CHAPTER 4

ANALYSIS OF WATER QUALITY AND POLLUTION LOADING IN THE BURIGANGA RIVER

4.1 Introduction

In the course of the present research a total of seven months were utilised for extensive field work to collect water samples both from river receptor points and wastewater discharge points. The field work was performed in two different phases to examine the temporal and the spatial variations of selected water quality parameters. Dry season was chosen for the first phase of field work and the samples were collected between the months of November 2008 and February 2009. The second phase of field work was conducted during the wet season, which was between the months of August and October 2009. Throughout the field work in situ measurements and laboratory analysis were carried out to determine the chemical composition of water samples. Further, the characteristics of ten physicochemical parameters (as mentioned in section 3.1) for both river and waste water were statistically analysed and compared with the DOE standards in order to identify the status of water quality of the Buriganga River. Based on these primary data this chapter provides a detailed and an up to date evaluation on the state of water quality and pollution in the Buriganga River.

4.2 Methodology

4.2.1 Sampling locations

Along the Buriganga River from upstream (Bosila bridge) to downstream (Hariharpara) five locations (receptor points) were selected in order to collect the water samples from the river. The sampling stations were chosen at a distance of minimum 0.5 km to a maximum of 5.5 km longitudinally away from the wastewater discharge points to understand the state of ambient water quality in the river. Samples were also collected from three main pollution discharge routes (discharge points) as identified in section

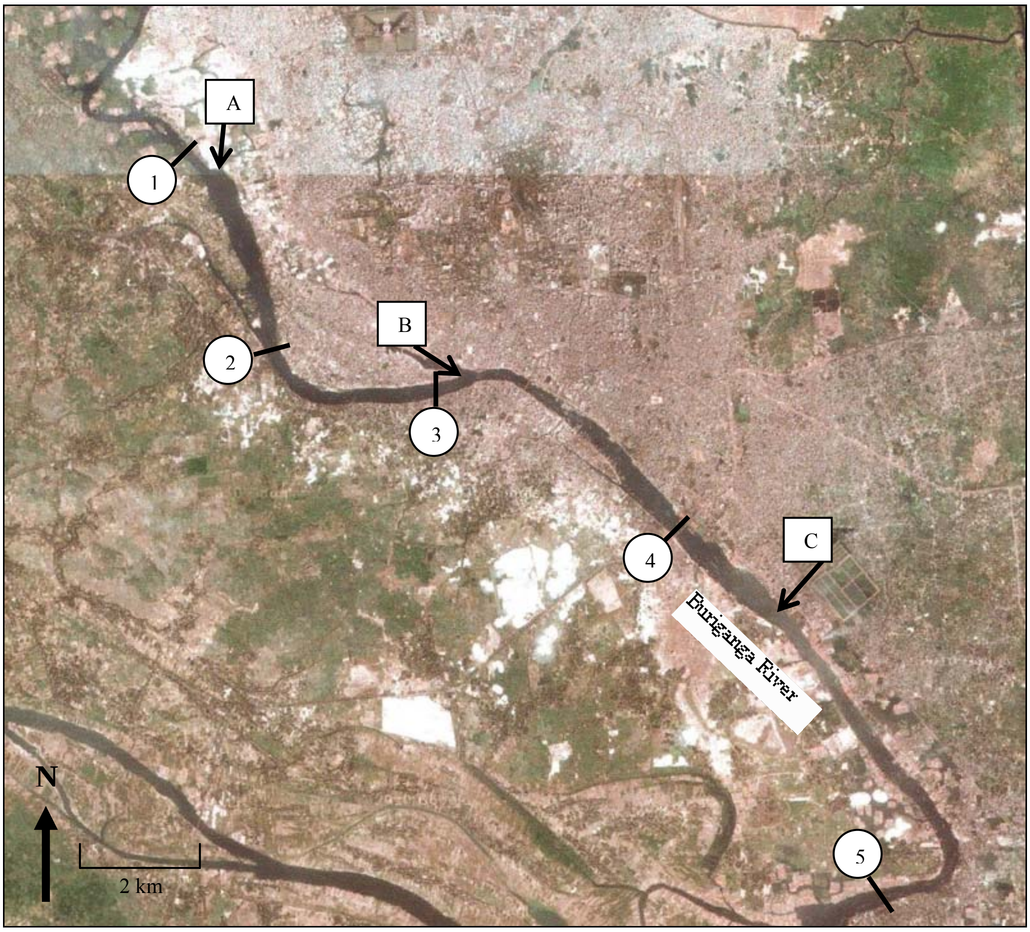
3.2.3. The locations of the sampling points have been illustrated in Figure 4.1. The latitude and the longitude of the sampling points (Table 4.1) were recorded with Garmin GPS 76 logger in order to have the consistency of sampling sites for subsequent sampling events. The water samples were collected from a depth of 1 (one) meter below the surface. The samples were gathered from eight different locations (including receptor and discharge points) in each season (dry and wet) on five different events (as listed in Table 4.2). Hence, a total of 80 water samples were collected for analysing ten water quality parameters.

4.2.2 In situ measurements and chemical analysis

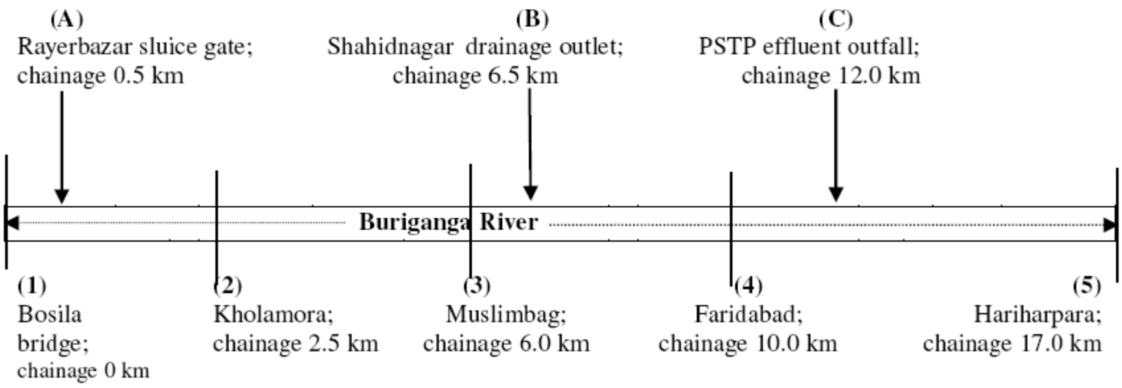
Temperature, DO, pH and EC_w were measured in every sampling event using the portable YSI 6600 Multi probe field analyser. The multi probe device was calibrated before each use as described in the user manual (YSI 2002).

Water samples were collected using a long-handled (about 1.5 m) grab sampler from each site and were immediately stored in ice before being transported to the laboratory for chemical analysis (tests for BOD_5, COD, phosphate phosphorus and ammonia nitrogen were performed at the Environmental Chemistry Lab of the Independent University in Bangladesh and the tests for Pb and Cr were performed at the Environmental Engineering Lab of BUET in Bangladesh). When the analysis of the samples could not be completed within 24 hrs, the samples were preserved with 0.8 ml sulphuric acid (H_2SO_4) for each litre of sample and then stored at 4 ^{0}C as recommended by Chapman and Kimstach (1992).

The chemical analyses in the laboratories were performed following the standard procedures of APHA (1998). The equipments and their detection limits are given in Table 4.3.



(a)



(b)

Figure 4.1. (a) A satellite map showing water sampling points in Buriganga River (Adapted and modified from: Google Earth 2010)

(b) A schematic diagram (with chainage distance) of the sampling points

Table 4.1. Geographical position (latitude and longitude) of the sampling points

Sampling points	**Locations**	**Buriganga chainage (km)**	**Latitude and Longitude**	**Remarks**
1	Bosila bridge	0.0	N 23.7433 ^{0} E 90.3458 ^{0}	River water
2	Kholamora	2.5	N 23.7191 ^{0} E 90.3591 ^{0}	River water
3	Muslimbag	6.0	N 23.7066 ^{0} E 90.3855 ^{0}	River water
4	Faridabad	10.0	N 23.6912 ^{0} E 90.4224 ^{0}	River water
5	Hariharpara	17.0	N 23.6326 ^{0} E 90.4634 ^{0}	River water
A	Rayerbazar sluice gate	0.5	N 23.7415 ^{0} E 90.3514 ^{0}	Wastewater discharge point
B	Shahidnagar drainage outlet	6.5	N 23.7102 ^{0} E 90.3903 ^{0}	Wastewater discharge point
C	PSTP effluent outfall	12.0	N 23.6745 ^{0} E 90.4443 ^{0}	Wastewater discharge point

Table 4.2. Sampling dates and weather condition

Sampling days	**Dates**	**Season**	**Weather condition**
1	12/12/2008	Dry	Cold, Clear
2	25/12/2008	Dry	Cold, Clear
3	24/01/2009	Dry	Cold, Clear
4	16/02/2009	Dry	Fine
5	14/03/2009	Dry	Fine
6	08/08/2009	Wet	Hot, Clear
7	22/08/2009	Wet	Hot, Cloudy
8	24/09/2009	Wet	Hot, Clear
9	8/10/2009	Wet	Fine
10	27/10/2009	Wet	Fine

Table 4.3. Test methods with detection limits and special equipments for chemical water quality parameters

Parameters	**Tests**	**Detection limits**	**Required special equipments**
BOD_5	Dilution method	No limit	BOD bottle
COD	Open Reflux method (two procedures for different detection limits)	0-50 mg/L > 50 mg/L	Reflux apparatus
Pb	Dithizone method	0-0.30 mg/L	Digital reactor block (HACH DR-2000)
Cr (VI)	Direct Air-Acetylene Flame method	No limit	Atomic Absorption Spectrophotometer (Shimadzu AA-6800)
PO_4-P	Amino Acid method	0-30 mg/L	Digital reactor block (HACH DR-2000)
NH_3-N	Ammonia-Selective Electrode method	0.03-1400 mg/L	pH meter with expanded millivolt scale (Omega PHH-65A)

4.2.3 Flow measurements for wastewater

The wastewater flow rates from the discharge points were measured by velocity-area method (Chitale 1974; USEPA 1997; Gore 2007). This technique comprises measuring the mean velocity and the flow area, and then computing the discharge from the continuity equation as:

$$Q = A * V \qquad (4.1)$$

where, Q = wastewater flow rate

A = cross-sectional area of the flowing wastewater

V = average velocity of the wastewater

The cross-sectional area was determined by the product of width and depth of the flowing wastewater which were discharged through open rectangular channels. The velocities of wastewater at the discharge points were measured by applying the float method (USEPA 1997; Cassidy 2003) during ten different sampling events. To perform this method, time was recorded with a stop watch for a buoyant object (half filled bottles) to float a specified distance along the flow of the wastewater. The velocities in each sampling event were calculated as the travel distance of the object divided by the recorded travel time (this procedure was repeated three times in each occasion and the average velocity was recorded).

4.2.4 Estimation of pollution load

Estimation of pollution load (amount of pollution) from the wastewater discharge points is an essential precursor to develop alternative and effective pollution abatement policies. For the purpose of the alternative pollution abatement policy analysis, the wastewater quality parameter of interest in this research was focused on BOD_5 loading and its interaction with DO levels in river water. The theoretical relationship between these two parameters was established mathematically from the oxygen sag curve (Figure 2.1) as described in Streeter and Phelps (1925). In this research, the pollution load was measured for BOD_5 using the averaging estimation approach (Dolan et *al.* 1981; Ferguson 1987; Preston *et al.* 1989; Letcher *et al.* 1999) as per following equation:

$$L_e = \left(1/n\sum_{i=1}^{n} Qi\right)\left(1/n\sum_{i=1}^{n} Ci\right) \qquad (4.2)$$

where,

L_e = Estimated pollution load

n = Number of samples taken during the study period

C_i = Concentration of the pollutant at the time of sampling

Q_i = Flow rate of wastewater at the time of sampling

4.2.5 Statistical analysis

One way analysis of variance (ANOVA) involving two factors (sampling locations and seasons) without replication was performed employing the statistical package *OpenStat* (Miller 2009) to determine the spatial and the temporal variability of different river water quality parameters. Box-and-whisker plots (Moore and McCabe 2006) were prepared for each water quality parameter to illustrate the distribution of water quality data. These plots show the minimum and the maximum values of a data set, together with the first quartile (lower 25th), the second quartile (median 50th) and the third quartile (upper 75th) values (Figure 4.2). These analyses were performed using PTS charts with EXCEL (PTS 2009).

In addition, the mean values of each water quality parameters were separately estimated using EXCEL and were subsequently compared with the DOE standards. However, in case of skewed distribution of data (as revealed from box-and-whisker plot) on water quality parameters, both median and mean values were compared with the DOE standards, following the recommendation of ANZECC (1992) that in case of skewed distribution of data, the median is the most appropriate measure of status. Furthermore, Pearson correlation coefficients (r) between different pairs of river water quality parameters were calculated and correlation for significance was tested by applying t-test (Moore and McCabe 2006). This analysis was done in order to understand the relationships among different water quality parameters.

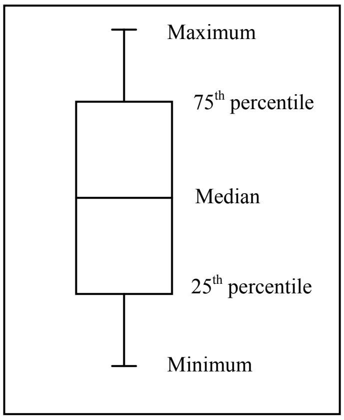


Figure 4.2. Illustration of a box-and-whisker plot

4.3 Results and discussions on river water quality parameters

4.3.1 Temperature

The average (± standard deviation) water temperature of the Buriganga River during the dry season varied between 20.4 (± 5.5) ^{0}C at station 1 and 21.0 (± 6.2) ^{0}C at station 2; while in the wet season it varied between 29.3 (± 1.4) ^{0}C at station 5 and 30.4 (± 1.1) ^{0}C at station 2 (Figure 4.3 and Table C.1 in Appendix C). The information on descriptive statistics of all river water quality parameters are provided in Appendix C (Table C.1 to C.10). The average water temperature during the sampling period was found within the DOE guideline values (20-30 ^{0}C) (Table 3.4), although in few sampling events the water temperature marginally exceeded the upper value of the guideline. Here, the lower value (20 ^{0}C) of the DOE guideline signifies the minimum recommended level and the upper value (30 ^{0}C) signifies the maximum recommended level for maintaining the ecosystem (BCAS 1999).

The ANOVA test results showed that there was no significant variation of temperature between sampling stations in either dry or wet season. However, a significant variation ($p<0.05$) was observed between dry and wet season in all sampling stations (Table D.1 in Appendix D). The median water temperature for the Buriganga River varied between 17.9 ^{0}C (station 1) and 18.9 ^{0}C (station 5) in dry season and 29.8 ^{0}C (station 1) and 30.4 ^{0}C (station 3) in wet season (Figure 4.4 and Table C.1 in Appendix C). The box-and-whisker plot (Figure 4.4) indicated a skewed distribution of dry season data towards the lower values of the DOE guideline and the median values were found 1-2 ^{0}C below the minimum acceptable level (20 ^{0}C) of DOE.

The temporal variation of surface water temperature is due to the influence of several climatic characteristics including air temperature, wind speed, total incident solar radiation and the duration of sunshine (Iltis *et al.* 1992). The average air temperature of the study area ranges between 12.7 ^{0}C and 32.5 ^{0}C in dry season and between 23.6 ^{0}C and 33.7 ^{0}C in wet season. Also, the average wind speed of the study area varies between 1.8-5.6 km/hr during dry season and 3.7-9.2 km/hr during wet season (Table 3.1). The effects of the climatic condition on the water temperature were logically very high as the samples were collected near from the surface (1 m depth). Hence, the temporal variation of water temperature was most likely influenced by the climatic condition of the study area. Overall, the observed data on water temperature indicated that the Buriganga River water was found suitable for aquatic ecosystem with no temperature stress during both dry and wet seasons.

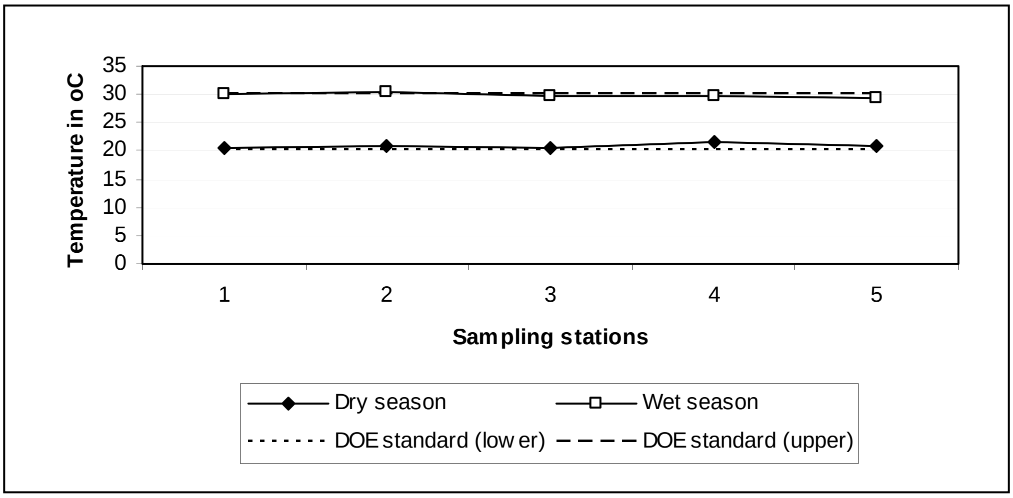


Figure 4.3. Spatial and seasonal variation of mean values of temperature compared to the DOE standard in Buriganga River water (2008-2009)

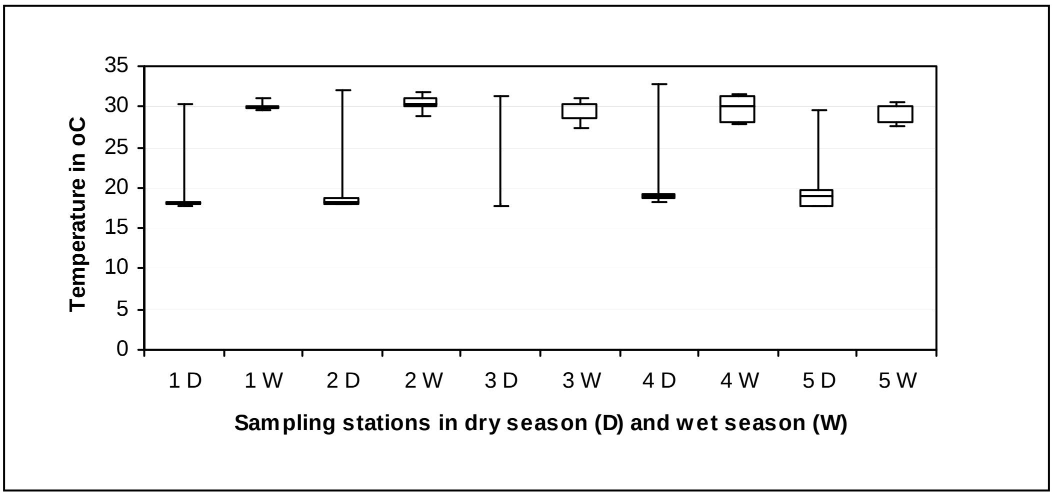


Figure 4.4. Box-and-whisker plot showing statistics on temperature of Buriganga River water for different sites and seasons (2008-2009)

4.3.2 pH

The average (± standard deviation) pH level of the Buriganga River during the dry season varied between 7.25 (± 0.2) at station 1 and 7.54 (± 0.4) at station 2; while in the wet season it varied between 7.18 (± 0.3) at station 1 and 7.65 (± 0.3) at station 4 (Figure 4.5 and Table C.2 in Appendix C). The average pH level of river water in all the stations during the sampling period was found within the DOE guideline values (6.5-8.5) (Table 3.4). The lower value (6.5) of the DOE guideline signifies the minimum recommended pH level and the upper value (8.5) signifies the maximum recommended pH level for maintaining the river ecosystem (BCAS 1999).

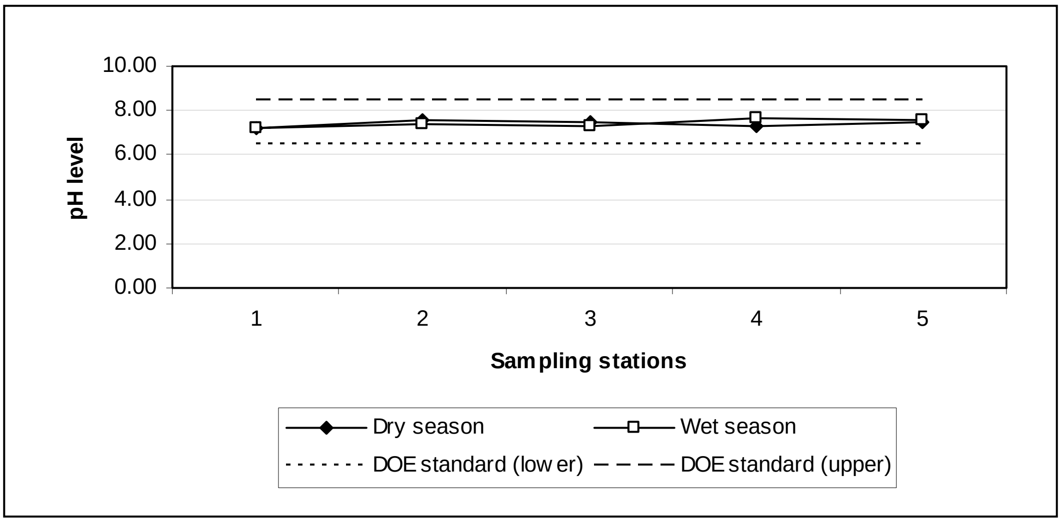


Figure 4.5. Spatial and seasonal variation of mean values of pH compared to the DOE standard in Buriganga River water (2008-2009)

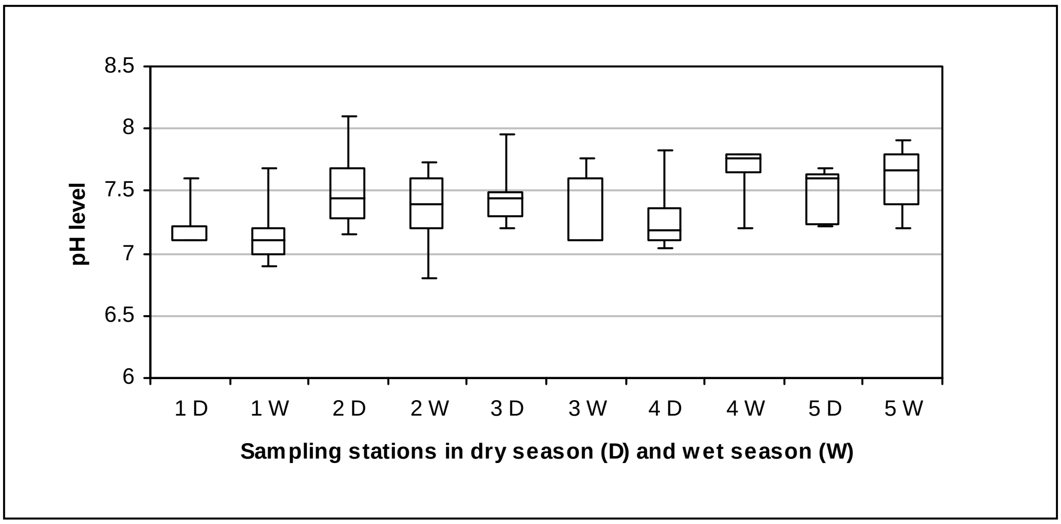


Figure 4.6. Box-and-whisker plot showing statistics on pH level of Buriganga River water for different sites and seasons (2008-2009)

The ANOVA test results showed that there was no significant variation of pH levels between sampling stations in either dry or wet season. Also there was no significant variation between dry and wet season data in any sampling station (Table D.2 in Appendix D). The median pH levels for the Buriganga River varied between 7.2 (station

4) and 7.6 (station 5) in dry season and 7.1 (station 1) and 7.8 (station 4) in wet season (Figure 4.6 and Table C.2 in Appendix C). The box-and-whisker plot (Figure 4.6) showed a symmetrical distribution of data, which also indicated the consistency of pH levels in the river water both spatially and temporally. Thus in general, the observed data on pH levels indicated that the Buriganga River water was safe from becoming any acidic or alkaline condition and that there had not been any effect of pH on the aquatic ecosystem during dry or wet season.

4.3.3 Dissolved oxygen

The average (± standard deviation) level of DO in the Buriganga River during the dry season varied between 0.7 (± 0.3) mg/L at station 2 and 1.2 (± 0.9) mg/L at station 5; while in the wet season it varied between 3.1 (± 0.6) mg/L at station 4 and 4.6 (± 0.7) mg/L at station 1 (Figure 4.7 and Table C.3 in Appendix C). The average DO values in the river water during the sampling period was found below the DOE guideline values (>5 mg/L) for maintaining the aquatic ecosystem (Table 3.4). In fact, the DO level never met the minimum DOE acceptable level on any of the sampling event in both dry and wet seasons. This indicated a serious degradation of river water quality in terms of depletion of DO.

The release of untreated domestic or industrial wastes high in biodegradable organic matter into the river possibly resulted in a marked decline in DO concentration downstream of the effluent discharge. This happens as a result of increased microbial activity (respiration) which may occur during the degradation of organic matter. In extreme cases where oxygen levels are very low in water, 'anaerobic conditions can occur (0 mgl^{-1} of oxygen), particularly close to the sediment-water interface as a result of decaying, sedimenting material' (Chapman and Kimstach 1992, p.65). Moreover, the oxidation of inorganic nutrients and naturally occurring organic matter, such as leaves and animal droppings that find their way into surface water may also contribute to the depletion of DO (Masters 2004). The effect of the oxygen depleting pollutants in the river is also possibly linked to the ratio of effluent load to river water discharge.

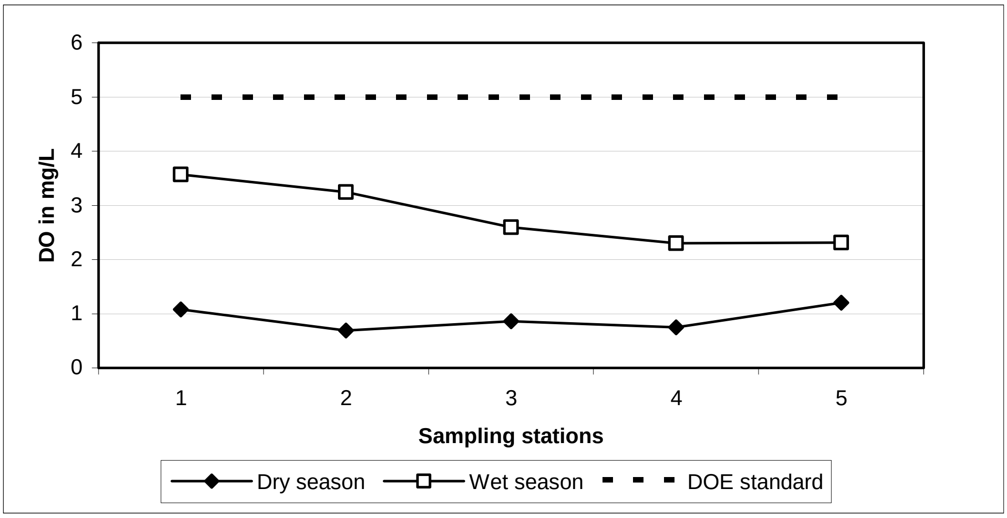


Figure 4.7. Spatial and seasonal variation of mean values of dissolved oxygen compared to the DOE standard in Buriganga River water (2008-2009)

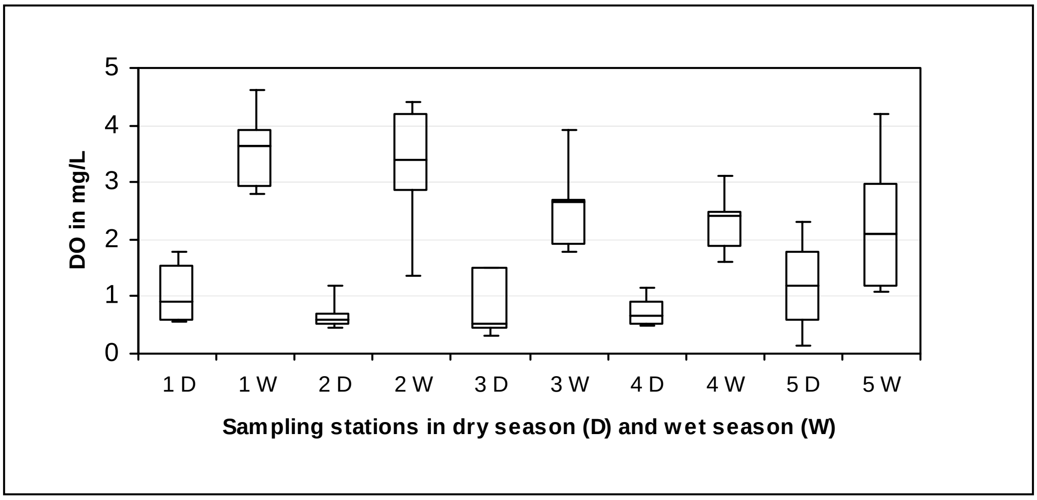


Figure 4.8. Box-and-whisker plot showing statistics on dissolved oxygen level of Buriganga River water for different sites and seasons (2008-2009)

The ANOVA test results showed that there was no significant variation of DO between sampling stations in either dry or wet season. However, there was a significant variation ($p<0.05$) between dry and wet season data for all sampling station (Table D.3 in Appendix D). This pattern was obviously influenced by the rate of river flow (Wright and Worrall 2001), which largely varied from low in dry season to high in wet season (Figure 3.2). However, the increased DO levels during the wet season still remained below the acceptable level specified by the DOE. The median values of DO concentrations varied between 0.5 mg/L (station 3) and 1.2 mg/L (station 5) in dry season and 2.1 mg/L (station

5) and 3.6 mg/L (station 1) in wet season (Figure 4.8 and Table C.3 in Appendix C). The box-and-whisker plot (Figure 4.8) indicated a symmetrical distribution of both dry and wet season data, which further justified the fact that in a specific season and along the full length of the river the DO concentration did not fluctuate much.

Adequate DO is absolutely an essential element to all forms of aquatic life and also to maintain a good water quality. As DO levels in water drops below 5.0 mg/L, the existence of aquatic life is threatened. Oxygen levels that remain below 1-2 mg/L for a few hours may destroy a large amount of fish population (Doudoroff and Shumway 1970). The observed data from this study indicated that the Buriganga River water was under DO stress and hence unsuitable for maintaining the aquatic ecosystem. This is the key environmental problem for the river that this research work is focused on with an objective to develop an alternative and cost-effective pollution management system through improvement of the DO concentration in the river water.

4.3.4 Biochemical oxygen demand

The average (± standard deviation) level of BOD_5 in the Buriganga River during the dry season varied between 23 (± 26) mg/L at station 1 and 48 (± 46) mg/L at station 2; while in the wet season it varied between 2.2 (± 2.1) mg/L at station 3 and 3.2 (± 3.1) mg/L at station 4 (Figure 4.9 and Table C.4 in Appendix C). The average BOD_5 values in the river water during the dry season did not meet the DOE guideline value (<6 mg/L) for maintaining the aquatic ecosystem (Table 3.4), while the values were found within the acceptable levels during the wet season. This indicates a degradation of river water quality in terms of increased loading of biodegradable wastes (Liston and Maher 1997; Chapman and Kimstach 1992) during the dry season. The observed data showed that the sampling station 2 was worst affected, which was possibly because of the input of organic matter from the tannery industries at Hazaribagh and Rayerbazar (located near discharge point A) and nearby sewage discharges from Kamrangir Char area. The measurement of the average concentration of BOD_5 in the Buriganga during the dry season also aligned with the results reported in the previous studies of Kamal (1996) and Magumdar (2005) and indicates a trend of further deterioration of water quality in terms of this parameter.

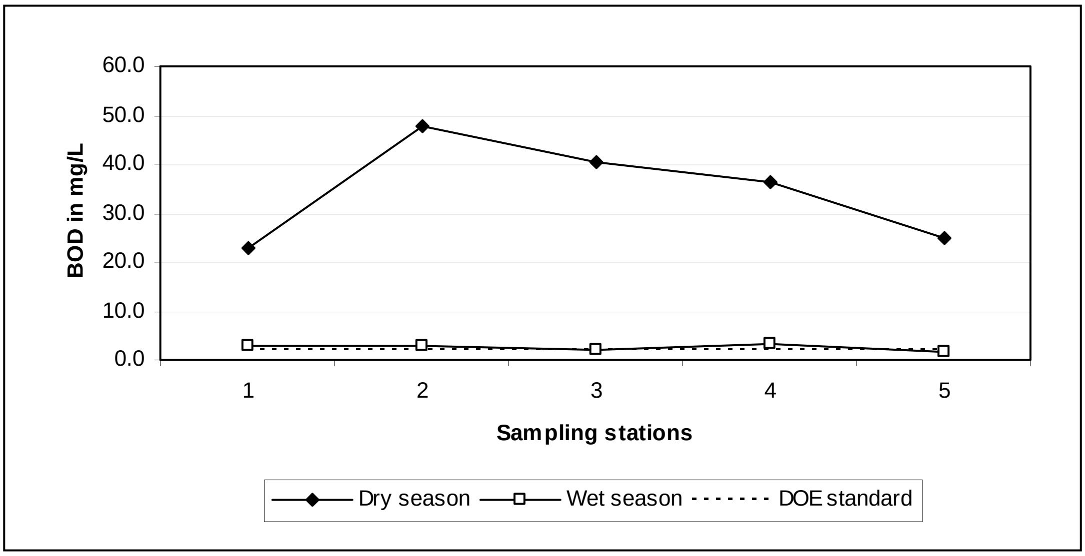


Figure 4.9. Spatial and seasonal variation of mean values of biochemical oxygen demand compared to the DOE standard in Buriganga River water (2008-2009)

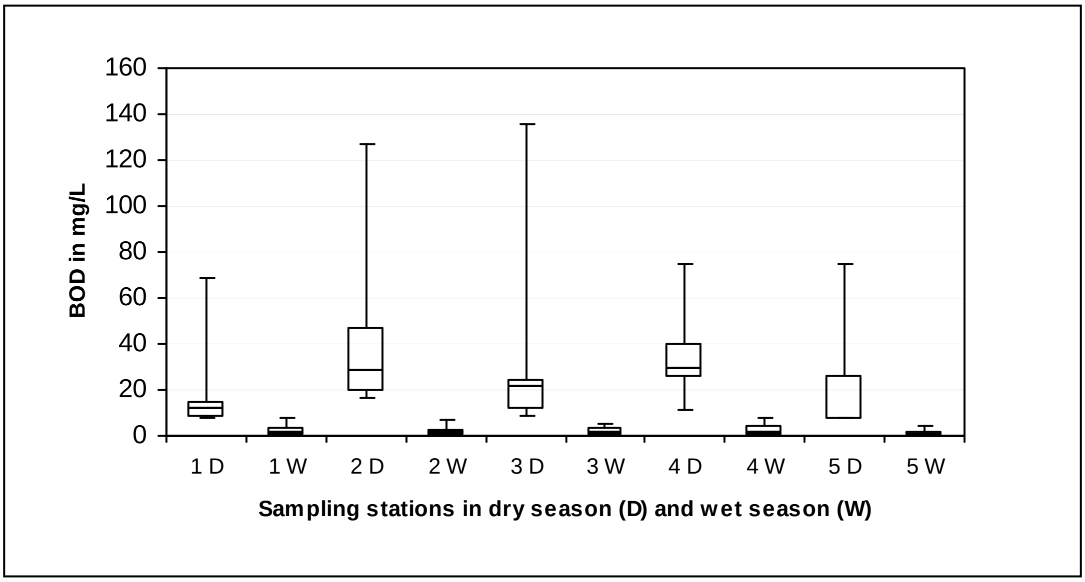


Figure 4.10. Box-and-whisker plot showing statistics on biochemical oxygen demand of Buriganga River water for different sites and seasons (2008-2009)

The ANOVA test results showed that there was no significant variation of BOD_5 between sampling stations in either dry or wet season. However, there was a significant variation ($p<0.05$) between dry and wet season data in all sampling stations (Table D.4 in Appendix D). The decrease in the level of BOD_5 during the wet season (high flow) was most likely caused by the dilution of biodegradable organic matter in the additional volume of river water. The median values of BOD_5 concentrations varied between 8.1

mg/L (station 5) and 29.5 mg/L (station 4) in dry season and 1.2 mg/L (station 5) and 2.1 mg/L (station 4) in wet season (Figure 4.10 and Table C.4 in Appendix C). The box-and-whisker plot (Figure 4.10) indicated a symmetric distribution for wet season data, however the dry season data showed a skewed distribution. The high level of BOD_5 also indicated the presence of excessive amount of microorganisms in the river water, which consumed high amount of oxygen for their metabolic activities and thus reduced the concentration of DO. Overall, the Buriganga River water was found unsuitable in terms of high BOD_5 particularly during the dry season for maintaining the aquatic ecosystem.

4.3.5 Chemical oxygen demand

The average (±standard deviation) level of COD in the Buriganga River during the dry season varied between 27 (± 4) mg/L at station 5 and 82 (± 39) mg/L at station 2; while in the wet season it varied between 8 (± 3) mg/L at station 5 and 30 (± 11) mg/L at station 2 (Figure 4.11 and Table C.5 in Appendix C). The average COD values in the river water during both dry and wet seasons were found above the DOE guideline (4 mg/L) for maintaining the aquatic ecosystem (Table 3.4). This indicated a degradation of river water quality in terms of increased loading of inorganic chemicals (Chapman and Kimstach 1992) during both dry and wet seasons. The observed data showed that the sampling station 2 was worst affected (maximum values), which was possibly because of the input of inorganic matter from the surrounding industrial zone (located near discharge point A and B), while the level of COD dropped along the downstream of the river.

The ANOVA test results showed that there was a significant variation ($p<0.05$) of COD data between sampling stations in either dry or wet season. This variation was probably influenced by the presence of greater number of industries surrounding the upstream region of the river compared to its downstream region. The ANOVA test also indicated a significant variation ($p<0.05$) of COD results between dry and wet season in all sampling stations (Table D.5 in Appendix D). The decrease in the level of COD during the wet season (high flow) compared to the dry season (low flow) was most likely caused by the dilution of inorganic chemicals in additional volume of river water.

The median values of COD concentrations varied between 26 mg/L (station 5) and 86 mg/L (station 2) in dry season and 7.1 mg/L (station 5) and 31 mg/L (station 2) in wet season (Figure 4.12 and Table C.5 in Appendix C). The box-and-whisker plot (Figure 4.12) indicated symmetry of distribution for both dry and wet season data and thus a similarity between mean and median results were observed. Overall, the observed data indicated that the Buriganga River water was found unsuitable in terms of high COD concentration for maintaining the aquatic ecosystem through out the whole year and along the full length of the river.

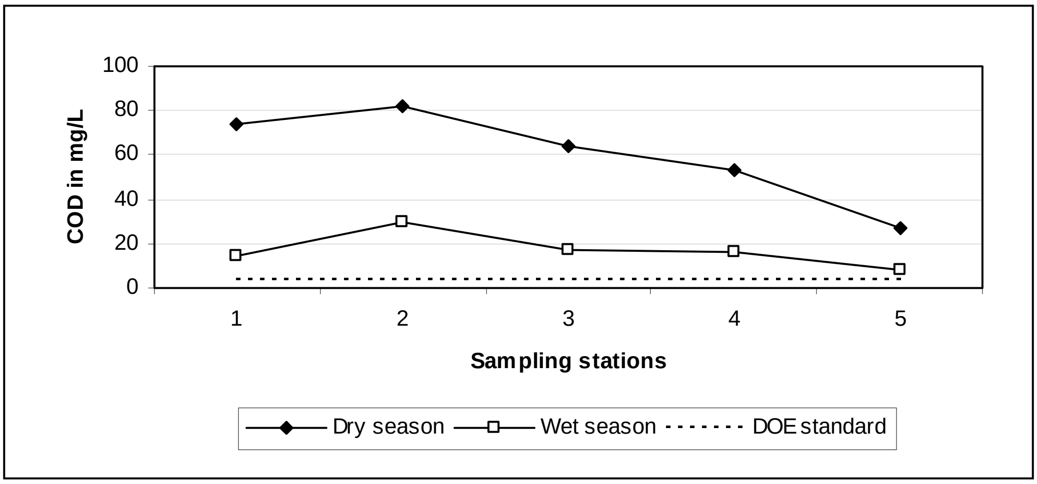


Figure 4.11. Spatial and seasonal variation of mean values of chemical oxygen demand compared to the DOE standard in Buriganga River water (2008-2009)

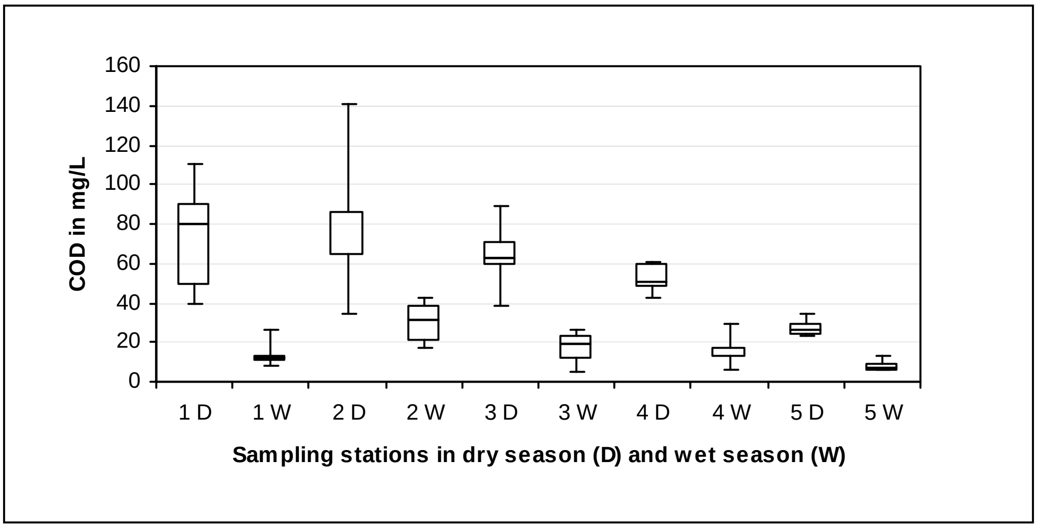


Figure 4.12. Box-and-whisker plot showing statistics on chemical oxygen demand of Buriganga River water for different sites and seasons (2008-2009)

4.3.6 Electrical conductivity

The average (± standard deviation) level of EC_w in the Buriganga River during the dry season varied between 610 (± 135) µS/cm at station 5 and 697 (± 81) µS/cm at station 2; while in the wet season it varied between 28 (± 17) µS/cm at station 5 and 152 (± 17) µS/cm at station 2 (Figure 4.13 and Table C.6 in Appendix C). The average EC_w values in the river water during the dry season were found unacceptable compared to the DOE guideline value (350 µS/cm) for maintaining the aquatic ecosystem (Table 3.4), while the values were found within the acceptable levels during the wet season. This indicated a degradation of river water quality in terms of increased salt concentrations (which is equivalent to dissolved solids) (Liston and Maher 1997; Chapman and Kimstach 1992) during the dry season. The observed data showed that the sampling station 2 was worst affected, which was possibly because of the input of tanning wastes from the industries at Hazaribagh and Rayerbazar (located near discharge point A). The observed levels of EC_w in the Buriganga for both dry and wet seasons during the study period were also found analogous with the values from the previous study of DOE indicating an increased tendency of the concentration of salts due to pollution (DOE 1993).

The ANOVA test results showed that there was no significant variation of EC_w between sampling stations in either dry or wet season. However, there was a significant variation ($p<0.05$) between dry and wet season data in all sampling stations (Table D.6 in Appendix D). In dry season (low flow condition) the total volume of water in the river decreased, which possibly caused the rise of EC_w in the river water. Moreover, the high level of EC_w during this season was most likely caused by the discharge of polluted water and/or the influence of tide. However, the EC_w levels were found to be greater in upstream region than the downstream region of the river. This may indicate that the high levels of EC_w in upstream region compared to the downstream region were more the result of incoming polluted water than the possible effect of any tidal influence (as mentioned in section 3.1.1). On the other hand, the decrease in the level of EC_w during the wet season (high flow condition) was most likely caused by the effect of dilution in additional volume of river water. The median values of EC_w varied between 593 (station-3) and 675 µS/cm (station-2) in dry season and 19 (station-5) and 145 µS/cm (station-2) in wet season (Figure 4.14 and Table D.6 in Appendix D). The box-and-whisker plot (Figure 4.14) indicated a symmetric distribution for both dry and wet season data.

Overall, the observed data indicated that the Buriganga River water was found unsuitable in terms of high EC_w particularly during the dry season for maintaining the aquatic ecosystem.

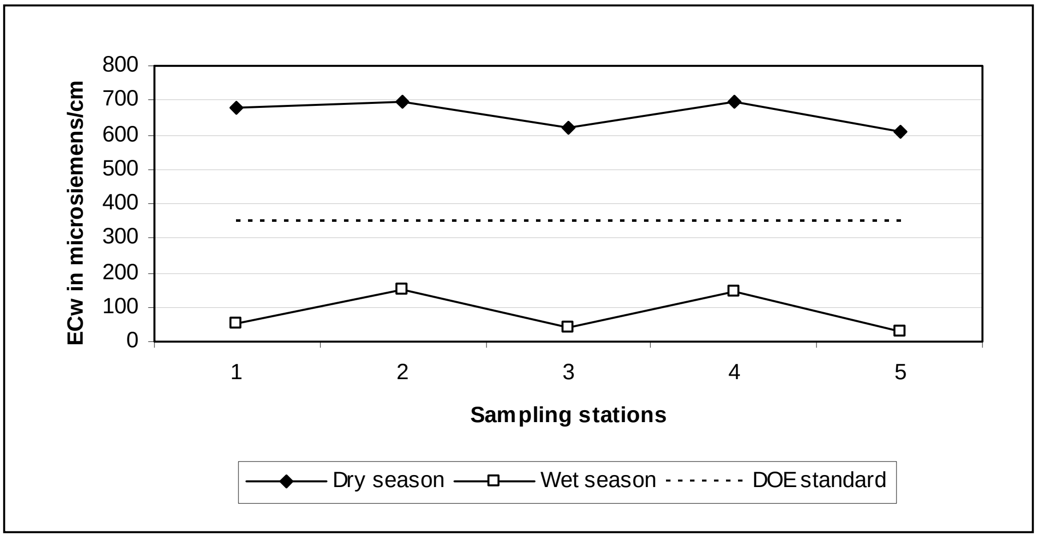


Figure 4.13. Spatial and seasonal variation of mean values of electrical conductivity compared to the DOE standard in Buriganga River water (2008-2009)

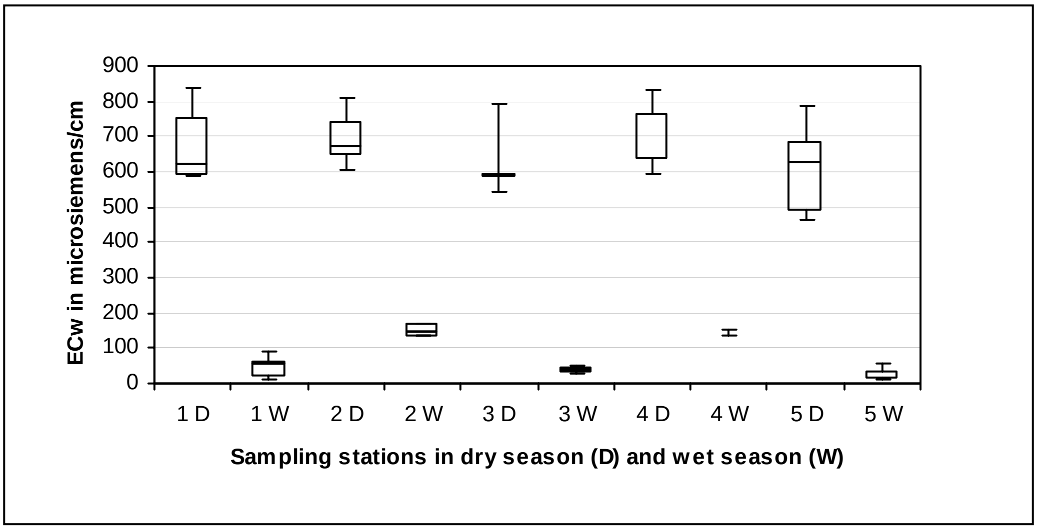


Figure 4.14. Box-and-whisker plot showing statistics on electrical conductivity of Buriganga River water for different sites and seasons (2008-2009)

4.3.7 Heavy metals: lead and chromium

The average (± standard deviation) level of lead (Pb) in the Buriganga River during the dry season varied between 0.002 (± 0.001) mg/L at station 5 and 0.01 (± 0.01) mg/L at station 3; while in the wet season it varied between 0 (± 0) mg/L at stations 1, 2, 3, 5 and 0.001 (± 0.001) mg/L at station 4 (Figure 4.15 and Table C.7 in Appendix C). All observed values during the study period on lead concentrations were found below the maximum allowable level (0.05 mg/L) as set by the DOE for maintaining aquatic ecosystem. However, any trace of the presence of Pb in the river water (particularly in station 3 during the dry season) should not be ignored as they are non-degradable (stock pollutant), and can accumulate and damage the water body (Chapman and Kimstach 1992). Although the source of Pb into the Buriganga River could not be directly identified, it could be possibly linked either with the industrial effluent, or with the oil spill from the river vessels.

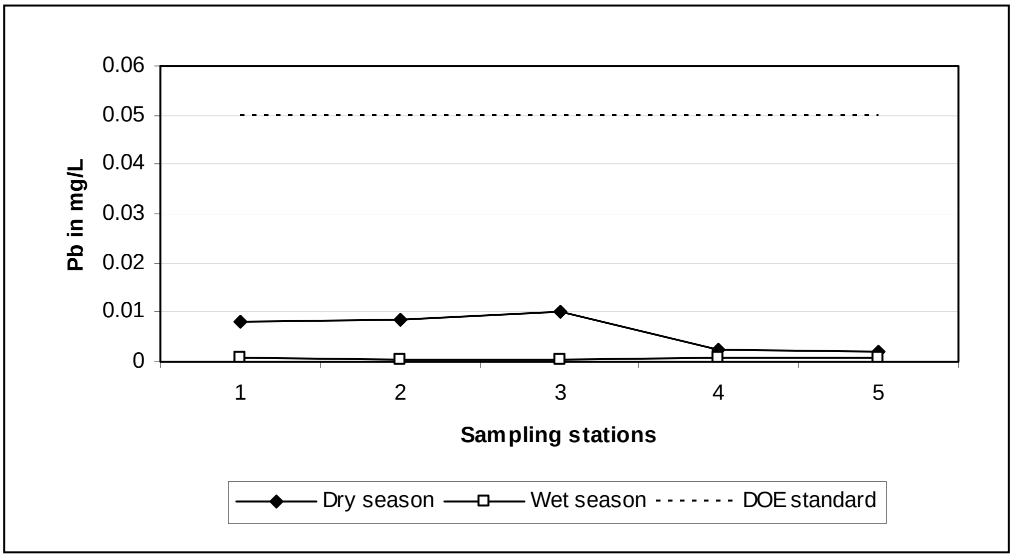


Figure 4.15. Spatial and seasonal variation of mean values of lead compared to the DOE standard in Buriganga River water (2008-2009)

The ANOVA test results showed that there was no significant variation of Pb concentration between sampling stations in either dry or wet season. However, there was a significant variation ($p<0.05$) between dry and wet season data in all sampling stations (Table D.7 in Appendix D). The box-and-whisker plot (Figure 4.16) did not indicate any major skew in the distribution of data on Pb concentration for both dry and wet seasons. The median values of the data set (Table D.7 in Appendix D) also remained within the DOE guideline values. Overall, the observed data indicated that the Buriganga River water was suitable in terms of Pb concentration during both dry and wet seasons for maintaining the aquatic ecosystem.

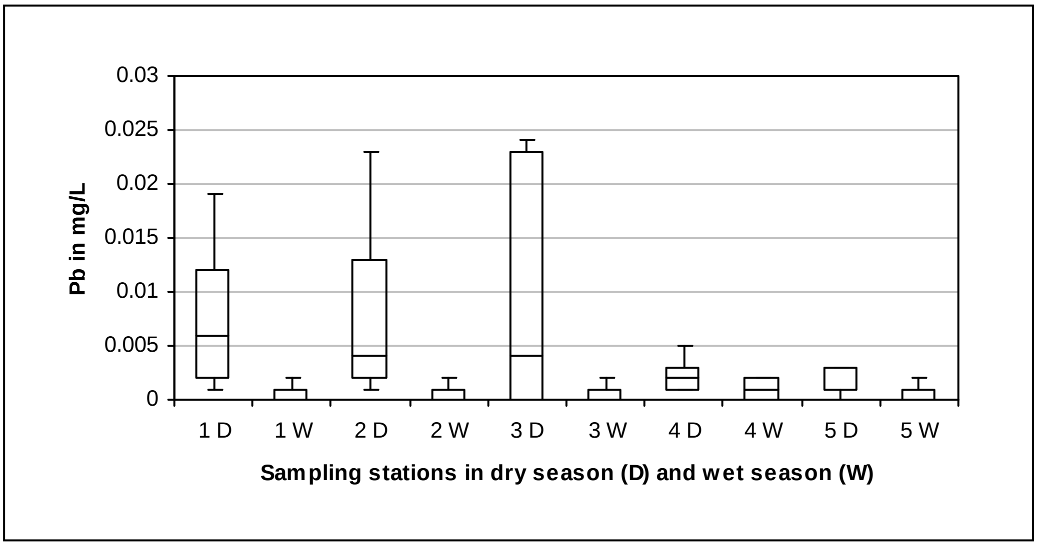


Figure 4.16. Box-and-whisker plot showing statistics on lead concentration of Buriganga River water for different sites and seasons (2008-2009)

The average (± standard deviation) level of chromium (Cr (VI)) in the Buriganga River during the dry season varied between 0.002 (± 0.002) mg/L at station 5 and 0.18 (± 0.06) mg/L at station 2; while in the wet season it varied between 0.001 (± 0.001) mg/L at station 5 and 0.19 (± 0.07) mg/L at station 2 (Figure 4.17 and Table C.8 in Appendix C). The average Cr (VI) concentrations in the river water at stations 2 and 3 were found unacceptable during both dry and wet seasons compared to the DOE guideline value (0.05 mg/L) for maintaining the aquatic ecosystem (Table 3.4), while the concentrations were found within the acceptable levels at other stations during both seasons. This was possibly caused by the release of effluent from the tannery industries located at Hazaribagh and Rayerbazar areas which rely on chrome tanning process (BKH 1995). Earlier, Kamal (1996) also identified traces of Cr (VI) near stations 2 and 3, however those values (up to maximum 0.007 mg/L) were found within the limits of the DOE guideline. Thus the results in the present study proved an increasing tendency of Cr (VI) concentration at stations 2 and 3 of the river.

The ANOVA test results showed that there was a significant variation ($p<0.05$) of Cr (VI) concentrations between sampling stations in either dry or wet season. This variation was possibly caused by the presence of such industries near sampling stations 2 and 3 which discharge Cr (VI) in their wastewater. The ANOVA test results also indicated a significant variation ($p<0.05$) of Cr (VI) concentrations between dry and wet season in all sampling stations (Table D.8 in Appendix D). The median values of Cr (VI) varied between 0.003 (station 5) and 0.18 mg/L (station-2) in dry season and 0 (station 5) and 0.19 mg/L (station 2) in wet season (Figure 4.18 and Table D.8). No significant skewness within the distribution of Cr (VI) data was observed as presented with the box-and-whisker plot in Figure 4.18. Thereby similar results on the state of Cr (VI) were obtained from both mean and median values. Overall, the observed data indicated that only the downstream (between stations 4 and 5) of the Buriganga River water was suitable for maintaining the aquatic ecosystem in terms of the presence of Cr (VI) concentration during both dry and wet seasons.

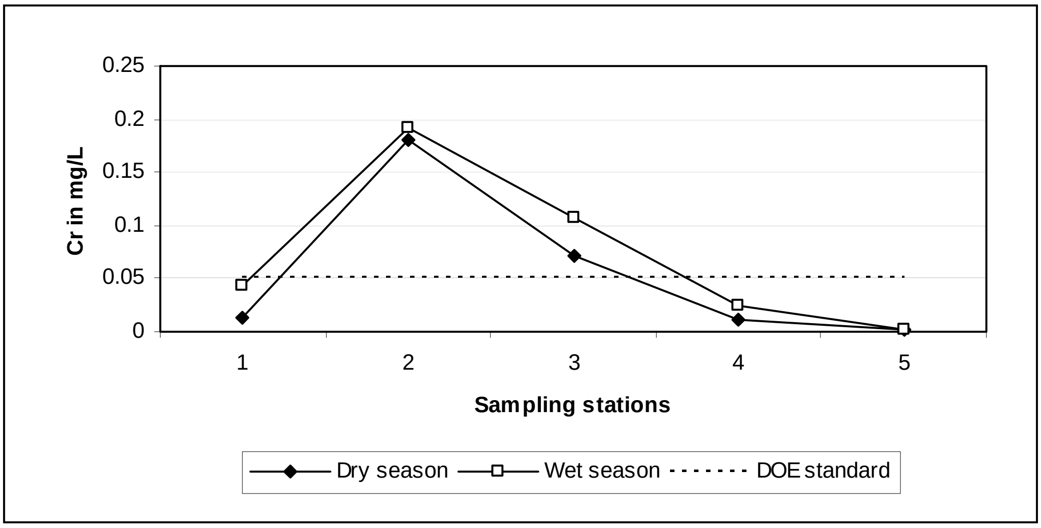


Figure 4.17. Spatial and seasonal variation of mean values of chromium compared to the DOE standard in Buriganga River water (2008-2009)

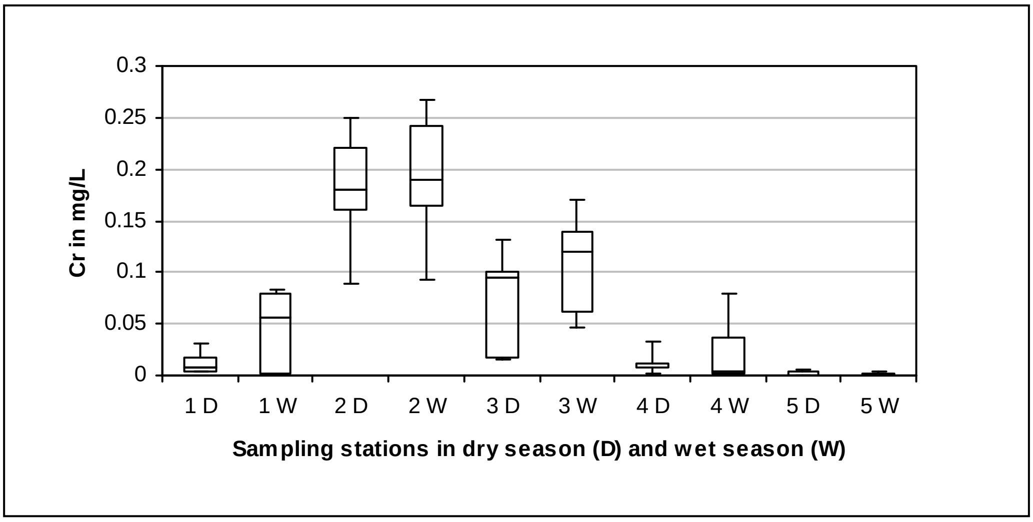


Figure 4.18. Box-and-whisker plot showing statistics on chromium concentration of Buriganga River water for different sites and seasons (2008-2009)

4.3.8 Nutrients: ammonia nitrogen and phosphate phosphorus

The average (± standard deviation) level of ammonia nitrogen (NH_3-N) in the Buriganga River during the dry season varied between 0.5 (± 0.4) mg/L at station 1 and 11.2 (± 1.7) mg/L at station 2; while in the wet season it varied between 0.1 (± 0.1) mg/L at station 1 and 8.8 (± 11) mg/L at station 2 (Figure 4.19 and Table C.9 in Appendix C). The observed data showed that the sampling stations 2 and 3 were worst affected with high concentration of NH_3-N and the average values during both dry and wet seasons did not meet the DOE guideline (1.2 mg/L) (Table 3.4). Moreover, when compared to the study of Kamal (1996) about three times higher values of NH_3-N concentration were found at these two sampling stations. This indicates an increasing trend of NH_3-N concentration in the Buriganga River particularly in stations 2 and 3.

The ANOVA test results showed that there was a significant variation ($p<0.05$) of NH_3-N data between sampling stations in both dry and wet seasons. This variation was probably influenced by greater discharge of this pollutant near the upstream region of the river compared to its downstream region. The ANOVA test also indicated a significant variation ($p<0.05$) of NH_3-N results between dry and wet season in all sampling stations (Table D.9 in Appendix D). The decrease in the level of NH_3-N during the wet season (high flow) compared to the dry season (low flow) was most likely caused by the dilution of inorganic nutrients in additional volume of river water.

The median values of NH_3-N concentrations varied between 0.3 mg/L (station-1) and 10.8 mg/L (station-2) in dry season and 0.09 mg/L (station-1) and 8.3 mg/L (station-2) in wet season (Figure 4.20 and Table D.9 in Appendix D). The box-and-whisker plot (Figure 4.20) indicates a symmetric distribution for both dry and wet season data and thus similar values for mean and median results were found. Overall, the observed data indicate that only the downstream (between stations 4 and 5) of the Buriganga River water was suitable for maintaining the aquatic ecosystem in terms of the presence of NH_3-N concentration during both dry and wet seasons.

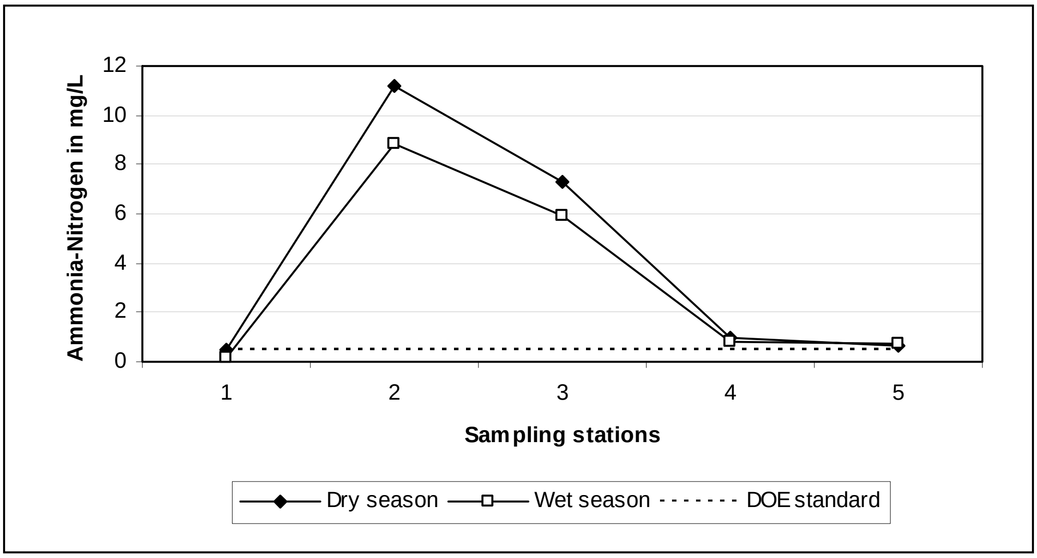


Figure 4.19. Spatial and seasonal variation of mean values of ammonia nitrogen compared to the DOE standard in Buriganga River water (2008-2009)

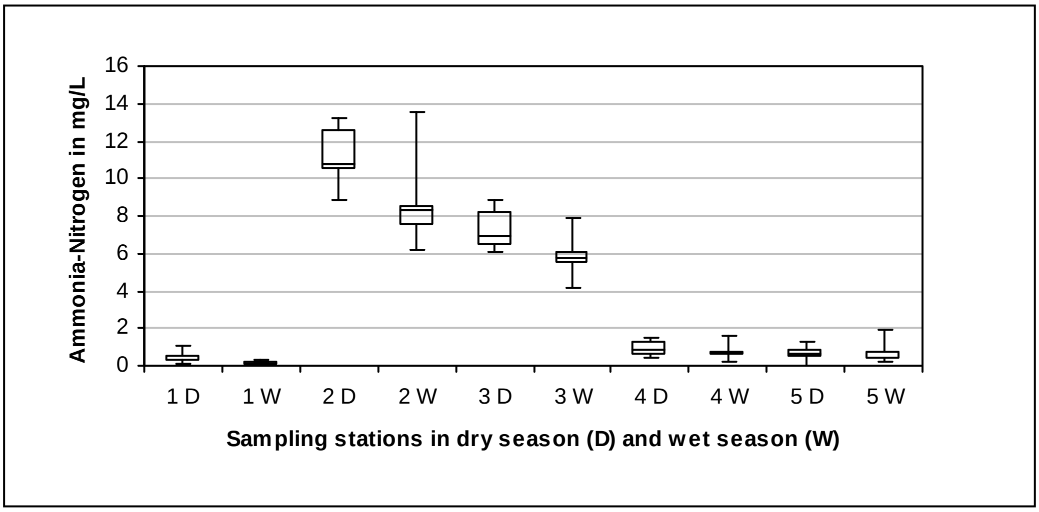


Figure 4.20. Box-and-whisker plot showing statistics on ammonia nitrogen concentration of Buriganga River water for different sites and seasons (2008-2009)

The average (± standard deviation) level of phosphate phosphorus (PO_4^{3-}-P) in the Buriganga River during the dry season varied between 0.4 ± (0.2) mg/L at station 4 and 0.7 (± 0.3) mg/L at station 5; while in the wet season it varied between 0.5 (± 0.4) mg/L at station 2 and 0.8 (± 0.4) mg/L at station 5 (Figure 4.21 and Table C.10 in Appendix C). All observed values of PO_4^{3-}-P concentrations were found below the maximum allowable level (6 mg/L) as set by the DOE guidelines for maintaining aquatic ecosystem.

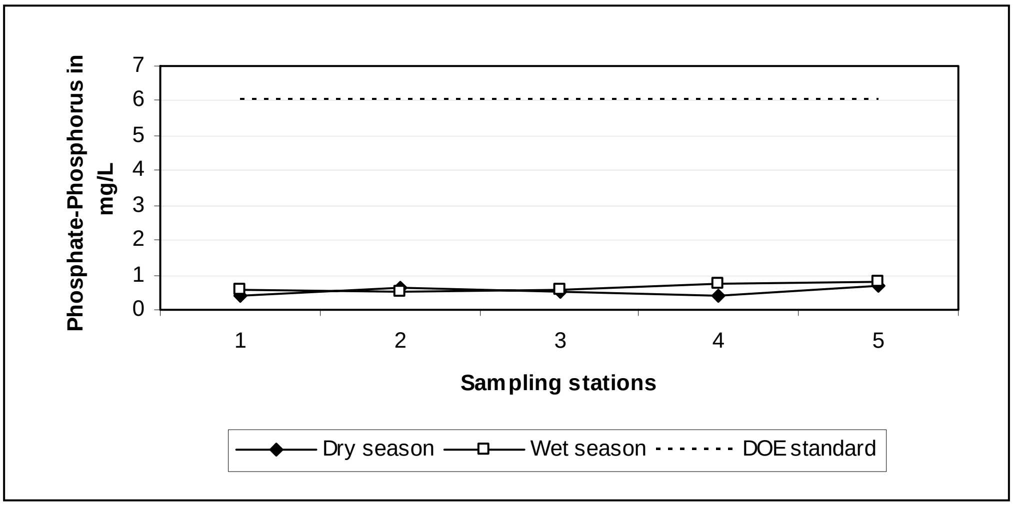


Figure 4.21. Spatial and seasonal variation of mean values of phosphate phosphorus compared to the DOE standard in Buriganga River water (2008-2009)

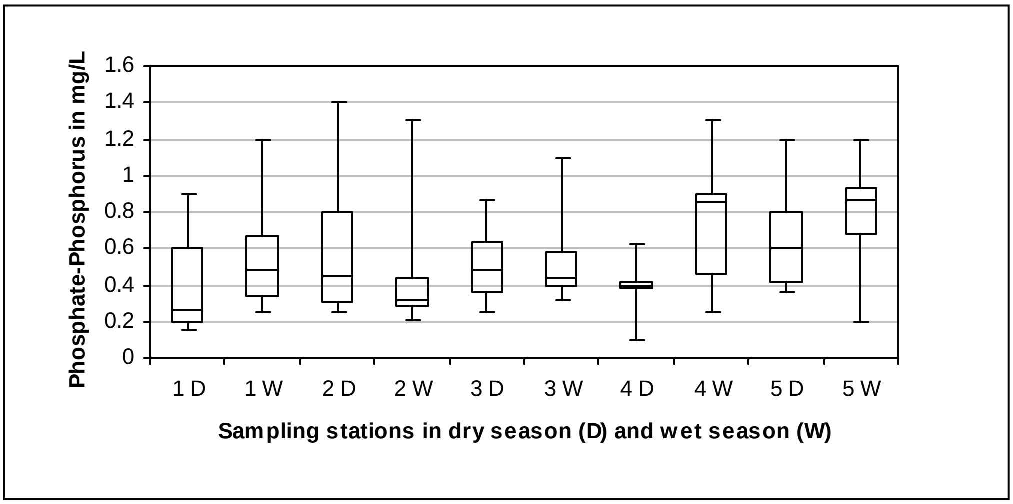


Figure 4.22. Box-and-whisker plot showing statistics on phosphate phosphorus concentration of Buriganga River water for different sites and seasons (2008-2009)

The ANOVA test results showed that there was no significant variation of PO_4^{3-}-P concentration between sampling stations in either dry or wet season. Also there was no significant variation between dry and wet season data in any sampling station (Table D.10). The box-and-whisker plot (Figure 4.22) showed a symmetric distribution of data on PO_4^{3-}-P concentration for both dry and wet seasons. The median values of the data set (Table D.10 in Appendix D) also remained within the DOE guideline values. Overall, the observed data indicated that the Buriganga River water was suitable in terms of PO_4^{3-}-P concentration during both dry and wet seasons for maintaining the aquatic ecosystem.

4.3.9 Correlation of river water quality parameters

A correlation analysis was performed in order to provide some basis for better understanding of the associations of water quality parameters for the Buriganga River in most recent time. The detailed analytical results are provided in Table E.1 (Appendix E) and the coefficient matrix is presented in Table 4.4. It is obvious that many factors, such as climatic, hydrological and geological conditions, directly or indirectly influence the correlation between different water quality parameters (Dodson 2005; Chapman and Kimstach 1992).

From the correlation matrix it appears that water temperature was positively correlated with DO and negatively correlated with COD and EC_w at $p = 0.001$. Dissolved Oxygen (DO) had significant negative correlations with BOD_5, COD and EC_w, at $p=0.001$ and with Pb at $p = 0.01$. Moreover, BOD_5, COD and EC_w showed positive correlation among each other at one percent significance level. Lead (Pb) showed positive correlation with BOD_5 and COD at one percent significance level. The EC_w was also found significantly correlated with Pb at $p = 0.01$. Interestingly, PO_4-P and pH were positively correlated only with each other at $p=0.001$ but they were not significantly correlated with any other parameter. The correlation between PO_4-P and pH is the result of the buffering power of phosphate ions. Ammonia nitrogen was significantly positively correlated with COD and Pb respectively at $p = 0.01$ and $p = 0.05$. Chromium (Cr) was found significantly positively correlated only with NH_3-N at $p=0.001$.

4.4 Waste water quality

The results on the composition of wastewater discharged from three different points into the Buriganga River are presented in Table 4.5 in terms of mean values and standard deviations. The descriptive statistics of wastewater quality data from ten different observations have also been provided in Table F.1 (Appendix F).

Table 4.4. Correlation coefficients matrix for water quality parameters in the Buriganga River (n=50)

	Temp.	**pH**	**DO**	**BOD_5**	**COD**	**EC_w**	**Pb**	**Cr**	**NH_3-N**	**PO_4-P**
Temp.	1	0.137	0.539***	0.06	-0.514***	-0.755***	-0.104	0.138	-0.057	0.092
pH		1	-0.136	0.175	-0.003	-0.05	0.231	-0.016	0.124	0.435***
DO			1	-0.443***	-0.571***	-0.739***	-0.367**	0.167	-0.149	-0.009
BOD_5				1	0.514***	0.504***	0.631***	0.104	0.206	-0.103
COD					1	0.705***	0.513***	0.23	0.314**	-0.084
EC_w						1	0.37**	-0.052	0.139	-0.193
Pb							1	0.112	0.262*	0.036
Cr								1	0.777***	0.037
NH_3-N									1	0.019
PO_4-P										1

Note: values with * represent significant at p=0.05; values with ** represent significant at p=0.01; values with *** represent significant at p=0.001

Table 4.5. Mean values with standard deviation of wastewater composition at different discharge points in the Buriganga River (n=10)

Parameters	**Unit**	**DOE standards** (for discharge as effluent in river water)	**Discharge points**		
			A Rayerbazar sluice gate	**B** Shahidnagar drainage outlet	**C** PSTP effluent outfall
Temp	^{0}C	30	30.1±4.8	29.5±4.1	26.7±6.3
pH	-	6.0-9.0	7.6±0.4	7.4±0.2	7.4±0.2
DO	mg/L	4.5-8.0	0.3±0.4	0.4±0.4	3.5±0.6
BOD_5	mg/L	40	966.1±295.6	1003.4±388.6	251.0±130.8
COD	mg/L	200	1156.9±365.3	1261.1±412.9	378.9±181.4
EC_w	µS/cm	1200	3939.3±929.9	903.5±493.4	458.9±300.7
Pb	mg/L	0.1	0.09±0.04	0.1±0.02	0.02±0.01
Cr	mg/L	0.1	13.3±6.9	0.2±0.4	0.02±0.02
NH_3-N	mg/L	50	83.5±26.9	47.2±8.2	4.1±2.2
PO_4-P	mg/L	35	4.3±2.0	16.9±4.4	5.9±1.0

The average temperature of the wastewater from all three discharge points were found within the acceptable limits specified by the DOE. However, the temperature of wastewater from discharge point A was marginally meeting the guideline value. The average pH values of the wastewater from all three discharge points were found within the acceptable limit of the DOE and considered to be neutral in terms of acidity or alkalinity.

The average DO concentrations in the wastewater discharged from point A and B were found to be in hypoxic to anoxic condition; while the average DO concentration at point C was 3.5 mg/L. However, none of the discharge points met the minimum acceptable level (4.5 mg/L) of DO concentration as set by the DOE. The relatively higher value of DO at point C was caused possibly by the effect of discharge of treated wastewater from the PSTP. The low DO concentrations in the wastewater from all the discharge points indicated the possibility of raw sewage released from the adjacent areas which are yet to be covered by the sewerage network of DWASA.

The average BOD_5 concentrations at discharge points A, B and C were found respectively more than 24, 25 and 6 (six) times higher than the recommended guideline specified by the DOE. The high values of BOD_5 could be linked to increased degradation of organic content (such as sewage) in the wastewater and thus causing the very low concentration of DO. Such high concentration of BOD_5 would most likely affect the natural assimilating capacity of the river and a reduction of BOD_5 levels are essential in order to protect the quality of the river water. Moreover, the impact of such high concentration of BOD_5 in the wastewater were reflected in the state of river water quality (Figure 4.9), where during the dry season the BOD_5 levels never reached the DOE guideline along the full length of the river. Station 2 (receptor point) was worst affected most likely because of the impact of BOD_5 loading from discharge points A and B

The average COD concentrations at discharge points A, B and C were found respectively more than five, six and two times higher than the recommended guideline of the DOE. These values were correlated to BOD_5 values and indicated the presence of industrial waste (oxidisable inorganic chemicals) in the effluent. The extent of COD pollution was so high that the river water could never (including both dry and wet seasons) reach up to the acceptable level of DOE guideline (Figure 4.11).

The average EC_w level of the wastewater discharged from point A was more than three times higher than the DOE guideline, while the levels were within the guideline values for discharge points B and C. This was most likely caused by the use of salts while processing the raw hides within the tanneries (BKH 1995), which were located within the drainage area of discharge point A. Although the level of EC_w in wastewater from discharge point A and B remained below the acceptable levels, Figure 4.13 indicated that during the dry season the EC_w level in the river water never dropped below the acceptable level. This was probably because the salts which were being discharged through the wastewater did not get enough water or time to be diluted within the length of the river.

The Pb concentration in wastewater discharged from points A and B marginally met the DOE guideline values and thereby probably the concentration levels within the river water were found below the acceptable level. However, appropriate measures should be taken to identify the sources of this non-decaying toxic substance before its level exceeds the acceptable limits. The wastewater from discharge point A contained very high Cr concentration, which was detrimental for the river ecosystem. Compared to discharge point A, relatively low concentration of Cr was found in the wastewater from discharge point B, but that value also exceeded the limit of the DOE guideline. The high concentrations of Cr were most likely a result of the effluent released from the tannery industries (as mentioned earlier in section 4.3.7) and were eventually being drained off into the Buriganga River through the discharge points A and B.

The results showed that the discharge point A exceeded the DOE limit of NH_3-N concentration by about two times, while the concentration was found within the limit at discharge point B and C. The high concentration of NH_3-N from discharge point A is most likely causing a negative impact on river water quality at stations 2 and 3 (Figure 4.19). The PO_4-P concentrations at all three discharge points were found within the DOE acceptable levels.

4.5 Flow rates of wastewater

The flow rates of wastewater from the three discharge points were estimated following the methodology as described in section 4.2.3. The results are presented in Figure 4.23. The data on observed average velocities and the calculated flow rates on ten different occasions for each discharge point are provided in Table G.1 (Appendix G).

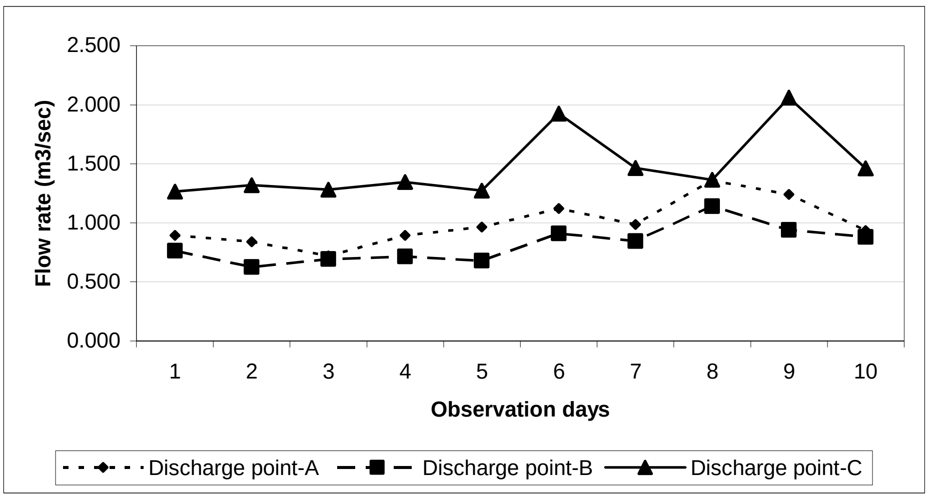


Figure 4.23. Flow rates of waste water at different discharge points

From these data, the average flow rates for three discharge points were estimated as 0.995 m^3/s at Rayerbazar sluice gate, 0.819 m^3/s at Shahidnagar drainage outlet and 1.476 m^3/s at PSTP effluent outfall. These results were used to calculate the pollution loading rate of BOD_5 in Buriganga River which is discussed in the following section.

4.6 Loading rates of BOD_5 at discharge points

The BOD_5 loading rates from the discharge points were estimated as discussed in section 4.2.4 and the results are presented in Table 4.6.

Table 4.6. BOD_5 loading rate in the Buriganga River

Discharge points	Average flow rate (m^3/s)	Average BOD_5 concentration (mg/L)	BOD_5 loading rate (tons/day)	Total BOD_5 loading (tons/day)
A	0.995	966	83	186
B	0.819	1003	71	
C	1.476	251	32	

The total loading of BOD_5 in the Buriganga River was estimated as 186 tons/day. Compared to the latest available study (Magumdar 2005), the BOD_5 loading in the present study increased at a rate of 12.5 percent per year, while the rate increased at 13.8 percent per year between 1996 and 2003 (Figure 4.24).

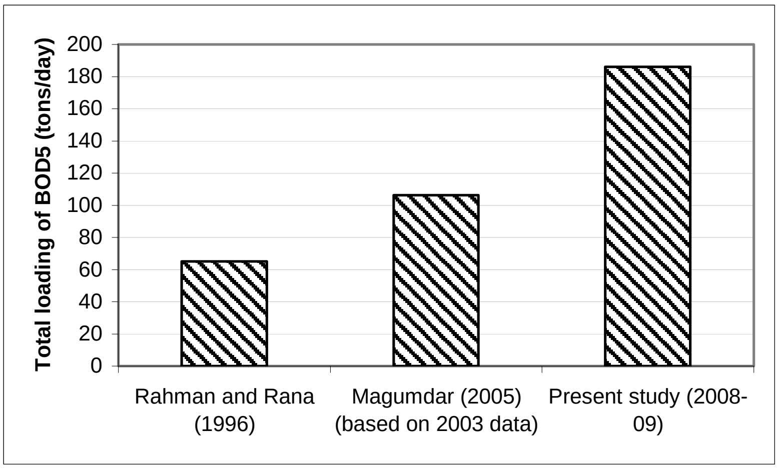


Figure 4.24. Estimated loading rate of BOD_5 in the Buriganga River

Overall, the results on BOD_5 loading rates showed that the contribution of pollution into the Buriganga River followed the order as Discharge point A>Discharge point B> Discharge point C. The drainage area and the size of population were found more for discharge point B compared to discharge point A. However, according to the estimations, discharge point B was contributing more pollution than discharge point A. This was possibly because of presence of greater number of industries (which do not have adequate wastewater treatment facilities) within the drainage area of discharge point A. Discharge point C contributes the least of pollution possibly because partially treated effluent (from the PSTP) is discharged through this point.

4.7 Transfer coefficients for discharge-receptor pairs

One of the important bases of the economic model formulation for pollution abatement policy analysis in this research is the calculation of a set of transfer coefficients that conveys the water quality response at a receptor point as a result of release of pollutant at a discharge point (source of pollution). Burn (1989) defined these coefficients as the function of physical characteristics of the portion of water body that provides the pathway from the discharge point to the receptor point. Hence, the transfer coefficients are used in simulating pollutant flows and they represent the degree to which pollution concentrations at a specific receptor point are increased by a one-unit increase in emissions from a specific discharge point (Tietenberg 2006). Generally, the transfer coefficients depend upon the flow, travel time and the geometry of the connecting pathway, as well as the reaction kinetics for any biological and chemical reactions that may occur in the water body (Burn 1989).

The nature of the BOD_5 is that it is a spatially distributed pollution, so the effluent discharges may not affect the quality of water (increase/decrease in DO concentration) at the point of discharge, but can affect the quality downstream (Eckenfelder 1980). Thus the DO transfer coefficients represent the increase in DO (mg/L) at receptor points resulting from decrease of BOD_5 (per ton/day) at discharge points. The transfer coefficients of the oxygen demanding wastes were calculated from the Streeter Phelps model of DO concentration (Streeter and Phelps 1925). They represent the amount of DO that is required for each ton/day of BOD_5 loading at each discharge point along the river. The inputs to the Streeter Phelps model that were required for each discharge-receptor pair were: the flow, the travel time, the deoxygenation and the reaeration rate coefficient, and the BOD_5 loading rates at the discharge points. The functional relationship for the transfer coefficient model was of the following form (Burn 1989, p.1015):

$$d_{ij} = \frac{L_i K^i{}_1}{Q_j \left(K^{ij}{}_2 - K^i{}_1 \right)} \left[e^{-K^i{}_1 t_{ij}} - e^{-K^{ij}{}_2 t_{ij}} \right] \qquad (4.3)$$

where,

d_{ij} = DO transfer coefficient;

Q_j = flow at the receptor location;

t_{ij} = travel time from the discharge to the receptor point;

$K^i{}_1$ = deoxygenation rate coefficient;

$K^{ij}{}_2$ = reaeration rate coefficient; and

L_i = BOD_5 loading rate at the discharge point

The average values of deoxygenation rate coefficients and reaeration rate coefficients for different segments of the Buriganga River were adapted from Ahmed and Mohammed (1988) as shown in Table 4.7. The input data for the Streeter Phelps model for different discharge-receptor pairs are provided in Table H.1 (Appendix H). The most deteriorating condition in terms of BOD_5 pollution in a river may occur when the river flow rate is minimum. In this study, the monthly average flow rates for the years 2005, 2006 and 2008 (Table A.1 in Appendix A) were considered and the lowest value from these was nominated for the Equation 4.3 to calculate the DO transfer coefficients. The calculated values of DO transfer coefficients are provided in Table 4.8.

Table 4.7. Average values of deoxygenation rate coefficient, $K^{i}{}_{1}$ and reaeration rate coefficient, $K^{ij}{}_{2}$ for different segments of the Buriganga River

River segments (between discharge and receptor points)	A-2	A-3	A-4	A-5	B-4	B-5	C-5
Deoxygenation rate coefficient, $K^{i}{}_{1}$ (day^{-1})	0.262	0.23	0.256	0.136	0.256	0.171	0.136
Reaeration rate coefficient $K^{ij}{}_{2}$ (day^{-1})	0.332	0.245	0.337	0.65	0.337	0.49	0.65

Adapted from: Ahmed and Mohammed 1988

Table 4.8. Dissolved oxygen transfer coefficients, d_{ij}

Discharge points	***Receptor points of measurement***			
	2	**3**	**4**	**5**
	Distance from Bosila bridge(km)			
	2.5	*6.0*	*10.0*	*17.0*
A	0.0119	0.0258	0.0518	0.0202
B	-	-	0.0320	0.0319
C	-	-	-	0.0195

4.8 Conclusion

The results for this study showed that the Buriganga River is certainly unfit for maintaining the aquatic ecosystem. More specifically, the test results revealed that the river water is unacceptable (as per DOE standards) for the parameters such as DO, BOD_5, COD, NH_3-N and Cr during both dry and wet seasons and for EC_w during only dry season. Whilst, temperature, pH, PO_4-P and Pb were found within the DOE acceptable limits in both dry and wet seasons.

The results from the river water quality study also showed no significant statistical difference between sampling stations (receptor points) in terms of parameters such as temperature, pH, DO, BOD_5, EC_w, Pb and PO_4-P, while the results showed a significant difference for COD, Cr and NH_3-N. The study indicated that the river is mostly affected near Kholamora (receptor point 2) and Muslimbag (receptor point 3) by the incoming wastewater from the nearby discharge points. Further, the test results showed that the incoming wastewater is in hypoxic to anoxic condition with very high concentration of BOD_5, COD, EC_w, Cr and NH_3-N compared to the DOE guideline values. The study also established information on BOD_5 loading rates, which is required for this research to analyse the effectiveness of alternative management strategies for pollution mitigation in the Buriganga River.