Report on Water Quality Survey and Pollution in Kurunegala, Sri Lanka

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WASPA Asia Project Report 6

This report in one in a series of project reports written by the Wastewater Agriculture and Sanitation for Poverty Alleviation in Asia (WASPA Asia) project. The WASPA Asia project aims to develop and test solutions for sanitation and wastewater management, to reduce the risks form wastewater use in agriculture. The approach involves the development of stakeholder coalitions at town and national level, called Learning Alliances, which will bring together the main stakeholders into a participatory process through which actions will be planned and implemented in a sustainable manner.

These project reports are essentially internal documents intended to inform the future activities of the project, particularly in relation to the development of Learning Alliances and participatory action plans. The reports have been made publicly available as some of the information and findings presented in them may be of use to other researchers, practitioners or government officials.

The WASPA Asia project is funded primarily under the EU Asia Pro Eco II Programme of the European Commission. It is being undertaken by the International Water Management Institute (IWMI), Sri Lanka; COSI, Sri Lanka; the International Water and Sanitation Centre (IRC), the Netherlands; NGO Forum for Drinking Water Supply and Sanitation, Bangladesh; and the Stockholm Environment Institute (SEI), Sweden. The project pilot cities are Rajshahi City in Bangladesh and Kurunegala City in Sri Lanka.

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Acronyms, Abbreviations and Sinhala Terms

APHA	American Public Health Association
AWWA	American Water Works Association
BOD	Biochemical Oxygen Demand
CEA	Central Environmental Authority
COD	Chemical Oxygen Demand
DO	Dissolved Oxygen
EC	Electrical Conductivity
ECL	Environmental Consultants Limited
FAO	Food and Agricultural Organization
GPS	Global Positioning System
HDPE	High Density Poly Ethylene
IWMI	International Water Management Institute
ISB	Industrial Services Bureau
MPN	Multiple Probability Number
NWSDB	National Water Supply and Drainage Board
SAR	Sodium Adsorption Ratio
TDS	Total Dissolved Solids
TN	Total Nitrogen
TP	Total Phosphorous
TSS	Total Suspended Solids
VCF	Vertical Centroid-of-Flow
WHO	World Health Organization
Anicut	Weir
Wewa	Irrigation tank

1 Introduction and Objectives

This report has been produced as part of the Wastewater Agriculture and Sanitation for Poverty Alleviation in Asia (WASPA Asia) project, funded by the European Commission under its Asia Pro Eco II Program. The objective of the project is to improve the livelihoods of urban and peri-urban farmers who are using wastewater in agriculture; and the communities who are responsible for producing the wastewater or consuming the agricultural produce. To do this a holistic approach and sustainable solutions are required along the whole chain of wastewater production and use; from improved sanitation to contaminant reduction, waste treatment, disposal, safe use in agriculture and promotion of hygiene behavior. At the same time a change of practice is required to integrate wastewater planning into urban water resource management, simultaneously applying technical solutions for wastewater treatment and disposal, and a range of preventive measures to mitigate health risks in the short term.

Before any such changes can be proposed or implemented it is necessary to have an understanding of the current conditions prevailing in the urban and peri-urban area of the two project research cities, Kurunegala in Sri Lanka and Rajshahi in Bangladesh. These include: wastewater production including its quantity and source; the quality of wastewater being utilized for agriculture; the impact of that use on agriculture and potential risks to health; and the sanitation conditions. To achieve this, a number of related studies have been undertaken under the WASPA Asia project, the results of which have been presented in a series of reports. This report presents the findings for the water quality assessment conducted in Kurunegala City in 2006 and 2007. It will be followed by further reports on water quality as a series of samples are taken over the project period. The findings of this study will also be combined with the findings of the agriculture, sanitation and stakeholder analysis to produce a more comprehensive report for Kurunegala City.

The main objective of the WASPA Asia project is to work with relevant stakeholders to develop participatory action plans to address issues relating to wastewater agriculture in Kurunegala and Rajshahi, and to learn lessons for other similar cities across Asia. This water quality analysis report will provide important information for the development of those participatory action plans. It will also provide a baseline against which to monitor the impacts of project interventions or other changes that may take place in the city during the project period.

The water quality component is divided into two parts. The first is the baseline survey which was conducted in July 2006 to provide an initial understanding of the water quality, and to test the sampling methodology and analysis. The second event was the first of a series of sampling events in the two agricultural seasons and will be refered to as the second monitoring event throughout this document. This report only presents one set of data from the regular monitoring and therefore the results cannot be said to be conclusive but only give an initial impression of conditions.

The three key reasons for conducting water quality analysis were:

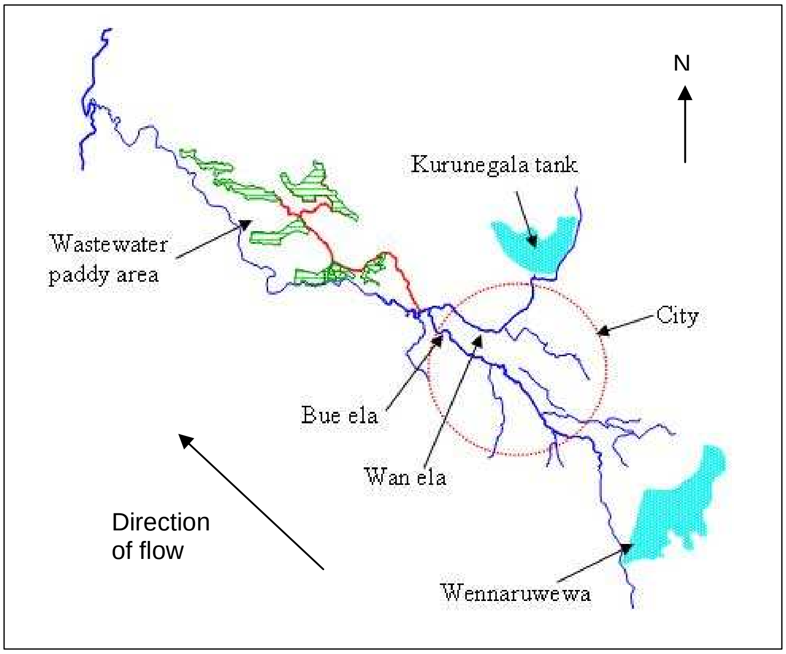
- To monitor the quality of water in drainage canals from the city to enable the project team to consider the possible health and environmental risks posed to the communities that live around the project area;
- To investigate the suitability of the water for use in agriculture, particularly in relation to the levels of nutrients and substances that may damage crops (such as heavy metals or salinity);
- To monitor the impacts of project interventions in terms of improved water quality; and
- To provide information to the Learning Alliances to help them to develop the participatory action plans.

A survey of point sources of pollution supports the water quality analysis by providing observational evidence of the types of industries, commercial units and other potential sources of pollution that exist in within the Kurunegala city limits. The current status of the work does not give any indication of the level of the pollution but the next step in the analysis is likely to be to try to better understand the pollution produced by key commercial units such as butchers, service stations, private hospitals and hotels.

2 Background

About 78% of Kurunegala town area is drained by two streams, the Wan Ela and the Beu Ela which confluence just before Wilgoda Anicut (weir) and flow on through agricultural land before joining the Maguru Oya (river) at Watawehera estate just outside the western boundary of Kurunegala Municipality (ECL 2000; National Water Supply and Drainage Board (NWSDB) 2005). The Beu Ela originates from the Wennaru Wewa (irrigation tank) and was origianally an irrigation canal but now acts as a city drain, although it is still used for irrigation (Figure 2.1). The wastewater generated in Kurunegala city is estimated to be 4620 m^3 day^{-1} (Ranaweera, 2005).

Figure 2.1: Schematic diagram of the study site



Currently urban runoff, untreated grey water and sewage are discharged into the urban drainage canals and streams in the project area (NWSDB 2005). Since there is no sewage system the majority of people living in the area, including the floating population of 200000 people, dispose of their waste using on-site sanitation methods. In addition there are areas where there are very limited on-site sanitation facilities, Wilgoda Pura being one such example. Where no sanitation facilities exist waste is dispoed of wherever possible, including the canals.

The NWSDB carry out routine water quality monitoring for drinking water sources and supplies in Kurunegala but the canal water quality has only been studied to a limited extent. The NWSDB feasibility study report (2005) concludes that the surface waters of Beu Ela and Wan Ela are extremely polluted and do not even comply with the discharge standards for industrial effluents. The tolerance limits for industrial effluents discharged on land for irrigation purposes and general standards for discharge of effluents into inland surface waters, used by the Central Environmental Authority (CEA), Sri Lanka for Environmental Regulation are given in Annex I. Standards are also being proposed for irrigation and other agricultural uses by CEA under the ambient water quality standards (CEA 2001; Annex II). In addition, any agricultural use downstream should satisfy the Guidelines for the Safe use of Wastewater, Excreta and Greywater in Agriculture (World Health Organization (WHO) 2006), which specifies physical, chemical and biological water quality requirements for various forms of agriculture based on crops and irrigation method. The Food and Agriculture Organization (FAO) also publishes water quality requirements for agriculture (Ayres and Westcot 1994; Pescod 1992). All these standards are refered to where appropriate in relation to the water quality analysis data for Kurunegala.

Sources of Pollution

Pollution sources can be categorised into two types: point and diffuse. Point source pollution is regarded as pollution released via discharges from discrete outlets such as pipes and effluent outfalls. These sources are generally man-made and mediated by man-made devices. Diffuse pollution (also known as non-point source pollution) occurs when there is no discrete or identifiable point of discharge and pollution enters the environment by a multitude of pathways, agricultural pollution from application of pesticides is one example of diffuse pollution.

The pollution of the canal water in the project area can be attributed to both point and non-point source pollution including:

- Small-scale industrial effluent discharged to canals;
- Wastewater and sewage discharged into canals;
- Dumping of solid waste into canals;
- Open defecation on canal banks and in open areas that washes into canals;
- Urban runoff and rainwater; and
- Chemicals and other wastes from upstream agricultural lands.

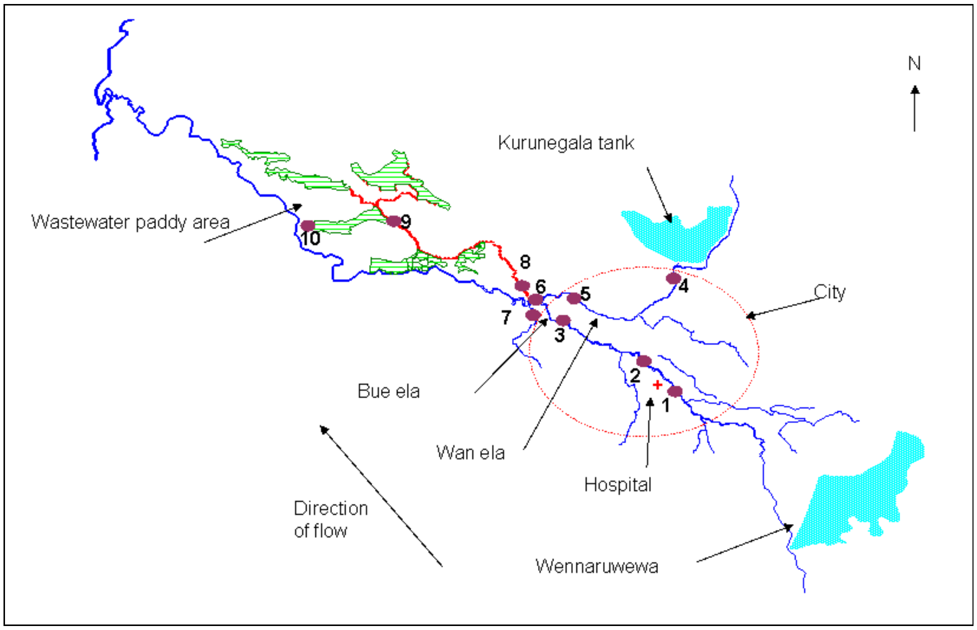
3 Methodology

Baseline Water Quality Survey

Samples were collected along the two streams, the Wan Ela and the Beu Ela in the urban area where the pollution occurs and downstream where the water is used for agriculture.

The sampling locations (marked 1 – 10), which are presented schematically in Figure 3.1 were selected considering the point sources of pollution and the suitability of making discharge measurements. This meant that locations next to the confluence or point sources of contamination were avoided, and straight and uniform channel areas free of eddies, slack water and excessive turbulence were selected instead. The locations were established with respect to GPS (Garmin GPS III® Plus) (Table 3.1). Permanent features were noted and photographed to facilitate easy identification of sample points in the future.

Figure 3.1: Sample locations



Ground water sample sites were selected on the two sides of the *anicut* where water is stored for irrigation purposes and there is the possibility of leaching from the canal (NWSDB 2005). Sample point 8 is a deep water well where the water is used for washing purposes and 7 is a shallow open well which is used for garden crops and could easily be contaminated with runoff. This well was chosen because it is close to the *anicut* and is an important source of water in the dry season. Most of the wells around the *anicut* area are not used for drinking water but the water is used for bathing, washing and cooking. Apart from the water held in the *anicut* there appear to be no other sources of contamination such as toilet pits close to the wells.

Table 3.1: Sample locations for the baseline survey

	Location	GPS Position		
1.	Beu Ela before the city and before the hospital (entry point to the city).	N: E:	07^0 080^0	28' 58.8'' 21' 77.2''
2.	Beu Ela after the hospital but before the main city drainage area.	N: E	07^0 080^0	31' 26.9'' 25' 74.6''
3.	Beu Ela before the confluence with the Wan Ela (exit point from the city).	N: E	07^0 080^0	28' 95.8'' 21'25.7''
4.	Wan Ela before the confluence with the Beu Ela (entry point to the city).	N: E	07^0 080^0	29' 83.0'' 22' 04.9''
5.	Wan Ela near the confluence with the Beu Ela (exit point from the city).	N: E	07^0 080^0	28' 58.9'' 21' 76.9''
6.	Starting point of the irrigation canal.	N: E	07^0 080^0	29' 29.9'' 20' 70.1''
7.	Well on the left back of the *anicut*.	N: E	07^0 080^0	29 30.1'' 20 69.8''
8.	Well on the right back of the *anicut*.	N: E	07^0 080^0	31'26.9'' 25' 74.6''
9.	Irrigation canal near the paddy lands (entry point to the paddy fields).	N: E	07^0 080^0	29' 50.6'' 20' 36.8''
10.	Drainage from the paddy land.	N: E:	07^0 080^0	29' 46.5'' 20' 28.3''

When collecting the samples the single vertical at centroid-of-flow (VCF) method was used for sampling (ref). Discrete samples were collected from each location in the centroid-of-flow for chemical and microbiological analysis because of the well mixed conditions (vertically and laterally) and shallow flows. The parameters for which the water was sampled are provided in Table 3.2, along with the method of collection, preservation and holding times. The analysis was conducted by the Industrial Technology Institute (ITI) in Colombo, an accredited laboratory, and analyses were performed under strict quality control and quality assurance guidelines using internationally accepted methods of analysis given in Annex III.

Measurements of temperature, pH and dissolved oxygen (DO) were conducted *in situ* using aSension TM 156 Multiparameter meter (U.S.A). The flow velocity measurements were also made.

Table 3.2: Sample type, preservation, holding times and sampling containers

Parameters	Sample	Container	Preservation	Holding time
• Total and Faecal Coliforms (TC & FC)	Discrete	Glass 125 ml sterilized	Cooled to 4^0C	6 hours
• Oil and Grease	Discrete	Glass 1-2 L	Hydrochloric acid (HCl) to pH <2	28 days
• 5-day Biochemical Oxygen Demand (BOD_5) • Total nitrogen (N) • Total phosphorous (P) • Turbidity • Total Suspended Solids (TSS)	Discrete	HDPE 1-2 L	Cooled to 4^0C	24 hours
• Heavy Metals	Discrete	HDPE 500 ml	Nitric acid (HNO_3) to PH <2	6 months
• Chemical Oxygen Demand (COD)	Discrete	HDPE 500 ml	Sulphuric acid (H_2SO_4) to pH <2	28 days
• Nitrite	Discrete	Plastic/Glass 100 ml	Cooled to 4^0C	48 hours
• Nitrate	Discrete	Plastic/Glass 100 ml	Cooled to 4^0C	14 days
• Parasite cysts/ova	Composite	Plastic cans 10 L	Ambient Temp	1-2 days

HDPE: High Density Poly Ethylene

Canal discharges were measured using a portable current meter (Valeport (UK) Model: 001) to facilitate calculation of the pollutant loads. For most locations the six-tenths-depth method of measuring the velocity from the water surface was used because of shallow flows. The two-point method of measuring the velocity at two-tenths-depth and then at eight-tenths-depths of the depth from the water surface was used where the water levels were high. The average of the two measurements was used as the mean velocity in this case. The measurements were made by the International Water Management Institute (IWMI) field staff. The discharge of each *ela* was calculated using their cross section.

Routine Water Quality Monitoring

Ten parameters were selected for routine monitoring based on the results of the baseline survey and studies conducted by the NWSDB and Peredeniya University. The second water quality monitoring was carried out on December 12, 2006. The water quality monitoring was done jointly with stakeholders NWSDB and Industrial Services Bureau (ISB) in Kurunegala. The samples were collected by the IWMI Field staff and the ISB laboratory staff.

Exactly the same locations as the baseline study were sampled for locations 1, 3 – 8, but location 2, which is after the hospital was moved to a more downstream site to include all the sources of pollution originating from the hospital as it was found that there are a number of other outlets from the hospital in addition to the outlet from the treatment plant. Location 9 and 10 were moved to a plot of paddy fields where the inlet and outlet to the plot could be easily located and where discharge measurement is possible (Table 3.3). The plot was selected such that the inflow to the selected paddy area is not diverted to other areas apart from the selected plot, which will be important for the agricultural study being conducted as part of the project. Global Positioning System coordinates were once again taken for all locations at the time of sampling.

Table 3.3: New sample locations for the second and future sampling events

Location	GPS Position
New location 2 after the hospital on Beu Ela	N: 07^0 28’ 34.5’’ E: 080^0 21’ 46.9’’
New Location 9	N: 07^0 29’ 44.0’’ E: 080^0 20’ 09.2’’
New Location 10	N: 07^0 29’ 45.5’’ E: 080^0 20’ 41.4’’

The same sampling methodologies were used but in this and subsequent sampling events, the ISB Laboratory staff made the field measurements and analysed the water for COD and TSS. The parameters BOD_5, total P, total N, calcium, magnesium and sodium were analysed by ITI as before. The ground water samples from locations 7 and 8 were tested at the NWSDB laboratory in Kurunegala free of charge as a courtesy to the project as it has been agreed that all results will be shared with them. Three composite samples from locations 2, 3 and 6 were collected for parasite cysts and ova testing and were analyzed by the Department of Parasitology, Faculty of Medicine, University of Colombo, as they were found to be the only laboratory that was familiar with analysis of wastewater for parasites. They used a modified analysis method by Ayres and Mara (1996).

Measurements of temperature, pH, DO and conductivity were conducted *in situ* and the flow velocity measurements were also made as in the baseline but with adjustments for shallow flows. All the tests performed on each site are provided in Table 3.4.

Table 3.4: Parameters monitored in the water quality survey

<table>
<tr><th>Site number</th><th>Test performed for the baseline survey</th><th>Tests performed for second and future sampling events</th></tr>
<tr><td>1, 4, 5, 9, 10</td><td rowspan="3">pH, temperature, BOD_5, COD, DO, TSS, TDS, conductivity, salinity, oil and grease, total N, ammoniacal N, nitrate N, nitrite N, total P, phospahte P, TC, FC, K, Na, Ca, Mg, B, heavy metals Hg, As, Cd, Ni, Pb, Cr, Cu and Fe.</td><td>pH, temperature, BOD_5, COD, DO, TSS, conductivity, total N, total P, Na, Ca, Mg, TC and FC.</td></tr>
<tr><td>2, 3, 6</td><td>pH, temperature, BOD_5, COD, TSS, conductivity, total N, total P, Na, Ca, Mg, TC, FC and parasite cysts and ova</td></tr>
<tr><td>7, 8</td><td>Color, turbidity, pH, conductivity, chloride, total Alkalinity, free ammonia, nitrate, nitrite N, fluoride, phosphate P, total hardness, total Fe, sulphate and manganese</td></tr>
</table>

Identifying Sources of Pollution

Point sources of pollution in Kurunegala city were identified as part of the study. As most of the industrial and commercial units in Kurunegala are located along the main roads the project team drove along the roads marking them on a map. The drainage network also runs along the road network and all units along the roads are draining into this system.

All units were be categorized with respect to the nature of business (such as hotels, hospitals, schools and vehicle service stations). The likely pollutants for each category will be identified. This will give an indication of the pollutants likely to reach the irrigated area but more importantly will enable the project team and stakeholders in the Learning Alliance to identify solutions to reduce or treat the pollution.

4 Water Quality Results and Discussion

This chapter summarizes the water quality results of the baseline survey and the first set of samples from the proposed water quality monitoring programme. The chapter discusses the implications of the results for agriculture, as well as possible explanations for the presence and concentrations of certain parameters.

Physical Parameters

Electrical Conductivity and Total Dissolved Solids

Electrical conductivity (EC) is a measure of the ions present in water as the conductivity increases with the number of ions. It is also effectively a surrogate for total dissolved solids (TDS) and is important for irrigation because it is a measure of the salinity of the water (Metcalf and Eddy 2003). The conductivity test does not identify the dissolved salts or the effects they may have on crops or soil, but it does indicate fairly reliably the degree with which a salinity problem is likely to occur. Salinity restricts the availability of water to plants by lowering the total water potential in the soil. Salinity also has an impact on crop physiology and yield with visible injury occuring at high salinity levels. Usually crop yield is independent of salt concentration when salinity is below some threshold level then yield gradually decreases to zero as the salt concentration increases to the level which cannot be tolerated by a given crop. Rice is a crop which is moderately sensitive to salt.

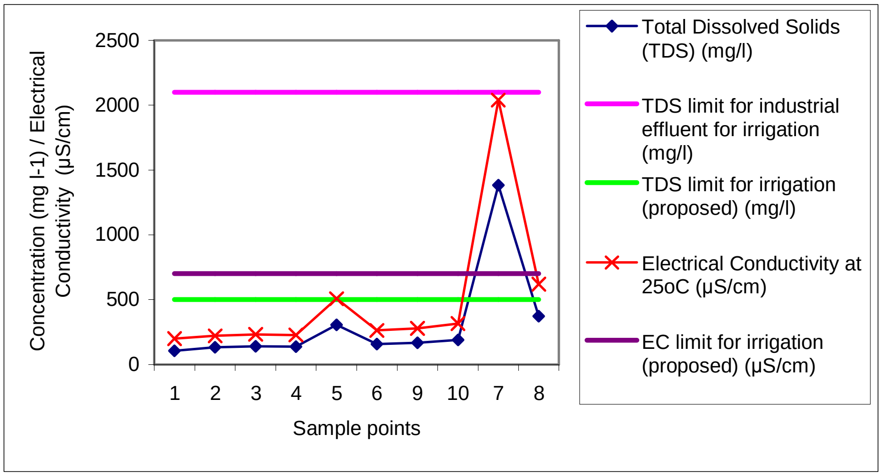
The FAO has developed guidelines for the evaluation of water quality for irrigation and suggests that there need be (Ayres and Westcot 1994):

- No restrictions on the use of irrigation water with an EC of 0.7 dS m^{-1} (700 μS cm^{-1}) or a TDS concentration of less than 450 mg l^{-1};
- Slight to moderate restrictions if concentrations are in the range 0.7 – 3.0 dS m^{-1} or a TDS concentration of 450 – 2000 mg l^{-1}; and
- Severe restrictions for irrigation water with an EC of greater than 3.0 dS m^{-1} or a TDS concentration of more than 2000 mg l^{-1}.

The proposed irrigation water quality standards for Inland Waters in Sri Lanka for EC and TDS are 0.7 dS m^{-1} (700 μS cm^{-1}) and 500mg/l respectively (Annex II).

The baseline samples taken of the wastewater used for irrigation in Kurunegala were all within the FAO guidelines for TDS and EC and the values at sample point 9, the start of the irrigated area, are 168 mg l^{-1} and 280 μS cm^{-1} respectively. Only one of the samples of ground water, which is not used for irrigation, was above the guideline values (Figure 4.1). Likewise, all the samples in the first set of regular monitoring were within the FAO guidelines and the proposed irrigation water quality guidelines in Sri Lanka (700 μS cm^{-1}). The highest conductivity value reported was 457 μS cm^{-1} at location 5 and the EC value at the start of the irrigated area (sample point 9) was 298 μS cm^{-1}.

Figure 4.1: Electrical conductivity and TDS at each sample point



Source: Baseline water quality survey, 2006; CEA, 2001

Temperature

The temperature of wastewater is also an important physical parameter particularly if it is being disposed of to open water bodies where it can affect aquatic life, because it is often warmer than local water bodies. Temperature also affects chemical reactions and reaction rates within the wastewater, thereby influencing its suitability for beneficial uses such as irrigation (Metcalf and Eddy 2003). The temperature of the canal water sampled ranged from 27 ^{o}C to 30 ^{o}C, with that of both wells being 29 ^{o}C. This is within the range for biological activity, which is an important factor for the biological treatment plant proposed by the NWSDB. It also supports the supposition of the project team that there is little or no industrial effluent entering the system since this would tend to increase the temperature, as industrial wastes are often of high temperature. It satisfies the Sri Lanka discharge standards, based on the receiving environment, of 40^{o}C[1].

Inorganic Non-metallic Constituents

Hydrogen-ion concentration: pH

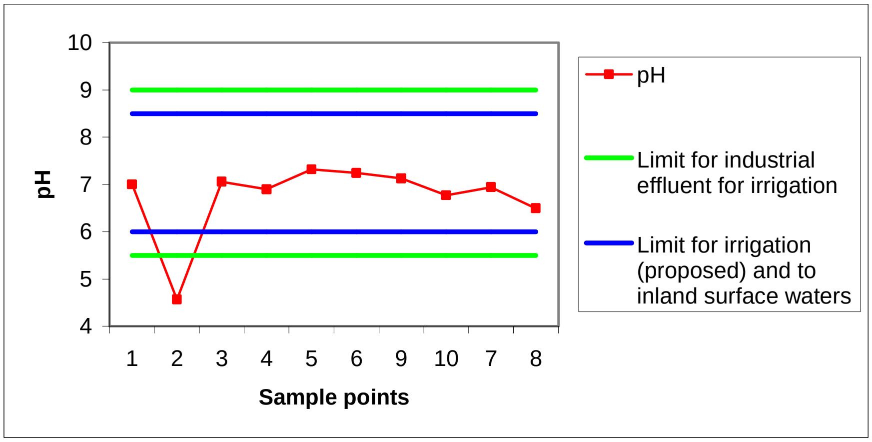
The hydrogen-ion concentration is an important quality parameter of both natural waters and wastewater. The usual means of expressing this is as pH, which his defined as the negative logarithm of the hydrogen-ion concentration. The pH range suitable for the existence of most biological life is quite narrow and critical, and is typically 6-9 (Metcalf and Eddy 2003). High pH values above 8.5 are often caused by high bicarbonate (HCO_3^-) and carbonate (CO_3^{2-}) concentrations, known as alkalinity (Bauder et al. 2004). High carbonates cause calcium and magnesium ions to form insoluble minerals leaving sodium as the dominant ion in solution.

[1] Although it is not truly accurate to compare the canal water with effluent discharge standards, no appropriate standard exists, therefore the discharge standard has been used to give an indication of the pollution. Evidently if the canal does not conform to the standards for discharge of industrial waste to open water bodies or irrigated land then it is heavily polluted.

Highly alkaline water can intensify sodic soil conditions, which will have implications for agriculture.

The samples from all locations except sampling point 2, the Beu Ela just after the hospital outlet were within this range and within the Sri Lanka limit for industrial wastewater being discharged to irrigated land (CEA 2001). The pH of location 2 in the second monitoring event is 7.56 and is within the limit (Figure 3.2). The pH in ground water samples 7 and 8 were 8.08 and 8.14 respectively.

Figure 4.2: Hydrogen ion concentration at each sample point measured as pH



Source: Baseline water quality survey; National Environmental (Protection and Quality) Regulations No.1 of 1990

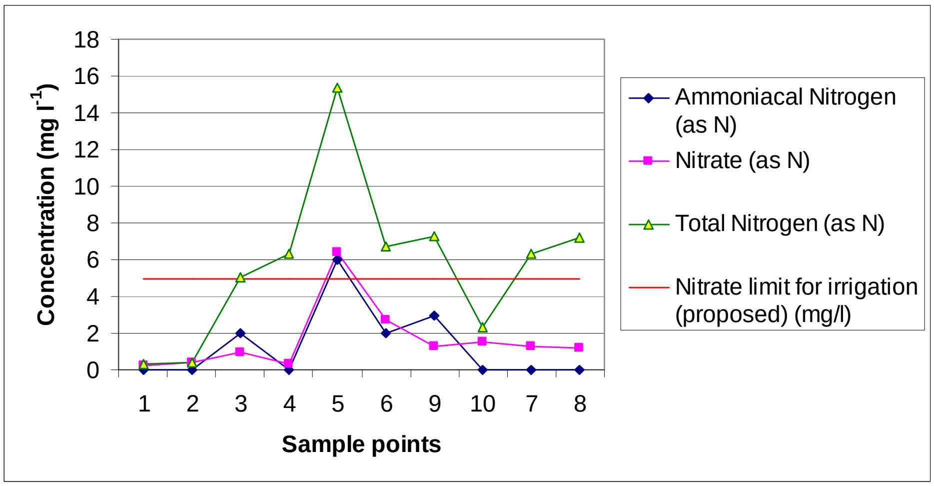
Nitrogen

Nitrogen is a necessary primary macronutrient for plants that stimulates plant growth and is usually added as a fertilizer but can also be found in wastewater as nitrate, ammonia, organic nitrogen or nitrite (FAO 2006). The most important factor for plants is the total amount of nitrogen (N) regardless of whether it is in the form of nitrate-nitrogen (NO_3-N), ammonium-nitrogen (NH_4-N) or organic-nitrogen (Org-N) but by reporting in the form of total nitrogen comparisons can be made (Ayres and Westcot 1994). If excess nitrogen is applied to the crop it can result in: over-stimulation and excessive growth which attracts pests; delayed maturity; or a reduction in the quality of the crop. The concentration of nitrogen required varies according to the crop with more sensitive crops being affected by nitrogen concentrations above 5 mg l^{-1}, whilst most other crops are relatively unaffected until nitrogen exceeds 30 mg l^{-1}. The sensitivity of crops also varies with the growth stage; high nitrogen levels may be beneficial during early growth stages but may cause yield losses during the later flowering and fruiting stages, consequently high nitrogen water, including domestic wastewater, can be used as a fertilizer early in the season but should ideally be reduced or blended with other sources of water later in the growth cycle (Ayres and Westcot 2004).

Nitrogen is known to be a sensitive component in rice culture because excessive nitrogen application can cause lodging[2] of rice plants (Yoon et al. 2001).

In general, the nitrogen levels in the project area were fairly low and were all below 30 mg l^{-1}. However, six of the samples were above the 5 mg l^{-1} proposed for irrigation water for Sri Lanka. The total nitrogen concentration of the ground water was among the highest of the samples but the NO_3-N was below the WHO (1998) Guidelines for Drinking Water Quality. The highest concentration of total N, NO_3-N and NH_4-N was found at sample point 5 on the Wan Ela, just before it joins the Beu Ela, however, given that the pH is 7.32 the ammonia level satisfies the minimum quality criteria of 9.1mg l^{-1} at pH<7.5 of the proposed ambient water quality standards for Sri Lanka. (Figure 4.3).

Figure 4.3: Nitrogen concentrations at each sample point



Source: Baseline water quality survey, 2006; CEA, 2001

The reported value for Total N (TN) is <5mg/l for all locations in the regular monitoring, however, this seems rather low for municipal wastewater especially for location 2. There may be several factors influencing this and further analysis of the data including cross-referencing with rainfall data and discharge data is required. In addition it is likely that inter-aboratory comparison of results will need to be adopted.

The ground water samples were not tested for TN but Kjeldal N was measured instead as the analysis was conducted for the project by the NWSDB. In future TN analyses the persulfate TN determination will be adopted to capture all forms of nitrogen including inorganic nitrogen. Ammoniacal N, nitrate and nitrite were tested only in ground water samples due to budgetary constraints and the greater relevance for drinking water but the results showed that they were well within the maximum desirable limit for drinking water. The free ammonia values reported are 0.53 mg l^{-1} and 0.31 mg l^{-1} respectively for locations 7 and 8. This is much higher than the maximum desirable level for drinking of 0.06 mg l^{-1} (SLS 614:1985 part 1).

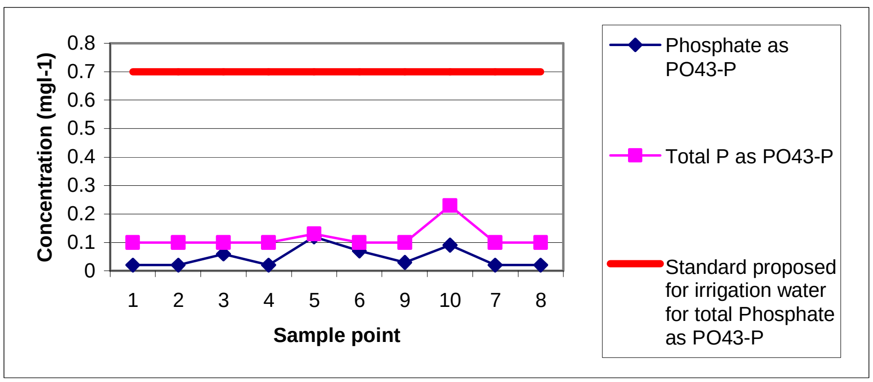
[2] Excessive growth of the plant causing it to collapse.

Phosphorous

Phosphorus is also a primary macronutrient that is essential to the growth of plants and other biological organisms but quantities can be excessive and if the concentrations in water are too high noxious algal blooms can occur. Phosphates are classified as orthophosphates, polyphosphates and organic phosphates. Municipal waste waters may contain between 4 and 16 mg l^{-1} of phosphorus as P (Metcalf and Eddy 2003). In Sri Lanka there is currently no limit on phosphorus levels in wastewater but the proposed limit has been set at 0.7 mg l^{-1} (Annex II; CEA 2001).

The concentrations of orthophosphate and total phosphate in locations 5 and 10 are relatively higher than other locations but do not exceed the proposed standard for irrigation and agriculture, and are considerably below the typical concentrations for wastewater quoted by Metcalf and Eddy (2003) (Figure 3.4). None the less they do indicate that there is some form of contamination at these points. With the limited current information it can be surmised that the cause of the peak at point 5 is domestic waste, including toilet waste, but that the peak at point 10 is more likely to be arising from agricultural run off of fertilizers applied to the paddy.

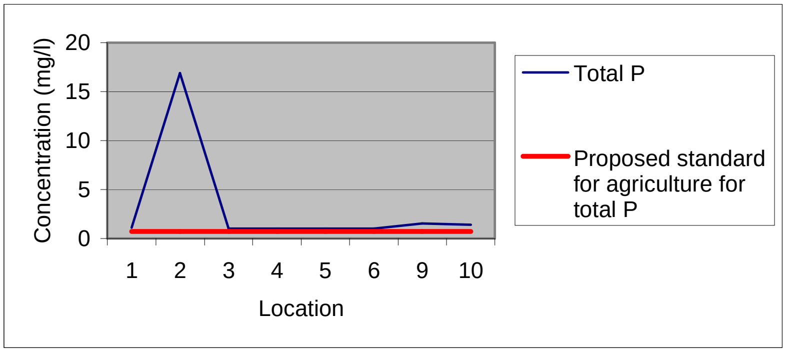
Figure 4.4: Phosphorous concentrations at each sample point in the baseline survey



Source: Baseline water quality survey; CEA 2001

During the second monitoring event the total phosphorous was tested in all location except the ground water wells. All the values reported exceed the proposed standard for irrigation and agriculture for total phosphate of 0.7 mg l^{-1}. Location 2 had the highest value at 16.9 mg l^{-1} which is characteristic of municipal wastewater quoted by Metcalf and Eddy (2003). The most upstream locations (location 1 on Beu Ela and Location 4 on Wan Ela) also have phosphorous values greater than 1 mg l^{-1} which could well originate from upstream agriculture.

Figure 4.5: Phosphorous concentrations at each sample point in the second monitoring event



Source: Second monitoring event, 2007; CEA, 2001

Note: P is recorded as PO_4^{3-}

Municipal wastewater with 6-20 mg l^{-1} phosphorous increases the productivity of the crops and when the concentration exceeds 20 mg l^{-1} the availability of copper, iron and zinc is reduced in alkaline soils (WHO 2006). The highest reported value in the survey in Kurunegala is less than 20 mg l^{-1} and therefore, it can be assumed that there is no negative effect. Wastewater normally contains low amounts of phosphorous, so its use for irrigation is beneficial and does not negatively impact the environment. This is the case even when wastewater effluents with high concentration of phosphorous are applied over long periods of time although, because phosphorous builds up at the soil surface, it can affect surface waters through soil erosion and runoff (WHO 2006).

Metallic Constituents

Trace quantities of many metals can be found in wastewaters, particularly industrial waste but also arising from domestic waste, for example from household cleaning products. Many of these metals are necessary for growth of biological life but only in trace concentrations; if the required concentrations are exceeded they can become toxic and thus interfere with the potential beneficial uses of wastewater (Metcalf and Eddy 2003). It is important to note that however high the metal content of irrigation water, it will not be absorbed by the plants unless it first reaches a threshold concentration in the soil and the metal is in a mobile phase. Metals are bound to soils with pH above 6.5 or with high organic matter content; below this pH adsorption sites are saturated and metals become mobile (WHO 2006).

The samples tested for the project were analyzed for a selection of metals that were either beneficial for plant growth, or are likely to cause damage to crops or impact on human health, these included: calcium, magnesium, potassium, sodium, iron, nickel, copper, cadmium, chromium, arsenic, lead, mercury and boron. Of these, potassium is a primary macro-nutrient, and calcium and magnesium are secondary macronutrients. Iron, boron and copper can help plant growth and development. Although boron is an essential element, it easily becomes toxic above the required level. All the others directly or indirectly affect the plant growth and development to various degrees and above different threshold levels.

Potassium

Potassium is not an integral part of any major plant component but it does play a key role in a vast array of physiological processes vital to plant growth, from protein synthesis to maintenance of plant water balance. Potassium is a macro-nutrient that is present in high concentrations in soils but is not bio-available since it is bound to other compounds. Generally, wastewater contains low potassium concentrations insufficient to cover the plant's theoretical demand, and use of wastewater in agriculture does not normally cause negative environmental impacts (Mikklesen and Camberato 1995).

Results show small variations of 3 mg l^{-1} to 4 mg l^{-1} within the Beu Ela but much higher variations within the Wan Ela of 3mg l^{-1} to 57 mg l^{-1}, which may originate from human faeces and urine disposal, as human faeces has on average 1.6% and urine has 3.7% (dry weight) potassium (Strauss 2000) (Annex VII and Annex VIII). The high potassium value in location 5 could be the result of faecal contamination from the shanty community but this is not confirmed. In the irrigation canal in the agricultural area the measured values vary between 2 and 3 mg l^{-1}.

Sodium Adsorption Ratio

The relative proportion of sodium to other cations is determined by the Sodium Adsorption Ratio (SAR). This index quantifies the proportion of sodium (Na^{+}) to calcium (Ca^{2+}) and magnesium (Mg^{2+}) ions in a sample. Calcium will flocculate (hold together), while sodium disperses (pushes apart) soil particles. This dispersed soil will readily crust and have water infiltration and permeability problems. Any increase in the SAR in irrigation water increases the SAR of the soil solution, which ultimately increases the exchangeable sodium by the soil, leading to the loss of permeability.

$$SAR = \frac{Na}{\sqrt{(Ca+Mg)/2}}$$ where concentration are in meq/l

$$SAR = \frac{Na^{+}}{\sqrt{Ca^{2+}+Mg^{2+}}}$$ where ionic concentrations of each is in mmol/l

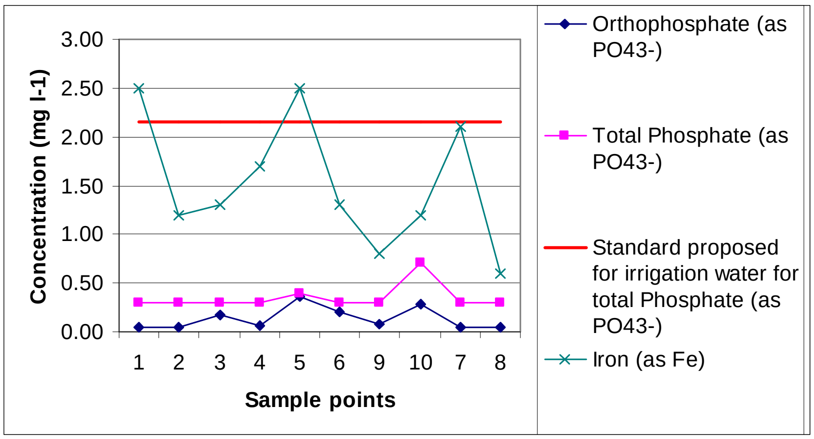
SAR varies between 0.44 to 1.05 for locations 1 to 10 in the baseline survey and 0.70 to 1.25 in the second monitoring event. The variation within within the irrigation canal is less at 0.78 to 1.05; and 1.25 to 1.17 for the respective sampling events. These values are far below the WHO (2006) restricted limits for irrigation water. The Proposed Ambient Water Quality Standard range for SAR for irrigation and agriculture in Sri Lanka is 6-15 (Annex II).

Iron

Excessive iron in wastewater can reduce the dissolved phosphorous component by precipitating the dissolved phosphate. Therefore, phosphorous might not be readily available for plant uptake in the presence of excessive iron. The concentration of iron ranged from 0.6 mg l^{-1} in one of the ground water samples to 2.5 mg l^{-1} in the in-flow to Beu Ela (point 1) and at point 5; however there was no clear pattern in the variability of iron concentrations (Figure 4.). The WHO recommended maximum concentration of Fe for crop production is 5mg l^{-1} and the reported values for the project samples are much below this level.

Iron was tested only in ground water samples in the regular monitoring and the concentrations are within the permissible maximum level for drinking of 1.0 mg l^{-1} proposed by SLS 614:1985 part 1.

Figure 4.6: Concentrations of macronutrient P and micronutrient Fe



Source: Baseline water quality survey, 2006; CEA, 2001

Boron

Boron (B) is an essential element for plant growth but in relatively small amounts. For example, for some plants 0.2 mg l^{-1} in irrigation water is essential but 1-2 mg l^{-1} may be toxic, although there is a wide range of tolerance between crops and most crop toxicity symptoms occur after concentrations in leaf blades exceed 250 mg kg^{-1} dry weight. Typical symptoms are a yellowing of leaves, spotting or drying of leaf tissue (Ayres and Westcot 2004). The CEA proposed standard in Sri Lanka for irrigation and agriculture is 0.5 mg l^{-1}. The water quality results indicate that boron is not detected where the limit of determination is 1 mg l^{-1}. A slight to moderate degree of restriction is recommened by WHO (2006) for wastewater having B levels 0.7 to 3mg l^{-1}. There is no restriction of use for waters containing <0.7mg l^{-1} (WHO, 2006). Therefore, B will be tested using a lower limit of determination in future monitoring events to confirm whether it is below 0.5mg l^{-1}.

Heavy Metals

The results of the water quality analysis showed that Ni, Cd, As, Pb and Hg were not detected in any of the samples. All samples except that from point 9 were found to contain some Cr but it ranged from 0.05 to 0.06 mg l^{-1} and was therefore below the national limit for Sri Lanka of 0.1 mg l^{-1} for effluents disposed of to surface water and below the limit of 1.0 mg l^{-1} for effluents disposed of to irrigated land (Annex I). Copper was only found to be present in the ground water (sample point 7) and only at a concentration of 0.01 mg l^{-1} which is the minimum quality standard proposed by the CEA. However, standards are not proposed for Cu for irrigation and agriculture. The WHO recommended maximum concentration is 0.2 mg l^{-1}, and Cu is toxic to a number of plants at 0.1-1.0 mg l^{-1} in nutrient solutions (WHO, 2006).

Organic Constituents

Dissolved Oxygen and Biochemical Oxygen Demand

The DO was measured *in situ* and the values were found to be in the range of 0.82 to 3.06 mg l^{-1} in all locations except location 2 which was high at 7.35 mg l^{-1}. This was unexpected because this point receives waste from the hospital where the treatment plant is currently not functioning. One possible reason for this is that there was a measurement error: if the DO probe was used during the warm up period the analyst may obtain a higher value than actual value. Alternatively the high value may have arisen if the stream was receiving more aerated water from somewhere or if the treatment plant was having some effect even if it was not treating the waste completely. This will be investigated in future sampling events.

The most widely used parameter to measure water quality and used in the design of effluent treatment plants is 5-day Biochemical Oxygen Demand (BOD_5). The determination of BOD_5 involves the measurement of the dissolved oxygen (DO) used by microorganisms in the biochemical oxidation of organic matter, and is a measure of organic pollution (Metcalf and Eddy 2003). In the analysis conducted by ITI the method used for BOD_5 analysis had a detection limit of 15 mg l^{-1} because the water was deemed to be wastewater. The results of the analysis were that all samples were below the limits of detection for the method used. However, a higher BOD_5 was expected and some other data sets from NWSDB and University of Peradeniya suggest that the BOD_5 should be in the range 90-160 mg l^{-1}. The concentrations may also have been low because the samples were taken during the rainy season but this does not account for the low DO which would imply a high BOD_5. This will therefore be reanalyzed in future sampling events and the effects of season and rainfall will be considered.

The current maximum limit for BOD_5 for industrial effluent discharged to agricultural land is 250 mg l^{-1} but this is high; the limit for discharge to open water bodies is only 30 mg l^{-1} and the proposed limits for ambient water quality range from 3 to 5 mg l^{-1} (Annex I). Therefore, in any future testing of BOD_5 it may be necessary to undertake an inter-laboratory comparison of results and also to use a method which has a detection limit of 5 mg l^{-1} which is the standard proposed for irrigation and agriculture. However, the proposed standard could be too stringent as municipal wastewater with BOD_5 110-400mg l^{-1} increases crop productivity (WHO 2006). Continuous irrigation and high organic matter contents may clog soil pores; however, this usually does not occur unless BOD_5 levels exceed 500mg l^{-1} (WHO, 2006).

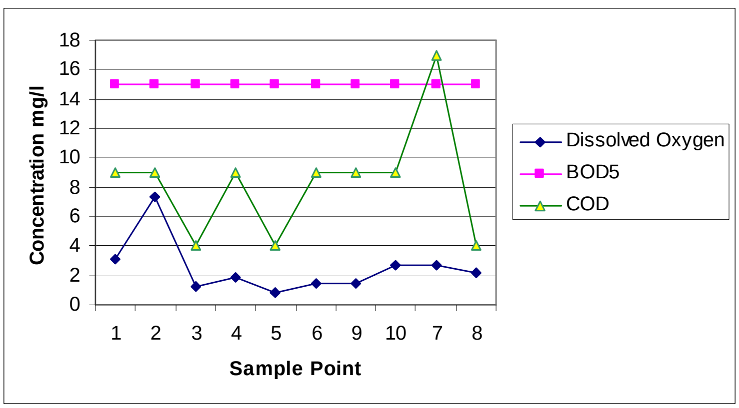
Chemical Oxygen Demand

Chemical oxygen demand (COD) is often measured in addition to or instead of BOD_5 as it has the advantage that it can be measured in a couple of hours and in many “known” waters (e.g. fresh water or wastewater) can be used to roughly calculate the BOD. The COD test is used to measure the oxygen equivalent of the organic material in wastewater that can be oxidized chemically using dichromate in acid solution (Metcalf and Eddy 2003).

There is no maximum permissible COD level defined for Sri Lanka for irrigation water for agriculture but there is a proposed minimum quality criterion of 40 mg l^{-1} for Class III waters (general waters). All the samples were within this limit in the baseline survey tested by ITI; though higher values were expected. Some other data sets from NWSDB and University of Peradeniya indicate that the COD could be much higher. As with BOD_5, the quantity of rain may have been a factor and will be considered in future sampling events. The COD results for the second monitoring event are higher as expected, ranging from 64 to 142 mg l^{-1} and the reported low values in the baseline survey could be due to some inaccuracy. Careful attention will be given in future monitoring events for both BOD and COD especially since the BOD_5 values for the first regular monitoring were also <15 mg l^{-1} which is unlikely for municipal wastewater and does not agree with the COD values.

The COD is within the general standards for discharge of effluents into inland surface waters, which is 250 mg l^{-1}. However, the proposed minimum quality criterion of 40 mg l^{-1} for Class III waters is exceeded. The COD to BOD_5 ratio is in the range 1:4 to 1:6 in all locations, which is unlikely, as there are no large industries in the project area. This high ratio may be due to an inaccuracy in low BOD_5 values reported. The likely ratio of COD to BOD_5 is 1:2 to1:4 for municipal wastewater.

Figure 4.7: Variation of DO, BOD and COD of locations in the project area



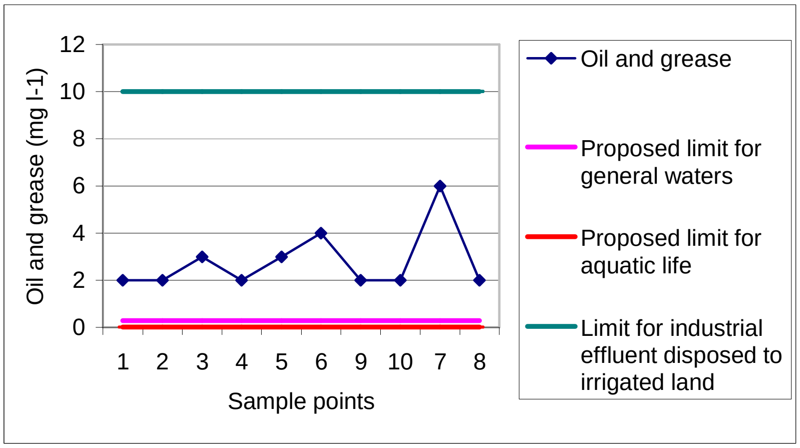
Source: Baseline water quality survey, 2006

Oil and Grease

The term oil and grease is commonly used and often included in environmental or wastewater quality standards. The term covers fats, oils, waxes and other related constituents of wastewater. Oils and greases are compounds (esters) of alcohol or glycerol (glycerin) with fatty acids. The glycerides of fatty acids that are liquids at ordinary temperatures are called oils and those that are solids are called fats. They can arise from all manner of sources including meats and meat processing, butter, margarine, cooking oil and vehicle oils. They can interfere with biological life at the water surface and also cause unsightly films (Metcalf and Eddy 2003).

There is no existing or proposed standards for oil and grease for irrigation and agriculture in Sri Lanka, although for bathing, aquatic life and general waters the oil and grease maximum permissible levels are 200 $\mu g\ l^{-1}$, 10 $\mu g\ l^{-1}$ and 300 $\mu g\ l^{-1}$ respectively. All the samples tested exceeded these limits (Figure 3.6) but the tolerance limit for industrial effluent discharged on land for irrigation of 10 mg l^{-1} was not exceeded (Annex I).

Figure 4.8: Oil and grease concentrations, and existing and proposed limits



Source: Baseline water quality survey, 2006; CEA, 2001

The presence of oil and grease has been one of the main complaints from the stakeholders already interviewed in Kurunegala including residents of the city, peri-urban farmers and representatives of the Municipal Council. The farmers are in contact with the wastewater and the oil and grease is undesirable. This is therefore one of the parameters that will remain in the sampling protocol and will be closely monitored. Work has also been initiated to try to determine the main sources of this pollutant.

Biological Parameters

The biological characteristics of water and wastewater are of fundamental importance to human health, in controlling diseases caused by pathogenic organisms of human origin (Metcalf and Eddy 2003). Untreated wastewater that includes fecal waste contains a variety of excreted organisms including pathogens at very high concentrations (Strauss 2000). Microbial evidence can therefore be used to indicate that a hazard exists in the environment but there is no perfect indicator organism for wastewater as excreted organisms range from bacteria to helminths, protozoa and viruses (WHO 2006). The most common indicator organisms used when monitoring water quality are coliforms and faecal coliforms (Ayers and Mara 1996). The coliform group of bacteria comprises mainly species of the genera *Citrobater, Enterobacter, Escherichia* and *Klebsiella*, and includes faecal coliforms of which

Escherichia coli (E-coli) is the predominant species (Pescod 1992). Ranges of values reported from different studies are given in Annex VIII for reference.

Sri Lanka does not currently have any guidelines for wastewater reuse, only for drinking water, but does propose total coliform (TC) guidelines for fish and aquatic life of 20,000 most probable number per 100 ml (MPN/100 ml) and for irrigation and agriculture of 1,000 MPN/100 ml (Annex II). Guidelines set by WHO for wastewater used in agriculture originally had a maximum faecal coliform (FC) geometric mean number per 100 ml of less than 1,000 for crops likely to be eaten raw, but no standard for irrigation of cereal crops (Pescod 1992).

The high level of total and faecal coliforms in samples tested in the baseline survey does not comply with the proposed water quality standards for irrigation and agriculture in Sri Lanka or the WHO guidelines for use of wastewater in agriculture (CEA 2001; WHO 2006). The highest contamination level was found in sample 5 (Wan Ela exit point from the city), which is close to the Wilgoda Line community, it may therefore be that Wilgoda Line is the source of this contamination, but further research is needed to confirm this as it could also be because it is the down stream point of the city and therefore contains the highest concentration of all the city waste. The water in the canal which takes water from the *anicut* to the paddy fields was found to have 5×10^5 MPN of coliforms /100ml. The water in the irrigation canal near the paddy lands (entry point to the paddy fields) had 16×10^4 MPN of coliforms/100ml, which is above the limits set by the WHO for wastewater used in agriculture (Table 4.1). The groundwater samples analyzed (7 and 8) also showed high faecal contamination. The well numbered sample point 8 is used for bathing but the water quality does not comply with the bathing water standards for Coliforms given in the CEA proposed water quality standards.

The microbiological analysis was carried out with strict quality control according to ITI, however the samples were incubated after 10 hours of sample collection therefore the 6 hour holding time was not satisfied (American Public Health Association 2001). Efforts will be made to prevent this from happening in future sampling events in order to achieve accurate results and a clear picture of the water quality situation in Kurunegala. However, more recent guidelines (Environment Protection Authority (EPA) 2006) have made provisions for a 24 hour holding time for microbiological analysis although a 6 hour holding time is preferable. Therefore, it is assumed that the errors are minimal as the samples were preserved by refrigeration (cooling to a temperature of $<4^oC$) immediately after collection and kept refrigerated until tested.

Table 4.1: Total coliform and faecal coliform concentrations

Location	Baseline survey, 2006		Second sampling event, 2007	
	Total coliforms MPN / 100 ml (confirmed MPN)	Fecal coliforms MPN / 100 ml	Total coliforms MPN / 100 ml (confirmed MPN)	Fecal coliforms MPN / 100 ml
1	3×10^5	3×10^5	>1000	210
2	9×10^4	9×10^4	>1000	290
2 duplicate			>1000	290
3	17×10^4	17×10^4	>1000	>1000
4	5×10^4	5×10^4	>1000	53
5	9×10^7	9×10^7	>1000	>1000
6	5×10^5	5×10^5	>1000	>1000
9	16×10^4	16×10^4	53	44
10	2100	2100	29	21
7	1400	500	12	07
8	8000	8000	Nil	Nil
Proposed Irrigation Standard Sri Lanka	1000	-		

MPN: Most probable number

What is more of a problem is the sensitivity of the test used, as the reported results for both total and faecal coliforms are the same for all locations except location 7 but it is usual to expect the faecal coliform numbers to be lower than the total coliform numbers. Consequently, in future monitoring events it is recommended to use a technique with higher sensitivity.

In the first of the regular sampling event the 6 hour holding time was satisfied and the detection limit of 1000 coliform/100 ml was used, which is the proposed standard for irrigation and agriculture in Sri Lanka. In this sampling event the results showed that the samples from all the locations from 1-6 exceeded the Sri Lankan proposed total coliform standard for irrigation and agriculture which is 1000 Coliforms/100ml. In locations 9 and 10 where the water it is used for irrigation and agriculture it is however much below the proposed standard at just 53 Coliforms/100ml and 29 Coliforms/100ml respectively. The wastewater travels some 2 km from the anicut in the irrigation canal to reach location 9 and it is likely the reduction of coliforms happens in this process. The seasonal effect and the effect of the 2 km strech of the irrigation canal and travel time are yet to be studied and understood with the future monitoring events. However, all locations except the deep water well at location 8 are fecally contaminated to some extent. The contamination levels at locations 3, 5 and 6 are much higher at >1000/100ml. These locations are the most downstream locations of Wan Ela and Beu Ela and the variation of fecal contamination from upstream to downstream are clear.

Parasite cysts and ova

Of the three sample locations tested, only one was positive for parasite eggs (Table 3.3). Only, pin worm eggs (*Enterobius vermicularis*) were found in the sample, indicating feacal contamination of the storage water. This was Location 6, where the water was held at the anicut for irrigation purposes. The water quality in the anicut did not satisfy the WHO quality criterion laid out in the guidelines for safe use of wastewater for irrigation and agriculture (WHO 2006). The sampling crew experienced a difficulty in collecting the sample from location 6 for parasite studies as the anicut was opened just before the sampling and much of the water had therefore drained away to the paddy fields. The sample was collected from the remaining water in the anicut and therefore, some of the content from the sediment may have been picked up as well. The open defecation practice of children in the wilgoda low income community could have contributed to this fidning. The inlet to the paddy field is some 2 Km away from the anicut and therefore, it is important to test location 9 for parasite cysts and ova in future monitoring events, to see the suitability of the water for irrigation and agriculture. The seasonal effects, effect of the 2 km stretch of the irrigation canal and flow rate are yet to be studied and understood with the future monitoring events.

Table 4.3: Parasite cysts and ova concentrations – Second Monitoring Event

Location	Presence of parasites	WHO standard for irrigation and agriculture (helminth eggs)
2	Nil	<0.1/litre
3	Nil	
6	Positive for helminths	

5 Loads of Selected Parameters

The discharge data was used in conjunction with the water quality data to calculate the overall pollutant loads for some of the key parameters. The discharge data are presented in Table 5.1 and in both sampling occasions the discharge of Beu Ela was greater than the discharge in Wan Ela. The discharge of Wan Ela increased approximately by an order of magnitute from location 4 to 5 indicating high wastewater discharge from the city center. The discharge of Beu Ela also increased from location 1 to location 3 however the magnitude of increase was less.

Table 5.1: Discharge at sample locations on 5th July 2006 and 12th December 2006

Location	Baseline discharge		Second sampling	
	Discharge (m^3s^{-1})	Discharge (m^3 day^{-1})	Discharge (m^3 s^{-1})	Discharge (m^3 day^{-1})
1 Beu Ela before the city and before the hospital (entry point to the city)	0.13	$1.13x10^4$	0.180	1.56 $x10^4$
2 Beu Ela after the hospital but before the main city drainage area	0.14	$1.20x10^4$	0.310	2.67 $x10^4$
3 Beu Ela before the fork (exit point from the city)	0.17	$1.47x10^4$	0.308	2.66 $x10^4$
4 Wan Ela near the tank (entry point to the city)	0.02	$1.73x10^3$	0.065	5.64 $x10^3$
5 Wan Ela before the fork (exit point from the city)	0.10	$8.64x10^3$	0.173	1.49 $x10^4$
6 Beginning of the Irrigation canal	0.10	$8.64x10^3$	Not measured[2]	Not measured[2]
9 Irrigation canal near the paddy lands (entry point to the paddy fields)	Current metering was not possible		0.054	1.61 $x10^3$
10 Drainage from the paddy land	Current metering was not possible		0.008	6.91 $x10^2$

[2]the anicut was opened at the time of the sampling and the flow was fluctuating.

The discharges of locations 9 and 10 were not measurable with the current meter as the channel width was too small and in future another method will be used, involving floats and a stop watch. Attention will be paid in future sampling programs to select an inlet and outlet where current metering is possible. The water level and flow rate measurements will be made more frequently to calculate the amount of water available for irrigation.

Calculation of the load of the various constituents is important to determine the total quantity of each constituent that passes a certain point in a given amount of time. The results from individual discrete samples can be mathematically converted to a composite value using three different weighting techniques based on time, stream flow and volume. Generally, a single set of field-measurement data is used to represent an entire stream cross section at a sampling site and can be useful when calculating chemical loads (www.water.usgs.gov). Composite values were calculated from the discrete concentration values (mg l^{-1}) based on time because of well mixed conditions and shallow flows which gives rise to uniform concentrations within a particular cross section.

If cross sectional data are used the following equation is required:

$$Load = k \int_t c(t)\, q(t)\, dt$$

Where
t = time in seconds
c(t) = Concentration at time (t) in mg l^{-1}
q(t) = Water discharge at time (t) in $m^3\, s^{-1}$

This can be used to derive the following equation for single data sets, which was used in this study:

Load = C.Q

C = concentration of the parameter (mg l^{-1})
Q = water discharge ($l\, s^{-1}$)

The loads of certain parameters were therefore roughly calculated, in kilograms per day (kg day^{-1}), using the baseline water quality data for locations 1 to 6 (Table 5.2). This is a crude estimation to indicate the loads brought into the anicut by the two canals and load exported to the agricultural area. The loads at locations 9 and 10 (inlet and outlet to the agricultural field) will be estimated more precisely in future monitoring.

Table 5.2: Pollutant loads calculated for the baseline survey

Parameter	**Load for each location (kg day^{-1})**					
	1	**2**	**3**	**4**	**5**	**6**
Nitrate-N	2.938	4.560	1.47	0.5536	55.296	23.328
Total N	3.164	4.68	74.09	10.99	133.06	57.89
Phosphate reactive-P	0.23	0.24	0.88	0.04	1.04	0.61
Total P	1.13	1.20	1.47	0.17	1.12	0.86
K	33.9	36	58.8	5.19	492.48	60.48
TSS	203.4	120	147	6.92	155.52	172.8

The location 3 and 5 loads indicate the nutrient loads brought into the anicut by the Beu Ela and Wan Ela respectively. It is clear from the results that the nitrate, total nitrogen and potassium loads brought by Wan Ela are much higher than the Beu Ela. The phosphorous load and TSS load are almost the same in both canals while the phosphate laod is slightly higher in Wan Ela.

Importance for Agriculture

Knowledge of the quality of irrigation water is important in judging its suitability for agriculture. The suitability of irrigation water depends upon several factors associated with characteristic of water, soil, plant and climate, and can be expressed by the following relationship (Gunawardhana 2005).

SI =f (QSPDC) SI = Suitability of irrigation water

Q = Quality of water i.e. total salt concentration, cationic and anionic composition

S = Physico-chemical properties of the soil profile

P = Salt tolerance characteristics of the crop at different growth stages

D = Drainage conditions

C = Climatic parameter

It evident from the water quality concentrations and loads presented in the above results that the nutrients nitrogen and potassium are available in the water in significant amounts but how farmers utilize these incoming nutrients is yet to be understood. The values calculated do not represent the spatial and temporal variation hence more frequent analysis are necessary along the canals and even within the farmers fields, as behavior of these NPK in the field is highly complex. Phosphate levels seem to be low but continuous additions of phosphate in low quantities are more important than for agriculture than a large, sudden inflow, so this could prove to be beneficial.

6 Industrial and Commercial Unit Survey Results and Discussion

The industrial and commercial units along main roads within the city limits and also by-roads in the city centre dispose of their wastewater to the main drainage canals. The roads draining into the Beu Ela include: Kurunegala-Colombo, Kurunegala-Kandy, Udawalpola Road, Wathhimi Road, Rajapihilla Mawatha and Borawewa Seelananda Mawatha are in the Beu Ela drainage basin. Those draining into the Wan Ela are: Kurunegala-Puttlam Road, Negombo Road, Kurunegala-Dambulla, Kachcheriya Road, Sooratissa Road, Baudhaloka Mawatha, Wilgoda Road Muslim Mosque Road, Dr. Silva Mawatha, Mihindu Mawatha, Main street, Bodhiraja Mawatha, Maliyadeva Street, Parakumba Street and St.Annes Road and Convet Road (Annex IV).

The NWSDB has identified and mapped the major inlets along Beu Ela and Wan Ela that they consider to be sources of pollution. There are 35 inlets along Wan Ela and 21 inlets along Beu Ela, including drains from four service stations, urban run-off, drainage from gardens, wastewater from commercial units, hotels, hospitals, clinics, schools and colleges, as well as from side drains reciving waste from other point sources (Annex V).

This data was complemented by a thorough study of the point sources of pollution entering the two canals, which was conducted by the project team and completed in January 2007. This survey catalogued 2727 units in the catchment area of the two canals Wan Ela and Beu Ela (Annex VI). There are no large scale industries in the project area that drain into canals; most of the wastewater appears to be domestic. The hospitals, vehicle service stations, and slaughter houses and meat stalls, hotels and restuarants, schools, technical colleges and tution classes were identified as significant sources of pollution in the area.

The National Teaching Hospital of Kurunegala is felt to be a major source of pollution, as the hospital treatment plant is currently not functioning. The hospital discharges a wastewater volume of 758 m^3 day^{-1} (NWSDB, 2005). Fortunately, the NWSDB has an on-going, long-term project, which specifically addresses the hospital wastewater treatment. In addition twelve major private clinics and medical labs were recorded in the cathment area, which generate hospital waste.

There are two large hotels, five medium-scale hotels and approximately 150 small hotels, restaurants and cafes, all of which can be assumed to be producing wastewater that contains oil, grease and detergent, as well as small pieces of food, which contribute to the organic load of the receiving waters. The hotels near the Kurunegala Tank in Wellangolla Road and North Tank Road do not drain into Wan Ela. The Hotels situated at Kurunegala Lake dispose of their waste to the lake (NWSDB, 2005).

A large number of units are concentrated in the city center and there is a high degree of pollution there which is responsible for the condition of Wan Ela. The drains along Muslim Mosque Road, Dr. Silva Mawatha, Main Street, Bodhiraja Mawatha, Maliyadeva Street and Parakumba Street are not well maintained and are silted, blocked and overflowing in several places with a large number of inlets from various commercial units. The Theliyagonna area along Kandy Road has a large number of meat stalls concentrated in one area, which is likely to have an impact on the water quality in terms of BOD and E. coli.

This initial data will be used to identify a selection of wastewater producers with whom to work. The team will conduct interviewes with the owners and managers to further identify the types and levels of pollutants, and to seek options for pollution reduction and treatment. This information will be provided to the Learning Alliance members and will feed into the participatory action planning process.

7 Conclusions

Most of the parameters tested in the baseline water quality survey were within the the proposed Sri Lankan standards for irrigation and agriculture, and the WHO guidelines for wastewater use in agriculture. Very low if any concentrations of heavy metals were recorded, and these will not therefore be tested in future monitoring events. The most concerning factor was that biological quality parameters were not satisfied.

It can be concluded that the major problem in using wastewater in agriculture in the project area is the high level of faecal contamination. The wastewater is mainly used for growing paddy and the health risks are therefore predominatly to agricultural workers and their families; consumers are less likely to be at risk because rice is always cooked. However, there is evidence that vegetables are grown occasionally in small plots which could affect consumers.

That said, the total coliform count was substantially lower in the agricultural area than further up-stream. This may be due to natural treatment processes in the 2 km strech of the irrigation canal where there are very few additional sources of pollution. This needs to be studied further to see if the natural processes can be enhanced, for example by slowing the flow and increasing retention time, or enhancing oxygenation.

There could also be health risks to the community that use contaminated ground water for washing, cooking and other purposes. Therefore, treatment methodologies and management strategies are needed to bring down the levels of coliform. The shanty community near location 5 (Exit point of Wan Ela) could be a significant source of pollution and are likely to be a source of faecal contamination, but further monitoring is required to confirm this. Another potential source is the abattoir that is located close-by, although it is not a large operation. The other sources of faecal contamination need to be identified, which can lead to inverventions to reduce and control the comtaminant at source.

Nutrients are clearly present in the wastewater, and in the case of phosphorus are generally high, although only the phosphate form is taken up by plants. The presence of nutrients can be beneficial for agricultural end use, but the quanitities need to be known before they can be taken advantage of. This is very difficult they may vary considerably over the year and because crop requirements also change throughout the growth cycle, which means that it could be quite a complex process to calculate how much N, P or K are available at certain relevant times.

The point source pollution survey identified some potential sources of nutrients but this was mainly of domestic origin – hotels, residencies, hospitals, schools and colleges. These were also the main sources of total coliforms and faecal coliforms identified. An additional source may be road run-off which would include animal faeces and effluent from abattoirs.

Although oil and grease were not monitored in the water quality survey a number of farmers reported them as a problem. The inventory of pollution sources identified a number of potential sources for this contaminant, especially vehicle service stations, and hotels and restaurants.

Clearly, the main recommendation to improve the quality of water in the canals that are used for agriculture is upstream intervetions to reduce pollution at source. In order to bring down the deterioration of the water quality, it is required:

- To work with the industries to improve the quality of thier discharges by introducing cleaner production techniques, Best Management Practices (BMPs) including structural BMPs and institutional options, and wastewater treatment.

- To improve the on-site sanitation facilities of low income communities including effective disposal. This must be appropriately designed to ensure that it is used and to avoid failure.

- To prevent solid waste from being dumped into the canals by ensuring regular collections, and by increasing composting and recycling in collaboration with the existing solid waste management programs in the area.

- To regularly remove solid waste from the canals.

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Annex I: National Environmental (Protection and Quality) Regulations No.1 of 1990

Table 1: General standards for discharge of effluents into inland surface waters

DETERMINANT	TOLERANCE LIMIT
Total Suspended Solids, mg/l, max	50
Particle size of total suspended solids	Shall pass sieve of aperture size 850 micro m.
pH value at ambient temperature	6.0 to 8.5
Biochemical Oxygen Demand-BOD_5 in 5 days at $20^{O}C$, mg/l, max	30
Temperature of discharge	Shall no exceed $40^{o}C$ in any Section of the Stream within 15 m down Stream from the effluent outlet.
Oils and greases, mg/l, max	10.0
Phenolic Compounds (as phenolic OH) mg/l, max	1.0
Cyanides as (CN) mg/l, max	0.2
Sulfides, mg/l, max	2.0
Fluorides, mg/l, max	2.0
Total residual chlorine mg/l, max	1.0
Arsenic, mg/l, max	0.2
Cadmium total, mg/I, max	0.1
Chromium total, mg/l, max	0.1
Copper total, mg/l, max	3.0
Lead, total, mg/l, max	0.1
Mercury total, mg/l, max	0.0005
Nickel total, mg/l, max	3.0
Selenium total, mg/l, mg	0.05
Zinc total, mg/l, max	5.0
Ammoniacal nitrogen, mg/l, max	50.0
Pesticides	Undetectable
Radio active material (a) Alpha emitters micro curie/ml (b) Beta-emitters micro curie/ml	 10^{-7} 10^{-8}
Chemical Oxygen Demand (COD), mg/l, max	250

Note 1: All efforts should be made to remove colour and unpleasant odour as far as possible.

Note 2: These values are based on dilution of effluents by at least 8 volumes of clean receiving water. If the dilution is below 8 times, the permissible limits are multiplied by 1/8 of the actual dilution.

Note 3: The General Standards cease to apply with regard to a particular industry when industry specific standards are notified for that industry.

Table 2: Tolerance limits for industrial effluents discharged on land for irrigation purpose

No	Determinant	Tolerance Limit
1	Total dissolved solid, mg/l, max	2100
2	pH value ambient temperature	5.5 to 9.0
3	Biochemical Oxygen Demand (BOD_5) in 5 days at 20^{o}C, mg/l, max	250
4	Oils and grease, mg/l, max.	10.0
5	Chloride (as Cl), mg/l, max.	600
6	Sulfate (as SO_4), mg/l, max.	1000
7	Boron (as B), mg/l, max.	2.0
8	Arsenic (as As), mg/l, max.	0.2
9	Cadmium (as Cd), mg/l, max.	2.0
10	Chromium (as Cr), mg/l, max.	1.0
11	Lead (as Pb), mg/l, max.	1.0
12	Mercury (as Hg), mg/l, max.	0.01
13	Sodium adsorption ratio, (SAR)	10 to 15
14	Residual Sodium Carbonate, mol/l, max	2.5
15	Radio active material: (a) Alpha emitters, micro curie/ml (b) Beta emitters, micro curie/ml	 10^{-9} 10^{-8}

Annex II: Proposed Ambient Water Quality Standards for Inland Waters Sri Lanka

Parameter	Unit, type of limit	CLASS 1 Waters	CLASS 11 Waters (Sensitive)				Class 111 Waters (General)
		Drinking water with simple treatment 2	Bathing 3	Fish and aquatic life 4	Drinking water, conventional treatment 5	Irrigation and agriculture 6	Minimum quality other uses 7
General							
1. Colour (after simple filtration	Pt mg/l, max	20	-	-	100	-	-
2. Total dissolved solids (TDS)	mg/l, max	-	-	-	-	500	-
3. Conductivity	dS/m, max	-	-	-	-	0.7	-
4. Odour	-	unobj	unobj	-	unobj	-	-
5. Taste	-	unobj	-	-	unobj	-	-
6. Turbidity	NTU, max	5	-	-	-	-	-
7. Sodium absorption ratio (SAR)	-	-	-	-	-	6-15	-
8. Residual sodium Carbonate (RSC)	meq./l, max	-	-	-	-	1.25	--
9. Total hardness	As $CaCo_3$ mg/l,	250 des, 600 max	-	-	-	-	-
10. pH	-	6.0-8.5	6.0-9.0	6.0-8.5	6.0-9.0	6.0-8.5	5.5-9.0
11. Dissolved Oxygen at 25^0C	mg/l, min	6	5	3	4	3	3
12. BOD (5 days at 20^0C or 3 days at 30^0C)	mg/l, max	3	4	4	5	5	5
Nutrients							
13. COD	mg/l, max	15	20	15	30	-	40
14. Nitrates (NO_3 – N)	mg/l, max	5	5	5	5	5	5
15. Total ammonia (NH_3-N) - pH < 7.5 pH= 8.0 pH= 8.5	mg/l, max	- - -	- - -	0.94 0.59 0.22	- - -	- - -	9.1 4.9 1.6
16. Total phosphate (PO_4-P)	mg/l, max	0.7	0.7	0.4	0.7	0.7	0.7
Other Substances							
17. Chlorides (Cl)	mg/l,max	200	-	-	200	100	-
18. Cyanides (CN)	mg/l, max	0.005	0.005	0.005	0.005	0.005	0.005
19. Fluorides (F)	mg/l, max	1.5	-	-	1.5	-	-
20. Sulphates (SO_4)	mg/l, max	250	-	-	250	1000	--
Metals							
21. Total cadmium (Cd)	µg/l, max	5	-	**H** **Cd** <60 0.2 60-120 0.8 120-180 1.3 >180 1.8	5	-	5
22. Total chromium (Cr)	µg/l, max	50	-	2	50	-	50
23. Total copper (Cu)	µg/l, max	-	-	**H** **Cu** <60 2 60-120 2 120-180 3 >180 4	-	-	100

24. Iron (Fe)	µg/l, max	300 des, 1000 max	-	300	200	-	-
25. Lead (Pb)	µg/l, max	50	-	**H** **Pb** <60 1 60-120 2 120-180 4 >180 7	50	-	50
26. Manganese (Mn)	µg/l, max	1000	1000	1000	1000	1000	1000
27. Mercury (Hg)	µg/l, max	1	1	0.1	1	1	2
28. Nickel (Ni)	µg/l, max	100	100	**H** **Ni** <60 25 60-120 65 120-180 110 >180 150	100	100	100
29. Selenium (Se)	µg/l, max	10	10	1	10	-	-
30. Zinc (Zn)	µg/l, max	1000	1000	30	1000	1000	1000
31. Boron (B)	µg/l, max	-	-	-	-	500	--
32. Total arsenic (As)	µg/l, max	10	50	50	10	50	50
33. Aluminium (Al)	µg/l, max	200	-	-	200	5.0	-
Organic Micro Pollutants							
34. Phenol index	µg/l, max	2	5	1	5	5	5
35. Oil and grease	µg/l, max	100	200	10	100	-	300
36. Anionic surfactants (detergent) as MBAS	µg/l, max	200	300	1000	200	1000	1000
37. Total pesticides	µg/l, max	10	30	30	30	50	50
Micro Organisms							
38. Total coliform	MPN/100 ml, (*P=95%)	5000	1000	20,000	5000	1000	-
39. Faecal coliform	MPN/100 ml, (*P=95%)	250 des, 600 max	50	-	-	-	-
40. Parsite cysts and ove	Not given	-					

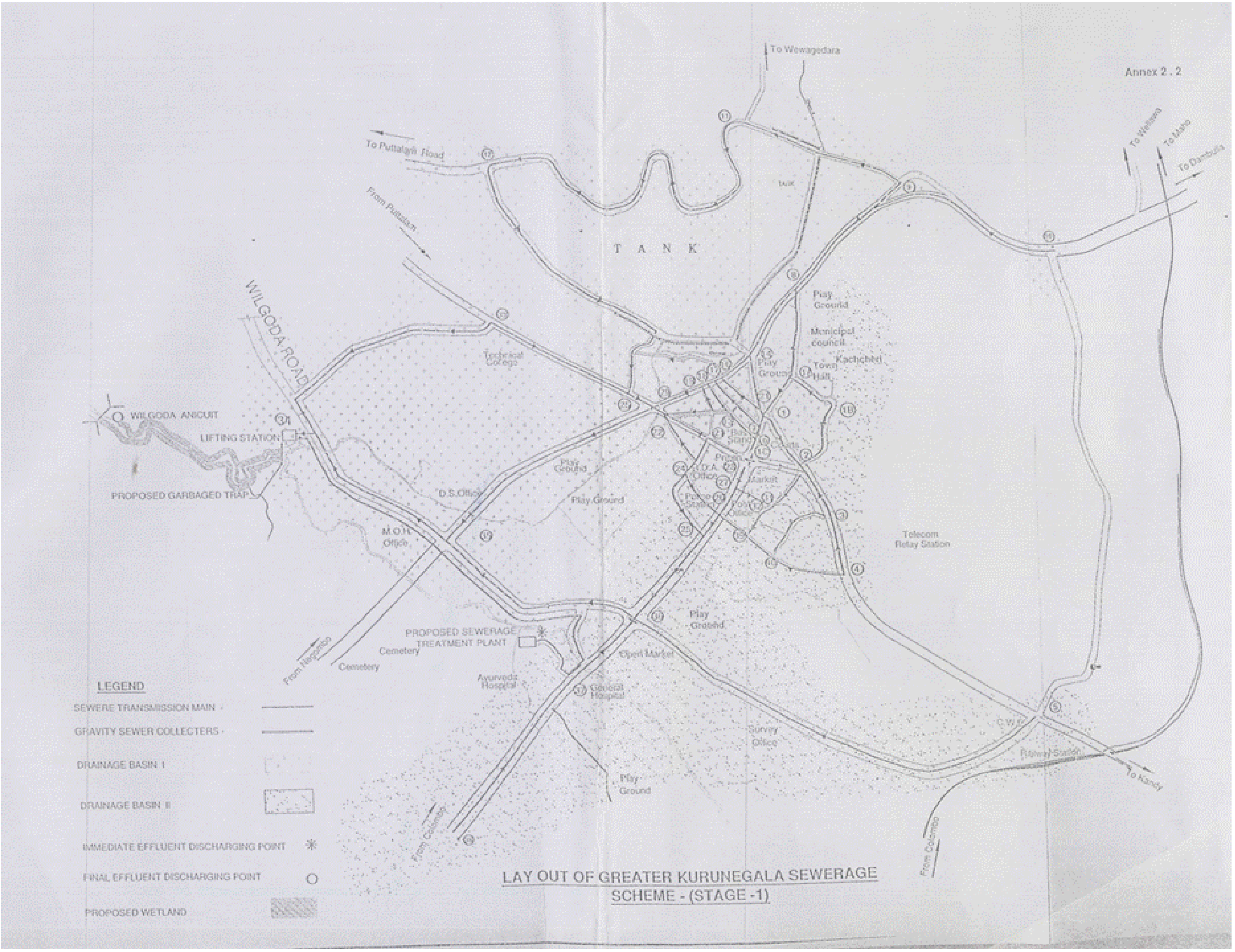
Source: Central Environmental Authority (2001)

Abbreviations : n = Natural or baseline values; H = Hardness in terms of $CaCO_3$ in mg/l; des = Desirable highest level; max = Maximum permissible substances; MBAS = Methylene blue active substances; *P=95% = 95% of the samples give a value that is equal to or less than the indicated limit; Mean – during longer period; Min. daily = average of daily waters; prevention of eutrophication, excessive weed growth, may require lower, site specific, for stagnant waters

Annex III: Standard Protocol Reference List for ITI and University of Colombo

Parameter	Methodology Reference	Limit of determination
pH at ^oC*	APHA 4500 – H^+B	-
Dissolved Oxygen *	APHA 4500 O G	-
Electrical Conductivity 25^{oC}	APHA 2510 B	-
Salinity	APHA 2520 B	-
Total Dissolved Solids (TDS)	CML 33	-
Nitrate (as N),	SLS 614 Part I 1983	-
Nitrite (as N),	APHA 4500 NO_2 B	0.01
Ammoniacal Nitrogen	APHA 4500 NH_3E	1
Total Nitrogen (as N)	APHA 4500 Norg B	1
Total Nitrogen (as N)	Organic+Inorganic	
Orthophosphate (as PO_4)	APHA 4500 – P E	0.05
Total Phosphate (as PO_4)	APHA 4500-P BandE	0.3
Potassium (as K^+)	APHA 3111 B	-
Sodium (as Na^+),	APHA 3111 B	-
Calcium (as Ca^{2+}),	APHA 3500 Ca – D	-
Magnesium (as Mg^{2+})	APHA 2340 and 3500 Ca D	-
Coliform / 100 ml confirmed MPN)	APHA 9221	-
Fecal coliform / 100 ml		-
COD,	APHA 5210 B	15
BOD_5 at 20^0C	Modified DIN 38409	15
Total Suspended solids	APHA 2540 D	-
Oil and Grease	APHA 5520 B	-
Iron (as Fe)	APHA 3111 B	-
Nickel (as Ni)	APHA 3111 B	0.1
Copper (as Cu)	APHA 3111 B	0.01
Cadmium (as Cd)	APHA 3111 B	0.02
Chromium (as Cr)	APHA 3111 B	0.05
Arsenic (as As)	APHA 3114 C	0.001
Lead (as Pb)	APHA 3111 B	0.1
Mercury (as Hg)	CML 42	0.001
Boron (as B)	APHA 3113 B	1
Lead (as Pb)	APHA 3111 B	0.1
Mercury (as Hg)	CML 42	0.001
Boron (as B)	APHA 3113 B	1

Annex IV: Drainage Area (Basins) of Wan Ela and Beu Ela



Annex V: Major Sources of Pollution along Wan Ela and Beu Ela

Location Number	**Major Sources of Pollution on Wan Ela**	**Location Number**	**Major Sources of Pollution on Beu Ela**
WE 1	Muthugala Service station – OG, soap and detergents	BE 1	From Blue Sky Hotel - Kitchen waste and soap
WE 2	Muthugala Service station - OG, soap and detergents	BE 2	Side drains from Negombo road
WE 3	Side road drains Wilgoda road - Soap and kitchen waste	BE 3	Side drains from Negombo road
WE 4	Drains from MC labour quarters	BE 4	National service station - OG and soap
WE 5	Drain through gardens (LPA)	BE 5	Drain through gardens (LPA) – Domestic waste
WE 6	Drain through gardens (low populated area)	BE 6	Causeway - urban runoff
WE 7	Drains from Walakumbura Mawatha	BE 7	Hospital sewerage treatment plant effluent
WE 8	Drain through gardens (LPA)	BE 8	Drain through gardens (LPA) – Domestic waste
WE 9	Drain through gardens (LPA)	BE 9	Drain under Sathosa – domestic waste
WE 10	Drain through gardens (LPA)	BE 10	Colombo road side drains - urban runoff
WE 11	Drain from closed rice mill	BE 11	Colombo road side drains - urban runoff
WE 12	Drain from Wilgoda road	BE 12	Drain from hospital
WE 13	Drain through gardens (LPA)	BE 13	Drain from hospital
WE 14	Drain from the Divisional Secretariat	BE 14	Drain through gardens (LPA) - urban runoff
WE 15	Drain through gardens (LPA)	BE 15	Drain from hospital - wards and lab
WE 16	Drain through gardens ((LPA)	BE 16	Drain from hospital - wards and lab
WE 17	Negombo road side drains	BE 17	From paddy fields – irrigation run-off
WE 18	Drain through gardens (LPA)	BE 18	Drain from hospital
WE 19	From paddy fields	BE 19	Drain from hospital
WE 20	Drain through Maliyadeva ground	BE 20	From paddy fields – irrigation runoff
WE 21	From St. Anne's ground	BE 21	From paddy fields – irrigation runoff
WE 22	Drain through farm house		
WE 23	Drain under Hatton National Bank		
WE 24	Puttlam road side drains		
WE 25	Drain from lorry park road		
WE 26	Drain from Meepitiya service station		
WE 27	Drian from Municipal Council Yard		
WE 28	Drain from town center		
WE 29	From Lakdas college		
WE 30	From Lakdas college		
WE 31	From Lakdas college		
WE 32	Drain from town center (P and G)		
WE 33	Drain from town center		
WE 34	Drain from town center		
WE 35	Coming from paddy fields		

Notes: LPA = Low Populated Area; OG = Oil and Grease

Source: NWSDB

Annex VI: Industrial and Commercial Catalogue

Number	Description
1-51	Colombo-Kurunegala Road from Kurunegala Hospital towards Colombo within kurunegala city limits
436 - 447	Colombo-Kurunegala Road from Udawalpola Junction to the Hospital
52 - 104	Colombo-Kurunegala Road from Colombo side to Kurunegala on the left side upto opposite Kurunegala Hospital
191 - 213	Colombo-Kurunegala Road from Colombo (opposite Kurunegala Hospital) side to Kurunegala on the left side upto Baudhaloka Mawatha junction
105-190	Jayanthipura Road and the lanes
214- 259	Baudhaloka Mawatha from Kurunegala Town to Wilgoda upto Wan Ela bridge
260-320	Baudhaloka Mawatha from Wan Ela bridge towards Kurunegala Town upto the junction
2651-2683	Units along Wilgoda Road from Anicut area upto Wan Ela Bridge
321-448	Colombo-Kurunegala Road from Baudhaloka Junction to Dambulla/Kandy Road Junction
449 -900	On Kandy Road
910 - 1076	On Dambulla Road from Dambulla to Colombo
1077-1088	Suratissa Mawatha: left from Dambulla-Colombo Rd when coming from Dambulla
1089-1122	Turning left from Suratissa Mw to Wathhimi Road on Wath Himi Road
1123-1137	On kachcheriya (District Secretariat) Road
1138-1169	On Kumaratunga Mawatha
1170-1192	On Rajapihilla Mawatha
1193-1321	On Udewalpola Road
1372- 1470	On Negombo Road
1471-1512	On Puttlam Road between Colombo-Puttlam Rd junction and Negombo-Puttlam road junction
1513-1843	On Puttlam Road between Negombo-Puttlam road junction and Thiththawella wewa along Puttlan Road
1844-1988	Main Street in City Center
1989-2048	Bodhiraja Mawatha in City Center from the end of DB Welagedara Street from Puttlam Road
2049-2077	St Annes Street
2078-2101	Bodhiraja Mawatha in City Center after Rio restaurant
2102-2153	Maliyadeva Street
2154-2252	Parakumba Street
2253-2329	Muslim Mosque Road
2330-2356	Dr.K.H.T.Silva Mw
2357-2399	Mihindu Mawatha
2400-2424	Sumangala Mawatha
2425-2455	Pubudu Mawatha
2456	Bright Bravo Building inside the Bus stand
2457-2500	First Floor
2501-2586	Second Floor
2587-2609	Ground Floor
2610	New Bus stand Building
2611-2650	Units occupied inside 2610
2684-2702	Wellangolla Road
2703-2719	North tank Road
2720-2727	Muthtettugala Rd from Kandy Road

Annex VII: Fertilizer Equivalent and Breakdown of Human Excreta

Table 1: Fertilizer Equivalent of Human Excreta

Element	Nutrient content (kg)			
	Nutrient in urine (500 l/year)	Nutrient in faeces (50 l/year)	Total	Required for 250 kg of cereals
N Nitrogen	4.0	0.5	4.5	5.6
P Phosphorus	0.4	0.2	0.6	0.7
K Potassium	0.9	0.3	1.2	1.2

Source: Strauss, 2000

Table 2: An Approximate Quantity and Quality Breakdown of Human Extreta

Quality and consistency	**Faeces**	**Urine**	**Combined**
Gram/capia/day (wet)	250	1200	1450
Gram/capia/day (dry)	50	60	110
Chemical composition (% of dry solids)			
Organic matter	92	75	83
Carbon	48	13	29
Nitrogen	4-7	14-18	9-12
Phosphorus	4	3.7	3.8
Potassium	1.6	3.7	2.7
Comparison with other wastes (% of dry solids)			
Human excreta	9-12	3.8	2.7
Plant matter	1-11	0.5-2.8	1.1-11
Pig manure	4-6	3-4	2.5-3
Cow manure	2.5	1.8	1.4

Source: www.water.usgs.gov

Annex VIII: Excreted organism concentrations in wastewater complied from different studies

Organism	Numbers in wastewater (per litre)
Bacteria	
Thermotolerant coliforms	10^8 - 10^{10}
Campylobacter jejuni	10 – 10^4
Salmonella spp.	1 - 10^5
Shigella spp.	10 - 10^4
Vibrio cholerae	10^2 - 10^5
Helminths	
Ascaris lumbricoides	1 - 10^3
Ancylostoma duodenale / Necator americanus	1 - 10^3
Trichuris trichiura	1 - 10^2
Schistosoma mansoni	ND
Protozoa	
Cryptosporidium parvum	1 - 10^4
Entamoeba Histolytica	1 - 10^2
Giardia intestinalis	10^2 - 10^5
Viruses	
Enteric viruses	10^5 - 10^6
Rotavirus	10^2 - 10^5

Source: WHO 2006; ND: Not done