Baseline Water Quality Survey for Rajshahi, Bangladesh

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NGO FORUM FOR DRINKING WATER SUPPLY & SANITATION

IWMI International Water Management Institute

COSI Community Self Improvement

SEI STOCKHOLM ENVIRONMENT INSTITUTE

IRC International Water and Sanitation Centre

ASIA PRO ECO II

EUROPEAID CO-OPERATION OFFICE

WASPA Asia: Project Report 7

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.

Contents

Annexes

List of Figures

List of Tables

Acronyms and Abbreviations

BCSIR	Bangladesh Centre for Scientific and Industrial Research
BOD	Biochemical oxygen demand
BSCIC	Bangladesh Small and Cottage Industry Corporation
BUET	Bangladesh University of Engineering and Technology
COD	Chemical oxygen demand
DO	Dissolved oxygen
EC	Electrical Conductivity
FAO	Food and Agriculture Organization
K	Potassium
MOP	Muriate of potash
N	Nitrogen
P	Phosphorous
RCC	Rajshahi City Corporation
RDA	Rajshahi Development Authority
SAR	Sodium Adsorption Ratio
TDS	Total dissolved solids
TSP	Triple super phosphate
TSS	Total suspended solids
VCF	Vertical at centroid-of-flow
WASPA	Wastewater Agriculture and Sanitation for Poverty Alleviation
WHO	World Health Organization

1. Introduction

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, Rajshahi in Bangladesh and Kurunegala in Sri Lanka. 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 baseline water quality assessment conducted in Rajshahi in February 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 Rajshahi 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 Rajshahi and Kurunegala, 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.

There are three main objectives for the water quality monitoring component of the project. These are:

- To monitor the quality of water in drainage canals from the city to facilitate consideration of 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 or substances (such as heavy metals or salinity) that may damage crops; and
- To monitor the impacts of project interventions in terms of improved water quality (this will be assessed at the end of the project and is not covered in this report).

2. Methodology

Sampling Strategy and Site Selection

A number of storm water drains (10) flow from the south of Rajshahi through the city to the north, either terminating in *beels* or in the Baranai River, some 15 km away. An initial assessment of the city was conducted at the beginning of the study and two project locations were identified where wastewater is being used in agriculture (see Clemett et al. 2006). These sites are situated along two of the city drains: Circuit House Drain, also known as Basuar Beel Drain because it drains through Bashuar Beel; and Dargapara Drain, also known as the Cantonment Drain because it flows through the cantonment agricultural area. The water survey and the observations of potential sources of pollution were undertaken along these two drains.

The Circuit House Drain starts in Ward 7 from the place identified as Circuit House Road. This drain flows through Ward 8, along the edge of Ward 6 and through Ward 3. It passes by the Rajshahi Metropolitan Police, Medicine Corner, Rajshahi Medical College Hospital, Clinic and Women's Complex. After that the Circuit House Drain enters Bashuar Beel, in Ward 14 and emerges at the other end of the *beel* before flowing through agricultural land in Ward 14, Paba Thana and Ward 17, and onto Baranai River (Figure 2.1).

The Dargapara Drain starts from Natore Road in Ward 9. It flows through Ward 10, Ward 14, and Ward 16, passing by Rajshahi Medical College, a women's hostel, Sadar (Main) Hospital, the Passport Office, the Fisheries Office and the Cantonment Area, as well as some densly populated residential areas. In Ward 16 a second drain joins the Dargapara Drain, bringing untreated industrial effluent from the Bangladesh Small and Cottage Industry Corporation (BSCIC) area and any residences also located there. The water from Dargapara Drain is used in Ward 14 (before the industrial wastewater enters the system) and Ward 16 where some areas are likely to be using wastewater containing industrial waste.

In Ward 17, in an area known as Terokhadia, the Circuit House Drain and the Dargapara Drain meet. The drain flows on and is continuously used for agricultural purposes, finally meeting the Baranai River approximately 11-12 Kilometers away from the place where both the drains meet (GIS map of Institute of Water Modeling).

Nine drain water sampling points were identified along these two drains both in more residential an in agricultural areas, where the wastewater is the only source of irrigation water. In addition two ground water sample sites were selected near the Basuar Beel (Figure 2.1) to investigate the effect of seepage from the unlined drains on ground water, as this is the main source of drinking water in Bangladesh. In Rajshahi, ground water is usually obtained from deep tube wells, which is the case near Bashuar Beel, therefore, the selected ground water sites are deep tube wells and the possibility of leaching from the drains is low but it required investigation never the less. The sites selected are listed in Table 2-1 and depicted in the map in Figure 2.1.

Table 2-1: Water quality monitoring site codes and descriptions

Site Code	Site Description – Baseline Survey
A	Circuit House Drain within the city
B	Circuit House Drain further along the system past residential areas
C	Circuit House Drain inlet to Basuar Beel
D	Bashuar Beel
E[1]	Circuit House Drain outlet from Basuar Beel and start of the agricultural area
G	Dargapara Drain entry point to the city
H	Dargapara Drain entry point to cantonment agriculture area
I	Dargapara Drain exit point from cantonment agriculture area
J	Dargapara Drain after confluence with industrial drain
X	Ground water well near Basuar Beel in Basuar Village
Y	Ground water well near Basuar Beel in Basuar Village

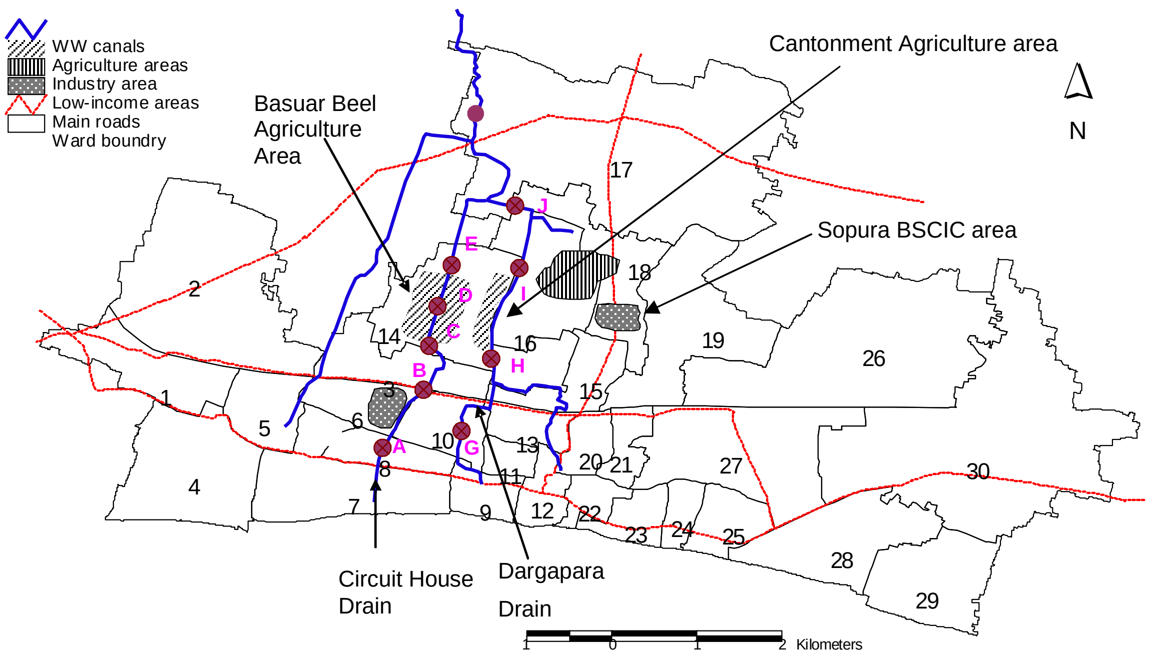


Figure 2.1: Sample locations

[1] A location F was planned beyond the agricultural area but was removed before sampling because of cost and time limitations and because it was not considered necessary for the objectives of the project.

Establishing Sampling Locations and the Limitations

The sites were selected based on drainage maps provided by the Rajshahi City Corporation (RCC) and Rajshahi Development Authority (RDA), and on physical observations in the site. It was intended that points A to C would be a continuous system and show the changes from within the city and across the low income area marked on the map (Figure 2.1), and on through the *beel* to the agricultural area. Unfortunately, due to the extensive drainage system running under the roads, the points A and B actually sampled did not connect with point C. This is a significant problem and has since been addressed so that future samples will be taken on a continuous drain. However, for the purpose of the baseline survey the existing samples are adequate as they still show:

- Wastewater quality within the city (A, B, G and H);
- Wastewater quality in the agricultural areas (E, I and J); and
- Changes in water quality across the *beel* (C, D and E).

The locations where the baseline samples were taken were established with respect to GPS (Garmin GPS III® Plus) (Annex I). The other permanent features available in the area were also noted and photographed. The photographs are given in (Annex II).

The exact sampling sites were selected considering the point sources and the suitability for measuring discharge: locations next to a confluence or point sources of contamination were avoided; straight and uniform channels free of eddies, slack water and excessive turbulence were selected.

Sampling Methodology

The single vertical at centroid-of-flow (VCF) method was used for sampling. Discrete samples were collected from each location in the VCF for chemical and microbiological analysis because of well mixed conditions and shallow flows. Composite samples were collected for parasitological analysis. The parameters for which the water was sampled are provided in Annex III along with the method of collection, preservation and holding times. The samples were delivered to Dhaka (which is five hours by road from the sample site) on the day of sampling. The analyses were conducted by the Bangladesh University of Engineering Technology (BUET) and the NGO Forum laboratory in Dhaka. The analyses were performed with strict quality control and quality assurance using the internationally accepted methods of analysis given in Annex IV.

Measurements of temperature, pH and conductivity were conducted in-situ by the Bangladesh Centre for Scientific and Industrial Research (BCSIR) staff. The samples collected to test for dissolved oxygen (DO) were fixed in the field and analysed on the following day at NGO Forum laboratory. Flow velocity measurements were also made.

Water samples from three sample locations A, B, and E were tested for nematode eggs. To do this 10 litre samples were collected from each and the analysis was performed at the

Department of Parasitology, Institute of Epidemiology, Disease control and Research, Mohakali, Dhaka. A modified method of Ayers and Mara (1996) was used. The sediment was allowed to settle overnight and a 50 µl drop was examined after centrifugation. This was a preliminary assessment to observe parasite positivity. The rest of the sample was preserved for further analysis.

Drainage channel flow rates were measured using floats and a stop watch no current meter was available. The discharge was calculated using the cross section of the canals. Efforts will be made in the future monitoring programs to measure flow with a current meter.

3. Surface Water Quality Results and Discussion

This chapter presents a summary of the surface water quality analysis data and implications for wastewater agriculture. It is divided by type of parameter and each type or individual parameter is discussed in relation to irrigation requirements and potential health risks, as appropriate and where possible. The full set of results and field measurements can be found in Annex V. Standards for irrigation water quality recommendations, Bangladesh standards for inland surface water, Bangladesh discharge standards and are given in Annex VI; Annex VII; Annex VIII and Annex IX.

The irrigation water quality recommendations provided by Ayres and Westcot (1985) which are quoted throughout this discussion, and given in Annex VI, require a short explanation as they include a number of assumptions. A basic assumption is that “restricted use” does not mean that the water is unsuitable for use but that there may be limitations on production and therefore special management may be required. Furthermore the divisions are somewhat arbitrary as there is not an absolute cut-off between “no restriction”, “slight restriction” and “severe restriction”, therefore a change of up to 20% above or below a guideline value will have little significance if considered in proper perspective with other factors affecting yield. Guideline values also assume certain irrigation practices appropriate for the crop.

Flow Measurements

To understand the water quality results obtained for some of the locations it may be necessary to refer to the flow rates. Low flows may for example explain high concentrations, and increased flows at a certain point may suggest the addition of new sources of water which may increase pollution loads or provide some dilution. The flow data is given here for reference.

The flow increased from A to B suggesting that new sources of wastewater enter between these locations. The flow at C was too low to measure. After point C the drain enters Bashuar Beel. A *beel* is usually described as a seasonal lake but Bashuar Beel does not dry up due to the constant supply of drainage water from the city, its extent does however fluctuate in accordance with rainfall (Table 3-1). The flow at location E was approximately half that within the city at B but similar to A.

On the other canal the discharge was fairly uniform between point G and H but increased by an order of magnitude from H to I: what causes this increased flow needs to be investigated. The discharge increased further at location J when the flow from the BSCIC area is added.

Table 3-1: Discharge at sample locations on 25th February, 2006

Location	Discharge ($m^3 s^{-1}$)	Discharge ($m^3 day^{-1}$)
A	0.0315	$2.72x10^3$
B	0.0745	$6.44 x10^3$
C	Not flowing	
D	Non-flowing water body	
E	0.035	$3.024x10^3$
G	0.050	$4.32 x10^3$
H	0.048	$4.147 x10^3$
I	0.444	$3.84 x10^4$
J	0.538	$4.65 x10^4$

Temperature

Temperature is an important physical parameter of wastewater, particularly if the wastewater enters open water bodies, because wastewater is often warmer than local water bodies, which has a direct effect on aquatic life as well as reducing the dissolved oxygen (DO) concentration in the water making oxygen less available for respiration. Temperature also affects chemical reactions and reaction rates within the wastewater, thereby influencing its suitability for irrigation (Metcalf and Eddy 2003). The temperature of the wastewater sampled in Rajshahi ranged from 23 to 27^{o}C. This is within the range for biological activity and is normal for water temperature in the area. It also suggests that there is limited industrial waste entering the system as this tends to increase the water temperature. The highest recorded temperature (27^{o}C) was in the beel and there was no peak observed in the industrial channel.

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 is 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). The normal range for irrigation water is pH 6.5-8.5 (Pescod 1992). High pH above 8.5 is often caused by high bicarbonate (HCO_3^-) and carbonate (CO_3^{2-}) concentrations; high carbonates cause calcium and magnesium ions to form insoluble minerals leaving sodium as the dominant ion in solution (Bauder et al. 2004). This alkaline water could intensify sodic soil conditions, which is detrimental to agriculture, but this does not appear to be a problem in the project area where the samples from all locations were within the range pH 5.5 - 7.01 (mildly acidic to neutral) (Annex V).

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) (Metcalf and Eddy 2003). The EC of irrigation water is important because it is a measure of the salinity of the water. The conductivity test does not identify the dissolved salts, or the effects they may have on crop or soil, but it does indicate whether a salinity problem is likely to occur. Dissolved salts increase the osmotic potential of soil water which results in plants expending more energy to take up the water, which leads to increased respiration and a progressive decline in plant yield as the osmotic pressure increases (Pescod 1992). 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.

The Food and Agriculture Organization (FAO) has developed guidelines for the evaluation of water quality for irrigation and suggests that there need be: 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} (Ayres and Westcot 1985).

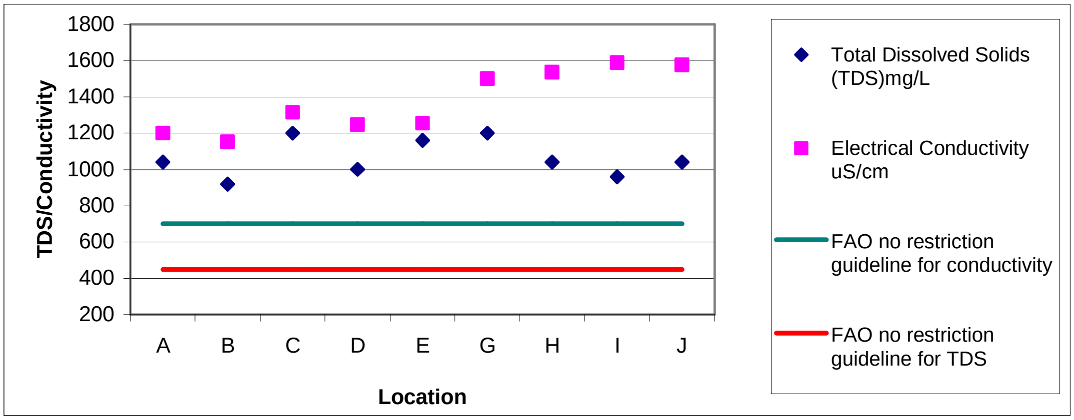
Table 3-2: Guidelines for interpretation of salinity for irrigation

	No restriction	Moderate restriction	Severe Restriction
EC (dS m^{-1})	<0.7	0.7 – 3.0	>3.0
TDS (mg l^{-1})	<450	450 – 2000	>2000

Source: Ayres and Westcot 1985

The samples taken of the wastewater used for irrigation in the project area were all within the range at which slight to moderate restrictions are advised (Figure 3.1).

Figure 3.1: Total dissolved solids and electrical conductivity at each sample point



Wastewater can also be defined as “strong”, “medium” and “weak”; in the case of TDS the values for these are 850 mg l^{-1}, 500 mg l^{-1} and 250 mg l^{-1}, implying that the drainage water in the canals can all be classified as strong wastewater; but they are also within the usual range for irrigation water, which is an EC of 0-3 dS m^{-1} and TDS 0-2000 mg l^{-1} (UN Department of Technical Cooperation for Development 1985; cited in Pescod 1992).

As the crops grown in Rajshahi vary (see Jayakody and Amin 2007) the threshold level for each will be different and some crops may be more suitable to grow in the area than others. Of the main crops grown wheat and papaya are moderately tolerant; rice, sugarcane, cabbage, cauliflower, spinach and potato are moderately sensitive; and none are in the sensitive category (Ayres and Westcot 1985).

There are also other considerations in addition to the direct effect of salinity on osmotic pressure. These are;

- Specific ion toxicity (sodium, boron and chloride);
- Interference with up-take of essential nutrients (potassium and nitrate) due to antagonism with sodium, chloride and sulfates; and
- It may have long term impacts on the soil structure (WHO 2006).

The last point is discussed further below.

Sodium Adsorption Ratio

Not only is the total salt concentration in irrigation water extremely important for agriculture but so too is the relative proportion of sodium to other cations, because sodium has a unique effect on soils. When present in its exchangeable form sodium changes the physico-chemical properties of the soil and has the ability to disperse soil particles when above a certain threshold value, relative to the concentration of total dissolved salts. This dispersion results in reduced air and water infiltration to the soil and the formation of a hard crust when the soil is dry (Pescod 1992).

The relative concentration of sodium is determined by the sodium adsorption ratio (SAR). This index quantifies the proportion of sodium ion (Na^+) to calcium ions (Ca^{2+}) and magnesium ions (Mg^{2+}) in a sample using either of the equations presented in Table 3-3.

Table 3-3: Calculation of sodium adsorption ratio

$SAR = \dfrac{Na}{\sqrt{(Ca+Mg)/2}}$	where concentrations are in meq/l
$SAR = \dfrac{Na^+}{\sqrt{Ca^{2+}+Mg^{2+}}}$	where ionic concentrations of each are in mmol/l

This ratio is important because calcium and sodium have different effects on the soil: calcium will flocculate (hold together), while sodium disperses (pushes apart) soil particles.

Water with low salinity content (<0.5 dS m^{-1}) leaches the soluble minerals and salts. If calcium is leached, soil structure can be destabilized and fine soil particles become dispersed and clog the pour spaces, leading to reduced water infiltration, soil crusting and crop emergence problems (Ayres and Westcot 1985; cited in WHO 2006).

In summary, high salinity water will increase infiltration, whereas low salinity water or water with a high sodium to calcium ratio will decrease infiltration: both factors may also operate at the same time, therefore it is important to consider both EC and SAR, and for this reason guidelines for potential irrigation problems relating to infiltration include both (Table 3-4).

Table 3-4: Guidelines for potential irrigation problems of infiltration rate of water to soil

	No restriction	**Moderate restriction**	**Severe Restriction**
SAR		**EC (dS m^{-1})**	
0-3	>0.7	0.7 – 0.2	<0.2
3-6	>1.2	1.2 – 0.3	<0.3
6-12	<1.9	1.9 – 0.5	<0.5
12-20	>2.0	2.9 – 1.3	<1.3
20-40	>5.0	5.0 – 2.9	<2.9

Source: Ayres and Westcot 1985

The reported SAR values for the locations sampled in Rajshahi were between 13.5 and 14.8. The FAO guidelines suggest severe restrictions for irrigation water with an EC <1.3 within this range of SAR, which were recorded for locations D and E. The EC values for all locations on the Dargapara Drain were >1.3 and the FAO guidelines therefore suggest moderate restrictions (Table 3-5).

Table 3-5: SAR and EC results for locations sampled in Rajshahi

Location	SAR	Electrical Conductivity (dS/cm)
D	13.5	1.246
E	14.0	1.255
G	14.8	1.501
H	13.6	1.535
I	13.7	1.589
J	14.0	1.575

Nutrients

Nitrogen

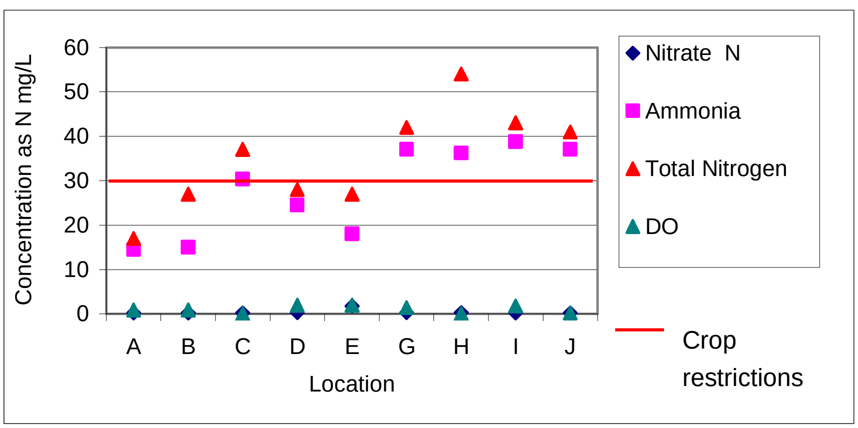
Nitrogen is a necessary primary macronutrient for plants that stimulates plant growth. It may be added as a fertilizer but can also be found in wastewater as nitrate, ammonia, organic nitrogen or nitrite (FAO 2006). Wastewater with a total nitrogen concentration of 80 mg l^{-1} is considered strong, 40 mg l^{-1} medium and 20 mg l^{-1} weak; and the usual total nitrogen concentration in wastewater treated in a conventional treatment plant is 50 mg l^{-1} (Pescod 1992).

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) and by reporting in the form of total nitrogen, comparisons can be made (Ayres and Westcot 1985). Most plants absorb only nitrates, but normally the other forms are transformed into nitrates in the soil. During this transformation several mechanisms such as volatilization result in the loss of some of the nitrogen so that only 50% of the ammonia and 30% of organic nitrogen are ultimately assimilated by the plants (WHO 2006).

If excess nitrogen is applied to a crop it can result in over-stimulation and excessive growth which increase susceptibility to pest and disease attacks, delayed maturity, failure to ripen, reduced crop quality and yield loss (Pescod 1992). 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. This means that water containing high nitrogen levels, 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 1985).

The usual range for nitrate-nitrogen in irrigation water is 0 – 10 mg l^{-1} and for ammonium-nitrogen is 0 – 5 mg l^{-1} (*ibid*). The total-nitrogen and ammonium-nitrogen levels were high in all locations and were well above the usual range for irrigation water but the nitrate concentration was very low in all samples and ammonia-N was the predominant form of nitrogen in the wastewater (Figure 3.2). This is due to the anaerobic conditions in the wastewater caused by the low dissolved oxygen.

Figure 3.2: Nitrogen concentrations at each sample location



In the Circuit House Drain the ammonia and total-N concentrations increased from A to B as did the flow, which suggests new sources of wastewater are entering the system between these two points, as is likely to be happening in the residential area. Point C had a high concentration of total and ammonium-N but this may relate to the low flow (see limitations section). The concentrations declined in the *beel* and are even lower in the *beel* effluent; this may be due to natural treatment processes taking place or dilution. The effluent from the *beel* still had substantially higher nitrogen concentrations than normal irrigation water but it was just below the value at which most crops are negatively affected.

The concentrations of ammomium-nitrogen and total nitrogen were higher on average in the Dargapara Drain than the Circuit House Drain. It is notable that the concentrations are fairly stable except for a peak in total nitrogen at point H. It is not clear why this peak exists and further analysis is required to determine this but it could be contributed by an in-flowing drain between location G and H. What factors cause the attenuation of this peak before location J is also not clear but since this water is used in agriculture between H and J it is possible that this is the cause; although the unexplained increase in flow between H and J may also contribute in some way. Notably the confluence with the industry drain did not show an increase in nitrogen, which is supported by the study on the types of industries in the area and that all of them have septic tanks for toilet waste (Sandoval, Ara and Clemett, 2007).

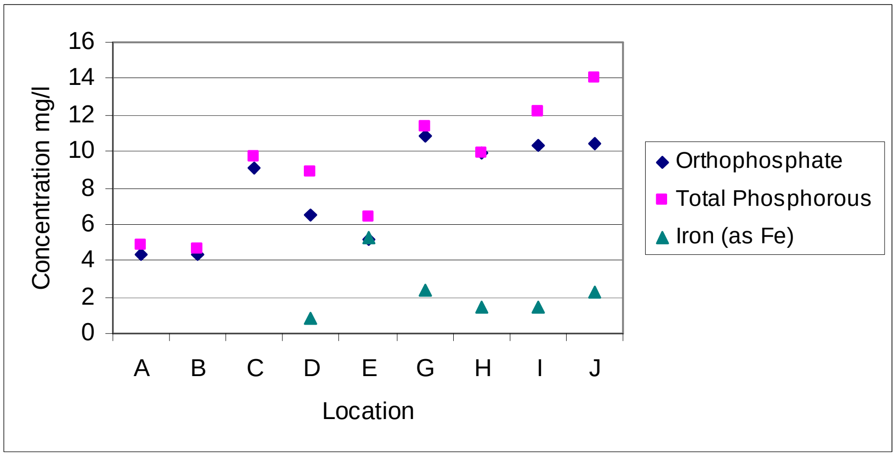
Phosphorous

Phosphorus is also a primary macronutrient essential to the growth of plants and other biological organisms; however, excess phosphorus can lead to noxious algal blooms in water bodies. Municipal wastewaters may contain between 4 and 16 mg l^{-1} of phosphorus as P and a typical value for wastewater treated in a conventional wastewater treatment plants is 10 mg l^{-1} (Metcalf and Eddy 2003; Pescod 1992). The usual range for phosphate-phosphorus (PO_4-P) in irrigation water is 0 – 2 mg l^{-1} (Ayres and Westcot 1985).

The orthophosphate concentrations were high compared to the total P, which indicates that the particulate phosphorous is low and the phosphorous is readily available for plants. In the Circuit House Drain both the total-P and PO_4-P concentrations decreased from C to D, possibly due to dilution but the further decline from D to E suggests that natural processes taking place in Bashuar Beel maybe contributing to its attenuation (Figure 3.3).

In the Dargapara Drain the total-P levels increase from H to J, the opposite of the observed trend for nitrogen (Figure 3.3 and Figure 3.2). The new sources of phosphorus entering the drain may be: more domestic waste; detergents from the industrial area (contributing to the concentration at J); and leaching of phosphorous from the agricultural area, especially if phosphate fertilizer is over applied (see Jayakody and Amin 2007 for a discussion of fertilizer application rates).

Figure 3.3: Phosphorous concentrations at each sample point



None of this has serious implications for agriculture except in as much as the application of phosphate fertilzers could potentially be reduced. The agricultural study undertaken by the WASPA Project team found that farmers tended to apply more than the recommended quantity of triple super phosphate (TSP) (Jayakody and Amin, 2007). It may however have implications for the environment down stream as phosphate is the main cause of eutrophication, therefore agricultural use of wastewater combined with reduced TSP application could be a generally beneficial option.

Potassium

Potassium (K) 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 macronutrient that is present in high concentrations in soils but is not bio-available since it is bound to other compounds. Generally irrigation water contains low potassium concentrations, insufficient to cover the plant's theoretical demand, and fertilizer application is almost always necessary as approximately 185 kg ha^{-1} is required. The use of wastewater in agriculture does not normally cause negative environmental impacts associated with potassium (Mikklesen and Camberato 1995; cited in WHO 2006).

The normal concentration of K in treated wastewaters is 30 mg l^{-1} and is 0-2 mg l^{-1} in irrigation water (Pescod 1992; Ayres and Westcot 1985). The reported K values for the Rajshahi drains are in the range of 21.4 to 35.7mg l^{-1} and the highest reported value is for the most downstream location on the Dargapara Drain. Potassium is likely to originate from the sewage and urine discharged into the drains, as human faeces has 1.6% and urine has 3.7% (of dry weight) potassium (Annex X and Annex XIII). The agriculture survey also found that many of the farmers were applying muriate of potash (MOP) at quantities in excess of those recommended by the government; considering the high concentrations in the wastewater it may be possible to reduce this and thereby provide a saving to the farmers (Jayakody and Amin 2007).

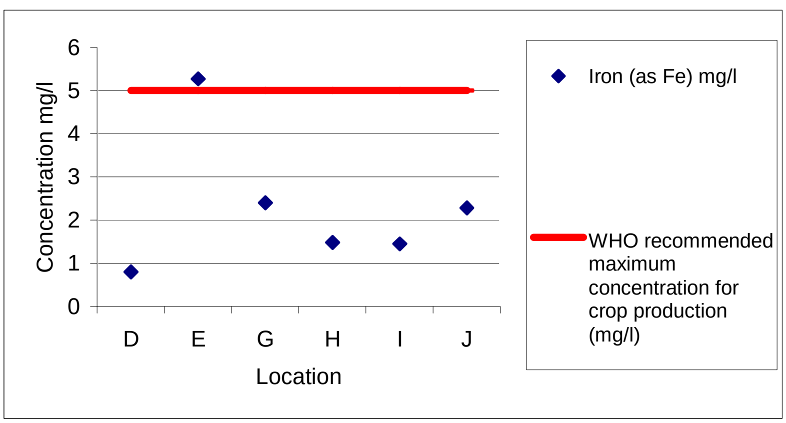
Metallic Constituents

Trace quantities of many metals can be found in wastewaters, particularly industrial waste but also arising from domestic waste, for example form 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 however, that metals will only be absorbed by plants once a threshold concentration has been reached in the soil and the metal is in a mobile phase, hence the concentration in irrigation water is not a direct reflection of the uptake of crops. 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).

All the samples except A, B and C were analyzed for a selection of metals that were either likely to cause damage to crops or impact on human health, these included: calcium (as Ca^{2+}); magnesium (as Mg^{2+}); potassium (as K^{+}); sodium (as Na^{+}); iron (as Fe); nickel (as Ni); copper (as Cu); cadmium (as Cd); chromium (as Cr); arsenic (as As); lead (as Pb); mercury (as Hg); and boron (as B). Of these, potassium is a primary macronutrient; and calcium and magnesium are secondary macronutrients (see preceding discussion). Iron, boron and copper are micronutrients which help plant growth and development but can be detrimental if threshold levels are exceeded. The others variously affect plant growth and development.

Excessive iron can reduce the phosphorous component in water 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 just 0.8 mg l^{-1} to 5.27 mg l^{-1} in the drainage water (Figure 3.4). The recommended maximum concentration of iron for crop production is 5 mg l^{-1} and sample E has exceeded this level (Figure 3.4). Location E also exhibits the lowest orthophosphate concentration but in general iron appears not to be of concern in these samples (Figure 3.3).

Figure 3.4: Concentrations of iron



Boron 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. There is however 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 1985). There is no guideline value for B in Bangladesh but FAO recommend slight restriction from 0.7-3.0 mg l^{-1} and severe restrictions for concentrations exceeding 3.0 mg l^{-1} (*ibid*). The concentrations in the samples ranged from 0.1 to 0.3 mg l^{-1}.

The WHO (2006) recommended maximum concentration of Cr for crop production is 0.1mg/l and sample J has exceed this value. Location J is after the industrial wastewater drain that discharges into the cantonment drain, so the Cr could originate from the industrial area, although no specific industry has been identified as being the source of this contamination. Further investigations into the possible contamination of soil and plant material, and identification of the potential source of the metal are advisable. The Ni, Cu and Hg levels are below the recommended maximum concentration of WHO for crop production (WHO 2006).

Given the low values and the very limited evidence for direct health impacts from chemical exposure associated with the use of wastewater in agriculture, chemicals are unlikely to be the main cause for concern in the project site. It has been shown that for most chemicals their concentrations in wastewater and wastewater produce will never be enough to result in acute health effects, and chronic health effects, such as cancer, are only likely after many years of exposure (*ibid).*

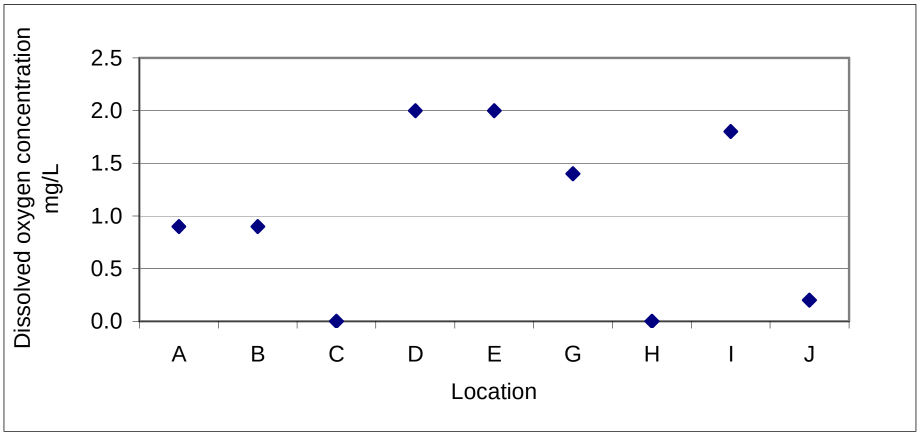
Organic Constituents

Dissolved Oxygen

The DO values ranged from 0 to 2 mg l^{-1}. Dissolved oxygen is important for aquatic life, and whilst aquatic life is not expected to exist in the drains it gives an indication of the likely impact on receiving water bodies, principally Baranai River. The optimal DO concentration for fish health is 5 mg l^{-1} and most species become distressed when levels drop to 4-2 mg l^{-1} (Francis-Floyd 2003).

Dissolved oxygen is also important for the microbial breakdown of waste in the water and for chemical reactions. The low levels of DO in the samples indicate high levels of pollution and are below the GoB (1997) standards for water usable for irrigation, recreation and fisheries of 5 mg l^{-1} or less (Annex VIII). The results also suggest some oxygenation in Bashuar Beel (Figure 3.5). The variability along Dargapara Drain is not easily explained and needs further observations in the field as well as more water quality analyses.

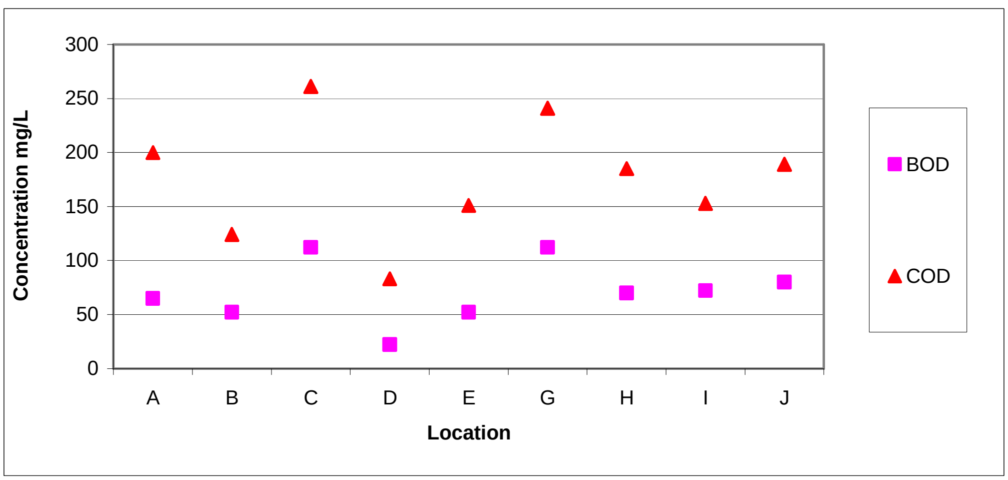
Figure 3.5: Variation in dissolved oxygen across sample locations



Biochemical Oxygen Demand

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 DO used by microorganisms in the biochemical oxidation of organic matter (Metcalf and Eddy 2003). In the Rajshahi samples the BOD_5 values were found to be in the range 22-112mg l^{-1} which is at the low end of the typical range for domestic wastewater described as 110-400 mg l^{-1} per day by Crites and Tchobanoglous (1998). The lowest reported value was in Basuar Beel at 22 mg l^{-1}, while all other locations had a BOD_5 of greater than 50mg l^{-1} (Figure 3.6). According to WHO (2006) municipal wastewater with BOD_5 concentration in the range of 110-400 mg l^{-1} can increase crop productivity and condition the soil if it is used for irrigation, and they report no negative effects until the BOD_5 reaches 500 mg l^{-1}. However the Bangladesh standard for water usable for irrigation is a BOD of 10 mg l^{-1} or less GoB 1997.

Figure 3.6: Variation in BOD and COD across sample locations



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 municipal 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).

The COD values in the samples tested ranged from 83 to 241mg l^{-1}, which is again low, given that Crites and Tchobanoglous (1998) quote a range of 250-1000 mg l^{-1} for domestic wastewater. The COD to BOD ratio was between 2:1 and 4:1 which is typical of untreated municipal wastewater (*ibid*). As with BOD, COD is substantially lower in the *beel* than in the drains (Figure 3.6).

Biological Characteristics

The biological characteristics of water and wastewater are of fundamental importance to human health, in controlling diseases caused by pathogenic organisms of human origin, and because of the role that they play in the decomposition of waste (Metcalf and Eddy 2003). Untreated wastewater that includes faecal waste contains a variety of excreted organisms including pathogens at very high concentrations. Microbial evidence can therefore be used to indicate that a hazard to human health exists in the environment. There is not however a perfect indicator organism for wastewater as excreted organisms range from bacteria to helminthes, protozoa and viruses (WHO 2006). The most common indicator organisms used when monitoring water quality are Coliforms and Faecal Coliforms. 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). It is however recommended that *E.coli*, not Coliforms, is used as an indicator for wastewater use in agriculture because the Faecal Coiform test may also include some non-faecal organisms (*ibid*). Despite this, it was necessary to use total Coliforms and Faecal Coliforms because of the availability of laboratories to perform the tests and other constraints.

The WHO 1989 guidelines for wastewater used in agriculture had a maximum Faecal Coliform of less than 1000 thermotolerant coli/100 ml for root crops likely to be eaten uncooked, and 10,000 thermotolerant coli/100 ml for leaf crops likely to be eaten uncooked, but no standard for irrigation of cereal crops (WHO 2006). The current guidelines do not have specific values but require a pathogen reduction target to be met through treatment, die-off, washing and irrigation method that results in similar levels to those set in the 1989 standards. These are a 7 log unit pathogen reduction for root crops likely to be eaten uncooked and a 6 long unit pathogen reduction for leaf crops likely to be eaten uncooked (WHO 2006).

The results for Total and Faecal Coliform in all tested drain water samples did not comply with the WHO guidelines for use of wastewater in agriculture (WHO 2006). The highest contamination level was in sample J (Dargapara Drain after joining with the Industrial waste canal) which is the most downstream location sampled in the study (Table 3-6). Therefore, it is likely the farmers are exposed to high levels of excreted organisms.

The water in the Basuar Beel Drain also had a high level of Total and Faecal Coliform. The people use this water for other purposes as well as agriculture, such as jute processing and washing kitchen utensils and clothes, and they are in primary contact with the wastewater. The water does not satisfy WHO guidelines for primary contact (Guideline for Safe Recreational Water Environments) and Bangladesh standards for recreational waters (WHO 2006; GoB 1997; Annex VIII). Therefore, it is likely that it is not only the farmers but also the residents around Basuar Beel who are exposed to high levels of excreted organisms, such as those listed in Annex XIII.

Table 3-6: Total Coliform and Faecal Coliform concentrations in water samples

Location	**Coliform Confirmed membrane filter (MF) colony forming units (CFU) /100 ml**	**Faecal Coliform confirmed MF (CFU) /100 ml**
A	190.0×10^6	23.9×10^3
B	174.0×10^6	11.9×10^3
C	19.4×10^6	23.5×10^3
D	3.0×10^6	23.5×10^3
E	1.6×10^6	3.9×10^3
G	14.2×10^6	3.9×10^3
H	18.2×10^6	7.8×10^3
I	16.6×10^6	439.2×10^3
J	13.4×10^6	6.2×10^6
WHO Guideline		1×10^3

Nematode Eggs

Sites A and B give an idea of the types of parasites present in the city area. Parasitic protozoa, hook worms, round worms and cestodes were found in the samples, indicating feacal contamination. The fluke eggs could be of animal origin, as they are not reported from humans in Bangladesh. Some of the round worm and cestode species could also be of animal origin and further examination is required for clarification (Table 3-7).

Table 3-7: Results of Parasitological Analysis

	Number per 50 µl		
Parasite	Location A	Location B	Location E
Cysts of *Entamoeba coli*	47	30	07
Ova of Fluke spp	12	15	1500
Larval forms (parasitic and non-parasitic)	08	05	2-3
Other worm eggs (*Ascaris* and Cestode spp)	28	33	1200
Ova of Hook worms	01	-	-

A high number of parasites (fluke spp. Ova, *Ascaris* and cestode spp.) were reported from location E, where the *beel* becomes a channel once again and enters the agricultural area; but no hook worms were reported from this site. The high number of flukes could be from cattle as there is an animal shed adjacent to the *beel*. It was observed that hanging latrines and the latrine overflow tubes were connected to the Basuar Beel as well as the Basuar Beel Drain. The high counts of parasites in sample E could account for this. Further analysis of the preserved samples will give a better picture of the parasite species distribution and the host origin.

Pollutant Loads of Selected Parameters

The quantity of water available for irrigation will be a major factor for farmers in determining the type of crops that can be grown and what type of irrigation techniques can be used. It will also influence the level of pollutants being transferred to the soil, and potentially the crop, during irrigation events.

The discharge data was used in conjunction with the water quality data to calculate the overall pollutant loads for some of the key parameters and the potential load to an irrigated field. The discharge data, which ranged from 2.72×10^3 to 4.65×10^4 m^3 day^{-1} is presented in Table 3-1.

Ideally measurements are taken across the cross-section of a stream and the load of each pollutant is calculated using the formula:

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

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}

However, it is common practice for a single set of field-measurement data to be used to represent an entire stream cross-section and given the uniformity of the drains being studied the following equation was used (www.water.usgs.gov):

$$\text{Load} = C.Q$$

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

The nutrients nitrogen, phosphorous and potassium are available in the water in significant amounts (Table 3-8) but how farmers utilize these incoming nutrients is yet to be understood. To do this it is necessary to review the agricultural survey data and to calculate the load based on the quantity of irrigation water pumped from the drain.

Table 3-8: Chemical loads calculated

Parameter	Load kg day^{-1} at each location						
	A	B	E	G	H	I	J
Ammonia (N)	39.4	96.6	54.4	159.8	150.1	1489.9	1720.5
Total N	46.2	173.9	81.7	181.4	223.9	1881.6	1906.5
Phosphate (PO_4)	11.7	28.0	15.7	46.8	40.9	394.8	483.14
Total P	13.1	29.8	19.2	49.3	40.9	468.5	651.0
K	-	-	81.0	123.6	111.1	1098.2	1660.0
TSS	244.8	450.8	483.8	604.8	373.2	1536.0	5115.0
BOD_5	176.8	334.9	157.3	483.8	290.3	2764.8	3720.0

The values calculated above 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 are highly complex.

In addition to the main nutrients, the loads of TSS and BOD_5 which are design parameters for wastewater treatment were also estimated.

4. Ground Water Quality Results and Discussion

The ground water quality in the area is considered separately because of the different use of this water source compared to the drain water. Ground water is not used for irrigation in this area but it is used for bathing, washing household items and most importantly drinking. This section reviews some of the key parameters for drinking water quality that were observed in the two well samples.

Table 4-1: Summary of ground water results and standards

Parameter	**Unit**	**X**	**Y**	Bangladesh drinking water standards	FAO drinking water guidelines
Nitrate (as N),	mg/l	0.4	0.2	10	50
Nitrite (as N),	mg/l	0.03	0.01	<1	3
Free Ammonia	mg/l	1.2	1.9	0.5	1.5
Total Nitrogen (as N)	mg/l	2	3.2	1	-
Orthophosphate (as PO_4)	mg/l	0.16	0.12	6	-
Total Phosphorous (as P)	mg/l	0.42	0.61	0	-
Boron	mg/l	<0.1	<0.1	0.2	-
Potassium	mg/l	1.6	2.7	12	-
Coliform	CFU/100 ml	49	20	0	0
Fecal Coliform	CFU/100 ml	Nil	Nil	0	0
COD	mgO_2/l	12	15	4	-
BOD_5 at 20^0C	mgO_2/l	<1	<1	0.01	0.01
DO	mgO_2/l	1.4	0.8	6	-
Total Suspended solids	mg/l	5	20	10	-
Iron (as Fe)	mg/l	4.49	6.95	0.3-1.0	0.3
Mercury (Hg)	mg/l	0.0009	0.0009	0.001	0.001
Arsenic (As)	mg/l	0.019	0.047	0.05	0.01
Cadmium (Cd)	mg/l	0.003	0.007	1.0	0.3
Chromium (Cr)	mg/l	0.1	0.1	0.05	0.05
Copper (Cu)	mg/l	0.02	0.03	1	1
Lead (Pb)	mg/l	0.48	0.55	0.05	0.01
Nickel (Ni)	mg/l	<0.02	<0.02	0.001	0.001

Nitrogen

The reported ammonia concentrations in the ground water samples were 1.15 mg l^{-1} and 1.90 mg l^{-1} which means that they are above the natural level in ground water of 0.2 mg l^{-1} (WHO 2003). This may be due to the proximity of the wells to the *beel* or to anaerobic conditions as anaerobic ground water may contain up to 3 mg l^{-1} (WHO 2003). The drinking water standard in Bangladesh is 0.5 mg l^{-1}, which is exceeded by the water in both wells, and one well exceeds the WHO guideline of 1.5 mg l^{-1}. Ammonia in drinking water is not of immediate health relevance but it could cause ordour problems at concentrations above 1.5

mg l^{-1}. The main cause for concern in drinking water is nitrate, which can interfere with the oxygen carrying capacity of the blood and can have serious implications for infants. Fortunately nitrogen is not present in the ground water in this form at any significant level and at 0.4 and 0.2 mg l^{-1} is well below the Bangladesh and WHO standards of 10 and 50 mg l^{-1} respectively. The total nitrogen concentration of the ground water is however above the Bangladesh standard of 1 mg l^{-1} (Table 4-1); FAO gives no guideline for this.

Metals

Of the metals analyzed, iron, arsenic, chromium, lead and nickel where near or exceeded either the Bangladesh or WHO guideline values in one or more wells (Table 4-1). However, the source of this contamination is not known and since only one sample has been collected it is very important not to draw too many inferences from this data. What is most important about these results is that they provide guidance on what should be monitored in future sampling events and enable the team to consider whether there are any possible sources of contamination if future sampling shows that there really is a problem.

The arsenic levels in the wells were close to the permissible limits for drinking water but did not exceed them. Arsenic has been a major problem in ground water in Bangladesh and Rajshahi is no exception (see Clemett *et al*. 2006).

The cadmium concentration in sample X was at the guideline level for WHO but did not exceed the Bangladesh guidelines; the sample from location Y exceeded both. In the short-term Cd can cause: nausea, vomiting, diarrhea, muscle cramps, liver injury and renal failure; and can in the long-term lead to kidney, liver, bone and blood damage, therefore it is important to monitor the level of Cd in the drinking water. It occurs naturally in many ores and is very often contributed to drinking water through the corrosion of galvanized pipes. There are also industrial sources of Cd including metal refineries, paints and waste batteries, which means that leaching from landfills or rubbish dumps may contribute (USEPA 2007). None of these sources have as yet been identified in Rajshahi but they should be considered by the project team and Learning Alliance members.

The chromium levels in the ground water sampled were double both the Bangladesh and WHO drinking water quality guidelines. Chromium can cause skin irritation and liver and kidney damage in the long-term. The main sources of Cr are usually steel and pulp mills or erosion of natural deposits; Cr is widely found in soils and plants. There is no obvious industrial source of Cr in the project area, therefore the soils may be the source, especially as Cr compounds bind to soil and are not likely to migrate from the surface to ground water (*ibid*).

Lead levels were very high at 10 times the Bangladesh guidelines and 50 times the WHO guidelines (Annex XII). Lead is known to impair the mental development of children and can cause kidney problems in adults. The most common source of Pb in many countries is corrosion of household plumbing, although erosion of natural deposits is also common (*ibid*).

The iron concentrations in the ground water samples were much higher than the Bangladesh drinking water standards at 4.49 and 6.95 mg l^{-1} (Table 4-1). This is typical of ground water across Bangladesh where iron concentrations are much higher than the WHO and national recommended limits, but there are no known human health implications (UNEP 2001). Iron is therefore more of a nuisance than a health problem as it causes the water to taste unpleasant and stains laundry at levels above 0.3 mg l^{-1}; but concentrations of 1–3 mg l^{-1} can be acceptable for people drinking anaerobic well water (WHO 2003). At the levels recorded there may be a risk of iron being stored in the body (WHO 2003).

Microbiological Quality

The groundwater samples showed Coliform contamination, which means that they do not conform to the Bangladesh and WHO guidelines of 0 CFU/100 ml; however they did not show any faecal contamination despite the fact that across Bangladesh 54 per cent of hand pumped tube wells were found to have fecal contamination, due to poor wellhead design, faulty construction and management, even though the aquifers themselves were not polluted (Hoque, 1998; cited in UNEP 2001). The tube wells analyzed under the WASPA project are both deep tube wells and are unlikely to be contaminated with Coliforms leaching from the Basuar Beel, the drains or even septic tanks.

5. Conclusions and Recommendations

Surface Water

The results show that the main potential health risk to farmers using wastewater in agriculture is microbial and parasitalogical contamination. This is also of concern for people residing near the drains and the *beel* as they have been observed to use the water for other activities such as bathing, washing household items and even rinsing meat and vegetables.

No other parameters are shown in the baselines survey to be a major risk to health from wastewater irrigation but chromium was above the WHO (2006) recommendations at location J and this should be monitored.

In terms of impacts on crops EC, TDS and SAR are of concern and based on the FAO (1985) guidelines, slight to moderate restrictions are advised in all locations, with severe restrictions advised for crops irrigated with wastewater from locations D and E.

Nutrients, N, P and K, were all high and the N levels could impact on crop yield or increase pest attacks. However, if correctly managed these nutrients could reduce the quantity of fertilizer applied and reduce costs for farmers.

The water quality in the *beel* appears to be better than in other locations possibly due to dilution or natural treatment processes such as sedimentation and microbial breakdown.

Ground Water

The water sampled in the tube wells exceeds WHO and Bangladesh drinking water standards for many parameters including both metals and Coliforms. The metals may be of long-term concern but the Coliforms may be of more immediate health significance. More tests are needed to confirm the observed levels of pollutants and further research is required to determine the sources of contamination.

Recommendations

As this is the first sampling event, further tests need to be undertaken. These results should be used to guide certain Learning Alliance members to monitor water quality, for example the Department of Public Health Engineering (DPHE) who are responsible for drinking water quality, and the Department of Environment who are mandated to monitor industrial effluent.

The results should be combined with the other studies and further research in order to identify sources of contamination and possible remediation strategies.

The nutrient values should be discussed with the Department of Agriculture Extension and the farmers. This could lead to recommendations to reduce fertilizer inputs, thereby reducing the costs to farmers and downstream pollution.

The effect of Bashuar Beel on water quality should be investigated further and the possible means of enhancing the processes discussed with Learning Alliance members.

6. Limitations

Sampling Locations

As discussed in the methodology the sampling locations were not ideal and will be relocated for subsequent sampling events. Locations A and C will be on the Circuit House Drain and will capture the quality of water from within the city and at the exit from the city. Consequently, although the new sample points can not be compared absolutely with the baseline points A and C, it is expected that the results should be similar. Ideally a new baseline survey should have been undertaken but given the financial limitations for water quality sampling in the project and the need to sample during the agricultural season, when the water quality is more relevant for the purposes of this study, it was decided that the next sampling event would be postponed until this time. Sample point B will be excluded in future events as it is felt that locations A and C are sufficient to capture the wastewater quality in the city.

Oil and Grease

In Bangladesh there are standards for the concentration of oil and grease that can be discharged to inland surface waters (10 mg l^{-1}), public sewers with secondary treatment plant (20 mg l^{-1}) and irrigated land (10 mg l^{-1}) (Annex IX). Unfortunately this was not tested in Rajshahi because the team could not find suitable testing facilities.

The term oil and grease is commonly used and often included in environmental or wastewater quality standards and includes fats, oils, waxes and other related constituents of wastewater. Oils and greases are compounds (esters) of alcohol or glycerol (glycerin) with fatty acids (Metcalf and Eddy 2003). They can arise from many 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. It is intended that, provided facilities can be identified, oil and grease will be analyzed in the next sampling event as it was identified by farmers as a problem.

Microbial Analysis

The microbiological analysis was carried out with strict quality control but samples were incubated within 24 hours of sample collection because of the distance between the project site and the NGO Forum laboratory. As a result the 6 hour holding time specified by the American Public Health Association (2001) was not satisfied. Fortunately, more recent guidelines published by the Environment Protection Authority (2006) have made provisions for a 24 hour holding time for microbiological analysis where a 6 hour holding time is not possible; therefore, it is assumed that the errors are minimal as the samples were preserved by refrigeration (cooling to a temperature $<4^{o}$C) immediately after collection and kept refrigerated until tested.

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Annex I: GPS Readings of Sample Locations

Location	Description of Location	GPS Position and Permanent Features
A (BBD)	BBD within the city before Lakshipur	N: 24^{o} 22 35.5 E: 088^{o} 34 18.1
B (BBD)	BBD past Lakshipur community	N: 24^{o} 22 35.5 E 088^{o} 34 18.0
C (BBD)	BBD entry point (inlet) to the Basuar Beel agricultural area	N: 24^{o} 22 43.4 E 088^{o} 34 23.7
D (BBD)	Bashuar Beel	N: 24^{o} 23' 13.2" E 088^{o} 35' 14.5"
E (BBD)	BBD exit point (outlet) from the Basuar Beel agricultural area	N: 24^{o} 23' 04.4" E 088^{o} 35' 34.4"
G (CD)	CD entry point to the city	N: 24^{o} 23' 17.6" E 088^{o} 35'43.8"
H (CD)	CD entry point (inlet) to cantonment agriculture area	N: 24^{o} 23' 32.4" E 088^{o} 35' 50.2"
I (CD)	CD exit point (outlet) from cantonment Agriculture Area	N 24^{o} 23' 32.4" E 88^{o} 35' 50.4"
J (CD)	CD after confluence with industrial drain	N: 24^{o} 23' 23.8" E 088^{o} 35' 24.8"
X (GW)	Ground water well near Basuar Beel in Basuar Village	N: 24^{o} 22' 13.1" E: 088^{0} 35 '23.4"
Y (GW)	Ground water well near Basuar Beel in Basuar Village	N: 24^{o} 23' 14.8" E: 088^{0} 35' 17.3"

Annex II: Photographs of Sampling Locations

Location A

Location B

Location C

Location D

Location E

Location G

Location H

Location I

Location J

Annex III: Sample Type, Preservation, Holding Times and Sampling Containers

Parameters	Sample	Container	Preservation	Holding time
Total and Faecal Coliforms	Discrete	Glass 125ml sterilized	Cooled to 4^0C	6 hours
Oil and Grease*	Discrete	Glass 1-2 L	HCl to pH <2	28 days
Heavy Metals	Discrete	High Density Poly Ethylene (HDPE) 500ml	Nitric acid (HNO_3) to PH <2	6 months
5-day Biochemical Oxygen Demand (BOD_5), Total nitrogen (N) and phosphorous (P), Turbidity, TSS	Discrete	HDPE 1-2 L	Cooled to 4^0C	24 hours
Chemical Oxygen Demand	Discrete	HDPE 500ml	Sulphuric Acid (H_2SO_4) to 4^0C	28 days
Nitrite	Discrete	Plastic/Glass 100ml	Cooled to 4^0C	48 hours
Nitrate	Discrete	Plastic/Glass 100ml	Cooled to 4^0C	14 days

*Not sampled in the baseline and will be included in future sampling

Annex IV: Analysis Methodology at BUET or NGOF Laboratory

Parameter	Methodology Reference	Limit of determination
pH at ^{o}C*	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 B&E	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 & 3500 Ca D	-
Coliform / 100 ml confirmed MPN)	APHA 9221	-
Fecal coliform / 100 ml		-
COD,	APHA 5210 B	15
BOD_5 at $20^{0}C$	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 V: Baseline Water Quality Results 25th February 2007

Parameter	Unit	A	B	C	D	E	G	H	I	J	X	Y
pH at ambient temperature		6.85	6.70	5.45	6	6.67	6.75	6.85	7.01	7.01	7	7
Temperature	^{0}C	21	21	22	27	25	23	24	24	25	25	23
Total Dissolved Solids (TDS)	mg/L	1040	920	1200	1000	1160	1200	1040	960	1040	*	*
Electrical Conductivity at 25^{oC}	µS/cm	1200	1152	1315	1246	1255	1501	1535	1589	1575	*	*
Nitrate (as N),	mg/L	0.2	0.2	0.2	0.3	1.8	0.3	0.3	0.2	0.2	0.4	0.2
Nitrite (as N),	mg/L	0.006	0.006	0.004	0.146	0.796	0.008	0.006	0.005	0.005	0.032	0.012
Free Ammonia	mg/L	14.5	15.0	30.4	24.5	18	37	36.2	38.8	37	1.15	1.9
Total Nitrogen (as N)	mg/L	17.0	27.0	37.0	28	27	42	54	43	41	2	3.2
Orthophosphate (as PO_4)	mg/L	4.30	4.35	9.05	6.48	5.18	10.83	9.87	10.28	10.39	0.16	0.12
Total Phosphorous (as P)	mg/L	4.85	4.62	9.72	8.9	6.35	11.4	9.87	12.2	14	0.42	0.61
Boron	mg/l	0.5	0.1	<0.1	0.1	0.2	0.2	0.1	0.3	0.3	<0.1	<0.1
Potassium	mg/l	*	*	*	21.4	26.8	28.6	26.8	28.6	35.7	1.6	2.7
Sodium (as Na),	mg/L	*	*	*	88.9	106.7	111.1	111.1	115.6	120	48.9	71.7
Calcium (as Ca),	mg/L	*	*	*	67.71	88.85	88.31	108.45	113.02	115.95	47.99	104.46
Magnesium (as Mg)	mg/L	*	*	*	18.9	27.56	24.08	25.61	28.69	30.63	9.25	26.71
Sodium Absorption Ratio (SAR)[1] calculated	mmol/l				13.51	13.99	14.82	13.57	13.73	14.02		
Coliform	CFU/ 100 ml	$190.0 x 10^6$	$174.0 x 10^6$	$19.4 x 10^6$	$3.0 X 10^6$	$1.6 X 10^6$	$14.2 X 10^6$	$18.2 X 10^6$	$16.6 X 10^6$	$13.4 X 10^6$	49	20
Fecal coliform		$23.9 x 10^6$	$11.9 x 10^6$	$23.5 x 10^6$	$23.5 X 10^3$	$3.9 X 10^3$	$3.9 X 10^3$	$7.8 X 10^3$	$439.2 X 10^3$	$6.2 X 10^6$	Nil	Nil
COD,	mgO_2/L	200	124	261	83	151	241	185	153	189	12	15
BOD_5 at 20^0C	mgO_2/L	65	52	112	22	52	112	70	72	80	<1	<1
DO	mgO_2/L	0.9	0.9	0.0	2	2	1.4	0.0	1.8	0.2	1.4	0.8
Total Suspended solids	mg/l	90	70	180	80	160	140	90	40	110	5	20
Iron (as Fe)	mg/l	*	*	*	0.8	5.27	2.4	1.48	1.45	2.28	4.49	6.95
Mercury (Hg)	µg/l	2.0	1.97	1.10	1.44	1.29	0.96	1.16	2.5	1.81	0.9	0.90
Arsenic (As)	mg/l	*	*	*	0.005	0.007	<0.003	<0.003	<0.003	0.005	0.019	0.047
Cadmium (Cd)	mg/l	*	*	*	0.003	0.007	0.004	0.008	0.006	0.006	0.003	0.007
Chromium (Cr)	mg/l	*	*	*	<0.02	0.04	0.05	0.08	0.09	0.12	0.11	0.1
Copper (Cu)	mg/l	*	*	*	0.04	0.06	0.02	0.03	0.04	0.04	0.02	0.03
Lead (Pb)	mg/l	*	*	*	0.31	0.4	0.4	0.36	1.03	0.44	0.48	0.55
Nickel (Ni)	mg/l	*	*	*	<0.02	<0.02	<0.02	0.03	,0.02	<0.04	<0.02	<0.02

Some samples not tested for certain parameters (due to budgetary constraints).

Note: SAR was calculated only for the drain water where the Ca, Mg and Na were tested.

Annex VI: Guidelines for Interpretation of Water Quality for Irrigation

Potential irrigation problem	Units	Degree of restriction on use		
		None	Slight to moderate	Severe
Salinity				
EC_w	dS/m	<0.7	0.7-3.0	>3.0
TDS	mg/l	<450	450-2000	>2000
				Infiltration
SAR				
0-3	EC_w	>0.7	0.7-0.2	<0.2
3-6		>1.2	1.2-0.3	<0.3
6-12		>1.9	1.9-0.5	<0.5
12-20		>2.9	2.9-1.3	<1.3
20-40		>5.0	5.0-2.9	<2.9
				Specific ion toxicity
Sodium (Na)				
Surface irrigation	SAR	<3	3-9	>9
Sprinkler irrigation	me/l	<3	>3	
Chloride (Cl)				
Surface irrigation	me/l	<4	4-10	>10
Sprinkler irrigation	me/l	<3	>3	
Boron (B)	mg/l	<0.7	0.7-3.0	>3.0
				Miscellaneous effects
Nitrogen (NO_3-N)	mg/l	<5	5-30	>30
Bicarbonate (HCO_3)	me/l	<1.5	1.8-8.2	>8.5
pH				Normal range 6.5-8.0

Source: Ayres and Westcot 1985

Annex VII: Irrigation Water Quality Standards: WHO and FAO

Parameter	FAO[1] (mg l^{-1})	Remarks
Aluminium (Al)	5.0	Can cause non-productivity in acid soils (pH < 5.5), but more alkaline soils at pH > 7.0 will precipitate the ion and eliminate any toxicity.
Arsenic (As)	0.10[2]	Toxicity to plants varies widely, ranging from 12 mg/l for Sudan grass to less than 0.05 mg/l for rice.
Beryllium (Be)	0.10	Toxicity to plants varies widely, ranging from 5 mg/l for kale to 0.5 mg/l for bush beans.
Cadmium (Cd)	0.01[2]	Toxic to beans, beets and turnips at concentrations as low as 0.1 mg/l in nutrient solutions. Conservative limits recommended due to its potential for accumulation in plants and soils to concentrations that may be harmful to humans.
Cobalt (Co)	0.05	Toxic to tomato plants at 0.1 mg/l in nutrient solution. Tends to be inactivated by neutral and alkaline soils.
Chromium (Cr)	0.10[2]	Not generally recognized as an essential growth element. Conservative limits recommended due to lack of knowledge on its toxicity to plants.
Copper (Cu)	0.20[2]	Toxic to a number of plants at 0.1 to 1.0 mg/l in nutrient solutions.
Fluoride (F)	1.0	Inactivated by neutral and alkaline soils.
Iron (as Fe)	5.0[2]	Not toxic to plants in aerated soils, but can contribute to soil acidification and loss of availability of essential phosphorus and molybdenum. Overhead sprinkling may result in unsightly deposits on plants, equipment and buildings.
Lead (Pb)	5.0[2]	Can inhibit plant cell growth at very high concentrations.
Lithium (Li)	2.5	Tolerated by most crops up to 5 mg/l; mobile in soil. Toxic to citrus at low concentrations (<0.075 mg/l). Acts similarly to boron.
Manganese (Mn)	0.20	Toxic to a number of crops at a few-tenths to a few mg/l, but usually only in acid soils.
Molybdenum	0.01	Not toxic to plants at normal concentrations in soil and water. Can be toxic to livestock if forage is grown in soils with high concentrations of available molybdenum.
Nickel (Ni)	0.20[2]	Toxic to a number of plants at 0.5 mg/l to 1.0 mg/l; reduced toxicity at neutral or alkaline pH.
Selenium (Se)	0.02	Toxic to plants at concentrations as low as 0.025 mg/l and toxic to livestock if forage is grown in soils with relatively high levels of added selenium. As essential element to animals but in very low concentrations.
Titanium (Ti)		Effectively excluded by plants; specific tolerance unknown.
Vanadium	0.10	Toxic to many plants at relatively low concentrations.
Zinc (Zn)	2.0	Toxic to many plants at widely varying concentrations; reduced toxicity at pH > 6.0 and in fine textured or organic soils.

[1] Threshold levels of trace elements for crop production
[2] WHO Recommended maximum concentration for crop production

The maximum concentration is based on a water application rate which is consistent with good irrigation practices (10000 m^3 ha^{-1} per year). If the water application rate greatly exceeds this, the maximum concentrations should be adjusted downward accordingly. No adjustment should be made for application rates less than 10000 m^3 ha^{-1} per year. The values given are for water used on a continuous basis at one site.
Source: Adapted from National Academy of Sciences (1972) and Pratt (1972): Cited in Ayres and Westcot 1985.

Annex VIII: Government of Bangladesh Standards for Inland Surface Water

Best practice based classification	Parameter			
	pH	BOD (mg l^{-1})	DO mg l^{-1}	Total Coliform number/ 100
Source of drinking water for supply only after disinfecting	6.5 - 8.5	2 or less	6 or above	50 or less
Water usable for recreational activity	6.5 - 8.5	3 or less	5 or above	200 or less
Source of drinking water for supply after conventional treatment	6.5 - 8.5	6 or less	6 or above	5000 or less
Water usable by fisheries	6.5 - 8.5	6 or less	5 or above	
Water usable by various process and cooling industries	6.5 - 8.5	10 or less	5 or above	5000 or less
Water usable for irrigation	6.5 - 8.5	2 or less	5 or above	1000 or less

Source: GoB 1997

Annex IX: Waste Discharge Quality Standards for Industrial Units in Bangladesh

Sl. No.	Parameter	Unit	Inland Surface Water	Public Sewer at secondary treatment plant	Irrigated Land
1	Ammoniacal Nitrogen (N molecule)	mg/l	50	75	75
2	Ammonia (free ammonia)	mg/l	5	5	15
3	Arsenic (As)	mg/l	0.2	0.05	0.2
4	BOD_5 20ºC	mg/l	50	250	100
5	Boron	mg/l	2	2	2
6	Cadmium (Cd)	mg/l	0.05	0.5	0.5
7	Chloride	mg/l	600	600	600
8	Chromium (total Cr)	mg/l	0.5	1.0	1.0
9	COD	mg/l	200	400	400
10	Chromium (hexavalent Cr)	mg/l	0.1	1.0	1.0
11	Copper (Cu)	mg/l	0.5	3.0	3.0
12	Dissolved Oxyzen (Do)	mg/l	4.5-8	4.5-8	4.5-8
13	Electrical Conductivity	micro mho/cm	1200	1200	1200
14	Total Dissolved Solids (TDS)	mg/l	2,100	2,100	2,100
15	Fluoride (F)	mg/l	7	15	10
16	Sulfide (s)	mg/l	1	2	2
17	Iron (Fe)	mg/l	2	2	2
18	Total Kjeldahl Nitrogen (n)	mg/l	100	100	100
19	Lead (Pb)	mg/l	0.1	1.0	0.1
20	Manganese (Mn)	mg/l	5	5	5
21	Mercury (Hg)	mg/l	0.01	0.01	0.01
22	Nickel (Ni)	mg/l	1.0	2.0	1.0
23	Nitrate (N molecule)	mg/l	10.0	Undetermined	10.0
24	Oil and grease	mg/l	10	20	10
25	Phenol compounds (C6 H5 OH)	mg/l	1.0	5	1
26	Dissolved Phosphorus (p)	mg/l	8	8	10
27	Radioactive materials	As determined by Bangladesh Atomic Energy Commission			
28	pH		6 to 9	6 to 9	
29	Selenium	mg/l	0.05	0.05	0.05
30	Zn (Zn)	mg/l	5.0	10.0	10.0
31	Total dissolved solid	mg/l	2,100	2,100	2,100
32	Temperature	Centigrade			
	Summer		40	40	40
	Winter		45	45	45
33	Total Suspended Solid (TSS)	mg/l	150	500	200
34	Cyanide (CN)	mg/l	0.1	2.0	0.2

Source: Bangladesh Environmental Conservation Act 1997

Annex X: Fertilizer Equivalent of Human Excreta

	Nutrient in Kg			
Element	Nutrient in urine (500 l/year)	Nutrient in faeces (50 l/year)	Total	Required for 250 kg of cereal crops
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

Annex XI: An Approximate Quantity and Quality Breakdown of Human Excreta

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 XII: Drinking Water Quality Standards

Water quality parameters	Unit	Bangladesh standards	WHO guideline values 1993
Aluminum	mg/l	0.2	0.2
Ammonia (NH_3)	mg/l	0.5	1.5
Arsenic	mg/l	0.05	0.01
Barium	mg/l	0.01	0.7
Benzene	mg/l	0.01	0.01
BOD_5 20ºC	mg/l	0.2	
Boron	mg/l	1.0	0.3
Cadmium	mg/l	0.005	0.003
Calcium	mg/l	75	
Chloride	mg/l	150-600*	250
Chlorinated alkenes			
Carbon tetrachloride	mg/l	0.01	0.002
1,1 Dichloroethylene	mg/l	0.001	
1,2 Dichloroethane	mg/l	0.03	0.03
Tetrachloroehylene	mg/l	0.03	
Trichlosoethylene	mg/l	0.09	
Chlorinated phenols			
Pentachlorophenol	mg/l	0.03	
2,4,6 Trichlorophenol	mg/l	0.03	0.02
Chlorine (residual)	mg/l	0.2	0.6 to 1.0
Chloroform	mg/l	0.09	0.2
Chromium (hexavalent)	mg/l	0.05	
Chromium (total)	mg/l	0.05	0.05
Chemical oxygen demand	mg/l	4	
Coliform (faecal)	N/100ml	0	0
Coliform (total)	N/100ml	0	0
Colour	Hazen Unit	15	15
Copper	mg/l	1	1
Cyanide	mg/l	0.1	0.07
Detergents	mg/l	0.2	
Dissolved oxygen	mg/l	6	
Flouried	mg/l	1	1.5
Hardness (as $CaCO_3$)	mg/l	200 to 500	
Iron	mg/l	0.3 to 1.0	0.3
Kjehldal nitrogen (total)	mg/l	1	
Lead	mg/l	0.05	0.01
Magesium	mg/l	30 to 35	
Manganese	mg/l	0.1	0.1
Mercury	mg/l	0.001	0.001
Nickel	mg/l	0.1	0.02
Nitrate	mg/l	10	50
Nitrite	mg/l	<1	3
Odour	mg/l	Odourless	
Oil and grease	mg/l	0.01	
pH		6.5 to 8.5	
Phenolic compounds	mg/l	0.002	
Phosphate	mg/l	6	
Phosphours	mg/l	0	
Potassium	mg/l	12	
Radioactive substances: Alfa radiation	Bq/l	0.01	
Beta radiation	Bq/l	0.1	
Selenium	mg/l	0.01	0.01
Silver	mg/l	0.02	
Sodium	mg/l	200	200
Suspended solids	mg/l	10	
Sulphide	mg/l	0	
Sulphate	mg/l	400	250
Total dissolved solids	mg/l	1000	1000
Temperature	ºC	20 to 30	
Tin	mg/l	2	
Turbidity	JTU	10	5
Zinc	mg/l	5	3

Annex XIII: Excreted organism concentration in wastewater

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