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Wastewater treatment wetlands

– A case study in Colombo, Sri Lanka

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ABSTRACT

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Water is a prerequisite for life on earth. Without adequate water sanitation several hazardous health and environmental consequences will follow. In many developing countries the fast urbanization rate is putting a great stress on the, if even existing, poorly developed treatment systems. A sustainable way for wastewater treatment, with or without additional purification, is the use of natural wetlands.

A new wastewater treatment plant is constructed in Ja-Ela, a suburb to Colombo, Sri Lanka. The area is of great interest due to its many industries and highways. The river Dandugam Oya is today working as a recipient for treated wastewater. Dandugam Oya is suffering from pollution and the performed studies show that the nutrient level is high and the oxygen level is very low. This may cause eutrophication and fish death, which earlier has been observed in Negombo Lagoon.

A small wetland (≈5 ha) is today located between the river and the wastewater outfall, and this study has focused on its treatment capacity. The wetland vegetation stands for a potential treatment, but the vegetation is not the only reason to wetland removal efficiencies. The major mechanisms for pollutant removal in wetlands include both bacterial transformations and chemical processes including adsorption, precipitation and sedimentation. In these processes wetland characteristics such as size, depth and retention time are important.

It was observed that the levels of pathogens coming from the old wastewater treatment plant were exceeding the recommended levels. Coliforms can be removed through adaptation to gravel and submersed plant parts biofilms. The studied wetland was not useful for this treatment purpose, mainly because its retention time was too short. For the same reason a large nutrient treatment is not to be expected, which demands the retention time to be fairly long because the nitrate molecules and the denitrification bacteria need time to interact.

Key words: Colombo, Sri Lanka, Natural wetlands, Wastewater treatment, Recipients

REFERAT

Avloppsvattenrening i våtmarker. En fallstudie i Colombo, Sri Lanka.
Lovisa Lagerblad

Vatten är en förutsättning för liv på jorden. Utan en god vattensanitet följer flera farliga hälso- och miljökonsekvenser. I många utvecklingsländer har urbaniseringen påverkat trycket på vattenreningsverken. Ett hållbart sätt att rena avloppsvatten är med hjälp av naturliga våtmarker.

En ny avloppsreningsanläggning byggs i Ja-Ela, som är en förort till Colombo, Sri Lanka. Området är viktigt eftersom det främst består av industrier och större vägar. Floden Dandugam Oya fungerar idag som mottagare av renat avloppsvatten från det reningsverk som är i bruk. Floden är mycket förorenad, och studien har visat på höga halter av näringsämnen och en mycket låg syrehalt. Detta kan leda till övergödning och fiskdöd, vilket man tidigare har observerat i Negombo Lagoon.

En mindre våtmark (≈5 ha) finns idag mellan floden och utloppet och den här studien har till syfte att studera dess potentiella reningskapacitet. De huvudsakliga mekanismerna för borttagande av föroreningar i våtmarker är bakteriella förändringar och kemiska processer såsom adsorption, utfällning och sedimentering. I våtmarksprocesserna spelar våtmarkens fysiska karaktär som storlek, djup och uppehållstid en mycket viktig roll.

Under studien observerades att halten av patogener från det gamla vattenreningsverket kraftigt överskrider de rekommenderade halterna. Coliformer kan tas bort genom att de fastnar på biofilmer, smågrus eller undervattensvegetation. Den studerade våtmarken var inte användbar för detta reningssyfte, främst på grund av att uppehållstiden var för kort. Man kan inte heller förvänta sig någon större näringsreduktion, vilket kräver en relativt lång uppehållstid och flera speciella våtmarksförhållanden.

Nyckelord: Colombo, Sri Lanka, naturliga våtmarker, avloppsvattenrening, recipienter

ABBREVIATIONS

BOD – Biochemical Oxygen Demand
COD – Chemical Oxygen demand
CW – Constructed Wetland
DO – Dissolved oxygen
MFS – Minor Field Study
NW – Natural Wetland
NWS&DB – National Water Supply and Drainage Board
Sida – Swedish International Development Cooperation Agency
TN (tot-N) – Total nitrogen
TP (tot-P) – Total phosphorus
TSS – Total Suspended solids
WW – Wastewater
WWTP – Wastewater Treatment Plant

PREFACE

This project has been carried out as a Minor Field Study (MFS), committed through the Committee of Tropical Ecology (ETA) Uppsala University and funded by Swedish International Development Cooperation Agency (Sida). Tutors are Andreas Bryhn, Geocentrum, Uppsala University and Elin Öman, Kalle Pakarinen and Magnus Olsson from Sweco International in Sri Lanka. The project was conducted within "Waste Water Disposal System for Ekala/Ja-Ela" a larger project funded by Sida with Sri Lanka National Water Supply & Drainage Board as project proponent.

The report at 22.5 hp will be a part of my Master Programme in Environmental and Aquatic Engineering. The report and the project are at a basic level, and for this reason the literature study and the background analysis and description will take as much space as the result and conclusions. Hence, this report can be good if the reader is interested in learning about wastewater, wetlands and recipients and to see this being applied in a specific case study. The report may also be of great interest for anyone who is interested in performing a similar study in a third world country at university level.

My personal goal was to learn about working in a third world country, and try to use my knowledge in practice. The aim was also to share knowledge with other students and professions and to create bonds between different countries and universities.

Uppsala, December 2009

Lovisa Lagerblad

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1 INTRODUCTION

Water is essential for the survival of all known forms of life, and there is no substitute for water. The availability of clean water is one of the most basic conditions for achieving sustainable development in the 21st century [Stikker, 1998]. In most countries water use have increased over recent decades due to population and economic growth, changes in life style, and expanding water supply systems [Bates, 2008]. Water scarcity is a key barrier to development, both economically and environmentally. It will affect health, mortality and the prospects for peace if nothing is done to correct the imbalance between supply and demand [Stikker, 1998]. Countries with good access to water often have proper sanitation, hygiene and economic development.

Liquid wastes such as untreated sewage or industrial waste are the major sources of pollutants in developing countries. One of the most striking examples of the negative impact of increasing human activities on natural water sources is the world's second largest lake; Lake Victoria. This important natural resource has become severely threatened by poorly controlled wastewater deposition into the lake [Kivaisi 2001]. A solution is well-organized sewage systems to manage to treat, clean and recycle water back to nature.

The technology for wastewater treatment is developing around the world. The understanding of the advantage of sustainable and natural methods for wastewater treatment is accelerating, and the last decade the research in this topic has been intensified [Kadlec & Wallace, 2009]. This study will focus on one of them: the use of natural wetlands for wastewater treatment in Sri Lanka, where water pollution problems have been emerging due to recent urbanization, industrialization, rural development, mining by-products, untreated sewage and increasing use of pesticides and agrochemicals [JICA, 2002].

One successful example of this method is found in the East Calcutta Wetlands, a 12,5 ha^2 area outside Calcutta (Kolkata) in India, that helps to purify the city's domestic wastewater. The wetland is the largest resource recovery system in the world. It has saved the city of Calcutta from constructing and maintaining a wastewater treatment plant [WWF India, 2009]. This is a unique proof that wetlands have a treatment capability that seems to be almost infinitely large.

1.1 Purpose of study

Main objective:

- Answer the question whether the wetland will have a positive treatment effect on the wastewater and if this will reduce the stress put on the river from the wastewater discharge.
- To develop a wetland model to examine its treatment effect on water discharged from a biological treatment plant. By analyzing today's situation it will be possible to predict tomorrow's with the increased wastewater flow.
- To analyze which water parameter that is the most critical to treat, in order to maintain a good water quality in the recipient.

Sub-objectives:

- To compare the suitability of different recipients of wastewater considering factors such as nutrients, oxygen, pathogens etc.
- Study the water and wastewater situation in Colombo.
- To examine the situation of wetlands in Sri Lanka.

- Understand the composition of wastewater.
- Examine the water quality in Dandugam Oya.

The result can be of great interest for further similar projects in the area. Furthermore, due to the urbanization of Colombo it is very reasonable to expect further development of wastewater treatment plants (WWTP). With more WWTP - more suiTable recipients for the treated wastewater will be necessary. It is also very important to keep track of the water quality in the river Dandugam Oya, particularly as the river falls into the sensitive and ecologically important Negombo Lagoon.

2 BACKGROUND

2.1 WASTEWATER AND WETLANDS

2.1.1 Wastewater characteristics

The main reason to treat wastewater, industrial and domestic, is to eliminate any substances that can cause harm to the environment and human life. Municipal sewage and industrial wastewater contains readily biodegradable organic matter (measured as BOD, COD and TOC), inorganic and organic chemicals, toxic substances and disease causing agents are frequently discharged into aquatic environments without treatment. This results in contamination of water that is then unsuiTable for humans, irrigation, fishing, or recreation [Kivaisi, 2001].

Depending on what the wastewater is containing, different methods of treatment are used. The primary contents to reduce from the water are organic substances and suspended soils (TSS). Reductions will also be achieved concerning total-N, ammonium (NH_4-N), total-P **[**Metcalf & Eddy, 2003].

2.1.2 Composition of wastewater

Phosphorus and Nitrogen
Phosphorus (P) is required for plant growth, and is frequently a limiting factor for vegetative productivity. Natural inputs of P are from surface inflow and atmospheric deposition which consists of both wet- and dry precipitation. Total-phosphorus, or total-P, includes both free phosphorus and phosphorus bound to organisms and minerals [Miljöbarometern, 2009]. When phosphorus and nitrogen are transported in water courses and finally disposes in the sea or a lake, the increased availability of nutrients causes algal increase. The algal enlargement can lead to loss of oxygen, dead bottoms and fish kills. The algal increase in fresh waters is limited by phosphorus while in the sea the limiting factor is often nitrogen. Therefore nitrogen causes most harm in the sea and phosphorus in fresh waters, such as lakes or rivers. [Kadlec&Knight, 1996]

Dissolved Oxygen
Dissolved Oxygen (DO) levels in natural and wastewaters depend on the physical, chemical and biochemical activities in the water body. The analysis for DO is a key test in water pollution and waste treatment process control. A low oxygen level can cause severe problems such as dead grounds, fish and bottom organisms kill [Metcalf & Eddy, 2003].

Pathogens
Pathogens (viruses, bacteria, fungi, and protozoa) are very common in untreated wastewaters. They can cause several serious diseases i.e. hepatitis, cholera, typhoid, polio, meningitis and salmonella. Due to the simple process required for removing such pathogens most WWTP accomplish necessary removals. There are three common disinfection processes; chlorination, ozonation and ultraviolet disinfection. Chlorination is the cheapest process and has been used widely, including in Sri Lanka. Other techniques to remove pathogens are factors as natural die-off, temperature, unfavourable water chemistry, predation and sedimentation [Kadlec&Knight, 2006].

Organic matter (substances)
Organic matter is measured as Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD). BOD is defined as the amount of oxygen required by microorganisms while stabilizing biochemically decomposable organic matter under aerobic conditions. High BOD makes the water turbid and prevents the sunlight from reaching deeper waters, some plants that need sunlight will die which may disturb the ecosystem. High BOD and COD can lead to lack of oxygen.

Total Suspended Solids
Total Suspended Solids (TSS) is the content of suspended solids in the water. A WWTP is constructed to remove TSS, but if this is not working, or if the water is not treated at all, it can cause severe harm to the recipient. TSS will accumulate around the outlet and can cause such a large oxygen reduction that the bottom organisms die [Tonderski *et al*, 2002].

Heavy Metals
Metals can, and do, exist naturally in water courses, and many animals, plants and humans are depending on metals for their survival. However, high concentrations of some metals, and especially heavy metals, can be extremely dangerous for living organisms. Effluents from industries; textile, tannery, pigment etc. contains considerable amounts of metal ions, among which some are extremely toxic. Metals can bioaccumulate in the food chain, which means that the toxic effect is more pronounced in animals at the higher levels [Ahluwalia & Goyal, 2005]. Metals can also enter the environment from stormwater runoff, and areas with highways and dense traffic have shown to have increased levels of Ca (calcium), Cu (copper) and Zn (zinc). The area in Ja-Ela has a lot of industries and the Negombo highway passes right through the area, so it is not surprisingly a critical area.

Color and turbidity
Wastewater can be turbid and/or colored. The color can come from industries, i.e. textile industry. Color can also come from humus, which makes the water brownish [Berg & McClaugherty, 2008]. Turbidity and color changes can reduce the photosynthesis, which in turn can be harmful for submerged plants and organisms. Turbidity in water is caused by suspended and colloidal matter such as clay, silt, plankton, finely divided organic and inorganic matter. Turbidity expresses how the light will interact with the water; either it will be scattered and absorbed or it will go unchanged through the sample [Eaton *et al*, 1995].

2.1.3 Wetlands

What is a wetland?
The following definition of wetlands was stated by the Ramsar Convention in 1971:

"Areas of marsh, fen, peat land or water, whether natural or artificial , permanent or temporary with water that is static or flowing, fresh, brackish or salt, including areas of marine water depth of which at low tide does not exceed six meters."

Wetlands are among one of the most important ecosystems on Earth. They cover 6% of the Earth's land surface and are found in all climates [International Year of Freshwater, 2003]. In the past wetlands were considered as wastelands that could be destroyed and changed for other purposes. This mentality caused major harm to many wetlands that was drained or used as dump sites for refuse and urban waste. With new knowledge we have come to understand that wetlands are both valuable and vulnerable. They work as important sources, sinks and transformers of a multitude of chemical, biological and genetic materials [Mitsch & Gosselink, 2007]. One of the wetlands' most important functions in nature is to work as the downstream recipient of water and waste from both natural and human sources. They can be said to work as a sponge that absorbs what it is given. They are important in the landscape by providing unique habitats for a wide variety of flora and fauna. They can also be used for agriculture, water purification and fisheries.

When people live spread out around the landscape the waste products are small compared to the surrounding environments assimilative capacity. When population increases, the ratio of waste products to natural assimilative capacity increases rapidly [Kadlec & Knight, 1996]. Areas earlier considered as waste lands will now be attractive for new housing complexes, infrastructure or recreation area. Wetlands in cities are therefore a rare view; they are drained up or built up, some of them are flooded and others are turned into arid land. Considering urban wetlands pollution it is necessary to understand that in some cases pollution of wetlands means the prevention of pollution of rivers, underground waters or coastal waters.

Natural wetlands vs. constructed wetlands
Wetlands can exist naturally and they can also be constructed. A constructed wetland can be built where there did not earlier exist a wetland. The environmental concerns and user conflicts associated with natural wetlands are problems rarely experienced with constructed wetlands. They can be built almost anywhere which makes them more useful than the natural ones that are confined by availability and proximity of the wastewater source. A constructed wetland is built depending on its function, i.e. whether its major role is to remove heavy metals, phosphorus or faecal coliforms. Typically a constructed wetland performs better than a natural wetland of an equal area since factors as bottom graduation, hydraulic regime, vegetation and other system factors can be managed as required [Reed *et al*, 1988 ; Chongrak Polprasert, 1999]

Classification:
Natural wetlands (NW)
The major distinction between wetlands is made by their salinity [Kadlec&Knight, 1996].

Natural freshwater wetland – salinities < 1000 mg/l
Natural saltwater wetland – salinities > 1000 mg/l

The two types of wetlands can each be divided into two major classes:

Natural freshwater wetland

- Freshwater marsh – dominated by plant species adapted to intermittent to continuous flooding.
- Freshwater swamp – dominated by tree species adapted to life in infrequent to prolonged flooded conditions.

Natural saltwater wetland

- Salt marsh – dominated by nonwoody plants living above the level of water.
- Forested salt water or mangrove – dominated by woody plant species.

Due to its high water content the soil is saturated and plant species which depend on aerobic soil are not found in these areas. Normally found plants are cattails, bulrushes and reeds [Kadlec & Knight, 1996].

Constructed wetlands (CW)
Constructed wetlands can be divided into two types: free water surface (FWS) and subsurface flow (SSF) (also called Vegetated Submerged Bed VSB). FWS constructed wetlands look a lot like natural wetlands in appearance and function. They often have a combination of open water areas, emerging vegetation and varying water depths. Shape, size and design are often functions of the site rather than some predetermined design criteria. SSF wetlands consist of gravel beds in which the water flows. Wetland vegetation may be planted in the gravel. In addition to shape and location, more design factors can be added, i.e. gravel shape and size and different vegetation. This can make a great difference in the treatment process [EPA, 2000].

2.1.4 Wetlands in Sri Lanka

Wetlands play a major role in Sri Lanka. They are used for many different things; agricultural products, medicinal herbs, raw material for handicrafts, fishing, plants of religious value, recreation etc. To get a view about their importance it can be said that amongst the total inland vertebrate species in Sri Lanka 30 % are ecologically dependent on wetlands. Among the migratory birds that visit Sri Lanka annually more than 50 % are dependent on wetlands. In Sri Lanka there are no large natural lakes, a “villu” is a floodplain lake, which often are a cut-off from a former river bend [Kotagama & Bambaradeniya, 2006].

Threats to wetlands in Sri Lanka
According to Scott (1989) the most frequently reported threat to wetlands in general appears to be siltation. When it comes to water pollution there are three different types of pollution that appear: organic pollution, chemical pollution and sewage disposal (which are a combination of both organic and chemical pollution), see Table 1 for contributory factors, impacts and affected wetlands (including wetland ecosystems and lagoons).

Table 1: Threats to wetlands in Sri Lanka and their impacts, modified from Kotagama and Bambaradeniya, (2006).

Contributory Factors	Impacts	Affected wetlands
Reclamation of land	Loss of wetlands and their biodiversity	Urban marshes (e.g. Muthurajawela)
Clearing of vegetation	Loss of habitats and species	Mangroves
Water pollution		
1. Organic pollution	1. Loss of species	1. Marshes (eg. Muthurajawela)
2. Chemical pollution	2. Loss of species, harmful effects on humans	2. Rivers (eg. Kelani river)
3. Sewage disposal	3. Eutrophication, spread of harmful diseases	3. Tanks, Marshes, Estuaries
Regulation of water flow	Disapperance of lowland wetlands	Villu ecosystems
Unplanned irrigation	Changes in water quality	Coastal lagoon
Mining (Sand)	Loss of habitats and species Seawater intrusion	Rivers, coastal zones

2.1.5 Wetlands and wastewater treatment

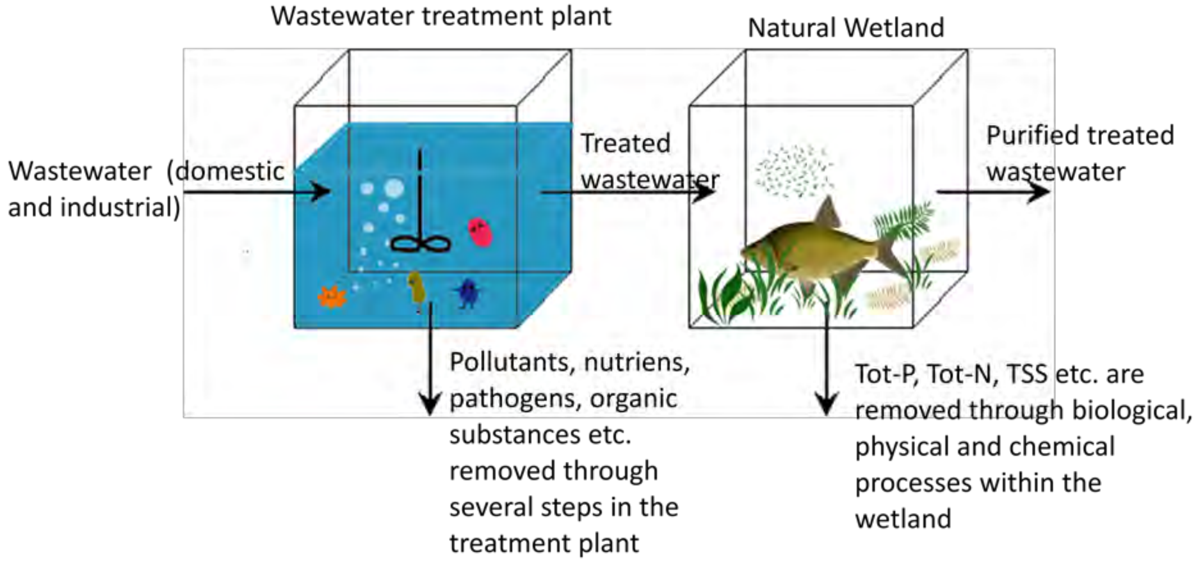

Figure 1: Wetlands treatment systems can provide a buffer between urban areas and lakes, rivers, estuaries, and oceans.

Wetlands remove pollutants in the wastewater through a complex variety of biological, physical and chemical processes, see Figure 1. The vegetation stands for a large quantity of the treatment, but vegetation cannot by itself account for the high pollutant removal efficiencies [Geersberg *et al,* 1986]. The major mechanisms for pollutant removal in wetlands include both bacterial transformations and chemical processes including adsorption, precipitation and sedimentation.

The treatment capacity also varies depending on climate characteristics such as temperature, rainfall and wind. Even more important are the characteristics of the wetland; size, depth, retention time and characteristics of the wastewater; flow and concentration of nutrients.

Vegetation
The plant rhizome provides surfaces for bacterial growth as well as filtration of solids. More importantly, the major benefits of plants in wetlands are the transfer of oxygen to the root zone. Plants can transport oxygen deeper than it would naturally travel by diffusion alone. The root zone will offer an oxidized environment in an otherwise anaerobic surrounding. The oxygen will in turn stimulate the decomposition of organic matter and the growth of nitrifying bacteria [Geersberg *et al*, 1986]. In a FWS (Free Water Surface) wetland the leaves, litter etc. serve as substrate for microbial growth when it contributes with nutrients to the microbial growth [Chongrak Polprasert, 1999]. In larger CW and NW the vegetation distribution plays an important role for the retention time. Heterogenity in vegetation distribution had a much greater effect on the flow than the variation in the bottom topography [Kjellin *et al*., 2006]. The emergent plants most frequently found in wastewater wetlands include cattails, reeds, rushes, bulrushes and sedges. They will absorb their nutrients form sediment or directly from the water and some have highly developed root systems in the sediment layer [Wenneberg & Gustafsson, 1992].

Size and volume
For a certain inflow, the size of the wetland will control the retention time of the incoming water. Deep wetlands mean a larger water volume and a larger retention time. Since it is the bottom area, not the water volume, which is responsible for most of the treatment process, it is preferable to increase the area and not the depth. [Ekologgruppen AB, 2005] The wetland's treatment capacity increases if the water flows over a maximum area. A round wetland will most probably not be as effective as an oval.

Phosphorus
Nutrient removal is depending on the amounts of nutrients entering the wetland. The nutrient load is controlled by two factors, the size of the inflow and the concentration of nutrients in the incoming water. Generally, nutrient reduction is increasing with increasing nutrient load [Ekologgruppen AB, 2005; Kadlec & Wallace 2009].

Phosphorus removal in constructed wetlands is limited to seasonal uptake by the plants. When the plants gets older their capacity to store phosphorus decrease, and when the plant die the phosphorus will be released to the soil. Newly planted soil or media will have a big sorption capacity, but as the soil gets older the capacity will decrease because the free sorption sites will be saturated [EPA, 2000]. A high initial removal rate of phosphorus by freshwater wetland will be followed by large exports of phosphorus within a few years [Moshiri, 1993].

Storage of phosphorus in natural wetlands depend on the removal of dissolved inorganic phosphorus (DIP) from the water by microbial and plant uptake, soil adsorption and incorporation of organic phosphorus into soil peat. The initial removal of DIP under natural loading levels is mainly due to microbial uptake. This microbial pool is small and quickly becomes saturated. Rooted emergent wetland vegetation takes up substantial quantities of phosphate, but after tissue death 35 to 75 % of the plant phosphorus is rapidly released. The long term phosphorus removal is shown to be sedimentation accumulation. The size of phosphorous adsorption and retention in soils is depending on several factors; redox potential, pH, Iron (Fe), Aluminium (Al) and Calcium (Ca) minerals, and the amount of native soil phosphorus. Experiences of the last three decades indicate that FWS wetlands can fulfil a useful role in phosphorus reduction in many situations [Kadlec & Wallace, 2009].

Nitrogen

Most wetlands are anaerobic processes with only smaller amounts of oxygen transported to the deeper zones by plant roots. This favours the denitrification process, that only occurs with low or none oxygen available, see Figure 2 for a simplified nitrogen cycle in a FWS wetland. Nitrification of ammonia is unlikely to occur in an anaerobic soil. In a soil with high oxygen levels the nitrogen can be transformed into ammonia. Thus in a wetland with both an aerobic and anaerobic zone nitrification can occur followed by denitrification (nitrates turns into gases). Another important process is the Anammox process. That is when the ammonium diffusing upwards from anoxic deep water is consumed by anammox bacteria below the oxic zone. Anammox bacteria are therefore linked to the removal of fixed inorganic nitrogen in the environment [Kuypers *et al.*, 2003]. Wetlands are generally effective as nitrogen traps, where the nitrification-denitrication process is the most important one, but processes as anammox do also exist. WWTPs can be necessary to remove further nitrogen if that is necessary [Dong & Sun, 2007].

Other factors and processes that reduce the amount of nitrogen in wetlands are absorption in plants and sedimentation of nitrogen bonded to particles, see Figure 2. The nitrogen assimilation in plants will, like for phosphor, be large during the growing period, followed by nitrogen releases if the plants are not harvested. Organic bound nitrogen can sediment, where the organic bounded nitrogen will be keep for a longer time. To summarize nitrogen removal in wetlands denitrification and sedimentation are the processes that can reduce the amount of nitrogen for a longer period of time. The magnitude of these reductions depends on many factors including temperature, season, organic carbon, and dissolved oxygen [Kadlec & Wallace, 2009]. However, a retention time shorter than 2 days will cause considerable changes in the nitrogen removal [Wennerberg & Gustafson, 1992].

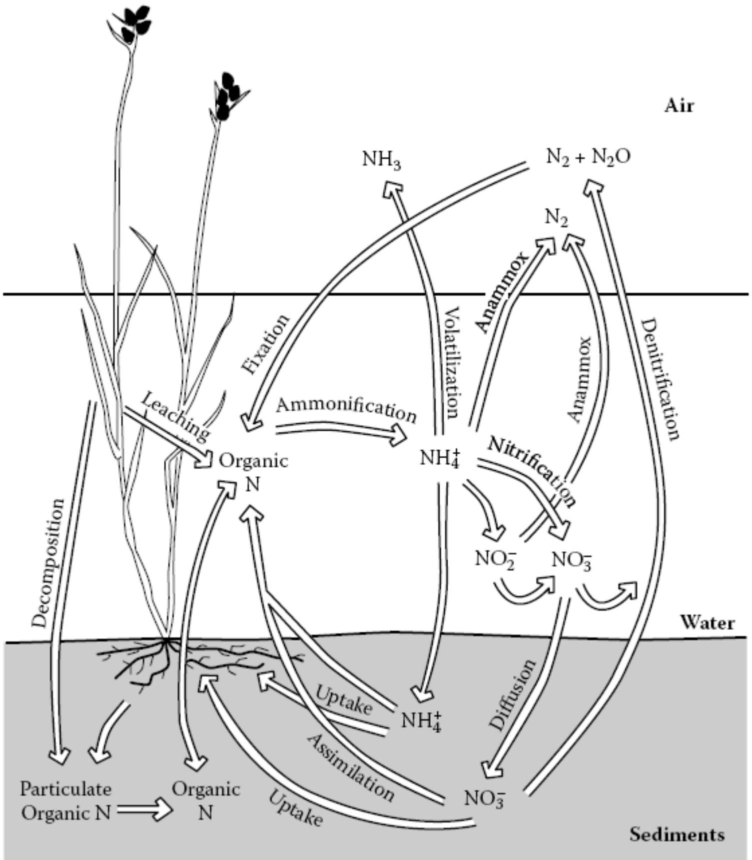

Figure 2: Simplified nitrogen cycle for a FWS treatment wetland [Kadlec & Wallace, 2009].

Bacteria and pathogens

Bacteria removal efficiency is a function of the inflow bacteria population. Removal efficiency is typically high at high inflow populations, but declines to negative efficiencies when inflow populations are lower than the in situ bacteria population.

Total coliforms are a group of closely related bacteria (family Enterobateriaceal) that have been used for many decades as the indicator of choice for drinking water. Few bacteria other than coliforms can metabolize lactose, therefore lactose is used as the basis for identification. Fecal coliforms are a subset of the total coliform group, where E.coli is the major subset of the fecal coliform group. They are distinguished in the laboratory by their ability to grow at elevated temperatures. Fecal coliforms and E.coli densities are typically much lower than those for total coliforms; thus they are not used as an indication for treatment effectiveness and post treatment contamination [Letterman, 1999].

Within a wetland there are a variety of potential treatment pathogen killers. FWS wetlands do reduce high numbers of incoming fecal and total coliforms, i.e. mortality has been found to be approximately 25% in a FWS wetland in Thailand [Polprasert, 1999]. The four major processes to reduce the amount of pathogens are:

- Solar disinfection – UV radiation is a potent agent for killing bacteria in a FWS wetlands.

- Predation – Most pathogens are food for nematodes, rotifers, and protozoa. But there is yet no method for quantification of this removal mechanism.

- Settling and Filtration – A measurable proportion of wastewater microorganisms are found either associated with particulates or as aggregates of many organism. In wetland environment, submersed plant parts and their associated biofilms form "sticky traps" for particles. These biofilms are capable of trapping considerable numbers of organisms.

- Mortality and regrowth – Pathogens typically do not survive longer than about 30 days in freshwater environment and about 50 days in soil environments. Similar survival conditions might therefore be assumed for wetlands, but there are many site-specific factors and processes which may materially increase or decrease survival.

There are yet no studies that can say how effective the processes are compared to each other. A wetland can reduce the levels of pathogens if the retention time is long enough, greater than about 10 days. The extent of removal is strongly dependent on the hydraulic efficiency of the wetland. Wetlands with vegetation appear to be slightly more effective for pathogen removal than natural treatment systems that have less physical contact between pathogens and biofilm surfaces [Kadlec & Wallace, 2009].

Total Suspended Solids
The water speed is reduced when the water enters a wetland. A reduced speed allows more suspended solids to sediment. Heavy metals, organic nitrogen, pollutants can be bound to the suspended material and sink to the bottom. Particles created by production in the aquatic environment (i.e. dead animal plankton) will also sediment. Generally the suspended soilds removal in FWS wetlands is very efficient. The net sedimentation is regulated by the balance between gross sedimentation and the re-suspension, which in turn depends on the water level, foraging wildlife and wind- and wave- induced mixing [Kadlec & Wallace, 2009]. Within the sediment the decomposition of organic matter will continue, and especially phosphorus can be stored in the sediment for a long time [Tonderski *et al.* 2002].

Biochemical Oxygen Demand
In FWS wetlands removal of the soluble BOD is mainly due to the attached microbial growth. But the wetland is only effective in reducing BOD as long as incoming BOD exceed the natural level at which the wetland operates. There are many different carbon conversion processes within a wetland, some which consume carbon and others that produce it.
All types of treatment wetlands have seasonally variable changes in BOD effluent quality. These seasonal changes are due to weather, plant biomass cycling, and water temperatures [Kadlec & Wallace, 2009].

2.1.6 Recipients

The water that receives the treated wastewater is called a recipient. The recipient can be a sea, a lake, a wetland, a river or a lagoon. Treated wastewater can also be used for i.e. irrigation, the wastewater will eventually penetrate down to the groundwater, this is called reuse of wastewater and is an interesting method with growing popularity. How the recipient will react depends on the wastewater composition and the structure of the recipient.

Water courses
In a water course, i.e. rivers and streams, the water is normally mixed. An emission of wastewater will follow the river flow as a concentrated plug and eventually be diluted and mixed with the water. If the wastewater contains high amounts of heavy metals or oxygen demanding matter, this plug can be devastating for the river's ecosystem. In rivers, especially the deep and slow streaming ones, is most of the activity process in the free water.

Lakes
Lakes can be of all different sizes and depths, they can be stagnant ones or just extended parts of a river. Depending on the lake's form their suitability as a recipient is determined. Common for lakes are that the sunlight is only able to penetrate to a short depth. This penetration depth is depending on the color and turbidity. Almost all photosynthesis and oxygen production is in this light part, and the bottom segment is often more or less anoxic and contains of dead algae and organisms.

Estuaries, coastal waters and sea
In coastal waters, where inland waters meet the sea, salt and fresh water will mix. Seawater has a higher density than fresh water, which will make the fresh water lay upon the salt water. A common phenomena is when salt water intrudes into a river, sometimes several of kilometres, which is the situation in Dandugam Oya [pers. comment Sunnit Pallegoda]. The water along the coastline is normally mixed quite well, but when shallow areas, like a bay, receive freshwater the salt water on the bottom will get trapped by the fresh water on top. When the salt water and fresh water don't get mixed the oxygen level will decrease in the lower parts. This is because all oxygen is used for decomposing of organic matter (algal and organisms die and fell down). A low oxygen level can be devastating for many organisms and cause damage to the ecosystem. [Svenskt Vatten, 2007].

2.2 COLOMBO CITY

Colombo, the commercial capital of Sri Lanka (see Figure 3), is suffering from serious water pollution from domestic and industrial wastewater. The Kelani River is the major source for supplying water to Colombo but it is contaminated with organic pollutants mainly from domestic and industrial wastewater [NWS&DB, 2009]. There is also a threat to the ground water, mainly rising from leaching agricultural wastewater and sewage from pit latrines. It is urgent to improve sewer systems and wastewater treatment facilities in these areas to conserve clean groundwater and an unpolluted environment. A vision for year 2025 predicts that the urban population will increase from today's 5,6 million to 15 millions. This will put a severe strain on the water resources and the infrastructure for water supply and sanitation [Lanka Jalani, 2008]. Colombo is a city with need for an extended wastewater system. This problem has fortunately not passed unseen, and several organisations are now working for improving the city's sewer system.

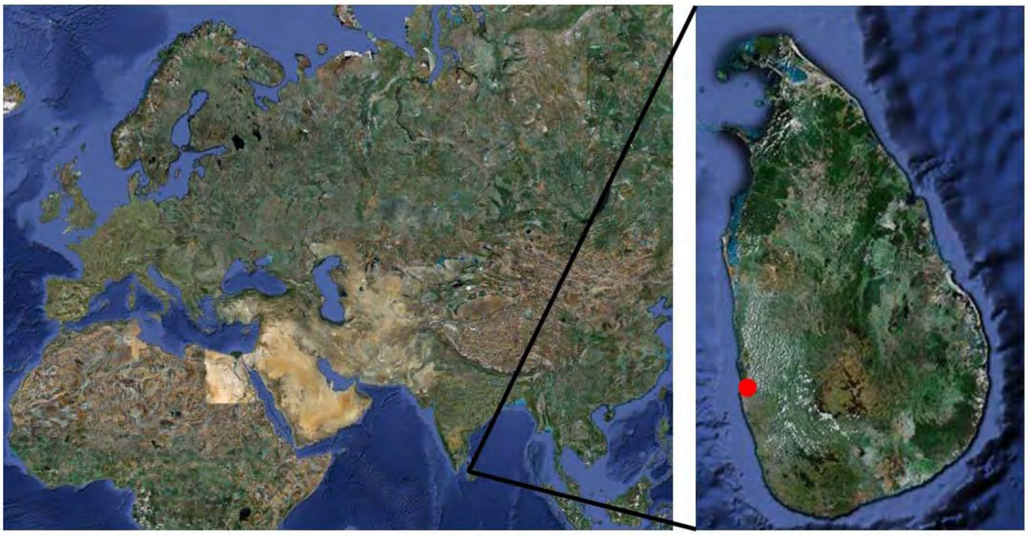

Figure 3: Map of Sri Lanka, the red dot shows the location of Colombo. Made by author with maps from Google earth.

2.2.1 Wastewater disposal system for Ja-Ela/Ekala and Ratmalana/Moratuwa

Based on a concessionary credit provided by Sida, Implementing Agency (project proponent) National Water Supply and Drainage Board (NWS&DB), commonly referred to as the Water Board, under the Ministry of Urban Development and Water Supply (MUDWS) of the Government of Sri Lanka, is building a Wastewater Disposal System for the two areas Ratmalana/Moratuwa and Ja-Ela/Ekala. These two areas are of extra importance due to their many industries. The Swedish consultant agency Sweco International in co-operation with EML Consultants, Colombo, are working as consultants. Contractors are the Danish company PIHL and China GEO, China. The project started in 2008 and is estimated to finish in a couple of years [ToR, 2007]. These Terms of Reference (ToR) quotes how NWS&DB has formulated their goal for the project:

"*The long-term objective is to contribute to improved health and living conditions for people in the Greater Colombo Area, improved environmental conditions in sensitive eco-systems and establish a sustainable development of the industrial areas around Colombo, through provision of sewerage networks and treatment facilities in Ratmalana/Moratuwa and Ja-Ela/Ekala Areas.*" [Quoted ToR, 2007, section 4 page 6]

2.2.2 Where to discharge the treated wastewater?

A WWTP needs to have an output for the treated wastewater. The natural way is to return the water to the environment. Different recipients are unequally suited for this mission. Some recipients can handle big fractions of heavy metals, and others are better for large quantities of organic matter. Even though the water is clean, it still consists of nutrients, phosphorus, nitrogen, organic matter etc. This will affect the recipient differently i.e. through eutrophication, pollution or other harmful ways [Svenskt Vatten, 2007].

At the WWTP, in Ratmalana and Ja-Ela, the responsible engineers have decided to have the outfall from Ratmalana into the sea and the outfall in Ja-Ela to either a river or to a wetland connected to the river. Behind these decisions are economical, social and environmental aspects, see Table 2.

Table 2: When the EIA was performed for the project three potential alternatives were studied. Social and technical reasons lead to the decision to put the outfall directly to the river. The Table shows how the different aspects were valued [EIA, 2003/04].

Discharge\Impact	Environmental	Economical	Social
Sea	Low	High	High
Negombo Lagoon	High	Low	High
Dandugam Oya	Low	Low	Low

2.2.3 Water and wastewater

According to a report from UNEP [2001] there are two main reasons for the water pollution in Sri Lanka;

- Pollution that arises from agricultural practise, urbanization and industrialization (see Figure 4).
- Indirect effects of pollution that are caused by deforestation, plantations and human settlements.

Agriculture is the most important economic sector in Sri Lanka, and the development of the agricultural sector enhanced the application of agrochemicals and fertilizers which in turn led to increased water pollution. The urbanization is significant in the Western Province and the urban land extent has been estimated to increase from 9% (1981) to 33% (2004) [Urban Development Authority (UDA), 2004]. Urbanization and industrialisation cause water pollution due to discharge of wastewater, sewage, solid waste, chemicals, heavy metals into different recipients. Kelani River and Dandugam Oya indicates these sorts of pollution. The Kelani River discharges 36,000 kg/day of COD, and the Dandugam Oya 20,500 kg/day of COD (calculated with the estimation of COD 28 mg/l from field measurment). The sea outfall in Mutwal discharges only 6000 kg/day of COD. It is also shown that the concentration of total and faecal coliforms is much higher in the outlet of Kelani than in the seawater above the Mutwal outfall. The high amounts of COD and BOD are primarily caused by sewage water [UNEP, 2001]. NWS&DB has carried out studies on Kelani River and one of their findings is that factories do not operate waste treatment plants during unobserved periods to save cost [NWS&DB[2], 2009].

Figure 4: A glue-factory in Ja-Ela releases their wastewater untreated into the public sewer system. Photo by author.

The nutrient pollution may cause eutrophication in natural waters. Frequent and high abundance of filamentous green algae in Negombo Estuary (commonly named Negombo lagoon) is an example of this increasing nutrient pollution problem. Negombo Lagoon suffers from both eutrophication and high pollution. This has happened before to another lagoon; Lunawa lagoon, which was considered to be biologically dead (but are now due to huge effort starting to recover) [Lunawaenv, 2008]. This lagoon, like Negombo, supported a large and important fisheries industry, which now is extinguished. A lake that is in the risk zone is the Bolgoda Lake. The lake receives wastewater from many industries in the surrounding areas of Ratmalana and Moratuwa.

There is only one conventional sewage system in operation in Colombo Metropolitan Region (CMR) and that covers 80% of the area. An estimation, made by NWS&DB 1993, claims that out of the 370000m^3/day wastewater that is produced in Greater Colombo Area (GCA) 280000m^3/day is sent back to the environment as wastewater.

3 SITE DESCRIPTION

3.1 SRI LANKA

Sri Lanka is a teardrop shaped island in the Indian Ocean south east of India, see Figure 3. It has an area that is a sixth of the size of Sweden and a population approximately twice as large as Sweden´s. The commercial capital is Colombo, a city that out of control grows bigger every day. Sri Lanka has been suffering from a civil war that has been raging since 1983 with only shorter periods of truce. The war is when writing this on its last stage, and in May 2009 the president Mahinda Rajapaksa declared the country's liberation from the LTTE. [Cummings *et al*., 2006]. In December 2004 Sri Lanka was strongly affected by an internationally devastating tsunami and 30,000 human lives were lost from the coastal belt. The coastal belt relies mostly of well water for drinking and many of these open dug wells were contaminated with saline water when the waves hit the coast. The tsunami caused a major damage along the coastline and even today these areas are not fully recovered [Sida, 2008 ; I.V.W. Ediriweera, 2009]. Colombo was not the worst damaged area, but reconstruction of damaged infrastructure along the coast was required. Today new housing complexes for victims are built in the suburbs of Colombo, and new pipes and wastewater treatment plants are being constructed. Many of these new projects are funded by aid organizations, helping the country recover after the war and the tsunami.

3.2 CLIMATE

The study area is located in the wet zone and hence it is influenced by the South West monsoons, *Maha* from Oct-Dec and *Yala* from April-June. [Pers. comment Sunnit Pallegoda, 2009-02-19] The typical rainfall for the wet zone areas is in the range of 2000-2500 mm/year [NWS&DB, 1996]. Sri Lanka in general has an annual mean rainfall of 1900 mm, which is two and a half times more than the world annual mean of 750 mm. The Gampaha District, in which the study area lies, has an annual mean rainfall of 2600 mm/year, see Figure 5 for monthly distribution. The rainfall is the major source to the groundwater [UNEP, 2001]. The temperature varies between 23-31 °C, with the highest temperature in April and the lowest in January.

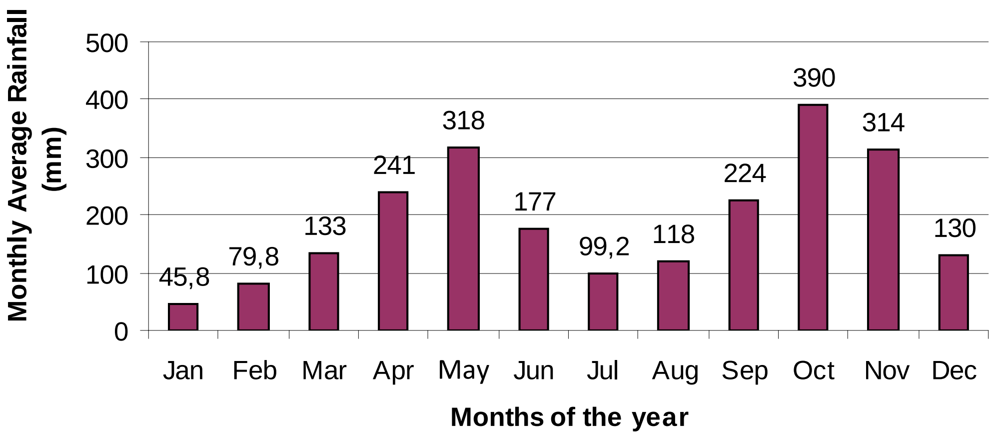

Figure 5: Monthly rainfall in Ja-Ela area. Based on Katunaya Met Station. Source Environmental Impact Assessment Ja/Ela (Supplementary) 2003/2004 NWS&DB.

3.3 GENERAL AREA DESCRIPTION

3.3.1 Dandugam Oya River

The Attanagalu Oya basin extends east-west through the central part of the Gampaha District, it lies between the Maha Oya basin to the North and the Kelani Ganga basin to the south.

Dandugam Oya is the lower reach of the river Attanagalu Oya that starts in Karasnagala and ends in Negombo Lagoon. The first 64 km is called Attanagalu Oya, and then the river change name and becomes Dandugam Oya for the last 10 km, which makes its total length 74 km. To Attanagalu Oya joins a couple of smaller rivers. Among them are Deeili Oya, Uruwal Oya and Diyalle Oya the major ones. See Appendix 2.

Attanagalu Oya and Dandugam Oya is part of the Gampaha district which is 1387 km^2 where 46 km^2 is water and marshes. The Attanagalu Oya basin extends east-west through the central part of Gampaha, in north it is defined by Maha Oya basin and to the south the Kelani Ganga basin.

Attanagalu Oya is used mainly for irrigation. It has 10 main anicuts and 27 pickup anicuts. The irrigation is used for paddy fields, and approximately 55% of the paddy fields in the district are irrigated with water from the river (the others are rain fed), which would represent an area of 103 km^2. The irrigation system is not using water from Dandugam Oya. The reason is that the water in the downstream regions receives saltwater that comes through backflow from Negombo Lagoon. Because of this backflow a couple of control gates are installed long the river. There are no hydropower stations along the river [Pers. comment Sunil Pallegoda, 2009-02-18 ; Irrigation Department, 2002]

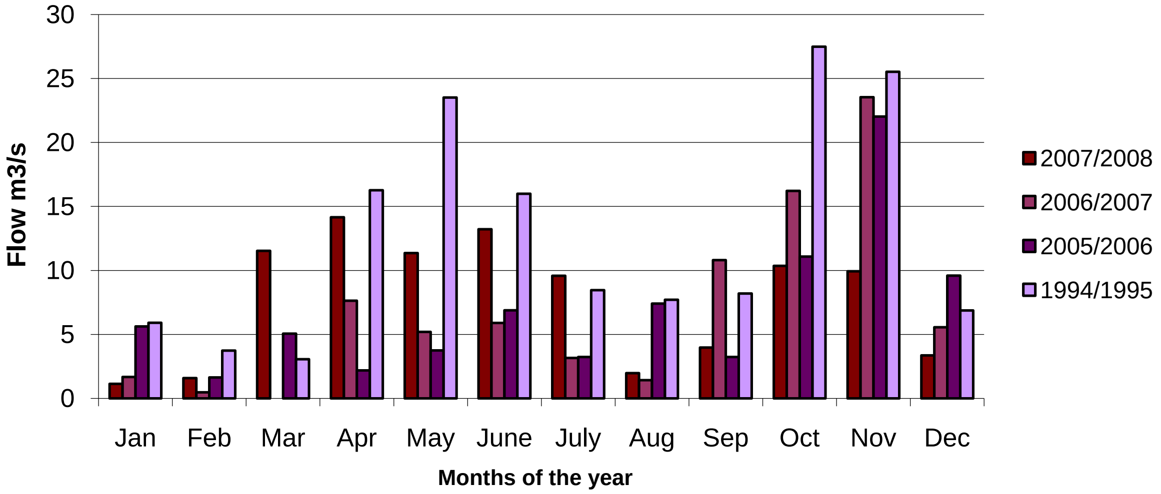

Figure 6: Mean monthly flow in Attangalu Oya. Compilation from average daily discharges of Attanagalu Oya at Dunamale, Department of Irrigation.

The mean monthly flow in Attanagalu Oya is built upon values collected in February 2009 from the Irrigation Department head office in Colombo. They measure the water flow daily at Dunamale located along Attanagalu Oya. The values presented in Figure 6 are mean values per month calculated from approximately 30 measurements/month. The data that has been compiled are from 4 periods; 1994/1995, 2005/2006, 2006/2007 and 2007/2008. Mean flow is calculated to 8,5 m^3/s.

3.3.2 Wetland

The wetland in the studied area is a part of a greater wetland area called Muthurajawela Marsh including the Negombo Lagoon, see Figure 14. It is approximately 50,000m^2 (see section 5.2). Due to seasonal variation in rainfall and evaporation the area under water is changing throughout the year. In January and February the rainfall over the area is the lowest in the year, see Figure 5. This is reflected in the wetland that is almost dried out during this period. Once or twice every year the wetland gets flooded (personal comment Charvdrika 2009-02-03, a neighbour to the wetland). The wetland lies with one side against the Dandugam Oya. During field visit several cows were pasturing the area, which affects the wetland vegetation, and may cause changes in the water retention time and flow pattern. See Figure 7-12 for photos from the wetland (taken by author and Suresh Dewasurendra).

Figure 7: Diyagowa, common plant in the wetland

Figure 8: Kirla Kirala, bird observed in wetland

Figure 9: The inlet channel into the wetland.

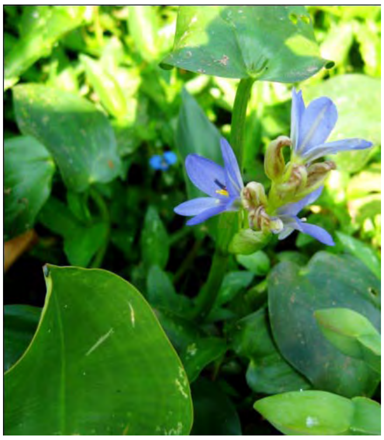

Figure 10: Common name is Japan Jabara, scientific name Eichhornia crassipes, common within the wetland

Figure 11: Common name Kankun, scientific name Ipomoea aquatica, found within the wetland

Figure 12: The author examining the wetland

3.3.3 The wastewater treatment plant in Ja-Ela

The Ja-Ela WWTP is located approximately 15 kilometers north of Colombo. The Colombo-Negombo highway passes through the area and serves as the main traffic artery. The sides of the highway are mostly taken up with commercial, industrial and residential buildings. The areas beyond the highway have been either suburban or even traditional rural land use [ToR, NWS&DB, 2007]

The catchment area consists of industries, residences and housing complexes. Table 3 presents the flow and composition of the incoming water. The WWTP's full capacity will be reached at 2030, when the design flow is 819 m^3/h. The capacity of the WWTP will be approximately 1/20 of the capacity of Henriksdal WWTP in Stockholm, Sweden [Stockholm Vatten, 2004].

Table 3: Design loads and flows of the Ja-Ela WWTP [EIA Ja-Ela 2003/04]

YEAR	**2007**	**2030**	Unit
Wastewater flow, domestic	3856	5690	m^3/d
Wastewater flow, industrial	2060	2560	m^3/d
Design flow (Qdesign)	620	819	m^3/h
BOD_5	3519	4382	kg/d
COD	9856	12269	kg/d
NH4-N	472	587	kg/d
N-tot	708	881	kg/d
P-tot	167	208	kg/d
TSS	4236	4899	kg/d

The catchment area consists of industries, and the WWTP will demand some pre-treatment before the raw wastewater (wastewater from industries) is allowed in. An effluent treatment facility within the industry discharging heavy metals will be more efficient than treating large volumes of mixed wastewater in the plant. The biological treatment is effective in removing organic pollutants, but heavy metals tend to accumulate in the sludge [Ahluwalia & Goyal, 2005]. The raw wastewater might also consist of substances that can harm the treatment process in the plant. Toxic substances, e.g. heavy metals and mineral oil, or very high level of organic substances can overload the joint WWTP. Therefore the National Water Supply & Drainage Board has set up water quality standards to what is accepted into the WWTP.

The wastewater goes through three main steps during the treatment process according to the design reports [NWS&DB, 2008]:

- pre-treatment
- biological treatment (denitrification, bio-p and nitrification)
- final sedimentation

Pre-treatment

The water will enter into a reception chamber. After the reception chamber the water proceed to a fine screen with 3mm slots. They are used for removing rags, paper and other large particles. The removed screening has a high level of water and contains sludge, which is non hygienic and might smell, therefore it needs to be washed and dewatered. The screening will then be compacted and disposed into a container. Probably it will end up as solid waste landfill [NWS&DB, 2008].

Sand trap
Wastewater always contains less or more sand. The WWTP in Ja-Ela is not a duplicated system (with both stormwater and wastewater), hence there will not be any sand coming from roads. But sand can come in through leaky pipes and from washing and cleaning at homes. Sand needs to be removed to avoid abrasive wear on pumps and mechanical equipment. To avoid that the sedimentation of sand is depending on the inflow, which can lead to improper sedimentation, the grit traps are equipped with an air mixer [NWS&DB, 2008].

Biological treatment
Biological treatment is working due to microorganisms' ability to transform contaminants in the wastewater. To be able to grow the organisms need energy which can be received by anaerobe or aerobe decomposition of organic material. In the studied WWTP the biological treatment starts with the denitrification process and ends with nitrification. This method is called predenitrification. The predenitrification process takes advantage of the already existing organic material in the WW. When the water enters the nitrification tank is the demand of low organic material fulfilled and the nitrification process can start. The nitrate is then re-circulated back to the denitrification tank, see Figure 13, which demands nitrate to work [Metcalf&Eddy, 2003]. The WWTP is reducing the phosphorus by exposing the microorganisms for anaerobic conditions, and an excess uptake of phosphorus will proceed when the sludge is aerated in the nitrification basin. Most of the bacteria will be removed is the sedimentation step [NWS&DB, 2008]. The treated water will probably (it is the most common way to kill pathogens in Sri Lanka, pers. comment Dr. Mahesh Jayaweera) be chlorinated, to kill pathogens, before it is released out to the recipient.

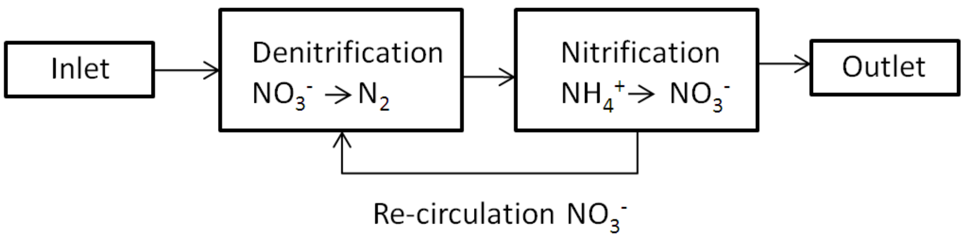

Figure 13: Schematic Figure of the pre-denitrification process. Constructed by author with information from Metcalf&Eddy, (2003).

3.3.4 Muthurajawela Marshes

Muthurajawela marsh is the largest saline peat bog in Sri Lanka, and together with Negombo estuary it forms an integrated coastal wetland ecosystem spanning 6232 ha. The marsh receives water from the Kelani river and the Dandugam Oya. The marsh plant community is unsTable and represents one of the final stages of succession toward dry land formation.

Muthurajawela receives and retains high loads of domestic and industrial wastes and sediment from both surrounding and upstream areas. Wetland plants are important for sedimentation, nutrient removal and toxic substances. During the rainy season the wetland acts as a retention area for run-off from surrounding higher grounds and floodwaters from the drainage basin.

The major disturbances and threats to the wetland is illegal reclamation of land, chemical pollution and eutrophication, due to agricultural fertilizers and pesticides [IUCN, 2006].

3.3.5 Negombo Estuary

Negombo Estuary is a very productive shallow coastal body of water. It is usually called Negombo Lagoon. It is interconnected with the Muthurahawela marsh, and is the final outpost for Dandugam Oya. The main activity in the lagoon is fishing, and it is inhabited by some very rare prawn- and crab species. Fishing in the lagoon is the primary economic source for over 3000 families.

Reduction of water depths in the narrow inlet/exit channels of the lagoon, as a result of the sedimentation, leads to reduces in the tidal exchange and flushing, which decreases the lagoon's water quality. This can be observed by the increased growth of the filamentous green algal Chaetmorpha spp. The algal is an indicator of the presence of high levels of nutrients in the estuary. The algal forms a thick layer on the water surface which harms the sea grass beds, which die off due to lack of sunlight [IUCN, 2006].

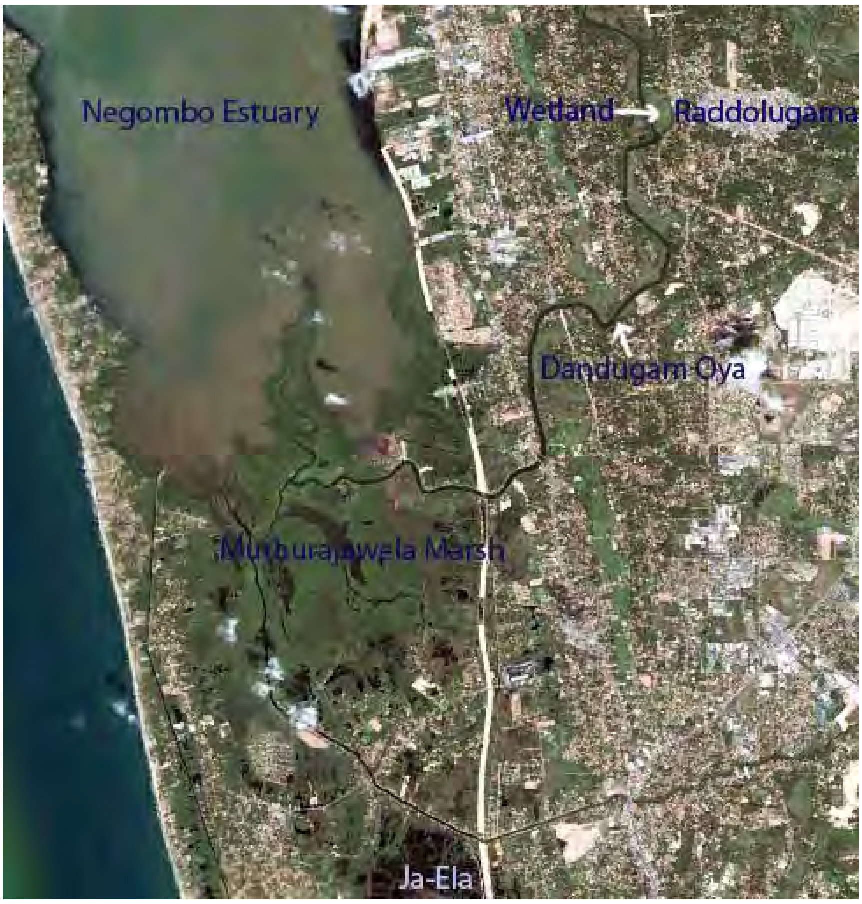

Figure 14: Map showing Negombo Estuary, Wetland, Raddolugama, Dandugam Oya, Muthurajawela Marsh and Ja-Ela. Made by author from Google Earth.

4 METHODOLOGY

The methodology is composed of six major sections:

1. A literature study was conducted in order to get a general understanding of the theory behind wastewater treatment and composition, recipients of wastewater and the general basics about natural wetlands and their treatment capabilities. The literature study also included a shorter study of wetlands in Sri Lanka.
2. A theoretical background analysis was conducted in order to define which variables that should be tested during fieldwork.
3. Fieldwork was carried out to measure the water quality at strategic points in the wetland and river and to establish the geographical coordinates of the wetland.
4. Laboratory work was conducted to assess the water quality.
5. Analyzing the results.
6. Discussion and conclusions based upon literature study and results from fieldwork.

4.1 PROJECT METHODOLOGY

By measuring the water quality at different positions in the wetland, it is possible to observe if an improved water quality (further purification) can be observed. This scenario can also be simulated with a simplified 2D model. The model is based on retention time calculations and generates approximated values on the wetlands treatment capacity. To be able to run the model, parameters as the wetlands area, inflow, outflow and vegetation are necessary [Kjellin *et al.*, 2006]. The parameters will be collected in field, see section 5.2.3 Fieldwork.

Analyses of the river were done by measurements of water quality at different locations in the river. The result from the measurement will be compared to the wastewater composition. The river's flow and variation during the year will also be implied in the analysis.

4.1.1 Literature study

The information gained for this project is mostly from books about wetlands and wastewater. Information about the water flow in Dandugam Oya was received during a visit to the governmental organisation Department of Irrigation. The source for the old river quality data was from the old feasibility study done for the Environmental Impact Assessment Report prepared by NWS&DB in 1996. Information about the wastewater entering the wetlands was collected at NWS&DB local office in Raddolugama. All information about the larger WWTP project was collected through project material like the Environmental Impact Assessment Report, ToR and personal comments from staff.

4.1.2 Interviews

Interviews were carried out throughout the project. Some of them were spontaneous and very informal while others were more planned and had some prepared questions. The interviews were always performed orally. Some field visits were combined with shorter interviews. The planned and longer interviews were performed with:

- Mrs. Priyanka Dissanayake, Environmental Scientist, IWMI (International Water Management Institute), Sri Lanka. 2009-02-03
- Sunnit Pallegoda, Divisional Assistant at NWS&DB in Gampaha District, 2009-02-19
- Dr. Mahesh Jayaweera, Head Division of Environmental Engineering, University of Moratuwa, Sri Lanka, 2009-02-24

4.1.3 Fieldwork

To test the water quality in Dandugam Oya, and in the wetland, water samples were taken and analyzed. The water was tested for 9 different parameters: Total-P and Total-N, Dissolved Oxygen, Total and faecal coliforms, Chemical oxygen demand (COD), Biochemical Oxygen Demand (BOD), Total Suspended Solids (TSS) and colors. The water samples were taken at seven different locations, five from the river and two from the wetland (Figure 15), which were chosen to represent the river and wetland characteristics.

Figure 15: The map shows the location of the water samples along Dandugam Oya. 6 is the most upstream measured point, 1 and 2 is from the wetland and 3, 4, 5 and 7 are downstream the wetland, with 7 close to the outlet into Negombo Lagoon. The map is created from Google Earth with the points position from the GPS measurements. In Appendix 1 the exact locations and position of the samples are given.

Dandugam Oya

In all locations a 5 l bucket, tied to a rope, was used for collecting the water. The best accuracy is received if the sample is taken from the part in the river that has the highest flow. This is usually in the centre of the river, and therefore the goal was to come out as far as possible from the shoreline. The rope tied to the bucket was 6 meters long, and the samples were taken an average 3 meters out in the river. When possible the sample was taken from a bridge and could therefore be taken from the middle of the river. The water was at all samples taken from the surface water, approximately at 0,1-0,5 m depth. The bucket was washed at every site with the local water before the samples were collected. From the bucket the water was pored into a plastic bottle à 1 litre that was filled to max, see Figure 16. From this bottle the water was to be analyzed for BOD, color, TSS, Total-N and Total-P. The water was also tapped into a smaller plastic bottle à 250 ml. This bottle was taken for the COD measurement. To conserve the sample 1 ml Sulphuric Acid (H_2SO_4) 0.025 M was added as soon the bottle was filled. The acid was added with a 5 ml pipette. For DO measurement water was collected in a 300 ml glass bottles with tapered and pointed ground-glass stoppers and flared mouths. The bottle was filled to the top, the cap was added and any extra water was removed. Then 1 ml of each $MnSO_4$ and Azide solution was added to store the sample. After the chemicals were added the bottle was slowly turned. The last type of sample, for measurement of pathogens, was taken directly into 125 ml sterilized dark glass bottles. Once collected they had to be kept in a cold place to prevent the bacteria from growing. They were therefore, as soon as they were taken, handled over to a bucket with ice bottles. At all places 4 different bottles were filled with water which leads to a total number of 20 bottles with water collected from the river.

Figure 16: Material used for collecting water samples: 1. Bucket, 2. Bottle for COD, 3. Sulphuric acid, 4. Bottle for DO, 5. Plastic 1 l bottle, 6. 5ml pipette. Photo by Suresh Dewasurendra.

Wetland

Two samples were collected from the wetland. The same bottles were used as for the river, and the same parameters were analyzed. 4 bottles were taken at each place, which leads to a total of 8 bottles with water from the wetland. The samples from the wetland inlet were taken at the immediate point the water left the pipe. The sample that was taken from within the wetland was supposed to be taken at the point where the water flows out to the river. But this specific point does not really exist in reality, so the samples were to be collected from points that could represent this point. This had to be done in places that looked like channels where the water was passing out. Only one good channel was to be found, and therefore the water was taken from that one. It was not possible to walk all the way down to the river because of the marshy ground and dense vegetation. The water from the wetland had a high turbidity, and did even contain some minor water bugs. Therefore the bucket was left for sedimentation for a couple of minutes before poring it over to the bottles.

At every site the time and specific coordinate for the sample was written down. The samples were stored in a cooler at < 10°C degrees overnight.

Why only seven samples?
The reason for the small number of samples was, above all, economics and time. The budget for water sampling was limited, and the different laboratories charged quite expensive costs for water quality testing. The laboratory chosen (Moratuwa University) was one of the cheapest, and they also allowed me to participate and conduct some of the work. This was very time consuming, because I had to understand what to do, and for this reason we did not have time to analyse more than the seven samples. It was also complicated to get the necessary materials (i.e. transport, bottles) and support to carry out the sampling procedure a second time, even if this had been to prefer for the study.

Wetland area
To be able to model the wetland its boundaries had to be confirmed. With the help of a portable GPS the wetland was manually mapped. The GPS had good satellite connection in the area, so there were no problems with the registrations. Manually the GPS was carried around the area, and the boundaries and the level above the sea were registered. At some points the terrain was difficult to force through and the boundaries were not clear. The altitude was measured at several points within the wetland. The accuracy of the data is poor. During field visit was also the water level in the wetland visual estimated.

4.1.4 Laboratory work

All the samples were analysed at University of Moratuwa, Civil Engineering Department, Environmental Division. Standard Methods for Examination of Water and Wastewater [Eaton *et al*, 1995] were followed in the analysis. The complete methodology and necessary preparatory work can be read from this book. The following section will in short explain the major steps and underlying theories that were used for each parameter.

Total-Phosphorus (TP) and Total-Nitrogen (TN)
The methodology used for TP and TN was UV visible spectrophometric method. As the method is very similar for both phosphorus and nitrogen, only a short explanation of TP will be presented. The samples were not filtrated through a membrane filter, and the result is therefore only total phosphorus and not total dissolved phosphorus. A phosphorus analysis is divided in two steps: a) conversion of the phosphorus to dissolved orthophosphate and b) colorimetric determination of dissolved orthophosphate. After step a) and b) is completed the samples will have a slightly blue color. The intensity of the color is corresponding to the concentration of phosphorus. A spectrophotometer measured the color and the result was compared to a calibrated graph of color versus the concentration of TP.

Dissolved Oxygen
DO was analysed with Azide Modification (see Figure 18). It is a method used for most wastewaters, effluents and stream samples. To be able to use this method two reagents had to be added immediately after collection to preserve the sample; 1 ml Manganous sulphate solution and 1 ml Alkali-iodide-azide reagent. In the lab the bottles were diluted with concentrated sulphuric acid (H_2SO_4) which dissoluted the MNO_2. 200 ml from the sample were handed over to a flask and 1 ml starch was added. The starch is used as a color indicator during the titration. A magnetic stirrer was used to mix the titrate with the sample. For titration of 200 ml sample $Na_2S_2O_3$ 0.025 M was used as a titrator. The sample was dark purple/blue at the beginning of titration because of the Iodide added earlier, but whit titration it turns clear and the titration ended.

Total and faecal coliforms
Multiple tube fermentation technique (see Figure 17) was used for analysing the total and faecal coliforms. Three different sample concentrations were used; 0.1 ml, 0.01 ml and 0.001 ml, which is lower concentrations than normal because of the assumed high conc. of coliforms [pers. comment Mrs. N.S. Gunathilake]. Five tubes of each concentration from each sample were prepared. They were diluted with distilled water and MacConkey Broth was added. MacConkey Broth contains nutrients and vitamins to the coliforms, and will make them grow. The tubes were then incubated in 37°C for 48 hours to ferment lactose. Depending on the amounts of coliform the tubes will produce gas or change color. A confirmatory test is done and the final combinations of positives (color change) are compared to a MPN (most-probable number) Index.

Chemical oxygen demand (COD)
For analyzing the COD Open Reflux Method was used. In field the samples were preserved by adding 2 ml conc. Sulphuric acid. COD is the amount of oxygen required to chemically oxidize the organic matter present in water. Most types of organic matter are oxidized by a boiling mixture of chromic and sulphuric acids. The sample is therefore mixed with potassium dichromate and silver sulphuric acid. The sample is refluxed under heat for two hours, and the remaining potassium dichromate is titrated. From the amount of needed titrant the oxidizable organic matter is calculated in terms of oxygen equivalent.

Figure 17: Multiple tube fermentation technique used for analysing the coliforms.

Figure 18: Azide Modification was used for the testing of BOD and DO.

Biochemical Oxygen Demand (BOD)
The BOD_5 Azide Modification (which is the same technique used for DO) was used for the testing of BOD. The major difference from DO is that the samples are diluted with aerated distilled water to ensure that the demand does not exceed the available oxygen. The level of oxygen is measured at start and after incubation in 5 days under a temp. of 20°C ± 1°C. The observed difference between day 1 and 5 is the BOD_5 value.

Total Suspended Solids (TSS)
The sample was mixed and 500 ml was filtered through a weighed and dried standard glass-fiber filter. The residue retained on the filter was dried to a constant weight at 103°C (this took approximately 1 h to obtain). The filter was weighted again and the increased weight is the amount of TSS.

Color
Color was analyzed with a UV visible spectrophotometer. 1 ml of each sample was analyzed for color intensity in three different wavelengths; 436nm, 525nm and 620nm.

4.1.5 Retention time of water in wetland

The major difference between the current situation and the situation with the new WWTP is that the incoming flow will increase and the concentration will be different. The increased flow will in turn affect the retention time of water within the wetland. The treatment process within the wetland is in many ways controlled by the retention time of the water, which is affecting the retention time of the pollutants, nutrients, bacteria etc.

The retention time of water within the wetland:

$$T_W = \frac{V}{Q} \tag{1}$$

Equation (1) from Håkanson, 1998.
where:
V = the volume of water in the wetland m^3
Q = the water discharge m^3/h

Comparison of parameters between wetland, river and wastewater discharge
To compare the different parameters collected in wetland and river with the operational target discharge to Dandugam Oya and the treated wastewater from Raddolugama, river mean quality was calculated. River mean quality could then be compared to the diluted wastewater. The dilution was based on river mean flow of 8,5 m^3/s. A comparison was also made with the tolerance limits (see Appendix 3) for the discharge to Dandugam Oya. The results are presented in Figure 20, 22, 24, 26, 28, 30, 32 and 34.

5 RESULTS

5.1 Water quality

Results from the water samples collected in Dandugam Oya and wetland 12th February 2009.

Total-P

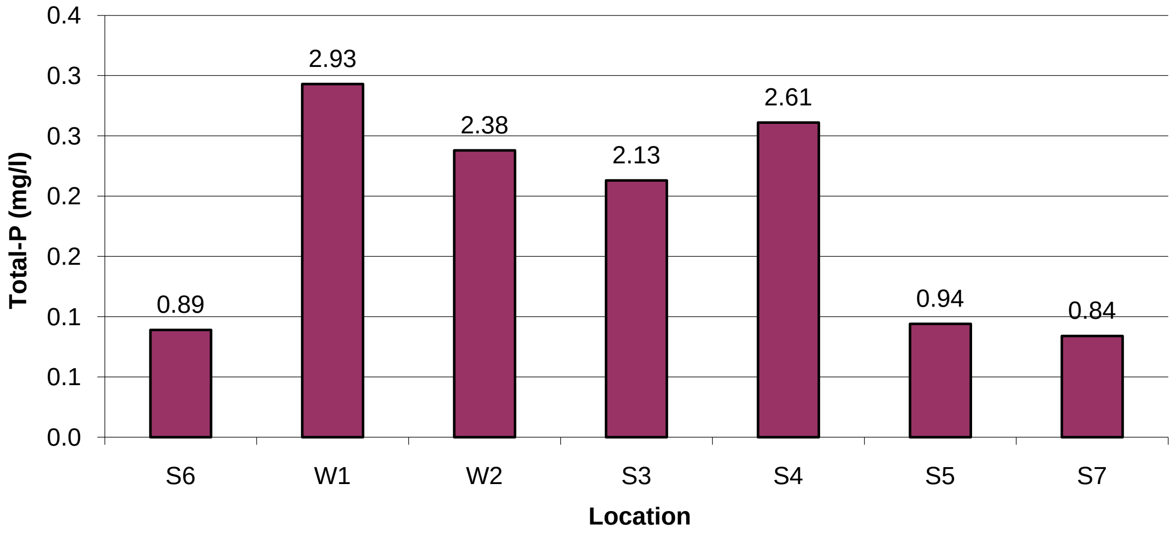

Figure 19: Total-P measured in the wetland and along the Dandugam Oya river.

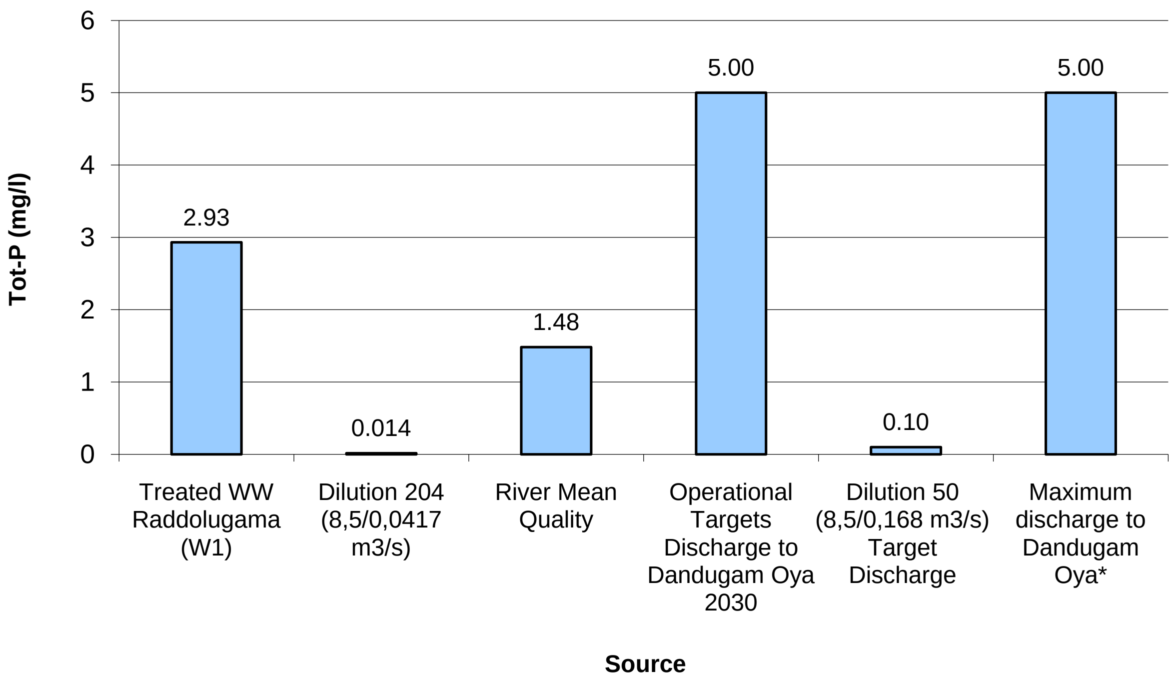

Figure 20: Comparison of the Total-P in wetland, river and target discharge.

Total-P was measured in all seven positions (Figure 19). S6 is the most upstream measured point, W1-W2 are from the wetland and S3, S4, S5 and S7 are downstream the wetland with S7 closest to the outlet in Negombo Lagoon. The highest measured value was from the treated wastewater from Raddolugama (W1), see Figure 20. When the treated WW enters the river it gets diluted 204 times and the concentration will then be almost imperceptible compared to the river concentration. The operational target discharge from the new WWTP is 5 mg/l, which also is the accepted phosphorus level for a WWTP in Sri Lanka. The WW from Raddolugama is below the maximum discharge level with 2,93 mg/l. With the estimated flow of 0,168 m^3/s it gets diluted 50 times and once again compared to the river mean quality it is a very low value. If we look at W1 and W2 we can see a small reduction in Total-P, which means that within the wetland the conc. of Total-P decreases.

Total−N

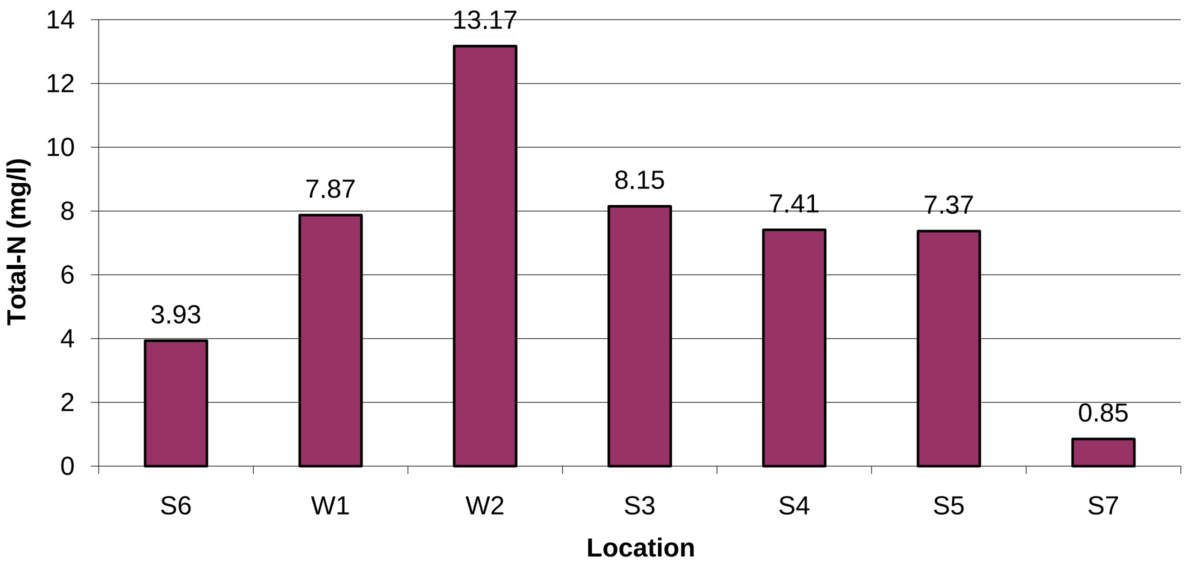

Figure 21: Total -N measured in the wetland and in the Dandugam Oya river.

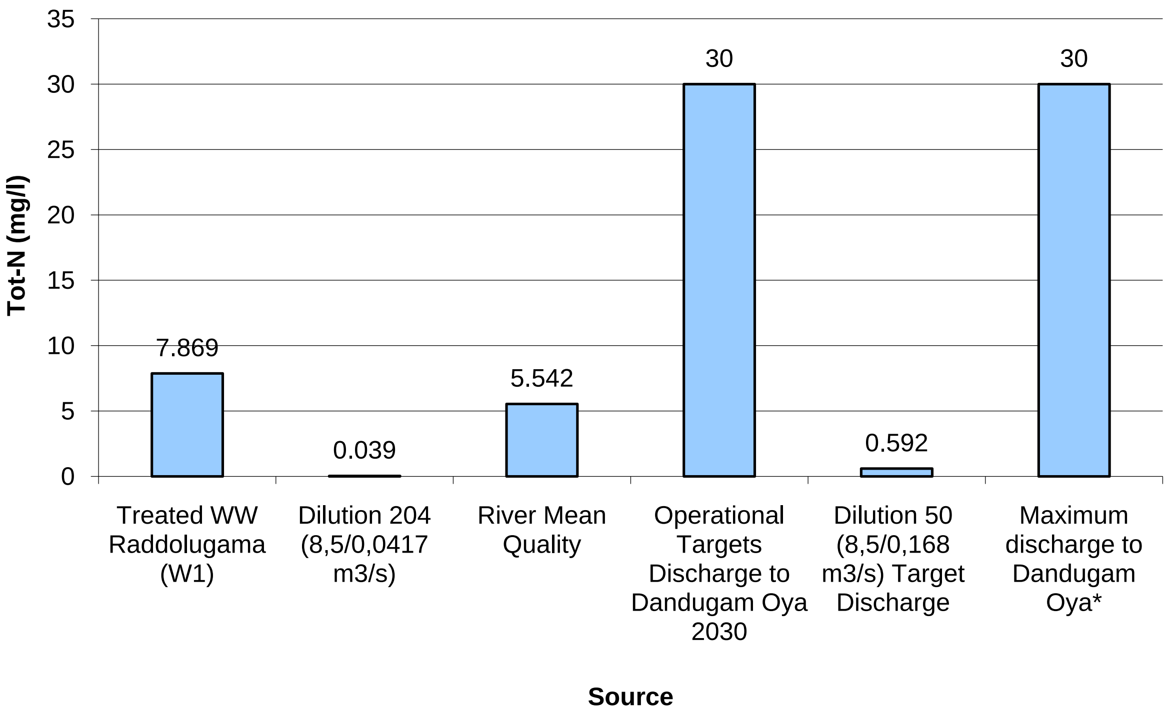

Figure 22: Comparison of the Total-N in wetland, river and target discharge.

The amount of Total-N was largest at point W2 (within the wetland) 13,17 mg/l (see Figure 21). This might show that the denitrification and nitrification process within the wetland was working poorly. The river Mean Quality at 5,542 mg/l was lower than the incoming water from W1, and when dilution was taken into account, Figure 22 shows that there will be no affection from the WW.

Dissolved oxygen

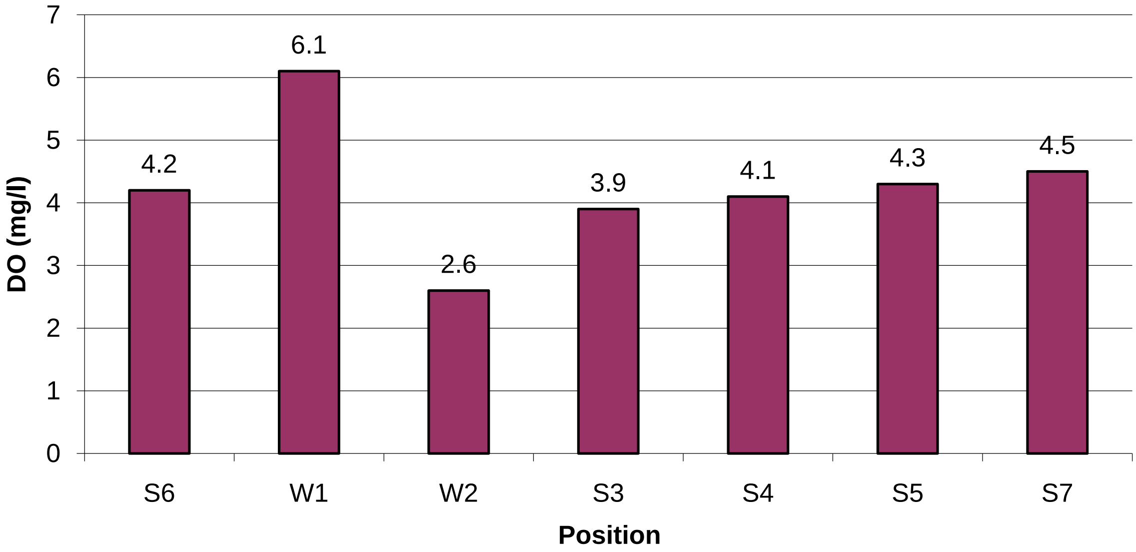

Figure 23: Dissolved Oxygen measured in the river and wetland.

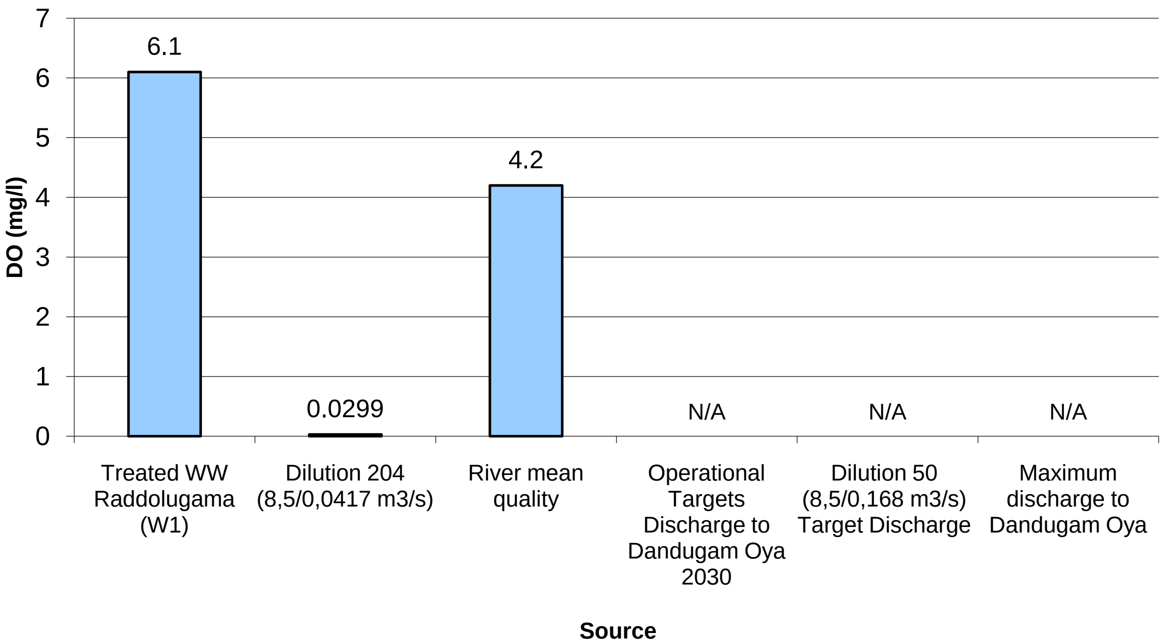

Figure 24: Dissolved Oxygen comparison between different sources, N/A means Not Available.

DO was measured at all locations. The highest amount was found in W1 and the lowest in W2, from Figure 23. The mean value in the river (S3-S7) is 4,2 mg/l. DO levels below 5 mg/l can cause fish dead, and the levels in Dandugam Oya are alarmingly low. The reason why the level was low in the wetland can because the water was stagnant and the oxygen cannot enter the water through normal mixing. Another reason can be the high temperature of the water, as warm water can hold much less oxygen than cold water [*pers. com. Priyanka Dissanayake 2009-02-03*]

Coliforms

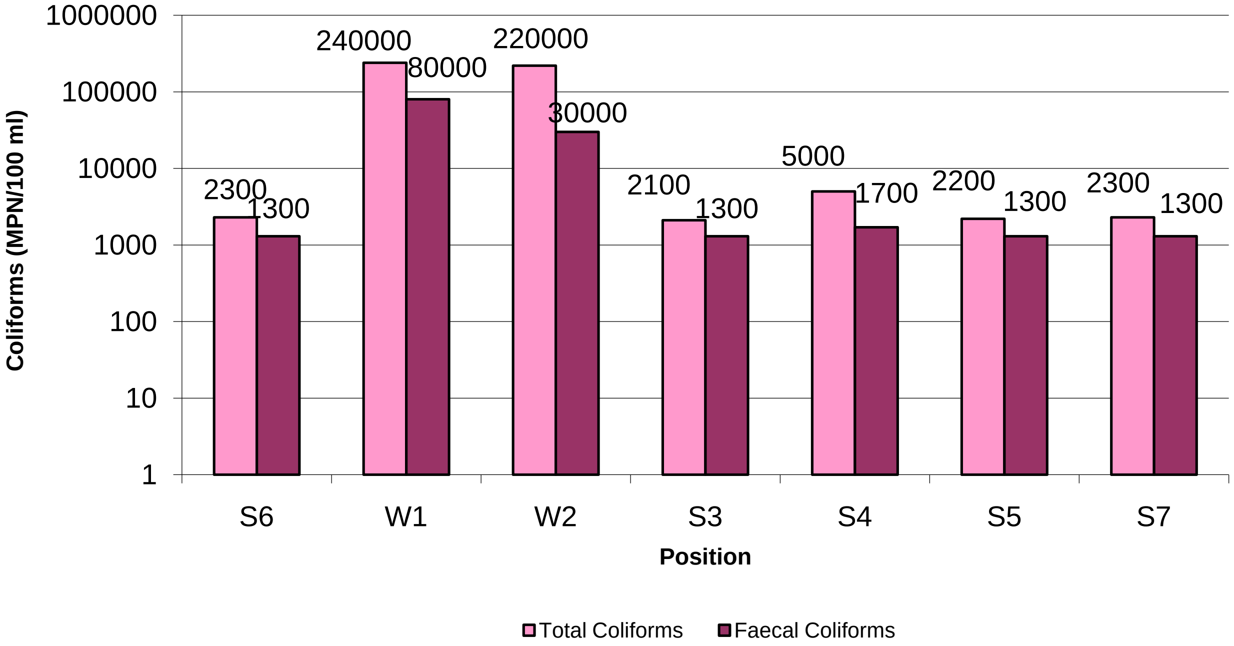

Figure 25: Total and Faecal Coliforms in wetland and river. Observe that the Y-axis is a log scale.

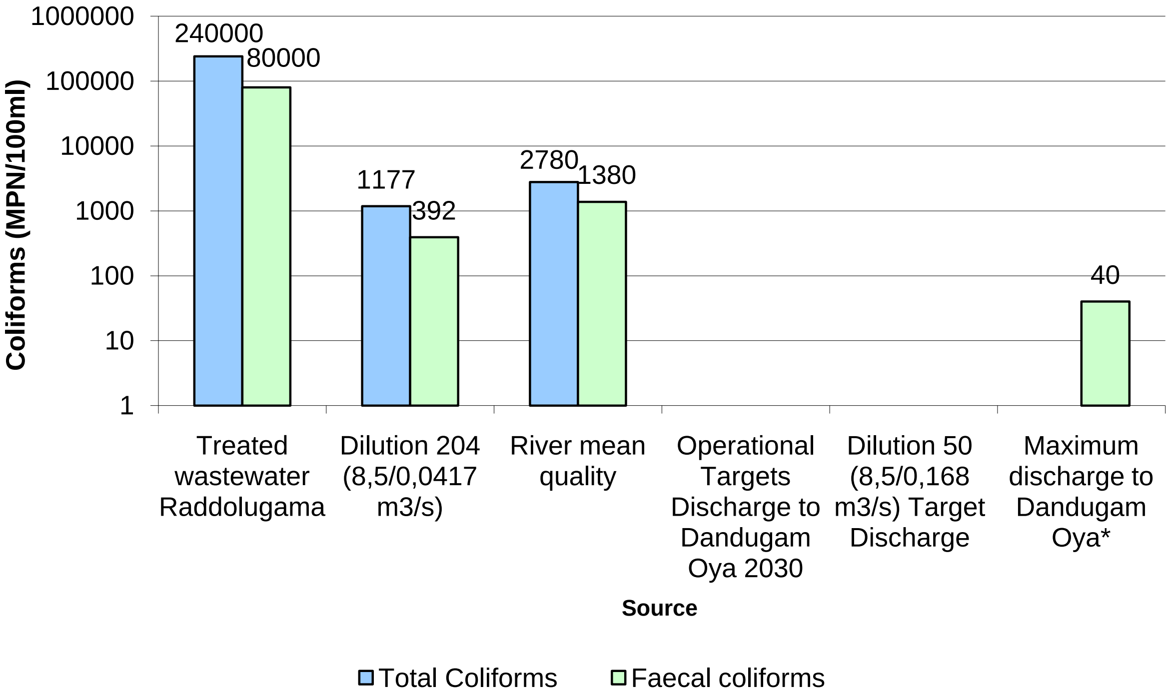

Figure 26: Comparison of total and faecal coliforms from different sources. Observe that the Y-axis is a log scale and that N/A means data is Not Available.

As seen in Figure 25 the amount of coliforms is extremely high in the wastewater from Raddolugama. This does probably indicate that there are some problems with the treatment process in the WWTP. Still we can see that the wetland decreases the faecal coliforms with 62.5 %. Along the river the amount of coliforms is fairly equal. The recommended value for WWTP discharge is 40 MPN/100 ml, and it is obviously highly exceeded. Even when the water is diluted 204 times the concentration of coliforms remains high above what is recommended, but slightly below the river mean quality (Figure 26).

Biochemical oxygen demand

Figure 27: BOD measurements from wetland and river.

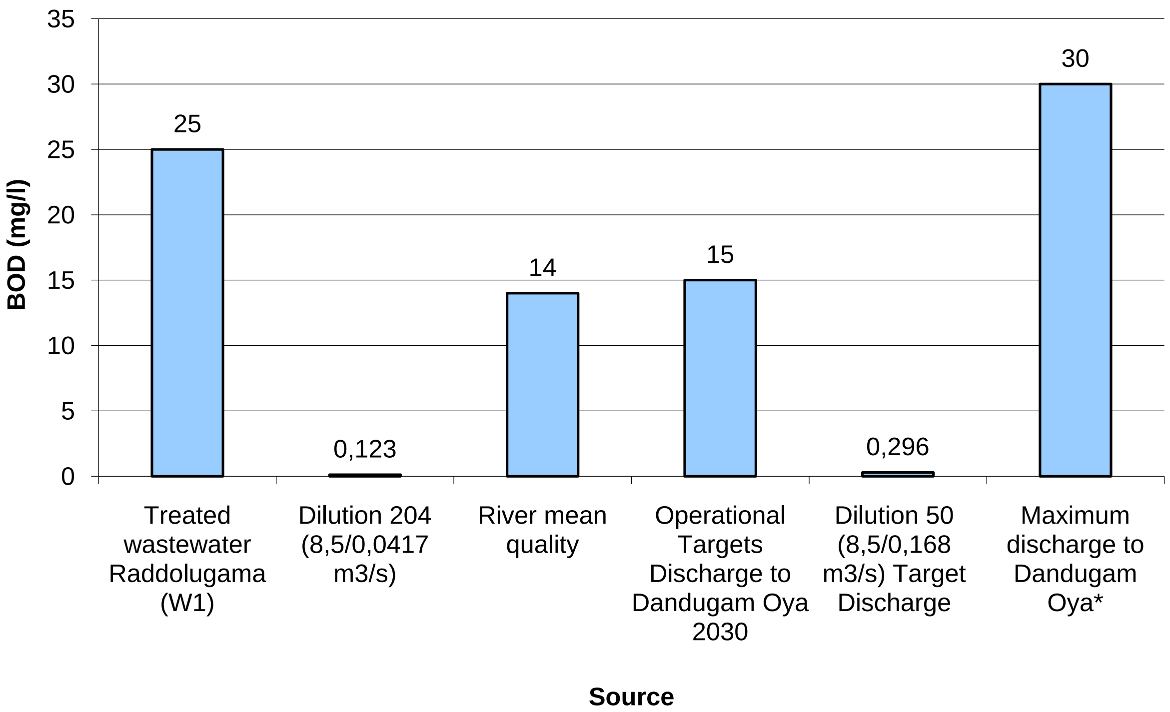

Figure 28: BOD comparison between different sources.

The variation in BOD within the river is large, and there is no clear difference between the BOD in the wetland and the river (Figure 27). It is also difficult to see any clear correlation between upstream and downstream values. The treated wastewater from Raddolugama W1 is almost twice as high BOD within the river (Figure 28). As long as the incoming BOD level is lower that the natural level of BOD within the wetland, it is possible to assume that the level will be reduced [Kadlec & Wallace, 2009]. It is interesting to see that the river mean quality and the operational target year 2030 is almost the same.

Chemical Oxygen Demand

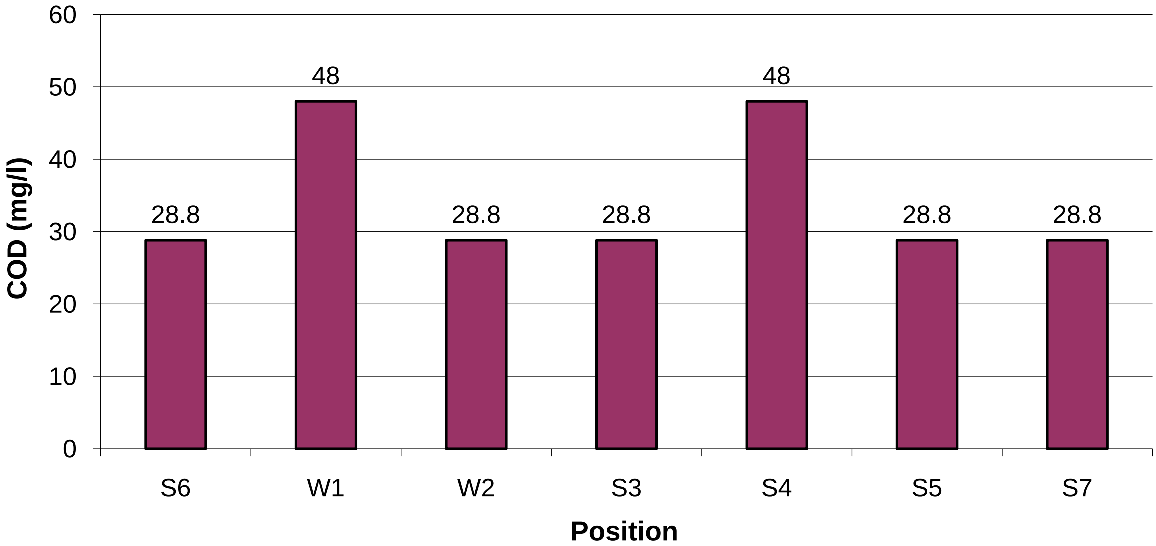

Figure 29: COD in river and wetland.

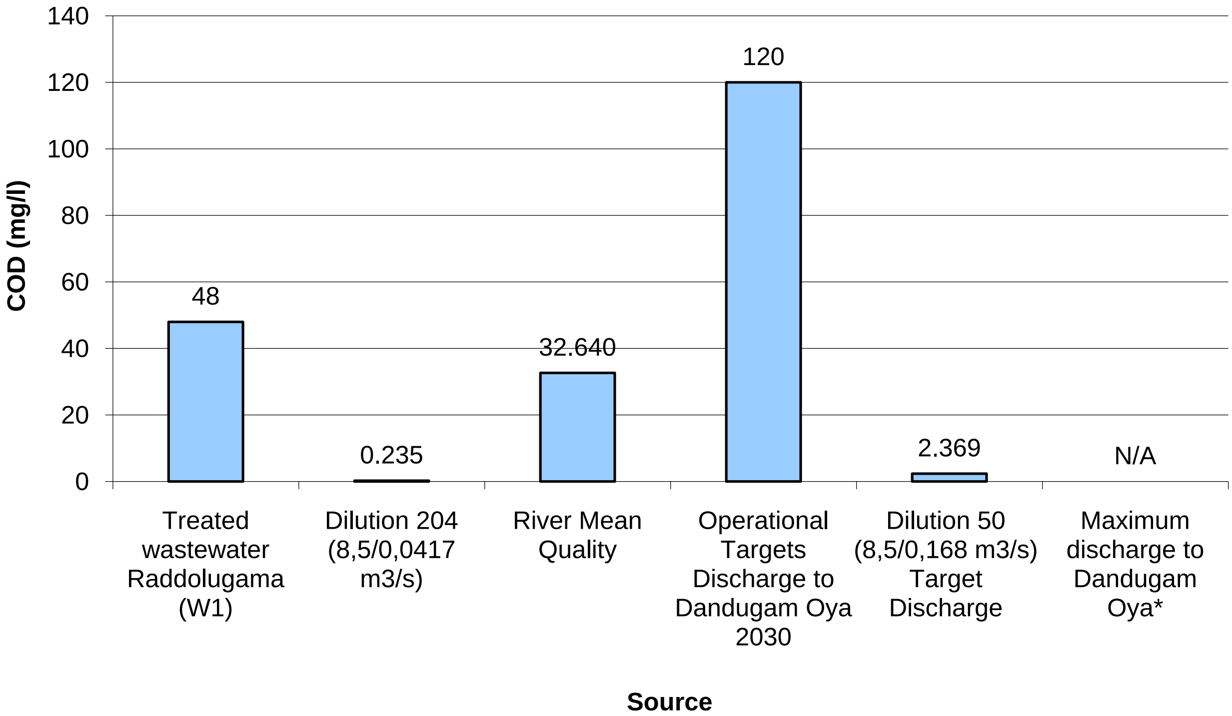

Figure 30: Comparison of COD between different sources.

The results shown in Figure 29 are not very reliable. This is so since the method the samples were analyzed with was probably not very accurate when handling small fractions of COD. But we can see that the level is very similar along the different sampling points. The operational target for 2030 is very high (Figure 30), and the treatment will probably result in a lower concentration.

Total suspended solids

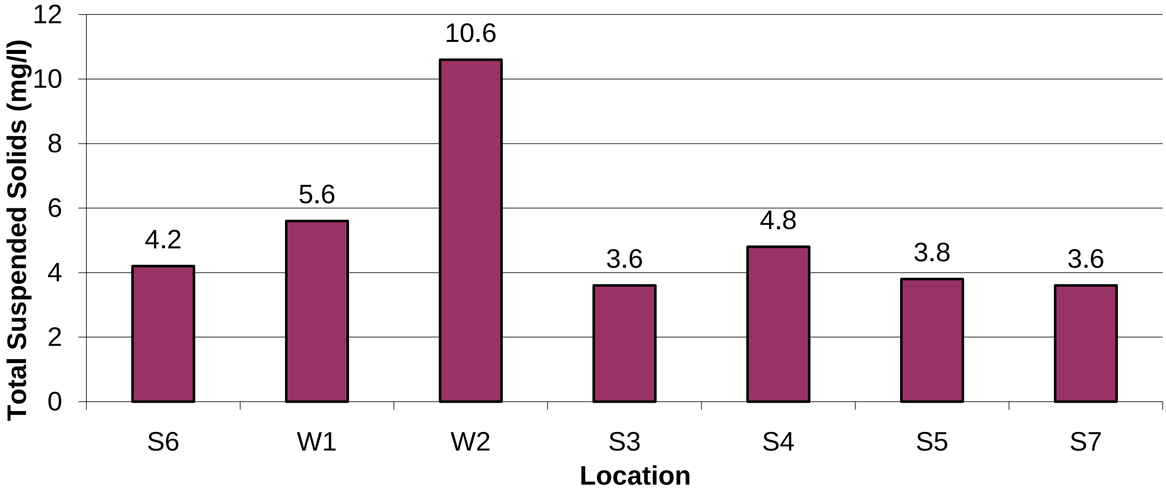

Figure 31: Total suspended solids (TSS) from wetland and river.

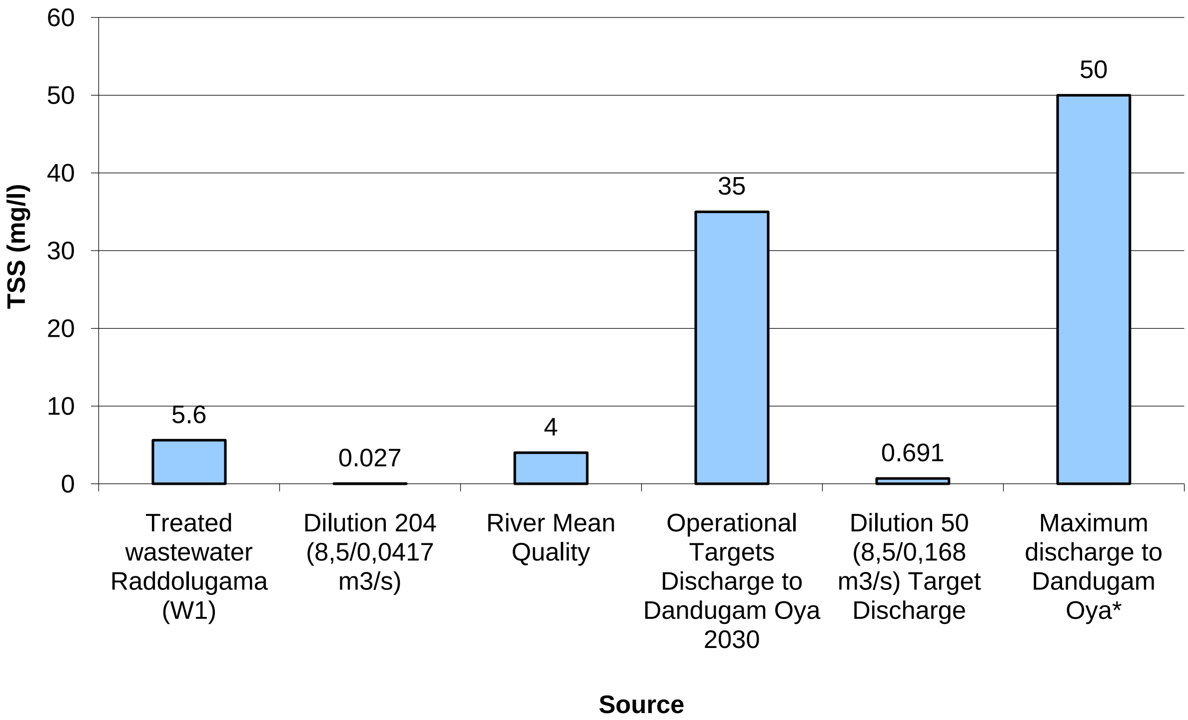

Figure 32: Comparison of total suspended solids.

It is seen in Figure 31 that amount of suspended solids was highest within the wetland (W2). This was probably because the water was being mixed during the sampling process. There were also cows pasturing the wetland, which causes the water to mix and suspended particles to re-suspend into the free water. The treated wastewater from Raddolugama (W1) was lower than the operational target discharge 2030, so it might be possible to assume that the operational target will be easy to achieve (Figure 32).

Color

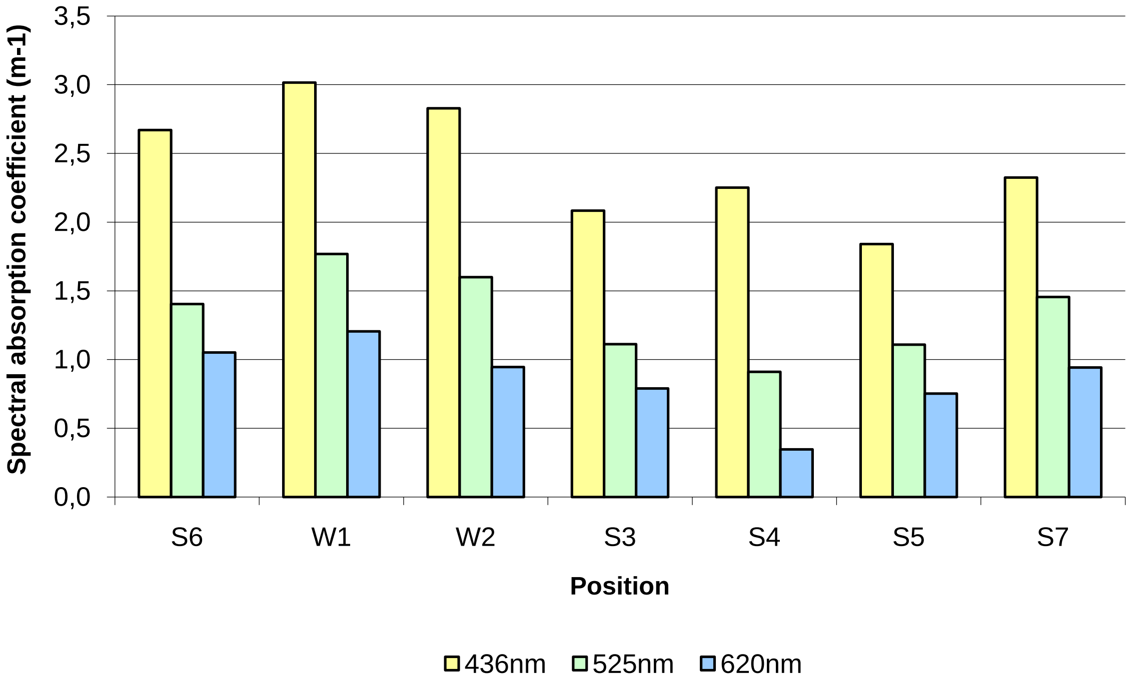

Figure 33: Color measurment in wetland and river. Three different wavelengths have been analyzed: 436 nm (yellow), 525 nm (red) and 620 nm (blue).

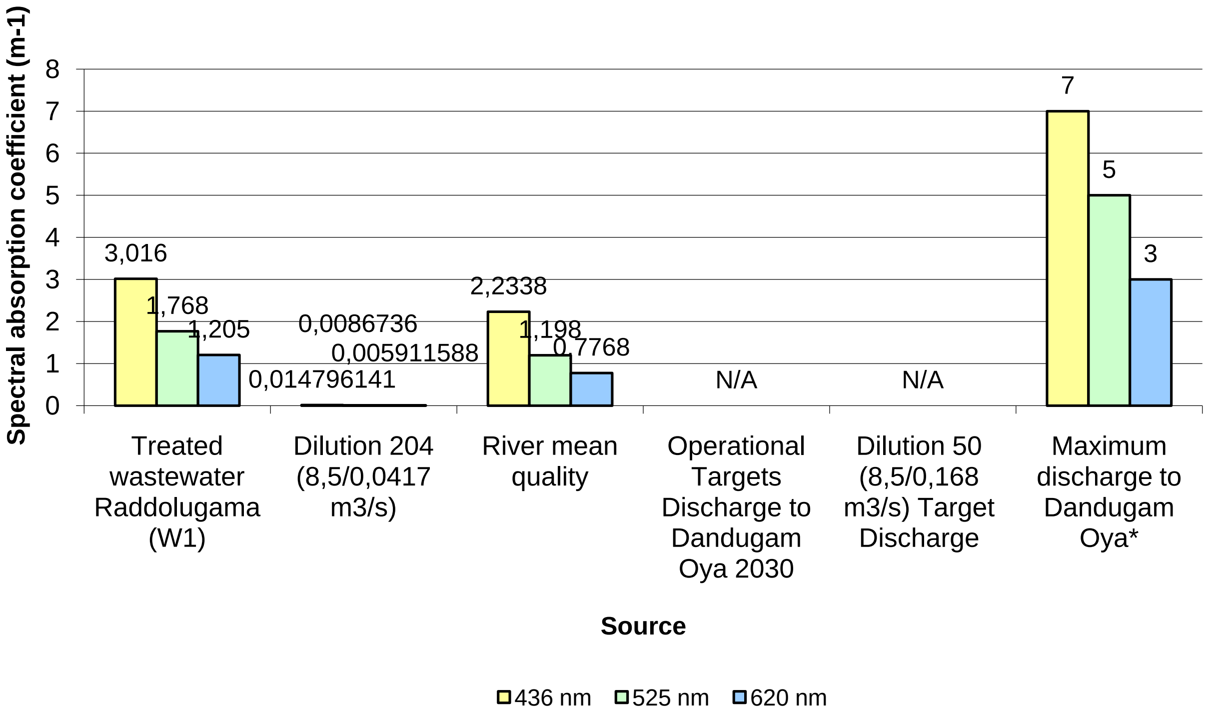

Figure 34: Color comparison. N/A means not available.

The shorter wavelength 436nm has the maximum spectral absorption coefficient at all sampling points (Figure 33). The river generally has a lower spectral absorption coefficient at all wavelengths than the treated wastewater from Raddolugama (Figure 34). The allowed maximum discharge to Dandugam Oya is approximately 2-3 times higher than the river mean quality. The operational targets discharge will probably be below the treated wastewater from Raddolugama due to improved treatment methods.

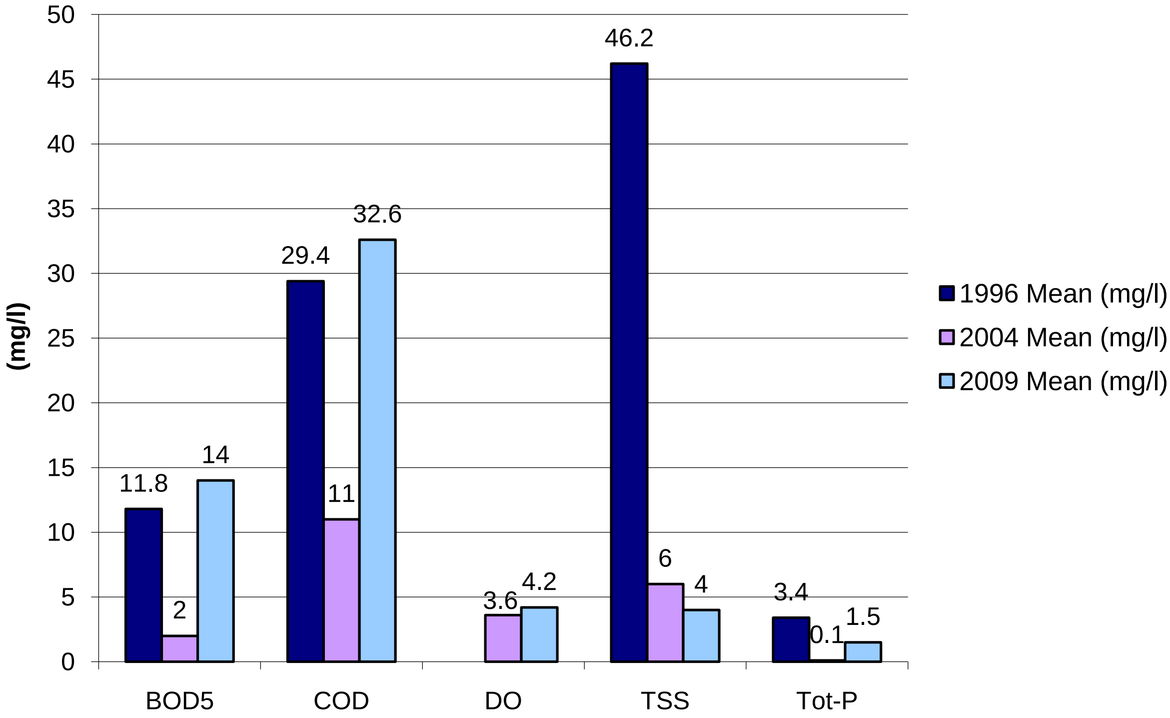

Figure 35: A comparison between water samples taken in Dandugam Oya at three different years. BOD from 2004 was measured as BOD_3. Tot-P was <0,1 mg/l year 2004.

Figure 35 presents a comparison between samples taken in Dandugam Oya year 1996, 2004 and 2009. Dissolved Oxygen was 2004 measured on site with electrometry principle (method APHA 4500-O G.) [EIA 2003/2004]. All samples year 2004 were collected from near the surface of the water body. At year 1996 DO were not measured [Feasibility Study 1996]. In year 1996 35 samples were collected.

5.2 Wetland and retention time

The area of the wetland is calculated with a polygon in ArcGIS (Figure 36). The polygon covers both the area with surface water and the area without surface water.

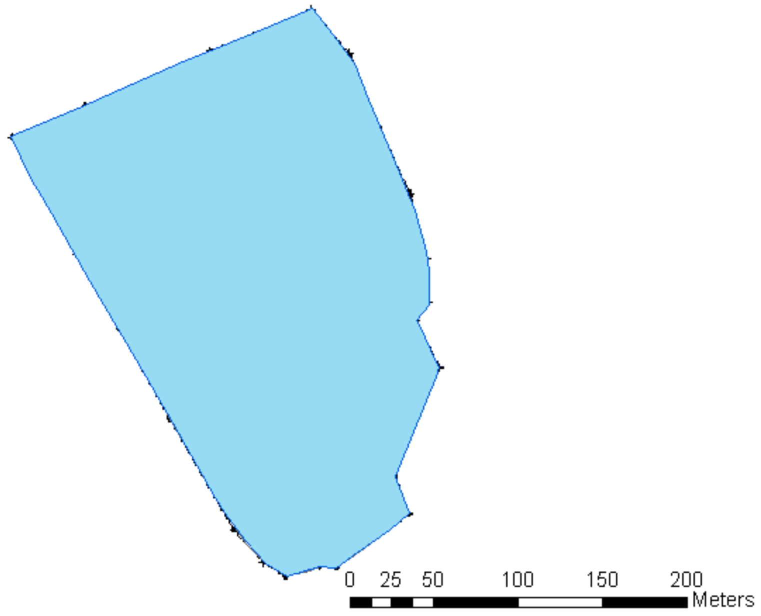

Figure 36: The area of the wetland is calculated by a polygon created in ArcGIS

From ArcGIS the area was calculated to:
$A = 51020\ m^2$

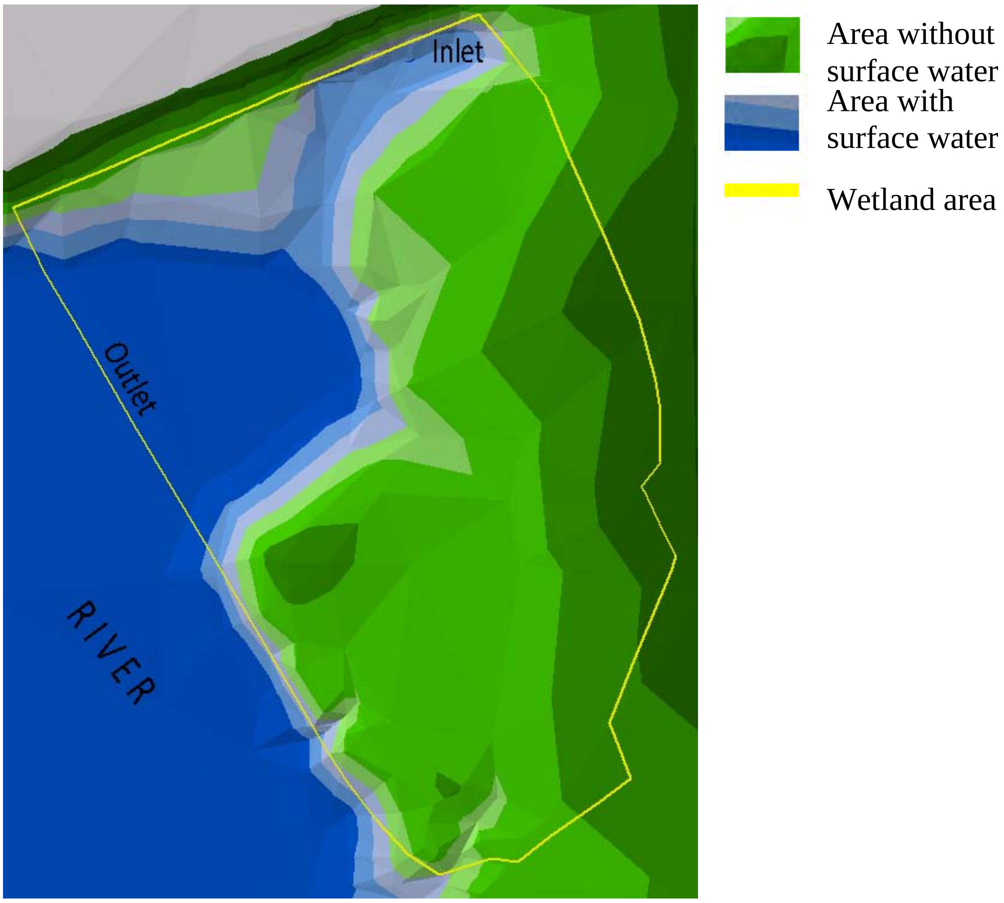

Figure 37: 3D wetland created is ArcGIS. The blue area is with surface water and the green area is without surface water. The inlet is in the top right corner, and the outlet is against the river.

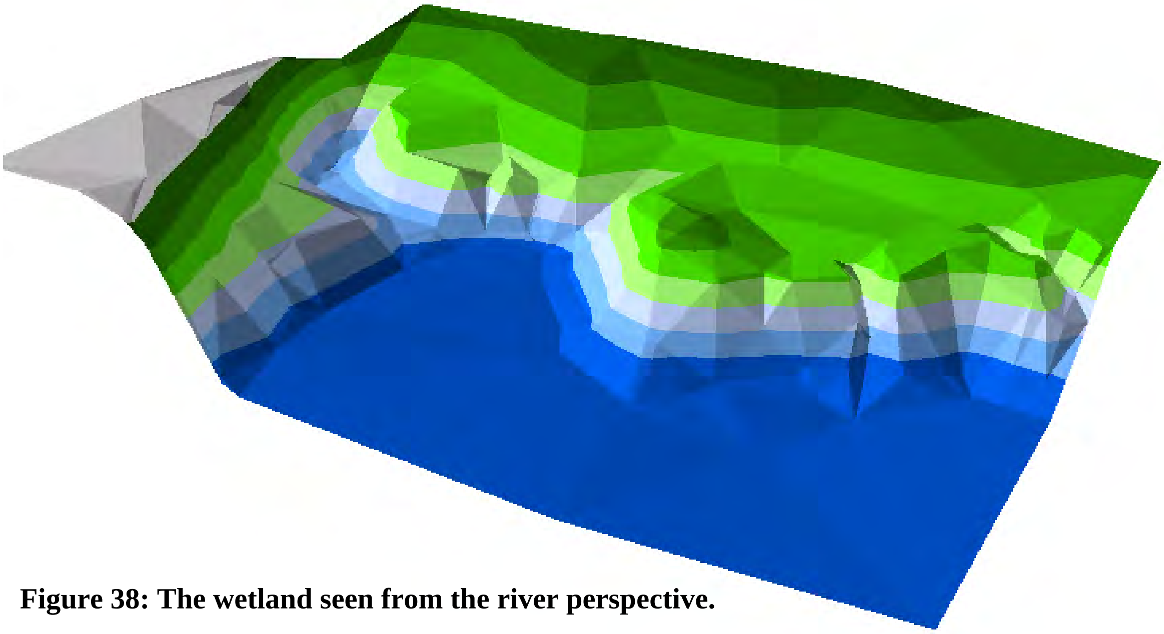

Figure 38: The wetland seen from the river perspective.

Figure 37 and 38 shows a 3D model over the wetland. In Figure 37 is the wetland area marked with a yellow line.

To be able to calculate the water retention time, the water volume needs to be known. This was done through a rough estimation by multiplying the area with surface water with the mean water depth. The mean water depth was during field visit estimated to 40 cm. The area with water is by ArcGIS calculated to approximately 12670 m^2, see Figure 39.

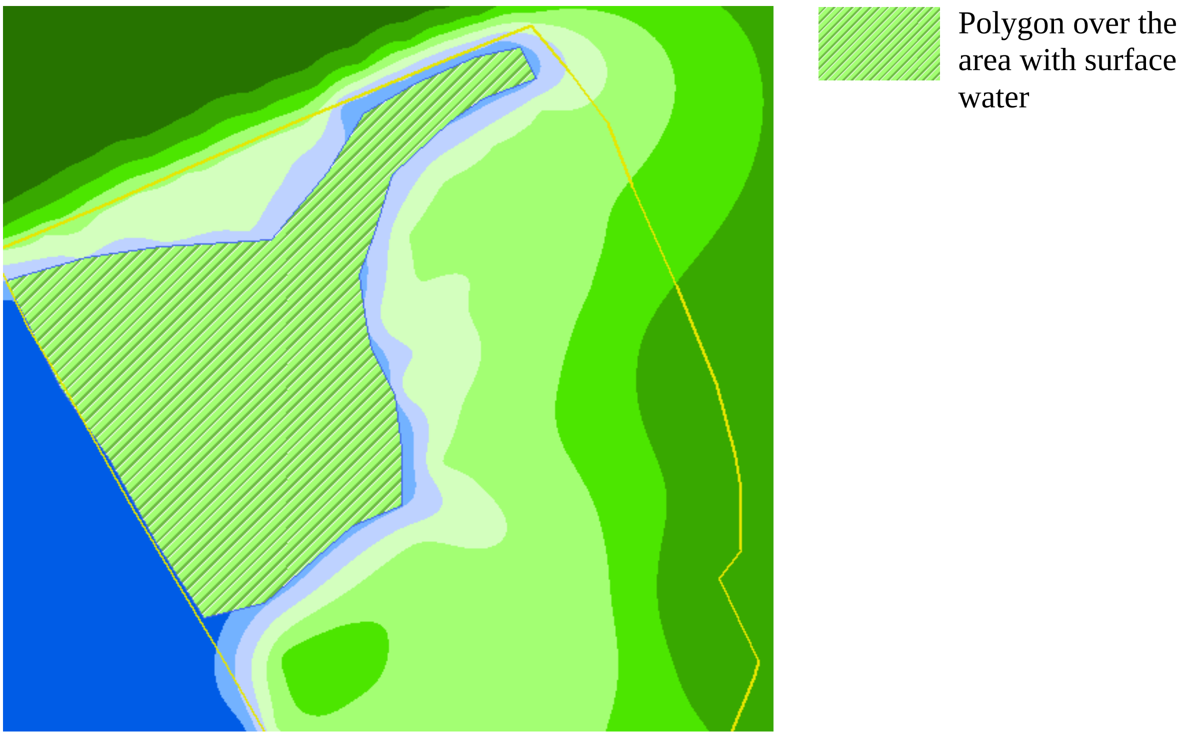

Figure 39: A polygon over the area with surface water is created to calculate the wetlands volume.

The water retention time within the wetland is calculated from:

$$T_W = \frac{V}{Q}$$

Where

V = A*D
A = 12670 m^2
D = 0,4 m

$$\Rightarrow V = A * D = 12670 * 0,4 = 5068\,\mathrm{m}^3$$

V ≈ 5100 m^3

The inflow Q_1 to the wetland (from the old WWTP in Raddolugama):

$Q_1 \approx 150\ m^3/h$

Q_1 together with the volume V gives us all the information to calculate the retention time T_{w1}:

$$T_{w1} = \frac{5100}{150} = 34h$$

With increased flow Q_2 (from the new WWTP, see Table 3) the retention time T_{w2} will be:
$Q_2 = 819\ m^3/h$

$$T_{w2} = \frac{5100}{819} = 6,3h$$

The area/volume – quotient:

12670/5068 = 2,5 m^{-1}

6 DISCUSSION

Wetland
The wetland in Ja-Ela is shallow with a large possible area for treatment. The wetland gets flooded during heavy rains, which results in more vegetation and a larger area being involved in the treatment process. One problem with the wetland is that it easily gets overgrown, and during filed visits canalling was observed. Canalling leads to a shorter way from the inlet to the outlet – and the retention time and treatment capacity decreases. During high levels of water the canalling problem will probably not be so large, but during dry season it will. The canalling is probably an effect of the high intensity of large vegetation. One way to prevent the high vegetation is to let animals pasture the area. Some cows were pasturing, but as they were tied to trees they could only eat from a smaller area. With more cows over a larger area, the canalling problem would perhaps decrease.

Improvements
To fully understand the potential treatment capacity of a wetland, qualified field investigations are required. What was measured here was only the XY positions of the wetland and the height Z at some points. For accurate predictions, and for use of modelling programs, more information is needed: the vegetation distribution, river water conductivity, the soil porosity in wetland, the amounts of nutrients in the soil, what type of vegetation, the water volume and retention time etc. If all these parameters had been collected a model of the particle distribution could have been developed. To evaluate a constructed wetland is much easier as the boundaries are clear, the inlet and outlet are much more obvious and the flow and retention time are easier to calculate.

Retention time
The theoretical retention time was calculated based on the wetland volume and the flux. The accuracy of the flux is fairly correct, but the volume of the wetland is a rough estimation. The wetland area is dynamic and changing over time depending on the climate and river flow. The retention time changes from 34 h to 6,3 h with the increased flow from the new WWTP. This is one fifth of the retention time, and it will affect the treatment capacity. This is, as mentioned, not very accurate values, but it is correct to assume a decreased retention time upon larger inflows.

Improvements
To receive a more accurate retention time the real retention time must be analysed. This can be done by tracer tests, but they are preferably performed in constructed wetland where the outlet is defined. The theoretical retention time must therefore be valued as a rough approximation.

Water sampling
The equipment was borrowed from the University of Moratuwa Environmental Division. As the bottles were said to be cleaned this was assumed, but probably the bottles were not really as clean as they could be. This could affect the results, especially if the bottles for the coliform samples were contaminated. The coliform is very sensitive to heat; therefore they must be set in a cold place as soon as possible after collection. This was done in the best way possible with the help of frozen water bottles, but the use of an icebox would be preferred. Even though the refrigeration was not optimal high levels of faecal coliforms were observed. The caps to the 1 l bottles and the coliform bottles were very old and not fully leakproof.

As the WWTP in Raddolugama uses a pump with a higher capacity than needed, they do not pump wastewater at all times. One consequence is that the water coming from the pipe only consists of groundwater at some times. The first attempt to take water from the inlet therefore had to be abandoned because the flow was assumed to be only groundwater. This assumption was made upon earlier investigation of the flow from the WWTP. The next try was done a couple of hours later, when the flow had increased remarkably, which indicated that the pumps were pumping wastewater. The accuracy and representativity of this sample is therefore to be discussed. Likewise, the wastewater composition may change from time to time.

The samples could easily be collected again because their exact location is available with a GPS. The parameters could also be analysed in the same way as within this project because the methods used are standard methods that can be found in common literature.

Improvements
When the samples were taken from the river they were only taken from approximately 3 m from the shoreline. The water could be stagnant and not fully representative. The best would have been to use a boat and take samples from the middle of the river.

All the parameters were only measured during one day. The samples were collected in mid-February, which is the second driest month in the Ja-Ela area (se Figure 5 monthly rainfall in Ja-Ela). The run-off from the catchment area is probably below annual mean value, and the evaporation is high due to the temperature. All these factors will contribute to changes in the concentrations of pollutants. The NWS&DB had in their investigation observed that industries let out untreated wastewater from their industries to save money. This is presumably not a regular habit, and the concentration of pollutants can be expected to be very high in some situations. Therefore more samples on different days should have been taken.

The data do not have a known degree of accuracy and precision, mainly because there are too few of them to allow for a statistical analysis of the accuracy. This reduces the defensible level, and it is difficult to validate the sampling procedures. Once again more samples should have been taken.

It would have been interesting to measure electrical conductivity (dissolved inorganic ions) as high values in a river may indicate salinity intrusion. Fresh waters normally have low values (< 1000) and sea waters have high values. Chloride also indicates salinity or pollution by domestic or industrial wastewaters. The fractions of heavy metals would also be an interesting factor to study, particularly as the Ja-Ela area is strongly affected by industries.

BOD_5, DO, COD, TSS and Color
BOD_5, DO, COD, TSS and color are all below the recommended values, and extra purification treatment is not essential to fulfil the governmental allowed levels (see appendix 3). However this is only adoptable for these specific measured values. The concentrations can change over months, even days, and it is particularly true when only a few samples have been collected. If you apply the concept of environmental quality standard, when you determine the degree of environmental conditions and requirements to avoid negative and damaging effects, influences, and consequences, it can be necessary to maximize the treatment below the allowed values.

As seen in the result section the diluted wastewater will be below the river quality at all parameters. Compared to the values measured inside the wetland, the inlet parameters are almost the same as the outlet. It is hard to see an improvement of the water quality. Probably this is because the water sample from within the wetland is not fully reliable; more samples would have given a much more accurate statistics.

The low oxygen level in Dandugam Oya observed 2009 (4,2 mg/l) was also observed in 2004 (3,6 mg/l), see Figure 35. Low oxygen levels can, as earlier mentioned (see section 5.1 Dissolved Oxygen), cause fish dead. Lunawa lagoon which earlier worked as a wastewater receiver, had an DO level of 1,2 mg/l when tested in 2004, which shows that the potential threat to Negombo Lagoon is severe. Compared to a river in Uppsala, Sävjaån, that has an oxygen level of 10 mg/l [SLU, 2009], Dandugam Oya has a very low level. High levels of organic matter (measured as BOD and COD), phosphorus and nitrogen can all cause lack of oxygen. High level of COD can be recognized as indications of industrial pollution. BOD may be resulting from domestic sewage.

The credibility of the oxygen results can be discussed, because it is rare to have extreme low oxygen levels in surface water (pers. comment Andreas Bryhn). The surface water normally gets oxygen saturation from exchange with air and oxygen production from plant photosynthesis. The oxygen level is probably low in the river, but most likely not as low in the surface water as this study showed.

Coliforms

The level of total coliforms is highly above the recommended level of 40 MPN/100 ml in both the wetland and the river. The coliform do consist of a major part of faecal coliform. The best way to remove coliforms in a treatment plant is with chlorination. Even though the UV and Ozoniation are better techniques, they are much more expensive and are not used in Sri Lanka (pers. comment Dr. Mahesh Jayaweera). The chlorination that is used in Raddolugama WWTP is the Tri Helagonon Methane (THM) and that can accumulate within the human body. Therefore it is not recommended to take drinking water downstream from where THM have been added to the outlet. In this case there is no such problem, as the water supply intake at Raddolugama is located about 4 km upstreams.

If you were to design a constructed wetland to take care of the coliform problem it would have to be very large (pers. comment Dr. Mahesh Jayaweera). Probably much larger than what is realistic. The coliform will be removed through adaptation to the biofilm surfaces on gravel (metal) and submersed plant parts in the wetland. When removing pathogens it is very important that the water is equally distributed throughout the wetland, but this is normally not the case in NW where the water tends to form into channels. A normal CW has several inlet zones to prevent channelling, and the proposed outfall to the wetland would only consist of one outlet. Therefore the wetland will probably not be very good for pathogen treatment as channelling has been observed. Furthermore the soil is too non-porous. A good porosity is around 50% in tropical areas (pers. comment Dr. Mahesh Jayaweera). The literature study showed that solar disinfection can kill bacteria, but that the fraction on the incoming solar radiation that is in the UV range is small. A wetland can reduce the levels of pathogen if the retention time is long enough, greater than about 10 days. Compared to what was calculated in section 6.4 the retention time will probably not be as long as 10 days.

We do observe a decreased level of faecal pathogens, from 80000 to 30000 MPN/100ml between the inlet and the wetland. The reason to why we see this is unknown. The literature (presented in 5.1.5) study showed that there are four major reasons to pathogen decreases, but yet no studies that can say how effective the processes are compared to each other. More studies on the pathogen survival pattern could maybe clear out why we did observe a decrease.

Phosphorus and nitrogen
The tot-P level in Dandugam Oya is below the tolerance limits (see Figure 20) and varies between 0,1-3,4 mg/l (see Figure 35). In Sävjaån, Uppsala, the mean level of tot-P for the same period (1996-2009) is 50µg/l = 0,05 mg/l.

Phosphorus and nitrogen is necessary for production at land and in water. Depending on the availability for organisms, which is not unlimited, one of the nutrients will be the limiting factor. Most researchers agree upon that phosphor is limiting in aquatic ecosystem (lakes, wetlands etc.), and nitrogen in marine environments [Tonderski *et al*, 2002]. Denitrification and sedimentation are two processes that can reduce the amount of nitrogen for a longer period of time in wetlands. However, a retention time shorter than 2 days will cause considerable changes in the nitrogen removal [Wennerberg & Gustafson, 1992]. The retention time must be fairly large because the nitrate molecules and the denitrification bacteria need to have time to interact [Tonderski *et al,* 2002]. Another important factor for the denitrification is the amount of organic matter for bacteria to decompose. The amount of organic matter is highly sufficient and will probably not be the limiting factor. It is also important to analyze the area/volume- quotient, a high quota is favourable because the active bacteria demands both areas and organic material for a proper denitrifiaction and nitrification.

General discussion
To construct a wetland for the last purification step, it might be good to look at which parameters that are most critical to improve. As the Negombo lagoon suffers from eutrophication it might be good to minimize the amount of nutrients. Phosphorus is a common regulatory limiting nutrient, and both P and N should be kept low. The low DO level in Dandugam Oya indicates that the river is in a severe condition. As mentioned earlier the river enters the Negomboo Lagoon, and if the river is bringing water with low oxygen, the lagoon will probably also be affected. The pathogen level can cause severe hazards for humans and the outgoing water from Raddolugama WWTP is far from satisfactory and should therefore be improved.

7 CONCLUSIONS

Wetlands are both valuable and vulnerable. One of the wetlands most important functions in nature is to work as the downstream recipient of water and waste from both natural and human sources [Mitsch & Gosselink, 2007]. East Calcutta Wetlands, a 12.500 ha area outside Calcutta in India, purifies the city's domestic wastewater. The wetland is the largest resource recovery system in the world and has saved the city of Calcutta from constructing and maintaining a wastewater treatment plant [WWF India, 2009].

The functional role of natural wetlands in water quality improvements has offered a compelling argument for wetland preservation, i.e. the Ramsar convention in 1979. Studies have shown that natural wetlands are able to provide high levels of wastewater treatment [Kadlec & Knight, 1996; Kadlec & Wallace, 2009; Mitsch & Gosselink, 2007].

The potential for application of wetland technology in the developing world is enormous. Most of the developing countries have warm tropical and subtropical climates that are conducive for higher biological activity and productivity, hence better performance of wetland systems [Kivaisi, 2001].

The literature study has shown that the potential for applying wetland technology in Sri Lanka is high. Sri Lanka has large wetland areas that could function for purification of treated wastewater. The studied WWTP in Ja-Ela, wetland and river Dandugam Oya could together function in harmony. The wetland's potential for wastewater treatment is not completely understood; too few samples were collected from within the wetland and the river to be able to predict the treatment capacity. With the new WWTP the flow into the wetland will increase, which in turn will affect the retention time. A shorter retention time will decrease the treatment capacity [Kadlec & Wallace, 2009].

The study shows that the levels of organic matter, nutrients, pathogens and suspended solids in Dandugam Oya are high. This was also observed in the earlier studies 1996 and 2004. The oxygen level is very low (see discussion for credibility in this measurement), high levels of organic matter (measured as BOD and COD), phosphorus and nitrogen can all cause lack of oxygen. This could be arising from industries and uncontrolled domestic sewage. Therefore the author recommends studies to investigate the leakage of industrial waste from industries in the area. It would also be interesting to study the possibility to use Muthurajawela marsh for purification of wastewater.

Wetlands are rare, important and unique, we need to use them wisely and protect them carefully.

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10 APPENDIX

Appendix 1

Table 4: Exact location, time and position of samples. See Figure 15 for a map over the points.

Sample	Date and time	Location	Position
W1	2009-02-11 p.m. 15.10	Discharging pipe at wetland	N7 08.517 E79 53.625
W2	2009-02-11 a.m. 11.15	From within wetland, approx 15 m from the river	N7 08.442 E79 53.558
S3	2009-02-11 a.m. 10.50	1,5 m from shoreline, approx 20 cm deep	N7 08.323 E79 53.602
S4	2009-02-11 a.m. 10.30	Middle of river, approx 30 cm deep	N7 07.981 E79 53.422
S5	2009-02-11 a.m. 10.10	2 m from shoreline, approx. 20 cm deep	N7 07.527 E79 53.565
S6	2009-02-11 a.m. 11.45	Under the bride, approx 3 meter out, 20 cm deep	N7 09.748 E79 53.681
S7	2009-02-11 p.m. 14.25	3 meter out, 20 cm deep	N7 06.609 E79 52.253

Appendix 2

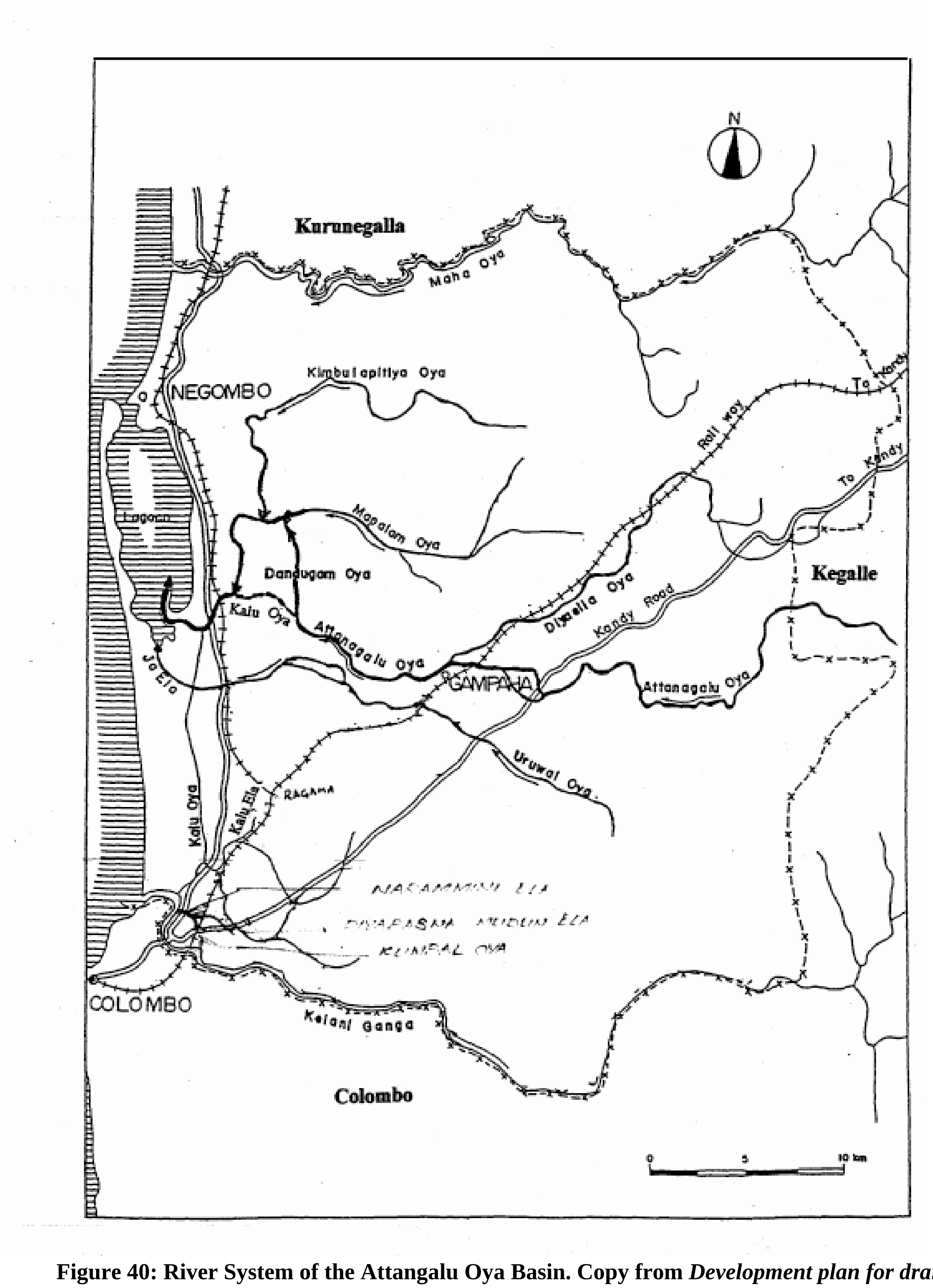

Figure 40: River System of the Attangalu Oya Basin. Copy from *Development plan for drainage work and Attanagalu Oya irrigation scheme in Gampaha district*, Irrigation Department, (2002).

Appendix 3

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Table 5: Tolerance limits for the discharge of industrial waste in to inland surface waters, selection by author.

No.	Parameter	Unit, type of limit	Tolerance Limit values
1	Total suspended solids	mg/l, max	50
2	Particle size of the total suspended solids	µm, less than	850
3	pH at ambient temperature		6.0-8.5
4	BOD	mg/l	30
9	Color	Wavelength Range	Maximum spectral absorption coefficient
		436 nm	7m-1
		525 nm	5m-1
		620 nm	3m-1
10	Dissolved phosphates (as P)	mg/l, max	5
11	Total Kjeldahl nitrogen (as N)	mg/l, max	150
12	Ammonical nitrogen (as N)	mg/l, max	50
28	Pesticides	mg/l, max	0.005
30	Faecal Coliform	MPN/100 ml, max	40