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Groundwater recharge in Jakkur Lake, Bangalore

Possibilities and risks of sewage water reuse

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Abstract
The aim of this project is to study the nitrate levels of the treated water flowing into Jakkur Lake in Bangalore, from the treatment plant situated at the inlet to the lake, and thereby evaluate the function of the lake as for secondary and tertiary wastewater treatment as well as an infiltration basin. Obtained nitrate levels are used as indicators to study the wastewater flow in the lake, and to find other possible inflows of sewage which can affect the lakes' total treatment efficiency. A literature study is done on wetlands and on groundwater recharge through infiltration basins, and the possibility of recharging groundwater below Jakkur Lake is evaluated. Water samples are collected around and in the lake and the samples are tested for nitrate, pH and total dissolved solids. Extra focus is put on research on nitrates in water.

The risks of groundwater recharge in Jakkur Lake include pollution of wells by bacteria, viruses, parasites and traces of medicine. Further geotechnical investigations need to be pursued mainly on the soil structure under and around the lake, and studies need to be performed on the retention time of the water in the lake. The technical limitations such as fluctuations in efficiency and pollutant migration must be minimized, which initially could be done by building a constructed wetland and controlling the inflow to the lake.

Keywords: Ecology, environmental engineering, water treatment, water supply, water shortage

Referat
I detta projekt studeras nitrathalterna i sjön Jakkur i norra Bangalore, som består av en naturlig våtmark samt en infiltrationsbassäng. Nitrathalter mäts dels i det behandlade avloppsvattnet som flödar till sjön från avloppsreningsverket vid sjöns inlopp, dels i sjön och i närliggande brunnar. Dessa värden används som indikatorer på avloppsvattnets flödesväg samt för att hitta övriga flöden av avloppsvatten in till sjön. Baserat på fältstudier och litteraturstudier görs en bedömning av huruvida sjön Jakkur är lämplig för sekundär och tertiär behandling av renat avloppsvatten. Litteraturstudier görs med fokus på reningsprocesser i våtmarker och infiltrationsbassänger. Tagna vattenprover analyseras även för pH-värde och TDS-halt. Extra fokus läggs på litteraturstudier av biokemiska processer för nitrat i vatten.

Riskerna med infiltration av renat avloppsvatten inkluderar föroreningar i grundvattnet av bakterier, virus, parasiter samt medicinrester. För att kunna utvärdera reningsprocesserna i marken behöver fler marktekniska undersökningar utföras både under och omkring sjön. Vidare behöver vattnets uppehållstid i sjön undersökas. De tekniska begränsningarna i form av fluktuationer i effektivitet hos våtmark och infiltrationsbassäng bör minimeras, vilket kan inledas genom att bygga en konstgjord våtmark och kontrollera inflödet av avloppsvatten in till sjön.

Preface

I would like to thank Sida and ATE for the possibility to do this project. I would also like to thank Mr. S. Vishwanath for his mentorship in India and for sharing his knowledge, Dr. Roger Herbert for his supervision, Biome Environmental Solutions for welcoming me into their office, Dr. Jenny Grönwall for her support in Bangalore, and Sara Jansson and Lina Danielsson for their guidance.

Introduction

As one of India's fastest growing cities, Bangalore experiences severe problems with providing enough water to its citizens. The natural percolation of rainwater is not enough to balance the groundwater level because of the amounts of groundwater being pumped up through private and municipal wells (Department of Mines and Geology 2011). There are no rivers or large natural lakes close to the city. To meet the city's water demand, water is pumped from the river of Cauvery, situated about 100 kilometers southwest of Bangalore. As access to municipal water is not always reliable or available, a huge amount of the population relies on private wells. Because of the many wells, the groundwater table on the outskirts of the city is declining and in many areas wells have to be drilled deeper after a few years because of a sinking groundwater table. Many wells reach down as far as 200 meters in order to reach deeper aquifers, while shallow wells are drying up (Government of India 2008). A method to restore the groundwater table and thereby prevent it from sinking further is to release treated sewage water back into the ground through an infiltration basin. Through natural processes in the ground, the treated water will be cleaned from various harmful elements during percolation through the soil, eventually reaching the groundwater table.

Figure 1: Jakkur Lake. In front are water hyacinths covering the shore. In the background are new residential buildings. (Photo: P. Sjöholm)

Aim

The aim of this project is to study the nitrate levels of the treated water flowing through Jakkur Lake (Figure 1) from the treatment plant situated at the inlet, and thereby evaluate the function of the lake as a wastewater treatment and a groundwater recharging system. High levels of nitrate in the lake are used as an indicator of the flow of the treated water from the treatment plant situated in the lakes' inlet. Obtained nitrate levels are used for studying the wastewater flow in the lake, and to find other possible sources of nitrate which can affect the lakes' total treatment efficiency. A literature study is done on groundwater recharge and the possibilities of recharging groundwater below Jakkur Lake are evaluated.

Background

Bangalore is traditionally a city of gardens, irrigation lakes and open wells. Before the huge increase of population, starting in the 1960's, percolation by rain was enough to balance the groundwater level and supply the citizens with water (Das, 2011). For irrigation purposes many reservoirs, locally called tanks, were built in the city during the last century. The remaining tanks are now used for storing drinking water, but most of them have recently been transferred into other kinds of infrastructure such as bus stations and sport arenas.

In the 1960's there were 280 tanks in Bangalore, of which 141 were big enough to be considered lakes. At this time, the population started growing rapidly and in 1971 the population reached 1.7 million. Since then the population has grown about five times its size and was estimated to 8.4 million in 2011. Of the 141 original tanks and lakes, only 67 are remaining. The IT-industry has bloomed and industrial areas have developed. In the 1970's, there was already a need for other sources of drinking water, and therefore the Cauvery River was tapped for the first time. Today Bangalore is dependent on both a high amount of private wells and the municipal pipe system tapping Cauvery.

Present water infrastructure in Bangalore

The estimated demand of water to the greater Bangalore area is around 1200 million liters per day, industrial needs excluded (Das 2011). 870 million liters per day is supplied by the municipal BWSSB, Bangalore Water Supply and Sewage Board. This leaves a shortfall of 330 million liters per day, which comes from groundwater sources like private wells. When the industrial needs of approximately 60 million liters per day are included, as well as leakages of up to 20% from the BWSSB-system, there is an enormous shortage of water in Bangalore. The shortage is estimated up to 400 million liters per day.

This shortage creates an uncertainty among the citizens which is seen e.g. as new houses are built. Most customers prefer to bore a private well before constructing the house, to ensure their supply of water. These wells are expensive to drill and are only affordable for people with a certain living standard. It is also common that a neighborhood share wells. The origin of the water in the wells is often not known, and therefore nothing is known about potential sources of pollution. Different types of domestic water purifiers, designed with techniques such as reverse osmosis and UV light, are often used to clean the water before using it.

In the city center, the level of the groundwater is rising due to leaking pipes and uncollected sewage. At the same time the ground water level is sinking in the outskirts of Bangalore (Vishwanath 2012). Wells have to be dug lower and a lot of households are not connected to the common water and wastewater pipe system. Since 2009, rainwater harvesting is mandatory for certain sites. The minimum requirement includes rainwater storage and ground recharge, which is done by leading rainwater to an open well.

An overview of Jakkur Lake

Jakkur Lake includes a wetland and a lake. The lake itself is manmade and around 200 years old. It was initially built to store rainwater. The main source of water today is treated sewage water from the treatment plant, and storm water. The flow has an assumed direction starting from the treatment plant in the north flowing towards the outlet in the south of the lake, see figure 2. Since this is a manmade lake it is likely not to be any groundwater flow into the lake at all, instead water is expected to flow downwards and sidewise into the ground. This flow will be further explained in the chapter "Groundwater recharge". Around the lake are different kinds of human activity, such as banana plantations, slums, a golf course, and newly built residential buildings. The village of Jakkur is situated some hundred meters south west of the lake.

Figure 2: Jakkur Lake with treatment plant, wetland and outlet marked (Google maps 2013)

Wetlands for sustainable water use

Technical aspects of wetlands

One of the most common natural wastewater treatment systems is wetlands. Wetlands play a number of roles in the environment such as water purification and flood control, and remove contaminants by physical, chemical, and biological processes (Garcia et al. 2010). A simplified sketch of a constructed wetland with a horizontal flow is shown in figure 5.

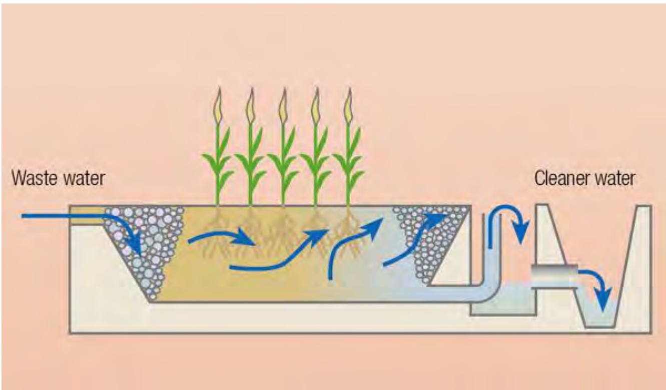

Figure 5: A sketch of a constructed wetland with a horizontal flow through filters, vegetation, and towards a specific outlet (LAND, 2009).

When sewage is released into an environment containing living microfauna and oxygen, a series of actions will take place. Among these actions is sedimentation, virus deactivation by UV-light, plant uptake of nutrients and bacteria competition amongst each other. Through contact with biofilms, plant roots and rhizomes, processes like nitrification, ammonification and plant uptake will decrease the nitrate level in the wastewater (Garcia et al. 2010). In the oxygen free parts of the sediment, denitrification will occur. As natural groundwater is characterized by low amounts of organic material, particles, metals, dissolved salts and microorganisms, these are the qualities that the system must fulfill.

Depending on the hydrology at the location, the flow through the wetland will either be horizontal or vertical or both. Vertical systems produce nitrified effluents, while horizontal systems often have very limited nitrification capabilities. In practice, these two types of systems are often combined to form hybrid wetlands, which provide higher removal efficiency.

To evaluate the system in Jakkur Lake for wastewater treatment, the flow of the water has to be known. This includes direction of the flow, level of the groundwater around the lake, volume of the lake, speed of the flow, sizes and numbers of inlets and outlets as well as knowledge about aquifers below and around the lake. The soil around the lake should be investigated and potential sources of pollution such as old landfills must be removed. It is always difficult to control the flow of the water in a natural system; therefore constructed wetlands are often used instead of natural ones. In a constructed wetland the flow is controlled as well as the location of different layers of filters consisting of fine-grained fractions. The function of these filters is to maximize the area of biofilm that the wastewater passes and thereby increase the microbial inactivation, but also to slow down the flow to increase sedimentation. The hydraulic retention time is an important parameter that influences the efficiency of nitrification, sedimentation, metal removal and microorganism reduction processes (Vymazal & Kröpfelová, 2009). Darcy's Law can be applied to describe the flow through a medium if the hydraulic potential and porosity of the ground are known, such as a flow through filters in a wetland.

As natural wetland systems in urban environments are sensitive and exposed, water cleaned by this method can never be guaranteed to be potable. The quality will differ depending on natural causes. Parameters suitable to monitor in a wetland are plant biomass, oxidation–reduction potential, chemical oxygen demand, temperature, dissolved oxygen, pH, ammonia, nitrate, phosphates and coliform bacteria.

Groundwater recharge through an infiltration basin

Infiltration basins have many advantages, such as decreasing storm water peak flows, reducing pollution of surface waters and recharging groundwater. The basics of groundwater recharge are to release water onto the ground or into an infiltration basin, letting the water pass downwards through filters of different kinds, and finally let it reach and refill the groundwater (WRD, 2013). For this to function, it is important to understand and monitor the flow of the water. In a natural system the water flows as in figure 6. Groundwater flows into the ground and slowly towards a well or discharge area.

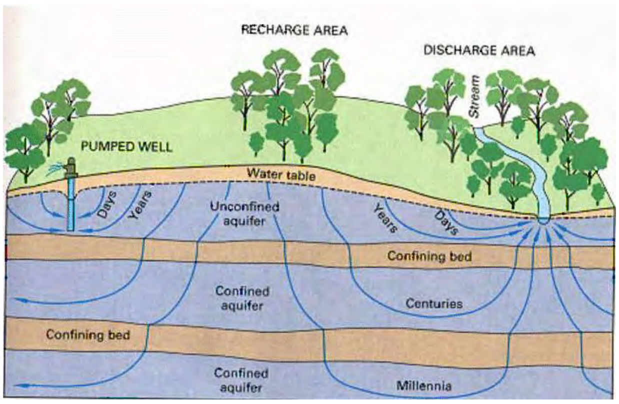

Figure 6: Groundwater flow in a natural system (Wikimedia Commons, 2005)

Since Jakkur Lake is a manmade lake, the water will flow in a different manner than it would in a natural lake. Jakkur Lake was initially built to store rainwater and the hydraulic potential is likely to vary between flooding and dry periods. The flow depends on the hydraulic potential in the ground and will flow from higher to lower potential (Hendriks 2009). Because of variation in hydraulic potential, the flow direction from the lake to the groundwater is likely to vary between positive and negative. A way to monitor the potential is to compare the groundwater level in wells situated around the lake, to the water surface of the lake. The hydraulic conductivity of the ground, which depends on soil structure, will affect the rate of water flow between the ground and the lake.

Because of the episodic nature of storm water runoff, combined with the large volume of water accumulated by urban storm water systems, infiltration and groundwater recharge processes beneath a storm water infiltration basin can occur rapidly depending on the hydrogeological conditions (O'Reilly et al., 2012). These factors result in a dynamic groundwater system beneath a storm water infiltration basin that is continuously adjusting to changing inputs, and such conditions can result in fluctuations in the groundwater quality. By adding treated sewage water to the infiltration basin, the quality of the recharged groundwater is very difficult to control.

Two major problems are encountered related to infiltration basins: clogging of the system and an eventual pollution of soil and groundwater (Le Coustumer et al. 2007). It has been shown that the top soil layer is an efficient pollutant barrier but pollutant migration is still an issue.

If treated sewage water is released into an aquifer, it will affect wells situated downstream in the same aquifer. If the movement of the water through the ground can be traced, affected wells can be mapped. This is an important step when aiming for implementing the system of infiltration basins on a larger scale.

Jakkur Lake is about 50 ha. Studies made in another local lake, Madivala, resulted in an estimated 20 liters of water percolating per square meter and day (Vishwanath 2012). In this number, evaporation is included. If we assume that conditions are similar around Jakkur Lake, by multiplying these numbers it shows that about 10 million liters per day can percolate from Jakkur Lake under the right conditions, such as a large hydraulic potential allowing water to percolate.

Risks in reusing treated sewage water

When treated sewage water flows into an ecosystem, high amounts of natural and unnatural elements will be released into the system. Human health risks in sewage are nitrate, bacteria, parasites, viruses, traces of medicines and heavy metals like cadmium, lead and copper. Medicines and hormones are most likely to end up in the drinking water since they are designed to pass through natural barriers, but will also end up in sediment and affect fish. Heavy metals come with sewage, air pollutants and storm water and will end up in the sediments, plants and fish. During an epidemic caused by e.g. cholera bacteria, sewage traces in drinking water is the largest risk factor because of the transport of bacteria. It is also notable that some antibiotics such as quinolones and tetracycline can remain active for long time periods and will gather in the sediments, increasing the risk of multi resistant bacteria to form (Mantecón et al. 2011).

Viral infections spread by water are e.g. SARS, hepatitis A, polio and polyomavirus infections. Among diseases caused by water spread bacteria can be mentioned typhoid fever, dysentery, legionnaires' disease and infections caused by salmonella bacteria (Wikipedia, 2012).

Fecal coliform bacteria inactivation in a sub-surface constructed wetland usually ranges between 1.25 and 2.5 log units. It must be taken into account that the concentration of coliform bacteria in wastewater is affected by daily fluctuations, so the highest concentration in the influent water will not necessarily coincide with the highest concentration in the effluent water (Garcia et al. 2010). Coliform bacteria can be used as an indicator of the reduction of other bacteria. The type of wetland chosen has a high impact on the reduction rate and it is important to keep in mind that the wetland in Jakkur Lake is not a constructed wetland but lacks many crucial parts of a constructed wetland such as filters and a controlled flow. The efficiency will be lower than for a constructed wetland.

Jakkur Lake is used by children for swimming and playing. The children seen in figure 7, helping out with sample nr. 4, claimed that there are faeces in the water downstreams and therefor they choose to swim close to the treatment plant instead.

Figure 7: Children helping out with sample nr. 4 (Photo: P. Sjöholm)

Benefits of reusing sewage water

The risks associated with sewage contamination in wells must be weighed against the economical, ecological, energy-saving and sustainable benefits gained. In comparison to transporting water in pipes from the Cauvery River, the benefits are huge. Costs are minimal, water losses are minimal, the bird life benefits from the wetland, and no energy input is needed to refill the wells. It is an ideal solution from all standpoints except health risks and ground pollution by e.g. heavy metals. These risks should be compared to the same risks in the alternatives, as an example water pipes might under low pressure take in pollutants through leaks. It has been shown that fecal coliform bacteria, up to around 160 per 100 ml, are present in the water supplied by pipes in many central areas of Bangalore (ATREE 2012). There is no Indian standard for the amount of fecal coliform bacteria in drinking water, but the Indian standard for *E. coli* bacteria in drinking water is zero. The WHO standard for fecal coliform bacteria in drinking water is zero.

Prevention of sewage contamination of wells

The initial way to prevent wells from being affected by sewage is distance or a non-leaking construction of wells reaching unaffected deeper aquifers. The further the distance from the wetland to the well, the longer time harmful elements will be degraded.

Reduction of pollutants can be modified by manipulating infiltration time, distance between well and wetland, pre-filtering, retention time of the water in the wetland, and annual maintenance of the wetland bottoms. Further the water can be treated with domestic water purifiers.

Nitrate in water

A relatively easy way to discover sewage contamination is by testing the level of nitrate in the water. Nitrate is easier to detect than e.g. microorganisms. Though nitrate itself is not part of the largest contamination risks considering human health, it can function as an indicator of sewage contamination.

Nitrates in groundwater and unmanaged leakages

The groundwater structure of Bangalore is complicated with aquifers extending below the groundwater table. There might be several aquifers on top of each other with impermeable or semi permeable layers in between. Shallow wells are therefore in general more affected by human activity while deep bored wells can in some cases remain more unaffected.

Nitrate is a substance that develops naturally from organic waste. It is formed by bacteria through nitrification when e.g. ammonium from urine is released into an environment with enough heat and oxygen. When a well is polluted by nitrate, uncollected sewage is often the reason. In nature, nitrate is absorbed by plants as nutrition, as part of a natural circulation. Problems occur when nitrate ends up in drinking water instead of in the ground. Other explanations for nitrate in a well, except sewage, are industrial impact or fertilizers. Since the city of Bangalore is very urbanized, fertilizers are in most cases unlikely to be the cause of nitrate pollution.

When sewage is uncollected, it percolates through the ground. Where it ends up depends on the structure of the ground and the aquifers. The shallow aquifers are more likely to be affected, since the sewage reaches these aquifers first. On the other hand, old unmanaged deep wells might function as macropores down to deeper aquifers and thereby transport pollutions very fast. In deeper aquifers with low amounts of oxygen, chemical reactions occur in a different way than close to the surface. It is likely that nitrates will remain for a longer time in the deeper aquifers because of a lack of plant roots for uptake and a lack of oxygen for bacterial degradation.

How fast sewage reaches the groundwater depends on the soil structure. The more microorganisms and plants, the more nitrate will be absorbed before percolating. Macropores such as abandoned deep wells raise dramatically the hydraulic conductivity, affecting the cleaning process. The soil of Bangalore is an old tropical soil, high in iron, silicate and aluminum complexes but low in carbon and nutrients. Since the soil is low in nutrients and carbon, it is likely to have a low microbiological activity and it is therefore a weak biological barrier for nitrate. On the other hand, the soil is dry and warm and it is very difficult for water to percolate through it before evaporating. Most of the water that reaches the ground evaporates. Leakages of sewage to the groundwater are, because of these conditions, most likely to come from deep pipes and through macropores rather than from open ditches. Since the groundwater level is higher in the central city, this area is more sensitive to pipe leakages.

Nitrate health risks

The risk associated with a high intake of nitrate is mainly methaemoglobinaemia (blue baby syndrome). This is caused by involvement of nitrate in the oxidation of normal Hb to metHb, which is unable to transport oxygen to the tissues (WHO, 2012). This mainly affects infants up to three months of age in combination with gastrointestinal infections. As most cases of infantile methaemoglobinaemia reported in the literature have been associated with the consumption of bacterially contaminated well water, the involvement of infections is highly probable. Therefore infants might be able to take in a larger amount of nitrate in an environment with higher hygiene standards. Few cases of methaemoglobinaemia have been reported in older children. For adults there might be an increased risk of gastric cancer related to a high intake of nitrate, but this is yet not proven scientifically. The largest risk that follows nitrates in a well is the potential leakage of sewage, and thereby greater health risks, into the well. These health risks might not be as easy to monitor, therefore it is better to use nitrate as an indicator.

Nitrate as a tracer

When treated sewage water is released into lakes it will recharge the groundwater while percolating. It is important to understand the flows so the impact on the ground water level and ground water quality can be monitored. To follow the flows, nitrate can be used as a tracer. If sewage water is released into a natural ecosystem, it will bring along high levels of nitrate. These levels will decrease along the way through the processes mentioned above, like plant uptake and nitrification, and eventually the water will be potable. When water samples are taken along the wetland and tested for nitrate, the flow of the sewage water is traced. Related to the time the sewage water remains in the wetland, nitrate levels are reduced. Therefore a decrease in nitrate level should follow in the direction of the flow.

As the nitrate levels are reduced, one can assume that the levels of other pollutants are reduced as well. This is never guaranteed though and e.g. temperature and nutrients can affect the involved processes. Bacteria, viruses and parasites will be reduced by a natural concurrence over nutrients, by sedimentation, by UV light and by predator microbes. Nitrate will be reduced by volatilization and by microorganisms and plants absorbing it, and the result becomes visible as an increase in biomass.

Material and methods

Scope of study

Initially, this project was to investigate nitrate levels in drinking water wells in a specific area in Bangalore. Upon arriving in Bangalore, it became apparent that this project could not be pursued, and instead the project was to address a sustainable drinking water system for Bangalore, which was of great interest to the local mentor. In particular, his vision included recharging groundwater below Jakkur Lake.

A major part of this project involves collecting water samples for nitrate analyses so as to study if there is any change in nitrate level in the wastewater passing through Jakkur Lake. As mentioned above, the aim of this study is to study the nitrate levels of the treated water from the treatment plant and thereby value the function of the lake as a wastewater treatment, find other possible sources of nitrate and investigate the relationship between the distance from the treatment plant and the nitrate levels in the water. Furthermore, general information on groundwater recharge is presented as a basis for evaluating the possibilities to recharge groundwater below Jakkur Lake.

In order to fulfill the aims of this study, water samples were taken from different parts of Jakkur Lake in order to study the nitrate levels in the flow from the sewage treatment plant. Samples from wells surrounding the lake were also taken for the possibility to see amounts of nitrates from the treatment plant in the wells, which could be an indicator of a flow from the lake into the underlying aquifer. The level of total dissolved solids, TDS, was measured as a parameter to value the correctness of the nitrate levels obtained. The level of TDS should follow the amount of nitrate more or less proportionally. As a request from the co-workers at the company hosting this project in Bangalore, Biome Environmental Solutions, general information on nitrates in water was given extra focus in this report.

Testing procedure

Samples were collected twice on two different occasions. Some locations were sampled both times, some only once. The water samples were taken by walking around the lake and sampling directly in clean PET bottles as in figure 3. Locations were chosen to cover the whole lake but also to cover interesting spots such as storm drains, places with high human activity and the outlet from the treatment plant. Some people moving in the area were interviewed, among these fishermen, young men swimming and women working with washing clothes. These interviews were done with the help of a co-worker from Biome Environmental Solutions. Questions were asked about how the people, active around the lake at the time of the interviews, experience the water quality of the lake. The aim was to get a better picture on which parts of the lake that were of special interest to sample. This led to us finding storm drains that we did not notice before. When possible, children playing in the lake were asked to take water samples to reach deeper spots away from the shore. No samples were taken from the middle of the lake because of practical obstacles. For the second sampling round, a TDS-meter was used but data was only collected from a limited number of points. All samples from the second water sampling round were tested for TDS at a later time.

Figure 3 (left): A sample is taken from the water flowing directly from the treatment plant into Jakkur Lake (Photo: P. Sjöholm).

Figure 4 (right): Two samples are being boiled dry as part of the testing procedure (Photo: P. Sjöholm).

The nitrate testing was done with a nitrate testing kit named TARA Water Testing Kit for pH and Nitrate. The name of the company manufacturing these kits is TARAenviro. The kit works by colorimetry, and three color examples were presented. Water from each sample was boiled dry, as in figure 4. Ammonia and phenoldisulphonic acid were added. The final occurring color was compared to the three colors represented. The first color, light yellow, represented nitrate levels of up to 10 mg/l. The second color, green, represented nitrate levels of up to 45 mg/l, as the WHO maximum contaminant level for nitrate in drinking water. The third color, dark yellow, represented nitrate levels of up to 100 mg/l.

Research on Jakkur Lake

Most of the data given on Bangalore and Jakkur Lake was collected by literature studies and interviews. Some information was collected during a conference including professionals and academics involved in the water infrastructure of Bangalore. Information on Jakkur Lake being a natural wetland was collected during a workshop that included members of the BWSSB. This workshop was called *Water Supply and Sanitation Solutions for Bangalore* and was held the 14^{th} of December 2012 in Bangalore.

Results

To map the flow from the sewage treatment plant through the wetland, water samples were collected around the lake. Samples were tested for temperature, nitrate, pH-value and TDS-value. The data from the water samples are presented in table 1. When the nitrate testing results showed a color seemingly in between the two given options of 0 mg/l and 45 mg/l (a mixture of yellow and green), the result was interpreted as 10-45 mg/l. The circumstances of the sampling site are described and whether the site was tested once or twice. Nitrate levels from the two occasions are followed by pH-levels, TDS-levels, temperatures and comments on each site. The TDS-values were not tested at the sampling location but were determined later at a temperature of 23.2 degrees Celsius. The pH-values were checked at the same time as the TDS-values.

Table 1: Collected data from water samples

Site no.	Position (amount of tests)	Nitrate level, sampled 9 Nov 2012 (mg/l)	Nitrate level, sampled 25 Nov 2012 (mg/l)	pH-value	TDS (ppm)	Temp. (Celsius)	Comments
1	Open well, south side (2)	0	0	7	1080	-	Used daily for drinking
2	Outside storm drain (2)	10-45	0	7	1110	-	
3	T-Plant side of pier (2)	0	0	8	1450	-	In the wetland and by the inlet to the lake
4	Lake side of pier (2)	10-45	10-45	7	1130	25	Among swimming children
5	From treatment plant (2)	0	0	9	1360	-	Square drain out from plant
6	Well/swimming pool (1)	10-45	-	5	-	-	High risk of urine contaminated sample
7	Borewell (1)	0	-	7	-	-	
8	West shoreline (1)	-	10-45	7	1120	25	By the shore among water hyacinths
9	Under white res. Houses (1)	-	45	7	1120	-	A slum situated close by
10	Close to washing point (1)	-	10-45	7	1120	25	People washing clothes and swimming close by
11	South west lakeside (1)	-	10-45	7	1120	25.5	Plenty of water hyacinths at the spot
12	At south gate (2)	-	10-45	7	1120	-	At the outlet of the lake

The sites tested are numbered and shown on the map in figure 9. Numbers with a red circle shows sites where nitrate was found in either one or both samples. The highest level of nitrate was found at site number 9.

Figure 9: The sites for sampling are marked, and sites where nitrate was found are marked with a red ring.

Discussion

Since the two water tests taken at different times from the outlet of the treatment plant had no traces of nitrate, the strategy of mapping the flow by the nitrate levels did not succeed. Instead, nitrate showed in the areas around the lake with most human activity. It appears, from the results, that Jakkur Lake does not only receive sewage from one stationary source, but from many small ones situated around the lake. There might also be sewage in the storm drains leading into the lake. Sewage water from the village of Jakkur is led to Jakkur Lake and it is likely that this sewage water does not pass the treatment plant. This has been assumed in earlier studies (Alakananda et al. 2011).

As for the nitrate testing kit, it was sometimes difficult to interpret the result. Often the result had a color matching none of the given ones. The range went from colorless to green. Since the highest and the lowest nitrate levels presented by the testing kit had the same color but in different intensities, it led to some confusion that might affect the results. Further the testing kit procedure was too slow to use out in the field, since the procedure to prepare one single sample took about half an hour. The TDS-levels are not correlated to the nitrate levels, which indicate errors in one or both of the measurement procedures.

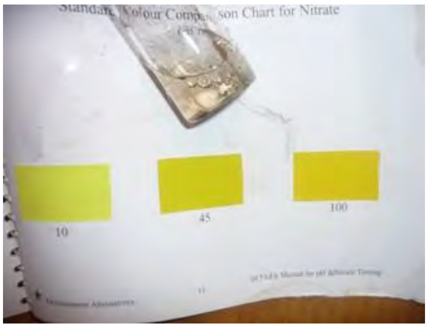

Figure 8: A test result as an example of the difficulties with colorimetry as the resulting color of the sample does not match any of the given choices (Photo: P. Sjöholm).

To be able to make further calculations on the cleaning efficiency of the wetland and the ground, there are many parts to further investigate. This includes retention time for the water in the wetland, the soil structure, the infiltration amount and direction, the ground quality in general, the inlets to the lake and possible sources of pollution other than treated sewage water. The direction of the flow in and around Jakkur Lake must be known, and it is likely that the wetland does not have a completed construction to function as a constructed wetland per definition. Neither the characteristics of a horizontal nor a vertical wetland matches the wetland in Jakkur Lake, where wastewater from the treatment plant is led to the wetland surface and then seems to flow mainly horizontally. This indicates that the wastewater never passes any kind of granular medium.

If municipal recharge of water could be put into function, it would be a huge ecological and economical relief on the water scarcity of Bangalore. For this to happen, the BWSSB must take on responsibility for the quality of the groundwater. As for now, this institution only has the responsibility for delivering piped water. In a city where the citizens rely on different sources of water such as rainwater, Cauvery water, tank water, bottled water, and water from bored and open wells, it is not sustainable that no municipal institution is responsible for groundwater quality. This question is highly political and a part of solving the water scarcity for the future generations of Bangalore.

Conclusions

When it comes to groundwater recharge by treated sewage water, the risks always have to be taken into account. Activity around and in the lake have to be strictly monitored to prevent e.g. sudden loads of pollutants. The technical limitations such as fluctuations in efficiency and pollutant migration must be minimized, which should be done by building a proper constructed wetland and controlling the inflow to the lake. The economical, political and ecological benefits of pumping less water from Cauvery River should be further studied.

As water is used for many other purposes than drinking, it is reasonable to supply water of different qualities depending on what the usage is. I suggest using Jakkur Lake as the infiltration basin that it is today, and develop the wetland into a proper constructed wetland. It is already a common habit for the people of Bangalore to use different water sources for different purposes. Therefore water supplied by the municipality for other usage than drinking could be one important step to handle the water scarcity. This water can be used for washing cars, cleaning drive ways, gardening etc, as long as information on the quality reaches the consumers. By reusing water, a huge amount of money and energy can be saved.

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