*International Research Journal of Environmental Sciences* ISSN 2319–1414
Vol. **7(12),** 40-55, December **(2018)** *Int. Res. J. Environmental Sci.*

# Impact of industrial pollution and seasonality on physicochemical and biological parameters of surface water around the BISIC industrial area of Rajshahi City, Bangladesh

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**Available online at: www.isca.in, www.isca.me**
Received 7th September 2018, revised 3rd December 2018, accepted 20th December 2018

## Abstract

*The present study has been carried out to investigate the effects of industrial pollution and seasonal changes on physicochemical and biological parameters of surface water from November 2014 to May 2018 of Bangladesh Small Cottage Industry Corporation (BSCIC), Rajshahi, Bangladesh. Three different water body sites indicated as spot-I, spot-II, and spot-III of BSCIC were selected owing to the proximity of the wastes thrown by the industries. Spot-I is a drain which is connected to the central drainage system of BSCIC. Spot-II is a pond which receives wastes only during the rainy season whereas Spot-III is a large canal and is connected to the two main drainage systems of Rajshahi City Corporation. Water samples were collected at monthly intervals from a depth of 20-30 cm below the surface from the study sites. Water quality parameters viz., physical (air and water temperature, transparency of water), chemical (pH, dissolved oxygen, $HCO_3$ alkalinity and free $CO_2$, total hardness, Ca- and Mg-hardness, total phosphate and nitrate, percent of saturation of oxygen, redox potential (Eh), $BOD_5$ and COD), and biological (phytoplankton and zooplankton, and total coliform bacteria) of the sites were evaluated. Pearson correlations analysis was used to find out the relationships among physical, chemical and biological parameters during all periods investigated. Anoxic conditions were found at spot-II and -III. The most important parameters of pollution like hardness, $BOD_5$, COD and coliform counts were higher at spot-I and -III compared to spot-II. Therefore, this study reveals that spot-I and -III were highly polluted compared to spot-I where moderate levels of pollution were observed.*

**Keywords:** Industrial pollution, seasonal variation, BSCIC, Water body, physicochemical parameters, biological quality.

## Introduction

The appreciation of the nature for a healthy environment is the most important need for today which will create a value to conserve and protect our atmosphere. Since the pollution and imbalancement of the ecosystem is the gift of urbanization and civilization, there is a need of sustainable development, use of modern technologies and proper town planning. Bangladesh has vast freshwater resources in the form of both lentic and lotic ecosystems. Each aquatic ecosystem is unique and has its own physical, chemical and biological characteristics. Although through aging all the characteristics gradually change under undisturbed condition, any disturbance of these natural processes by human intervention is likely to result in negative environmental consequences[1]. Bangladesh, one of the most densely populated countries in the world is facing a very serious problem of water pollution owing to the development of industrial infrastructure without following the environmental laws; lack of the water resources management plan and policies; lack of awareness among the common people etc. Consequently, its freshwater habitats as like as the other developing countries of the world are no exception among the most threatened valuable ecosystems[2].

Rajshahi, a 130 years old city is one of the eight metropolitan cities of Bangladesh. It is situated in the north-western part of Bangladesh. Bangladesh Small Cottage Industry Corporation (BSCIC) industrial area established in 1961 on 95.71 acres of land on the city's outskirts. According to BSCIC, the numbers of industrial units present in 2017 were 202 and the number is expecting to increase to 500 by 2020. These small and large industrial units produce a large amount of industrial wastes which are indiscriminately discharged into the nearby ponds, marshlands, lakes, and Padma River by receiving canal. Several studies have reported severe groundwater pollution around Dhaka Export Processing Zone (DEPZ) due to the disposal of various types of industrial wastes directly to the water body[2,3]. A recent study has evaluated the impact of open dumping of municipal waste on surface water, groundwater, and soil in Rajshahi City[4]. Various adverse effects including the presence of high levels of Biological Oxygen Demand ($BOD_5$), Chemical Oxygen Demand (COD) etc. have been reported. However, since the industrial effluents lead to a great diversity in physical, chemical and biological characteristics, a separate study is required for each waste water habitat. Therefore, physicochemical characteristics and its relationship to the biological parameters is necessary to evaluate the trophic status and productivity levels for suitable management. To the best of our knowledge, the impact of the BSCIC industrial effluents and seasonal variation on the physicochemical and biological qualities of surface water in and around the industrial areas of BSCIC, Bangladesh has never been investigated.

The present study was specifically targeted to assess the severity of BSCIC industrial effluents and to unveil its impact upon the physicochemical and biological parameters of Rajshahi City Corporation drainage and BSCIC industrial area. The study has been conducted from November 2014 to May 2018. A detail investigation of some important physical, chemical and biological parameters including air and water temperature, transparency of water, pH, dissolved oxygen, $HCO_3$ alkalinity and free $CO_2$, total hardness, Ca hardness, Mg- hardness, total phosphate and nitrate, percent of saturation of oxygen, redox potential (Eh), $BOD_5$ and COD, phytoplankton and zooplankton, and total coliform bacteria were taken under consideration during the whole study period to assess the impact of industrial wastes on the water body.

## Methodology

**Study Area and Collection of Samples:** The present work has been carried out from November 2014 to May 2018 in three different water bodies which are indicated as spot-I, spot-II, and spot-III. Spot-I is an I-shaped drain with an area of 706 $M^2$ and is connected to the central drainage system of BSCIC industrial area. Spot-II is a derelict pond and has an area of 7507 $M^2$ which receives waste products of BSCIC industrial area only during the rainy season. Spot-III is a large canal with an area of 1298 $M^2$ which is connected to the two main drainage systems of Rajshahi City Corporation. The data obtained during the 43 months study period have been analyzed separately as the summer, monsoon and winter to shed light on the seasonal changes. Summer was considered from March to June, monsoon was from July to October, while winter from November to February. Water samples were collected from a depth of 20-30 cm below the surface using a 250 mL glass stopper bottle from all three spots on monthly basis between 8.30am-11.30am between the $25^{th}$ and $30^{th}$ day of each month from November to May (2014-2018).

**Determination of Physical Parameters:** Air and water temperature were recorded by a centigrade thermometer. Depths of the ponds were measured by a long graduated pole scaled in centimeter. The data were expressed in centimeter. By using a Secchi-disc, water transparency was determined.

**Determination of Chemical Parameters:** A digital pH meter (HANNA model) was used to measure the pH. The Winkler's method (modified) was used to determine dissolved oxygen (DO) in the water samples. $HCO_3$ alkalinity and free $CO_2$ were determined by titrimetric method[5]. Total hardness, Ca hardness, Mg hardness were estimated by following the method of Mishra et al.[6]. $BOD_5$ was determined by dilution method according to A.P.H.A.[7]. The resultant data were expressed in mg/L. COD was measured following the ferrous ammonium sulfate method according to A.P.H.A.[7]. Total phosphate and nitrate were estimated by following the procedure described by Gautam[8].

**Determination of Biological Parameters: Enumeration of the Phytoplankton and Zooplankton:** Using plankton net of standard bolting silk cloth no-25 (mesh size 0.03–0.04 mm), the samples of planktons were collected and subsequently, transferred into the glass bottles where they were preserved permanently in Transeau's solution. Enumeration of the phytoplankton and zooplankton were performed according to the "drop method". The organisms were expressed as cells per liter (units/L) of the sample irrespective of whether they were solitary cells, colonies or filaments or part thereof. Percentage composition and relative abundance of phyto and zooplankton were calculated. Seasonal variation and abundance of the groups of both phytoplankton and zooplankton were also noted. The estimation of the abundance of planktons was performed according to the following formula[5]:

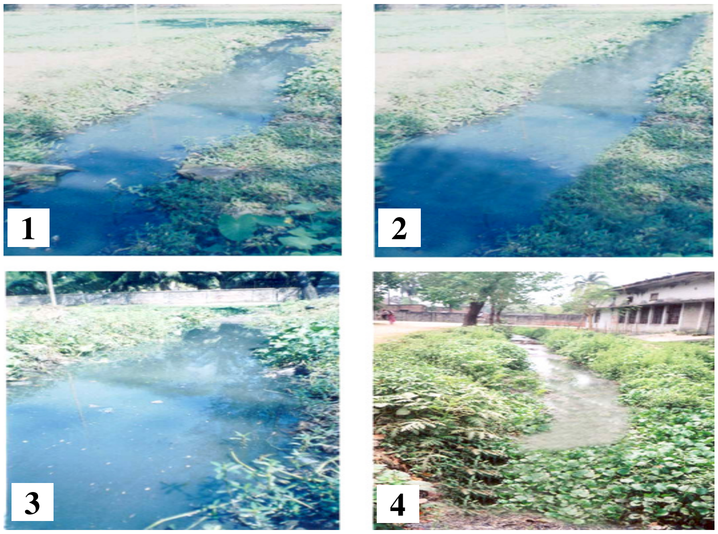
$$N = \frac{(a \times 1000)C}{L}$$

Where: *N*, *a*, *C*, and *L* are the number of plankton per liter of original water, average number of plankton in all counts in the counting unit, volume of original concentrate in mL, and volume of water passed through the net, respectively.

**Bacteriological Analysis:** Total coliform bacteria were observed seasonally for one year (July 2017 to May 2018) in all three study spots. Standard Total Coliform Membrane Filter Method according to A.P.H.A.[9] was used for the determination of the total number of coliform bacteria in the test samples. Briefly, in sterilized bottles the samples of water were collected. 1 mL of water from each bottle was taken in another sterilized bottle and made up to 100mL with double distilled water. Subsequently, filtration of the samples was performed with a rated pore diameter for the complete retention of coliform bacteria. The membrane filters were then exposed to a culture medium, called "M-Endo medium" for the growth of the coliform bacteria. It was then incubated at 35ºC for 24 hours. All bacteria that produced a red colony with a metallic (golden) sheen in the incubation period were considered members of the coliform group. The total numbers of colonies in the culture medium were determined. The total number of coliform bacteria in each of the colony was counted separately by an optical magnifying glass. The unit was expressed in TTC/100mL.

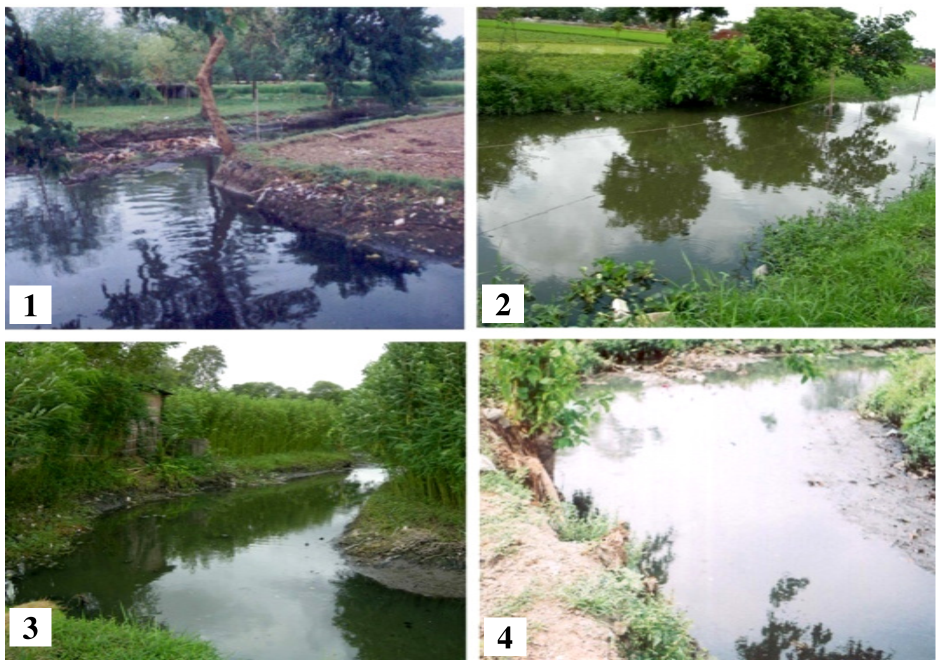
The following equation was used to calculate the density of coliform bacteria: (Total) coliform colonies/100mL = coliform colonies counted x 100 /mL Sample filtered.

**Statistical Analysis:** The sample mean and standard deviation (SD) for each value was calculated. Pearson correlation analysis was used to find out the relationships among physical, chemical and biological parameters during all periods investigated.



(A)

(B)



(C)

**Figure-1**: Photographs showing seasonal changes at (A) Spot-I in 1) Summer, 2) Post monsoon, 3) Monsoon, and 4) Winter; (B) Spot-II in 1) Summer, 2) Post monsoon, 3) Monsoon and 4) Winter; (C) Spot-III in 1) Summer, 2) Post monsoon, 3) Monsoon and 4) Winter.

## Results and discussion

The effect of the industrial effluents and seasonal variations on physical (air and water temperature, transparency of water, average depth of water), chemical (pH, free $CO_2$ and $HCO_3$ alkalinity, total hardness, calcium hardness, magnesium hardness) and biological (phytoplankton and zooplankton) parameters is summarized in Table-1.

**Water and Air Temperature (°C):** Temperature measurement is considered as one of the most important physical parameters for assessing water quality since it affects chemical and biological indicators of surface water. Temperatures of air and water varied over a range of 14.5-38ºC and 13.5- 35ºC; 13.5-37ºC and 12.5-34ºC; and 12-36.5ºC and 11-33ºC at spot-I, spot-II, and spot-III, respectively. The water temperature followed the seasonal pattern (minimum in winter and maximum in summer) and fluctuated according to the prevailing atmospheric temperature. The results are in line with Karne and Kulkarni[10] and also with the findings of other studies[11,12]. From mid-June the water level began to rise rapidly and reached its maximum in August to September. Subsequently, the water level decreased rapidly from October and the level appeared to have reached its seasonal minimum in summer. The water temperature remains higher during summer due to greater solar radiation, low water level, low velocity, and clear atmosphere. On the other hand, the minimum water temperature in the rainy and winter months can be explained on the basis of frequent clouds, high percentage of humidity, high current velocity and high water level. Water temperature was found to be positively correlated with air temperature of the studied biotope which was statistically significant at 0.01 level. Temperature was also found to be positively correlated with transparency, pH, $HCO_3$, $NO_3$, BOD, COD, phytoplankton, zooplankton at 0.01 level and with transparency, BOD at 0.05 level. Temperature was negatively correlated with $CO_2$, calcium hardness, DO at 0.01 level and with average depth, rH2 at 0.05 level (Table 2-7).The average normal temperature of water bodies can range from 0°C in winter to above 30°C in summer. However, one of the factors that affect water temperature is the temperature of the air above the water. If the temperature of air increases by 1°C, surface water temperatures will also likely to increase about 0.6–0.8°C[13].

**Depth of Water (cm):** Another parameter which is important for assessing aquatic ecosystems functional stability is the depth of water[14,15]. The average water depths ranging from 65-160cm, 121-421cm, 100-320cm at spot-I, spot-II and spot-III, respectively. The range of seasonal variations were 85-127cm, 210-283cm, 150-217cm in winter; 65-100cm, 121-180cm, 100-143cm in summer and 135-160cm, 290-421cm, 260-320cm in monsoon at spot-I, spot-II and spot-III, respectively. The minimum depth of water was recorded during summer due to higher rate of evaporation and less rainfall whereas the depth reached its maximum during monsoon season owing to heavy rainfall. A similar finding was observed by Sultana and Khondker[11]. Average depth was found to be positively correlated with magnesium-hardness, BOD at 0.01 level and with total-hardness, $PO_4$, $NO_3$, COD at 0.05 level. It was negatively correlated with transparency, $PO_4$, phytoplankton, zooplankton at 0.01 level and with air and water temperature at 0.05 level.

**Water Transparency (cm):** Water transparency is often used as a water quality indicator. Since water is transparent and colorless, it transmits light and enables aquatic plants to photosynthesis. A decrease in water transparency indicates high sediment pollution and increased algae growth. The range of transparency values were found to varying from 5.5-16cm, 12-45cm, 7-29.5cm at spot-I, spot-II and spot-III, respectively. At spot-I and spot-III, the transparency values were minimum during monsoon and maximum during summer. The minimum transparency during monsoon reflecting excess sediment (soil material) or other suspended material, like algae, in water. Rainwater might bring in a lot of dissolved, undissolved inorganic and organic materials that made the water turbid. The maximum transparency during summer is due to less rainfall and minimum silt deposition. These observations are in agreement with the findings of previous studies[12, 16]. However, the transparency readings have been consistently low at spot-I indicating poor water quality. On the other hand, the maximum value of transparency was observed during winter and minimum during the monsoon at spot-II because it is a pond which receives wastes only during the rainy season. Transparency showed a positive correlation with air and water temperature, phytoplankton, zooplankton at 0.01 level and also with air and water temperature, pH at 0.05 level. It was negatively correlated with average depth, calcium hardness at 0.01 level and with $CO_2$, magnesium hardness at 0.05 level (Table-2-7).

**Hydrogen Ion Concentration (pH):** The hydrogen ion concentration (pH) influences the normal physiological function of aquatic organisms such as the exchange of ions with the water and respiration. The range of pH values at spot-I, spot-II and spot-III were found to varying from 6-7.8; 6.5-8.1; and 6-7.8, respectively. The pH value was minimum in winter while maximum in summer at spot-I and spot-II. Similar seasonal variations were observed by other previous studies[10,17]. Higher pH in summer may be due to the increased photosynthetic assimilation of dissolved inorganic carbon resulting in an increase of pH[18]. A relatively wide range of pH (6.0-9.0) is optimum for the normal physiological processes of most aquatic biota. However, if the pH level goes too low or too high, there will have some lethal effects on aquatic organisms like reproduction and growths will diminish[19], mortality rates will be higher. Since the pH of a body of water may be affected by many factors like aquatic plant photosynthesis, high water temperatures and super saturation of dissolved gasses etc., therefore, high mortality rate due to high pH caused by the above mentioned factors make it difficult to correlate with pH alone. pH was positively correlated with air temperature, water temperature, $HCO_3$, $PO_4$, $NO_3$, BOD, phytoplankton at 0.01 level and with water temperature, transparency, COD at 0.05 level. It was negatively correlated with total hardness, magnesium hardness, Eh, $CO_2$ at 0.01 level and with rH2 at 0.05 level (Table-2-7).

**Free Carbon Dioxide (mg/L):** The presence of carbon dioxide ($CO_2$) and bicarbonates in water is important for the growth of aquatic plant. Carbon dioxide in a water system is generally derived from various sources e.g. atmosphere, respiration of plants and animals, bacterial decomposition of organic matter. However, the $CO_2$, pH and alkalinity are directly related to each other, since the pH depends upon the free $CO_2$ and bicarbonate level. Free $CO_2$ values were ranging from 130-230mg/L, 31-80 mg/L, and 128-253 mg/L at spot-I, spot-II, and spot-III, respectively. Maximum free $CO_2$ was recorded in winter at all spots and minimum in summer except spot-III. Elevated levels of $CO_2$ indicate a high rate of photosynthesis and respiration in winter[20,21]. Free $CO_2$ showed a positive correlation with magnesium-hardness, Eh at 0.01 level. It showed negative correlation with air temperature, water temperature, pH, $HCO_3$, $NO_3$, BOD, and COD at 0.01 level and with transparency, calcium hardness, and phytoplankton at 0.05 level.

**Bicarbonate Alkalinity (mg/L):** Alkalinity which is another water quality parameter refers to the buffering capacity of water. Hydroxides, carbonates, and bicarbonates; in addition to other materials, are the most important contributors of alkalinity. The bicarbonate alkalinity values of the water bodies fluctuated between 40-85mg/L at spot-I, 110-195mg/L at spot-II and 35-116mg/L at spot-III. During the summer, the value of alkalinity was maximum while minimum during the winter. High bicarbonate content during summer season might be due to decrease in water level by evaporation; additionally, decomposition processes coupled with the mixing of sewage and industrial effluents which produce free $CO_2$[12]. Most of the bicarbonate which become carbonic acid when the pH falls below 4.3 can be toxic. However, carbonate alkalinity was not detected from any of the studied spot. The bicarbonate alkalinity was found to be positively correlated with air temperature and water temperature, pH, $NO_3$, BOD, COD, phytoplankton, zooplankton at 0.01 level and negatively correlated with $CO_2$, Eh at 0.01 level (Table-2-7).

**Total Hardness (mg/L):** Calcium and magnesium constitute the total hardness of water. Total hardness values were found to range from 260-460mg/L at spot-I, 168-380mg/L at spot-II and 280-480mg/L at spot-III (Table-1). At spot-I, the lowest value was observed during summer while the highest was recorded in monsoon season which are supported by other studies[22,23]. At spot-II, the minimum hardness was recorded during winter and the maximum was observed during summer season. The results obtained are in agreement with Hujare[12] and also with other previous studies[24,17] that have recorded the maximum total hardness in summer and minimum in winter. At spot-III, minimum value was recorded in monsoon and maximum value was in winter. Results of Rajput et al.[20], and Pandhe et al.[25] are similar to the present study who have shown that the maximum values of hardness were observed in winter. The high values of hardness may be due to low water level and high rate of decomposition and evaporation; therefore, concentrating calcium and magnesium salts[26]. In correlation analysis, total hardness had exhibited a positive correlation with calcium hardness, magnesium hardness, $NO_3$, BOD, COD, zooplankton at 0.01 level and with average depth at 0.05 level. It showed negative correlation with pH at 0.01 level and with phytoplankton at 0.05 level. There is a positive correlation between calcium hardness and total hardness. This finding is also supported with the work of Awasthi and Tiwari[16].

The monthly values for water calcium (Ca) hardness found to vary from 136.5-241.5mg/L at spot-I, 88.2-273mg/L at spot-II and 115.5-273mg/L at spot-III. The highest amount of Ca hardness was recorded in winter at all spots and minimum in summer except spot-I. Similar observations were reported by Prasad and Singh[21] and Devi and Anandhi[23]. The level was low in September probably due to its utilization by the biotic community[23]. At spot-I, the minimum value was recorded in monsoon and maximum in winter which was also observed by Homyra and Naz[27]. Ca hardness was positively correlated with total hardness at 0.01 level and negatively correlated with magnesium hardness, $NO_3$, COD, zooplankton at 0.01 level; and with $CO_2$, phytoplankton at 0.05 level. The values of magnesium hardness were found to vary from 11.96-71.25mg/L at spot-I, 5.37-42.9mg/L at spot-II and 16.06-71.5mg/L at spot-III. The maximum value of Ca hardness was recorded in winter at all spots and minimum in summer except spot-I The maximum amount of Mg hardness was observed during monsoon and minimum in summer at spot-I. Homyra and Naz[27] also noticed the same phenomena. The maximum value in monsoon is due to discharge of small scale industrial effluents. At spot-II, maximum value was recorded in summer and minimum in monsoon. These findings agree with other previous studies[23,24]. At spot-III, both the higher and lower values were recorded in summer. In the present study, periodicity of calcium and magnesium hardness did not show any fixed pattern. An inverse relationship was present between Ca and Mg hardness. Similar observations were also made by Gautam[8] while working in river Ganga. Magnesium hardness was found to be positively correlated with average depth, $CO_2$, total hardness at 0.01 level. It was negatively correlated with pH, calcium hardness at 0.01 level and with transparency at 0.05 level.

**Phosphate (mg/L):** Although all aquatic organisms require phosphorous as an essential nutrient, excess can be considered to be a pollutant. Phosphate content varied from 0.7-1.48mg/L and 0.72-1.58mg/L. The concentration of phosphate was highest in monsoon and lowest in summer at spot-I and spot-III, respectively. The rain water during the monsoon season brings phosphate from the surrounding area resulted in a high level of phosphate. The maximum amount of phosphate was observed at spot-III because of the discharge of contaminated municipal sewage containing decayed organic matter and effluent waste from many kinds of industries. In the present study, the content of phosphate measured follows the similar seasonal trend reported by Hujare[12], Mruthunjaya and Hosmani[22], Awasthi and Tiwari[16], Homyra and Naz[27] and Gautam[8]. However, opposite seasonal variation was observed at spot-II (ranged from 0.09-0.16mg/L) where minimum value was recorded in monsoon and maximum in summer. Similar seasonal trend was observed by Garg et al.[28]. In correlation analysis, phosphate showed a positive correlation with transparency, pH, and phytoplankton at 0.01 level and with average depth, $NO_3$, phytoplankton at 0.05 level. It was negatively correlated with average depth, $NO_3$ at 0.01 level.

**Nitrate (mg/L):** Bacteria which break down ammonia ($NH_3$) first into nitrite and subsequently to nitrate, the less toxic form is required for aquatic biota in order to synthesize amino acids and proteins. The values of water nitrate were found to vary from 0.24-0.98mg/L, 0.016-0.052mg/L and 0.24-0.98mg/L at spot-I, spot-II and spot-III, respectively. Higher concentrations of nitrates were reported in monsoon and low levels in winter at spot-I and spot-III. Similar seasonal pattern was also observed by other workers[28,12]. Nitrate was found to be positively correlated with air temperature, water temperature, pH, $HCO_3$, BOD, COD at 0.01 level and with average depth, $PO_4$ at 0.05 level. It was negatively correlated with $CO_2$ at 0.01 level and calcium hardness, $PO_4$ at 0.05 level.

**Dissolved Oxygen (mg/L):** Dissolved oxygen (DO) which reflects the physical and biological processes in aquatic bodies and health of an aquatic ecosystem. The values of DO were found to be in anoxic condition at spot-I and spot-III. Only at spot-II, DO value was found to vary from 1.05-2.16 mg/L. Minimum DO was observed during monsoon and maximum during the winter. These results are in agreement with the findings of other previous studies[17,20,21,23].

Generally, low dissolved oxygen concentration is associated with contamination of water by organic matter and sometimes oxygen totally disappears from water giving rise to a condition of anoxia. However, the concentration of DO can also be affected by water temperature and BOD. The solubility of oxygen increases with the decrease of water temperature and solubility of oxygen is low at higher temperature. DO was found to be positively correlated with percentage of saturation of oxygen at 0.01 level and negatively correlated with air temperature, water temperature, BOD, COD at 0.01 level.

**Saturation of Oxygen (%):** Percentage of saturation of oxygen in water of the spot-II ranged from 13-23%. The lowest value of percentage of saturation of oxygen was observed in monsoon and highest in winter. These results are in agreement with Homyra and Naz[27], who have recorded minimum value in winter season and maximum during the monsoon season. Percentage of saturation of oxygen was found to be positively correlated with DO at 0.01 level and transparency at 0.05 level. It was negatively correlated with BOD, COD at 0.01 level (Table-3, 6).

**Oxidation-Reduction Potential(mv):** Oxidation-reduction potential(mv) value was found to vary from 0.25-0.47 mv at spot-II. The lowest value was recorded in summer and highest in winter. The value of oxidation-reduction index found to vary from 14.40-29.13 throughout the period of study. The minimum value of oxidation-reduction potential/index was recorded in monsoon and maximum in winter. The presence of higher amount of organic matter may result in lower values of Eh and rH2 in water. If the ecosystem has organic material, the concentration of reduced form is higher which results in lower Eh and rH2 values. With respect to oxidation-reduction characteristics, pH was always observed neutral to alkaline. Oxidation-reduction potential was found to be positively correlated with $CO_2$ at 0.01 level and rH2 at 0.05 level. It was negatively correlated with pH, $HCO_3$ at 0.01 level (Table-3, 6). Oxidation-reduction index was found to be positively correlated with Eh at 0.01 level (Table-4, 7) and negatively correlated with water temperature, pH at 0.01 level.

**Biochemical Oxygen Demand(mg/L):** Biochemical oxygen demand ($BOD_5$) indicates the amount of organic matter present on the water systems. In the present study, the $BOD_5$ value varied from 11.94-42.44mg/L at spot-I, 0.42-1.05mg/L at spot-II and 19.89-39.79mg/L at spot-III. The minimum BOD was recorded in winter and maximum in monsoon at spot-I and spot-III. Similar findings were also documented by Chatterjee and Raziuddin[29]. High concentration of dissolved and suspended solids during monsoon season resulted in an increased the level of $BOD_5$[30]. Lower $BOD_5$ values in winter indicated poor biological activity of microorganisms at lower temperature. Only at spot-II, maximum value was recorded in summer and minimum in winter. The results of the present study are supported by other previous studies[10,31]. The $BOD_5$ values increased during summer season due to increased biological activities at elevated temperature, whereas the lowest $BOD_5$ in winter indicated lower biological activity[26].

An inverse correlation between dissolved oxygen and $BOD_5$ in a polluted stream was observed in the present study, where the decrease in DO value resulted in an increased $BOD_5$ value. Similar observation was reported by Sivakumari[24]. BOD was found to be positively correlated with air temperature, water temperature, average depth, pH, $HCO_3$, $NO_3$, COD at 0.01 level and with air temperature at 0.05 level. It was negatively correlated with $CO_2$, DO, percentage of saturation of oxygen at 0.01 level and with total hardness at 0.05 level (Table-2-7). During the study period, COD found to follow a trend almost similar to those of $BOD_5$. COD values were found to vary from 920-1440mg/L, 76-204mg/L, 920-1480mg/L at spot-I, spot-II and spot-III, respectively. The minimum COD was recorded in winter and maximum in monsoon at Spot-I and Spot-III. Only at spot-II, maximum value was recorded in summer and minimum in winter. COD was found to be positively correlated with air and water temperature, $HCO_3$, $NO_3$, BOD at 0.01 level and with average depth, pH at 0.05 level. It showed negative correlation with $CO_2$, DO, percentage of saturation of oxygen at 0.01 level and with total hardness, calcium hardness at 0.05 level (Table-2-7).

**Chemical Oxygen Demand (mg/L):** Another important parameter for measuring water quality is the chemical oxygen demand (COD), which measures the oxygen equivalent of the organic matter. Potassium dichromate, a strong chemical oxidant in sulphuric acid solution was used to oxidize organic matter[32].

The minimum COD was recorded in winter and maximum in monsoon at spot-I and spot-III. These results agree with the findings of Chowdhury et al.[33]. A heavy load of organic and inorganic pollution is usually observed when the COD value is high, and consequently, more oxygen is needed to oxidize under increased thermal conditions[34]. Only at spot-II, maximum COD was recorded in summer and minimum in winter. These findings are in line with other previous studies[10,24,23,31].

The higher COD values in summer may be due to the increase of biodegradable and non-biodegrade matter and lower depth in water body.

**Table-1:** Seasonal variation, Minimum and Maximum value, Mean and SD value of physical, chemical and biological parameters of water in the spots from November to May (2014-2018).

| | Winter (Nov-Feb) (2013-17) | Summer (Mar-Jun) (2014-17) | Monsoon (Jul-Oct) (2014-16) | Min and Max value | Mean ($\overline{x}$) | SD (σ) |
|---|---|---|---|---|---|---|
| Air temperature (°C) | | | | | | |
| Spot-I | 14.5-26.0 | 28.0-38.0 | 23.5-30.0 | 14.5-38.0 | 26.36 | ±6.66 |
| Spot-II | 13.5-26.5 | 27.5-37.0 | 23.0-33.5 | 13.5-37.0 | 26.03 | ±6.45 |
| Spot-III | 12.0-26.0 | 26.5-36.5 | 23.0-33.0 | 12.0-36.5 | 25.17 | ±6.56 |
| Water temperature (°C) | | | | | | |
| Spot-I | 13.5-23.5 | 24.0-35.0 | 19.5-28.0 | 13.5-35.0 | 24.2 | ±5.63 |
| Spot-II | 12.5-25.0 | 23.5-34.0 | 19.5-31.0 | 12.5-34.0 | 23.55 | ±5.67 |
| Spot-III | 11.0-24.0 | 23.0-33.0 | 19.0-30.0 | 11.0-33.0 | 22.79 | ±5.54 |
| Average depth (cm) | | | | | | |
| Spot-I | 85-127 | 65-100 | 135-160 | 65-160 | 108.84 | ±29.28 |
| Spot-II | 210-283 | 121-180 | 290-421 | 121-421 | 241.37 | ±91.04 |
| Spot-III | 150-217 | 100-143 | 260-320 | 100-320 | 192.79 | ±72.77 |
| Transparency (cm) | | | | | | |
| Spot-I | 7-10 | 10-16 | 5.5-8 | 5.5-16.0 | 9.10 | ±2.6 |
| Spot-II | 20-45 | 30-42 | 12-19 | 12-45 | 25.66 | ±8.98 |
| Spot-III | 13-19 | 22-29.5 | 7-12 | 7.0-29.5 | 17.53 | ±6.66 |
| pH | | | | | | |
| Spot-I | 6.0-7.5 | 7.2-7.8 | 6.5-7.8 | 6.0-7.8 | 7.08 | ±0.54 |
| Spot-II | 6.5-7.7 | 6.6-8.1 | 7.2-7.9 | 6.5-8.1 | 7.52 | ±0.36 |
| Spot-III | 6.0-7.4 | 6.9-7.7 | 6.4-7.8 | 6.0-7.8 | 6.99 | ±0.57 |
| Free $CO_2$ (mg/L) | | | | | | |
| Spot-I | 145-230 | 130-170 | 140-190 | 130-230 | 169.65 | ±25.20 |
| Spot-II | 33-80 | 31-73 | 33-65 | 31-80 | 49.84 | ±13.22 |
| Spot-III | 180-253 | 140-195 | 128-210 | 128-253 | 186.02 | ±27.55 |
| $HCO_3$ (mg/L) | | | | | | |
| Spot-I | 40-75 | 55-85 | 55-75 | 40-85 | 61.51 | ±11.42 |
| Spot-II | 110-175 | 130-195 | 140-185 | 110-195 | 161.05 | ±19.72 |
| Spot-III | 35-60 | 50-116 | 50-78 | 35-116 | 60.23 | ±13.98 |
| Total-hardness (mg/L) | | | | | | |
| Spot-I | 270-440 | 260-400 | 264-460 | 160-460 | 350.33 | ±47.31 |
| Spot-II | 188-380 | 220-300 | 190-340 | 168-380 | 275.30 | ±47.52 |
| Spot-III | 280-480 | 310-440 | 280-392 | 280-480 | 363.58 | ±50.07 |
| Ca- hardness (mg/L) | | | | | | |
| Spot-I | 147.0-241.5 | 147.0-231.0 | 136.5-231.0 | 136.5-241.5 | 176.30 | ±27.16 |
| Spot-II | 102.9-273.0 | 88.2-210.0 | 105.0-210.0 | 88.2-273 | 170.98 | ±37.66 |
| Spot-III | 147.0-273.0 | 115.5-256.2 | 147.0-241.5 | 115.5-273 | 190.80 | ±47.70 |

| | Winter (Nov-Feb) (2013-17) | Summer (Mar-Jun) (2014-17) | Monsoon (Jul-Oct) (2014-16) | Min and Max value | Mean $(\bar{x})$ | SD (σ) |
|---|---|---|---|---|---|---|
| Mg- hardness (mg/L) | | | | | | |
| Spot-I | 21.59-61.73 | 11.95-59.17 | 31.11-71.25 | 11.96-71.25 | 42.46 | ±12.92 |
| Spot-II | 15.49-36.84 | 13.35-42.9 | 5.37-36.84 | 5.37-42.90 | 25.45 | ±7.46 |
| Spot-III | 16.35-65.88 | 16.06-71.49 | 32.09-51.73 | 16.06-71.49 | 42.16 | ±12.57 |
| $PO_4$-P (mg/L) | | | | | | |
| Spot-I | 0.74-1.16 | 0.70-1.2 | 0.76-1.48 | 0.7-1.48 | 0.99 | ±0.19 |
| Spot-II | 0.01-0.14 | 0.13-0.16 | 0.09-0.12 | 0.09-0.16 | 0.11 | ±0.018 |
| Spot-III | 0.88-1.4 | 0.72-1.38 | 0.74-1.58 | 0.72-1.58 | 1.08 | ±0.22 |
| $NO_3$-N (mg/L) | | | | | | |
| Spot-I | 0.24-0.62 | 0.62-0.8 | 0.72-0.98 | 0.24-0.98 | 0.56 | ±0.18 |
| Spot-II | 0.016-0.052 | 0.022-0.05 | 0.022-0.05 | 0.016-0.052 | 0.03 | ±0.01 |
| Spot-III | 0.24-0.62 | 0.52-0.8 | 0.78-0.98 | 0.24-0.98 | 0.65 | ±0.17 |
| DO (mg/L) | | | | | | |
| Spot-I | Anoxia | Anoxia | Anoxia | Anoxia | Anoxia | Anoxia |
| Spot-II | 1.26-2.16 | 1.19-1.75 | 1.05-1.47 | 1.04-2.16 | 1.49 | ±0.29 |
| Spot-III | Anoxia | Anoxia | Anoxia | Anoxia | Anoxia | Anoxia |
| % of saturation | | | | | | |
| Spot-II | 14-23 | 15-21 | 13-19 | 13-23 | 17.70 | ±2.60 |
| Eh (mv) | | | | | | |
| Spot-II | 0.3-0.47 | 0.25-0.46 | 0.28-0.39 | 0.25-0.47 | 0.34 | ±0.05 |
| $rH_2$ | | | | | | |
| Spot-II | 25.68-29.13 | 24.99-28.92 | 14.4-27.34 | 14.4-29.13 | 26.39 | ±2.12 |
| $BOD_5$(mg/L) | | | | | | |
| Spot-I | 11.94-27.85 | 22.55-41.11 | 21.22-42.44 | 11.94-42.44 | 28.25 | ±6.97 |
| Spot-II | 0.42-0.84 | 0.42-1.05 | 0.63-0.98 | 0.42-1.05 | 0.71 | ±0.17 |
| Spot-III | 19.89-27.85 | 22.55-34.48 | 25.2-39.79 | 19.89-39.79 | 27.39 | ±4.57 |
| COD (mg/L) | | | | | | |
| Spot-I | 920-1360 | 1040-1360 | 1040-1320 | 920-1440 | 1142.33 | ±108.43 |
| Spot-II | 76-196 | 76-204 | 88-200 | 76-204 | 132.84 | ±37.07 |
| Spot-III | 920-1240 | 1000-1280 | 1000-180 | 920-1480 | 1126.51 | ±120.93 |
| Phytoplankton | | | | | | |
| Spot-I | 5850-12150 | 14100-23150 | 4500-9600 | 4500-23100 | 11972.1 | ±5622.52 |
| Spot-II | 8700-14550 | 16350-27600 | 6150-14400 | 6150-27600 | 14065.1 | ±6051.37 |
| Spot-III | 6450-10350 | 10500-19650 | 3450-7200 | 3450-19650 | 9770.93 | ±4861.72 |
| Zooplankton | | | | | | |
| Spot-I | 10501-3000 | 1650-4500 | 600-3450 | 600-4500 | 2347.67 | ±1210.62 |
| Spot-II | 1500-3750 | 2550-6000 | 750-3900 | 750-6000 | 3087.21 | ±1479.23 |
| Spot-III | 750-2400 | 900-4200 | 450-2400 | 450-4200 | 1646.51 | ±1010.21 |

**Table-2:** Relationship between physical, chemical and biological parameters in the spot-I during the period of study from November to May (2014-2018).

| Water Variables | Positive Significant | | Significant | Negative Significant | | Non Significant |
|---|---|---|---|---|---|---|
| | 0.01 level | 0.05 level | | 0.01 level | 0.05 level | |
| AT | WT, Tra, pH, $HCO_3$, $NO_3$, BOD, Phy, Zoo. | COD | Ca-H, $PO_4$. | $CO_2$, | AD | TH, MgH. |
| WT | AT, Tra, pH, $HCO_3$,$NO_3$, BOD, Phy, Zoo. | COD | CaH, $PO_4$. | $CO_2$, | AD | TH, MgH. |
| AD | MgH. | TH. | $CO_2$, $HCO_3$, $PO_4$, COD, $NO_3$, | Tra, Phy, Zoo, | AT, WT. | pH, CaH, BOD. |
| Tra | AT, WT, Phy, Zoo. | pH, | $HCO_3$, CaH, $NO_3$, BOD, COD. | AD | $CO_2$, MgH. | TH, $PO_4$, |
| pH | AT, WT, $HCO_3$, $PO_4$, $NO_3$, BOD, Phy. | Trans | CaH, COD, Zoo. | TH, MgH, $CO_2$. | | AD |
| $CO_2$ | MgH, | | AD, TH. | AT, WT, pH $HCO_3$, $NO_3$, BOD. | Tra, CaH, Phy. | $PO_4$,COD, Zoo. |
| $HCO_3$ | AT, WT, pH, $NO_3$, BOD, | | AD, Tra, CaH $PO_4$, COD, Phy, Zoo. | $CO_2$. | | TH, MgH. |
| TH | MgH. | AD. | $CO_2$, CaH. | pH | Phy | AT, WT, Tra, $HCO_3$, $PO_4$ ,$NO_3$ BOD, COD, Zoo. |
| CaH | | | AT, WT, Tra, pH, $HCO_3$, TH, $NO_3$, Phy, Zoo. | MgH, | $CO_2$ , | AD, $PO_4$, BOD, COD. |
| MgH | AD, $CO_2$, TH. | | | pH, CaH, Phy | Tra, Zoo | AT, WT, $HCO_3$, $PO_4$, $NO_3$, BOD, COD |
| $PO_4$ | pH, | $NO_3$, | AT, WT, AD, $HCO_3$, BOD. | | | Tra, $CO_2$, TH CaH, MgH, COD, Phy, Zoo. |
| $NO_3$ | AT, WT, pH, $HCO_3$, BOD, COD. | $PO_4$, | AD, Tra, CaH, Phy, Zoo. | $CO_2$, | | TH, MgH. |
| BOD | AT, WT, pH, $HCO_3$, $NO_3$, COD. | | Tra, $PO_4$, Phy, Zoo. | $CO_2$, | | AD, T-H, Ca-H, Mg-H |
| COD | $NO_3$, BOD. | AT, WT | A.Dp, Trans, pH, $HCO_3$, Phy, Zoo. | | | $CO_2$, TH, CaH, MgH, $PO_4$. |
| Phy | AT, WT, Tra, pH, Zoo. | | $HCO_3$,CaH, $NO_3$ ,BOD, COD | A.Dp, MgH. | $CO_2$, TH, | $PO_4$ |
| Zoo | AT, WT, Tra, Phy. | | pH, $HCO_3$, CaH. | AD, $NO_3$, BOD, COD | MgH. | $CO_2$, TH, $PO_4$. |

AT=Air Temperature, WT=Water Temperature, AD=Average Depth, Tra=Transparency, pH=Hydrogen-Ion Concentration, $CO_2$=Free Carbon dioxide, $HCO_3$=Bi-Carbonate Alkalinity, TH=Total-Hardness, CaH=Calcium Hardness, MgH=Magnesium Hardness, $PO_4$=Phosphate, $NO_3$=Nitrate, BOD= Biochemical Oxygen Demand, COD=Chemical Oxygen Demand, Phy=Phytoplankton, Zoo=Zooplankton.

**Table-3:** Relationship between physical, chemical and biological parameters in the spot-II during the period of study from November to May (2014-2018).

| Water Variables | Positive Significant | | Significant | Negative Significant | | Non Significant |
|---|---|---|---|---|---|---|
| | 0.01 level | 0.05 level | | 0.01 level | 0.05 level | |
| AT | WT, $HCO_3$ BOD, COD, Phy. | Tra, Zoo. | pH, $NO_3$ | DO, | | AD, $CO_2$, TH, CaH, MgH, $PO_4$, %, Eh, $rH_2$ |
| WT | WT, $HCO_3$ BOD, COD, Phy. | Tra, Zoo. | pH, $NO_3$ | DO, | $rH_2$ | AD, $CO_2$, TH, CaH, MgH, $PO_4$, %, Eh. |
| AD | | | pH, $NO_3$, TH, CaH. | Tra, $PO_4$, Phy, Zoo. | | AT, WT, $CO_2$, $HCO_3$, MgH, DO, %, Eh, $rH_2$, BOD, COD. |
| Tra | $PO_4$, Phy, Zoo. | AT, %. | WT, pH, $HCO_3$, TH, MgH, DO, $rH_2$, BOD. | AD | | $CO_2$, CaH, $NO_3$, Eh, COD. |
| pH | $HCO_3$ | WT | AT, AD, Tra, TH, CaH, MgH, %, BOD, Phy. | $CO_2$, Eh. | $rH_2$ | $PO_4$, $NO_3$, DO, COD, Zoo. |
| $CO_2$ | Eh | | $PO_4$, $NO_3$, $rH_2$, BOD, COD, Zoo. | pH, $HCO_3$. | | AT, WT, AD, Tra, TH, CaH, MgH, DO, %, Phy. |
| $HCO_3$ | AT, WT, pH, Phy. | | Tra, TH, CaH, MgH, BOD, COD, Zoo. | $CO_2$, Eh. | | AD, $PO_4$, $NO_3$, DO, %, $rH_2$, |
| TH | CaH, MgH. | | AD, Tra, pH, $HCO_3$, $NO_3$, DO, %. | | | AT, WT, $CO_2$, $PO_4$, Eh, $rH_2$, BOD, COD, Phy, Zoo |
| CaH | TH | | AD, pH, $HCO_3$, $NO_3$, DO. | | | AT, WT, Tra, $CO_2$, MgH, $PO_4$, %Eh, $rH_2$, BOD, COD, Phy, Zoo |
| MgH | TH | | Tra, pH, $HCO_3$, $NO_3$, DO, %, Phy, Zoo. | | | AT, WT, AD, $CO_2$, CaH, $PO_4$, Eh, $rH_2$, BOD, COD. |
| $PO_4$ | Tra | Phy | $CO_2$, DO, %Eh, $rH_2$, Zoo. | AD | $NO_3$ | AT, WT, pH, $HCO_3$, TH, CaH, MgH, BOD, COD. |
| $NO_3$ | | | AT, WT, AD, $CO_2$, TH, CaH, MgH, Eh, $rH_2$, BOD, COD, Zoo. | | $PO_4$ | Tra, pH, $HCO_3$, DO, %, Phy. |
| DO | % | | Tra, TH, CaH, MgH, $NO_3$, Eh, $rH_2$. | AT, WT, BOD,COD. | | AD, pH, $CO_2$,$HCO_3$, $NO_3$, Phy, Zoo. |
| % | | | pH, TH, MgH, $PO_4$, $rH_2$, Phy, Zoo. | BOD, COD. | | AT, WT, AD, $CO_2$, $HCO_3$, CaH, $NO_3$, Eh. |
| Eh | $CO_2$ | $rH_2$ | $PO_4$, $NO_3$, DO,BOD, COD, Zoo. | pH, $HCO_3$,. | | AT, WT, AD, Tra,TH, CaH, MgH, %, Phy. |
| $rH_2$ | | Eh | Tra, $CO_2$, $PO_4$, $NO_3$, DO, %, Phy, Zoo. | | WT, pH | AT, AD, $HCO_3$, TH, CaH, MgH, BOD, COD. |
| BOD | AT, WT, COD. | | Tra, pH, $CO_2$, $HCO_3$, $NO_3$ Eh, Phy, Zoo. | DO, % | | AD, TH, CaH, MgH, $PO_4$, $rH_2$. |
| COD | AT, WT, BOD. | | pH, $HCO_3$, $NO_3$, Eh, Phy, Zoo. | DO, % | $rH_2$ | AD, Tra, pH, TH, CaH, MgH, $PO_4$. |
| Phy | AT, WT, Tra, $HCO_3$, Zool. | $PO_4$ | pH, MgH, %, $rH_2$, BOD, COD. | | AD | $CO_2$, TH, CaH, $NO_3$, DO, Eh. |
| Zoo | Tra, Phy | AT, WT. | $CO_2$, $HCO_3$, MgH, $PO_4$, $NO_3$, %, Eh, $rH_2$, BOD, COD. | AD | | pH, TH, CaH, DO. |

AT=Air Temperature, WT=Water Temperature, AD=Average Depth, Tra=Transparency, pH=Hydrogen-Ion Concentration, $CO_2$=Free Carbon dioxide, $HCO_3$=Bicarbonate Alkalinity, TH=Total-Hardness, CaH=Calcium Hardness, MgH=Magnesium Hardness, $PO_4$=Phosphate, $NO_3$=Nitrate, DO=Dissolved Oxygen, %=Percentage of Saturation of Oxygen, Eh=Oxidation Reduction Potential, $rH_2$=Oxidation Reduction Index, BOD= Biochemical Oxygen Demand, COD=Chemical Oxygen Demand, Phy=Phytoplankton, Zoo=Zooplankton.

**Table-4:** Relationship between physical, chemical and biological parameters in the spot-III during the period of study from November to May (2014-2018).

| Water Variables | Positive Significant | | Significant | Negative Significant | | Non Significant |
|---|---|---|---|---|---|---|
| | 0.01 level | 0.05 level | | 0.01 level | 0.05 level | |
| AT | WT, pH, $HCO_3$, $NO_3$, Phy. | Tra, BOD. | MgH, COD, Zoo. | $CO_2$, CaH. | | AD, TH, $PO_4$. |
| WT | WT, pH, $HCO_3$, $NO_3$, Phy. | Tra, BOD. | MgH, COD, Zoo. | $CO_2$, CaH. | | AD, TH, $PO_4$. |
| AD | BOD | $PO_4$, $NO_3$, COD. | pH, TH, CaH. | Tra, Phy, Zoo. | | AT, WT, $CO_2$, $HCO_3$, MgH. |
| Tra | Phy, Zoo. | AT, WT. | pH, $HCO_3$, MgH. | AD, CaH. | . | $CO_2$, TH, $PO_4$, $NO_3$, BOD, COD. |
| pH | $HCO_3$, $NO_3$, BOD, Phy, Zoo. | COD | AD, Tra, MgH $PO_4$, Phy, Zoo. | | TH, CaH. | $CO_2$ |
| $CO_2$ | CaH, | | TH | AT, WT, pH $HCO_3$, $NO_3$, BOD, COD. | | AD, Tra, MgH, $PO_4$, Phy, Zoo. |
| $HCO_3$ | AT, WT, pH, $NO_3$, BOD, COD. | Zoo | Tra, $PO_4$, Phy. | $CO_2$. | | AD, TH, CaH, MgH. |
| TH | CaH, MgH. | | AD, $CO_2$.. | Zoo | pH, BOD, COD | AT, WT, Tra, $HCO_3$, $PO_4$ ,$NO_3$ Phy. |
| CaH | $CO_2$, TH. | | AD, $PO_4$. | AT, WT, Tra, MgH, Zoo. | pH, $NO_3$, COD, Phy. | $HCO_3$, BOD. |
| MgH | TH. | | AT, WT, Tra, pH, $NO_3$,Phy. | CaH | | AD, $CO_2$, $HCO_3$, $PO_4$, BOD, COD, Zoo. |
| $PO_4$ | | AD, $NO_3$, | pH, $HCO_3$, CaH, BOD. | | | AT, WT, Tra, $CO_2$, TH, MgH, COD, Phy, Zoo. |
| $NO_3$ | AT, WT, pH, $HCO_3$, BOD, COD. | AD, $PO_4$, | MgH | $CO_2$, | CaH | Tra, TH, Zoo. |
| BOD | AD, pH, $HCO_3$, $NO_3$, COD. | AT | WT, $PO_4$. | $CO_2$, | TH | Tra, Ca-H, Mg-H Phy, Zoo. |
| COD | $HCO_3$$NO_3$, BOD. | AD, pH, Zoo. | AT, WT. | $CO_2$ | TH, CaH. | Tra, MgH, $PO_4$, Phy. |
| Phy | AT, WT, Tra, Zoo. | | pH, $HCO_3$, $PO_4$., | AD | MgH | $CO_2$ TH CaH $NO_3$, BOD, COD. |
| Zoo | Tra, Phy. | $HCO_3$ | AT, WT, pH, COD. | AD, TH CaH | | $CO_2$, MgH, $PO_4$. $NO_3$, BOD. |

AT=Air Temperature, WT=Water Temperature, AD=Average Depth, Tra=Transparency, pH=Hydrogen-Ion Concentration, $CO_2$=Free Carbon dioxide, $HCO_3$=Bicarbonate Alkalinity, TH=Total-Hardness, CaH=Calcium Hardness, MgH=Magnesium Hardness, $PO_4$=Phosphate, $NO_3$=Nitrate, BOD= Biochemical Oxygen Demand, COD=Chemical Oxygen Demand, Phy=Phytoplankton, Zoo=Zooplankton.

**Table-5:** Correlation co-efficient (r) between different physico-chemical factors and plankton in the study spot-I during the period of study from November to May (2014-2018).

| | X1 | X2 | X3 | X4 | X5 | X6 | X7 | X8 | X9 | X10 | X11 | X12 | X13 | X14 | X15 | X16 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| X1 | 1 | 979** | -.347* | .559** | .697** | -.635** | .516** | -0.235 | 0.078 | -0.251 | 0.166 | .611** | .568** | .355* | .601** | .404** |
| X2 | | 1 | -.352 | .551** | .663** | -.602** | .481** | -0.195 | 0.088 | -0.219 | 0.129 | .560** | .525** | .326* | .600** | .416** |
| X3 | | | 1 | -.804** | -0.158 | 0.11 | 0.04 | .380* | -0.149 | .416** | 0.08 | 0.155 | -0.005 | 0.055 | -.882** | -.721** |
| X4 | | | | 1 | .339* | -.312* | 0.233 | -0.286 | 0.164 | -.340* | -0.138 | 0.077 | 0.164 | 0.01 | .855** | .692** |
| X5 | | | | | 1 | -.874** | .738** | -.436** | 0.129 | -.456** | .416** | .650** | .557** | 0.259 | .410** | 0.258 |
| X6 | | | | | | 1 | -.772** | 0.267 | -.368* | .428** | -0.301 | -.566** | -.507** | -0.138 | -.348* | -0.246 |
| X7 | | | | | | | 1 | -0.183 | 0.257 | -0.296 | 0.221 | .545** | .474** | 0.237 | 0.257 | 0.076 |
| X8 | | | | | | | | 1 | 0.067 | .859** | -0.205 | -0.212 | -0.119 | -0.181 | -.365* | -0.231 |
| X9 | | | | | | | | | 1 | -.453** | -0.194 | 0.043 | -0.007 | -0.061 | 0.165 | 0.209 |
| X10 | | | | | | | | | | 1 | -0.084 | -0.212 | -0.103 | -0.131 | -.410** | -.314* |
| X11 | | | | | | | | | | | 1 | .352* | 0.164 | -0.039 | -0.032 | -0.028 |
| X12 | | | | | | | | | | | | 1 | .612** | .416** | 0.107 | 0.204 |
| X13 | | | | | | | | | | | | | 1 | .750** | 0.2 | 0.21 |
| X14 | | | | | | | | | | | | | | 1 | 0.039 | 0.099 |
| X15 | | | | | | | | | | | | | | | 1 | .683** |
| X16 | | | | | | | | | | | | | | | | 1 |

X1= Air Temp.$^0$C, X2= Water Temp.$^0$C, X3= Av depth (cm), X4 =Transparency (cm), X5= pH, X6= Free $CO_2$ mg/l, X7= $HCO_3$ Alk.mg/l, X8= Total-hardness mg/l, X9= Ca-hardness mg/l, X10= Mg-hardness mg/l, X11= $PO_4$ mg/l, X12= $NO_3$ mg/l, X13= $BOD_5$ mg/l, X14= COD mg/l, X15= Phytoplankton, X16= Zooplankton. ** Correlation is significant at the 0.01 level (2-tailed). *Correlation is significant at the 0.05 level (2-tailed).

**Table-6:** Correlation co-efficient (r) between different physico-chemical factors and plankton in the study spot-II during the period of study from November to May (2014-2018).

| | X1 | X2 | X3 | X4 | X5 | X6 | X7 | X8 | X9 | X10 | X11 | X12 | X13 | X14 | X15 | X16 | X17 | X18 | X19 | X20 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| X1 | 1 | 973** | -0.252 | .345* | 0.277 | -0.066 | 446** | -0.167 | -0.205 | -0.006 | -0.021 | 0.051 | -.614** | -0.152 | -0.252 | -0.285 | .630** | 500** | 572** | .388* |
| X2 | | 1 | -0.193 | 0.282 | .327* | -0.092 | .421** | -0.191 | -0.218 | -0.029 | -0.039 | 0.083 | -.615** | -0.145 | -0.298 | -.329* | .638** | .503** | .514** | .337* |
| X3 | | | 1 | -.849** | 0.1 | -0.117 | -0.029 | 0.102 | 0.192 | -0.079 | -.524** | 0.067 | -0.104 | -0.237 | -0.071 | -0.137 | -0.035 | -0.071 | -.802** | -.724** |
| X4 | | | | 1 | 0.144 | -0.104 | 0.225 | 0.054 | -0.021 | 0.111 | .439** | -0.194 | 0.136 | .333* | -0.181 | 0.031 | 0.025 | -0.057 | .861** | .626** |
| X5 | | | | | 1 | -.818** | .745** | 0.217 | 0.073 | 0.248 | -0.261 | -0.016 | -0.078 | 0.121 | -.988** | -.329* | 0.064 | -0.236 | 0.254 | -0.037 |
| X6 | | | | | | 1 | -.706** | -0.236 | -0.229 | -0.085 | 0.233 | 0.082 | -0.005 | -0.091 | .822** | 0.217 | 0.015 | 0.29 | -0.205 | 0.046 |
| X7 | | | | | | | 1 | 0.12 | 0.026 | 0.154 | -0.19 | -0.13 | -0.247 | -0.021 | -.728** | -0.177 | 0.247 | 0.002 | .441** | 0.224 |
| X8 | | | | | | | | 1 | .766** | .611** | -0.112 | 0.051 | 0.13 | 0.042 | -0.225 | -0.125 | -0.181 | -0.163 | -0.066 | -0.139 |
| X9 | | | | | | | | | 1 | -0.041 | -0.054 | 0.049 | 0.091 | -0.017 | -0.077 | -0.11 | -0.129 | -0.096 | -0.189 | -0.292 |
| X10 | | | | | | | | | | 1 | -0.108 | 0.018 | 0.091 | 0.086 | -0.255 | -0.058 | -0.122 | -0.135 | 0.131 | 0.144 |
| X11 | | | | | | | | | | | 1 | -.344* | 0.191 | 0.191 | 0.235 | 0.094 | -0.191 | -0.063 | .306* | 0.231 |
| X12 | | | | | | | | | | | | 1 | -0.245 | -0.258 | 0.062 | 0.052 | 0.201 | 0.096 | -0.075 | 0.073 |
| X13 | | | | | | | | | | | | | 1 | .863** | 0.01 | 0.18 | -.852** | -.618** | -0.133 | -0.148 |
| X14 | | | | | | | | | | | | | | 1 | -0.187 | 0.045 | -.683** | -.476** | 0.15 | 0.003 |
| X15 | | | | | | | | | | | | | | | 1 | .320* | 0.008 | 0.272 | -0.271 | 0.043 |
| X16 | | | | | | | | | | | | | | | | 1 | -0.203 | -0.132 | 0.015 | 0.046 |
| X17 | | | | | | | | | | | | | | | | | 1 | .758** | 0.241 | 0.279 |
| X18 | | | | | | | | | | | | | | | | | | 1 | 0.052 | 0.186 |
| X19 | | | | | | | | | | | | | | | | | | | 1 | .733** |
| X20 | | | | | | | | | | | | | | | | | | | | 1 |

X1= Air Temp.$^0$C, X2= Water Temp.$^0$C, X3= Av depth (cm), X4 =Transparency (cm), X5= pH, X6= Free $CO_2$ mg/l, X7= $HCO_3$ Alk.mg/l, X8= Total-hardness mg/l, X9= Ca-hardness mg/l, X10= Mg-hardness mg/l, X11= $PO_4$ mg/l, X12= $NO_3$ mg/l, X13= DO mg/l, X14=% of sat of $O_2$, X15= Eh mv, X16= r $H_2$, X17= $BOD_5$ mg/l, X18= COD mg/l, X19= Phytoplankton, X20= Zooplankton. **Correlation is significant at the 0.01 level (2-tailed). *Correlation is significant at the 0.05 level (2-tailed).

**Table-7:** Correlation co-efficient (r) between different physico-chemical factors and plankton in the study spot-III during the period of study from November to May (2014-2018).

| | X1 | X2 | X3 | X4 | X5 | X6 | X7 | X8 | X9 | X10 | X11 | X12 | X13 | X14 | X15 | X16 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| X1 | 1 | .965** | -0.146 | .367* | .689** | -.535** | .556** | -0.255 | -.484** | 0.2 | -0.204 | .511** | .310* | 0.24 | .523** | 0.253 |
| X2 | | 1 | -0.118 | .339* | .683** | -.536** | .467** | -0.189 | -.486** | 0.266 | -0.25 | .501** | 0.268 | 0.215 | .479** | 0.239 |
| X3 | | | 1 | -.923** | 0.035 | -0.039 | -0.074 | 0.028 | 0.185 | -0.144 | .332* | .371* | .438** | .329* | -.812** | -.605** |
| X4 | | | | 1 | 0.219 | -0.189 | 0.256 | -0.127 | -.398** | 0.245 | -0.262 | -0.152 | -0.266 | -0.168 | .877** | .668** |
| X5 | | | | | 1 | -.778** | .676** | -.310* | -.387* | 0.058 | 0.161 | .694** | .489** | .375* | 0.293 | 0.252 |
| X6 | | | | | | 1 | -.521** | 0.28 | .477** | -0.17 | -0.015 | -.559** | -.499** | -.501** | -0.205 | -0.208 |
| X7 | | | | | | | 1 | -0.298 | -0.188 | -0.115 | 0.105 | .404** | .493** | .396** | 0.298 | .348* |
| X8 | | | | | | | | 1 | .446** | .559** | -0.045 | -0.253 | -.301* | -.324* | -0.098 | -.413** |
| X9 | | | | | | | | | 1 | -.493** | 0.276 | -.329* | -0.288 | -.328* | -.351* | -.404** |
| X10 | | | | | | | | | | 1 | -0.299 | 0.058 | -0.026 | -0.012 | 0.231 | -0.027 |
| X11 | | | | | | | | | | | 1 | .340* | 0.074 | -0.045 | -0.242 | -0.079 |
| X12 | | | | | | | | | | | | 1 | .593** | .487** | 0 | -0.041 |
| X13 | | | | | | | | | | | | | 1 | .831** | -0.198 | -0.058 |
| X14 | | | | | | | | | | | | | | 1 | -0.162 | 0.1 |
| X15 | | | | | | | | | | | | | | | 1 | .456** |
| X16 | | | | | | | | | | | | | | | | 1 |

X1= Air Temp.$^0$C, X2= Water Temp.$^0$C, X3= Av depth (cm), X4 =Transparency (cm), X5= pH, X6= Free $CO_2$ mg/l, X7= $HCO_3$ Alk.mg/l, X8= Total-hardness mg/l, X9= Ca-hardness mg/l, X10= Mg-hardness mg/l, X11= $PO_4$ mg/l, X12= $NO_3$ mg/l, X13= $BOD_5$ mg/l, X14= COD mg/l, X15= Phytoplankton, X16= Zooplankton. **Correlation is significant at the 0.01 level (2-tailed). *Correlation is significant at the 0.05 level (2-tailed).

**Biological Parameters: Phytoplankton and zooplankton (units/L):** Biological parameters have enormous importance from ecological point of view. All forms of natural and artificial water bodies contain variety of organisms, both plants and animals as their natural flora and fauna. Phytoplankton forms the main producers of an aquatic ecosystem which control the biological productivity. Abundance and diversity of plankton could be used as a measure of effect produced by pollutants in aquatic habitats. However, their diversity, population and abundance are related to certain environmental factors. Turbidity, transparency, current velocity and fluctuating water levels affect the algal abundance and diversity[35]. A close relationship between transparency, current velocity and algal population was noticed by Tiwari[36]. Phytoplankton and zooplankton abundance were found to vary from 4500-23100 units/L, 6150-27600 units/L, 3450-19650 units/L and 600-4500 units/L, 750-6000 units/L and 450-4200 units/L at spot-I, spot-II and spot-III, respectively. The maximum and minimum density of both phytoplankton and zooplankton were recorded during summer and monsoon season respectively which are also supported by Tiwari[36]. Higher pH besides the temperature during summer can be another factor for summer maxima of total phytoplankton density[12]. Phytoplankton communities are very sensitive to environmental changes and therefore, these species are used as indicators of water quality[37]. In the present study, phytoplankton was positively correlated with air and water temperature, transparency, pH, $HCO_3$, $PO_4$, zooplankton at 0.01 level and with $PO_4$ at 0.05 level. It was negatively correlated with average depth, magnesium-hardness at 0.01 level and with $CO_2$, total hardness, calcium hardness at 0.05 level. Zooplankton was found to be positively correlated with air and water temperature, transparency, phytoplankton at 0.01 level and with air and water temperature, $HCO_3$ at 0.05 level. It was negatively correlated related with average depth, total hardness, calcium hardness at 0.01 level and with magnesium hardness at 0.05 level (Table 2-7).

According to Rai and Hill[38], higher densities of total coliform bacteria portray the difference between clean and polluted water. Total coliforms are used as a reliable indicator to measure the degree of pollution[39]. The range of total coliform colonies was found to vary from 35,000-70,000 TCC/100 mL at spot-I, 1,000-1,700 TCC/100 mL at spot-II and 190,000-3,00,000 TCC/100 mL at spot-III (Table 8). Coliforms reached their maximum levels (3,00,000 TCC/100 mL) at spot-III in summer and minimum (1,000 TCC/100 mL) in winter at spot-II. The lowest densities were recorded in the winter and highest in summer at spot-I and spot-III. At spot-II, the lowest densities were found in winter and highest in monsoon. Mean and SD values were 160,000 TCC/100 mL, 1,000 TCC/100 mL, 730,000 TCC/100 mL and ±17559.42, ±351.19, ±55075.71 at the spot-I, spot-II and spot-III, respectively. Higher densities of total coliform bacteria were recorded in summer and minimum in winter at spot-I and spot-III. Seasonal fluctuations of bacterial population observed in the present study are also supported by Ahmed and Begum[40]. The coliform count was found maximum in monsoon indicated contamination from flushing of floor into the water body due to high rainfall. Increased coliform levels in water in the summer could be related to the higher concentration of organic matter, low water level and high temperature. Higher densities of total coliform bacteria were observed in summer and monsoon than in winter because bacteria can survive in warm condition[41].

## Conclusion

Environmental impact assessment and monitoring of environment especially the water and waste water at proper time intervals are important to trace the extent of pollution in water reservoirs, such as rivers, lakes, beels and pond. The present study demonstrates that spot-I and spot-III were the most polluted since these two spots are the constant dumping stations of industrial and municipal wastes. However, spot-II is a pond which receives effluent discharge only during monsoon due to the overflow of nearby spot-I. The $BOD_5$ and COD values indicate that spot-II is highly eutrophic and polluted. Therefore, even though industrial effluents enter this spot only during monsoon season, the quality, and quantity of industrial effluent is worse enough to modify its trophic status. Awareness building is one of the major fundamental needs for the industrialist that they should not dump off untreated effluent in the aquatic ecosystem. Environmental education program should be implemented properly at both formal and non-formal educational level by taking the help of educational boards, Government and Non-Government Organizations. The environmental laws should be implemented more effectively. The industries need to comply to the effluents standards before discharging into the surface drain, so that surface and groundwater contamination can be controlled. In developing countries like Bangladesh a special attention should be given to these aspects.

**Table-8:** Seasonal variation, Minimum and Maximum value, Mean and SD value of total coliform bacteria TCC (Total Coliform Colonies) /100 mL in the three study spots from July to May (2017-2018).

| Name of element | Monsoon (Jul-Oct) | Winter (Nov-Feb) | Summer (Mar-May) | Mini and Max value | Mean ($\bar{x}$) | SD (σ) |
|---|---|---|---|---|---|---|
| Total Coliform Colonies (TCC/100mL) | | | | | | |
| Spot-I | 55,000 | 35,000 | 70,000 | 35,000-70,000 | 160,000 | ±17559.42 |
| Spot-II | 1,700 | 1,000 | 1,400 | 1,000-1,700 | 1,000 | ±351.19 |
| Spot-III | 2,40,000 | 1,90,000 | 3,00000 | 190,000-300,000 | 730,000 | ±55075.71 |

## Acknowledgments

The experiments were conducted in the laboratory of Phycology and Limnology under the Department of Botany at Rajshahi University, Rajshahi, Bangladesh.

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