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Assessment and Suggestions for Improvements to the treatment Process for the Raddolugama water treatment Plant

M.Eng in Environmental Engineering and Management

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"The performance of each unit in water treatment process will only be as good as the Designer the builder and especially the Operator allow it be"

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Dr Paramasivam
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Statement:

"This thesis is submitted to the Department of Civil Engineering of the University of Moratuwa, Sri Lanka, as a partial fulfillment of the requirement for Master of Engineering in Environment Engineering and Management."

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Declaration:

This thesis has been not been previously presented in whole or part to any University or Institute for a higher degree.

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Date S.G.J.Rajkumar

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I wish to express gratitude to my beloved wife Subashini and Children Vaishaavi, Bahiravi & Gangesh for the encouragement and moral support provided during the study.

ABSTRACT

Raddolugama Housing Scheme was constructed in 1982, closer to the Seeduwa town in the Gampaha district. The scheme is provided with pipe borne water supply and sewer system.

Raw water for pipe borne water supply is abstracted from Dandugam-Oya and treated by a conventional treatment process to satisfy Sri Lanka standards for potable water. But there have been instances of Colour in treated water being higher than the value stated in the standards, which is attributed to raw water quality.

Quality of raw water abstracted from the stream varies with the weather. During the rainy period raw water has high turbidity and low Colour, whereas dearth of rain for prolonged period changes the raw water quality to low turbidity and high Colour. The contributory factors for such changes are excessive erosion in the upstream during rain, whereas dearth of rain for prolonged period results in increase in evaporation, lower flow in the river, excess abstraction of water for water supply and irrigation and accumulation of organic and inorganic compounds on the river bed.

Objective of this study is to identify the reason for Colour (yellowish brown) in the treated water and suggest mitigatory measures to improve treatment process and assess the cost of production of water.

A detailed study was undertaken on variation of raw water quality, hydraulic design of the plant and chemical dosing arrangements. Improvement in treated water quality was achieved by relocating the point of dosing of chemicals and enhancing coagulation. As a result Colour and Turbidity of treated water was reduced by 49.5% and 47.9% respectively

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LIST OF ABBREVIATION

AAS - Atomic Absorption Spectrophotometer

AWWA - American Water Works Association

BOD - Biological Oxygen Demand

COD - Chemical Oxygen Demand

DI - Ductile Iron

DO - Dissolved Oxygen

EC - European Commission

EPA - Environmental Protection Agency

MGD - Million Gallons per Day

NTU - Nephelometric Turbidity Unit

NOM - Natural Organic Matter

NWSDB - National Water Supply and Drainage Board

PAC - Power Activated Carbon

PPM - Parts Per Million

Redox - Reduction – oxidation

SI - Saturation Index

THM - Tri-Halo Methane

UV - Ultra Violet rays

WHO - World Health Organization

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1. INTRODUCTION

1.1 GENERAL DESCRIPTION

National Water Supply and Drainage Board (NWSDB) is the lead agency for the supply of safe potable water in Sri Lanka, by operating and maintaining 269 pipe borne water supply schemes in the urban and peri- urban areas and 17000 tube wells operated with hand pump in the rural areas. Present coverage is around 5 million people, which accounts for 30% of the countries population. Other stakeholders such as local authority, Estate management, Water Resources Board, Mahaweli Authority, community and privately owned and Non Governmental Organisations are also involved in provision of potable water. In addition there are over one million dug wells in use. Many of these perennial wells were constructed by individuals or with the support of local community. The quality and quantity of water abstracted from each source varies through out the year.

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Raddolugama Water Supply scheme is one of the schemes maintained by NWSDB. This scheme is located 20km North West of Colombo at close proximity to Seeduwa Town. The scheme was commissioned in 1982 with a maximum treatment capacity of $4500m^3$/day (1MGD) to provide safe drinking water to the residents of Raddolugama housing scheme. Raw water is abstracted from Dandugam-Oya. An intake well is constructed along the left bank of Dandugam-Oya and raw water is pumped 3.5km along a 300mm diameter Ductile Iron pipe to the treatment plant located at Raddolugama.

Quality of raw water is improved by treating to satisfy Sri Lanka Standard for potable water by a conventional treatment process. Present operation and maintenance cost is Rs 9/- for a cubic metre of water produced. The break down of costs is shown in fig 1.1

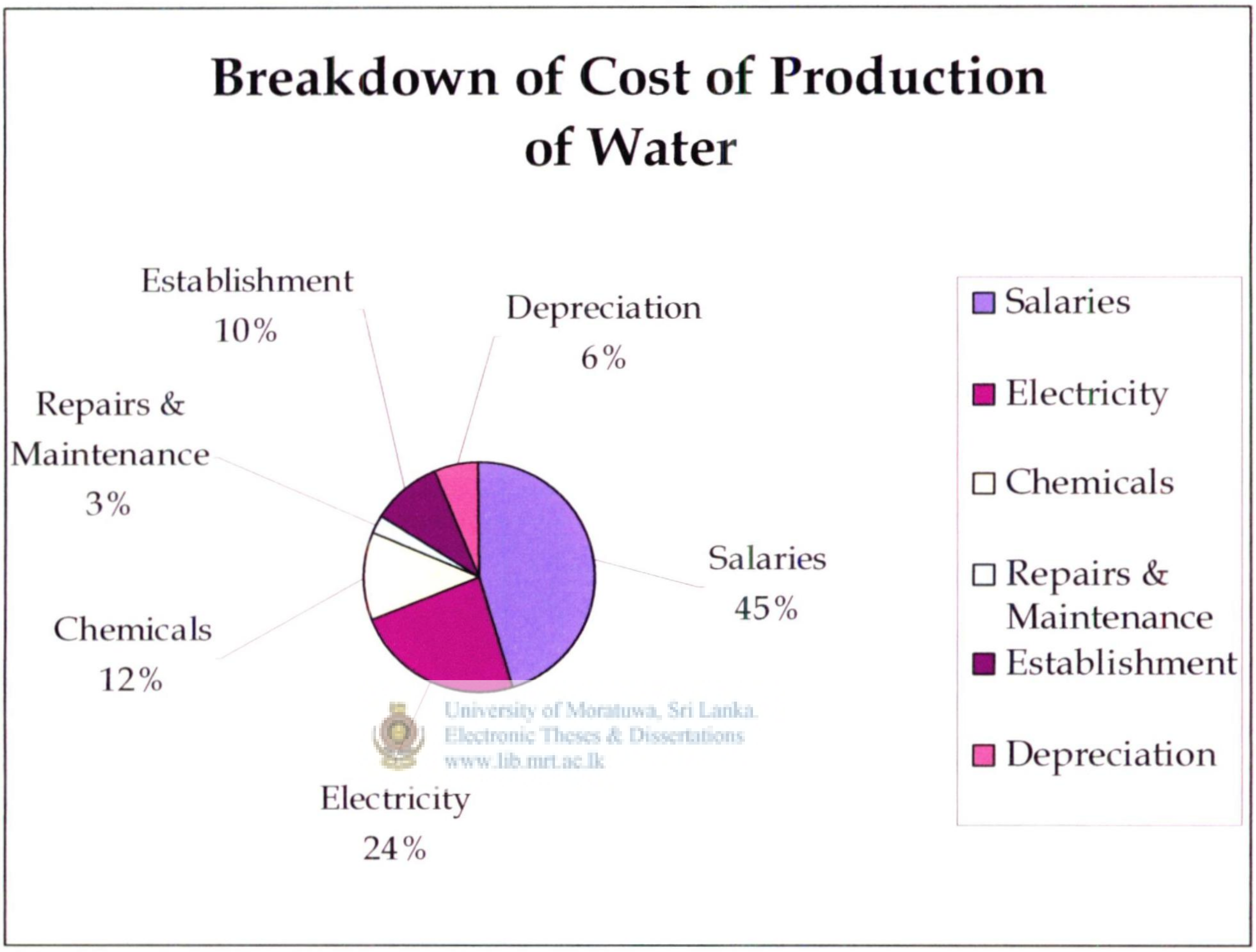

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Fig 1.1 Breakdown cost for production of treated water

NWSDB is a semi government organisation with the monopoly in providing safe drinking water to many major towns in Sri Lanka. The water tariff is determined by the treasury with the concurrence of NWSDB. Tariff is imposed according to the category such as domestic, commercial, Industrial, Institution etc. Due to the absence of scheme specific tariffs, not all water supply schemes are financially viable. Some of them are profitable while some others are able to recover only cost such as operation and maintenance and recurrent expenditure, while many small schemes operate at a loss.

Presently cross subsidy from profit making schemes to non-profit making schemes enable NWSDB to operate at break-even. In the recent past steps have been taken to reduce the cost of operation by out sourcing some activities such as water meter reading, provision of new service connection, attending leaks, laying of new pipe extension and construction activities. This has enabled to reduce the cadre to 8 person per 1000 connection where as the bench mark is 5 person per 1000 connection.

1.2 WATER SECTOR ORGANIZATIONS

Currently there are number of organizations involved in the provision of potable water in Sri Lanka. They are namely, National level organizations, Local Government Organisations, Other National agencies, Private sector and non- governmental organizations. Presently there are 152 Urban and 690 rural water supply schemes operating in Sri Lanka.

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National Water Supply and Drainage Board (NWSDB) is the leading national organization for supply of potable water in Sri Lanka, which operates 269 pipe borne water supply schemes of which 145 are urban water supply schemes and 124 rural water supply schemes. Other than this, there are 17,000 hand pump operated tube wells maintained across the Island. It is mandatory that each tube well installed has a water consumer society, with one of its member being trained in the operation and maintenance of the hand pump. The community is empowered to maintain the hand pump and iron removal plant installed in some places where iron content in raw water is high.

There are other organizations such as the Local authorities (Municipal Councils, Urban Councils etc.), Water Resource Board, Mahaweli Authority, Plantation Trust, Agrarian Services, Private Sector Organisations and Non Governmental Organistions involved in provision of potable water . But their coverage is limited to certain areas. Presently Municipal Council operates two water supply schemes, the Urban Council operates five water Supply Schemes, balance 566 rural water schemes are operated by the Pradeshiya Sabhas (local authorities lower than the Urban Councils or similar to the Village Councils) and the Community based organizations. It is estimated that around 5000 hand pump tube wells constructed by Water Resources Board are operated by Pradeshiya Sabhas.

There have been instances some state organistions find it difficult to operate and maintain financially unviable water supply schemes as such they are pursuing to hand over those schemes to the NWSDB to operate and maintain.

1.3 RAW WATER SOURCE - DANDUGAM-OYA

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Dandugam-Oya originates from Attanagalu Oya and flows into the Negambo lagoon. Water level in Dandugam-Oya varies significantly through out the year. Level is high during the rainy season and low during dearth of rain. Variation of water level correspondingly changes the quality of water. During rainy period water has high turbidity and reasonable colour and alkalinity. Where as dearth of rain for long period colour is high, turbidity and alkalinity is low. Water level being low enables flow of saline water from down stream towards the intake. As a mitigatory measure an anicut is constructed one km down stream from the intake as in fig. 1.4 to prevent saline water intrusion during high tide from the Negambo lagoon. This anicut is operated during the months of February to March and August to September which are the driest period of the year.

Upstream of the intake about 4km distance at Bolanda another anicut is constructed as in fig 1.4 to regulate flow along Dandugam-Oya and divert water for irrigation.

Effluent from the Raddolugama housing scheme waste water treatment plant is discharged 1.5km down stream from the intake to prevent contamination of raw water. Where as there are number of industries on the upstream which have their own waste water treatment plants and at times discharge effluent exceeding the standards established by Central Environment Authority for discharge into inland water ways. Effluent from industries such as tannary and textile dying mills were polluting the stream intermittently. Most instance Chemical Oxygen Demand (COD) of Dandugam - Oya water is less than 10 mg/l. However if the effluent discharged from the factories exceeds the standards, COD of raw water in Dandugam- Oya could be as high as 20 to 25 mg/l.

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1.4 RAW WATER INTAKE

Raw Water under gravity flows along 300mm diameter Ductile Iron (DI) pipes into a circular wet well of 4m diameter constructed on the left bank of Dandugam-Oya as shown in fig. 1.2. These Ductile Iron pipes are placed at different levels as shown in the fig.1.3 to facilitate abstraction of water at high and low water level in the stream. Screens are provided at the inlet to remove debris and floating matter. The retention time at the intake well is 19 seconds, which enables solids such as grit and large organic matter to settle at the bottom of the well. A sludge pump is used to remove sludge settled at the bottom of the well. Centrifugal pumps located adjacent to the intake, pump raw water to the treatment plant along a 300mm diameter ductile iron pipe of length 3.5km

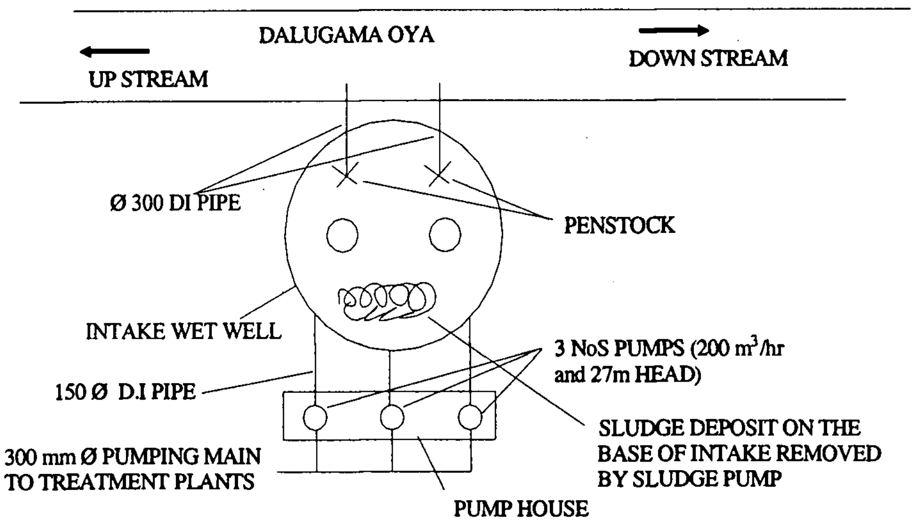

Fig. 1.2 Details of Raw water Intake

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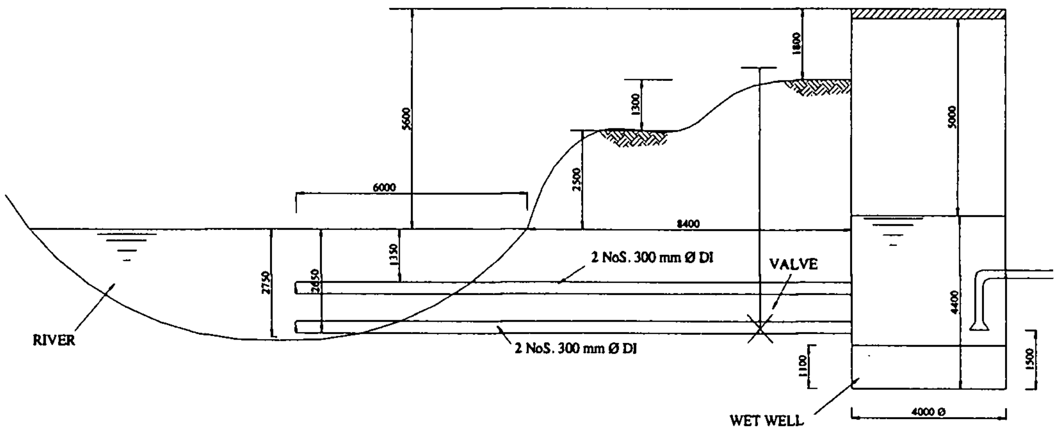

Fig. 1.3 Sectional Elevation of intake

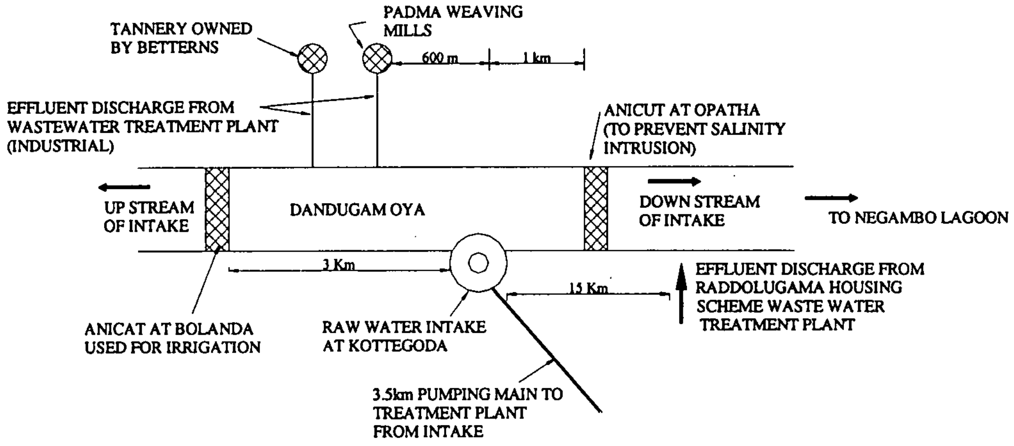

Fig. 1.4 Plan View of Intake on Dandugam-Oya

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1.5 GENERAL DESCRIPTION OF WATER TREATMENT PLANT

Raw water abstracted from a surface or underground needs treatment to ensure water is safe for human consumption. Quality of treated water is checked for physical and chemical parameters in accordance with WHO guidelines or Sri Lanka standard for potable water. However the treated water quality depends on many factors such as raw water quality, unit process applied in treatment, application of chemicals for coagulation and flocculation, type of disinfection, retention time allocated for each unit process and avoidance of short circuiting within the treatment process.

Traditionally self-purification was widely encouraged in Europe. Even now many treatment plants located along river Rhine practice the same. Some plants at the end of treatment, pump treated water into the ground and thereafter is abstracted from borehole wells within a controlled area and pumped into the distribution system. Some schemes disinfect abstracted water from borehole with Ultra Violet rays (UV) before distributing the water to the consumer.

However with the increase of population, self- purification methods (mainly underground) is not possible at all locations and improved methods such as, micro straining, ozonation, UV treatment and membrane filtration are being considered.

The treatment process could be advanced and complicated if the raw water consists of impurities and elements, which are undesirable and toxic substance such as pesticides, herbicides, heavy metals and complex organic matter.

Treatment cost covers major portion of the cost of production of water which includes cost of chemicals, electricity, operation and maintenance, replacement and refurbishment and disposal of sludge.

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Treatment plant may operate at less than its capacity which would require in-depth analysis or study on each unit operation of the plant. The reasons for plant not operating at the design capacity could be due to electro mechanical failure, design faults, constrains in free flow of water from one unit to the other and mal-functioning within the units.

Most surface water unlike ground water has high turbidity. Reduction of turbidity is achieved with coagulation, flocculation, sedimentation and filtration. The function of coagulation and flocculation process is to combine finely divided particles and colloidal matter to form settleble floc, which

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could remove considerable amount of impurities in the sedimentation tank such that the water flowing into the filter will have turbidity around 20 to 30 NTU for optimal performance of the filter.

Dissolved Oxygen (DO) content in surface water at 30°C is around 7mg/l and reduces along with the depth of water. As such aeration is not necessary. But if raw water is abstracted from a impounded reservoir or non-flowing river, aeration may be required as water is in anoxic state during prolong drought. However aeration of surface water reduces the pH and makes the water aggressive which has undesirable effect on the structures, pipes and fittings.

Designed capacity of Raddolugama water treatment plant is 1MGD (4500m^3). Present production rate varies from 3600 to 4300m^3/ day, with an average of 4000 m^3/ day. Presently treated potable water from the plant is supplied to Army hospital (75m^3), Board of Investment (BOI) approved industry (945 m^3), people living in Raddolugama housing scheme and adjacent areas (2500m^3). As such non revenue water is 13%. Distribution of treated water is shown in fig 1.5.

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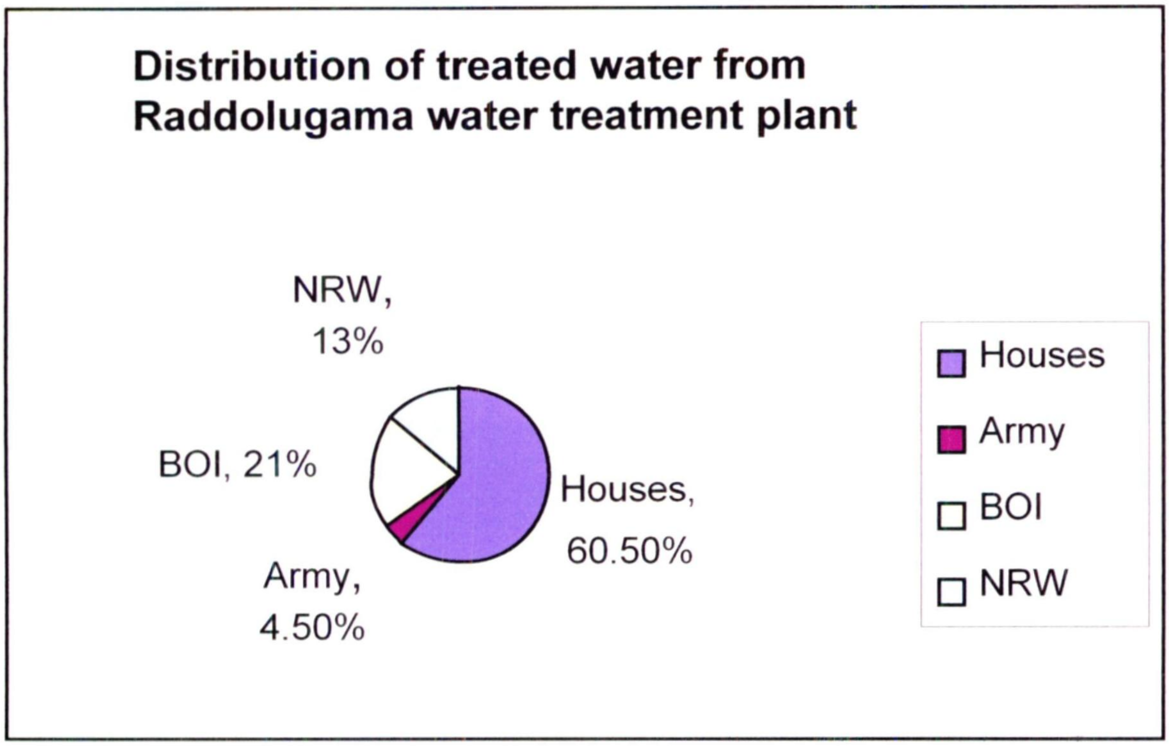

Fig. 1.5 Distribution of Treated Water

The treatment plant consists of a step aerator, rapid mixing chamber, pulsator, two rapid sand filters and clear water tank. The treatment process has the following functions:

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- Aeration
- Coagulation
- Clarification
- Filtration
- Chlorination

Raw water from the intake flows over a step aerator (length 4.9m, width 0.9m, fall height 3m) comprising of 5steps in series, which cascades into a chamber and over flows a weir where Chemicals such as alum and lime are added. Coagulated water is allowed to flow into a pulsator. The operation of the pulsator is set to a frequency of 7 sec for suction and 2 sec for drop.

Coagulated and flocculated water flows across the sludge blanket within the pulsator which removes the colloidal and dissolved particles before flowing into the rapid sand filter. The rapid sand filter is operated at constant head and backwashed as the flow rate is reduced considerably.

Filtered water from the rapid sand filter flows into a clear water tank consisting of baffles enabling plug flow. Chlorine is added at the inlet of the clear water tank such that adequate contact time is available for disinfection. Chlorinated water is pumped to a water tower and distributed to the users. The flow chart and flow diagram of the treatment process is given in fig 1.6 and fig 1.7 respectively.

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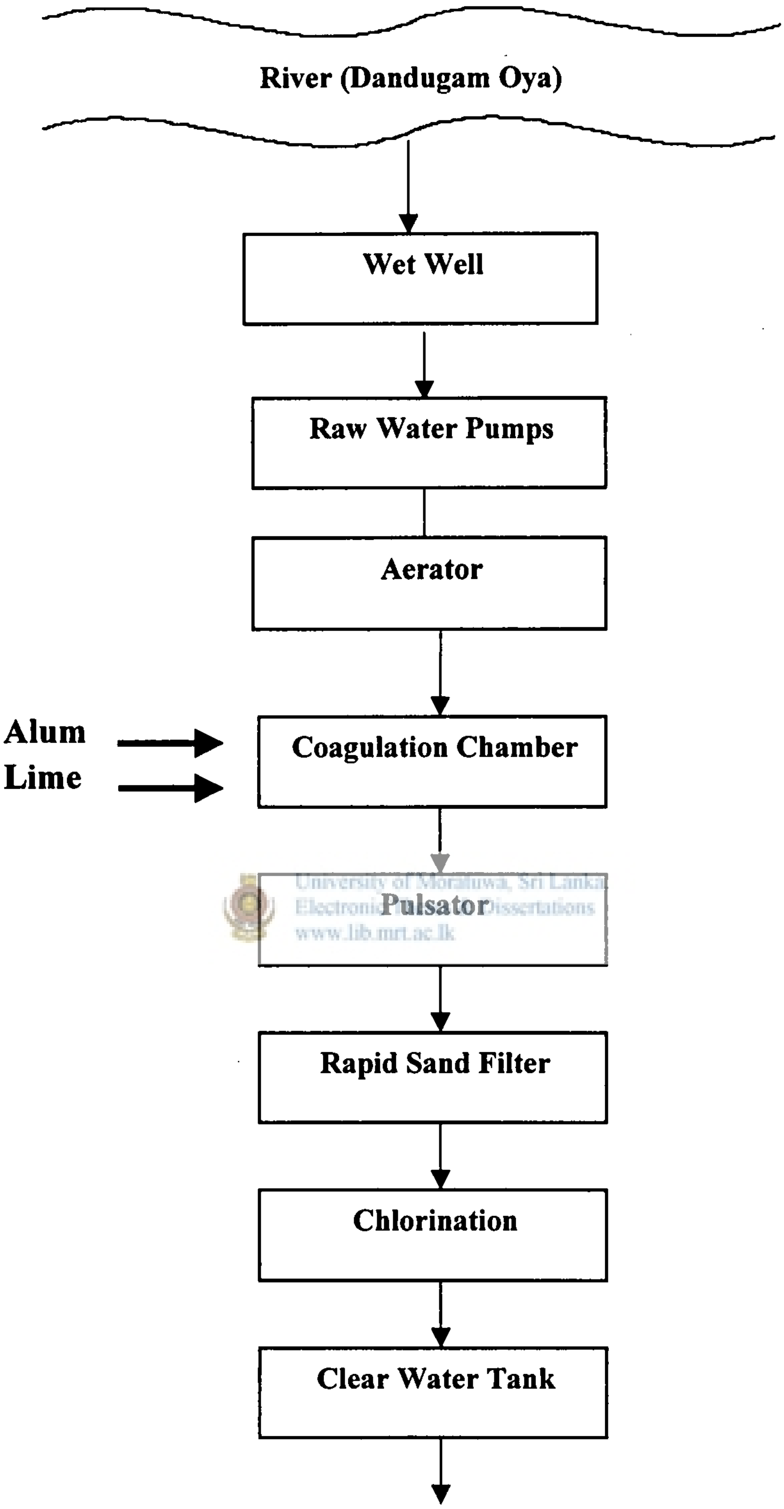

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Fig 1.6 Flow Chart of Raddolugama Water Treatment Process

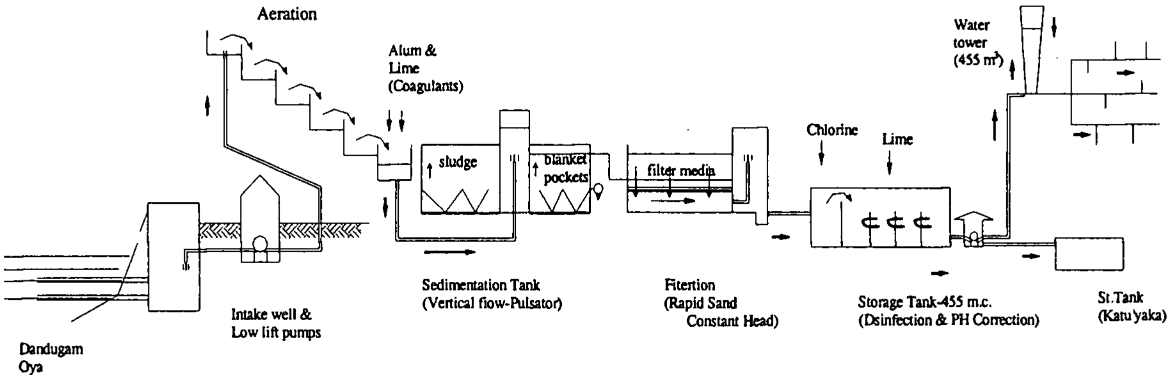

Fig 1.7 Flow Diagram of Water Treatment Plant at Raddolugama

Efficiency of the plant performance is improved by optimisation of treatment process, which involves complete understanding of the function of each unit process. Performance of treatment could be enhanced by effective use of chemicals. But the amount of chemicals added depends on the raw water quality, the point of application, mixing ability, variation in pH, alkalinity, variation in the other physical and chemical parameters and the sequential arrangement of each unit process. As far as the treatment plant at Raddolugama is concerned the following areas need to be studied in detail.

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- Whether each unit process is functioning well.
- Whether the selection of the treatment units in the process is justifiable.
- Whether the plant is operating within the design parameters.
- What are the deficiencies in the operation of each process units?

1.6 OPTIMISATION IN TREATMENT PROCESS

1.6.1 DETERMINING DESIGN PARAMETERS AND OPTIMISATION

Very few treatment plants in developing countries operate according to the design, due to:

- Designer having no information of the variations in raw water quality for long period of time.
- The method of determining design parameters from bench scale laboratory testing of raw water not being well understood.
- Cost of obtaining basic information being prohibitive.
- Characteristics of raw water being changed in response to changing weather condition and intent properties, such as the level at which water being abstracted.

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In the absence of specific information, the designer tends to copy existing plants. But if the operator understands the background, he may be able to improve the plant performance.

1.6.1.1. Basic requirement for optimisation

Optimising the performance of existing water treatment plants must be handled by the plant operators, since the design and construction have been completed. The problems that may occur, have been built into the plant and cannot be easily corrected. As such the plant performance is in the hands of those who operate it, from manager to the operator and general worker in the plant itself. It is necessary to train the operators to carryout the work diligently. The training should include

- Fundamentals of water treatment plant operation.
- Operation of the specific plant.
- Understanding of the raw water characteristics and the quality standards to be met for the treated water.

1.6.1.2 Assessing the plant and identifying the defects

The best way to observe the plant operation is to follow the same route the water treatment takes place, starting from raw water intake and follow the treatment process upto the treated water reservoir.

Initially observe the operation of each unit and notice the obvious problems and identify possible solution. Carry-out routine sampling to assess the performance of each unit.

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The problems with the plant could be due to the design and several other reasons such as;

- The selected process is not suitable for raw water to be treated. Since, correct information on raw water characteristics not being available at the time of design.
- Designs not suited to the level of operation and maintenance of the plant.
- Flow rates, surface loading, retention time and velocity of water at each unit process being not within the allowable range.
- Addition of chemicals not done at the appropriate location
- Routine Maintenance not undertaken properly.

1.7 EXISTING PROBLEMS IN THE TREATMENT PROCESS

Dearth of rain for prolong period, results in lowering of water level and flow in Dandugam-Oya. The water is murky (yellowish brown) in Colour as shown in the figure 1.8

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Fig 1.8 View of Dandugam-oya at Intake (Original in Colour)

During this period the Colour of water is higher than Turbidity and alkalinity is low (<50 mg/l). There have been instances the Biochemical Oxygen Demand (BOD) of raw water increase up to 10 mg/l and dead fish is found floating in the intake well as shown in the figure 1.9 and treated water exhibit light yellowish colour as shown in fig 1.10 which is above the limit for colour stipulated in the treated water quality standards.

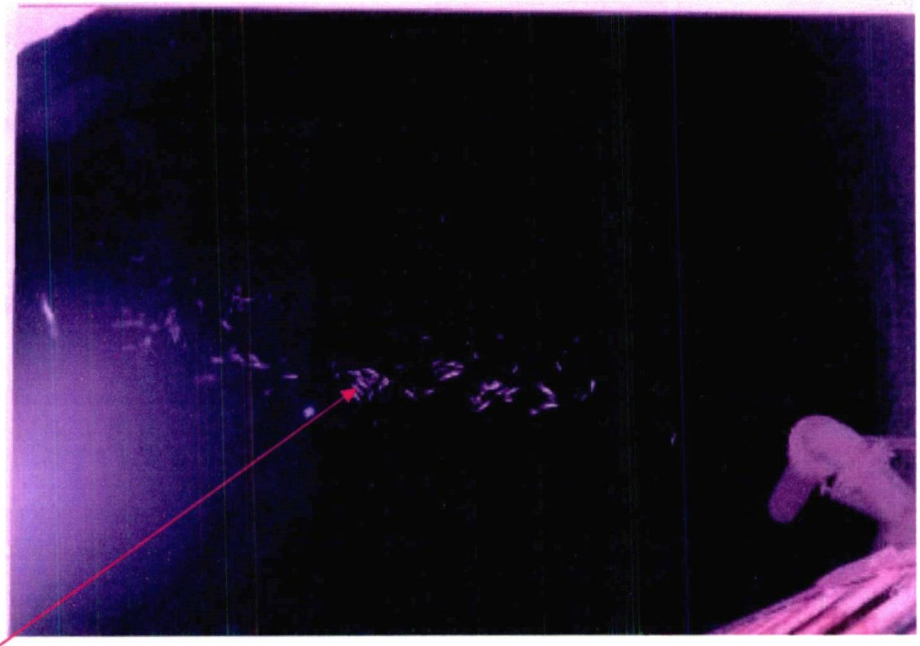

Fig 1.9 Dead fish floating in the intake well (Original in Colour)

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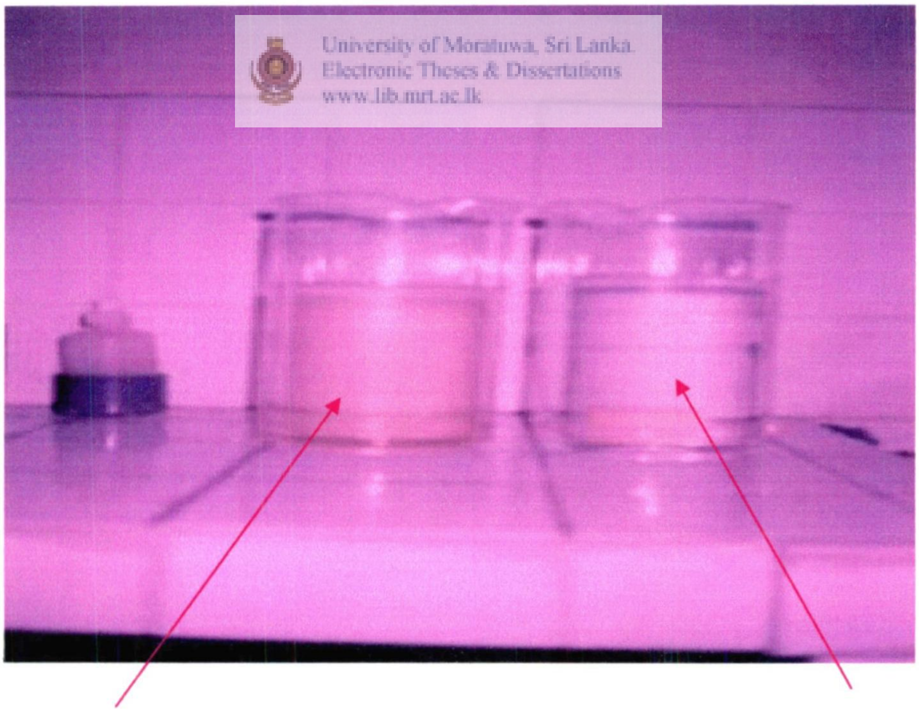

Fig 1.10 Comparison of colour in treated water (Original in Colour)

1.8 OBJECTIVE OF THE STUDY

Objective of this study is to identify the reason for colour (yellowish brown) in the treated water and suggest mitigatory measures to improve treatment process and assess the cost of production of water.

1.9 COMPOSITION OF THE REPORT

The report consists of six chapters and attachments.

Chapter 1 : Gives introduction and details of the sector in Sri Lanka

Chapter 2 : Review of literature related to reason for increase in colour in raw water, method of removal of colour and water chemistry.

Chapter 3 : Describes the methodology in solving the colour problem in treated water by identifying the short coming in each unit process of the treatment plant at Raddolugama.

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Chapter 4 : Observation on the data collected, treatment plant design, operation and expenditure incurred in producing treated water.

Chapter 5 : Discussion of results

Chapter 6 : Conclusions and Recommendations.

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2.0 LITERATURE REVIEW

2.1 COLOUR IN WATER AND REMOVAL

2.1.1 Colour in Water

Natural waters are yellow and brown in colour due to the presence of Natural Organic Matter (NOM) or humic substance which originates from vegetation due to decaying of leaves of trees and plants, soil (peat), domestic waste water and industrial waste water which can form complex organic compounds.

Organic compounds producing colour are derived from soil humus, which are produced by decay of vegetation called humic substance as in fig. 2.1. This humic substance in natural water can be distinguished as humic acid, fulvic acid and hymatomelanic acid of which according to Schippers (1990) studies from various water has shown 90% is fulvic acid and balance is humic and hymatomelanic acid.

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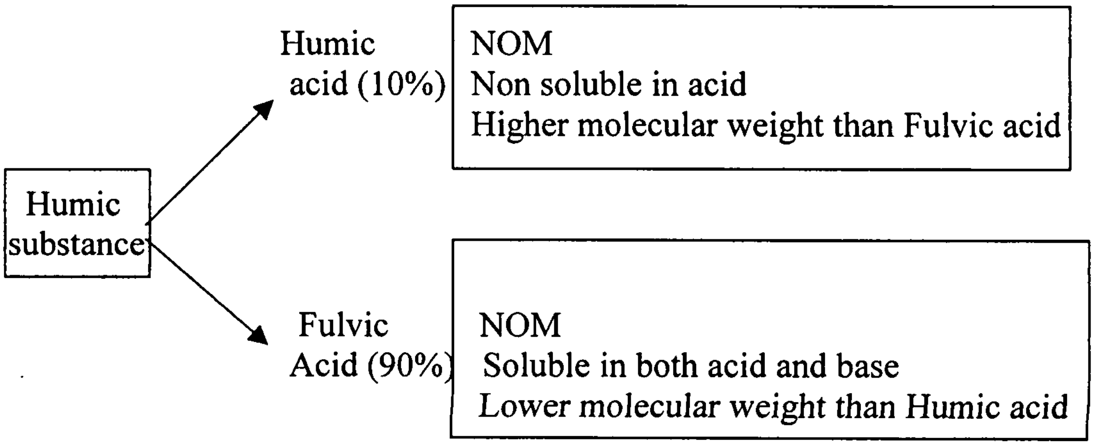

Fig. 2.1 Decaying of humic substance
(Schippers 1990)

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Colour in water can be classified as “true” and “apparent”. True colour in water is due to dissolved substances ($<0.001\ \mu m$) such as Humic substances. Apparent colour is due to colloidal ($0.001\mu m < C < 1\mu m$) substance such as Clay, Ferric hydroxide $[Fe(OH)_3]$ brown in colour and Manganese dioxide (MnO_2) black in colour and suspended matter ($>1\ \mu m$) due to the presence of micro organisms such as Algae.

Natural organic matter (NOM) comprises largely of humic and fulvic acids. Humic acid is soluble in strong base, but not soluble in strong acid where as fulvic acid is soluble in both acids and base. Humic acid molecular weight ranges from several hundred to few thousands which agglomerate into colloidal particles with much higher molecular weight which is composed of aromatic compounds with carboxyl, phenolic and quineid groups which have high cation exchange capacity, and can concentrate or bind on metal ion. Fulvic acids are similar to in structure of humic acid, but lower in molecular weight.

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Humic substance has chemical nature such that hydroxide, carboxyl, methoxyl and quionid groups which are hydrophilic and negatively charged. According to Sanks (1980) the magnitude of the negative charge depends on degree of ionization, which is depends on the pH of the water

2.1.2 Removal of colour

Colour is a measure of dissolved matter. Where as turbidity is a measure of suspended matter. Mechanism involved in removal of colour is entirely different from removal of turbidity. According to Sanks (1980) removal of clay turbidity is best within the pH range of 5 to 7.5 whereas removal of colour is best within the pH range from 4 to 6. As such the dosage of

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coagulant is depended on the initial concentration of colour. At optimum pH, residual colour decreases proportionally with increase in coagulant dose, this may increase concentration of turbidity. Mechanism of colour removal can be regarded as chemical precipitation than coagulation. This is due to the difference between particle causing turbidity and those responsible for colour.

Turbidity is due to hydrophobic compound like clay which has electrical charge as a result adsorption of foreign ions onto the surface. Whereas hydrophilic colour particles are due to ionogenic chemical group which have compounds such as carboxyl, hydroxyl, methoxyl and quionoid groups.

According to AWWA (1971) and Shanks (1980) colour produced by humic substance from organic compounds in potable water can be reduced either by

(a) Chemical Oxidation using Oxidation agents such as Chlorine (Cl_2), Ozone (O_3), Potassium Permanganate ($KMnO_4$) and Chlorine dioxide (ClO_2) where Oxidation agents Oxidises parts of the molecules of the humic substances which contribute colour.

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(b) Coagulation with Alum (Al^{3+}) or Ferric (Fe^{3+}) salts which produces insoluble compounds.
(c) Adsorption with Activated Carbon (which is an expensive process.)
(d) Air stripping
(e) Ion exchange
(f) Reverse osmosis (R.O)

According to Shanks (1980) free chlorine added to humic substance produces Trihalomethene (THM) which is carcinogenic. As a mitigatory measure Environmental Protection Agency (EPA) has set a standard for THM as 80 μg/l.

Bacterial degradation of organic matter produces humic substance as such removal of colour from humic substance by bacterial oxidation in the Schmutzdeche of the slow sand filter is not possible. Further the pore size of bacteria which forms the Schmutzdecke and sand in the slow sand filter is bigger than the size of dissolved substance produced from true colour.

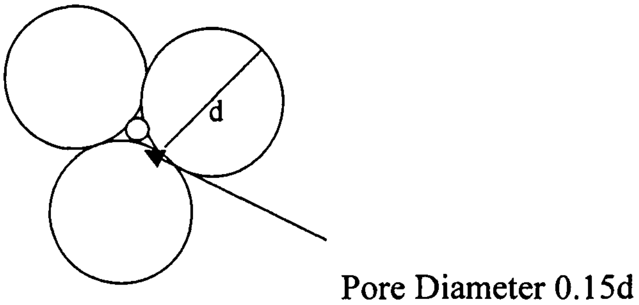

Fig 2.2 Relationship of Particle size

Mathematically it is proved the pore diameter of spherical grains of diameter d is 0.15d as shown in 2.2. The average diameter of sand in slow sand filter is 0.3mm. As such pore size of slow sand filter is 0.045 mm (45µm). Similarly size of bacteria is 1µm and the pore size within the bacteria is 0.15 µm. whereas humic substance comprises of dissolved particles which is less than 0.001µm. As such humic substance producing colour cannot be removed by slow sand filter as the particle size of humic substance (0.001µm) is less than the pore size of sand (45µm) and the layer formed by bacteria (0.15µm) in slow sand filter.

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Colour in water can be removed by coagulation with Alum or Ferric Salt. Alum is most effective in the pH range of 5 to 6. Where as ferric sulfate is most effective in the pH range 4 to 5. Coagulation followed by flocculation and sedimentation has the ability to remove flocs formed from colour.

Humic substance reacts with positively charged monomeric and polymeric aluminium hydrolysis products to form colloidal precipitates which agglomerate into large flocs by addition of alum that act as destabilising agents. The stoichiometry involves precipitation and adsorption due to coagulation. The alum dose will depend on the concentration of colour in raw water.

2.2 ADSORPTION BY ACTIVATED CARBON

Activated carbon is produced from carbonaceous materials such as coal, nut shell, wood, lignite, peat, coconut shell, petroleum coke which are subjected to selective oxidation either thermally or chemically to produce highly porous structure which have a surface area exceeding 2000m^2/g according to Sanks (1980). High porosity and large surface area gives activated carbon unique adsorptive properties. Commercially granular and powdered activated carbons are produced. They are widely used to remove taste, odour and colour from water which originates from organic substance by adsorption mechanism.

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2.2.1 Powdered activated carbon (PAC)

Powdered activated carbon (PAC) is a black powder which is finely ground and insoluble. It is applied to water either through dry feed machine or as carbon slurry. PAC is applied in water treatment before filtration. Point of application would depend on many factors such as

- Adequate contact time (5 to 15 minutes)
- Adequate mixing in large volume of water
- Impurities amenable to adsorption.

However according to Sank (1980) advantages of removal of taste, odour and colour producing compounds by adsorption before chlorination has to be considered before application of PAC. Generally application PAC to flocculation or sedimentation basin is not effective unless the colour and turbidity are high. Addition of PAC on the top of the filter is not encouraged as the contact time is limited. Many treatment plants in USA use activated carbon with average dosage varying from 2.8 mg/l to 5.1 mg/l to lower dosage of 0.5mg/l.

2.3 REMOVAL OF TURBIDITY BY COAGULATION

Turbidity is a measure of suspended matter in water which could be clay, silt, and non living organic particulate matter or plantation such as Natural organic matter (NOM) or Micro-organism. NOM consists mostly Humic substance in the nature.

Turbidity and alkalinity can be defined as high or low according to the values given in Table 2.1. As such turbidity and alkalinity can have four combinations as listed below:

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Table 2.1 Defining low or high Turbidity and alkalinity

Turbidity	Alkalinity, as CaCo3
Low - <10 TU (Less than)	Low <50 mg/l (Less than)
High - >100 TU (More than)	High >250 mg/l (greater than)

(a) High Turbidity and High Alkalinity
(b) High Turbidity and Low Alkalinity
(c) Low Turbidity and High Alkalinity
(d) Low Turbidity and Low Alkalinity

2.3.1 Raw water with High Turbidity and High Alkalinity

Water with this combination is easy to treat, as coagulation is effective. Cationic polymer, Alum or Ferric salts provides good destabilization resulting in large concentration of particles which permits easy flocculation and agglomeration. Effective pH for Alum and Ferric salts for coagulation and flocculation are 6 to 7 and 5 to 7 respectively. pH is controlled by addition of a base such as lime.

2.3.2 High Turbidity and low alkalinity

Low alkalinity results in low buffering capacity. This results change in pH with addition of Alum or Ferric salts and base have to be added to prevent lowering of pH.

2.3.3 Low Turbidity and High alkalinity

Addition of bentonite clay will increase turbidity which will enable coagulants such as Alum and Ferric salts to be effective. Otherwise large doses of coagulant needs to be added, resulting in precipitation of large quantity of $Al(OH)_3(s)$ or $Fe(OH)_3(s)$ which is gelatinous. Even coagulant aid such as stable clay or activated silica may be added to reduce the dosage of coagulant and to produce a more settlable and dewater-able floc.

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2.3.4 Low Turbidity and Low alkalinity

This combination water is difficult to coagulate. At low turbidity polymers do not work. Clay may be added to increase turbidity. Addition of coagulants such as Alum or Iron salt is ineffective, due to lowering of pH than the required range for coagulant to be effective to form precipitates of Al

$(OH)_3(s)$ and $Fe(OH)_3$ from sweep flocculation. Low turbidity contributes to low rate of flocculation resulting in low rate of agglomeration.

2.3.5 Raw water with high turbidity

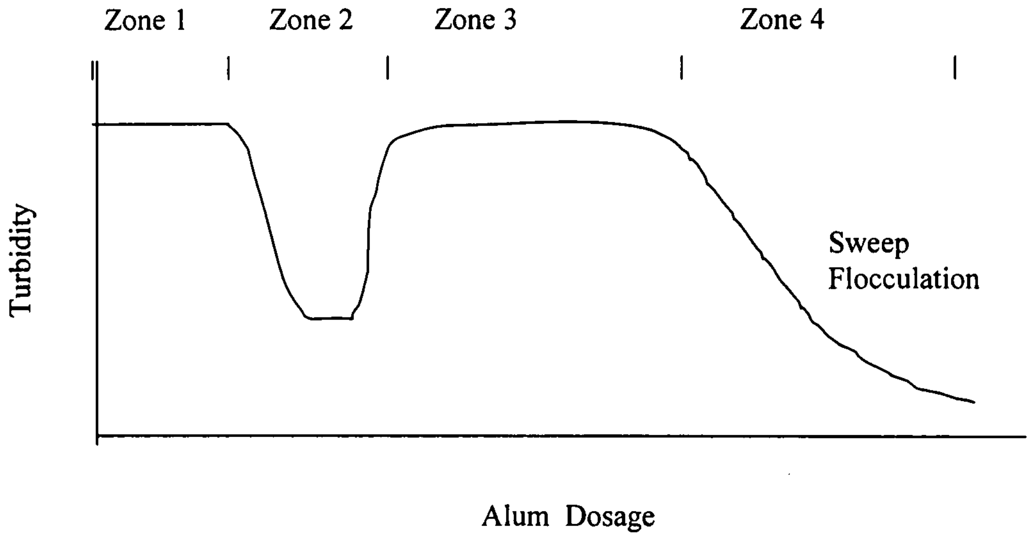

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Fig 2.3 Variation of residual turbidity of water with high turbidity

Addition of alum and variation of residual turbidity for water with reasonably high turbidity is shown in fig 2.3. Each stage of variation is separated into zones and description is given below:

Zone 1 – Destabilisation

Low alum dose is sufficient for alum to destabilise. The negatively charged turbidity particle is attracted and adsorbed onto positively charged Al^{3+}.and destabilised.

Zone 2 - Optimum dosage of coagulant.

Higher dosage effectively destabilise and sufficiently adsorbs positively charged which have been added to neutralize the negatively (-ve) charged colloids.

Zone 3 - Restabilisation

Higher dosage (overdose) adsorption of aluminium polymer is sufficient to produce a positively (+ve) charged stable suspension.

Zone 4 - Sweep flocculation

Highest alum dosage is applied in this region resulting in precipitation of large amount of solid aluminum hydroxide $Al(OH)_3$ and concurrent removal of original turbidity by adsorption and enmeshment of the suspended particles.

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2.3.6 Raw water with Low turbidity

Addition of alum and variation of residual turbidity for water with low turbidity is shown in fig 2.4. Each stage of variation is separated into zones as done in the case of high turbidity. However there is no variation in the residual turbidity in Zone 1, 2, and 3. Significant reduction in residual turbidity occurs in Zone 4.

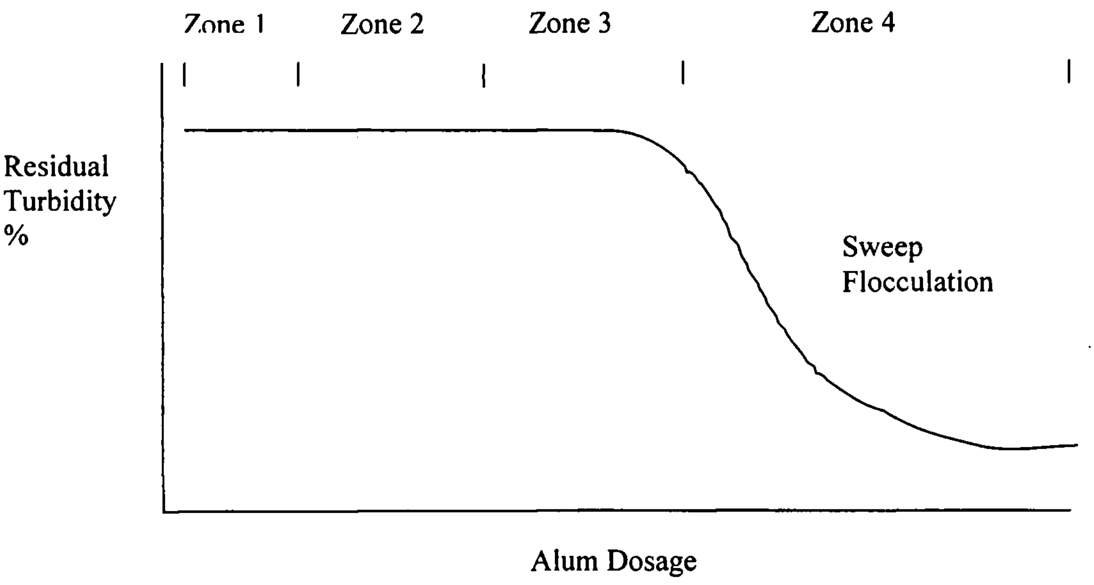

Fig 2.4 Variation of residual turbidity with Low turbidity

Low turbidity water has insufficient contact opportunity after destabilisation which permits agglomeration unlike in the case of high turbidity water, which results in addition of high alum dose leading to sweep flocculation and reduction of residual turbidity as shown in fig 2.4

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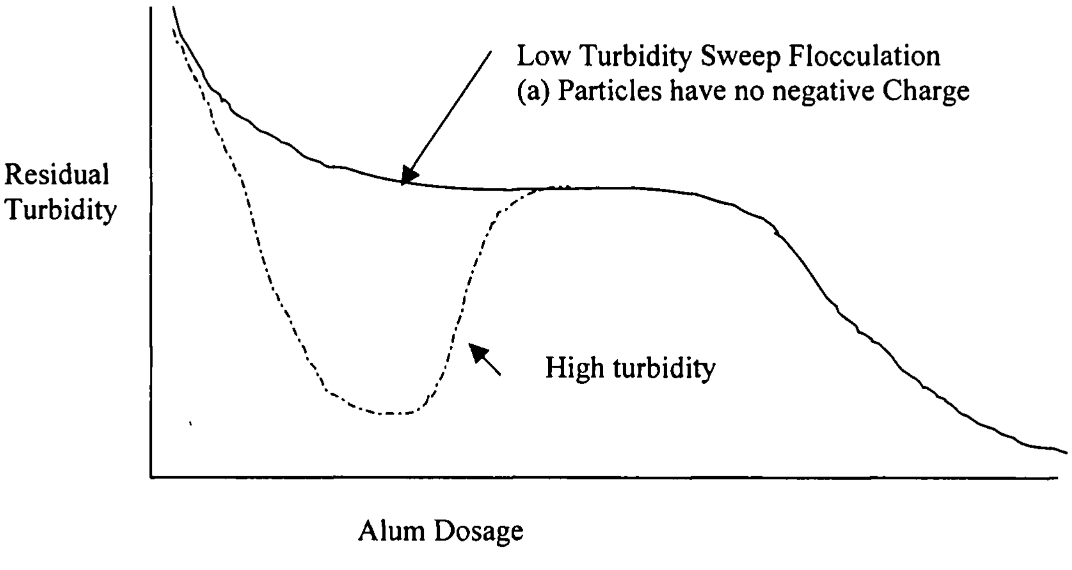

Fig 2.5 Variation of Residual Turbidity with Alum Dosage for water with low and high Turbidity

The variation of residual turbidity with dosage of alum in high turbidity and low turbidity water is shown in fig 2.5. Optimum dosage of alum to be added under different types of water significantly varies. Most instances addition of alum (sweep flocculation) for low Turbidity water is higher than for high turbidity water, as the particles in the water may also serve as nuclei for the precipitation of $Al(OH)_3$ (s) and increase the rate of precipitation. The rate of floc formation with increase in the number of suspended particles is shown fig 2.6. Accordingly formation of flocs is higher with increase in suspended particle resulting in improved settling ability. As such optimum dosage of alum required to reduce turbidity to required level could be determine from fig 2.7.

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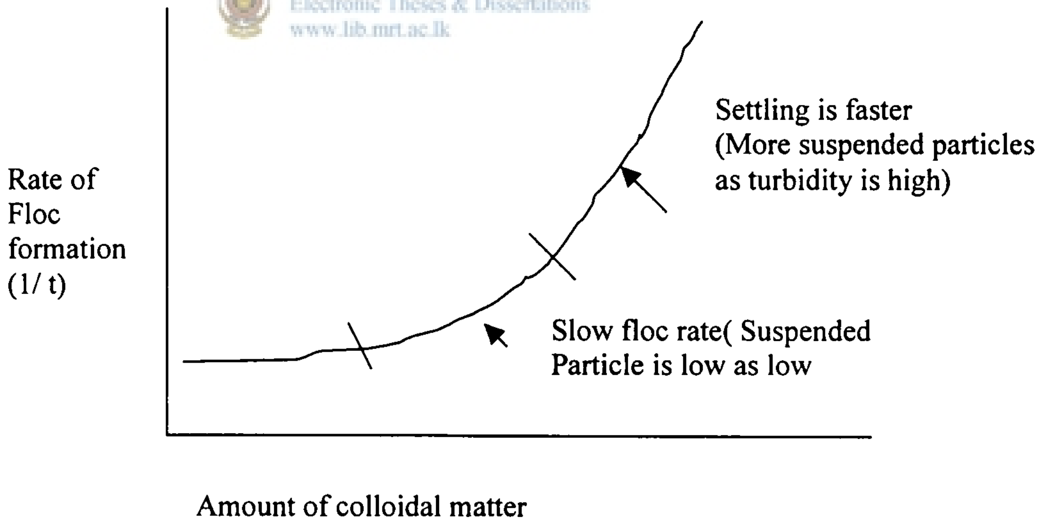
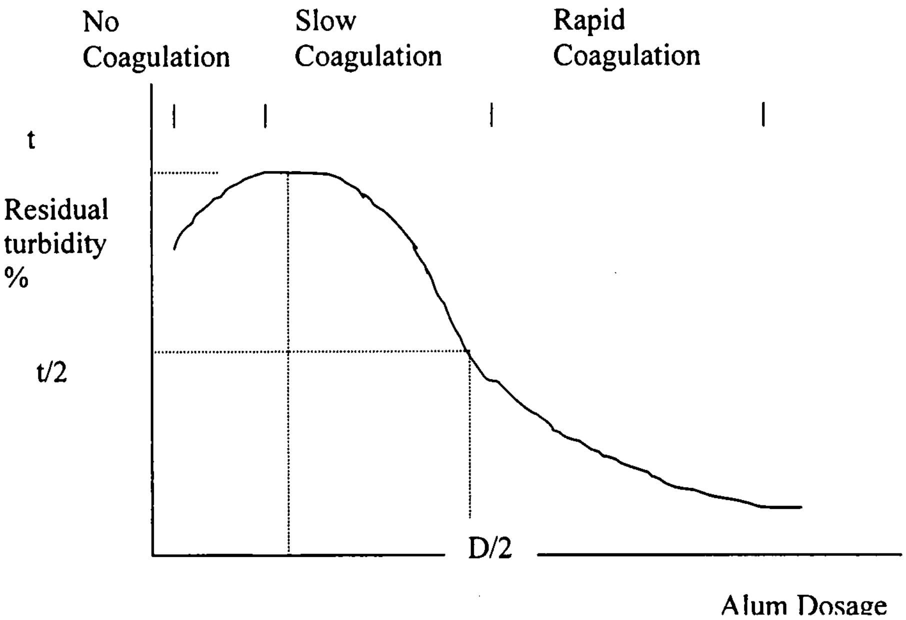


Fig 2.6 Rate of floc formation with variation in Colloidal Matter



D/2 is the Alum required to reduce the turbidity by 50%

Fig 2.7 Variation in residual turbidity with increase in Dosage of Alum

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2.3.7 Reaction Schematics of Coagulation

Coagulation in water treatment occurs in two stages, such as

(a) Adsorption of the soluble hydrolysis species such as $Al(OH)^{2+}$, $Al(OH)_2^{+}$, $Al_7(OH)_{17}^{4+}$ on the colloids and destabilisation, which is very fast and takes less than 1sec

(b) Sweep flocculation by enmeshment of colloids, where the colloids are entrapped within the precipitated aluminum hydroxide, which is slower and takes about 1to 7 seconds.

Chemical stochiometry of coagulation with alum is given as follows:

$$Al_2(SO4)_3.\ 14.3\ H_2O \longrightarrow Al(H_2O)_6{}^{3+} + SO_4{}^{2-} + H_2O$$

$$Al(H_2O)_6{}^{3+} + SO_4{}^{2-} + H_2O \xrightarrow[]{\text{Fast } (10^{-4} \text{ to1sec})} Al(OH)^{2+} + Al(OH)_2{}^{+} + Al_7(OH)_{17}{}^{4+}$$

(Soluble hydrolysis species)

$$Al(OH)^{2+} + Al(OH)_{2+} + Al_7(OH)_{17}{}^{4+} \xrightarrow[]{\text{Fast to slow, 1 to 7 sec}} Al(OH)_3\ (s)\downarrow$$

Adsorption and destabilisation is effective if the coagulant is dispersed properly in the raw water stream as quick as possible (less than 0.1 sec) such that the hydrolysis product will (0.01 to 1 sec) destabilise the colloids. Sweep flocculation is due to colloid entrapment or Enmeshment amidst the aluminum hydroxide precipitate. According to Stumn and Morgan (1981) rapid formation of precipitation occurs when the solution is over saturated.

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$$Al(OH)_3(s) \rightarrow Al^{3+} + 3OH^{-} \quad \text{where } Ks=10^{-33}$$

$$\text{Over saturated ratio} = \frac{[Al^{3+}]\,[OH^{-}]^3}{10^{-33}} = 100$$

Concentration of Alum required at pH of 6.5 to produce over saturation of 100 is 0.001 mg/l as $Al_2(SO_4)_3$ .14.3 H_2O. But minimum alum dosage under normal water treatment is 10mg/l which is considerably oversaturated by 10^4 times beyond the requirement for over saturation, resulting in rapid precipitation and producing sweep floc.

Coagulation is dependent on alkalinity of the water. The stochiometry is as follows:

$$Al_2(SO_4)_3\ 14.3\ H_2O + 3\ Ca\ (HCO_3)_2 \longrightarrow 3CaSO_4 + 2Al(OH)_3 + 6\ CO_2 + 14.3\ H2O$$

Colour and turbidity removal occurs simultaneously during Coagulation. But if the raw water has high colour and low turbidity, Colour and turbidity react differently during coagulation.

Raw water with high colour and low turbidity consist of free humic and fulvic acids remaining in the solution as such the coagulants first reacts with the soluble organic to form colloidal precipitates. There after, reacts with components contributing to turbidity and form colloidal matter. As a result the required coagulant dosage is higher than for removal of either colour or turbidity separately.

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2.4 FLOCCULATION

Destabilsed colloidal suspension agglomerates or grows in the flocculation stage. Destabilisation is controlled by chemistry of the process whereas flocculation is a result of collision between destabilised colloidal particles leading to the formation of flocs.

Flocculation occurs in two mechanisms namely

(a) Perikinetic – Agglomeration of particle less than one micro metre (1μm) due to thermal motion of fluid molecules.

(b) Orthokinetic – Induced by velocity gradient (G Value) in the fluid

Perikinetic is a slower process, whereas Orthokinetic is faster. Average retention time for orthokinetic process is 30minutes which is controlled by velocity gradient (G-Value). Optimum effect of flocculation is achieved by restricting velocity gradient to satisfy the following conditions

$$10s^{-1} < G < 100\ s^{-1}$$

and

$$20{,}000 < GT < 200{,}000 \quad \text{where T is the flocculation time}$$

If G value exceeds $100s^{-1}$, velocity gradient (shearing forces) is high and breakage of flocs which are weak in structure is inevitable.

Major mechanism in sludge blanket clarifier is Orthokinetic due to fluctuating velocities which results in better contact between particles during agglomeration.

2.4.1 Mechanical horizontal Flocculation (Orthokinetic)

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Velocity Gradient is expressed by Camp and Strain (1943) equation as

$$G = [P/UV]^{½}$$

where P is Power input in watt,

V is Volume of System in cubic metre and

U is Dynamic viscosity of liquid which is 10^{-3} kg/m/s for water.

The limiting factor for velocity gradient is given by two conditions namely

$$25\ s^{-1} < G < 75\ s^{-1}$$

$$20{,}000 < GT < 200{,}000$$

Some limiting factors for velocity gradient are as follows:

- Smaller velocity gradient bigger the limiting size
- Flocs produced under higher velocity gradients, though smaller in size, are denser. Accordingly tapered flocculation with diminishing velocity gradient is more effective than uniform velocity gradient during flocculation.

2.4.2 Sludge blanket Clarifier

Sludge blanket clarifier in fig 2.8 is also referred as clari-flocculator. The sludge blanket in the flocculation zone functions as a fluidized bed with hydro-dynamical similarities and dissimilarities to a horizontal flow flocculator. The interaction of solid liquid system induces a fluctuating velocity similar to a turbulent field where the velocity is in the transitional range.

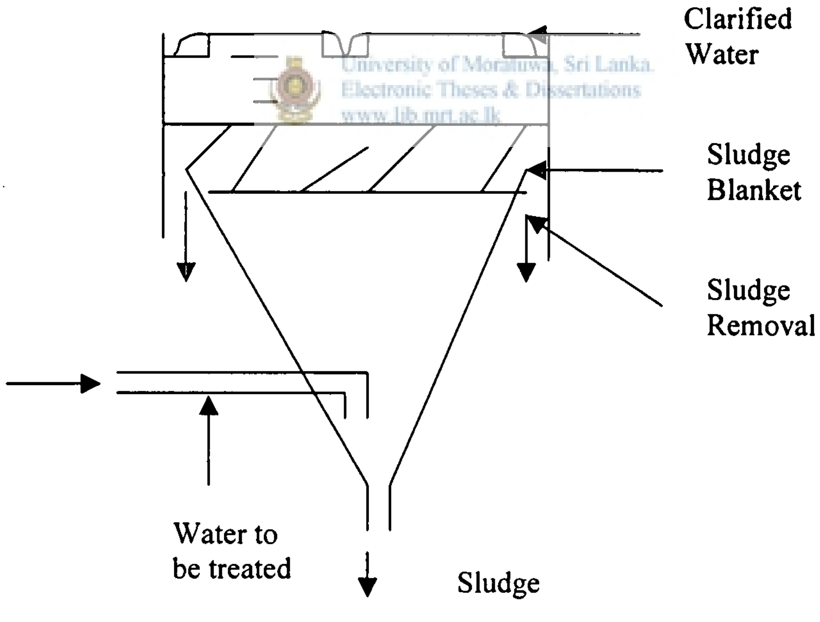

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Fig 2.8 Sludge Blanket Clarifier (Steady flow)

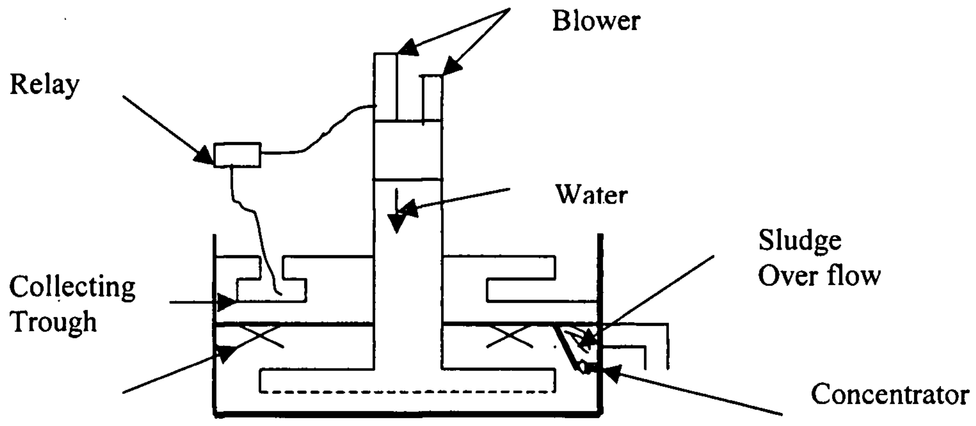

Fig 2.9 Unsteady Discharge Clarifier (Pulsator By Degremont)

Pulsator developed by Ms Degremont in fig 2.9 is similar to the sludge blanket clarifier. But vacuum is created by a pump which interrupts the water level control valve at preset time intervals, causing the water in the central compartment to discharge through the perforated pipe system at high rates in order to attain uniform flow distribution and to agitate the sludge blanket. Excess sludge from the sludge blanket flows into the concentrator and removed by operation of a valve.

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The behaviour of the sludge blanket reactor is depended on

- Velocity gradient (G- value)
- Residence time
- Solid concentration

Pulsator operates in two half cycles. First half cycle, air valve is closed and water rises in the vacuum chamber, while the clarified water is at rest and sludge settles. Second half of the cycle commences as the water in the vacuum chamber reaches the preset height and air valve is opened by the relay switch. The water in the vacuum chamber flows through the sludge blanket and enters the clarified part before flowing into the collecting trough. The sludge in the clarifier rises with the flow of water and excess sludge enters concentrator. The compacted sludge in the concentrator is removed automatically. Once the water in the vacuum chamber falls to a preset level the cycle begins again.

The similarities of sludge blanket clarifier and horizontal flow flocculator lies in the fluid system functions like turbulent field. The dissimilarity is high concentration of solids. Concentration of solids or particle is measured as Volume fraction (Ω). Rate of agglomeration can be improved by enlarging volume fraction ($\Omega = \Pi d^{3}/6 \text{ x } n$) by adding coagulants such as Alum or Iron salts which de-stabilises or reduces zeta potential and increases agglomeration

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The sludge blanket in a clarifier has concentration upto 1000mg/l which is about 100 times higher than in a separate system. Higher concentration of flocs has high volume fraction of particle (Ω) which increases the reduction factor (n_o/n) of particle in the effluent.

High floc concentration in sludge blanket is achieved in a upflow system. Accordingly high surface loading of 3 to 5m/h can be achieved, which is 2 to 3 times high than the horizontal flow sedimentation basin.

Sludge blanket clarifier or clarifier flocculator (clari-flocculator) unit is sensitive to temperature rises and increase inflow, which tends to upset the sludge blanket resulting in increase in suspended solid discharge due to break- through from density effects. When water warms up rapidly, gases

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comes out of the solution. During flocculation, tiny bubbles are released and enmeshed in the floc particles and reducing the density of the floc which tends to float than sink. Thermal effects could be controlled by polyelectrolyte. Even use of activated silica or coagulant aid with addition of clay will increase concentration of the floc and yield superior performance

Theoritical expression developed by Borid for settling velocity of a suspension V_s is given as

$$V_s = V_p\,(1 - f\,\Omega^{2/3}) \text{ where}$$

V_s – Settling velocity of the suspension
V_p – Velocity of the individual particle of a suspension
f -- Shape factor (2.78 for ferric and alum floc)

Ω – Floc volume fraction

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In the absence of a separate flocculator and settling tank both of these functions will take place in the Pulsator. Whereby, flocculation and settling is combined, such that a dense sludge blanket is formed. This is ideal for heavy turbidity condition. The particles contributing to turbidity will be captured. However changes in flow could adversely affect the performance.

The performance of the Pulsator would depend on the

(a) Rate of flow (changes of flow has adverse effect)
Critical formation of settlable floc which relates to the input is dependent on the overflow rate.
(b) Over flow rate
(c) Critical formation of settleable floc which relates to time of agitation and amount of energy input.

Many sludge blanket clarifiers such as pulsators are patented and have number of advantages namely;

(a) Capital cost is low. Since combination of flocculator and sedimentation into single structure

(b) Operating cost is low, as minimum power requirement

(c) No mechanical equipment less maintenance.

Raw water with low turbidity cannot be treated in a horizontal flow flocculator. The performance is poor due to insufficient contact opportunity, whereas sludge blanket unit is more desirable, as heavy blanket in clarifier will agglomerate with raw water having low turbidity and have higher flocculation efficiency in the sludge blanket system.

There are problem with raw water having low turbidity, as the system is dynamic and trying to build a blanket which does not exists initially as such, micro-flocs tend to overflow into the weir, further an unstable blanket is formed. This is improved by adding soil suspension like bentonite clay. But raw water with medium to heavy turbidity (from 80 to 200 TU) has improved performance.

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According to Wagner (2001) under tropical condition the stability of the blanket declines during the afternoon (12.00 Noon). The flocs disintegrate into smaller flocs. It is hypothesised that adsorption of the infra red rays of the sun and thermal stratification of water in the pulsator along with the depth, causes this instability due to production of density currents at the surface of the blanket. This is averted by covering the clarifier

The draw back of sludge blanket clarifier is that it is not suitable for stop start operation. The performance depends on a number of parameters such as effectiveness of coagulation and formation of sludge.

2.5 SETTLING VELOCITY OF FLOC PARTICLE

Settling velocity of a floc particle depends on the type of floc and the temperature. Colour particles produce fragile floc with Alum. Algae produce medium floc with Alum, where as Turbidity particle produces strong floc with Alum. Settling velocities of different type of flocs according to Hudson (1970) is given in Table 2.2.

Settling velocity (V_p) of a floc according to Hudson (1970) is depended on number of parameters namely temperature, floc age, accumulation of turbidity, floc volume fraction (Ω), of which settling velocity increases with temperature, floc age and accumulation of turbidity. But floc Volume fraction in the fluidized bed is depended on the upflow velocity

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Table 2.2 Different type of floc and settling velocities (Hudson (1970)

Kind of floc		**Settling velocities for floc particle at 15^0C in mm/s**
Fragile floc	Colour removal with Alum	0.61 - 1.22
Medium floc	Algae removal with Alum	1.02 - 1.52
Strong floc	Turbidity removal with Alum	1.22 - 1.78

2.6 THEORY OF FILTRATION MECHANISM AND RELATED VARIABLE

Filtration is a process to remove particulate matter in water which comprises of dissolved matter (<0.001 μm) colloidal matter (0.001 μm < colloidal matter < 1 μm) and suspended matter (> 1 μm). Removal takes place by straining or attachment on to the media. However the material deposited can get detached due to increase in shearing forces as the filter clogs.

2.6.1 Straining

According to Boller (1980) and Harzig (1970) as described by James M. Montgomery (1985), Straining is an important removal mechanism when the ratio of particle size to media size in porous media is greater than 0.2.

$$\text{For Straining} \quad \frac{\mathrm{dp}\ \text{(Particle Size)}}{\mathrm{dm}\ \text{(Media size of Porous media)}} > 0.2 \qquad \text{or} \qquad \frac{\mathrm{dm}}{\mathrm{dp}} < 5$$

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According to (Ives 1982), granular media filtration by straining is undesirable, due to increase in head loss as a surface mat is formed. Other investigation (Eisenklam 1979, Marauders 1965) suggests particles size greater than 100μm straining is the dominant mechanism in porous media.

2.6.2 Transport Mechanisms

Transport Mechanism shown in fig 2.10 have been postulated by Ives (1967) as

- Interception
- Sedimentation
- Diffusion
- Impaction - inertia of particle approaching a collector
- Hydro dynamic forces - depended on the physical properties of the filtration system.

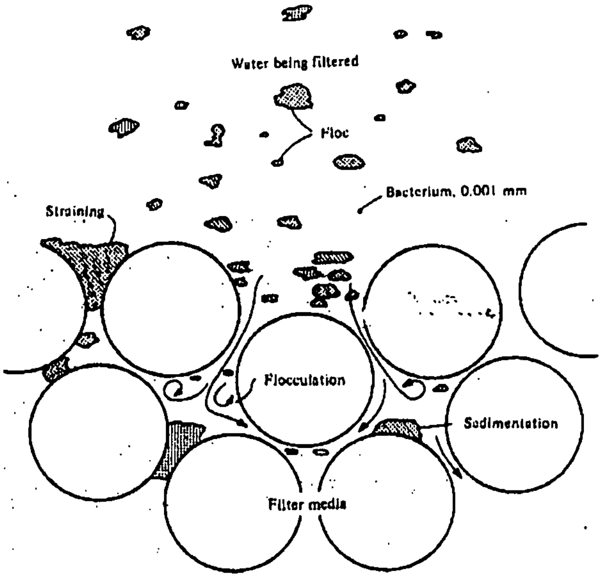

Fig 2.10 Transport mechanism taking place in a filter (Ives 1967)

a. Interception

This is valid for laminar flow, where spherical particles and particulates remaining in fluid stream line that pass within a distance from the collector surface of half the particulates diameter from the collector surface are said to be intercepted.

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b. Sedimentation

Particles with density higher than water tend to deviate from the fluid stream due to sedimentation. Discrete particles with higher density (1-5 kg/m^3) such as iron oxide [$Fe(OH)_3$] particles are captured at much higher efficiency $\eta_s = 10^{-2}$ to 10^{-1}

$$\eta_s = \frac{\Delta P}{18p} \times \frac{gd}{V_o}$$

g - gravitational constant

$\Delta\rho$ density difference between the particulate and water &

V_o is the superficial Velocity

c. Diffusion:

Particles deviate from fluid stream lines due to diffusion. This is influenced by particles in the colloidal range (< 1µm). Brownian motion affects the movement of colloidal particles but has only minor influence on transport of particles larger than 1µm (Smoluchowshi 1917). For particle size less than 1µm collision frequency function for Brownian transport is given by Smoluchowshi (1917)

$$\beta = \frac{8}{3} \alpha k \frac{T}{\mu}$$

β – Collision frequency

T – Absolute temperature (K)

k – Boltzman's Constant

µ - Dynamic viscosity

α – Collision efficiency factor

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(α – Collision efficiency factor defined as a ratio of successful to unsuccessful particle collision with a range of values of $0 < \alpha < 1$)

d. Impaction: Inertia of particle approaching collector is greater than hydraulic forces tending to sweep the particles past the collection. However this mechanism is insignificant.

e. Hydrodynamic forces: This Mechanism is not important under low Reynolds number (laminar flow). However as the velocity and turbulence increase this mechanism may contribute to particulate capture. Some particles may be transported by hydrodynamic forces out of the fluid stream lines to the collector surface.

2.6.3 Attachment Mechanism

Attachment occurs by particle deviation from normal stream line path and making contact with media particles. Particles approaching the surface of the media, short- range, surface forces will influence particle dynamics. Collision of particles and media to be successful particles has to be destabilized. Yao (1968), Stein (1940) and Kavanaugh (1974) have shown theoretically and experimentally that particle capture is possible when surface charge of the particulate matter and media are opposite. According to Yao et al (1971) if the particulate matter in the incoming water is destabilized, collection of particulate matter on the surface of the media which is covered with deposited particle is possible. This condition according to Stumm and O'melia (1967) is analogous to coagulation.

2.6.4 Detachment Mechanisms

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Hydro dynamic shearing forces increases as the velocity increases in the pores of the filter media, as particulate matter get collected within the pores. If the shearing forces exceeds the surface chemical forces holding the particles to the surface, deposited solid can be detached and re-entrained in the water

2.7 EFFECT OF PARTICLE SIZE AND REMOVAL

The graph in fig 2.11 is used to predict the removal efficiency for varying particle size in filters. Accordingly, particle size above approximately 40μm straining may be the control removal mechanism. Where as, for particle size of approximately 1μm and below, diffusion will control transport of particle.

Between 40μm and 1μm particle size interception and gravity sedimentation dominate particle capture. Removal efficiency is lowest around particle size 1μm.

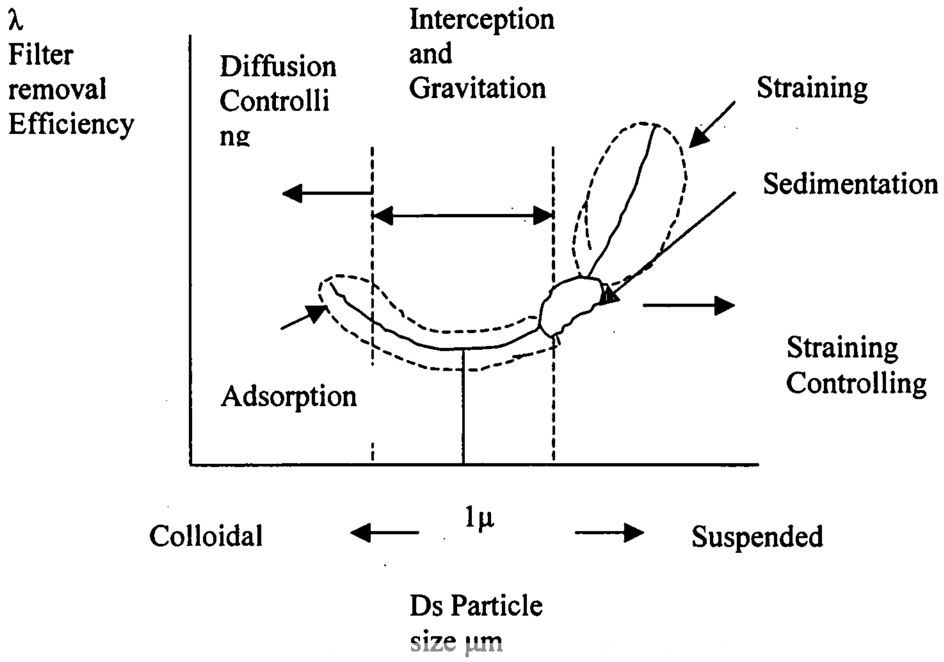

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Fig 2.11 Removal efficiency for varying particle size in a filter (Ives 1967)

2.7.1 Optimisation of granular filter

Performance of filter can be measured as production efficiency. It is defined as the ratio of the effective filtration rate to the design filtration rate (Ives 1967).

$$\text{Production Efficiency} = \frac{(\text{UFRV} - \text{UBWV})/(t_f + t_b)}{\text{UFRV}/t_f}$$

UBWV = Unit Filter Back Wash Volume

UFRV = Unit Filter Run Volume

t_f = Filtration time

t_b = Backwash time

t_b is small compared to t_f as such t_b can be neglected

$$\text{Production Efficiency} = \frac{\text{UFRV} - \text{UBWV}}{\text{UFRV}}$$

While designing backwash volume is assumed as 2 to 3 % of filter run volume. This is applicable for temperate climate. However it could be as high as 5 to 6 % for tropical climate as in Srilanka.

2.8 FILTRATION RATE CONTROL & METHODS

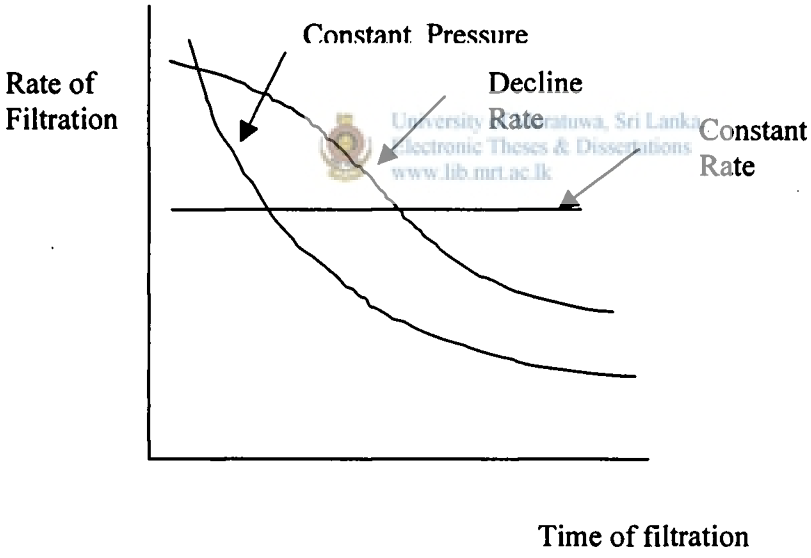

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Fig 2.12 Typical rate of filtration patterns during a filter run (Baumann and Outman, 1970)

Driving force in operation of the filter is the pressure drop applied across the filter. This is classified into three types namely:

- Constant pressure filtration
- Constant rate filtration
- Variable Declining Filtration

The graph in fig 2.12 shows the rate of filtration with time for different types of filter

2.8.1 Constant Pressure Filtration

The total pressure drop applied across the filter through out the filter run is taken into account and constant pressure is applied. Beginning of filter run, the filter permeability is high and the rate of filtration is very high. But with time suspended matter clogs the filter and permeability decreases.This method is not widely used as it requires large volume of storage for water.

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2.8.2 Constant rate Filtration

Constant rate filtration is achived by flow control valve. In Degremont filter design, the filtration rate is held constant by partialisation box or siphon arrangement as shown in fig 2.13 located at the outlet of each filter. This device creates a significant headloss when the filter is clean, which is reduced when the filter is completely clogged.

The siphon consists of two concentric tubes with flow passing from the inside branch to the outside branch with air introduced at the top of the siphon to control its flow. The unit consists of a valve C connected to a spring which is connected to a float.

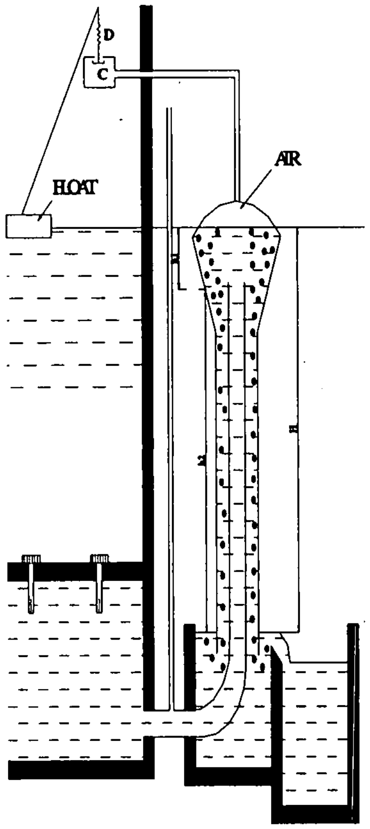

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Fig 2.13 Constant rate Rapid Sand Filter Siphon arrangement

Constant rate is maintained by float being maintained at the same level. As the filter clogs outflow drops and necessary adjustment occurs in the flow of air by the action of the spring. When the filter is completely clogged no more air enters. If the filter is not washed, output will start to drop. Consequently the partialization box provides automatic head loss compensation.The disadvantage of constant rate filtration is the quality of filtered water is not good as that from declining rate filter operation.

2.8.3. Declining rate filtration

Declining rate filter operates at an intermediate manner to constant rate operation and constant pressure. The principle difference between declining rate filtration to constant rate or constant pressure is the influent flow splitting and type of influent arrangement which results in providing less available head.

The advantage of declining rate filter is

- Better effluent quality
- Less available head loss

2.8.4 Problems in Rapid Sand Filter

The problems in rapid sand filtration are

- Bed Shrinkage
- Gravel Displacement
- Penetration of Coagulated matter
- Mud Ball formation

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2.8.4.1 Bed Shrinkage

Ineffective back washing results in compaction which leads to bed shrinkage. Clean media grain, even at terminal head loss rest directly against each other with little compaction. But, dirty grains of the media are kept a part by layers of soft filtered material which increase head loss, bed compression and shrinkage. This results in cracks and separation of the media from the filter walls and allows water to pass rapidly through the cracks. Short circuiting through cracks, receives little or no filtration. The bed volume of filter is not fully utilized.

2.8.4.2 Gravel Displacement

Supporting gravel of the filter media can be washed into the over lying filter media if the back washing valve is opened too quickly or part of under drain system is clogged resulting in unequal distribution of the back wash flow, resulting in increased velocity and displacement of gravel yielding to sand boil and media getting washed into the drainage system as shown in fig 2.14

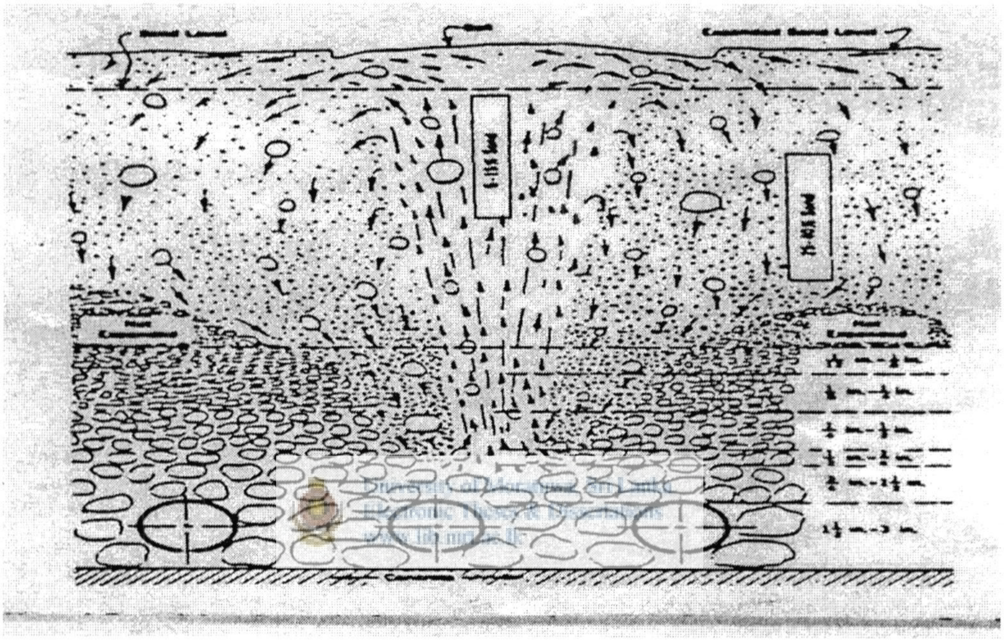

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Fig 2.14 Sand boil disturbing under lying gravel layers (after Baylis)

2.8.4.3 Penetration of Coagulated matter

Coagulated and flocculated water produces flocs with sizes varying from 2 to 0.1 mm downwards. The flocs are captured in the sand media by simple straining at the top and some penetrate into the bed. Initially most of the flocs are lodged within 100 mm from the top of the filter bed as shown in the fig 2.15.

Fig. 2.15 Collection of floc on the filter bed

(Original in Colour)

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These flocs are exceptionally strong, but can subsequently break as the hydraulic gradient increases. As filtration proceeds the flocs lodged between the sand grains beneath the surface as in fig 2.16 (a) reduces free void area and increases flow velocity and further penetrates into the filter bed, resulting in rapid increase in headloss and shortening the filter run.

If the penetration is greater as in fig 2.16 (b) & fig 2.16 (c) the possibility of floc passing into coarser underlying layers would result in break through.

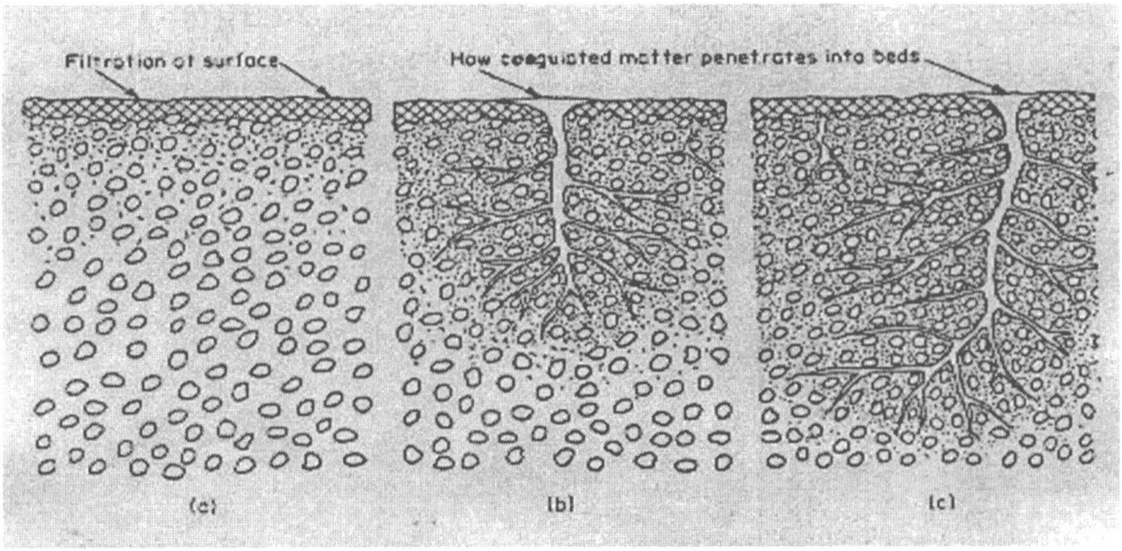

Fig 2.16 Behaviour of filter bed with increase in penetration of coagulated matter (Baumann, et al, 1971)

2.8.4.4 Mud Ball formation

Improper back washing results in accumulation and growth of flocculated matter which is sticky and this matter grows by adhering to the flocs in the incoming water which is known as mud balls. The mud ball grows and get compacted eventually reaching a density greater enough to sink into the sand during back washing as shown in fig 2.17

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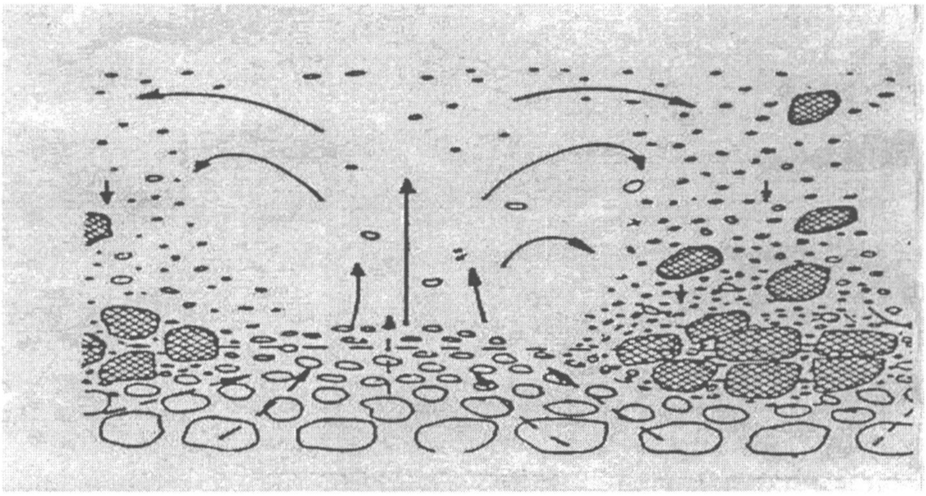

Fig 2.17 Mud balls clogging bottom of filter.

Some of the mud balls clumps together in the bed and form mud deposits at the bottom of the sand bed or against the side wall of the filter.

The large mud balls sinks into the filter bed during back washing and creates inactive zones during filtration which results higher filtration rates leading to breakthrough. How ever air wash followed by back wash is not recommended.

2.9 BACKWASHING OF FILTERS

According to Huisman (1986) air-washing is used during backwashing as a means of additional agitation. But air wash prior to backwashing with water is not recommended. Since air is expected to scour the grains to remove accumulated impurities from the filter grains surface and subsequently water wash is expected to flush loosened material upwards out of the filter. But due to large difference in specific gravity of air and the surrounding water the air rises, entraining the neighboring water (This is similar to an air lift pump with no supply of water from below). The water displaced has to flow back into the space between the jets of air, taking pollutions from the surface into the filter media.

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This return flow could be prevented by filter bed agitation with air must be accompanied with limited upward flow of wash water such that no filter bed expansion occurs. This combined air-water wash for 2 to 3 minute produces vigorous scrubbing of the sand grains and loosening of strongly adhering coating on the filter grain.

Loosen material is removed by subsequent baskwash with water alone for 3 to 5 minute at rates sufficient to produce 10 to 30% expansion of filter media.

In average 2-3% of treated water in used for bachwashing. How ever these parameters are applicable to temperate climate. Where, the density of water is high. Under tropical climate like in Srilanka expansion may have to be increased to 50 to 60 % withbackwashing to be continued for about to 5 to 6 minutes resulting in 5 to 6% of treated water being used for backwashing due to low density and viscosity of water at higher temperature.

2.9.1 Operation of filter for backwashing

Once the head loss in the filter reaches 1m , the filter needs to be washed. Backwashing operation is done in the following manner:

1. Initially inlet valve to the filter is closed.
2. Thereafter the outlet valve of the filter is closed.
3. Wash water drain of the filter is opened.
4. Wash water valve is opened partly.
5. Air scour valve is opened
6. After three minutes the air scour valve is closed.
7. Washed water valve is opened fully.
8. Wash water is allowed to flow into the filter for six minutes and there after the wash water valve is closed.
9. Filtering cycle is started by opening the inlet valve first and thereafter the out let valve is opened.

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Wash water to the filters is pumped from the clear water tank. When the water level in the wash water tank lowers the flow rate keeps reducing as back washing is continued.

Compressed air for back washing is supplied by two compressors. Air flow rate is kept reducing during the air scouring

2.10 WATER STABILITY - LANGLIER INDEX

Aeration of surface water is not required as it adds cost for pumping from one to three meters and also increasing the oxygen content and makes the water more aggressive As a result distribution system, appurtenances at home like Brass taps valves etc. gets damaged. Additional cost has to be incurred in the treatment process to reduce aggresivity.

2.11 CHEMISTRY OF IRON IN WATER

2.11.1 pE-pH diagram

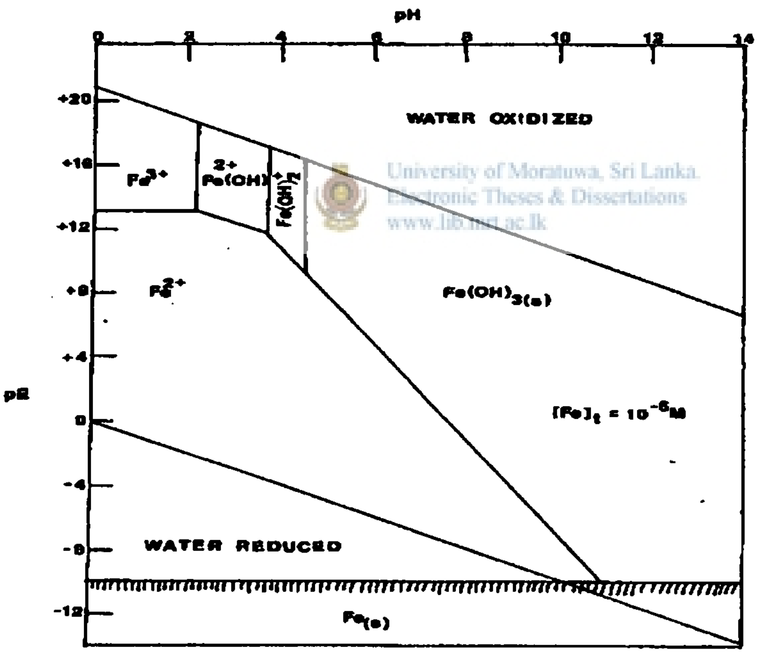

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Fig 2.18 pH-pE stability diagram for the iron system (Faust and Aly 1998)

Iron in water may exist in the following forms, as:

a) Dissolved as ions

b) Suspended

c) Colloidal

d) Inorganic complexes

e) Organic complexes

The solubility of iron under different condition at equilibrium is shown by means of a redox potential (pE) and pH graph in fig 2.18. The diagram is developed with help of the Nernst equation. The two variables, pE and pH, can be used to define areas in which a given iron species is stable or predominant. The diagram is also useful in determining the pE-pH conditions under which Fe^{2+} is oxidised to Fe^{3+} with oxygen as an electron acceptor and subsequently precipitated as $Fe(OH)_3$.

Most natural waters are in anoxic or aerobic state and have pH values ranging from 5.0 to 8.8 and pE values ranging from +2 to +12 (Faust & Aly, 1998). But during dry weather, bottom layer of surface water source may be predominantly in anaerobic or anoxic state. Thus the Fe^{2+} ion would be predominant iron species in the absence of electron acceptor such as O_2. In order to oxidise Fe^{2+} to Fe^{3+}, it is necessary to raise both pE and pH values according to the pH-pE diagram. pE could be raised by addition of electron acceptors such as oxygen, chlorine, potassium per manganate, ozone or chlorine dioxide and pH could be raised, by addition of calcium hydroxide or sodium hydroxide.

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Natural water contains solutes like CO_2 and sulphur species, which are dissolved. These contribute to precipitation of iron. The areas on the diagram can be identified by using distinctive patterns for the species $Fe(OH)_3$ (representing limonite other hydrated ferric oxide minerals), $FeCO_3$ (siderite), $Fe(OH)_2$, and FeS_2 (pyrite). According to Faust and Hunter (1967) "Increase or decrease in the sulphur activity would have relatively little effect in the pyrite boundary. It could be seen from the chemical equilibrium, which was considered in making the diagram given in fig 2.18 Whereas the pH- Eh diagram in fig 2.19 illustrates the range at which $FeCO_3$ is formed.

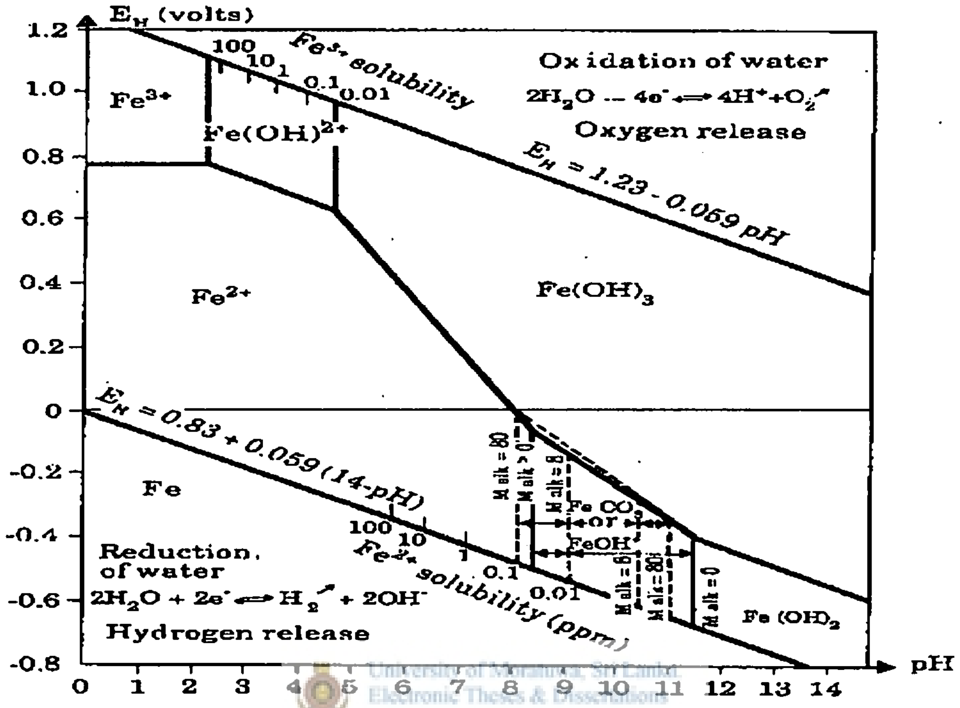

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Fig 2.19 Stability fields of ferrous and ferric species
(Degremont Hand book 1991)

The interpretation of the pH -pE diagram in fig 2.18 and pH- Eh in fig 2.19 lead to the following conclusions (Manahan, 1994):

- At very high hydrogen ion activity and low electron activity (an acidic oxidising medium) Fe^{3+} ion is predominant.(Mainly $Fe(OH)_3$ is predominant)
- At a relatively high hydrogen ion activity and high electron activity (an acidic reducing medium). Fe^{2+} ion is predominant some ground water contains appreciable levels of Fe^{2+} under this condition. In most natural

water systems the solubility range of Fe^{2+} is very narrow because of the precipitation of FeS_2 or $FeCO_3$.

- In basic (alkaline) reducing medium, with low hydrogen ion activity and high electron activity, solid Fe $(OH)_3$ is stable.

2.11.2 Kinetics of iron oxygenation

Oxygenation of iron in water follows the following sequential steps:

Step 1.

Oxygen molecules are transferred from gaseous phase (air) to liquid phase (water)

Step 2.

Reaction occurs between dissolved oxygen and Fe^{2+} to form insoluble Fe^{3+}. The hydrolysis process is given by the following equations:

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$$\begin{array}{lcl}
4\,Fe^{2+} + O_2 + 2H_2O & \longrightarrow & 4\,Fe^{3+} + 4\,OH^- \\
4\,Fe^{3+} + 4\,OH^- + 8H_2O & \longrightarrow & 4\,Fe(OH)_3 + 8H^+ \\
\hline
4Fe^{2+} + O_2 + 10\,H_2O & \longrightarrow & 4\,Fe\,(OH)_3 + 8\,H^+
\end{array}$$

From the above equation, it can be derived that to oxidise 1mg of Fe^{2+} to Fe^{3+} about 0.14 mg of oxygen is required. Normally the saturation concentration of oxygen in Sri Lanka is around 8 mg/L as the ground water temperature is 28^0C. Therefore, the oxygen concentration in aerated water is theoretically sufficient for complete oxidation of Fe^{2+}, of which its concentration ranges upto 20 mg/L.

Stumm and Lee (1961) extensively studied iron oxygenation kinetics. They reported that the rate of oxydation of iron (II) ion is of the first order with respect to both the concentrations of Fe^{2+} and dissolved oxygen and of second order with respect to the OH^- ion, but independent of Fe^{3+}.

$$\frac{d[Fe2+]}{dt} = k\, pO_2\, [Fe^{2+}]\, [OH^-]^2$$

Where $[Fe^{2+}]$ =concentration of Fe^{2+} (mol/L)

k =reaction rate constant (L^2/ mol^2 atm min)

pO_2 =Partial pressure of Oxygen (atm)

$[OH^-]$ =concentration of hydroxyl ion (mol/ L)

t =time in minutes

2.11.3 Iron Removal and effect on Organic Substance

Organic matter in water forms Organic acid such as humic and fulvic acid which forms complexes with iron and retards removal of iron from water. Oxidation of such water by keeping high state of redox potential (Eh) enables ferrous ion to be oxidized to ferric readily. However aeration is ineffective in complex situation of this nature.

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3.0 METHODOLOGY OF STUDY

3.1 PROBLEM ANALYSIS

Light yellowish colour appears in treated water during prolonged drought. The study was undertaken in the following manner.

1. Chemical analysis is done for raw water to identify the reasons for appearance of colour (occasionally) in treated water

2. The performance of each unit process given below was analysed
    a) Aerator
    b) Chemical dosing system
    c) Pulsator.
    d) Rapid sand filters.
    e) Chlorinator.

    With special attention being given to
    - Formation of sludge blanket in the Pulsator
    - Cracks appearing on the top of the filter and mud ball formation.
    - Back washing of filter which includes :
        a) Back washing rate
        b) Air Scouring rate
        c) Size of filter media and height
        d) Level of water above the filter media

3. Suggest modification to the plant and demonstrate removal of colour under varying raw water quality.

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FLOW CHART OF ANALYSIS

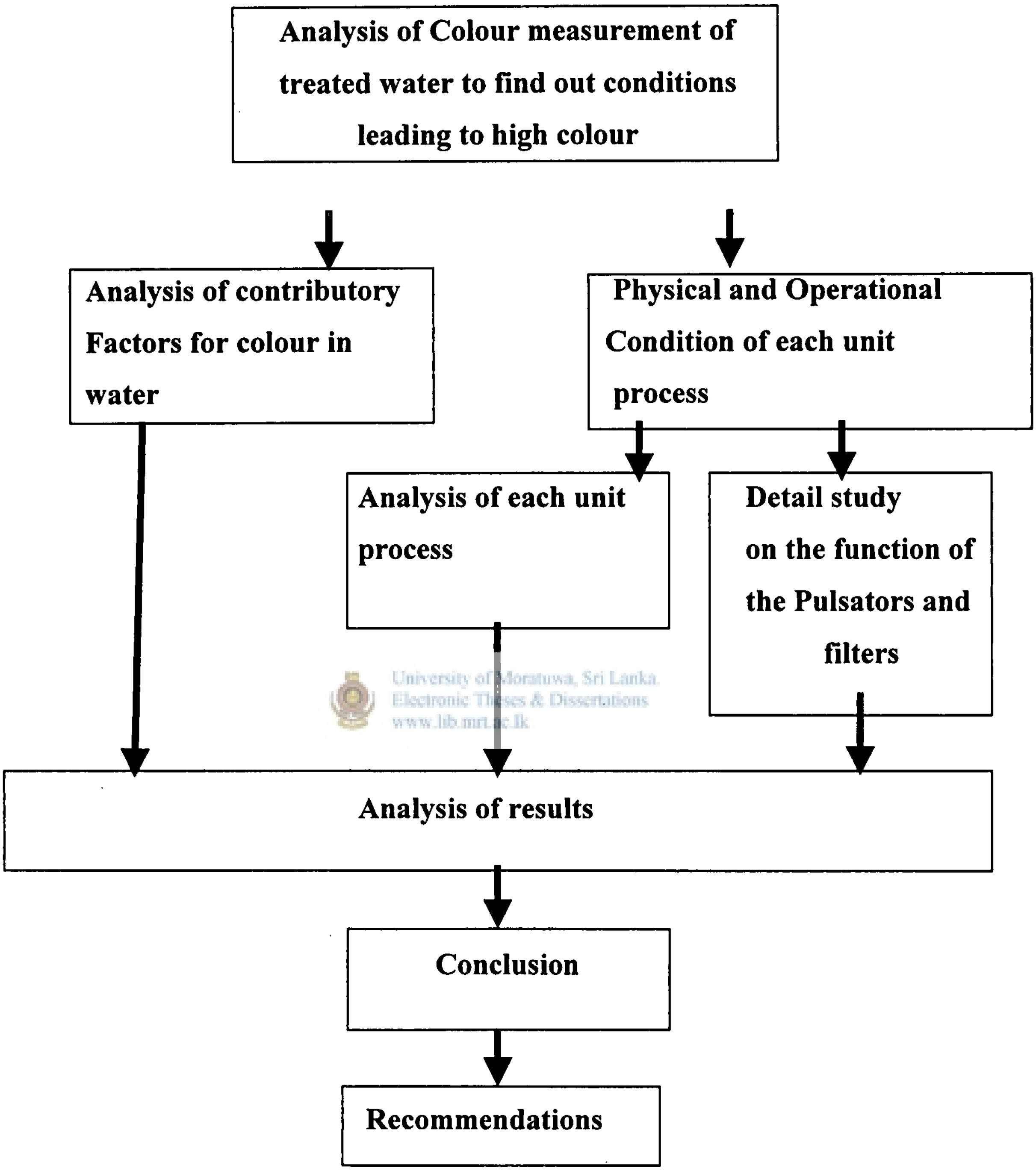

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Fig 3.1 Flow Chart of Analysis

3.2 METHOD OF ANALYSIS

3.2.1 Chemical analysis of raw water from Dandugam-Oya

a) Raw water and treated water quality is monitored through out the year at the NWSDB laboratory for the following parameters for varying physico-chemical treatment process.

Water Quality Parameters

Physical

Turbidity
Colour
pH

Chemical

Total alkalinity
Hardness
Conductivity
Redox potential
Dissolved Oxygen
Total iron
Chloride
Fluoride
Free Ammonia
Nitrite
Nitrate

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b) Intermittent water samples were collected before and after each unit process at different period of the year and tested for all parameters mentioned above. These measurements were taken to get an idea of the change in water quality with the variation of raw water quality at different stages of treatment. Significant variation in concentration of iron in water was observed which had considerable impact on the treated water quality.

Equipments

Sample collector
pH meter/ Redox Potential meter
Dissolved oxygen meter
Colour Comparator
Turbidity meter

3.3 JAR TEST

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The jar test is carried out to determine the optimum coagulant dose for a given sample of water. Different doses of coagulant are added simultaneously to several samples of water to be tested under identical condition. The optimum dose is the dose which will in a moderate time, produce a floc which will settle and have suitable filterability properties and have minimal residual turbidity.

3.3.1 Jar test procedure

- Six 1 litre Pyrex beakers were filled with 1litre of the water to be tested and placed under the stirrer on Jar test apparatus.
- Place 2ml, 4ml, 6ml, 8ml and 12ml of 0.5% Alum solution (5g/l) in each of the test tubes.

- The stirrer is turned on to 100rpm add alum solution mentioned above is added to six beakers simultaneously.
- Stirring is continued for 20 to 30sec
- Speed is reduced to 30rpm for 20 minutes.
- After 20 minutes of stirring at 30rpm switch off the apparatus and allow the sample to stand for 30minutes. Observe the time for floc particles to settle out in each beaker.
- Measure the following:
  (a) Initial pH and turbidity of the water.
  (b) Turbidity in the beaker after 30minutes of settling period
  (c) pH of the water in the beaker considering to be the optimum having regard to the flocculation and settling time.

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4.0 OBSERVATIONS, DATA AND RESULTS

4.1 RAW WATER QUALITY DATA

The Physico – Chemical quality of raw water in Dandugam-oya from the year 2001 to 2005 is listed in Table A. The Fig 4.1 to 4.10 shows the variation of Turbidity, Colour, pH, Iron, Alkalinity, Hardness, Chemical Oxygen Demand, Dissolved oxygen during this period.

4.1.1 Turbidity

Variation of turbidity is shown in fig 4.1. According to the data, highest turbidity of 51 NTU was recorded in November 2003. In average turbidity ranges from 10 to 30 NTU

4.1.2 Colour

Variation of Colour is shown in fig 4.2. According to the data highest colour of 222Hazen Unit was recorded in November 2003. Unlike turbidity there is significant variation of colour through out the period the data was collected. In average Colour ranges from 40 to 100 Hazen units. Unlike most flowing surface water the value of colour is higher than turbidity in Dandugam-oya.

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4.1.3 pH

Variation of pH is shown in fig 4.3. Raw water pH ranges between 6.5 and 6.8.

4.1.4 Iron

Fig 4.4 shows the variation of Iron in raw water. According to the data highest value of iron was observed in April 2003. The Iron content in raw water varies between 0.3 and 1.5mg/l.

4.1.4 Alkalinity

Variation of alkalinity is shown in fig 4.5. Highest value of alkalinity of 100mg/l was observed in May 2003. According to the data alkalinity ranges from 10 to 40 mg/l.

4.1.5 Hardness

Fig 4.6 shows the variation of Hardness of raw water. Highest value of hardness amounting to 80mg/l was observed in September 2001. According to the data hardness ranges from 20 to 50mg/l.

4.1.6 Chemical Oxygen Demand (COD)

Variation of Chemical Oxygen Demand is shown in figure 4.7. Highest Chemical Oxygen Demand amounting to 36mg/l has been recorded in Feb 2004. According to the data COD ranges from 7 to 17mg/l

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4.1.7 Dissolved Oxygen

Fig 4.8 shows the variation of dissolved oxygen. Highest recorded dissolved oxygen is 6.8mg/l in March 2001. According to the data dissolved oxygen in raw water ranges from 5 to 6mg/l.

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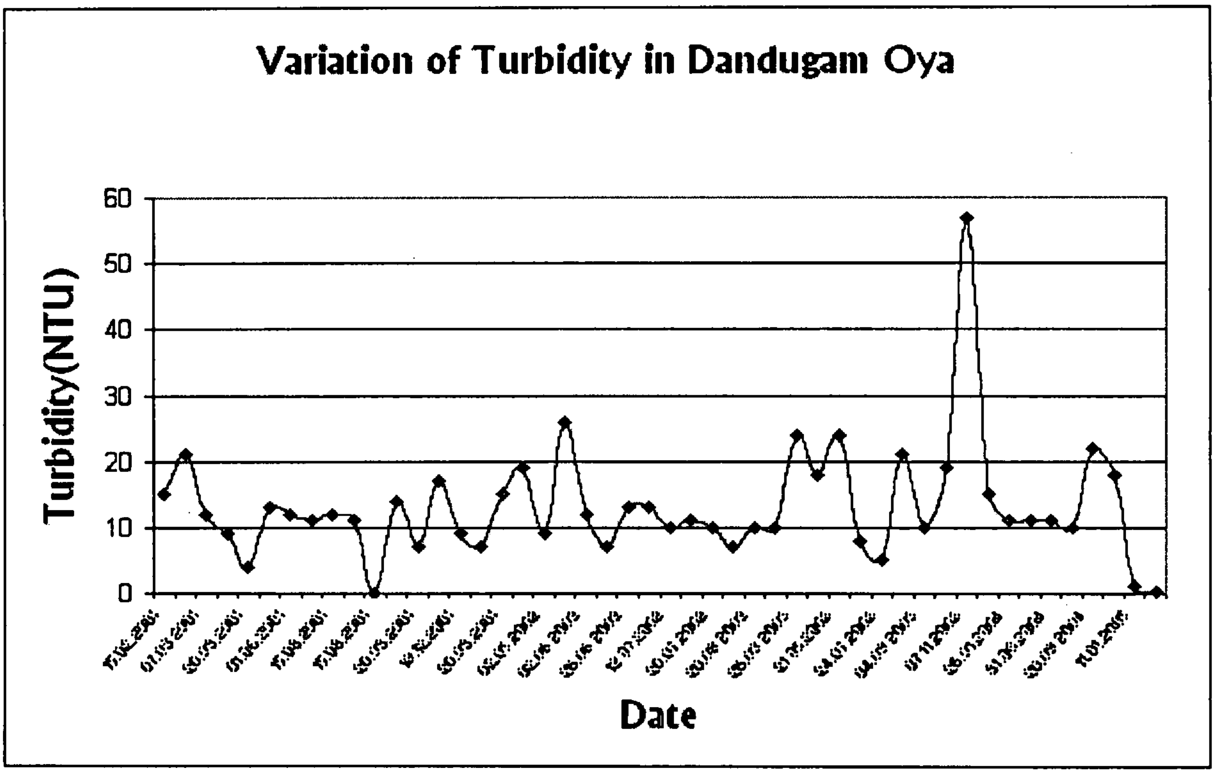

Fig 4.1 Variation of Turbidity in Raw water from Dandugam Oya

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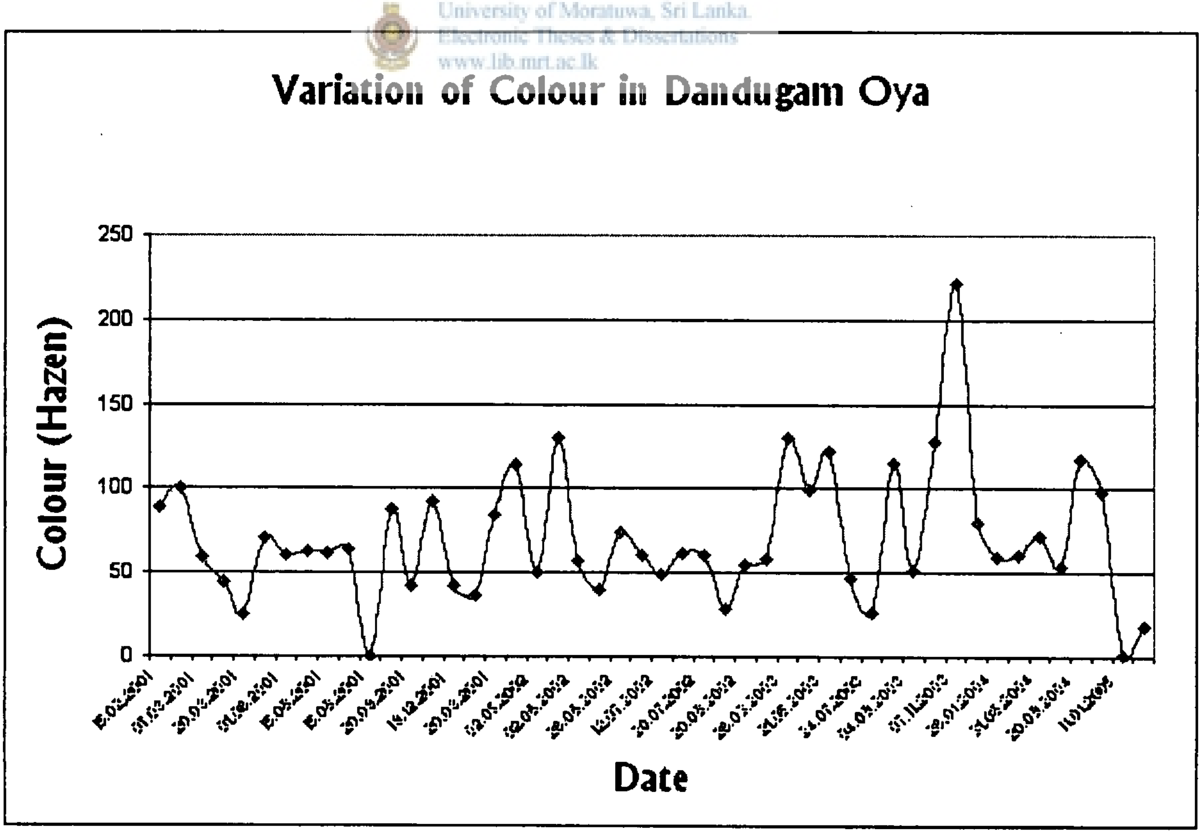

Fig 4.2 Variation of Colour in Raw water from Dandugam Oya

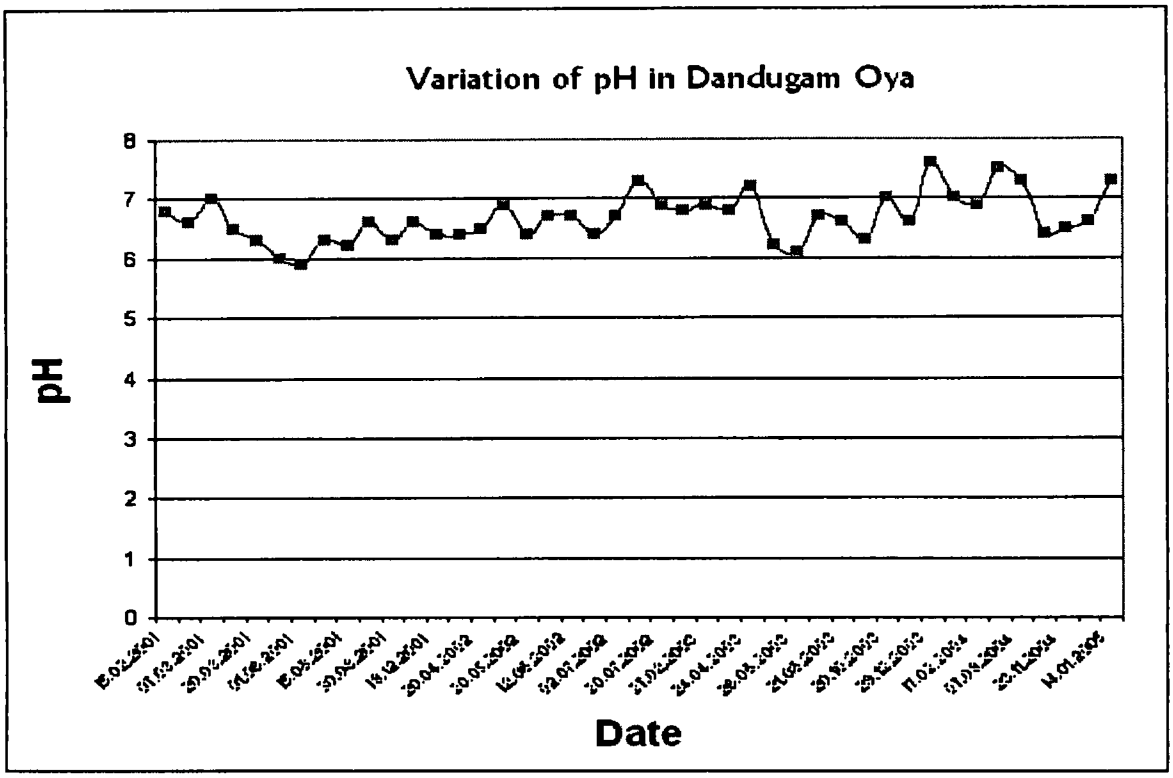

Fig 4.3 Variation of pH in Raw Water from Dandugam Oya

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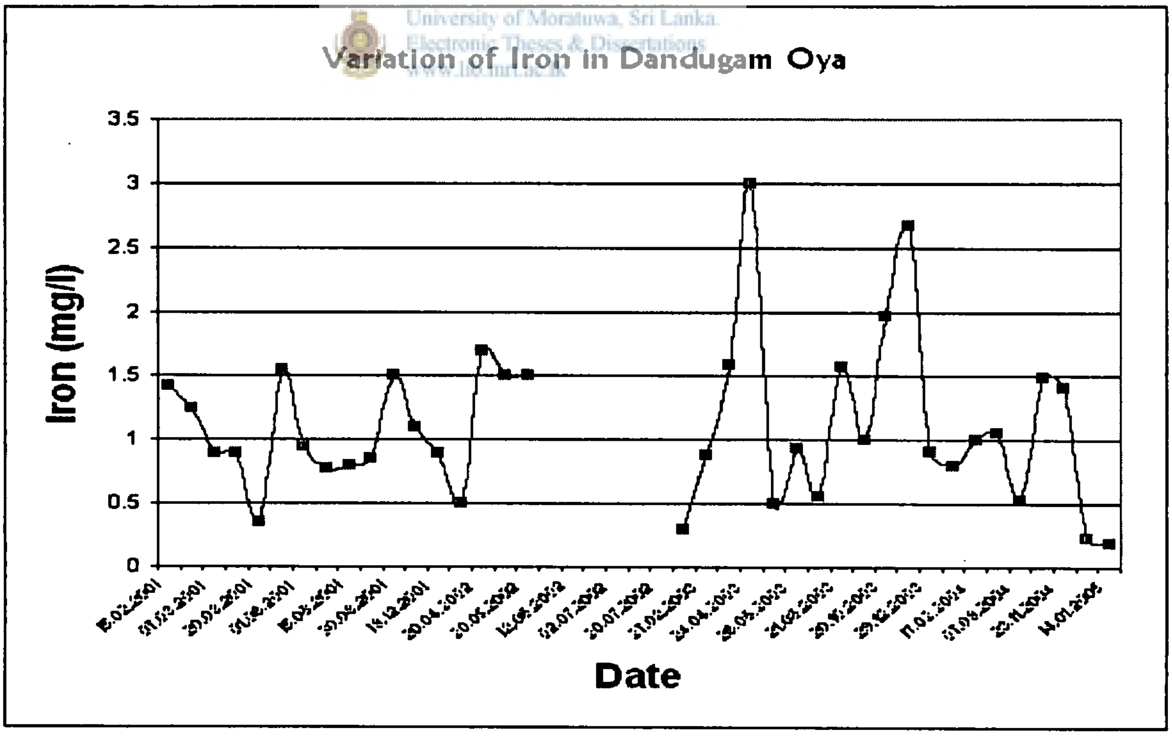

Fig. 4.4 Variation of Iron in Raw Water from Dandugam Oya

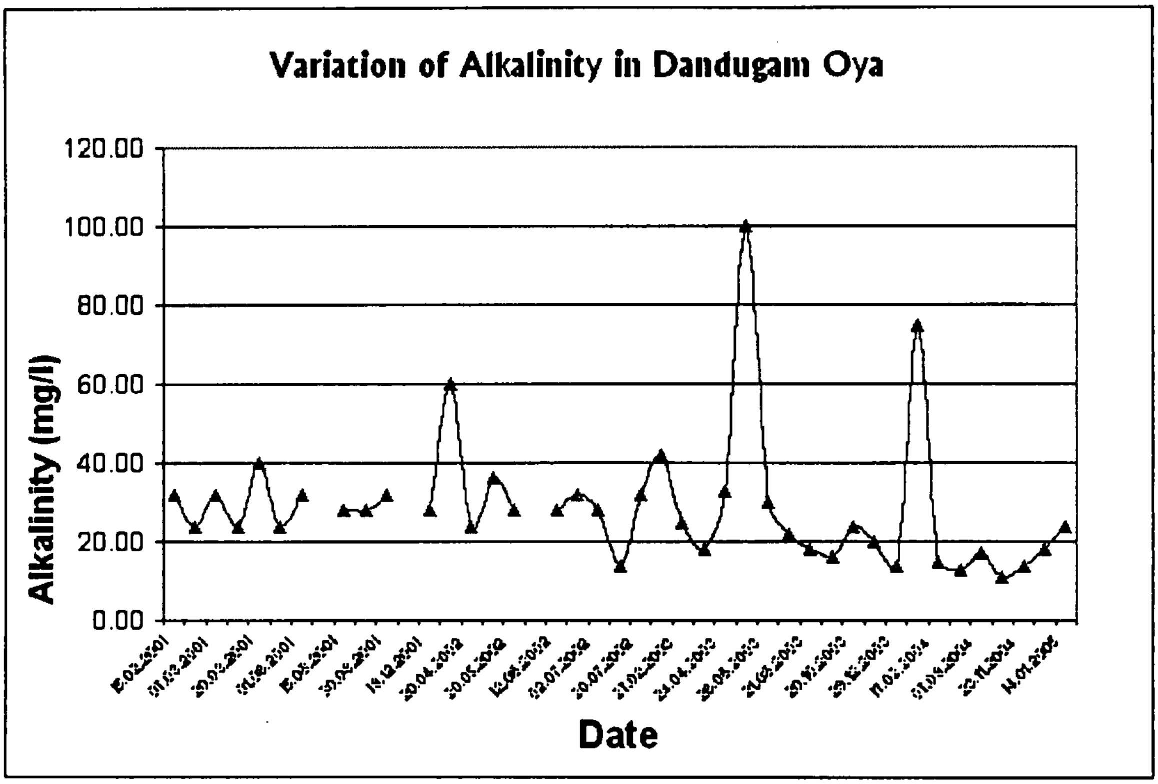

Fig. 4.5 Variation of Alkalinity in Raw Water from Dandugam Oya

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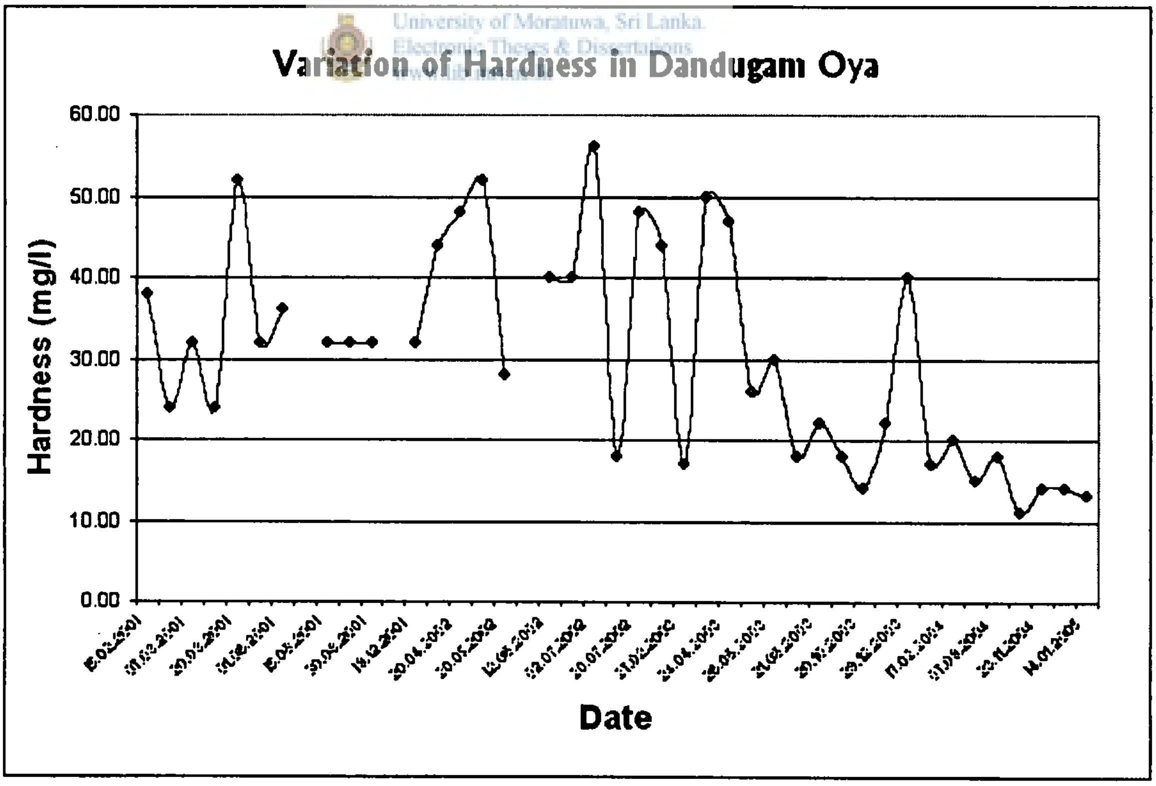

Fig. 4.6 Variation of Hardness in Raw Water from Dandugam Oya

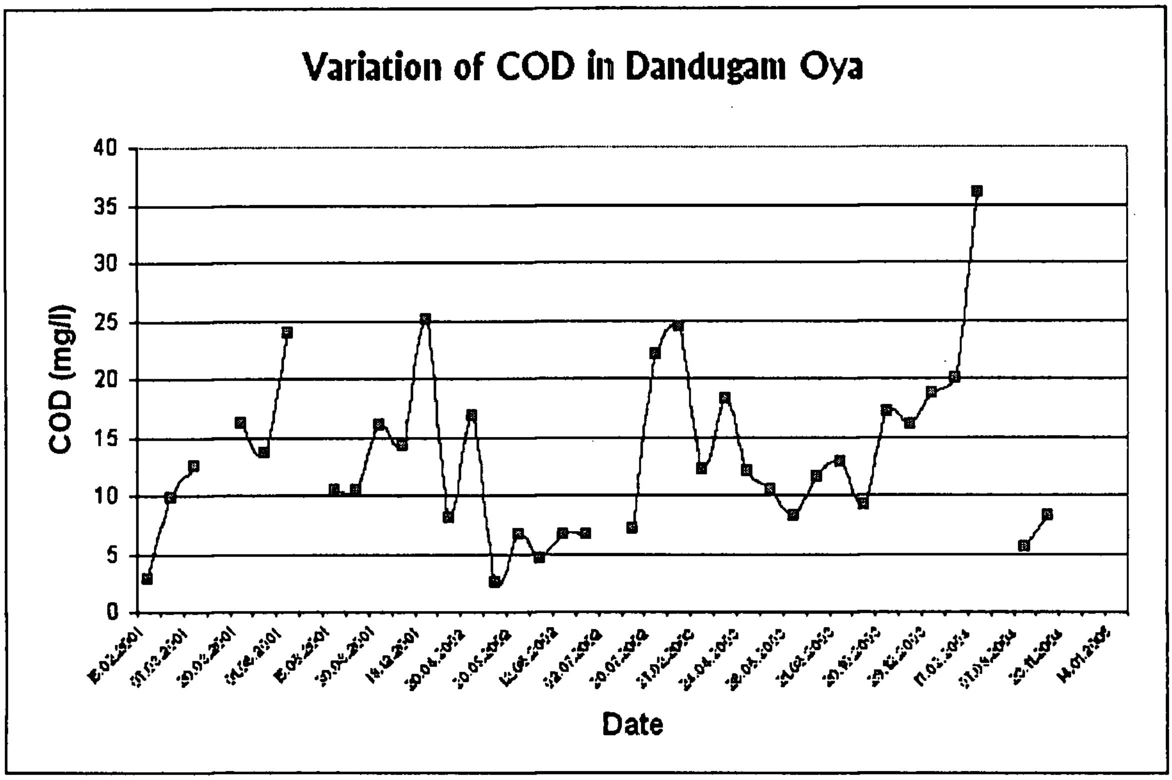

Fig 4.7 Variation of COD in Raw Water from Dandugam Oya.

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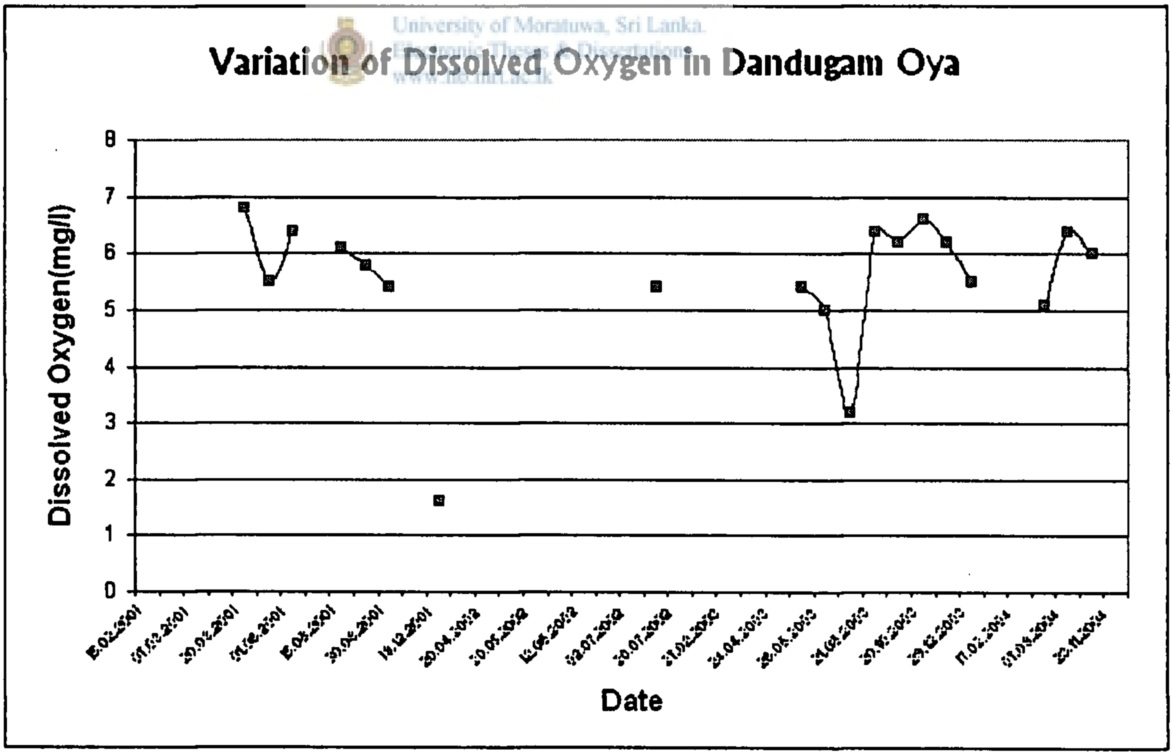

Fig 4.8 Variation of Dissolved Oxygen in Raw Water from Dandugam Oya.

4.2 TREATED WATER QUALITY DATA

The physico - chemical quality of treated water from the year 2003 to 2005 is listed in Table B-1. The fig 4.9 to 4.11 shows the variation of Turbidity, Colour and pH of treated water during this period. Necessary changes to improve coagulation by shifting the dosing point were done in May 2004. There was a significant improvement on the treated water quality. The details are given below.

4.2.1 Turbidity

Variation of Turbidity of treated water is shown in fig. 4.9. According to the data highest turbidity of treated water of 9 NTU was recorded in October 2004. In average the treated water turbidity varies between 1 to 4 NTU which is within the limit stipulation by Sri Lanka standards for drinking water. Average Turbidity of treated water before and after May 2004 is 2.9NTU and 1.51NTU respectively. As such 47.9% reduction in the Turbidity was achieved with the modification.

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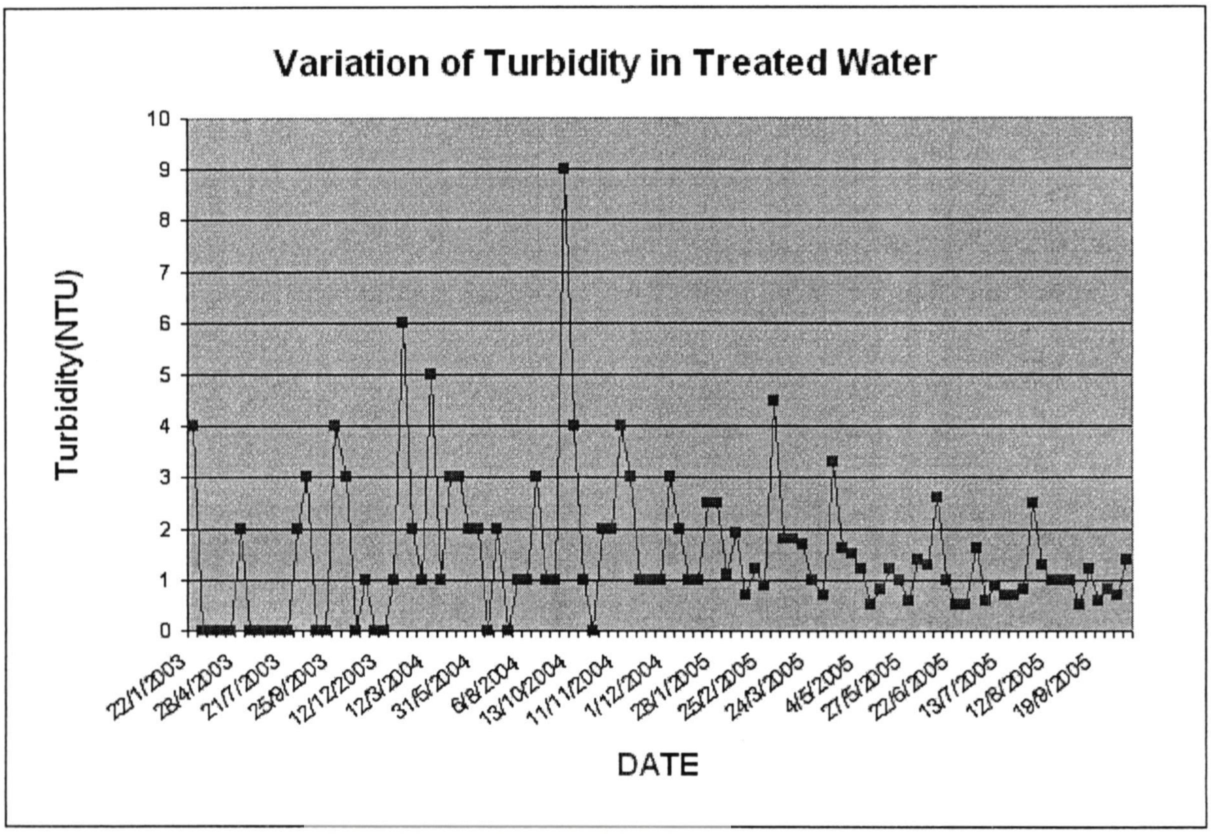
4.2.2 Colour

Variation of Colour of treated water is shown in fig 4.10. Colour of treated water exceeds the limit given in Sri Lanka standards for drinking water (30 Hazen units) in January 2003, July 2003 and January 2004. However the colour of treated water improved after necessary changes were made to enhance coagulation in the treatment process in May 2004. The average colour of treated water before and after May 2004 was 9.41Hazen and 4.66Hazen respectively. As such the reduction in colour of 49.5% was achieved

4.2.3 pH

Variation pH is shown in fig 4.11. Treated water pH ranges between 7 and 8



4.9 Variation of Turbidity in Treated Water

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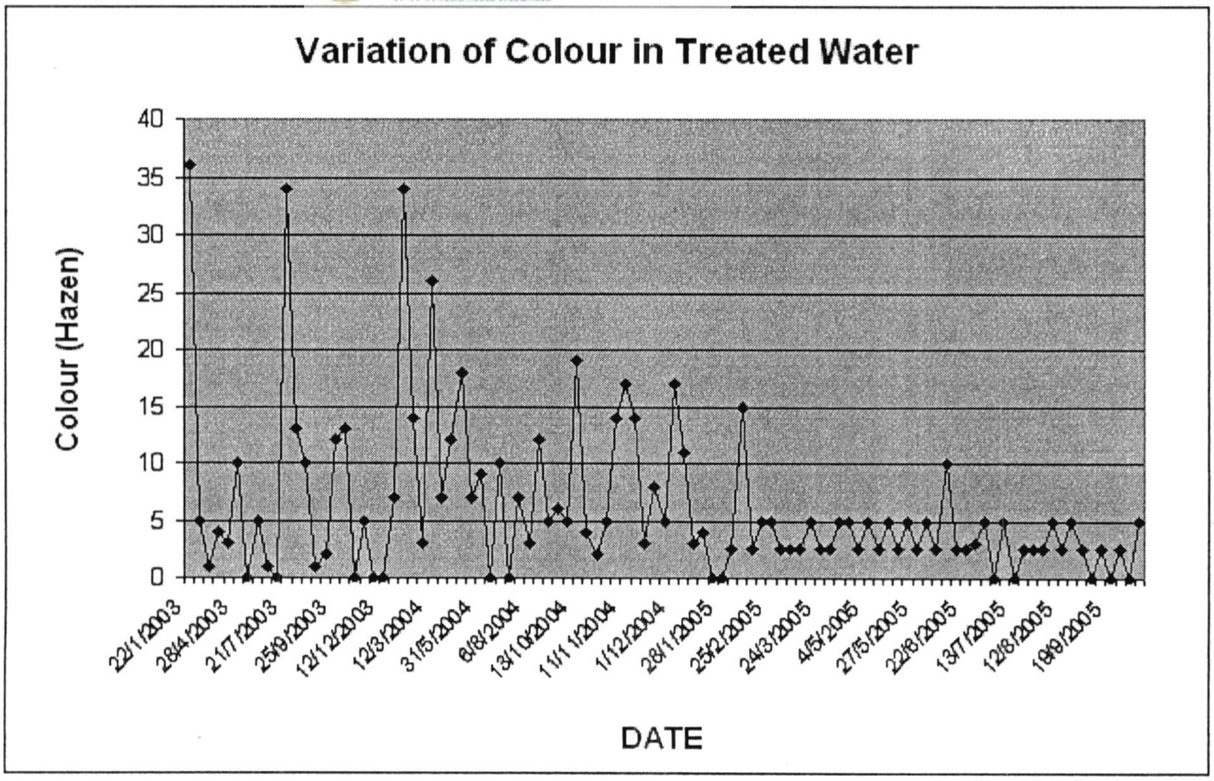
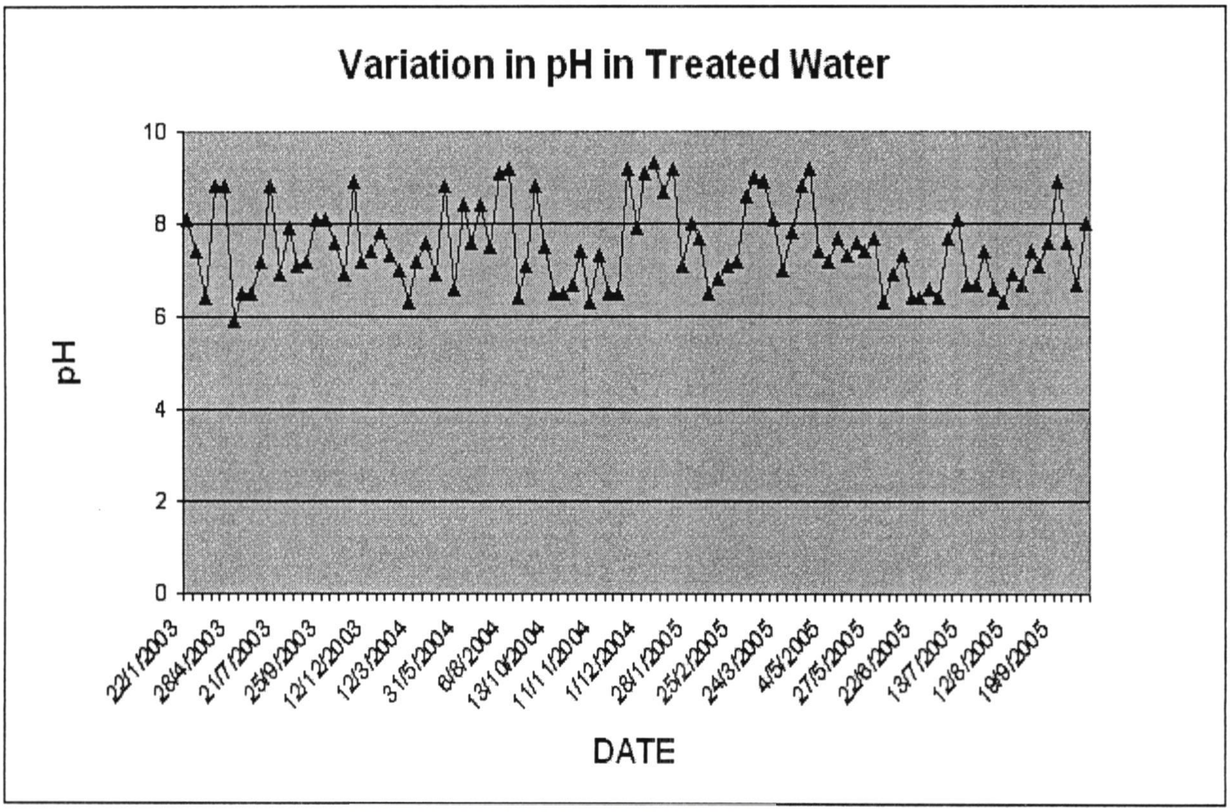


4.10 Variation of Colour in Treated Water



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4.11 Variation of pH in Treated Water

4.3 HYDRAULIC DESIGN OF TREATMENT PLANT

4.3.1 Production Capacity

Design capacity 4500 m^3/d (1MGD)

Maximum production at present is 4300 m^3/d

4.3.2 Water Source & Intake

a Water Source - Dandugam-Oya

b Intake well - 4 m in diameter 9.4 m deep Constructed on the banks of Dandugam-Oya.

c Retention time at Wet well

$$= \frac{V}{Q} = \frac{4.4 \times \pi \times 9.4^2/4}{4300\ m^3/d}$$

$$= 18.5\ \text{sec}$$

4.3.3 Intake Facilities

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a. Raw water is abstracted by 4 nos 300mm diameter DI pipe placed at 1.3m level difference, of which two pipes are placed at same level.

b. Wet well is connected to raw water pumps by 150 mm diameter DI Pipes.

c. Raw water is pumped via 300 mm DI pipe to the treatment plant located at Raddolugama Housing Scheme which is situated 3.5 km away from the Intake.

d. 3 Nos centrifugal pumps with 200 m^3/h capacity and 27m head are used as raw water pumps.

4.3.4 Treatment facilities

a Aerator

Type step aerator (Cascading) as shown in fig. 4.12

Size of step is 0.9 m width x 1 m length x 0.6 m height fall

Number of steps = 5 steps
Height of water fall = 0.6 m x 5 steps
= 3 m

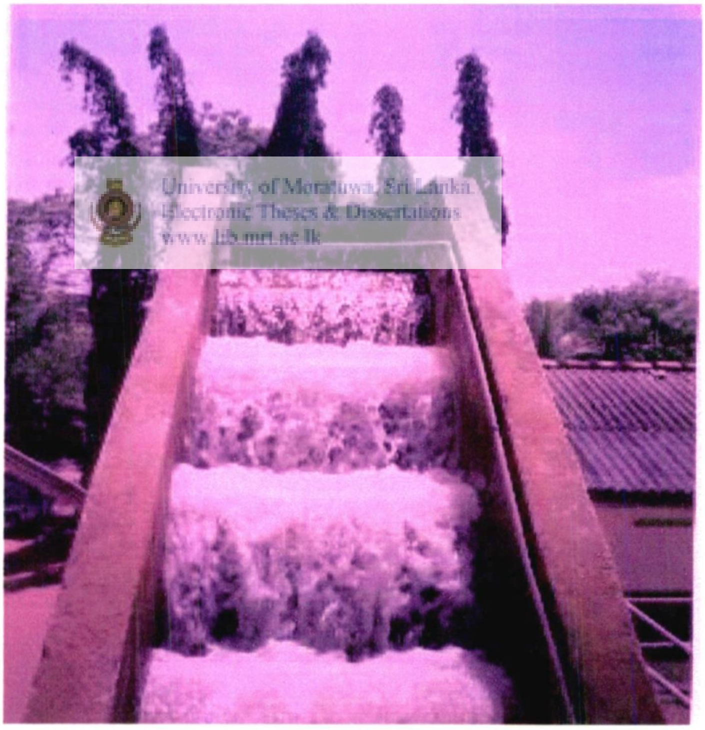

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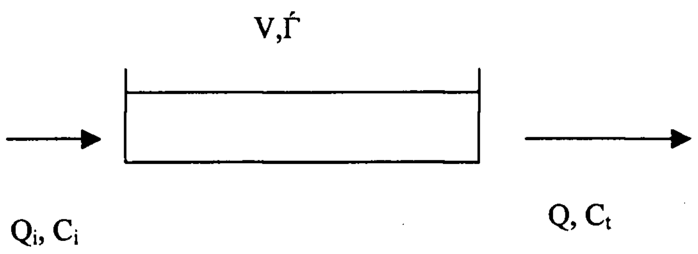
Fig 4.12 Step aerator in Water treatment plant
(Original in colour)

Calculation of Oxidation Potential of step aerator



Assuming step aeration is completely mixed and steady state condition

$dc/dt = k_2\ (Cs - Ci)$ .... (1)

where k_2 is gas transfer coefficient or efficiency coefficient

But $QCi\ dt + V\ dc = QCt\ dt$ .... (2)

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Where $Q = V/\acute{\Gamma}$, $V = Q\,\acute{\Gamma}$ ....(3)

Substituting (1) , (2) & (3) $QCidt * Q\,\acute{\Gamma} k_2 Cs - Ct)\ dt = Q\ Ct\ dt$

$$Ci + k_2\ (Cs - Ct) = Ct$$

$$k_2 = Ct - Ci\ /\ Cs - Ct$$

Water quality measurements taken before and after aeration are given in table 4.1

Table 4.1 Water Quality Measurements taken on the aerator to compute oxidation potential.

(Date 20- 08 – 2004 at 13.00 to 15.00 hrs)

Parameter	Unit	Before aeration	After aeration
Dissolved Oxygen	mg/l	5.3	5.8
Fe2+	mg/l	0.01	0.02
Fe3+		1.04mg/l	1.14mg/l
Colour	Pt/Co	58	64
Turbidity	NTU	14	14
Temperature	^{0}C	29	30
Redox potential	mv	553	603

where Cs at 30^{0}C is 7.7 mg/l

K_2 =(5.8-5.3) / (7.7- 5.8) =0.26

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Oxidation potential of aerator is 0.26

Calculation of Aggressivity of water before and after aeration

Water Quality before and after aeration on 17- 03- 2003 is given in table 4.2

Table 4.2 Water quality before and after aeration

Parameters	Before aeration	After aeration
Colour (Hazen Units)	60	50
Turbidity (N.T.U)	26	80
pH	6.2	6.8
Electrical conductivity μs/cm	63.3	56.2
Total alkalinity (as CaCO3) mg/l	8	24
Total Hardness (as CaCO3) mg/l	14	14

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Calculation of Saturation Index before aeration

Total Dissolved Solids (TDS) can be computed from the formulae

$0.55 < TDS/EC < 0.7$

Influent EC =63.3 μs/cm

TDS/EC =0.6

TDS =0.6 x EC =0.6x 63.3 =37.98 mg/l

$$CO_2 + H_2O \xrightarrow{K_1} H^+ + HCO_3^-$$

Where $K1 = [H^+][HCO_3^-]/[CO_2]$

$[CO_2] = [H^+][HCO_3^-]/K_1$

pH =6.2

-log H+ =6.2

$H^+ = 10^{-6.2}$

Alkalinity =[HCO_3^-] =8mg/l

Substituting $[CO_2]$ = $[10^{-6.2}]$ $[10^{-3}x8/61]$/ $[4.71x10^{-7}]$ g mol/l

=0.28x $10^{-2.2}$x 44x 103 mmol/l

=7.77 mg/l

Hardness =14mg/l

Ca^{2+} =40 x 14/100 =5.6 mg/l

pHs =2.2 – log$[Ca^{2+}]$ – log [HCO_3^-]

=2.2 – log $[5.6x10^{-3}/40]$ – log [$8x10^{-3}$ /61]

=2.2 – (-3.85) – (- 2.71)

= 8.76

Saturation Index SI =pH actual – pHs

=6.2- 8.76

=-2.56

Raw Water is aggressive

Similarly for water after aeration

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Aerated water EC =56.2 μs/cm

TDS/EC =0.6

TDS =0.6 x EC =0.6x 56.2 =33.72 mg/l

Substituting in K_1 =[H^+] [HCO_3^-]/ $[CO_2]$

$[CO_2]$ =[H^+] [HCO_3^-]/ K_1

pH =6.8

-log H^+ =6.8

H^+ =$10^{-6.8}$

Alkalinity =[HCO_3^-] =24mg/l

Substituting $[CO_2]$ = $[10^{-6.8}]$ $[10^{-3}x24/61]$/ $[4.71x10^{-7}]$ g mol/l

=13.24x 10^{-5}x 44x 103 mmol/l

=5.83 mg/l

Hardness =14mg/l

Ca^{2+} =40 x 14/100 =5.6 mg/l

pHs =2.2 - log[Ca^{2+}] - log [HCO_3^-]

=2.2 - log [$5.6x10^{-3}$/40] - log [$24x10^{-3}$ /61]

=2.2 - (-3.85) - (- 3.41)

= 9.46

Saturation Index SI =pH actual - pHs

=6.8- 9.46

=-2.66

Saturation index of aerated water (-2.66) >Saturation index of Raw Water (-2.56). Hence aerating surface water aggressivity is increased

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b Rapid Mixing (Coagulation)

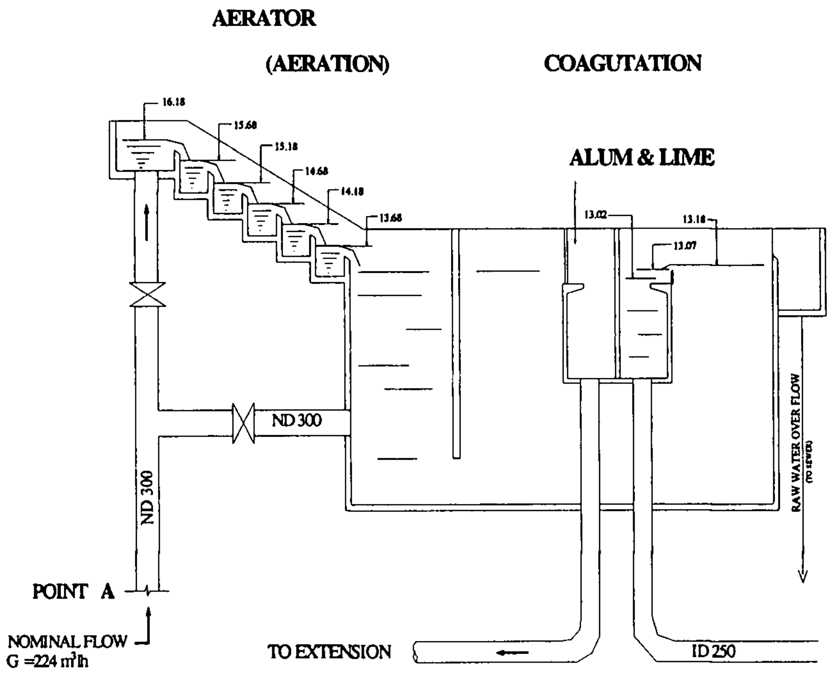

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Fig 4.13 Details of Aerator and Coagulation Chamber

Aerated water is allowed to flow over a weir. Alum 10ppm and lime 2.5 ppm are dosed and water flows into a chamber of 1 m length 0.5 m width and 4.2 m depth as shown in fig. 4.13

Height of fall is 0.75 m

Volume of coagulation chamber $= 1 \times 0.5 \times 4.2$ m

$= 2.1 \text{ m}^3$

$$\text{Retention time} = \frac{V}{Q} = \frac{2.1}{4300/24 \times 3600} = 42.2 \text{ Sec.}$$

Energy of dissipation

$$E = Q\,(m^3/s)\ \Delta h\,(m)\ \rho(kg/m^3)\ g(m/s)$$

$$= \frac{4300}{24 \times 3600} \times 0.75 \times 1000 \times 9.8$$

$$= 365.8 \text{ Joules}$$

$$G = \sqrt{E/V\acute{\eta}}$$

$$\text{Where } \acute{\eta} = 10^{-3} \text{ kg m}^{-1} \text{ s}^{-1}$$

$$G = \sqrt{\frac{365.8}{10^{-3} \times 2.1}}$$

$$= 417.4 \text{ s}^{-1}$$

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c. Pulsator

$$\text{Dimension} = 9.5 \times 9.5 \times 4.2 \text{ m}$$

$$= 379.05 \text{ m}^3$$

$$\text{Detention Time} = \frac{379.05}{4300/24}$$

$$= 2.11 \text{ hrs}$$

$$\text{Velocity} = \frac{4300/24}{9.5 \times 9.5} = 1.98 \text{ m/hr}$$

Time taken for rise of water in pulsator 10 sec

Time taken to drop water in pulsator is 2 sec.

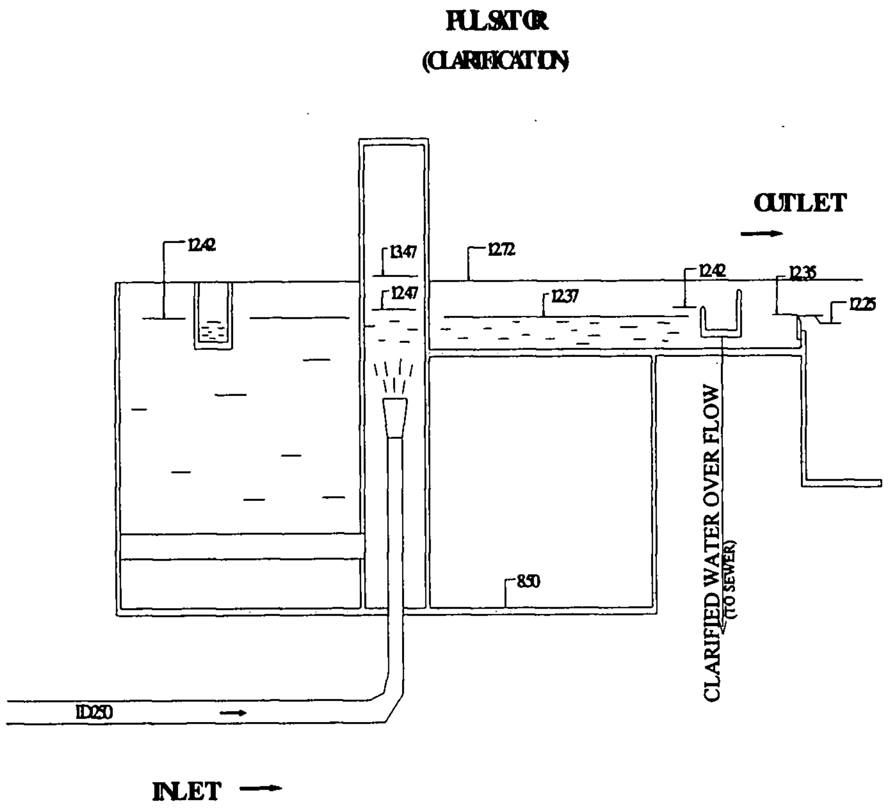

Fig 4.14 Details of Pulsator

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Pulsator is designed for a sludge blanket of 0.7m thickness as shown in fig. 4.14. The sludge blanket oscillates with the pulse create at an interval of 20 seconds. Flow of water is upwards and solids are captured on the sludge blanket.

How ever the Pulsator is open to sky and experiences temperature variation during the day. By noon sun is directly above the pulsator resulting in thermal stratification. Consequently the sludge blanket in the pulsator becomes unstable, disintegrates and allows flocs to flow into the rapid sand filter. Thermal stratification could be prevented by covering the pulsator and preventing direct sunlight falling on the pulsator.

This situation deteriotes with raw water having low turbidity and high colour, and formation of sludge blanket is not possible with low turbidity and enabling colour particle to flow into the rapid sand filter without being captured in the pulsator. This situation may be remedied by adding bentonite or recycling of sludge settled in the wet well and enhancing the turbidity of raw water to be treated.

d. Rapid Sand Filter

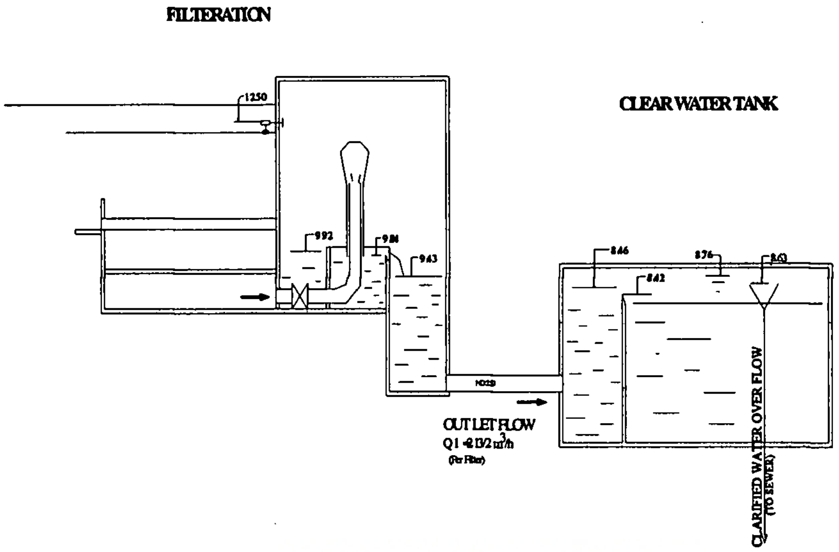

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Fig 4.15 Details of Rapid Sand Filter and Clear Water Tank

Type - Gravity down flow as shown in fig. 4.15

Number - 2

Dimension = Width 3m x Length 6m x 2 nos beds

Surface area of each bed = 18 m^2

Filtration rate = (4300/2)/ 18

= 119.4 m/day (4.97m/hr)

Flow control : Constant rate filtration

Filter sand

Effective Size	0.65 mm
Uniformity Coefficient	1.65
Thickness of supporting Layer	500 mm

Under Drain : Perforated Pipe

Air Scour rate : 48 m/hr (0.8 m^3/m^2 minute)

Back wash rate : 24 m/hr (0.4 m^3/m^2 minute)

(e) Clear water reservoir

Dimension: length 20m X width 17m X depth varies from 1.3m to 1.8m

Capacity : 455m^3

Detention time : 2.5 hours

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(f) Back wash system of filters

Back washing along with air scouring and surface sweeping takes 4 to 5 minutes.

Back wash water : Received from clear water tank

Wash water pump : Guinerd Type NE 12 x 25

Capacity : 250 m^3/hr

Total Head : 7m

Power rating : 11kW

Nos : 2

(g) Air scour system of filter

Air receiver : Reciprocating compressor. Hibon make
Type : SN V6
Capacity : 955 STP
Pressure : 300 mb
Power rating : 15 kW
Nos : 2

(h) Chemical feeding system

Alum feeding system

Feeding point : Rapid mixing basin
Type of Alum : Lump from basin
Alum solution tank : 3.2 m^3 2 Nos Size 1.5 x 1.5 x 1.45 m
with stirrers (1.1 kW)
Alum pump : 310 l/hr & 0.75 kW rating

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Lime feeding system

Type of lime : Quick lime
Feeding point : Rapid mixing chamber
Lime slaker : 4m^3 2 Nos size 1.5 x 1.5 x 1.85 m
with stirrers 1.1 kW
Lime milk transfer: Horizontal Volute type
Pump : a) 120 l/hr & 0.37 kW and
b) 200 l/hr & 0.55 kW

Chlorination system
Type of chlorine : Liquefied chlorine in cylinders
Feeding point : Post chlorination to filtered water channel
Chlorinator : 1.8 kg/hr x 2 units
Chlorinator make : Wallace & Tieranan
Pump for feed water: $5m^3$/hr with 33m head and 1.5 kW rating

4.4 CHEMICAL DOSING SYSTEM

4.4.1 Alum dosing system

4.4.1.1 Out Line of the system

Alum is used as coagulant to remove dissolved suspended and colloidal particles which contribute to colour and Turbidity. Alum is stored in bags and dissolved in alum solution tanks and dosed with required strength after aeration before the pulsator at the weir for coagulation.

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The average Al_2O_3 content in aluminum sulphate $[Al_2(SO_4).18H_2O]$ is 17% and is expected to feed alum solution with a chemical strength of approximately 25% Al_2O_3 by weight at the dosing point.

4.4.1.2 Specification

Alum Solution tank
Volume 3.2 m^3
Number of Units 2
Alum pump
Capacity 310 l/hr
Power rating 1.75

4.4.2 Preparation and Dosing of Alum Solution

4.4.2.1 Preparation

Alum solution as 25% alum stone is prepared

V = Volume of Alum solution tank

P = $[Al_2 (SO4)_3 .18\ H_2O]$ alum stone weight kg

$P/1000\ V$ = $25 / 100$

$$P = \frac{25}{100} \times V \times 1000\ \text{Kg}$$

$$= 250\ V\ \text{Kg}$$

4.4.2.2 Dosing

Dosage of alum is determined by Jar test carried out routinely in the laboratory. Dosage is quantified in mg/l.

The alum feeding rate is given as:

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W_{A1} = required Alum Quantity g/Sec.

L_{A1} = required Alum Solution g/Sec.

L_A = feeding rate of 25% Alum solution l/min

D = Dosage mg/l.

Q = Treatment capacity m^3/Sec.

W_{AI} = $Q \times D$

25 = W_{A1}/L_{A1}

L_{A1} = $4 \times W_{A1} = 4 \times Q \times D$

$$L_A = \frac{4 \times Q \times D \times 60\ \text{l/min}}{1000}$$

For example

If D = 10 ppm (g/m^3)

Q = 3600 m^3/day = 0.04 m^3/

L_A = $\frac{4 \times 0.04 \times 1 \times 60 \text{ l/m}}{1000}$

= 0.096 l/min

Required alum a day = D x Q

= 10 g/m^3 x 3600 m^3/day

= 36000 g/day

= 30 kg/day

But Al_2O_3 content in Aluminum sulphate Al_2SO_4 18 H_2O is 17%

Actual Wt. of Alum = $\frac{30}{17/100}$

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= 176 kg/day

Alum dosage per day 4 bag 50 kg is 200 kg / day as such usage is reasonable

4.4.3 Lime Dosing System

4.4.3.1 Out lines of the system

Powdered Lime is dissolved in a lime slaker. The lime milk produced in the lime slaker is fed to lime storage container by the milk transfer pump and prepared with specified chemical strength of lime milk.

Lime Slaker

Volume 4.0 m^3

Number 2 Nos Units

Lime pump

Capacity a) 120 l/hr with 0.37 kw rating
b) 200 l/hr with 0.55 kw rating

4.4.3.2 Preparation of lime Milk

Lime [$Ca(OH)_2$] is dissolved by lime slaker and this slaker produces lime milk. Lime containing more than 93% CaO is used such that lime milk will produce 10% $Ca(OH)_2$ by weight.

4.4.3.3 Pre – lime dosing

Raw water is tested in the Jar test to determine the pre lime dose. If dosage in ppm (g/m^3) is D, treatment capacity (m^3/sec) is Q, Required lime (g/sec) is L, quantity of lime required (L) and lime milk (LM) is calculated as follows.

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$L = Q \times D \text{ (g/sec)}$

$LM = 10L/100$

$= 10 L$

$LM = 10 \times DQ$

Where LM = Required Quantity of Lime Milk (Cc/sec) [10% by weight]

Eg: Lime Dosage $D = 2.5 \text{ mg/l}$.

$Q = 3600 \text{ m}^3\text{/day} = 0.04 \text{ m}^3\text{/s}$

$L = Q \times D$

$= 0.04 \times 2.5 \text{ g/sec}$

$= 0.1 \text{ g/sec}$

$$\begin{aligned} LM &= 10 \text{ x } L \\ &= 10 \text{ x } 0.1 \quad = \quad 1 \text{ g/sec} \\ &= 1 \text{ cc/sec} \\ &= \frac{1 \text{ x } 3600 \text{ l/sec}}{1000} \\ &= 3.6 \text{ l/hr} \end{aligned}$$

$$\begin{aligned} \text{Amount of Lime required} &= D \text{ x } Q \\ &= 2.5 \text{ (g/ms) x } (0.04 \text{ m}^3\text{/sec}) \\ &= 0.096 \text{ gm/sec} \\ &= 0.096 \text{ x } 3600 \text{ x } 240 \\ &= 9000 \text{ gm} \\ &= 9 \text{ kg./day} \end{aligned}$$

But lime $Ca(OH)_2$ contains more than 93% CaO

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$$\begin{aligned} \text{Actual amount of Lime} &= \left[\frac{9}{9.3/100}\right] \text{X } \frac{1}{10/100} \\ &= 96.7 \text{ kg/day} \end{aligned}$$

But lime used per day at the plant is 100kg/day as such the usage is reasonable.

4.4.4 Clear Water Reservoir

Clear water reservoir is shown in fig. 4.15 of length 20m width 17m and depth varies from 1.3 to 1.8m. Baffle wall is constructed with the reservoir to facilitate plug flow, which provides adequate contact time for chlorination.

$$\begin{aligned} \text{Volume of Clear Water Reservoir} &= 20 \text{ x } 17 \text{ x } \left(\frac{1.8 + 1.3}{2}\right) \\ &= 527 \text{ m}^3 \end{aligned}$$

Design usage volume = 455 m^3

Daily Supply of water 4300 m^3/day

Detention time = $455/4300_y$

= 2.53 hours

4.4.5 Disinfection

4.4.5.1 Out line of the disinfection system

Liquefied chlorine is used as a disinfectant. It is stored in 68 kg cylinders. Chlorine is with drawn from the containers and gasified prior to entering the chlorinators and mixed with water leaving the rapid sand filters.

Non availability chlorine gas bleaching powder is dosed at the entry point of the clear water tank.

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4.4.5.2 Dosing

Dosage

Post Chlorination max 3 ppm

Required chlorine is calculated as follows:

$$CG = D\ g/m^3 \times Q\ m^3/hr. \times 0.001\ kg/hr$$

Where CG = Required Chlorine kg/hr

D = Dosage mg/l.

Q = Treatment Capacity m^3/hr

Required Chlorine

CG = Required Chlorine kg/hr

D = Dosage (0.003 mg/l).

Q = Treatment Capacity 4300 m^3/day or 180m3/hr

CG = D x Q

= 0.003 kg/m^3 x 180 m^3 / hr

= 0.54 kg/hr

Total chlorine required for a day = 0.54 x 24

= 12.96 kg

68 Kg of chlorine is used for 6 days as such

Daily consumption = 68/6

= 11.33 Kg

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Chlorine usage is justifiable

4.5 COST OF WATER PRODUCED AT RADDOLUGAMA WATER TREATMENT PLANT

4.5.1 PRODUCTION AND CONSUMPTION OF TREATED WATER

Average daily production of treated water is 4000 m^3 (Presently)

Table 4.3 Daily consumption of water in Raddolugama

Category of consumer	Consumption m^3/day
Domestic	2425
Board Quarters	7
Schools	6
Government Quarters	21
Government Institution	2
Army	74
Police	2
Hospitals	1
Commercial institution	36
Industry/ Construction	1
BOI approved Industries	945
Religious Institutions	18
NWSDB premises	1
Total Daily Consumption	3542

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Average daily water consumption =3542 m^3 /day

NRW = (4000-3542)/3542

= 12.9%

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4.5.2 COST OF TREATED WATER

Break down of cost for treating water on monthly basis

Electricity = Rs 375,000/-
Salary for staff of 44nos = Rs 400,000/-
Repair and maintenance of
Equipment, machinery and vehicle = Rs 50,000/-
Chemicals = Rs 150,000/-
Total monthly expenditure = Rs 1,000,000/-

Unit cost of water supplied = Rs. 1,000,000/ 3542x30
= Rs 9.40 per Cu.m

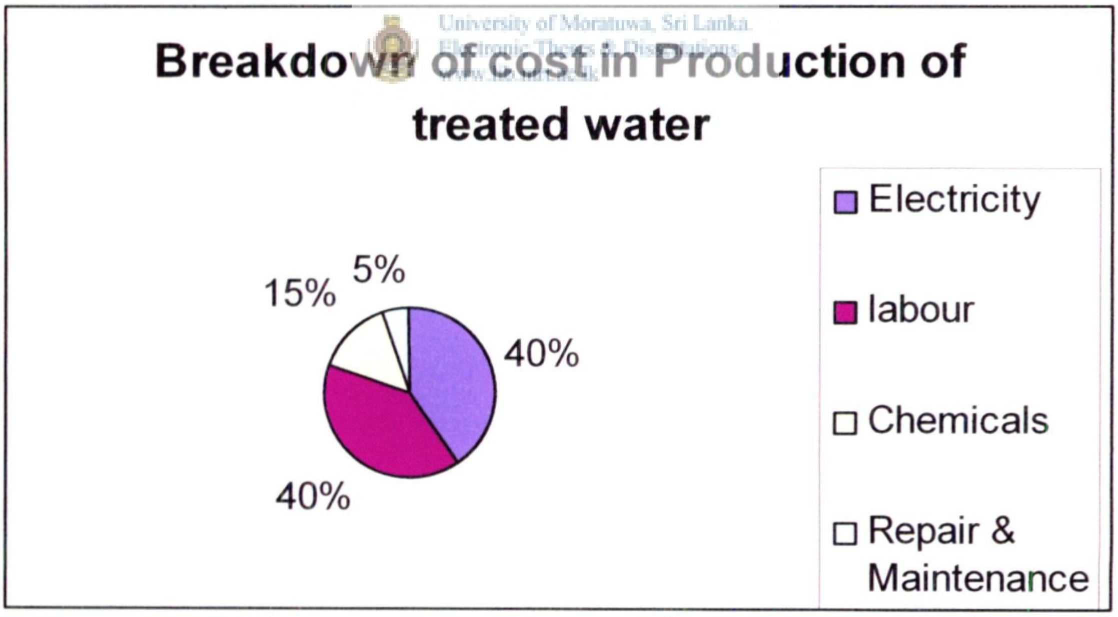

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Fig 4.16 Breakdown of cost of Production of treated water

5.0 ANALYSES AND DISCUSSION OF RESULTS

5.1 DANDUGAM-OYA WATER QUALITY AND VARIATION

Raw water quality data from 2001 to 2005 and additional data collected during the study are used for the purpose of analyzing the water quality variation in Dandugam - Oya. Accordingly

- Colour of raw water varies between 40 and 100 Hazen units whereas turbidity varies between 10 to 30 NTU. Most surface water has High Turbidity and Low Colour. Whereas raw water in Dandugam Oya has high colour and low turbidity.

- pH varies from 6.5 to 6.8.

- Alkalinity varies between 10 and 40 mg/l. Raw water has low alkalinity (<50 mg/l) as such the buffering capacity is low.

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- Hardness of water varies between 20 and 50 mg/l. Hence the raw water is soft (Hardness <75 mg/l as CaCO3).

- Dissolved Oxygen in raw water varies between 5 to 6 mg/l while the saturated Oxygen content at 30° C is 7.7 mg/l. Hence need for aeration of surface water does not arise, except for removal of odour which occurs occasionally. Additional cost is incurred to lift raw water by 4m for aeration. Further aggressivity of water is increased by aeration.

5.2 IMPROVEMENT TO ENHANCE COAGULATION

The treatment process for raw water with the above physico chemical composition has to be handled carefully. Alum and lime used for coagulation and pH adjustment respectively are being added to a chamber located before the pulsator as in fig. 5.1 where the hydraulic jump creates a velocity gradient of 417s^{-1}. Where as, by shifting the dosing point to the top of the aerator, as shown in fig. 5.2 the velocity gradient could be increased to 1344 s^{-1}, as shown in the calculation given in Annex A.

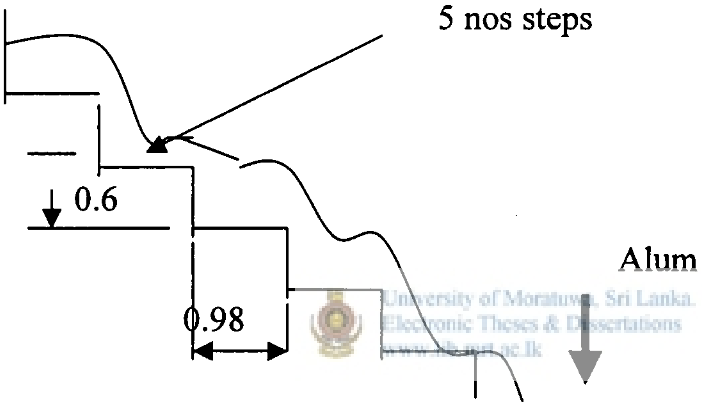

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Fig 5.1 Alum Dosing after Step aerator

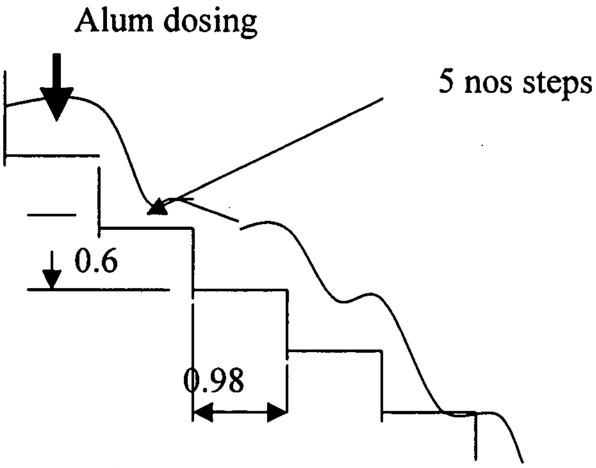

Fig 5.2 Alum dosing before Step aerator

The velocity gradient G is increased from 417.4 s^{-1} to 1344 s^{-1} by shifting the dosing point of Alum, which would improve coagulation and optimises the use of alum. Further single point dosing of chemicals to the chamber prior to the pulsator was modified by having a horizontal perforated pipe being placed on the top of aerator to improve dispersion, blending of coagulant before hydrolysis and polymerisation are complete as in fig 5.3.

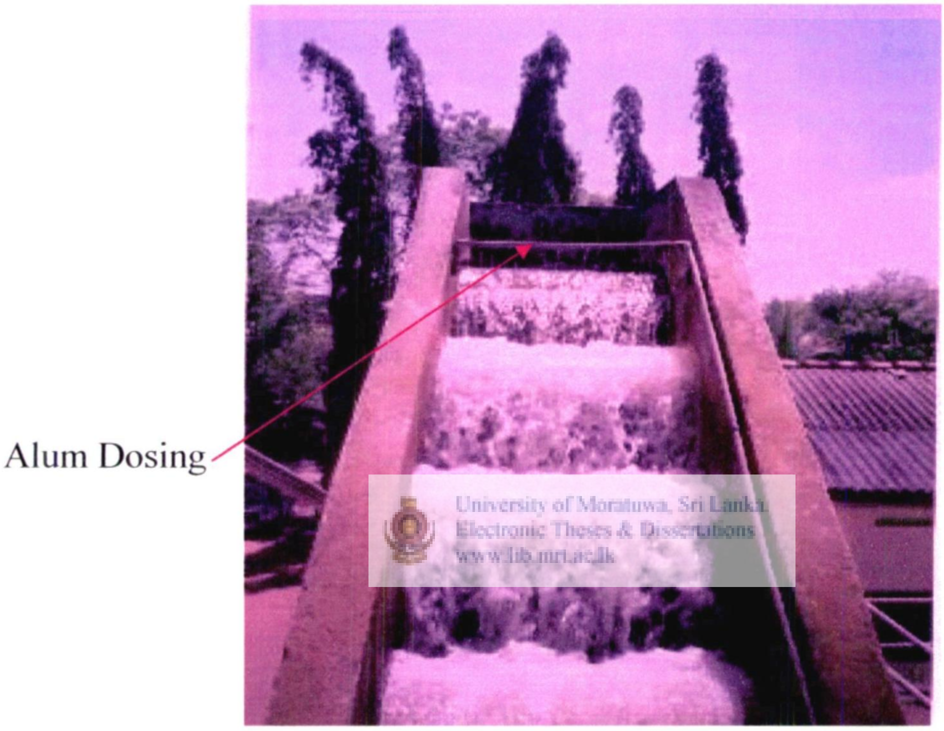

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Fig 5.3 Dosing Alum on top of aerator
(Original in Colour)

Modification and shifting the point of coagulation resulted in improved treated water quality. The average turbidity and colour of treated water before and after May 2004 are 2.9NTU and 1.51 NTU and 9.41Hazen Units and 4.66Hazen units respectively. As such the reduction of turbidity is 47.9% and colour is 49.5%. Since the only change that was done on the plant was the change of the coagulant dosing point, this improvement in performance can be largely attributed to the proper location of the coagulant dosing point, to achieve a G value of 1344 s^{-1}.

5.3 IMPROVEMENT TO CLARIFICATION PROCESS

Pulsator is an advanced clarification process with sludge blanket to remove agglomerated particles. Formation of sludge blanket is dependent on the turbidity of raw water. When the raw water has low turbidity addition of bentonite or recirculation sludge settled in the intake well enhances the formation of sludge blanket.

Sunlight directly falling on the pulsator creates thermal stratification which affects the stability of the sludge blanket. Disintegration of sludge blanket into minute sludge particle is visible by mid day when the sunlight directly falls on the pulsator.

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6.0 CONCLUSIONS AND RECOMMENDATIONS

6.1 CONCLUSIONS

The following conclusions can be drawn from this study

1. According to the Physico Chemical composition, raw water in Dandugam Oya
    (a) Has high colour (40 to 100 Hazen Units) and low turbidity (10 to 30 NTU)
    (b) Has low buffering capacity due to the low alkalinity (10 to 40 mg/l)
    (c) and is soft (hardness 20-50 mg/l)

2. Dissolved Oxygen in raw water varies from 5 to 6mg/l. As such aeration is essential only to remove undesirable odour in raw water which may occur occasionally. Otherwise aeration of surface water increases aggressivity (Saturation index $<<0$) and additional cost is incurred to pump water by 4m to the inlet of the aerator.

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3. Higher velocity gradient ($1344s^{-1}$) can be achieved by adding alum on the top of the aerator instead of dosing into the chamber prior to the pulsator.

4. Coagulation of chemicals added is improved by dosing alum through a multi perforated horizontal pipe which enhances dispersion and mixing than dosing from single point.

5. Build up of sludge blanket in the clarifier depends on the turbidity of raw water. High turbidity with low colour will produce strong sludge blanket, where as low turbidity and high colour will produce weak sludge blanket with lower removal efficiency, resulting in flow through condition in the clarifier and clogging the filter, which has to be avoided.

6. Thermal stratification occurs due to direct sunlight falling on the pulsator and creates instability to the sludge blanket This could be avoided by providing a cover above the pulsator.

7. Amount of chemicals, such as Alum, lime and chlorine is not varied according to the flow of water for treatment during the day and night. Production of treated water is reduced during the night whereas is high during the day varying with the demand. Excessive use of Alum and lime during the night contributes to formation of gelatinous matter on the top of the filter which contributes to formation of cracks on the surface of the filter bed.

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6.2 RECOMMENDATIONS

Based on the observation, the following recommendations are made.

1. Colour in treated water is due to lack of knowledge of the operating staff on proper operating procedure under different raw water condition which occurs during different period of the year. Capacity building of Operating staff is essential with more responsible personnel involved in the management of treatment plant with knowledge on water chemistry and treatment process.

2. Optimization on the use of chemicals such as Alum, lime and Chlorine by varying the dosage according to the production quantity of treated water should be carried out.

3. Ensure the sludge blanket remains in the clarifier (Pulsator) during prolonged drought as the turbidity will be low. If sludge blanket does not exist or gradually disappears steps should be taken to recycle the sludge deposited in the base of the wet well or add bentonite slurry to the wet well to enhance the raw water turbidity.

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4. Aeration of surface water is not necessary as the dissolved oxygen level is high. Aeration leads to increase in aggresivity of water and reducing the pH which causes damage to the concrete structure of the unit process and lime may have to be added such that the Saturation Index (SI) is kept above zero to make treated water non aggressive. As such, by-passing the aerator is recommended. However under unusual circumstance when odour is encounted in treated water aeration may be considered.

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ANNEX A

Calculation on comparison of coagulation for dosing of Alum after and before aeration.

Aerated water is allowed to flow over a weir. Alum 10ppm and lime 2.5 ppm are dosed and water flows into a chamber of 1 m length 0.5 m width and 4.2 m depth as shown in fig. 5.1

Height of fall is 0.75 m

Volume of coagulation chamber $= 1 \times 0.5 \times 4.2$ m

$= 2.1$ m^3

Energy of dissipation

$$E = Q(m^3/s)\ \Delta h\ (m)\ \rho(kg/m^3)\ g(m/s)$$

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$$= \frac{4300}{24 \times 3600} \times 0.75 \times 1000 \times 9.8$$

$$= 365.8 \text{ Joules}$$

$$G = \sqrt{E/V\eta}$$

Where $\eta = 10^{-3}\ kg\ m^{-1}\ s^{-1}$

$$G = \sqrt{\frac{365.8}{10^{-3} \times 2.1}}$$

$$= 417.4\ s^{-1}$$

Retention time $= \frac{V}{Q} = \frac{2.1}{4300/24 \times 3600} = 42.2$ Sec.

But the dosing point of Alum was changed to the top of the Aerator as in fig 5.2

Where the width of aerator is 0.9 m , depth of water 150mm and length is 1.0m

Volume of coagulation chamber =0.9 x 1 x 150/1000= 0.135 m^3

Total Detention time = 42.2 +5 x 0.135/ (4300/24x3600)

= 55.75sec

$$E = \frac{4300}{24 \times 3600} \times 0.5 \times 1000 \times 9.8$$

= 243.9 Joules

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$$G = \sqrt{\frac{243.9}{10^{-3} \times 0.135}}$$

$= 1344\ s^{-1}$

Table B Raw water Data (2001- 2005) – Dandugam-oya

Parameters		Dates	15/02/2001	22/02/2001	07/03/2001	08/03/2001	0/03/2001	30/04/2001
PHYSICAL	1	Appearance	turbid	turbid	turbid	turbid	turbid	turbid
QUALITY	2	Color (Hazen unit)	89	100	59	44	25	71
	3	Odour						
	4	Taste						
	5	Turbidity (NTU/FTU)	15	21	12	9	4	13
CHEMICAL	6	pH	6.80	6.60	7.00	6.50	6.30	6.00
QUALITY	7	Electrical Conductivity at 25⁰C - (ms/cm)	83.30	46.20	58.30	45.70	73.30	51.40
	8	Chloride (as Cl) -mg/l	17.00	15.00	18.00	9.00	10.00	11.00
	9	Free Residual Chlorine (as Cl_2) - mg/l						
	10	Total alkalinity(as $CaCo_3$) -mg/l	32.00	24.00	32.00	24.00	40.00	24.00
	11	Ammonium (as N) -mg/l	0.37	0.15	0.01	0.00	0.16	-
	12	Albuminoid Ammonia						
	13	Nitrate (as N) - mg/l	0.00	0.01	0.02	0.03	0.01	0.01
	14	Niitrite (as N) - mg/l	7.04	7.48	11.44	8.80	9.68	4.40
	15	Fluride (as F) - mg/l	0.24	0.00	0.18	0.02	0.00	0.01
	16	Posphate (as PO_4) - mg/l	0.34	0.14	0.27	0.59	0.48	0.21
	17	Total Residue - mg/l						
	18	Total Hardness(as $CaCo_3$) -mg/l	38.00	24.00	32.00	24.00	52.00	32.00
	19	Total Iron (as Fe) - mg/l	1.42	1.25	0.90	0.90	0.35	1.55
	20	Sulphate (as SO_4) - mg/l	1.00	2.00	7.00	11.00	0.00	4.00
	21	Sulphide, Hydrogen (as H_2S) - mg/l	0.00	0.01	0.01	0.01	0.00	-
	22	Total suspended solid-mg/l	-	-	18.00	20.00	13.00	15.00
	23	Chemical Oxygen Demand (COD) - mg/l	2.80	9.89	12.60	-	16.20	13.61
	24	Dissolved Oxygen (DO)-mg/l				-	6.80	5.50
	25	Residual Chlorine (as Cl_2) - mg/l						
	26	Calcium (as $CaCO_3$)-mg/l						
	27	Magnesium (as Mg)-mg/l						
	28	Manganese (as Mn)-mg/l						
	29	Aluminium (as Al) - mg/l	-		0.00	-	0.01	-
	30	Arsenic (as As) – mg/l						
	31	Cyanide (as Cn) - mg/l						
	32	Mercury (Total as Hg)-mg/l						
	33	Selenium (as Se) - mg/l						
	34	Lead (as Pb) - mg/l						
Heavy	35	Cadmium (as Cd) - mg/l						
Metals	36	Znic (as Zn) - mg/l						
	37	Copper (as Cu) - mg/l						
	38	Chromium (as Cr) - mg/l						
BIOLOGICAL QUALITY	39	Biochemical Oxygen Demand (BOD) - mg/l						
	40	Total Coloforms at 35⁰C/100ml						
	41	Escherichia Coli at 44⁰C/100ml						

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Parameters		**Dates**	1/06/2001	16/08/2001	15/08/2001	15/08/2001	15/08/2001	30/08/2001
PHYSICAL QUALITY	1	Appearance	turbid	turbid	turbid	turbid	turbid	Turbid
	2	Color (Hazen unit)	61	63	62	64	0	88
	3	Odour						
	4	Taste						
	5	Turbidity (NTU/FTU)	12	11	12	11	0	14
CHEMICAL QUALITY	6	pH	5.90	6.30	6.20	6.60	6.80	6.30
	7	Electrical Conductivity at $25^{0}C$ - (ms/cm)	59.20	67.00	66.00	66.40	103.00	72.00
	8	Chloride (as Cl) -mg/l	13.00	17.00	16.00	21.00	22.00	19.00
	9	Free Residual Chlorine (as Cl_2) - mg/l						
	10	Total alkalinity(as $CaCo_3$) -mg/l	32.00	-	28.00	28.00	20.00	32.00
	11	Ammonium (as N) -mg/l	0.28	-	0.17	0.16	0.10	-
	12	Albuminoid Ammonia						
	13	Nitrate (as N) - mg/l	0.00	-	0.02	0.01	0.00	0.00
	14	Niitrite (as N) - mg/l	5.28	-	3.90	0.90	1.20	1.70
	15	Fluride (as F) - mg/l	0.17	-	-	0.00	0.11	0.00
	16	Posphate (as PO_4) - mg/l	2.26	0.08	0.30	0.51	0.74	0.40
	17	Total Residue - mg/l						
	18	Total Hardness(as $CaCo_3$) -mg/l	36.00	-	32.00	32.00	40.00	32.00
	19	Total Iron (as Fe) - mg/l	0.95	0.78	0.80	0.85	0.03	1.50
	20	Sulphate (as SO_4) - mg/l	0.00	1.00	1.00	1.00	18.00	0.00
	21	Sulphide, Hydrogen (as H_2S) - mg/l	0.00	-	-	0.00	0.00	-
	22	Total suspended solid-mg/l	6.00	-	-	-	-	-
	23	Chemical Oxygen Demand (COD) - mg/l	24.02	-	10.50	10.50	19.80	16.10
	24	Dissolved Oxygen (DO)-mg/l	6.40	-	6.10	5.80	6.50	5.40
	25	Residual Chlorine (as Cl_2) - mg/l						
	26	Calcium (as $CaCO_3$)-mg/l						
	27	Magnesium (as Mg)-mg/l						
	28	Manganese (as Mn)-mg/l			0.18	0.04	0.33	-
	29	Aluminium (as Al) - mg/l	-	-	-	-	-	-
	30	Arsenic (as As) - mg/l						
	31	Cyanide (as Cn) - mg/l						
	32	Mercury (Total as Hg)-mg/l						
	33	Selenium (as Se) - mg/l						
Heavy Metals	34	Lead (as Pb) - mg/l						
	35	Cadmium (as Cd) - mg/l						
	36	Znic (as Zn) - mg/l						
	37	Copper (as Cu) - mg/l						
	38	Chromium (as Cr) - mg/l						
BIOLOGICAL QUALITY	39	Biochemical Oxygen Demand (BOD) – mg/l						
	40	Total Coloforms at $35^{0}C$/100ml						
	41	Escherichia Coli at $44^{0}C$/100ml						
	42	Fecal Steptococci at $37^{0}C$/100ml						

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Parameters		**Dates**	20/09/2001	20/09/2001	19/12/2001	20/03/2002	20/03/2002	20/04/2002
PHYSICAL QUALITY	1	Appearance	clear	turbid	turbid			
	2	Color (Hazen unit)	42	93	42	36	85	114
	3	Odour						
	4	Taste						
	5	Turbidity (NTU/FTU)	7	17	9	7	15	19
CHEMICAL QUALITY	6	Pump house	6.40	6.60	6.40	6.40	7.00	6.50
	7	Electrical Conductivity at 25⁰C - (ms/cm)	80.00	41.00	69.00	60.00	52.00	58.00
	8	Chloride (as Cl) -mg/l	20.00	14.00	25.00	19.00	-	14.00
	9	Free Residual Chlorine (as Cl_2) - mg/l						
	10	Total alkalinity(as $CaCo_3$) -mg/l	40.00	-	28.00	60.00	-	24.00
	11	Ammonium (as N) -mg/l	-	-	0.11	0.10	0.23	0.11
	12	Albuminoid Ammonia						
	13	Nitrate (as N) - mg/l	2.60	3.90	3.90	0.80		0.50
	14	Niitrite (as N) - mg/l	0.01	0.01	0.01	0.01		< 0.01
	15	Fluride (as F) - mg/l	0.10	0.00	0.00	0.10		< 0.01
	16	Posphate (as PO_4) - mg/l	0.80	0.30	0.40	1.20		0.20
	17	Total Residue - mg/l						
	18	Total Hardness(as $CaCo_3$) -mg/l	80.00	-	32.00	44.00		48.00
	19	Total Iron (as Fe) - mg/l	1.30	1.10	0.90	0.50		1.70
	20	Sulphate (as SO_4) - mg/l	3.00	2.00	2.00	1.00		< 1.00
	21	Sulphide, Hydrogen (as H_2S) -mg/l			-			
	22	Total suspended solid-mg/l				-		-
	23	Chemical Oxygen Demand (COD) - mg/l	-	14.30	25.10	8.10	6.80	16.90
	24	Dissolved Oxygen (DO)-mg/l			1.60			
	25	Residual Chlorine (as Cl_2) - mg/l						
	26	Calcium (as $CaCO_3$)-mg/l			-			
	27	Magnesium (as Mg)-mg/l						
	28	Manganese (as Mn)-mg/l						
	29	Aluminium (as Al) - mg/l						
	30	Arsenic (as As) - mg/l						
	31	Cyanide (as Cn) - mg/l						
	32	Mercury (Total as Hg)-mg/l						
	33	Selenium (as Se) - mg/l						
	34	Lead (as Pb) - mg/l						
	35	Cadmium (as Cd) - mg/l						
Heavy Metals	36	Znic (as Zn) - mg/l						
	37	Copper (as Cu) - mg/l						
	38	Chromium (as Cr) - mg/l						
BIOLOGICAL QUALITY	39	Biochemical Oxygen Demand (BOD) - mg/l			1.00	2.00	0.00	1.00
	40	Total Coloforms at 35⁰C/100ml						
	41	Escherichia Coli at 44⁰C/100ml						
	42	Fecal Steptococci at 37⁰C/100ml						

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Parameters		Dates	02/05/2002	20/05/2002	02/06/2002	12/06/2002	26/02/2002	02//07/2002
PHYSICAL QUALITY	1	Appearance						
	2	Color (Hazen unit)	50	130	57	40	74	61
	3	Odour						
	4	Taste						
	5	Turbidity (NTU/FTU)	9	26	12	7	13	13
CHEMICAL QUALITY	6	pH	6.90	6.40	6.70	6.70	6.40	6.70
	7	Electrical Conductivity at 25^{0}C - (ms/cm)	52.00	52.00	62.00	65.00	59.00	56.00
	8	Chloride (as Cl) -mg/l	10.00	10.00	-	12.00	10.00	12.00
	9	Free Residual Chlorine (as Cl_2) -mg/l						
	10	Total alkalinity(as $CaCo_3$) - mg/l	36.00	28.00	-	28.00	32.00	28.00
	11	Ammonium (as N) -mg/l	0.18	0.20	0.38	0.20	0.23	0.10
	12	Albuminoid Ammonia						
	13	Nitrate (as N) - mg/l	1.10	0.80	1.30	1.00	1.00	1.10
	14	Niitrite (as N) - mg/l	< 0.01	< 0.01	< 0.01	0.01	0.01	< 0.01
	15	Fluride (as F) - mg/l	< 0.10	< 0.10	< 0.10	0.10	0.10	0.10
	16	Posphate (as PO_4) - mg/l	0.30	0.20	0.50	0.30	0.20	0.30
	17	Total Residue - mg/l						
	18	Total Hardness(as $CaCo_3$) - mg/l	52.00	28.00	-	40.00	40.00	56.00
	19	Total Iron (as Fe) - mg/l	1.50	1.50				
	20	Sulphate (as SO_4) - mg/l	2.00	5.00	1.40	0.90	1.60	1.00
	21	Sulphide, Hydrogen (as H_2S) - mg/l			4.00	4.00	5.00	1.00
	22	Total suspended solid-mg/l	-	0.00	-	21.00	0.00	0.00
	23	Chemical Oxygen Demand (COD) - mg/l	2.50	6.60	4.60	6.60	6.60	0.00
	24	Dissolved Oxygen (DO)-mg/l			-			
	25	Residual Chlorine (as Cl_2) - mg/l						
	26	Calcium (as $CaCO_3$)-mg/l						
	27	Magnesium (as Mg)-mg/l						
	28	Manganese (as Mn)-mg/l						
	29	Aluminium (as Al) - mg/l						
	30	Arsenic (as As) - mg/l						
	31	Cyanide (as Cn) - mg/l						
	32	Mercury (Total as Hg)-mg/l						
	33	Selenium (as Se) - mg/l						
	34	Lead (as Pb) - mg/l						
Heavy Metals	35	Cadmium (as Cd) - mg/l						
	36	Znic (as Zn) - mg/l						
	37	Copper (as Cu) - mg/l						
	38	Chromium (as Cr) - mg/l						
BIOLOGICAL QUALITY	39	Biochemical Oxygen Demand (BOD) - mg/l	0.00	0.00	0.00	0.00	0.00	0.00
	40	Total Coloforms at 35^{0}C/100ml						
	41	Escherichia Coli at 44^{0}C/100ml						

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Parameters		Dates	12/07/2002	20/07/2002	20/07/2002	20/08/2002	20/08/2002	2/02/2003
PHYSICAL QUALITY	1	Appearance						
	2	Color (Hazen unit)	49	62	61	28	55	58.00
	3	Odour						
	4	Taste						
	5	Turbidity (NTU/FTU)	10	11	10	7	10	10.00
CHEMICAL QUALITY	6	pH	7.30	7.00	6.90	6.80	6.70	6.90
	7	Electrical Conductivity at $25^{0}C$ - (ms/cm)	68.00	78.00	74.00	95.00	83.00	59.00
	8	Chloride (as Cl) -mg/l	8.00	16.00	8.00	17.00	11.00	***22.00***
	9	Free Residual Chlorine (as Cl_2) -mg/l						
	10	Total alkalinity(as $CaCo_3$) - mg/l	14.00	24.00	32.00	42.00	20.00	25.00
	11	Ammonium (as N) -mg/l	0.12	0.50	1.50	2.10	0.42	
	12	Albuminoid Ammonia						
	13	Nitrate (as N) - mg/l	1.10	0.60	0.80	1.20	0.80	1.00
	14	Niitrite (as N) - mg/l	0.01	< 0.01	< 0.01	0.01	< 0.01	0.01
	15	Fluride (as F) - mg/l	< 0.10	0.20	0.10	0.20	< 0.10	***0.19***
	16	Posphate (as PO_4) - mg/l	0.40	0.80	0.20	0.20	-	
	17	Total Residue - mg/l						
	18	Total Hardness(as $CaCo_3$) - mg/l	18.00	32.00	48.00	44.00	28.00	17.00
	19	Total Iron (as Fe) - mg/l				0.30	0.90	0.88
	20	Sulphate (as SO_4) - mg/l	1.20	1.20	0.70			
	21	Sulphide, Hydrogen (as H_2S) -mg/l	2.00	1.00	2.00	1.00	3.00	
	22	Total suspended solid-mg/l	0.00	9.00	-	-	4.00	
	23	Chemical Oxygen Demand (COD) - mg/l	7.20	11.50	22.00	24.40	2.50	12.20
	24	Dissolved Oxygen (DO)-mg/l	5.40	3.60	-	-	-	
	25.00	Residual Chlorine (as Cl_2) - mg/l						
	26	Calcium (as $CaCO_3$)-mg/l						
	27	Magnesium (as Mg)-mg/l						
	28	Manganese (as Mn)-mg/l						
	29	Aluminium (as Al) - mg/l						
	30	Arsenic (as As) - mg/l						
	31	Cyanide (as Cn) - mg/l						
	32	Mercury (Total as Hg)-mg/l						
	33	Selenium (as Se) - mg/l						
	34	Lead (as Pb) - mg/l						
	35	Cadmium (as Cd) – mg/l						
	36	Znic (as Zn) - mg/l						
	37	Copper (as Cu) - mg/l						
	38	Chromium (as Cr) – mg/l						
BIOLOGICAL QUALITY	39	Biochemical Oxygen Demand (BOD) - mg/l	0.00	0.00	-	-	0.00	
	40	Total Coloforms at $35^{0}C$/100ml						
	41	Escherichia Coli at $44^{0}C$/100ml						

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Parameters		**Dates**	26-03-2003	24-04-2003	21.05.2003	26.06.2003	24.07.2003	21.08.2003
PHYSICAL QUALITY	1	Appearance						
	2	Color (Hazen unit)	130.00	99.00	122.00	47.00	26.00	115.00
	3	Odour						
	4	Taste						
	5	Turbidity (NTU/FTU)	24.00	18.00	24.00	8.00	5.00	21.00
CHEMICAL QUALITY	6	pH	6.80	7.20	6.20	6.10	6.70	6.60
	7	Electrical Conductivity at 25^{0}C - (ms/cm)	60.00	102.00	96.00	62.00	62.00	58.00
	8	Chloride (as Cl) -mg/l	***10.00***	***15.00***	***2.00***	***4.00***	***8.00***	***6.00***
	9	Free Residual Chlorine (as Cl_2) -mg/l						
	10	Total alkalinity(as $CaCo_3$) - mg/l	18.00	33.00	100.00	30.00	22.00	18.00
	11	Ammonium (as N) -mg/l						
	12	Albuminoid Ammonia						
	13	Nitrate (as N) - mg/l	0.80	0.10	1.30	1.20	0.90	0.30
	14	Niitrite (as N) - mg/l	lt 0.001	0.006	lt 0.01	lt 0.01	lt 0.01	lt 0.01
	15	Fluride (as F) - mg/l	***0.10***	***lt 0.10***	***lt 0.01***	***lt 0.01***	***lt 0.01***	***lt 0.01***
	16	Posphate (as PO_4) – mg/l	0.12	0.09	0.32	0.38	0.15	0.45
	17	Total Residue - mg/l						
	18	Total Hardness(as $CaCo_3$) - mg/l	50.00	47.00	26.00	30.00	18.00	22.00
	19	Total Iron (as Fe) - mg/l	1.59	3.00	lt 0.01	0.93	0.56	1.57
	20	Sulphate (as SO_4) – mg/l	lt 01	lt 01	1.00	2.00	lt 1	lt1
	21	Sulphide, Hydrogen (as H_2S) -mg/l	0.011	0.010	lt 0.01	lt 0.01	lt 0.01	lt 0.01
	22	Total suspended solid-mg/l						
	20	Chemical Oxygen Demand (COD) - mg/l	18.30	12.00	10.50	8.30	11.60	12.80
	24	Dissolved Oxygen (DO)-mg/l			5.40	5.00	3.20	6.40
	25	Residual Chlorine (as Cl_2) - mg/l						
	26	Calcium (as $CaCO_3$)-mg/l						
	27	Magnesium (as Mg)-mg/l						
	28	Manganese (as Mn)-mg/l						
	29	Aluminium (as Al) - mg/l						
	30	Arsenic (as As) - mg/l						
	31	Cyanide (as Cn) - mg/l						
	32	Mercury (Total as Hg)-mg/l						
	33	Selenium (as Se) - mg/l						
	34	Lead (as Pb) - mg/l						
	35	Cadmium (as Cd) - mg/l						
	36	Znic (as Zn) - mg/l						
	37	Copper (as Cu) - mg/l						
	38	Chromium (as Cr) - mg/l						
BIOLOGICAL QUALITY	39	Biochemical Oxygen Demand (BOD) - mg/l						
	40	Total Coloforms at 35^{0}C/100ml						
	41	Escherichia Coli at 44^{0}C/100ml						
	42	Fecal Steptococci at 37^{0}C/100ml						

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Parameters		Dates	04.09.2003	20.10.2003	07.11.2003	29.12.2003	26.01.2004	17.02.2004
PHYSICAL QUALITY	1	Appearance						
	2	Color (Hazen unit)	51.00	128.00	222.00	80.00	59	60
	3	Odour						
	4	Taste						
	5	Turbidity (NTU/FTU)	10.00	19.00	57.00	15.00	11	11
CHEMICAL QUALITY	6	pH	6.30	7.00	6.60	7.60	7.00	6.90
	7	Electrical Conductivity at 25^{0}C - (ms/cm)	67.00	59.00	74.00	69.00	64.00	104.00
	8	Chloride (as Cl) -mg/l	***4.00***	***12.00***	***7.00***	***9.00***	***12.00***	***21.00***
	9	Free Residual Chlorine (as Cl_2) -mg/l						
	10	Total alkalinity(as $CaCo_3$) - mg/l	16.00	24.00	20.00	14.00	75.00	15.00
	11	Ammonium (as N) -mg/l						
	12	Albuminoid Ammonia						
	13	Nitrate (as N) - mg/l	0.60	0.60	0.50	0.70	0.20	0.50
	14	Niitrite (as N) - mg/l	lt 0.01	lt 0.01	lt 0.01	lt 0.01	lt 0.01	lt 0.01
	15	Fluride (as F) - mg/l	***0.21***	***lt 0.01***	***lt 0.01***	***0.06***	0.30	lt 0.01
	16	Posphate (as PO_4) - mg/l	0.36	0.43	0.33	0.25	0.30	0.10
	17	Total Residue - mg/l						
	18	Total Hardness(as $CaCo_3$) - mg/l	18.00	14.00	22.00	40.00	17.00	20.00
	19	Total Iron (as Fe) - mg/l	1.01	1.97	2.67	0.91	0.80	1.00
	20	Sulphate (as SO_4) - mg/l	lt 1		1.00	2.00	1.00	1.00
	21	Sulphide, Hydrogen (as H_2S) -mg/l	lt 0.01	lt 0.01	lt 0.01	lt 0.01		lt 0.1
	22	Total suspended solid-mg/l						
	23	Chemical Oxygen Demand (COD) - mg/l	9.20	17.20	16.00	18.80	20.00	36.00
	24	Dissolved Oxygen (DO)-mg/l	6.20	6.60	6.20	5.50		
	25	Residual Chlorine (as Cl_2) - mg/l						
	26	Calcium (as $CaCO_3$)-mg/l						
	27	Magnesium (as Mg)-mg/l						
	28	Manganese (as Mn)-mg/l						
	29	Aluminium (as Al) - mg/l						
	30	Arsenic (as As) - mg/l						
	31	Cyanide (as Cn) - mg/l						
	32	Mercury (Total as Hg)-mg/l						
	33	Selenium (as Se) - mg/l						
	34	Lead (as Pb) - mg/l						
	35	Cadmium (as Cd) - mg/l						
	36	Znic (as Zn) - mg/l						
	37	Copper (as Cu) - mg/l						
	38	Chromium (as Cr) - mg/l						
BIOLOGICAL QUALITY	39	Biochemical Oxygen Demand (BOD) - mg/l						
	40	Total Coloforms at 35^{0}C/100ml						
	41	Escherichia Coli at 44^{0}C/100ml						

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Parameters		Dates	31.08.2004	07.09.2004	20.09.2004	23.11.2004	11.01.2005	28
PHYSICAL QUALITY	1	Appearance						
	2	Color (Hazen unit)	72	54	118	98	10	2
	3	Odour						
	4	Taste						
	5	Turbidity (NTU/FTU)	11	10	22	18	2	1
CHEMICAL QUALITY	6	Pump house	7.50	7.30	6.40	6.50	6.40	7.
	7	Electrical Conductivity at 25^{0}C - (ms/cm)	84.00	108.00	59.00	52.00	70.00	7
	8	Chloride (as Cl) -mg/l	16.00	21.00	12.00	10.00	20.00	1
	9	Free Residual Chlorine (as Cl_2) - mg/l						
	10	Total alkalinity(as $CaCo_3$) -mg/l	13.00	17.00	11.00	14.00	16.00	1
	11	Ammonium (as N) -mg/l				0.70	0.17	0.
	12	Albuminoid Ammonia						
	13	Nitrate (as N) - mg/l	0.40	0.01	lt 0.01	2.20	4.40	3.
	14	Niitrite (as N) - mg/l	0.01	0.40	0.40	lt 0.01	0.02	0.
	15	Fluride (as F) - mg/l	lt 0.01	lt 0.01	0.29	0.16	0.12	lt
	16	Posphate (as PO_4) - mg/l	0.40	1.03	0.46	0.32	0.18	0.
	17	Total Residue - mg/l						
	18	Total Hardness(as $CaCo_3$) -mg/l	15.00	18.00	11.00	14.00	14.00	1
	19	Total Iron (as Fe) - mg/l	1.06	0.53	1.49	1.41	0.23	0.
	20	Sulphate (as SO_4) - mg/l	lt 0.01	0.60	lt 0.01	1.00	1.00	2.
	21	Sulphide, Hydrogen (as H_2S) - mg/l	lt 0.01	lt 0.01			0.01	lt
	22	Total suspended solid-mg/l						
	23	Chemical Oxygen Demand (COD) - mg/l		5.60	8.20			
	24	Dissolved Oxygen (DO)-mg/l	5.10	6.40	6.00			
	25	Residual Chlorine (as Cl_2) - mg/l						
	26	Calcium (as $CaCO_3$)-mg/l						
	27	Magnesium (as Mg)-mg/l						
	28	Manganese (as Mn)-mg/l						
	29	Aluminium (as Al) - mg/l						
	30	Arsenic (as As) - mg/l						
	31	Cyanide (as Cn) - mg/l						
	32	Mercury (Total as Hg)-mg/l						
	33	Selenium (as Se) - mg/l						
	34	Lead (as Pb) - mg/l						
	35	Cadmium (as Cd) - mg/l						
	36	Znic (as Zn) - mg/l						
	37	Copper (as Cu) - mg/l						
	38	Chromium (as Cr) - mg/l						
BIOLOGICAL QUALITY	39	Biochemical Oxygen Demand (BOD) - mg/l		0.30	0.80			
	40	Total Coloforms at 35^{0}C/100ml						
	41	Escherichia Coli at 44^{0}C/100ml						
	42	Fecal Steptococci at 37^{0}C/100ml						

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Table B-1 Treated Water Quality Data (2003 to 2005)

DATE	COLOUR (Hazen)	TURBIDITY (NTU)	pH
22/1/2003	36	4	8.1
10/2/2003	5	0	7.4
20/3/2003	1	0	6.4
28/3/2003	4	0	8.8
23/4/2003	3	0	8.8
28/4/2003	10	2	5.9
22/5/2003	0	0	6.5
26/5/2003	5	0	6.5
7/6/2003	1	0	7.2
27/6/2003	0	0	8.8
21/7/2003	34	0	6.9
26/7/2003	13	2	7.9
5/8/2003	10	3	7.1
21/8/2003	1	0	7.2
8/9/2003	2	0	8.1
25/9/2003	12	4	8.1
2/10/2003	13	3	7.6
10/10/2003	0	0	6.9
6/11/2003	5	1	8.9
29/11/2003	0	0	7.2
12/12/2003	0	0	7.4
2/1/2004	7	1	7.8
19/1/2004	34	6	7.3
13/2/2004	14	2	7
20/2/2004	3	1	6.3
12/3/2004	26	5	7.2
26/3/2004	7	1	7.6
1/4/2004	12	3	6.9
26/4/2004	18	3	8.8
14/5/2004	7	2	6.6
31/5/2004	9	2	8.4
18/6/2004	0	0	7.6
29/6/2004	10	2	8.4
12/7/2004	0	0	7.5
27/7/2004	7	1	9.1
6/8/2004	3	1	9.2
10/9/2004	12	3	6.4
17/9/2004	5	1	7.1

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DATE	COLOUR (Hazen)	TURBIDITY (NTU)	pH
30/9/2004	6	1	8.8
6/10/2004	5	9	7.5
13/10/2004	19	4	6.5
20/10/2004	4	1	6.5
25/10/2004	2	0	6.7
29/10/2004	5	2	7.4
3/11/2004	14	2	6.3
11/11/2004	17	4	7.3
12/11/2004	14	3	6.5
17/11/2004	3	1	6.5
24/11/2004	8	1	9.2
25/11/2004	5	1	7.9
1/12/2004	17	3	9.1
8/12/2004	11	2	9.3
21/12/2004	3	1	8.7
31/12/2004	4	1	9.2
7/1/2005	0	2.5	7.1
28/1/2005	0	2.5	8
2/2/2005	2.5	1.1	7.7
9/2/2005	15	1.9	6.5
11/2/2005	2.5	0.7	6.8
17/2/2005	5	1.2	7.1
25/2/2005	5	0.9	7.2
2/3/2005	2.5	4.5	8.6
9/3/2005	2.5	1.8	9
16/3/2005	2.5	1.8	8.9
23/3/2005	5	1.7	8.1
24/3/2005	2.5	1	7
30/3/2005	2.5	0.7	7.8
6/4/2005	5	3.3	8.8
7/4/2005	5	1.6	9.2
20/4/2005	2.5	1.5	7.4
4/5/2005	5	1.2	7.2
11/5/2005	2.5	0.5	7.7
13/5/2005	5	0.8	7.3
18/5/2005	2.5	1.2	7.6
25/5/2005	5	1	7.4
27/5/2005	2.5	0.6	7.7
1/6/2005	5	1.4	6.3
8/6/2005	2.5	1.3	6.9

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DATE	COLOUR (Hazen)	TURBIDITY (NTU)	pH
9/6/2005	10	2.6	7.3
15/6/2005	2.5	1	6.4
22/6/2005	2.5	0.5	6.4
29/6/2005	3	0.5	6.6
30/6/2005	5	1.6	6.4
6/7/2005	0	0.6	7.7
12/7/2005	5	0.9	8.1
13/7/2005	0	0.7	6.7
20/7/2005	2.5	0.7	6.7
29/7/2005	2.5	0.8	7.4
3/8/2005	2.5	2.5	6.6
10/8/2005	5	1.3	6.3
12/8/2005	2.5	1	6.9
17/8/2005	5	1	6.7
24/8/2005	2.5	1	7.4
25/8/2005	0	0.5	7.1
6/9/2005	2.5	1.2	7.6
19/9/2005	0	0.6	8.9
23/9/2005	2.5	0.8	7.6
28/9/2005	0	0.7	6.7
30/9/2005	5	1.4	8

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Table B-2 Variation of water quality before and after Treatment (17-03-2001)

Date		17-03-2001								
	Parameters	**Maximum Desirable Level**	**Maximum Permissible Level**	**Raw Water Intake**	**After Areation**	**After Addition of Lime & Alum**	**After Pulsator**	**Before Filtration**	**After Filtration**	**After additon of clorine and lime**
	Physical Quality									
1	Colour (Hazen Unit)	5	30	60	50	75	<10	<10	<10	<10
2	Turbidity (N.T.U)	2	8	26	80	33	5.0	4.9	5.3	5.0
	Chemical Quality									
1	pH	7-8.5	6.5-9	6.2	6.8	6.4	6.0	6.0	6.0	6.0
2	Electrical Conductivity us/cm	750	3500	63.3	56.2	120	150	140	110	158
3	Chloride (as Cl) mg/l	200	1200	12	12	12	12	14	14	16
4	Free residual chlorine mg/l	0.2		-	-	-	-	-	-	-
5	Total Alkalinity (as $CaCO_3$) mg/l	200	400	8	24	16	-	-	8.0	-
6	Free Ammonia mg/l	0.06		0.06	0.06	0.02	<0.02	0.04	<0.02	0.02
7	Albuminoid Ammonia mg/l	-	-	-	-	-	-	-	-	-
8	Nitrate (as N) mg/l	10		1	0.3	1	1.2	1.1	0.5	1.5
9	Nitrite (as N) mg/l	0.01		0.005	<0.001	<0.001	<0.001	0.005	0.001	<0.001
10	Fluoride (as F) mg/l	0.6	1.5	0.09	<0.01	0.04	<0.01	0.06	<0.22	0.12
11	Total Phosphates (as PO_4) mg/l	2.0		<0.04	<0.04	0.04	0.04	0.04	0.04	<0.04
12	Total Residue mg/l	500	2000	42.2	37.46	80	100	93	73	105
13	Total Hardness (as $CaCO_3$) mg/l	250	600	14	14	32	30	30	30	32
14	Total Iron (as Fe) mg/l	0.3	1	1.2	1.1	1.3	0.03	0.3	0.2	0.2
15	Sulphate (as SO_4) mg/l	200	400	4.0	1.0	25	32	36	30	33
						**				

** Alum 5.5 ppm Lime 3.2 ppm

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Table B-3 Water Quality upstream of intake and treatment plant (14-08-2001 to 19-08- 2001)

	DATE	14-08-01	14-08-01	14-08-01	15-08-01	15-08-01	15-08-01	15-08-01	19-08-01
	TIME	17.00	17.30	17.45	11.45	13.00	13.20	13.25	9.00
	Parameters	**Bolanda**	**Down Stream of Pathma Weaving Mills**	**Water Discharge from Padma Weaving Mills**	**Raw water Intake Raddologama (Kotugoda)**	**Raw Water Intake Raddolugama**	**Raw water Raddolugama Treatment Plant**	**Treated Water at Treatment Plant**	**Raw Water Intake Raddolugama (Kotugoda)**
	Physical Quality								
	Appearance	Slightly Turbid / coloured	Slightly Turbid / coloured		Turbid	Turbid	Coloured	Clear	Clear
1	Colour (Hazen Unit)	80	92	-	62	88	64	11*	42
2	Turbidity (N.T.U)	13	15	-	12	14	11	0	7
	Chemical Quality								
1	pH	6.4	6.2		6.2				
2	Electrical Conductivity us/cm	64	70	1305	66	6.3	6.6	6.4	6.4
3	Chloride (as Cl) mg/l	18	20	169	16	72	66.4	103	80
4	Free residual chlorine mg/l					19	21	22	20
5	Total Alkalinity (as $CaCO_3$) mg/l	28	28	500	28				
6	Free Ammonia mg/l					32	28	20	40
7	Ammonium mg/l	0.21	0.33		0.17				
8	Nitrate (as N) mg/l	0.8	0.1		3.9		0.16	0.1	
9	Nitrite (as N) mg/l	0.001	0.003		0.02	1.7	0.9	1.2	2.6
10	Fluoride (as F) mg/l	0.11	0.05		0	0	0.006	0.002	0.01
11	Total Phosphates (as PO_4) mg/l	0.4	0.32		0.3	0	0	0.11	0.1
12	Total Residue mg/l					0.4	0.5	0.7	0.8
13	Total Hardness (as $CaCO_3$) mg/l	28	28	44	32				
14	Total Iron (as Fe) mg/l	0.77	1.35		0.8	32	32	40	80
15	Sulphate (as SO_4) mg/l	1			0.1	1.5	0.85	0.03	1.3
16	Hydrogen Sulphite mg/l H_2S	0.001	0	-	-	0	1	18	3
17	Manganese mg/l	0.15	0.33	-	0.18	-	0.002	0.003	
18	COD mg/l	14	11.6	204.00	10.5	-	0.04	0.33	
19	Dissolved Oxygen mg/l			-	6.1	16.1	10.5	19.8	
20	BOD mg/l					5.4	5.8	6.5	

* **Colour in Treated Water**

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Table B-4 Raw water and Treated water Quality (15- 08-2001 to 31-07-2002) (Colour in treated water *)

	DATE	15-08-2001		05-02-2002		31-07-2002	
	TIME	13.20	13.20	7.05	7.05		
	Parameters	**Raw Water at Treatment Plant**	**Treated Water**	**Raw Water at Treatment Plant**	**Treated Water**	**Raw Water at Treatment Plant**	**Treated Water**
	Physical Quality						
	Appearance	Coloured	Clear	Turbid	Clear	Turbid	Clear
	Odour / Tasle	Odour Present	Unpleasant	-	-	-	-
1	Colour (Hazen Unit)	64	11*	37	0	35	0
2	Turbidity (N.T.U)	11	0	8	0	8	0.0
	Chemical Quality						
1	pH	6.6	6.4	6.5	7.2	6.9	7.2
2	Electrical Conductivity µs/cm	66.4	103	53	84	75	1/4
3	Chloride (as Cl) mg/l	21	22	15	16	9	13
4	Free residual chlorine mg/l						
5	Total Alkalinity (as $CaCO_3$) mg/l	28	20	28	28	75	114
6	Free Ammonia mg/l						
7	Ammonium mg/l (NH_4^+)	0.16	0.1	0.17	0.02	0.39	0.22
8	Nitrate (as N) mg/l	0.9	1.2	7.04	18.9	5.2	4.4
9	Nitrite (as N) mg/l	0.006	0.002	0.01	0.01	0.02	0.01
10	Fluoride (as F) mg/l	0	0.11	0	0	0.1	0.2
11	Total Phosphates (as PO4) mg/l	0.5	0.74	0.4	0.3	0.3	0.2
12	Total Residue mg/l						
13	Total Hardness (as CaCo3) mg/l	32	40	60	84	32	48
14	Total Iron (as Fe) mg/l	0.85	0.03	0.8	0	0.7	0.1
15	Sulphate (as SO_4) mg/l	1	18	2.0	19.0	2	23
16	Hydrogen ulphide mg/l H_2S	0.002	0.003	-	-	-	-
17	Manganese mg/l	0.04	0.33	-	-	-	-
18	COD mg/l (10 mg/l permissible)	10.5	19.8	3.04	0.0	26.2	22
19	Dissolved Oxygen mg/l	5.8	6.5	-	-	-	-
20	BOD mg/l						

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Table B-5 Water Quality Variation along Dandugam-Oya (15-08-2001)

	DATE	15/08/2001				15/08/2001		
	TIME	12.30	12.25	12.30	11.45	13.20	13.25	
	Parameters	Down Stream of Pathma Weaving Mills	Upstream of Bolandha	Down Stream of Bolanda	Kotugoda Intake for Raddolugama WSS	Raw Water at Raddolugama Water Treatment Plant	Treated Water Sump at Treatment .Plant	Remarks
	Physical Quality							
	Appearance	Slightly Turbid Coloured	Slightly Turbid Coloured	Slightly Turbid Coloured	Slightly Turbid Coloured	Coloured	Clear	
1	Colour (Hazen Unit)	68	70	72	62	64	0	
2	Turbidity (N.T.U)	13	13	13	12	11	0.0	
3	Odour	Present	Present	Present	Present	Present	Not Present	
	Chemical Quality							
1	pH	6.2	6.4	6.4	6.2	6.6	6.4	
2	Electrical Conductivity us/cm	66.6	66	66.3	66.8	66.4	12-Apr	
3	Chloride (as Cl) mg/l	22	23	23	16	21	22	
4	Free residual chlorine mg/l							
5	Total Alkalinity (as $CaCO_3$) mg/l	28	28	32	28	28	20	
6	Ammonia m(mg/l N)	0.17	0.27	0.13	0.14	0.16	0.1	
7	Albuminoid Ammonium mg/l							
8	Nitrate (as N) mg/l	1.7	0.8	0.5	0.9	0.9	1.2	
9	Nitrite (as N) mg/l	0.004	0.002	0	0.1	0.05	0.02	
10	Fluoride (as F) mg/l	0	0.01	0	0.03	0	0.11	
11	Total Phosphates (as PO_4) mg/l	0.2	0.65	0.84	0.33	0.51	0.74	
12	Total Residue mg/l							
13	Total Hardness (as $CaCO_3$) mg/l	36	40	32	32	32	40	
14	Total Iron (as Fe) mg/l	0.81	0.87	0.85	0.8	0.85	0.03	
15	Sulphate (as SO_4) mg/l	0	2	0.0	1.0	1	18	COD of Treated Water Does not conform to SLS .
16	Hydrogen Sulphide mg/l H_2S	0	0.002	0.002	0	0.002	0.003	
17	Manganese mg/l	0.25	0.19	0.17	0.18	0.04	0.3	
18	COD mg/l (Permissible 10 mg/l)	8.16	5.8	12.80	10.5	10.5	19.8	
19	Dissolved Oxygen mg/l	6.6	5.9	6.6	6.1	5.8	6.5	
20	BOD mg/l							

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Table B-6 Water Quality Variation along Dandugam-Oya (17-08-2001)

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	Date	17/08/2001 Dadugam Oya at Raddolugama Treatment Plant									
	Time Samples	12.15	12.20	12.30	13.10	13.15	12.00	12.00	12.00	12.00	12.00
	Parameters	**Inteke Site Surface Water**	**Kotugoda Intake Well**	**Near Pathma Weaving Mills**	**After Industrial Zone Kotugoda**	**Main Kotugoda Bridge**	**Raw Water at Raddolugama**	**After Aeration**	**ier Clarif Before filtration**	**After Filtration**	**Final Water**
	Physical Quality										
1	Colour (Pt Co)	97	110	71	73	82	107	87	4	0	0.5
2	Turbidity (N.T.U)	15	17	12	15	15	20.0	17	0	0	0.0
	Chemical Quality										
1	pH	6.6	6.4	6.4	6.2	6.6	6.2	6.5	6.3	6.3	7.1
2	Electrical Conductivity us/cm	80.2	80.9	67	74.6	67.2	83.4	77.6	85.4	84.9	106.5
3	Chloride (as Cl) mg/l										
4	Free residual chlorine mg/l										
5	Total Alkalinity (as $CaCO_3$) mg/l										
6	Free Ammonia mg/l										
7	Ammonium mg/l										
8	Nitrate (as N) mg/l										
9	Nitrite (as N) mg/l										
10	Fluoride (as F) mg/l										
11	Total Phosphates (as PO_4) mg/l										
12	Total Residue mg/l										
13	Total Hardness (as $CaCO_3$) mg/l										
14	Total Iron (as Fe) mg/l	1.13	2.12	0.86	1.39	1.01	1.87	1.87	0.21	0.02	0.02

Table B-7 Water Quality Variation along Dandugam-Oya and treated water (29-08-2001)

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	DATE	29/08/2001		
	TIME	11.40 a.m.	10.35 a.m	10.38
		Opatha Down Stream of Industrial Zone	Kotugoda Intake	Treated water from Raddolugama Plant
	Test Value	Sample 01	Sample 02	Sample 03
1	Colour (Hazen Unit)	40	50	10
2	Odour	Unobjectionable	Unobjectionable	Unobjectionable
3	Taste			Unobjectionable
4	Turbidity NTU	2.5	3	0.5
5	pH at 25° C	6.8	6.8	7
6	Electrical Conductivity at 25° C µs/cm	85	84	123
7	Chloride (as Cl) mg/l	9	10	12
8	Total Alkalinity (as CaCo3) mg/l	22	22	22
9	Free ammonia (as NH_3) mg/l	0.01	0.01	0.01
10	Albuminoid Ammonium (as NH_3) mg/l	0.02	0.02	0.01
11	Nitrate (as N) mg/l	less than 0.1	less than 0.1	less than 0.1
12	Nitrite (as N) mg/l	less than 0.01	less than 0.01	less than 0.10
13	Fluoride (as F) at 25° C mg/l	less than 0.1	0.1	less than 0.1
14	Total Phosphates (as PO_4) mg/l	0.16	0.16	less than 0.10
15	Total Solids at 103-105°C mg/l	62	64	80
16	Total Hardness (as $CaCO_3$) mg/l	17	17	42
17	Total Iron (as Fe) mg/l	0.77	0.8	less than 0.10
18	Sulphate (as SO_4) mg/l	less than 8	less than 8	10
19	Phonemic compounds (as Phonemic OH) mg/l	less than 0.02	less than 0.02	less than 0.02
20	Oil & Grease mg/l	less than 1	less than 1	less than 1
21	BOD at 20° C	less than 2	less than 2	-
22	Calcium (as Ca)	2	2	14
23	Magnesium (as Mg) mg/l	3	3	2

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Table B-8 Water Quality Variation along Dandugam-Oya and treated water (05-09-2001)

	DATE **TIME**	**05/09/2001** **11.00 a.m.**	**04/09/2001** **20.25 p.m**	**05/09/2001** **1.30 p.m**
		Upstream Bolanda Anicut	**Kottegoda Intake**	**Treated Water From Raddoluwa Plant**
	Test Value	**Sample 01**	**Sample 02**	**Sample 03**
1	Colour (Hazen Unit)	30	40	10
2	Odour	Unobjectionable	Unobjectionable	Unobjectionable
3	Taste			Unobjectionable
4	Turbidity NTU	3.5	2.5	0.65
5	pH at 25° C	6.8	6.8	6.8
6	Electrical Conductivity at 25° C µs/cm	64	77	144
7	Chloride (as Cl) mg/l	8	8	13
8	Total Alkalinity (as $CaCO_3$) mg/l	21	23	23
9	Free ammonia (as NH_3) mg/l	0.02	0.02	0.02
10	Albuminoid Ammonium (as NH_3) mg/l	0.01	0.02	0.02
11	Nitrate (as N) mg/l	0.1	0.1	less than 0.1
12	Nitrite (as N) mg/l	less than 0.01	less than 0.01	less than 0.01
13	Fluoride (as F) at 25° C mg/l	0.1	less than 0.1	less than 0.1
14	Total Phosphates (as PO_4) mg/l	0.12	0.18	0.12
15	Total Solids at 103-105°C mg/l	40	48	78
16	Total Hardness (as $CaCO_3$) mg/l	24	24	45
17	Total Iron (as Fe) mg/l	0.9	1.7	0.1
18	Sulphate (as SO_4) mg/l	less than 10	less than 10	31
19	Phenolic compounds (as Phenolic OH) mg/l	less than 0.02	less than 0.02	less than 0.02
20	Oil & Grease mg/l	less than 2	less than 2	less than 2
21	Clacium (as Ca) mg/l	4	4	14
22	Mangnesium (as Mg) mg/l	3	3	2
23	Lead (as Pb) mg/l	less than 0.1	less than 0.1	less than 0.1
24	Copper (as Cu) mg/l	less than 0.05	less than 0.05	less than 0.05
25	Manganese (as Mn) mg/l	0.13	0.06	0.25
26	Zinc (as ZN)	less than 0.1	less than 0.1	less than 0.1
27	Aluminium (As Al)	less than 2	0.2	less than 0.1
28	COD mg/l	22	22	10
29	Cadmium (as Cd) mg/l	less than 0.05	less than 0.05	less than 0.05
30	Cyanide (as CN) mg/l	less than 0.05	less than 0.05	less than 0.05
31	Selenium (as Se) mg/l	less than 0.001	less than 0.001	less than 0.001
32	Chromium (as Cr) mg/l	less than 0.05	less than 0.05	less than 0.05

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Table B-9 Water quality variation at different locations 19- 01- 2004 to 30 – 01- 2004 (Colour in treated water)

Date	Sampling Point	Time	Colour Pt.Co.	Turbidity FTU	pH	Dissolved Oxygen mg/l	C.O.D mg/l	E.C µc/cm	Chloride mg/l	Total Iron mg/l
19-01-2004	Kalu Ela	11.00	110	39	7.1		13.9	65		2.2
19-01-2004	Bolanda anicut	11.35	218	15	7.2		5.6	68		0.9
19-01-2004	Raw water at intake	10.45	88	24	7.1		17.4	74		1.8
19-01-2004	Surface water near intake	10.40	111	18	7.0		11.1	73		1.1
19-01-2004	Treated water	10.10	34	6	7.3		9.7	127		0.1
29-01-2004	Raw water at treatment plant	5.00	11	20	7.4		12.1	101	17	
29-01-2004	Filtered water	5.00	50	3	7.2		10.8	433	101	
29-01-2004	Treated water	5.00	123	9	7.3		18.2	413	96	
29-01-2004	Raw water at treatment plant	11.20	24	20	7.3		23.6	143	33	
29-01-2004	Filtered water	11.20	31	4	7.2		9.4	192	38	
29-01-2004	Treated water	11.20	81	5	7.2		16.8	352	77	
29-01-2004	Kalu Ela	14.50	74	12	7.0	3.74	25.6	75	16	
09-01-2004	Raw water at intake	15.10	63	13	7.1	0.52	26.9	205	47	
30-01-2004	Surface water near intake	11.25	86	12	7.1	0.9	22.9	100	19	
30-01-2004	Raw water at intake	11.35	218	16	7.2	0.58	49.8	134	29	

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Table B-10 Water quality variation at different locations on 02- 02- 2004 - (Colour in treated water)

Date	Sampling point	Time	Colour Pt.Co.	Turbidity FTU	pH	E.C µS/cm	D.O mg/l	Total iron mg/l	Ammonia mg/l	Nitrate mg/l	Phosphate mg/l	pH	Alkalinity mg/l	Chloride mg/l
02-02-2004	Before aerator	16.20	218	41	7.1	193		0.2	0.80	0.50	0.07	7.1	18	43
02-02-2004	Before filter	16.25	24	5	7.2	241		0.3	0.17	0.50	0.22	7.2	22	44
02-02-2004	Filtered water Outlet No 1	16.30	5	2	7.2	248		0.6	0.13	0.40	0.42	7.2	22	46
02-02-2004	Filtered water Outlet No 2	16.30	6	2	7.2	255		0.6	0.13	0.50	0.15	7.2	21	49
02-02-2004	Treated water at sump	16.35	97	21	7.2	264		1.6	0.33	0.40	0.48	7.2	20	51
02-02-2004	Raw water 0.5m from bottom	17.00	266	50	7.0	1280		1.6	0.39	0.00	0.29	7.0	19	343
02-02-2004	Raw water 1.0m from bottom	17.00	140	29	7.2	237	1.46	2.9	0.45	0.10	0.18	7.2	43	35
02-02-2004	Raw water 1.5m from bottom	17.00	164	31	7.3	126	2.34	2.6	0.40	0.20	0.13	7.3	20	25
02-02-2004	Raw water 2.0m from bottom	17.00	99	19	7.3	119	2.85	1.0	0.25	0.30	0.04	7.3	30	16
02-02-2004	Raw water 2.5m from bottom	17.00	76	16	7.4	94	1.34	1.0	0.29	0.30	0.11	7.4	17	17
02-02-2004	Raw water 0.5m from bottom	18.00					1.02							
02-02-2004	Raw water 1.0m from bottom	18.00					1.98							
02-02-2004	Raw water 1.5m from bottom	18.00					1.78							
02-02-2004	Raw water 2.0 from bottom	18.00					3.26							
02-02-2004	Raw water 2.5m from bottom	18.00					2.96							
02-02-2004	Down stream of anicut	18.00	102	20	7.2	6270		1.4	0.86	0.30	0.78	7.2	30	1574

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Table B-11 Variation of redox potential along each unit process on 26/06/2003

Ambient temperature 29.6^{0}C

Location	pH	Redox potential mV	Eh= V+ 203 mV
Intake Raw water	6.5	355	558
After pumping at intake	6.5	361	564
Aerator	6.4	331.8	534.8
After adding lime and alum	5.4	257	560
Outlet of Pulsator	7.7	290	493
Outlet of the filter	7.5	285	488
After addition of lime and chlorine at clear water tank	7.9	500	703

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Table B-12 Variation of water quality measured at different location of treatment process on 30- 1- 2004 at 11.00am

Location	**Temp °C**	**pH**	**Redox potential mV**	**E_h E_h=V+203 mV**	**Dissolved Oxygen mg/l**
Raw water at Dalugam –oya	31	7.2	214	417	0.9
Surface of wet well	29	7.2	179.6	382.6	0.58
Before aeration	30.2	6.8	62.3	265.3	
After aeration and after adding alum 17mg/l	30.4	5.73	121.6	324.6	
After aeration and after adding lime	29.5	6.6	107.6	310.6	
Top of Pulsator	29.8	6.6	107.6	310.6	
Top filter after adding Chlorine (PreChlorination)	29.8	6.6	136.5	339.5	
Top of filter	30	4.4	162.6	365.6	
After filtration	29.5	6.6	196	399	
Treated water after chlorination	29.9	6.9	400	603	

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Table B-13 Variation of Ferrous, Ferric and dissolved Oxygen at various location of the treatment process (20-08-2004)

Location	Fe^{2+} mg/l	Fe^{3+} mg/l	Dissolved oxygen mg/l
Dadugam- oya	0.00	1.14	6.2
Intake well	0.02	1.31	5.4
Aerator Starting point	0.01	1.04	5.3
Aerator bottom	0.02	1.14	5.8
Top of Pulsator	0.01	0.12	6.9
Top of Filter	0.00	0.19	6.7
Filtered water	0.00	0.11	5.7
Treated water	0.01	0.11	6.8

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