially exposed for this variation. There is usually not a problem to monitor variations in the water level for surface waters and it is possible to estimate the capacity by observation. The size and capacity of a ground water aquifer is more uncertain to estimate and has to be pumped over a longer period, where the hydraulic property in the ground, water level and ground water flow direction should be documented to get an overview of the aquifer. The advantages of doing this will be:

- The capacity of the aquifer will be documented.
- It will be possible to estimate the reject water's influence on the ground water quality.
- In a long term perspective the need of water may increase and it is therefore important to check the aquifers' ability to meet these challenges.
- The ground water flow direction will determine vulnerable spots in the aquifers catchment area that could affect the water quality.
- It will be possible to determine borewells that are vulnerable to water shortage

With today's procedures in terms of installing a plant, it will be impossible for Naandi to monitor the source over a longer period of time before the plant is built. The period of time from the decision of building a plant is taken to the plant is operated is only 90 days. The plants' water source will at many sites be a new borewell and this will also do it difficult to monitor the source over a longer period of time before the plant is built. It is necessary to implement a more proper analysis of the water source if the plants and the operation of this shall develop further in the future. A possible solution to this is that Naandi gets more involved in the decisions of the choice of water source and the presurvey of it. A proper monitoring of the water source should be implemented in the building process. This implementation should include test pumping and aquifer monitoring during the construction period. This will give an estimate of the capacity, changes in the water level, and ground water flow direction. How the seasonal variation will affect the recharge of the aquifer and ground water flow direction, can be monitored and documented after the plant is installed and in operation.

The water quality is also important to analyse thoroughly before the plant is installed. In terms of the possible seasonal variations in the water quality, water samples should be collected and analysed over several months. In addition to a 20-parameter test, the fouling potential in the source must be examined. The advantages of better presurveys of the water quality will be:

- It will indicate if there is a significant seasonal variation in the water quality.
- It will indicate the lowest expected water quality in the source and at which time this occurs.
- It will determine the necessity of pretreatment.
- It will indicate the expected maintenance- and operation costs of the plant.

It will, as mentioned not be possible for Naandi to implement a long time survey of the water source before the decision of building a plant is taken. Several water samples should instead be analysed during the building process of the plant, to get as much information about the water quality as possible before the treatment step is installed. During the operation of the plant it is important to analyse water samples regularly.

Collecting raw water samples was a problem at most of the plants visited. An easy solution to solve this problem will be to install a crane on the water supply pipe. Water samples from the water source could then be taken and analysed in addition to the water samples of the product water.

These recommendations will lead to more work and increased costs for Naandi. It is important that Naandi and the plants develop their procedures over time so they always are able to offer the best solutions. In long term, the costs of doing this will be profitable and lead to more sustainable plants.

The raw water quality is one of the most important factors to document in terms of further development of the plants. If the water quality is thoroughly analysed and known before installation of the pretreatment, can the pretreatment step be adapted after the water quality at the site and the most effective treatment solution can be chosen. Problems such as broken membranes and inefficient pretreatment can be prevented due to this. The recovery rate may also increase due to a pretreatment step that adapts the water quality at the site. Another fact is the financial part. The operation and maintenance cost is financed by water sale. It is therefore important that the expected maintenance- and operation costs are well documented before the plant is installed. This will be important when the plant is handed to the village after five years.

Analyses of the raw water during the operation of the plant are important so the reject waters influence on the water source can be monitored. An increase of Fluoride and TDS in the source is not desirable and it is important to observe possible changes. Regularly water analysis of the source will reveal if the water quality in the source improves or get worse in a long-term view. The efficiency of treatment for the different treatment equipments in the plant can also be monitored when the water quality in the source is known. It is possible to adjust the pretreatment after the quality of the water. Regular analysis of the raw water will reveal the plants potential to increase the recovery rate, if the water quality improves due to seasonal variation. The pretreatment cost will be reduced as a result of increased water quality and less need for pretreatment.

8.2 Detecting of potential foulants in the water source

Sources of fouling can be divided into four categories and more than one category could occur in the same plant *(Baker, 2004)*. It is important to detect the fouling potential in the water, but is also important to detect what kind of fouling the plant has to deal with to ensure that the right and most effective pretreatment is installed. Possible methods that could detect and/or indicate the fouling potential and the fouling sources are listed below.

8.2.1 20-parameter test

The 20-parameter water analysis Naandi uses, will give information about the basic chemical and physical parameters in the raw water and the major anions and cations that may scale.

8.2.2 Langlier Saturation Index (LSI)

The Langlier saturation index is used to predict Calcium carbonate ($CaCO_3$) scaling in brackish water. Precipitation of $CaCO_3$ occurs when the solubility limit is exceeded. Higher temperatures, calcium concentrations and alkalinity levels will together with high pH decrease the solubility.

Below is it showed how the pH will affect the solubility of $CaCO_3$.

$Ca^{++} + HCO_3^- <-> H^+ + CaCO_3$ *(Thermax LTD)*.

As the equation shows, the equilibrium can shift from the right side to the left side by adding H^+ as an acid to the solution.

The LSI test is based on saturation of Calcium carbonate in the concentrate and it is defined as pH of the concentrate minus the pH of a saturated concentrate.

$LSI = pH_{concentrate} - pH_{Saturated\ concentrate}$

A negative LSI indicates no scale tendency, zero LSI indicates that the concentrate is at equilibrium and a positive LSI indicates scale tendency in the concentrate. *(Boerlage, 2001)*.

8.2.3 Silt Density Index (SDI)

Silt density index (SDI) is used to specify the rate of fouling caused by suspended and colloidal particles in the feed water. The test is empiric and based on filtering of raw water through a membrane with pore size of 0.45 µm, given a specific time and pressure. The SDI value represents the % plugging of the filter per minute and will indicate the fouling potential in the water. Typically deep wells will have a SDI below 3 and surface water over 5 *(CSM, 2010)*. SDI values over five indicate that the water has a high potential to foul the membrane and pretreatment steps are necessary. The SDI test can be carried out as described below or taken with electronic equipments.

The procedure are based on ASTM test D4189-82 *(DOW, 2010d).*

Equipment:

- Pump
- Pressure regulator
- 1 to 5 bar manometer
- 47 mm diameter membrane filter with 0,45 µm pore size
- Filter holder
- Stop watch

Procedure:

During this test the feed pressure has to be 2.1 bar constantly. Changes over 1^0 C in the water could affect the result

- Filter 500 ml of sample water through the membrane filter and measure initial time t_0
- Keep the filter in operation for 15 minutes
- After 15 minutes, again measure the time to filtrate 500 ml sample water t_1
- The calculation of the SDI:

$$SDI = \frac{\% P_{30}}{T} = (1 - \frac{t_0}{t_1}) * \frac{100}{15}$$

SDI = Silt density index
$\%P_{30}$ = % plugging at 2.1 bar
T = Time between start of the first measurement and the start of the second measurement
t_0 = Time required to collect the first 500 ml sample
t_1 = Time required to collect the second 500 ml sample after 15 minutes (T)

When t_1 is four times t_0 the SDI value is 5. Total blockage of the filter gives a SDI value of 6.7. Generally a spiral wound membrane will require a SDI value below 5, but a lower SDI value is better *(Baker, 2004)*.

The colour or/and the composition of the layer on the used filter could be useful in the terms of roughly identification of the fouling substance. *(Hem and Thorsen, 2008)*, *(Mosset et al., 2008)*.

Dark brown: Humic

Yellow/brown: Organics

Red/brown: Iron

Gray: clay/silt (minerals) or Activated carbon

Gelled: Biofouling

Particles: Suspende solids

There are some limitations using the SDI test. The SDI test is based on dead end filtration compared to a RO module that is based on cross flow filtration. There are different forces in the two systems that affect the particles on the membrane surface in different ways. Particles that will not foul a RO membrane might foul the 0.45 µm filter. There are also colloids with sizes less than 0.45 µm that could foul the membrane, but will not foul the 0.45 µm filter *(Paul and Abanmy, 1990)*. Water sources with a high amount of naturally organic matter could also fail the SDI measurements *(Hem and Thorsen, 2008)*. The SDI test will therefore not give a 100 % correct answer about the fouling potential in the water, but it will give a good indication, in lack of other methods.

8.2.4 Turbidity

Turbidity measures the relative amount of light that passes through a solution. The amount of suspended solids in the solution will decide how much of the light that is going through. Turbidity is determined as Nephholometric Turbidity Units (NTU) *(Hydranautics, 2010)*. Typical suspended and colloidal matter as clay, silt, finely divided organic and inorganic matter, plankton and microscopic organisms affect the turbidity in the water. Typically 1 NTU is the maximum turbidity level for spiral wound RO membranes *(United States Environmental Protection Agency Office of Water, 2005)*. Levels above this will tend to foul the membrane *(CSM, 2010)*. Turbidity measurement is only an indicator of the concentration of particles in the feed water. This is because the turbidity does not say anything about the size of the particles in the solution. A large particle will maybe not foul the RO membrane but rise the NTU value. The NTU value will not say anything about the particle amount in the solution, as thousands of small particles could give the same NTU value as one large particle *(Paul and Abanmy, 1990)*. It does not need to be any relation between SDI and turbidity *(Chakravorty and Layson, 1997)*, but together they will give an indication of the fouling potential in the water.

8.2.5 SUVA

Specific Ultraviolet Absorbance (SUVA) is a method that roughly calculates and characterizes the organic carbon in the water that more significantly leads to fouling. This method is generally used for surface water where organic fouling could be a problem. Organic carbon in the water can either be characterized as hydrophilic (tend to dissolve in the water) or hydrophobic (tend to not dissolve in the water). Studies have shown that hydrophobic organic carbon more significantly leads to fouling and a high SUVA value will indicate a greater fraction of hydrophobic organic carbon in the water. A SUVA value higher than 4 L/(m*mg) is considered to be difficult to treat.

Following equation is used to determine SUVA:

$$SUVA = \frac{UV_{254}}{DOC}$$

SUVA = Specific ultraviolet absorbance (L/mg*m)

UV_{254} = UV absorbance at 254 nm (1/m)

DOC = Dissolved organic carbon

It can been estimated to use values of total organic carbon (TOC) instead of DOC.

(United States Environmental Protection Agency Office of Water, 2005).

8.3 Handling membrane reject water with regard to fluoride

Methods to insure that the fluoride level does not rise further in the affected locations must be considered. Proper handling of fluoride rich reject water is one method that can prevent this.

To solve this potential challenge two different approaches have been studied.

- The first is a system that collects the fluoride in the reject water. The remanding water can be discharged in a matter that does not affect the water source. The requirement must be that over 50 per cent of the fluoride is removed from the reject water, so the water that is discharged has a lower content of fluoride than the water taken up from the water source.
- The second option is to lead the reject water away from the plant/source. This is consistent with what is practiced today, and is also the cheapest solution.

8.3.1 Purification of reject water

There are several benefits of purifying the reject water. The water will be handled locally and potential hazards will not be moved to another location. The purified reject water can be infiltrated back to the ground and help regenerate the groundwater, or be treated again in the RO system to reduce water consumption. The disadvantage of doing this is the fact that this will lead to increased expenditures.

Reject water does not need to be treated to the same level as drinking water. The main objective will be to treat it to a level where the fluoride amount in the treated water is lower than the amount that occurs naturally in the area.

8.3.2 Disposal of reject water without treatment

Leading the reject water out of the plant without any form of treatment is the chosen solution for all of Naandis plants. It is several factors that have done this to a preferred solution: low cost, no strict rule related to reject water disposal and the fact that no extra contaminant are added to the water other than the ones who was there from before.

It is important to consider if the reject water can be disposed close to the plant or if it need to be sent far away. The plants visited had done this differently. It is suspected that the way it is solved at the different plants are done in terms of convenience, and not in terms of which choice was the best for the water source.

8.3.2.1 Disposal of reject water close to the source

If it is decided to let the reject water out close to the water source/well, it must be considered what kind of influence this could have on the water source. If the reject water contains high levels of fluoride or other unwanted substances, it will be undesirable to lead the reject water out locally. There is no definitive answer on how high these levels should be before deciding to lead the water far away, but if the water source deteriorates over time, this can be a clear indication. With regards to fluoride, the goal must be a water source that maintains a level of under 1,0 mg F/l. Not everybody in the villages uses the water from the treatment plant as drinking water, therefore must the water treatment plant take a collective responsibility to not degrade the water source further.

When choosing to dispose the reject water close to the source or plant, there are some minimum precautions to follow:

- Try to achieve the greatest possible distance between outlet and intake. This distance must be so considerable that water is not in direct contact with the intake, but not greater than it will help to regenerate the water source.
- If the water source/well is located lower in the terrain than the reject outlet, it is important to lead the reject water away to prevent it from flowing directly to the water source. This was observed at some locations and is examples of poor reject water handling.
- Make sure that the outlet goes at least two meters away from the plant, and leads the water away from the plant. The water can cause rot and excavation around the building, in addition to making the plant less hygienic.

8.3.2.2 Disposal of reject water far away

Naandis guidelines when constructing a new water treatment plant with RO, is to lead the reject water far away from the site through piping or drainage ditches. As observed, this was not always followed. The reason for leading the reject water far away must be to protect the source, and choosing this for all plants as a safety instruction, does not always needs to be necessary.

If deciding to lead the reject water away from the source, a few factors need to be considered.

- If the raw water is of relative good quality, and the reject water therefore contains small quantities of unwanted substances, it may be more appropriate to keep the water in a more local water cycle.
- If the water source suffers from water shortage, leading the reject water far away can worsen the situation. By leading the water out locally some of it might infiltrate back into the ground. This must of course be considered in accordance with the quality of the reject water.
- It is important to know where the reject water ends up. If it affects water sources used by others, it must be redirected.

8.4 Removal techniques to purify fluoride rich reject water

All the methods that are mentioned in this chapter have been shown to be capable of removing fluoride under the right conditions. Our assessment of which methods that may be suited is based on four criteria:

- The method has to be social accepted for the users.
- The method has to be designed to deal with the given water quality.
- The method has to be easy to operate and maintain for the operator.
- The method has to be economically viable.

The treatment methods are only meant as an insight into possible technology solutions that must be considered more closely if it is implemented. Costs are not calculated properly and it is not made any attempts if it will work on reject water from the RO plant. The developments of this method are always continuing and must be taken to advice when going forward. There are other technologies for removing fluoride that are not mentioned here. However, the four process presented in this chapter is the techniques considered to be most relevant. The different techniques can be split into these two categories.

- **Precipitation techniques**
- **Adsorption and ion exchange techniques**

Common for both techniques is that fluoride is gathered up, instead of passing true as in the RO unit. This will result in a product that contains a high level of fluoride. The product material must be disposed of or regenerated in a proper way, or else the whole process is wasted.

8.4.1 Precipitation techniques

Precipitation processes involves adding of chemicals to make the fluoride precipitating. Chemicals may be calcium or aluminium salts. This technique requires daily dosing of precipitation chemicals, and the precipitation technique produces a certain amount of sludge every day that has to be handled.

8.4.1.1 Lime and aluminium

Lime and aluminium as precipitations chemicals are common within water treatment. As defluoridation, lime and aluminium are used in different methods, either applying one of the substances or combine them. Lime is added to the water as Calcium hydroxide, also called slaked lime $Ca(OH)_2$ and works as a flocculating agent or pH adjustment. The aluminium is added as aluminium sulfate $Al_2(SO_4)_2$, and works as a flocculating agent.

The Nalgonda process is developed in Nalgonda district, India. It was developed as a method for cleaning drinking water on a community or household scale. The process is aluminium sulfate coagulation, flocculation and sedimentation. The aluminium sulfate is added to remove the fluoride from the water, while the lime is added to ensure pH adjustment. *(Feenstra et al., 2007)*, *(Fawell et al., 2006)*.

There are several different designs of the Nalgonda technique. The most common is the design of two buckets, where one bucket is the treatment bucket, and the other one is the clean water bucket. In the treatment bucket the aluminium and lime are mixed rapidly with the raw water, followed by a slow mixing to build up flocs. The aluminium and lime are added simultaneously, and the lime dosage is fixed at 5 per cent of the added aluminium *(Fawell et al., 2006)*. The flocs that were formed are then left to settle, before the water is lead through a simple filter to the clean water bucket. In this way it works as a batch system, treating approximately 20 litres a time. For treating the reject water from Naandis RO-plants, it will need to handle 1000 l/hr for up to ten hours based on the observed drinking water treatment plants. This can be solved in two different ways; developing a larger batch system consisting of large tanks, or designing a system that continuously treats the reject water directly. Because the fluoride is only loosely bound to the aluminium hydroxide flocks, it would be advisable to discard the precipitate between batches, or each day in a continuous process.

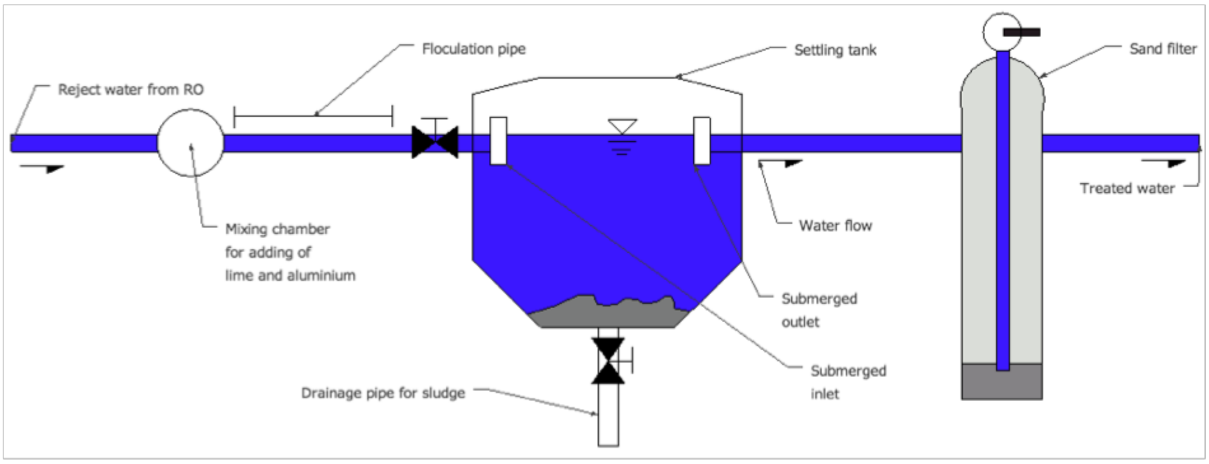

Figure 16: Shows a conceivable treatment system after the Nalgonda method. This is only to illustrate a possible construction for continuous treatment. Design by (Havig and Holstad, 2010).

Digest and discussion of the process:

- The removal performance is usually not sufficient for reaching under 1 mg F/l, even when the appropriate doses are used *(Feenstra et al., 2007)*. However it has shown to remove about 70 per cent of fluoride, which is good enough for the treatment of reject water.
- If run like a batch system, each batch will take approximately 1 *hour (Feenstra et al., 2007)*.
- The process is established in both India and Tanzania. The National Environmental Engineering Research Institute in India developed it as a low cost treatment process, however as a drinking water treatment, and not as a treatment system for reject water in RO plants.
- Treatment costs are low, as the equipment is low tech and the chemicals are cheap.
- Advantages are: Low costs in installing and use, established technique, shown to be workable in rural areas.
- Disadvantages are: The treatment efficiency is limited to about 70 per cent *(Feenstra et al., 2007)*. The process is also less effective if the fluoride level is high in the contaminated water. A larger dose of aluminium sulfate may then be

needed, which can lead to a risk of getting rest aluminium in the treated water *(Feenstra et al., 2007)*. This larger dose will also result in more sludge production, and can create a disposal problem. The system also requires more space than other defluoride systems.

The Nalgonda technique is well proven for removing fluoride. It has problems removing over 70 per cent, and does not always deliver drinking water quality. But the requirement is only to remove over 50 per cent of the fluoride and it may therefore be a good solution. It has been proven to be a cost-effective method, since the installation is cheap and the chemicals that are needed are common and affordable. The main concern with this method is how to deal with the sludge created, and how to dispose it. The sludge is quite toxic because it holds all the removed fluoride in a concentrated form. It must therefore be discarded in a proper way, and kept away from children, animals and food production.

8.4.1.2 Fluidized bed reactor

Fluidized bed reactor can be used to remove several different substances such as fluoride, phosphate, softening and heavy metals *(DHV, 2010)*. The heart of this system is the reactor. It is partially filled with a seed material called pellets, usually sand or other minerals. The water is pumped in an upward direction to keep the pellet in a fluidized state. To make the targeted component to crystallize on the pellet, a reagent dose is added. As the pellets grow, they become heavier and move to the bottom of the reactor. With intervals, an amount of the biggest pellet is removed, and fresh new pellets are added. The reagent that is used for fluoride removal is calcium salt. It is added to the water to the point where the solubility of CaF_2 is exceeded, and fluoride converts into solid crystals that bind to the pellets. The reaction is as followed:

$$Ca(OH)_2 \Rightarrow Ca^{2+} + 2OH^-$$

$$Ca^{2+} + 2F^- \Rightarrow CaF_2$$

The Crytalactor® is a fluidized bed reactor developed in Netherland by DHV. It was designed for recovery of unwanted substances in industrial wastewater. In the reactor the fluoride is removed from the water, while calcium pellets are been created. The bottom of the reactor has a feed line for untreated water, reagent feed for calcium, and pellet discharge for the grown pellets. The effluent of purified water is placed at the top of the reactor. The system is continuous and can be constructed in all sizes. As seed material, ordinary quartz sand is used. The four steps found in other precipitation processes; coagulation, flocculation, separation and dewatering of the sludge, are combined into one step in the Crytalactor®. The unit is also made compact due to the high surface loading (40-120 m/h) *(DHV, 2010)*. However, the fluidized bed reactor is best suited for water with higher fluoride concentrations > 10mg/l *(Feenstra et al., 2007)*. It may therefore be more suited for treating reject water with higher concentration than observed at the visited plants.

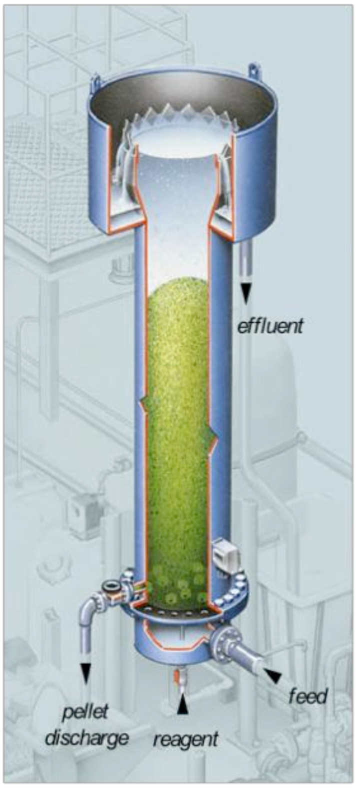

Figure 17: *Shows the Crytalactor® created by DHV.* (DHV, 2010).

Digest and discussion of the process:

- The system is originally designed to treat industrial wastewater with much higher fluoride concentration than normally in the nature, but if the concentration of fluoride is high > 10mg/l it could work.
- The system runs continuously and not as a batch system.

- The Crytalactor® is well tested and several system have been delivered to different industries who needed to treat their waste water, but not as a small-scale plant suited for 1000 l/hr *(DHV, 2010)*.
- Operation cost is believed to be low, since the chemical use is cheap and available, the rest product is almost water free, and the used pellets can be sold as industrial product. The installation cost is unknown but believed to be higher, due to a more advanced and technical solution.
- Advantages are: Compact installation, rest product with extremely low water content, and the calcium fluoride pellets produced have a so high purity that they can be reused in other industries.
- Disadvantages are: More expensive technology, more complicated to run, and need a high concentration of fluoride to function properly.

The laboratory scale model tested on this technology *(Aldaco et al., 2004) and (Aldaco et al., 2007)*, are exposed for a much higher level of fluoride than was observed at the different treatment plants. It is therefore uncertain if it can handle the low concentration from the RO reject water. The advantage of a low-volume waste product rather than bulky sludge, together with a compact design, makes it an interesting technology. DHV who developed the Crytalactor® have been asked to look at the possibility of making a compact plant for treating 1000 l/hr with fluoride amount between 4 to 12 mg/l. They concluded with that the scale of the system resembled their pilot plant and that is possible to produce. Nevertheless the fluoride concentration is likely to be too low to be removed efficiently *(DHV, 2010)*. They also suggested that ion-selective ion exchange or activated alumina is more effective, and expected to be cheaper with the concentration of fluoride that was mentioned.

8.4.2 Absorption techniques

Adsorption and ion exchange is a process where water passes through a contact bed and the fluoride is removed by ion exchange or surface chemical reaction with the material in the bed. After a period of operation, the material will be saturated and has to be refilled, changed or regenerated. Absorbents used for fluoride removal can be activated alumina, bone charcoal, limestone or synthetic ion exchange resin. *(Feenstra et al., 2007)*.

8.4.2.1 Activated alumina

Activated alumina is manufactured from aluminium oxide (Al_2O_3), and the product is highly porous with a large surface area. When water passes through the activated alumina, fluoride and other pollutions are absorbed on the surface of the grains. The effectiveness of the filter is depending on the contact time, capacity of the alumina, and pH. The longer the contact time between the water and the activated alumina, less fluoride will be in the effluent water. The effectiveness of the alumina is highly depending on the pH of the water, the optimum level is about pH 5-6. After several uses the grains get saturated with pollution, this depending on the amount of pollutions in the water. When this happen the grains will need to be regenerated or changed. The most common regeneration process is done by use of caustic soda (NaOH) and sulphuric acid (H_2SO_4). A caustic soda mix is passed through the filter, and washes out the fluoride. The residual caustic soda is then washed out with water, and the grains are neutralized with sulphuric acid. During this process some of the alumina is lost, and the capacity of the remaining alumina is reduced. After several regenerations the alumina has to be replaced. The regeneration can be done locally on the plant or be recycled at the dealer. If done locally, a system collecting the caustic soda is needed as it will contain high levels of fluoride.

An activated alumina filter is usually a column filter filled with alumina. Water goes upstream and the alumina becomes saturated from the bottom and up. To prevent the alumina from becoming completely saturated, the material needs to be regenerated at regular intervals. An activated alumina filter are able to derogate fluoride in water if fluoride level are between 4 and 15 mg/l *(Sirmurali and Karthikeyan, 2008)*. However, the higher the levels of fluoride in the water are, the faster the filter gets saturated. A survey conducted in India *(Sirmurali and Karthikeyan, 2008)*, tested how long a specific filter can produce water quality of < 1mg F/l in relation to the concentration of fluoride. Fluoride concentrations of 4mg F/l of water delivered 16 liters before the concentration exceeded 1 mg F/l in the effluent. At 8 mg F/l of water this was reduced to 6.9 liters, and by 12 mg F/l it was further reduced to 4.4 liters *(Sirmurali and Karthikeyan, 2008)*. This was just a small laboratory scale, but shows that the capacity of treatment before the filter needs to be renewed or regenerated is highly depending on the raw waters' fluoride level. The level of fluoride in the water source will most likely also vary with the season, and must therefore be taken into account when planning regenerating intervals.

Optimal pH is between 5 and 6 but it has shown to work properly up to pH 7 *(Sirmurali and Karthikeyan, 2008)*. Waste product after this process is relative small. Beside the used alumina that needs to be sent away, waste product consists of the caustic soda mix used for regenerating the filter. This mix contains a high level of fluoride and must be handled properly.


Picture 5 and 6: To the left is used activated alumina. The right picture shows a column filter filled with alumina. Both picture are taken at Devarapalli, Andhra Pradesh, India (Havig and Holstad, 2010).

Digest and discussion:

- The system is designed to treat water with relative high levels of fluoride and arsenic. It can easily produce water with fluoride level down to < 1mg/l, and is therefore well suited for treating reject water *(Fawell et al., 2006)*.
- The system can be run as a batch system or continuous, but usually it is run continuously.
- The system is produced in all sizes from small household filters connected to the tap at home, to large systems treating 1000 x 10^3 liters per day. (Constructed in South Africa, treating water of approximately 8 mg F/l *(Feenstra et al., 2007)*.)

- Operating cost was previously considered to be high due to chemical cost and low availability of activated alumina on the market, but this is no longer the case. Experience from India, Thailand and China indicated that activated alumina might be an affordable solution *(Feenstra et al., 2007)*. With regard to purify drinking water and not treat reject water.
- Advantages are: proven effectiveness, available technology, and relative compact design.
- Disadvantages are: More costly than for instance Nalgonda techniques, and a used regeneration solution contains a high level of fluoride that has to be handled.

Activated alumina is a well-proven technique for treating drinking water, and will most likely work well in the treatment of reject water, given that the fluoride level is under 15 mg/l *(Sirmurali and Karthikeyan, 2008)*. A water treatment plant run by Water Health located in Devarapalli, Andhra Pradesh, India, had installed an activated alumina and UV plant for treating fluoride rich ground water into drinking water. The plant produced 1000 litres per day and replaced its alumina every three month. They had solved the problem with toxic regeneration solution by leading it together with the flush water out to a pool where it vaporized and left the solution in a concentrated form. They abandoned the activated alumina system and changed to a RO system because of high fluoride concentration in the raw water. Nevertheless, as mentioned earlier the purpose with treating reject water is not to get the fluoride level down to drinking water standard, only down to a level lower than the raw water.

8.4.2.2 Limestone absorbent

Limestone or Calcium carbonate ($CaCO_3$) can be used to absorb fluoride. Other experiments have also assessed how to improve this filter. Adding of CO_2 during filtration or adding of acid in the water prior to filtration, has improved the technique (Nath and Dutta, 2009). By passing CO_2 through the lime stone filter during filtration, Ca^{2+} activity increases, and precipitation of CaF_2 occurs due to dissolution of calcite by CO_2. By adding an acid to the water, the pre-acidified water generates high concentration of Ca^{2+} in the filter due to dissolution of $CaCO_3$ by the acids *(Nath and Dutta, 2009)*. Acetic acid and Citric acid was chosen in the experiments, since they both are edible and do not add any harmful contaminants to the water. This filter then work as a combined precipitation and absorption technique.

A limestone filter can consist of one or several columns filled with granular calcite or crude limestone crushed to 3-4mm size *(Nath and Dutta, 2009)*. The filter effectiveness highly depends on the pH of the water. A lowering of the pH will increase the removal performance of fluoride. As mentioned earlier the CO_2 or acid lowers the pH, and increases the effectiveness. If the filter is operated without this pH lowering, a high contact time is important. Several columns with Calcium ($CaCO_3$) that makes the water pass through at a slow rate, could be an affordable and easy solution. The treatment effect is probably limited to only 30 - 50 per cent *(Turner et al., 2008)*, and may therefore be seen upon as more preventive measures for reducing fluoride level. In the study done by *(Nath and Dutta, 2009)*, a batch test with crushed limestone and acidified fluoride solution, showed that it could reduce the fluoride concentration from 10 mg/L to 1,74 mg/L and 0,977 mg/L, depending on which acid was chosen. Although absorption of fluoride on limestone surface did take place in this test, precipitation was the major mechanism of fluoride removal *(Nath and Dutta, 2009)*. Contact time for reaching acceptable levels depends on the dosage of acid. As in the other techniques, the filter media and precipitant must be handled appropriately after it has been saturated.

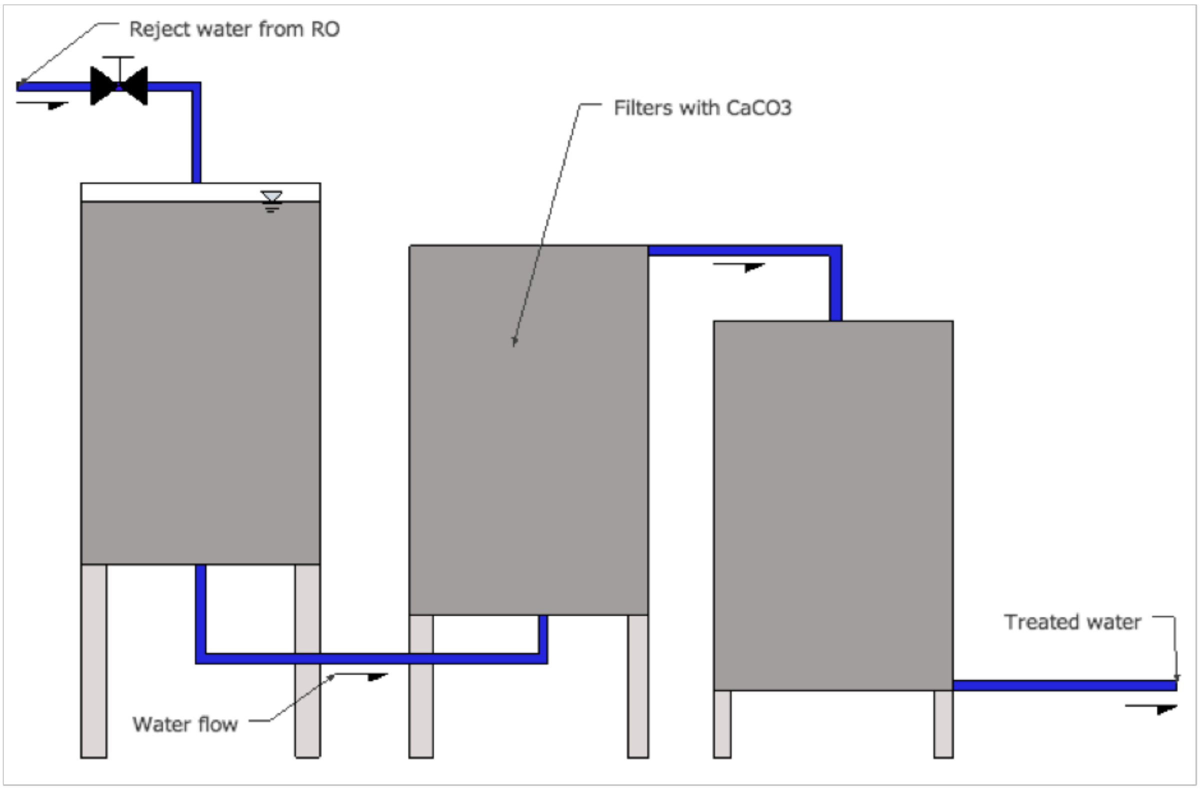

Figure 18: Shows a conceivable treatment system with Limestone or Calcium carbonate ($CaCO_3$). This filters is without adding of pH adjustment. Design by (Havig and Holstad, 2010).

Digest and discussion:

- The system with adding of acid or CO_2 has been proven to deliver water quality down to < 2 mg F/l *(Nath and Dutta, 2009)*, *(Turner et al., 2008)*. But without a pH lowering adding, it may be better suited for treating reject water with higher fluoride levels and less stringent requirements for low fluoride level in effluent water.
- Test done by *(Nath and Dutta, 2009)*, *(Turner et al., 2008)* has prove that the filter can deliver water with less than < 2 mg F/l if adding of acid or CO_2 to the filter. Without the pH lowering as acid or CO_2, it will have a much lower treatment effect and may be better suited for treating reject water with very higher fluoride level.
- The system can be run as a batch system to increase the contact time, or as a continuous system where the size of the columns is increased.
- Operating cost is believed to be very low. Limestone is a low-cost material, and is the only expense if run without use of acid or CO_2.

- Advantages are: Simple technology and easily available raw material
- Disadvantages are: Not a well proved technology, low efficiency without CO_2 or acids, and increase of calcium level in effluent water.

Limestone defluoridation is not as well proven as the other techniques. It has relative low efficiency without pH adjustment, and would therefore need high concentration of fluoride in the water to make an impact. If run with a pH adjustment the costs of operation will increase and make the technique less attractive. As economy probably is the most important factor, limestone without adding of pH adjustment is the most promising techniques. It can be a good preventive measure in areas with high fluoride level.

Conclusion

Several problems and challenges related to the operation of the plants were observed. Bore wells with water shortage, damaged membranes caused by fouling, high maintenance cost caused by inefficient pretreatment and low recovery are all challenges that can be related to the water source. We suggest that Naandi do a more thorough survey of the water source in terms of water quality and capacity before the plant is buildt and monitore this further during the operation of the plant. This can prevent the mentioned challenges and problems and lead to a more efficient operation of the plant due to economy, operation and maintenance.

There is no definitive answer of how high the levels of fluoride in the reject water can be before considering treatment measures. Treat the water twice is a tremendous disadvantage and is therefore only advisable in extreme situations. After studying the different techniques, limestone absorbent without pH lowering is what we believe to be the best option. This is because it is most likely of lowest cost and easiest to operate, including the fact that treating reject water should only be advised with very high levels of fluoride, where this filter works best. Another idea may be to change the whole treatment system to a system that takes up the fluoride instead of passing it through. Nevertheless, the different techniques mentioned will have increased costs with increase fluoride level, in contrary to RO where it will be the same.

We can neither prove that leading the reject water away or leading it just out the back of the building will affect the water source. We can therefore not give any other advice for future plants than the precautions mentioned previously. Nevertheless there are two changes in the existing plants that we think are advisable. The first is to redirect the reject water in Mattampalli and Pedhavedu so the water does not run directly back into the well. The other is to make sure that the reject water in Kavuru, Remalli, Neppalli, and Kacharam is let out further away from the plant to prevent damaging the building, and keep the surroundings in a more hygienic condition.

Suggestions for further work

Experiences made during the work with this thesis, has lead to suggestions for further work. The suggestion bellow can be of interest for Naandi to work further with.

- Build a small treatment system to treat fluoride rich reject water, and test the efficacy and cost expenses of running this.
- Make a long-term analysis of the raw water quality at selected locations to see if raw water quality deteriorates over time. To determine whether it is necessary to take measures to protect the water source further.
- Develop an inexpensive and effective pretreatment for the RO treatment plant.

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Attachments

Appendix 1: Observations done at Naandis drinking water treatment plants.

Appendix 2: Analysis of water samples taken at Naandis drinking water treatment plants.

Appendix 1:

Observations done at Naandis drinking water treatment plants.

Andhra Pradesh, India.

CHECKLIST USED AT THE PLANTS: 2

BOWRAMPETA, GAGILLAPUR, MATTAMPALLI, PEDHAVEDU. 17 - 18 JUNI 2010 3

GOGULAMPADU 05/07-2010 5

KAVURU 10/07-2010 6

KOLALAPUDI 10/07-2010 8

UPPUTURU 10/07-2010 10

REMALLI 19/06 2010 13

NEPPALLI 19/06 2010 16

KACHARAM 23/08 2010 18

NELLUTLA 23/08 2010 20

DEVARAPULLI 23/08 2010 22

Checklist used at the plants:

- Number of users
- Hours of operation each day
- How long has it been in operation
- What are the raw water source
- Has there been any problem with the raw water source
- Get some data of the water source
    - Ground soil
    - Are there some high parameter in the raw water
    - Are there water scarcity
    - Are there some pollution in the area
    - Etc.
- How is it been operated and maintained
- Has there been any problem with some of the equipments
- What test where made before installing this plant
- Are the users satisfied?
- Electric power been used and pressure on the RO membrane
- Differential between inflow and outflow.
- How is the plant built up, producer, type of elements and capacity
- Where is the reject water been lead
- Take picture of the area and the latest test report of the purified water
- Draw a simple sketch of the area
- Take water sample of reject water and raw water

Bowrampeta, Gagillapur, Mattampalli, Pedhavedu. 17 - 18 juni 2010

It is made a common summary of the observations done at the plants in Bowrampeta, Gagillapur, Mattampalli and Pedhavedu. The checklist is not used.

- There was no sign of water scarcity in the area we visited.
- There where high level of hardness in the water due to limestone in the ground.
- All the plants visited where standard TATA plants with 6 membranes and no sand or carbon filter.
- Half of the plants we visited had some sort of leak. Usually in the feed pump or where the pipes are connected.
- They were all delivering between 50/50 to 60/40 % in reject/product water.
- All the plants delivered treated water of good quality, well within the levels recommended by the government (IS 10500).
- Most of the plant where connected to the local water systems through a well and a water tower.
- There seems to be little control on where the reject water where lead. At Mattampalli and Pedhavedu is the reject water lead back to the top of the well.
- The plants seemed to be well maintained. Membranes are washed with treated water two times per day. A technician visiting the plants every 15 day to:
    - Wash the storage tanks and UV lamp
    - Change of cartridge filters, if they not already are changed due to pressure fall.
    - See if something was broken, and order spare parts.
    - Take water sample once a month of the treated water.
- No water samples were taken under the visit.

Picture 1: Mattmapalli, the drinking water treatment plant is built close to the villages well and water tower (Havig and Holstad, 2010)

Picture 2 and 3: Bowrampeta (left), TATA RO module. Mattampalli (right), water flow measurements on a TATA RO module (Havig and Holstad, 2010)

Gogulampadu 05/07-2010

Remarks: The checklist was not used when visiting this plant.

- The plant use a bore well as water source
- It is problems due to the water quality. Silt in the water leads to damaged membranes
- Before installation there was taken a 20 parameter analysis of the raw water. The fouling potential in the raw water was not measured. There were not conducted tests on how the raw water source would respond to extra load, since the water source is the village responsibility.
- The plants RO module is produced by TATA and a dual-media filter is retrofitted and used as pre-treatment.
- The reject water is leaded by pipe to an old well 10 meters from the plant.

Picture 4 and 5: Gogulampadu, the drinking water treatment plant (left) and the plants bore well (right) (Havig and Holstad, 2010)

Picture 6: Gogulampadu, the reject water was leaded to this well. (Havig and Holstad, 2010)

Kavuru 10/07-2010

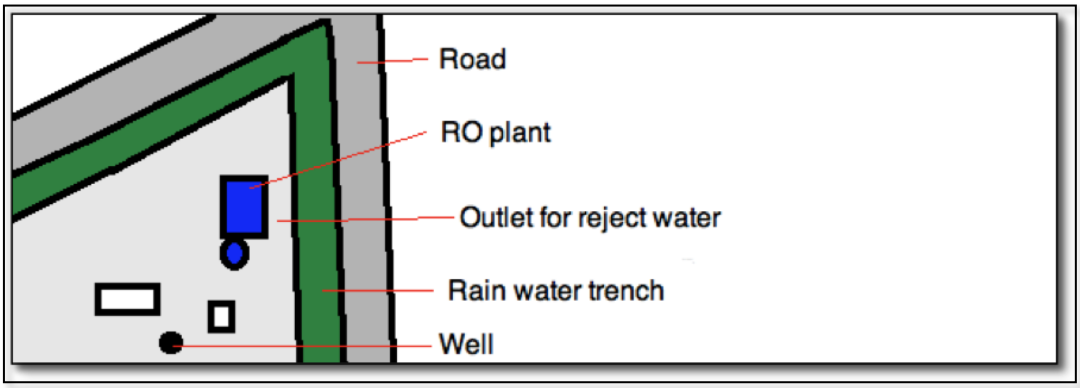
Remarks: The plant was without electricity under the visit.

- 300 users.
- 8 hour of operation every day.
- In service from 15 august 2008.
- Ground water.
- They have experience no problem with the well or the quality of the water.
  - Sediment well, 150 feet deep, located 15 meter away from the plant.
  - Relative good water quality and no water scarcity.
  - Sand ground.
- Membranes washed one time every day for 5 minute. Cartridge filters changes every 30 day or if the pressure difference is more than 0,8. Membrane filter is never changed. Storage tank are cleaned every 15 day.
- The plant has not experienced any specific maintenance problems.
- Before installation there was taken a 20 parameter analysis of the raw water. The fouling potential in the raw water was not measured. There were not conducted tests on how the raw water source would respond to extra load, since the water source is the village responsibility.
- The users were satisfied with the water.
- Plant performance: Theoretical capacity $1m^3/h$. No measurements were done due to lack of power.
- The plants RO module is produced by TATA. No extra filters are installed.
- Reject water are led to the back of the building, no specific infiltration attempted.
- No water samples taken, since the power was out

Picture 7 and 8: Kavuru, the drinking water purification plant (left), and reject water expiry (right) (Havig and Holstad, 2010).

Picture 9 and 10: Kavuru, the plants RO module (left) and UV disinfection module (right) (Havig and Holstad, 2010).

Drawing of Kavuru:



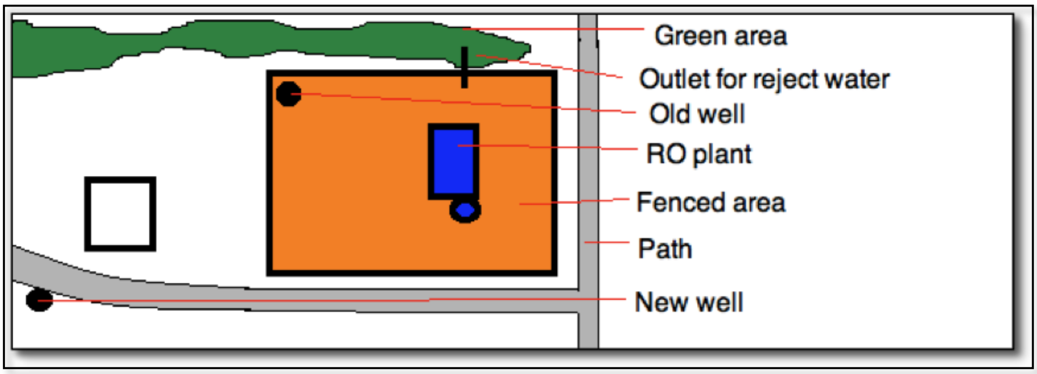
Kolalapudi 10/07-2010

Remarks: The plant was without electricity under the visit.

- 250 users
- 8 hour of operation every day
- In service from January 2009
- Ground water
- They have had one well that had dried up, and have drilled a new well ca. 15 meter away.
    - Rock well, 150 feet deep, 15-20 metres away from the plant.
    - Some water scarcity, and high level of fluoride
    - Sand and rock ground
- Membrane washes two times every day for 15 minutes. Changes of cartridge filters when needed or every 30-day. Chemical cleaning of membrane when needed due to pressure drop. Storage tank are cleaned every 15 day.
- The plant has not experienced any specific maintenance problems.
- Before installation there was taken a 20 parameter analysis of the raw water. The fouling potential in the raw water was not measured. There were not conducted tests on how the raw water source would respond to extra load, since the water source is the village responsibility.
- The users were satisfied with the water, and the operator had done extra effort to increase users from 200 to 250.
- Plant performance: Theoretical capacity $1 m^3/h$. No measurements were done due to lack of power.
- The plants RO module is produced by Malthe Winje. No extra filters are installed.
- The reject water is leaded into a green area behind the plant. There is no specific infiltration, but this solution is better than many other solutions that have been observed.
- It was collected samples of reject and raw water.


Picture 11 and 12: Kolalapudi, the drinking water purification plant (left), and the plants RO module (right) (Havig and Holstad, 2010).

Drawing of the Kolalapudi:



Upputuru 10/07-2010

Remarks: One of the membranes had a damage o-ring, so the plant did not operate optimal. There would be expected to find higher turbidity in the purified water, and wrong readings on the gauges due to this. Plant has experienced problems due to high turbidity in the raw water.

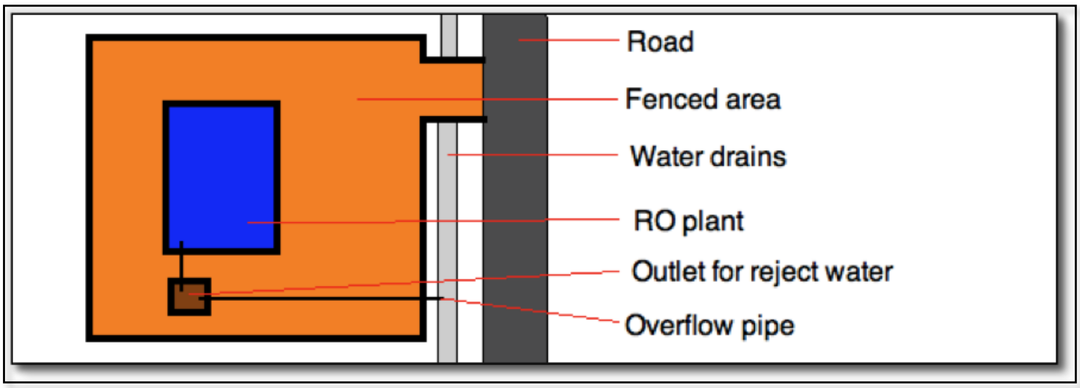
- 450 users
- 10 hour of operation every day
- In service from November 2009
- Surface water from a rainwater pond 500 meters away.
  - Water scarcity in summer due to the reservoir drying up
  - River water is used when water level is low in pond
  - Varying quality of raw water
- Membrane washes two times a day for 10 minutes. Changes of cartridge filters when needed. Storage tanks cleaned every 15-day. Membrane cleaned with chemicals every 20-day. Membranes have never been changed.
- The plants problem is the high maintenance cost compared to other plant. This is due to the fact that the raw water source has a high turbidity.
- Before installation there was taken a 20 parameter analysis of the raw water. The fouling potential in the raw water was not measured. There were not conducted tests on how the raw water source would respond to extra load, since the water source is the village responsibility.
- The users were satisfied with the water, and they were concerned about keeping the plant in operation, despite its problems.
- Plant performance: Theoretical capacity 1m^3/h
  - Used 14amp
  - Reject water 1000l/h
  - Product water 1200l/h
  - RO inlet 10kg/cm^2
  - RO outlet 3kg/cm^2.
- The plants RO module is produced by TATA and has extra filters.
- The reject water is lead to an infiltration pit outside the plant. The pit got an overflow pipe that runs under the ground to the water drains alongside the road.

At closer inspection, it seems that most of the water goes through the pipe, and only a small part infiltrated on site.

Picture 13: Upputuru, the drinking water purification plant (Havig and Holstad, 2010).

Picture 14 and 15: Upputuru, sand filter followed by a activated carbon filter, 10 micron bag filter, 5 micron bag filter and a UV unit (left upper corner) (left). Reject water handling (right) (Havig and Holstad, 2010).

Drawing of Upputuru:



Remalli 19/06 2010

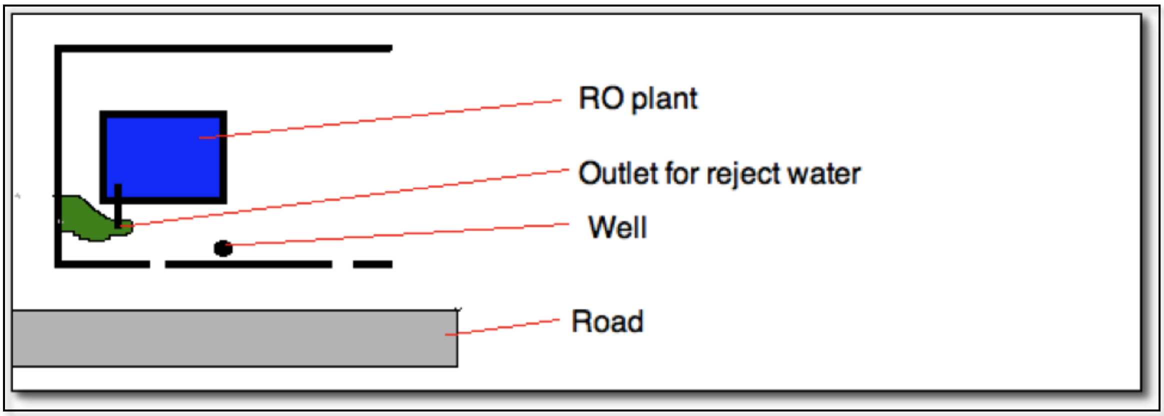
Remarks: High-pressure pump was leaking.

- 300 users
- 10 hour of operation every day
- In service since April 2010
- Well water
    - Well 5 meter away from plant
    - Relative good water quality, and no water scarcity
- Membrane washes three times a day for 20 minutes. Changes of cartridge filters every 15-day. Backwash of sand and carbon filter before starting the plant every day. Never cleaned the membranes with chemicals. Membranes have never been changed.
- High-pressure pump was leaking, even though the plant was only 3 months old.
- Before installation there was taken a 20 parameter analysis of the raw water. The fouling potential in the raw water was not measured. There were not conducted tests on how the raw water source would respond to extra load, since the water source is the village responsibility.
- The users seemed satisfied with the plant, and there was a long cue in front of the plant with people waiting to fill their cans.
- Plant performance: Theoretical capacity $1m^3/h$
    - Used 11amp
    - Reject water 1100l/h
    - Product water 600l/h
    - Reuse water 100l/h
    - RO inlet $5kg/cm^2$
    - RO outlet $3kg/cm^2$.
- The plants RO module was produced by Thermax and has extra filters.
- Reject water are lead out to the side of the building into some bushes.
- It was taken water samples of the reject and raw water.

Picture 16 and 17: Remalli, the cue in front of the water purification plant (left), and the reject water expiry (right) (Havig and Holstad, 2010).

Picture 18 and 19:Remalli, dual media filter followed by activated carbon filter (left), and the membrane filter modules (right) (Havig and Holstad, 2010).

Drawing of Remalli:



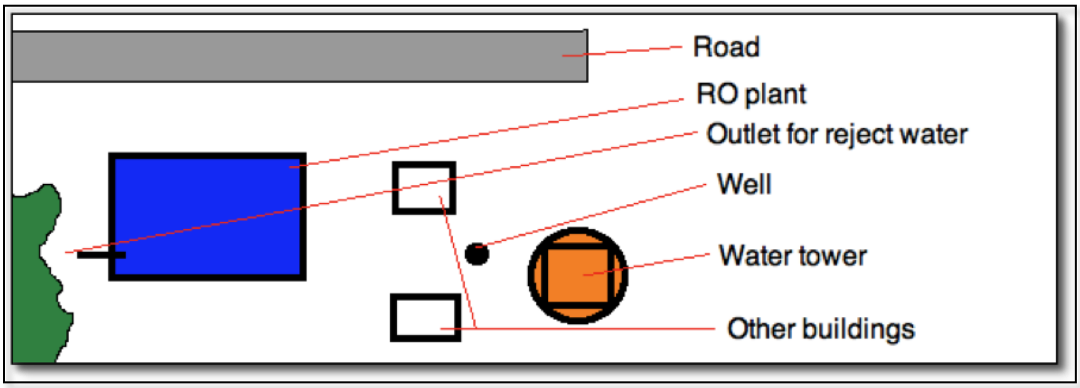
Neppalli 19/06 2010

Remarks: Very few users, plant seemed to work perfect, raw water quality so good that people chose not to buy the purified water.

- 20 users.
- 2 hours of operation every second day.
- In service since April 2010.
- Well water
  - 5 meter away
  - Connected to a water tower
  - Good water quality and no water scarcity
- Run and maintained after the Thermax handbook.
- Just some miner leakages.
- Just tested the standard 20-parameter test before installing.
- Plant was installed to remove high TDS in the water.
- The plants RO module is produced by Thermax. The plant have extra filters and use chemicals to adjust pH and anti scalent.
- Plant performance: Capacity $1m^3/h$
  - Used 13 Amp
  - Reject water 1100l/h
  - Product water 1000l/h
  - Reuse water 400l/h
  - RO inlet $5kg/cm^2$
  - RO outlet $6,5kg/cm^2$.
- Reject water is been lead out of the building into some bushes.
- It was taken samples of the reject and raw water.


Picture 20 and 21: Neppalli, the water purification plant (left), and the bore well (right) (Havig and Holstad, 2010).

Drawing of the Neppalli:



Kacharam 23/08 2010

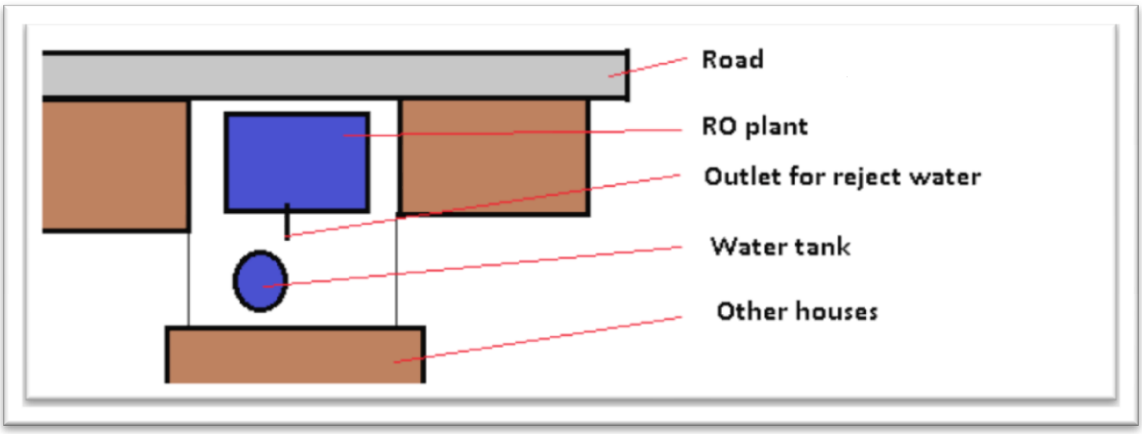
Remarks: No power available between 11am to 6pm, high level of fluoride in raw water.

- 150 users, 253 registered.
- 6 hours of operation every day.
- In service since October 2007
- Well water
    - From central well for the village
    - Gets water before chlorination of main water supply
    - No water scarcity
- Run and maintained after standard procedures
- Have had some problem with the high-pressure pump.
- Before the plant was installed, the standard 20-parameter test was taken.
- The plant was installed to remove high TDS in the water, and remove fluoride.
- The plants RO module was produced by TATA plant. The plant have only tree membranes instead of six, this reduce the capacity to 0,5 m^3/h. The system was installed without extra sand and carbon filters.
- Plant performance: Capacity 0,5m^3/h
    - No power
- Reject water is lead out to the ground.
- It was taken samples of the reject water.


Picture 22 and 23: Katcharam, the water purification plant (left), and the plants RO module (right) (Havig and Holstad, 2010).

Picture 24: Katcharam, the plants raw water intake (nearest pipe), and the reject water expiry (Havig and Holstad, 2010).

Drawing of Katcharam:



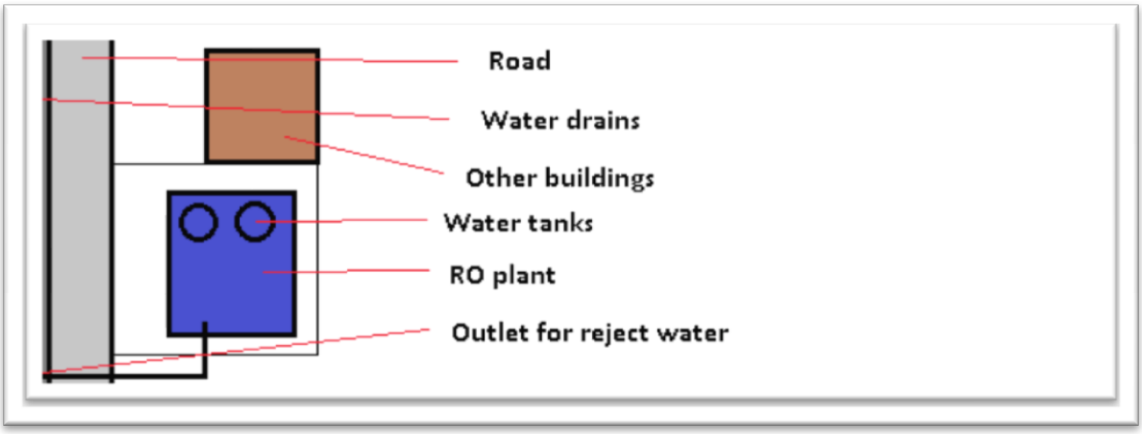
Nellutla 23/08 2010

Remarks: Plant with many users, in proximity to Hyderabad.

- 325 users, 847 registered.
- In service since November 2008
- Well water
    - 150 meter away
    - From central well for the village
    - No water scarcity
- Operated after standard procedures.
- Water was leaking from micro filters and feed pump. Changed the feed pump once since installation.
- Before the plant was installed, the standard 20-parameter test was taken.
- Plant was installed to remove high TDS in the water and fluoride.
- The plants RO module is produced by TATA. The plant has no extra filters.
- Plant performance: Capacity $1m^3/h$
    - Used 10 Amp
    - Reject water 1500l/h
    - Product water 1000l/h
    - Reuse water (none)
    - RO inlet $6kg/cm^2$
    - RO outlet $5kg/cm^2$
- Reject water is been lead out to a ditch, who runs along the road.
- It was taken samples of the reject water.

Picture 25 and 26: Nellutla, the water purification plant (left), and the plants RO module (right) (Havig and Holstad, 2010).

Drawing of Nellutla:



Devarapulli 23/08 2010

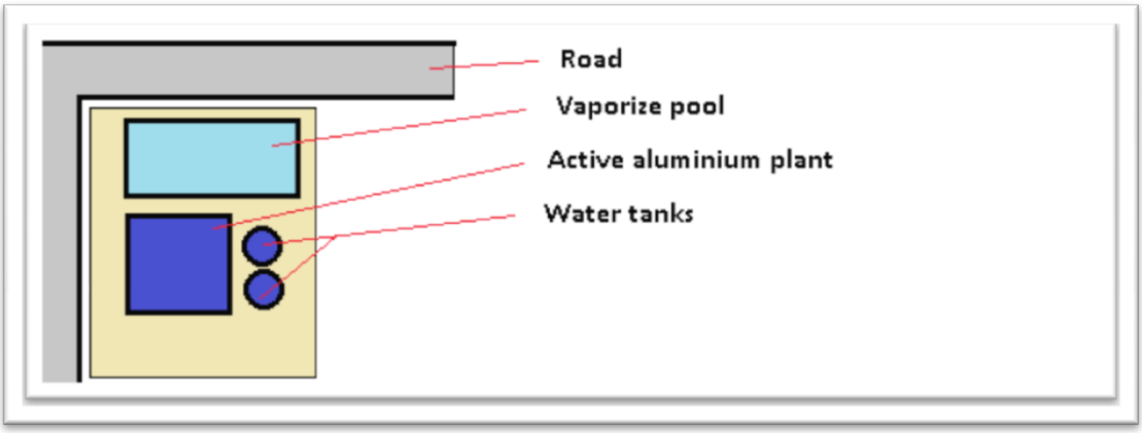
Remarks: Test plant from Water Health using active aluminium and a dry bed to collect fluoride. The treatment step is changed to RO.

- Relative small plant, producing 1000 litre per day.
- In service for several years, but with problems. Not in operation before the treatment step are changed.
- Well water
  - Firs well ran out.
  - Next well had sufficient water, but fluoride level was too high for the plant to handle.
- The activated aluminium was changed every tree month, and flush water was vaporized in a bed beside the plant so the removed fluoride could be collected.
- After changing the well, the system could not handle the extra fluoride. The result was treated water with high levels of fluoride and high maintenance cost.
- Plant was installed as a test plant by Water Health to remove fluoride n the water. The advantage of this system compare to RO membrane system is that you get a much better utilization of the water you have available.
- The plant using active aluminium to remove fluoride. The system consisted of:
  - Sand filter
  - Active carbon filter
  - Active aluminium filter
  - 3 micro filters
  - UV
- Plant performance: Capacity 0,1 m^3/h
- Reject water is been led out to a pool, where it is supposed to vaporize and leave the fluoride and other substances in dry form.
- The plant was not working, so no samples were taken.

Picture 27: Devarapulli, the water purification plant. (Havig and Holstad, 2010).

Picture 28 and 29: Devarapulli, activated aluminium (left), and the plants UV disinfection unit. (Havig and Holstad, 2010)

Drawing of Devarapulli:



Appendix 2:

Analysis of water samples taken at Naandis drinking water treatment plants.

Andhra Pradesh, India.

TABLE 1: RAW WATER QUALITY. 2
TABLE 2: PRODUCT WATER QUALITY. 3
TABLE 3: REJECT WATER QUALITY. 4

Table 1: Raw water quality.

Water samples taken by Naandi are marked in blue. Water samples taken by (Havig and Holstad, 2010) are marked in black.

Date of samples			08.02.2010	30.09.2009	25.04.2009	10.07.2010	16.01.2010	16.09.2009	10.07.2010	19.07.2010	04.01.2009	19.07.2010	14.12.2009
District			Nalgonda	Prakasham	Prakasham	Prakasham	Guntur	Prakasham	Prakasham	Krishna	Krishna	Krishna	Krishna
Village			KACHARAM	UPPUTURU	UPPUTURU	UPPUTURU	KAVURU	KOLAPUDI	KOLAPUDI	REMALLI	REMALLI	NEPPALI	NEPPALi
CONSTITUENTS	UNITS	STANDARD IS:10500											
pH		6.5 - 8.5	7,2	7,4	7,0	7,4	6,8	7,2	7,3	7,5	6,9	7,8	7,1
Colour	hazen units	<5	Colorless	White turbidity	L. yellow	Slightly brownish	Colorless	Colorless	Clear	Clear	Colorless	Clear	Colorless
Electrical Conductivity (E.C.)	micro mohs	-	1860,0	799,0	1115,0	910,0	2232,0	1613,0	2400,0	2300,0	1439,0	900,0	1004,0
Turbidity	NTU	<5	0,5	16,2	2,4	0,6	0,4	2,7	0,8	0,8	0,8	0,2	NIL
Total dissolved Solids	Mg/l	<500	1279,0	568,0	770,0	590,0	1550,0	1139,0	1540,0	1500,0	992,0	580,0	709,0
Total Hardness as **$CaCO_3$**	Mg/l	<300	496,0	128,0	160,0	644,6	1112,0	416,0	130,6	636,5	560,0	330,5	280,0
Non Carbonate Hardness as **$CaCO_3$**	Mg/l	-	NIL	NIL	NIL		852,0	156,0			320,0		NIL
Calcium Hardness as **$CaCO_3$**	Mg/l	-	328,0	80,0	112,0		712,0	312,0			360,0		176,0
Alkalinity to Phenolphthalein as **$CaCO_3$**	Mg/l	-	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL
Alkalinity to Methyl orange as **$CaCO_3$**	Mg/l	<200	520,0	160,0	200,0	556,2	260,0	260,0	230,7	436,7	240,0	354,3	360,0
Calcium as **Ca**	Mg/l	<75	131,2	32,0	44,8	195,8	284,8	124,8	27,7	99,6	144,0	52,2	70,4
Magnesium as **Mg**	Mg/l	<30	40,3	11,5	11,5	37,7	96,0	25,0	14,9	94,2	48,0	48,6	25,0
Sodium as **Na**	Mg/l	-	179,9	107,9	162,6		40,9	157,1			78,0		89,0
Potassium as **K**	Mg/l	-	4,7	3,1	3,1		0,8	6,2			4,0		3,1
Silica as **SiO_2**	Mg/l	-	48,0	29,0	32,0		32,0	48,0			30,0		30,0
Iron as **Fe**	Mg/l	<0.3	NIL	NIL	NIL	0,8	NIL	NIL	0,3	0,3	NIL	0,3	NIL
Chloride as **Cl**	Mg/l	<250	283,7	120,5	234,0	592,8	531,9	226,9	178,6	540,0	297,9	121,8	106,4
Sulphates as **SO_4**	Mg/l	<200	263,0	212,0	276,0	70,0	210,0	428,0	200,0	115,0	177,0	65,0	103,0
Nitrates as **NO_3**	Mg/l	<45	59,0	34,0	37,0		40,0	59,0			36,0		32,0
Fluoride as **F**	Mg/l	<1	3,8	0,5	1,1	0,6	1,1	1,8	0,4	0,6	1,2	0,4	0,8

Table 2: Product water quality.

The water samples are taken by Naandi.

Date of samples			30.03.2010	28.05.2010	05.05.2010	01.05.2010	21.06.2010	25.03.2010	24.06.2010	24.03.2010	24.05.2010	11.05.2010	19.04.2010	03.06.2010	27.03.2010
District			Ranga reddy	Ranga reddy	Nalgonda	Nalgonda	Guntur	Prakasham	Prakasham	Krishna	Krishna	Krishna	Krishna		Warangal
Village			BOWRAMPETA	GAGILLAPUR	MATTAMPALLI	PEDHAVEDA	KAVURU	KOLAPUDI	UPPUTURU	REMALLI	NEPPALI	NEPPALI	NEPPALI	KACHARAM	NELLUTLA
CONSTITUENTS	UNITS	STANDARD IS:10500													
pH		6,5 - 8,5	6,6	6,5	6,6	6,5	6,6	6,5	7,3	7,5	6,6	6,8	6,3	6,5	6,5
Colour	hazen units	<5	Colorless	<1	<1	1,0	1,0	<1	<1	<1	<1	<1	<1	<1	Colorless
Electrical Conductivity (E.C.)	micro mohs	-	66,0	109,0	142,0	161,0	106,0	209,0	188,0	2150,0	28,0	129,0	1265,0	118,0	126,0
Turbidity	NTU	<5	NIL	<1	<1	<1	<1	<1	1,0	4,0	<1	<1	<1	<1	NIL
Total dissolved Solids	Mg/l	<500	46,0	57,0	89,0	99,0	64,0	134,0	115,0	1376,0	20,0	78,0	797,0	74,0	105,0
Total Hardness as **$CaCO_3$**	Mg/l	<300	8,0	30,0	34,0	36,0	18,0	30,0	18,0	725,0	8,0	14,0	43,0	30,0	16,0
Non Carbonate Hardness as **$CaCO_3$**	Mg/l	-	NIL	10,0	NIL	NIL	2,0	5,0	NIL	325,0	NIL	NIL	3,0	NIL	NIL
Calcium Hardness as **$CaCO_3$**	Mg/l	-	8,0	22,0	26,0	20,0	10,0	20,0	8,0	360,0	4,0	4,0	16,3	20,0	8,0
Alkalinity to Phenolphthalein as **$CaCO_3$**	Mg/l	-	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL
Alkalinity to Methyl orange as **$CaCO_3$**	Mg/l	<200	20,0	20,0	34,0	36,0	16,0	25,0	40,0	400,0	12,0	24,0	40,0	34,0	40,0
Calcium as **Ca**	Mg/l	<75	3,2	8,8	10,0	8,0	4,0	8,0	3,2	144,0	1,6	2,0	6,5	8,0	3,2
Magnesium as **Mg**	Mg/l	<30	NIL	1,9	1,9	3,9	1,9	2,4	2,4	88,7	1,0	2,4	6,5	2,4	1,9
Sodium as **Na**	Mg/l	-	9,0	8,9	19,7	24,0	16,0	29,7	29,8	126,0	4,6	22,8	163,5	16,8	17,7
Potassium as **K**	Mg/l	-	1,0	0,3	0,1	1,0	0,7	9,3	5,2	1,4	0,7	2,1	90,5	0,5	2,0
Silica as **SiO_2**	Mg/l	-	2,0	2,6	3,6	3,2	2,4	6,8	6,7	47,3	1,4	3,8	0,2	4,1	2,0
Iron as **Fe**	Mg/l	<0,3	NIL	0,0	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	<0,01	0,0	NIL
Chloride as **Cl**	Mg/l	<250	7,1	12,8	15,6	23,0	10,6	18,0	25,5	404,0	2,8	12,8	95,7	19,9	21,2
Sulphates as **SO_4**	Mg/l	<200	12,0	4,1	12,3	16,0	0,6	3,0	6,9	77,5	0,4	10,3	3,4	3,3	20,0
Nitrates as **NO_3**	Mg/l	<45	4,0	8,0	8,1	3,0	25,2	53,2	<0,1	17,7	0,9	11,8	291,1	2,7	4,0
Fluoride as **F**	Mg/l	<1	NIL	0,1	0,2	0,6	0,6	<0,1	0,7	1,3	0,3	<0,1	<0,1	0,1	NIL

Table 3: Reject water quality.

The water samples are taken by (Havig and Holstad, 2010).

Date of samples			10.07.2010	10.07.2010	10.07.2010	19.07.2010	28.08.2010	24.08.2010
District			Prakasham	Prakasham	Krishna	Krishna	Warangal	Nalgonda
Village			KOLAPUDI	UPPUTURU	REMALLI	NEPPALI	NELLUTLA	KACHARAM
CONSTITUENTS	UNITS	STANDARD IS:10500						
pH		6.5 - 8.5	7,8	7,6	7,8	7,6	7,6	7,3
Colour	hazen units	<5	Clear	Slightly brownish	Clear	Clear	2	2
Electrical Conductivity (E.C.)	micro mohs	-	3600,0	1420,0	3250,0	1400,0	2090,0	3180,0
Turbidity	NTU	<5	1,0	0,5	1,1	0,3	2,0	3,0
Total dissolved Solids	Mg/l	<500	2300,0	920,0	2100,0	900,0	1148,0	1739,0
Total Hardness as **$CaCO_3$**	Mg/l	<300	546,7	289,7	852,7	453,4	560,0	950,0
Non Carbonate Hardness as **$CaCO_3$**	Mg/l	-					60,0	190,0
Calcium Hardness as **$CaCO_3$**	Mg/l	-					220,0	130,0
Alkalinity to Phenolphthalein as **$CaCO_3$**	Mg/l	-	NIL	NIL	NIL	NIL	NIL	NIL
Alkalinity to Methyl orange as **$CaCO_3$**	Mg/l	<200	346,0	346,0	675,7	550,8	500,0	760,0
Calcium as **Ca**	Mg/l	<75	111,0	34,3	179,5	73,2	88,0	52,0
Magnesium as **Mg**	Mg/l	<30	65,4	49,6	98,2	65,7	82,6	199,0
Sodium as **Na**	Mg/l	-					235,0	325,0
Potassium as **K**	Mg/l	-					5,0	10,0
Silica as **SiO_2**	Mg/l	-					48,2	62,9
Iron as **Fe**	Mg/l	<0.3	0,2	0,8	0,2	0,3	0,1	0,1
Chloride as **Cl**	Mg/l	<250	377,6	231,4	1075,9	174,6	355,0	567,0
Sulphates as **SO_4**	Mg/l	<200	320,0	125,0	190,0	110,0	56,3	84,7
Nitrates as **NO_3**	Mg/l	<45					24,6	42,8
Fluoride as **F**	Mg/l	<1	0,4	0,6	0,6	0,4	2,1	2,2