Chapter – IV

HYDROLOGICAL SET UP OF WETLANDS

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4.1 Introduction:

The hydrological set up is an integral part of evaluation of health of any wetland ecosystem. The hydrology employs the influences upon the diverse assemblage of biotic components, and consequently gives a picture of environmental suitability of water in order to maintain various life forms. The water quality (physico-chemical and bacteriological parameters) study of wetlands is also a part of its hydrology. The changes in the quality of water certainly affect the distribution and survival of different organisms in and around wetlands *(Sylas & Sankaran, 2014)*. Consideration of water quality is important in wetland habitat evaluation because a host of interacting physical and chemical factors can influence the levels of primary productivity and resultantly influence the trophic structure as well as the total biomass throughout the aquatic food web *(Wetzel, 1975)*. Therefore, the water quality monitoring is an ideal tool for establishing the baseline data for assessing the pollution status as well as for the conservation and management of wetlands, specifically where the water resource is not well managed as in case of Malda district.

4.2 General study on wetland hydrology and water quality of Malda district:

The database, that has been generated as the outcome of present research is capable to prove that the wetlands in Malda district have the potential to control flood and recharge the ground water for further usage throughout the year. In the present study, most of the wetlands, in Malda district are linked with the major rivers (Mahananda, Fulahar, Kalindri, Tangan) and act as a buffer for excess rain. By soaking excess water like sponge, the wetlands are potential to mitigate the frequent flood hazard in Malda district and replenish the ground water recharge. Generally, wetland has two types of water storage: 1. Static wetland water storage that remains almost same over long period; and 2. Dynamic wetland water storage, which is considered as the difference between pre-monsoon and monsoon water level. Out of the total depth of dynamic storage, few amounts gets evaporated, few amount is infiltrated below the ground to replenish the ground water and remaining amount is used for agricultural purpose for the land, surrounding the respective wetlands. In Malda district, no such data is found regarding evapotranspiration, but the neighbouring district of Dakshin Dinajpur records an average 0.9 meter of water to be evaporated during 16 years, from 2000 to 2016 *(Paul, 2017)*. Within the remaining portion of dynamic wetland water storage, 40 % is utilized for agricultural purpose, whereas, 60 % of water is infiltrated and recharge the ground water.

The wetlands of Malda district contain some specific physical, chemical and bacteriological components through analyzing which the water quality study is made. A general survey of the physico-chemical factors of wetland water such as water temperature, pH, turbidity, total dissolved solids, conductivity, total hardness, dissolved oxygen, chloride, fluoride, iron content etc. along with bacteriological components namely; total and fecal coliform have been made.

4.2.1 Description of physico-chemical and bacteriological parameters of wetland water:

The physico-chemical components of the wetland water are found significantly fluctuating with the seasonal variability in Malda district.

4.2.1.1 Physical parameters:

1. ***Water temperature*** is an essential physical parameter, which influences the physical, chemical and biological behavior of aquatic life. Temperature alters the dissolve oxygen concentration in water body, and make oxygen less available for the respiration and metabolic *(Tank & Chippa, 2013; Jalal & Sanalkumar, 2012)* and physiological activities of aquatic organisms including their life processes like feeding, reproduction, movements and distribution *(Rani et al., 2012)*. The standard temperature for sustaining the aquatic life varies between 28° C to 30° C *(Weldermeriam, 2013)*. The wetlands in Malda district record more or less identical water temperature with maximum during pre-monsoon, followed by monsoon and post-monsoon season. Wetland water temperature ranges from 20° C to 25° C during post monsoon to 29° C to 33° C during pre-monsoon period.
2. ***Turbidity*** is a key component of water quality measurement. Turbidity is the measure of light, scattered by suspended particles such as clay, silts, finely divided organic matter, plankton and other microscopic organisms *(Verma et al., 2012)* that are generally invisible to the naked eye. These suspended particles absorb more light and results in rising of the water temperature. In the wetlands of Malda district, the turbidity is recorded within the permissible range between 5 to 10 NTU (Nephelometric turbidity unit). Turbidity is observed to be highest during the monsoon, followed by post-monsoon

and pre-monsoon season. High turbidity in the wetlands of Malda district signifies the presence of large amount of suspended solids, which eventually results into eutrophication and thereby decreases the dissolved oxygen level.

4.2.1.2 Chemical parameters:

3. The ***pH*** (“Potential of hydrogen”/“Power of hydrogen”) measures the concentration of hydrogen ion in water *(Verma et al., 2012)*. At a given temperature the intensity of the acidic or basic character of water is indicated by its pH value. All the biochemical activities and retention of physico-chemical attributes of the water greatly depend on pH of the surrounding water *(Jalal and Sanalkumar, 2013)*. The pH measurements range on a scale from 0 to 14, with 7.0 considered to be neutral. Solutions with a pH value below 7.0 are considered acidic and above 7.0 are considered alkaline. In the present study, the pH value is found relatively lower in post-monsoon and slightly higher during pre-monsoon which maintains a consistent record above 7.0 almost in all the wetlands under study. The hard water may be detrimental to the vital biological process and can cause several aesthetic problems and hazards. The lower pH during the monsoon may be due to dilution of alkaline substances (household products). However, the pH level within the wetlands under study is restricted between the recommended range (6.5 – 8.5) for human use and it can be termed safe to the aquatic life as per BIS (2012) and APHA (2017).

4. ***Conductivity*** is a measure of ions. Conductivity estimates the total amount of dissolved solids in the wetland water *(Tank & Chippa, 2013)*. Electrical conductivity depends on the concentration and nature of the ionized substances dissolved in water, representing the total ion content *(Zacheus & Martikainen, 1997)*. The dissolved salts in association with solutions of most inorganic compounds such as alkalis, chlorides, sulfides and carbonate are relatively good conductors. The permissible range of conductivity is restricted to 400 µ.s. In the present study the conductivity of wetland water is consistently recorded to be higher during pre-monsoon and relatively lower in post-monsoon season but within the permissible range. Relatively high values of conductivity within wetlands of Malda district could be due to high ionic concentration, pollution status, trophic levels, presence of domestic effluents and other organic matter present in water.

5. Another component of water quality measurement is ***Total dissolved solids*** (TDS.), which signifies the inorganic pollution load in the wetland water. Its

concentration is the sum of cations (positively charged) and anions (negatively charged) in the water. It refers to the total amount of ions, including minerals, salts or metals, dissolved in a given volume of water (mg/L), and also referred to as parts per million (ppm). Being an indicator for rapid plankton growth and sewage contamination, TDS evaluates the fitness of wetland water. Further, the quantity of TDS determines the colour and electrical conductivity of the water body. In the study area, dissolved solid is found to be fluctuating markedly with the seasonal variation in almost all the wetlands with higher value during pre-monsoon, followed by monsoon and post-monsoon season. The wetlands, adjacent to urban area in Malda district records consistently high level of dissolved solids throughout the year.

6. ***Dissolved oxygen*** (DO) is regarded as one of the best indicators in order to assess the health of wetland and water body *(Edmondson, 1965)*. It is a measure of the amount of oxygen available for the biochemical activity in a given amount of water. It plays a key role in the waste-water treatment process and at the same time it has large effects on chemical and biological processes in wetland ecosystem. The concentration of dissolved oxygen is highly dependent on temperature, salinity and biological activity in the water column. Oxygen content is important for direct needs of many organisms and affects the solubility of many nutrients and therefore the periodicity of aquatic ecosystem *(Wetzel, 1983)*. The adequate presence of dissolved oxygen is necessary for aerobic biological activities and it indicates healthy aquatic life within the wetland system *(Maurya & Singh, 2016; Yadav & Yadav, 2017)*. In the present study, the wetlands record high amount of dissolved oxygen during monsoon and post-monsoon whereas, relatively lower amount has been recorded during pre-monsoon period, when the water level is low. The depletion of oxygen during pre-monsoon indicates the presence of high organic loads in the form of free floating macrophytes, which prevent light penetration into water, and results in the lower rate of photosynthesis by phytoplankton. Simultaneously high amount of dissolved oxygen in the wetlands under study, which is noticeable during monsoon and post-monsoon period, is possibly a contribution of brisk photosynthesis by submerged and floating aquatic plants.

7. ***Total hardness*** (TH) is a complex mixture of cations and anions *(Qureshimatva et al., 2015)*. Hardness is a measure of the capacity of water to precipitate soap. Soap is precipitated chiefly by calcium and magnesium ions, present in the surface and ground water mainly as carbonates and bicarbonates *(Tank & Chippa, 2013; Mandal, 2012)*. Therefore, total hardness can be equivalent to the total calcium and magnesium hardness,

expressed in milligrams per liter (mg/L). Some cations like iron, strontium, magnesium and anions, such as carbonates, bicarbonates, sulphate, chloride, nitrate and silicates contribute to hardness in the aquatic ecosystem. In the wetlands of Malda district, hardness is found to be fluctuating with seasonal variation, and records maximum during pre-monsoon, followed by monsoon and post-monsoon. Recorded hardness is within the permissible level (600 mg/L). The wetlands adjacent to the urban area in the entire district records high level of hardness round the year and is considered hard water (>100 mg/L), which is considered as pernicious as soft water for the human consumption.

8. ***Chloride*** is considered as one of the most important inorganic anion in water. The primary sources of chloride content in water body include wastewater from industries and municipalities, agricultural runoff, produced water from gas and oil wells etc. Chloride concentrations in freshwater is generally taken as an indicator of sewage pollution *(Wetzel, 1966)*. High chloride content in wetland water indicates the pollution of animal origin *(Munawar, 1970)*, through runoff load from peripheral area. In the present study, the chloride content is noted to be more or less same in almost all the water bodies of Malda district throughout the year. Maximum chloride concentration in wetland water is found during the post-monsoon season. Higher concentration of chloride may be attributed to increase the organic waste of human origin along with the runoff water.

9. ***Fluoride*** is an essential naturally occurring compound derived from fluorine. Fluoride is found negligible within the wetlands and somewhere it is recorded below detectable limit in Malda district.

10. In the present study, the ***iron*** and ***manganese*** are found to be fluctuating and somewhere almost negligible. The water bodies record maximum iron content during post-monsoon, followed by monsoon and pre-monsoon. Some of the wetlands under study represent iron content beyond the permissible limit (0.3 mg/L). The manganese content is almost below detectable limit throughout the entire study period in all the wetlands.

11. ***Arsenic*** is introduced into the wetland and water body through the dissolution of rocks, minerals and ores, from the industrial effluents, including mining wastes, and via atmospheric deposition *(IPCS, 1981; Hindmarsh & McCurdy, 1986)*. The main adverse effects reported to be associated with long-term ingestion of inorganic arsenic by humans are cancer, skin lesions, developmental effects, cardiovascular disease, neurotoxicity and diabetes *(IPCS, 2001)*. West-Bengal is one of the worst arsenic affected areas in the

world arsenic scenario. Malda district, especially the low land region *(Diara)* containing blocks namely English Bazar, Manikchak, Kaliachak 1, 2, 3 encounter immense health hazards from various types of skin manifestations and other arsenic toxicity such as Melanesia, keratosis, hyperkeratosis, and cancer. However, in the present study arsenic content is recorded very less in wetland water, especially during the pre-monsoon, whereas monsoon and post-monsoon record somewhere below detectable limit.

12. ***Nitrogen*** in wetland water is necessary to sustain biotic production in the wetlands. Surface water contains the amount of nitrate due to leaching of nitrate with the percolating water *(Gopalkrushna, 2011)*. Nitrates are contributed to the fresh water through various natural sources and due to human activities such as, runoff of nitrate rich fertilizers and animal manure into the water supply. From the present investigation, it is noted that the nitrate concentration is found consistently below detectable limit across all the seasons in wetlands under study.

4.2.1.3 Bacteriological parameters of wetland water:

In addition to the physico-chemical water quality indicators, bacteriological parameters of the wetland water have also been tested in laboratory. From the biological perspective, coliform counts have been taken into consideration for water quality measurement. Coliforms are bacteria that are always present in the digestive tracts of animals, including humans, and are found in their wastes. They are also found in plant and soil material. The presence of these bacteria indicates that whether the water is contaminated with feces or sewage, and has the potential to cause disease. Water pollution, caused due to fecal contamination is a serious problem due to the potential for contracting diseases from pathogens (disease causing organisms). So, testing of coliform bacteria in the wetland water sample is considered as a reasonable indication of whether other pathogenic bacteria are present or not. Coliform bacteria are generally of two kinds: 1. Total coliform and 2. Fecal coliform.

1. ***Total coliform gives*** the information about coliform bacteria *(Jalal & Sanalkumar, 2012)* that are found in the soil, water that has been influenced by surface water, and in human or animal waste.

2. ***Fecal coliforms*** are the group of the total coliforms that are considered to be present specifically in the gut and feces of warm-blooded animals. The origins of fecal coliforms are more specific than the total coliform group of bacteria, where the former is considered to be much accurate indication of animal or human waste than the later one. In the present study, the coliform content is found to be fluctuating within wetlands

which record maximum count of total and fecal coliform during post-monsoon season, followed by monsoon and pre-monsoon period in the wetlands under study.

4.3 Analysis of physico-chemical and bacteriological parameters of selected wetlands:

For the determination of physico-chemical and bacteriological quality of wetland water, field survey has been carried out for a period of consecutive three years from March 2015 to February 2018, covering three seasons viz. pre-monsoon (March-May), monsoon (June-September) and post-monsoon (October-February). During field study, the water samples have been collected in separate disinfected polyethylene cans from a depth of about 1.0 to 1.5 meter from the selected wetlands *(Plate 4.1a & c)*. At the respective sampling sites *(Map 4.4)* a total of 15 water quality parameters have been quantified in the laboratory, by following the BIS May, 2012; APHA, AWWA and WEF, 2017, presented in table no. 4.1 *(Appendix-8).*

Plate 4.1a: *Water sample collection during monsoon*

Plate 4.1b: *Water level measurement during post-monsoon*

Plate 4.1c: *Water sample collection during pre-monsoon*

Plate 4.1: *Wetland water level measurement and water sample collection during study*

4. 1 Details of wetland water components, instruments used, unit of measurement and permissible limit during study period

Sl. No.	Wetland water quality parameters	Instrument used	Unit of measurement	Permissible limit (BIS)	Remark
			A. Physical parameters		
1.	Water temperature	Mercury thermometer	°C		APHA 2550
2.	Turbidity	Turbidity Meter	Nephelometric turbidity unit (N.T.U.)	5	APHA 2130
			B. Chemical Parameters		
1.	Ph	pH Meter	-	6.5 – 8.5	APHA 4500-H^+
2.	Conductivity	Conductivity Meter	µ.s.	400	APHA 2510
3.	Total Dissolved Solid	Conductivity Meter	Parts per million (ppm)	200	APHA 2540
4.	Dissolved Oxygen	DO Meter	mg/L	18	APHA 4500-O
5.	Total Hardness	Titration method	mg/L	600	APHA 2340
6.	Chloride		mg/L		APHA 4500-Cl
7.	Iron		mg/L		APHA 3500-Fe
8.	Fluoride		mg/L		APHA 4500_F^-
9.	Arsenic		mg/L		APHA 3500-As
10.	Nitrate		mg/L		APHA 4500-NO_3^-
11.	Manganese		mg/L		APHA 3500-Mn
			C. Bacteriological parameters		
1.	Total coliform	MPN – Most probable number	MPN/100 ml	Shall not be detectable in any 100 ml sample	APHA 9222
2.	Fecal coliform	MFT – Membrane filter tube	MPN/100 ml	Shall not be detectable in any 100 ml sample	APHA 9222

Source: *BIS May, 2012; APHA, AWWA & WEF, 2017*

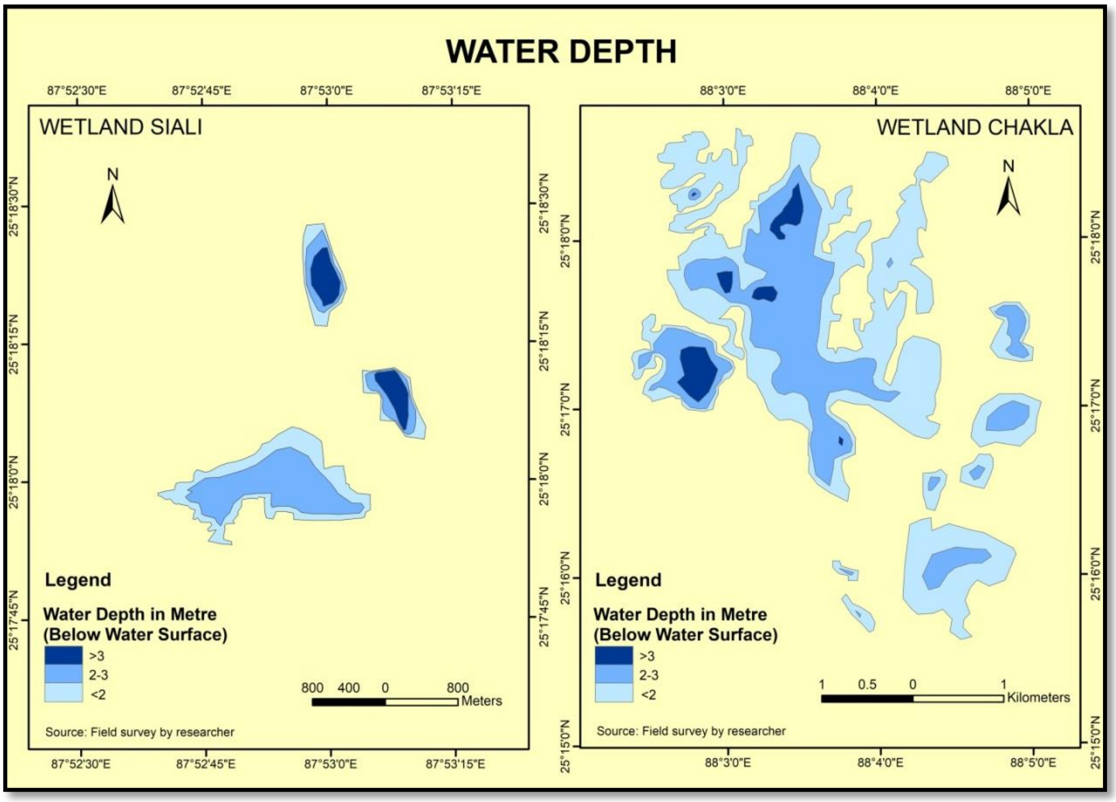
4.3.1 Siali wetland

4.3.1.1 Wetland hydrology:

Siali wetland is fed by the surface drainage of the catchment area and is well connected with Kankhor and Kali koshi, two tributaries of River Baramasia, which ultimately meets River Mahananda. The water level records minimum depth of < 2 meter, whereas the monsoon and post-monsoon record peak water level of 3.5 and 3.0 meter respectively in certain portion of this water body *(Map 4.1)*. Shallow water depth is recorded in the south, whereas maximum water depth is recorded in the north of Siali wetland. Large sections of wetland region turn into mud banks/ mud flats during the dry season, while the many marshy pockets remain become shallow. Siali wetland exerts a significant influence on the hydrological cycle. This water body initially alters the flood flows, and subsequently recharges the ground water table. The field study reveals that, this wetland is capable to store 3.5 meter water as extra amount during monsoon seasons, which is amounted to volume 554,358 m^3 of water. Therefore, Siali wetland plays the role to reduce down the flood peak of River Fulahar. Moreover, the dynamic water storage of this particular wetland is recorded 1.7 meter during the study, in which 0.9 meter gets evaporated *(Pal, 2017)*. Out of the remaining portion (0.8 meter) of dynamic water storage, approximately 60 % gets infiltrated as ground water recharge through Siali wetland.

4.3.1.2 Physico-chemical and bacteriological parameters:

For assessing the water quality of Siali wetland, certain relevant parameters have been analyzed from the sample water collection. All the parameters are displayed in mean value of data along with Standard Error of Mean (SEM) and Standard Deviation *(Table no. 4.2) (Appendix-8)*. The seasonal variation of these parameters has been presented in the following figure 4.1 (a, b), 4.2 (a to h) and 4.3 (a, b).



Map 4.1: *Water depth of wetland Siali and Chakla in meter (below water surface)*

4.3.1.2.1 Physical parameters:

In the present study, seasonal variability of water temperature has been observed maximum during summer, comparatively less during monsoon and minimum during post-monsoon season. In Siali wetland the ***water temperature*** generally ranges from 24°C ($\bar{X}$=24.43; σ=0.38) to 32.5°C ($\bar{X}$=31.77; σ=0.64) throughout the year. Water temperature records small variations from pre-monsoon (31.77°C) to monsoon (28.40°C) and post-monsoon (24.43°C) season *(Table 4.2) (Figure 4.1a).*

The ***turbidity*** of Siali wetland water is moderate to high and found within the permissible limit of 5 N.T.U. Turbidity value ranges from 1.51 N.T.U. ($\bar{X}$=2.18; σ=0.58) to 4.86 N.T.U. ($\bar{X}$=4.54, σ=0.59), with maximum concentration during monsoon (4.89 N.T.U.), and minimum during pre-monsoon (1.51 N.T.U.) *(Table 4.2) (Figure 4.1b)*. Turbidity reduces the light penetration into wetland water which eventually affects the photosynthesis process of phytoplankton as well as reduces the productivity of the entire wetland ecosystem *(Abujam et al., 2012).*

4.3.1.2.2 Chemical parameters:

The ***pH*** of this wetland water ranges from 7.01 ($\bar{X}$=7.17; σ=0.14) to 7.62 ($\bar{X}$=7.53; σ=0.11) throughout the study period. In Siali wetland, the pH is recorded high during the pre-monsoon (7.62), followed by monsoon (7.32) and post-monsoon (7.04) period *(Table 4.2) (Figure 4.2a)*. The pH is somewhat alkaline during pre-monsoon, which may be associated with active photosynthesis. Water pH has been recorded declining during monsoon which may be due to the higher run off from the adjacent catchment area *(Map 4.2)*, having slightly acidic soil or due to the luxuriant growth of emergent macrophytes.

During the entire study period, covering three years in Siali wetland ***conductivity*** records from 120.9 µ.s. ($\bar{X}$=125.17; σ=3.97) to 146.9µ.s. ($\bar{X}$=143.87; σ=3.01). Conductivity is found seasonally fluctuating with its peak value during pre-monsoon (146.907µ.s), followed by monsoon (126.80µ.s) and post-monsoon period (120.90µ.s) *(Table 4.2) (Figure 4.2c)*.

Siali wetland records the ***total dissolved solid*** (tds) content from 50.7ppm ($\bar{X}$=58.70, σ=7.21) to 86.7 ppm ($\bar{X}$=78.50, σ=7.71) throughout the study time *(Table 4.2) (Figure 4.2b)*. There is a marked seasonal variation in dissolved solid with the highest value during pre-monsoon (86.70ppm), followed by monsoon (65.30ppm) and post-monsoon (50.70ppm). The relatively high value of dissolved solid during rainy period may be due to addition of domestic waste water, garbage and sewage etc. in the natural surface water body *(Verma et* *al., 2012)*. The high concentration of TDS from the surrounding locality *(Map 4.2)*, where the photograph has been taken (shown by red arrow), enhances the nutrient status of water body which eventually results into eutrophication in this wetland.

Dissolved oxygen is another chemical water quality parameter, which is used as an index of water quality, primary production and pollution. Siali wetland water records the concentration of dissolved oxygen from 4.1 mg/L ($\bar{X}$=4.37; σ=0.25) to 6.7 mg/L ($\bar{X}$=6.43; σ=0.25) throughout the entire study period. Highest do is recorded during post-monsoon (6.70mg/L), followed by monsoon (4.90mg/L) and remain almost same during pre-monsoon *(Table 4.2) (Figure 4.2d)*.

In the present study, the wetland water ***hardness*** ranges from 104 mg/L ($\bar{X}$=112; σ=6.93) to 155 mg/L ($\bar{X}$=155; σ=12.28). Marked seasonal fluctuation is recorded with highest value in pre-monsoon (159mg/L), which is quite high than the normal water condition and is termed hard water. Total hardness in wetland water has gradually been reduced down in monsoon (120mg/L) and post-monsoon (104mg/L) period *(Table 4.2) (Figure 4.2e)*.

The ***Chloride*** content is recorded from 72.01 mg/L ($\bar{X}$=72.04; σ=0.02) to 78.43 mg/L ($\bar{X}$=78.43; σ=0) throughout the study period. An increasing trend of chloride from monsoon (73.17mg/L) with maximum during post-monsoon (78.43mg/L) and a declining trend in pre-monsoon (72.01mg/L) period have been recorded in this water body *(Table 4.2) (Figure 4.2f)*. The gradual increase of chloride concentration in the wetland water indicates the influence of organic waste of human origin with runoff water from the peripheral villages.

The chemical component of ***iron*** is found consistently low throughout the year, which ranges from 0.15 mg/L ($\bar{X}$=0.19; σ=0.04) to 0.69 mg/L ($\bar{X}$=0.58; σ=0.10). The obtained level of iron is significantly high during post-monsoon (0.7mg/L) and low during pre-monsoon (0.15mg/L).

Fluoride and ***arsenic*** concentration has been found very less irrespective of all the seasons. Fluoride ranges from 0.17 mg/L ($\bar{X}$=0.18; σ=0.01) to 0.30 mg/L ($\bar{X}$=0.30; σ=0.01) with maximum value during post-monsoon and minimum during pre-monsoon *(Figure 4.2h)*. Arsenic content within wetland water records 0.01 to 0.02 mg/L during the entire study period.

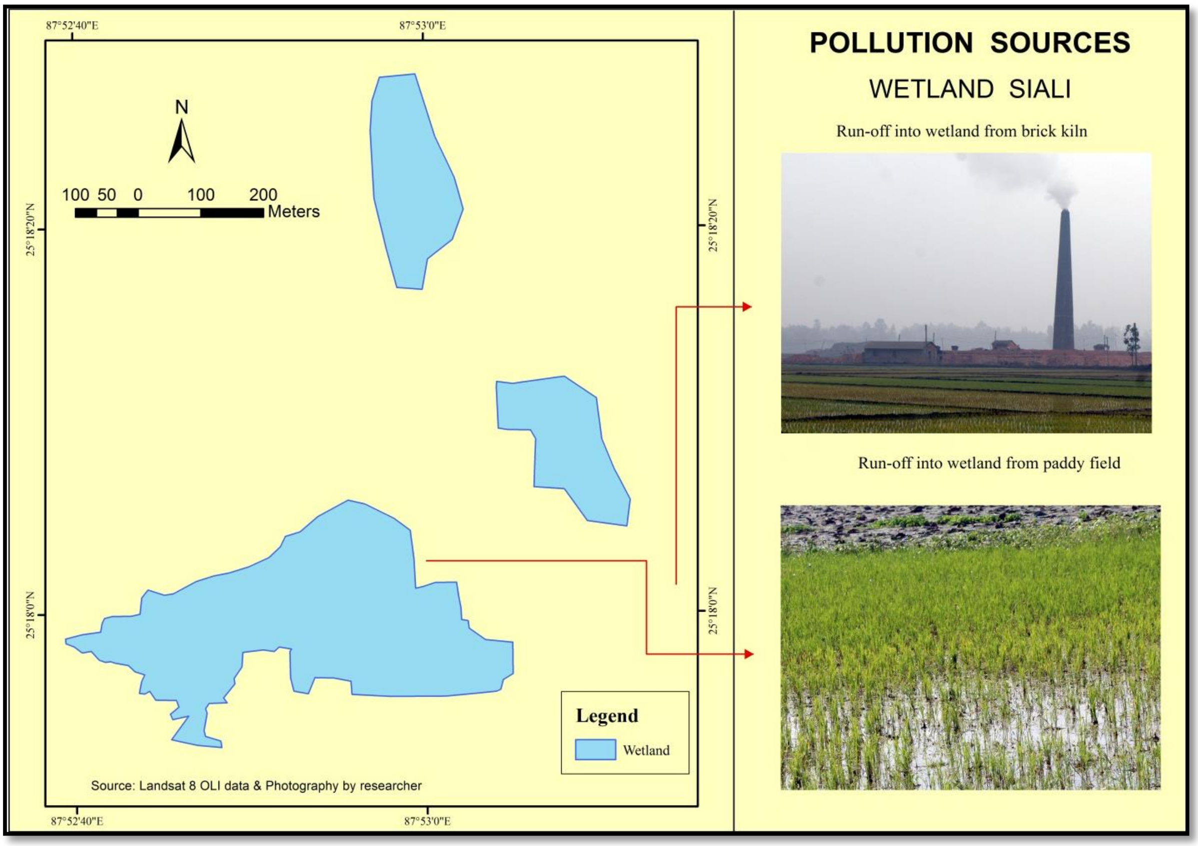
Other two chemical components ***nitrate*** and ***manganese*** are found below detectable limit throughout the entire study period.

Table 4.2 Statistical result on physic-chemical and bacteriological parameters of Siali wetland

Parameters	Pre-monsoon			Monsoon			Post-monsoon		
	Mean		Std. Deviation	Mean		Std. Deviation	Mean		Std. Deviation
	Statistic	Std. Error	Statistic	Statistic	Std. Error	Statistic	Statistic	Std. Error	Statistic
Water temperature	31.77	0.37	0.64	28.40	0.60	1.04	24.43	0.22	0.38
pH	7.53	0.06	0.11	7.40	0.043	0.075	7.17	0.081	0.14
Conductivity	143.87	1.73	3.01	129.77	1.51	2.61	125.17	2.28	3.95
Total dissolved solid	78.50	4.45	7.71	67.47	1.30	2.25	58.70	4.16	7.21
Turbidity	2.18	0.33	0.58	4.54	0.34	0.59	3.48	0.30	0.51
Total hardness	150.00	7.09	12.28	126.00	3.00	5.20	112.00	4.00	6.93
Dissolved oxygen	4.37	0.15	0.25	5.37	0.29	0.50	6.43	0.15	0.25
Chloride	72.04	.013	0.023	73.17	0.100	0.17	78.43	0.00	0.00
Iron	0.19	0.02	0.035	0.43	0.015	0.025	0.58	0.057	0.098
Fluoride	0.18	0.003	0.006	0.23	0.00	0.00	0.30	0.007	0.012
Arsenic	0.01	0.002	0.003	0.00	0.00	0.00	0.01	0.002	0.003
Total coliform	4.67	0.67	1.15	7.00	0.00	0.00	12.67	0.67	1.16
Fecal coliform	0.33	0.33	0.58	1.00	0.00	0.00	2.00	0.00	0.00

Source: *1. Water sample collected from field study*

2. Water sample tested by P.H.E. Department, under Malda Polytechnic, Govt. of West Benga



Map 4.2: *Run-off from agricultural field into Siali wetland*

4.3.1.2.3 Bacteriological parameters:

The bacteriological analysis has been conducted in the laboratory to access the total coliform and fecal coliform. In the present study, ***total coliform*** counts ranges from 4 MPN ($\bar{X}$=4.67; σ=1.15) to 14 MPN ($\bar{X}$=12.67; σ=1.16) per 100 ml water. Maximum total coliform is recorded during winter months (14MPN/100 ml), followed by monsoon (7MPN/100ml) and pre-monsoon (4MPN/100ml) *(Table 4.2) (Figure 4.3 a&b)*. The present investigation reveals an increasing trend in the concentration of total coliform during the monsoon and post-monsoon period, which may be due to the large accumulation of land run-off in wetland water, and results into high bacterial population within wetland water.

Fecal coliform records as low as 0 to 3 MPN ($\bar{X}$=2; σ=0) per 100ml wetland water.

4.3.2 Chakla wetland

4.3.2.1 Wetland hydrology:

The hydrological activity of the *Tal* physiographic region is evident from the fact that, large number of perennial rivers, including mighty River Ganga, traverse through this zone. Moreover, there are strong evidence of shifting river channels, and is normally subjected to inundation regularly. By regular inflow of Nuna and Bhoga inlets (of River Mahananda) from north and south respectively, the water spread area of this wetland gets enlarged. Due to favourable slope condition and consequent run-off, most of the tract remains submerged under considerable depths of water during the monsoon rains. The water level significantly varies from < 2 meter during pre-monsoon to > 3.5 meter during monsoon season in several parts of this vast water body *(Map 4.1)*. Maximum water depth is noticeable in the north and western pockets, whereas the rest of the portions display low to moderate water depth within wetland. The field study reveals that, Chakla wetland is capable to store 2.0 meter water as extra amount during monsoon period, which is amounted to volume 42,314,620 m^3 of water. Therefore, Chakla wetland, being a vast water body plays the role of buffer to soak excess water from wetland catchment as well as reduce down the flood peak of River Mahananda. Moreover, the dynamic water storage of Chakla wetland is recorded 1.25 meter during the study, in which a specific amount of water (0.9 meter) gets evaporated. Out of the remaining portion (0.35 meter) of dynamic water storage, a large amount (approximately 60 %) gets infiltrated as ground water recharge through this natural entity.

4.3.2.2 Physico-chemical and bacteriological parameters:

4.3.2.2.1 Physical parameters:

The physico-chemical and bacteriological parameters of the sample wetland water are displayed in the following table 4.3 as well as represented in figure 4.1, 4.2 and 4.3.

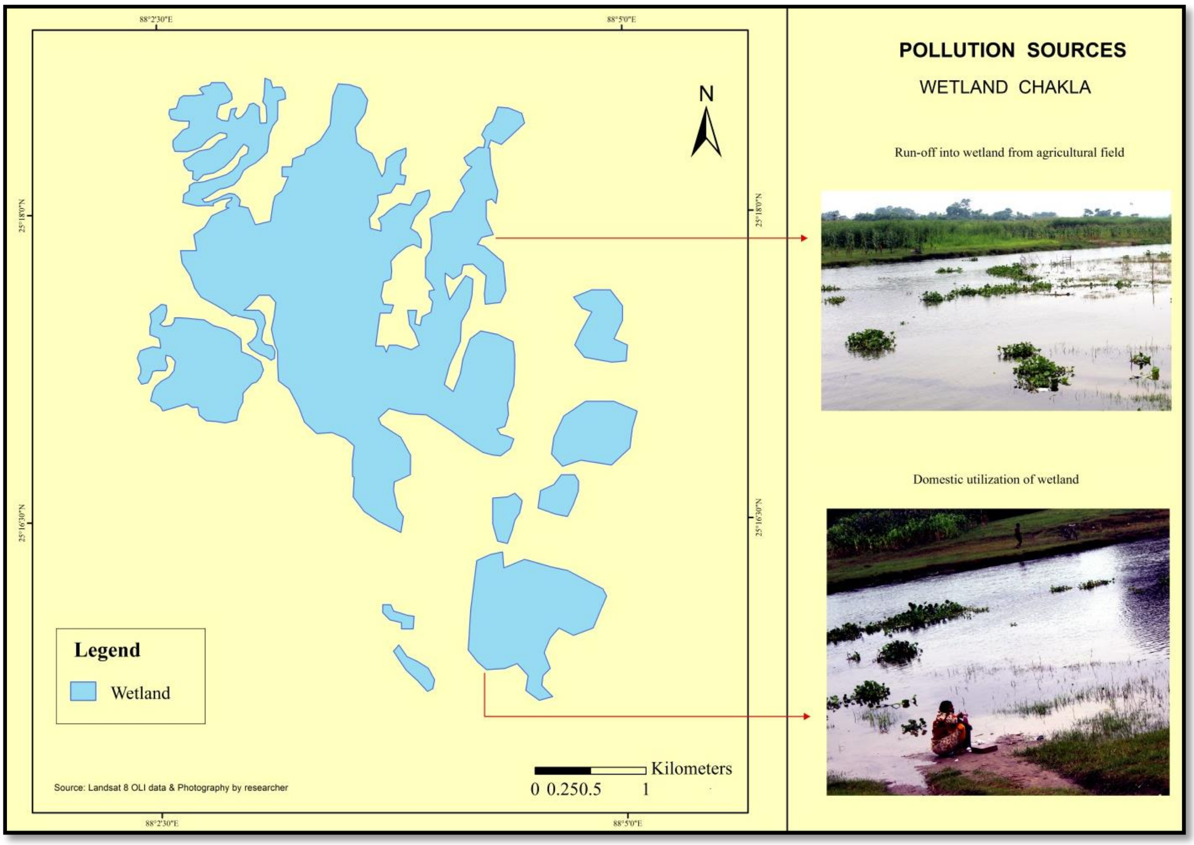
Chakla wetland records ***water temperature*** ranges from 23.5°C ($\bar{X}$=23.7; σ=0.20) to 31.7°C ($\bar{X}$=31.23; σ=0.40) throughout the year, with the highest recorded value during pre-monsoon (31.70°C), followed by monsoon (27°C) and post-monsoon (23.70°C) *(Figure 4.1a)*.

In the present study, the ***turbidity*** in wetland water ranges from 4.35 N.T.U. ($\bar{X}$=4.39; σ=0.06) to 6.92 N.T.U. ($\bar{X}$=6.53; σ=0.54) which exceeds the permissible limit of 5.00 N.T.U. as proposed by BIS and APHA. Wetland water turbidity is found maximum during the monsoon period (6.92 N.T.U.) and least turbidity is obtained during pre-monsoon (4.35 N.T.U.) *(Table 4.3) (Figure 4.1b)*. High turbidity signifies the presence of large amount of suspended solids within this water body *(Verma et al., 2012)*. This also indicates the high rate of siltation, so as to decrease the depth of this wetland complex.

4.3.2.2.2 Chemical parameters:

The water ***pH***, which is governed by the equilibrium between carbon-di-oxide, carbonate and bicarbonate ions, mostly lies within the range of 6.73 ($\bar{X}$=6.96; σ=0.20) to 7.61 ($\bar{X}$=7.54; σ=0.08) throughout the study period. The pH of Chakla wetland complex is observed to be slightly acidic (6.73) during post-monsoon; which has turned to alkaline range (7.61) during pre-monsoon. The pH record is considered to be conducive for the aquatic ecosystem in this wetland *(Table 4.3) (Figure 4.2a)*.

The recorded ***Conductivity*** of Chakla wetland is restricted between 103.5 µ.s. ($\bar{X}$=104.97; σ=2.20) to 159.8µ.s. ($\bar{X}$=138.47; σ=18.50) throughout the year with lower amount during post-monsoon (103.50µ.s.) and higher in pre-monsoon (159.80µ.s.) period *(Table 4.3) (Figure 4.2c)*. In this water body, there is a striking seasonal variation in conductivity, but confined within the permissible range of 400 µ.s (BIS and APHA).



Map 4.3: *Agricultural and domestic sewage inflow into Chakla wetland*

Table 4.3 Statistical result on physic-chemical and bacteriological parameters of Chakla wetland

Parameters	Pre-monsoon			Monsoon			Post-monsoon		
	Mean		Std. Deviation	Mean		Std. Deviation	Mean		Std. Deviation
	Statistic	Std. Error	Statistic	Statistic	Std. Error	Statistic	Statistic	Std. Error	Statistic
Water temperature	31.23	0.23	0.40	27.00	0.00	0.00	23.70	0.12	0.20
pH	7.54	0.04	0.077	7.34	0.12	0.21	6.96	0.12	0.204
Conductivity	138.47	10.68	18.50	115.33	6.33	10.97	104.97	1.27	2.20
Total dissolved solid	66.87	3.52	6.10	57.00	0.58	1.00	51.57	1.27	2.19
Turbidity	4.39	0.032	0.06	6.53	0.31	0.54	5.60	0.00	0.00
Total hardness	95.33	3.33	5.77	78.00	8.00	13.86	54.00	5.03	8.72
Dissolved oxygen	4.17	0.067	0.12	5.57	0.37	0.64	6.57	0.13	0.23
Chloride	29.30	1.72	2.98	29.53	2.33	4.04	40.24	0.00	0.00
Iron	0.71	0.12	0.21	0.50	0.00	0.00	1.03	0.21	0.36
Fluoride	0.23	0.01	0.012	0.20	0.00	0.00	0.17	0.01	0.012
Arsenic	0.00	0.00	0.00	.000	0.00	0.00	0.013	0.01	0.003
Total coliform	0.00	0.00	0.00	8.33	0.33	0.58	18.00	1.00	1.73
Fecal coliform	0.00	0.00	0.00	2.33	0.33	0.58	8.67	0.67	1.155

Source: *1. Water sample collected from field study*

2. Water sample tested by P.H.E. Department, under Malda Polytechnic, Govt. of West Bengal.

Total dissolved solid in Chakla wetland ranges from 50.3 ppm ($\bar{X}$=51.57; σ=2.19) to 73.9 ppm ($\bar{X}$=66.87; σ=6.10) throughout the study period. In the present study, TDS is visibly low during post-monsoon (50.30ppm) and higher during pre-monsoon period (73.90ppm) and its concentration is well within the permissible limit *(Table 4.3) (Figure 4.2b)*. High loading of dissolved solid factor could be associated with the dissolution of ions in the water, which signifies the inorganic pollution load in wetland water *(Map 4.3)*.

Dissolved oxygen is a parameter in aquatic ecosystem, which greatly affects the physical, chemical and biological process of the wetland ecosystem. Do significantly ranges between 4.1 mg/L ($\bar{X}$=4.17; σ=0.12) to 6.7 mg/L ($\bar{X}$=6.57; σ=0.23) during the entire study period *(Table no. 4.3) (Figure 4.2d)*. The result shows that there is a gradual increase of dissolved oxygen during post-monsoon period (6.70mg/L), which is attributed to low ambient atmospheric temperature. Chakla wetland records minimum dissolved oxygen during pre-monsoon (4.10mg/L), which may be due to the presence of high organic loads in this wetland complex *(Map 4.3)*.

Total hardness in wetland water records an average value of 44 mg/L ($\bar{X}$=54; σ=8.72) to 102 mg/L ($\bar{X}$=95.33; σ=5.77), across all the seasons and considered to be soft water. Maximum water hardness is recorded during pre-monsoon (102.00mg/L), whereas minimum in post-monsoon (44.00mg/L) season *(Table 4.3) (Figure 4.2e)*.

In the present study, the ***chloride*** concentration significantly fluctuates from 27.2 mg/L ($\bar{X}$=29.53; σ=4.04) to 40.24 mg/L ($\bar{X}$=40.24; σ=0). The post-monsoon (40.24mg/L) records maximum chloride content, which remain almost same during pre-monsoon (27.58mg/L) and monsoon (27.20mg/L) *(Table no. 4.3) (Figure 4.2f)*. The chloride concentration in post-monsoon may be due to the accumulation of domestic sewages from neighboring village sites and cattle sheds, immediately after the heavy shower *(Map 4.3)*.

Iron concentration in Chakla wetland ranges between 0.47 mg/L ($\bar{X}$=0.71; σ=0.21) to 1.28 mg/L ($\bar{X}$=1.03; σ=0.36) throughout the study period. Maximum concentration of iron is recorded in post-monsoon (1.28mg/L), whereas minimum in pre-monsoon (0.47mg/L) *(Figure 4.2g)*. Iron content is directly related with the zooplankton diversity *(Pal et al., 2015)*, which is truly maintained in case of diverse faunal composition in Chakla wetland.

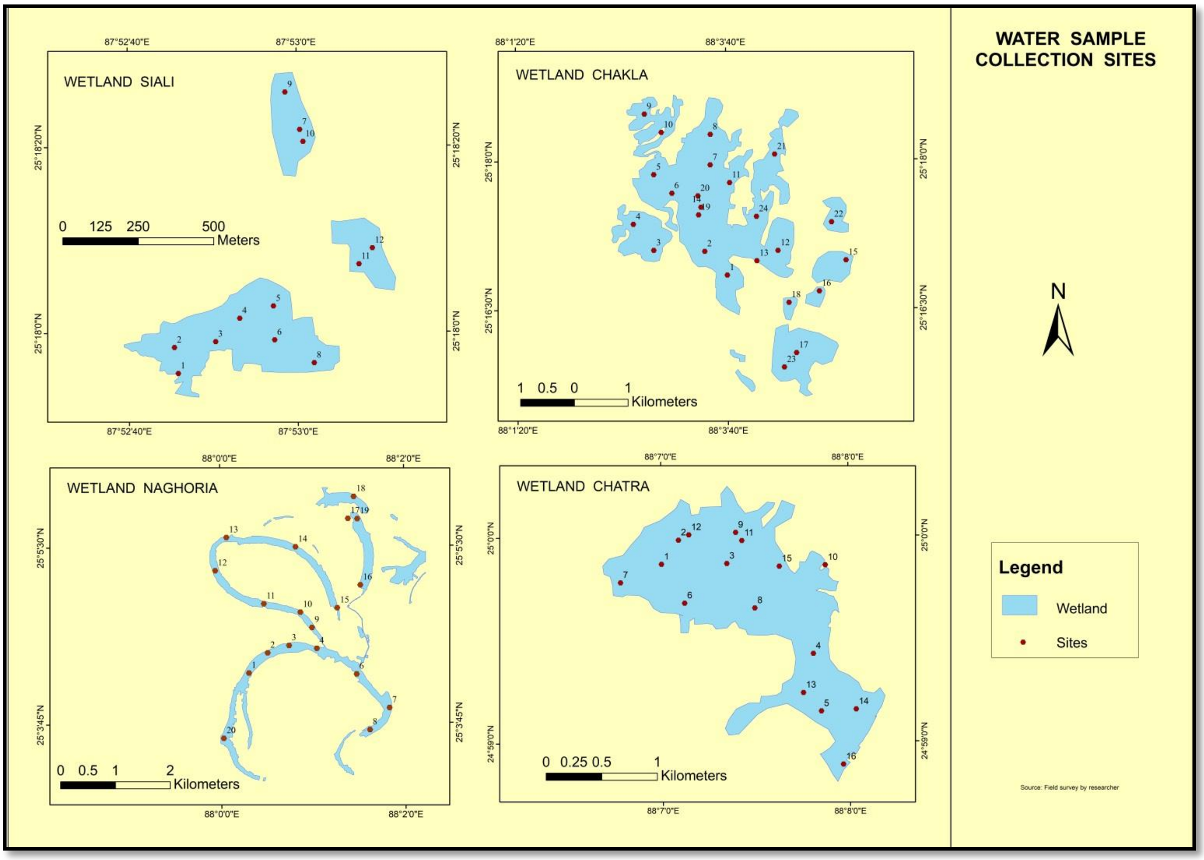
The ***fluoride*** content has been recorded very less, as well as restricted between 0.16 mg/L ($\bar{X}$=0.17; σ=0.01) to 0.24 mg/L ($\bar{X}$=0.23; σ=0.01) across all the seasons *(Figure 4.2h)*. The ***arsenic*** content is found negligible, ranges from 0 to 0.016 mg/L throughout the study period.

The ***nitrate*** and ***manganese*** are recorded consistently low across all the seasons in the surface water in spite of several agricultural practices at the periphery of wetland complex.

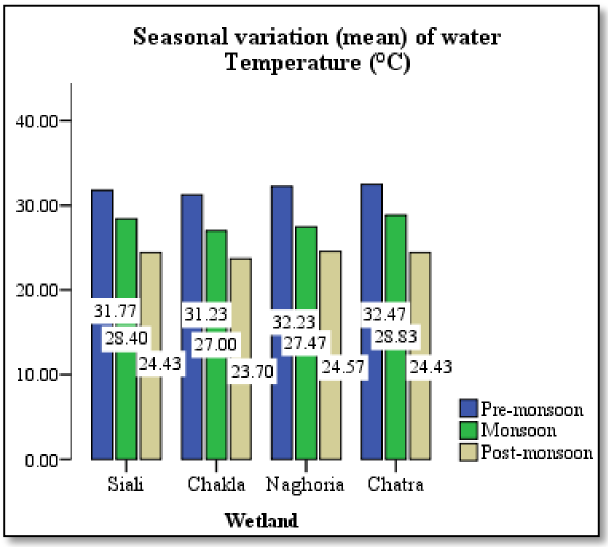
4.3.2.2.2. Bacteriological parameters:

In the context of bacteriological analysis the presence of ***total coliform*** is consistently high, and ranges between 0 to 20 MPN ($\bar{X}$=18; σ=1.73) per 100 ml water. Post-monsoon (20.00MPN/100ml) records a higher load of organic compounds in Chakla wetland, whereas pre-monsoon records 0.

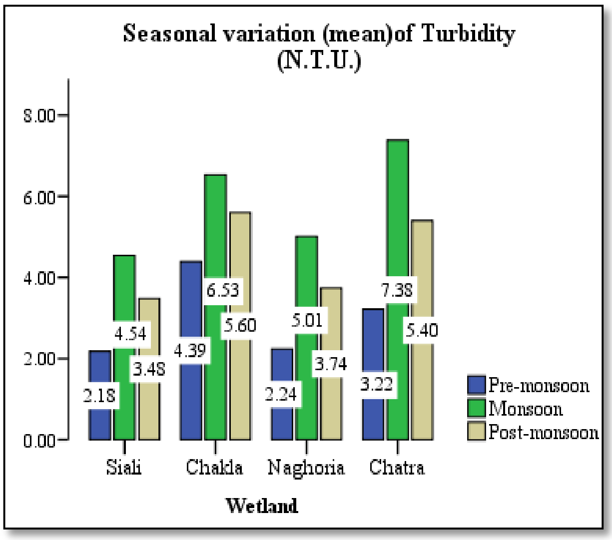
Fecal coliform is found lower, ranges from 0 to 10 MPN ($\bar{X}$=8.67; σ=1.16) per 100 ml water with highest amount in post-monsoon (10.00MPN/100ml) *(Table 4.3) (Figure 4.3 a&b)*.



Map 4.4: *Water sample collection sites from selected wetlands*

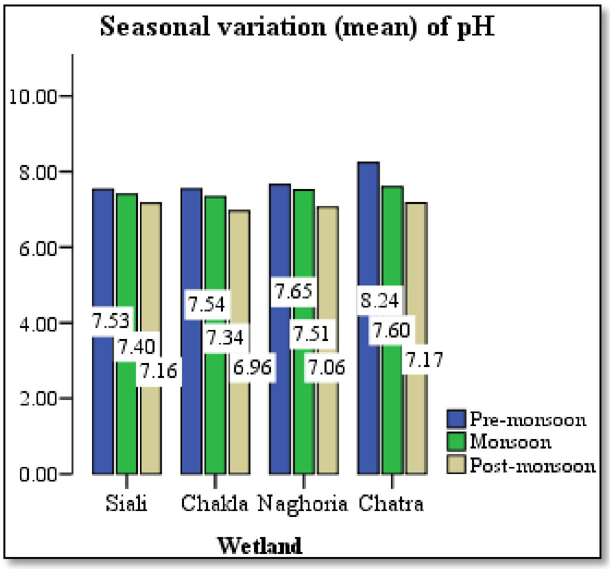


(a)

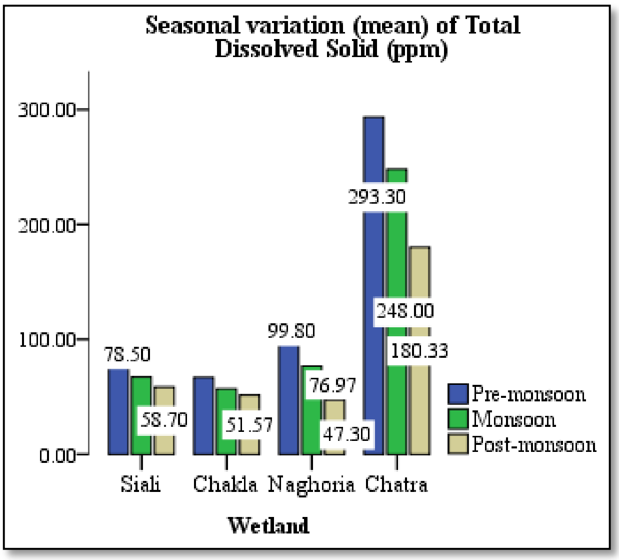


(b)

Figure 4.1: *Seasonal variations of physical water quality parameters between selected wetlands*

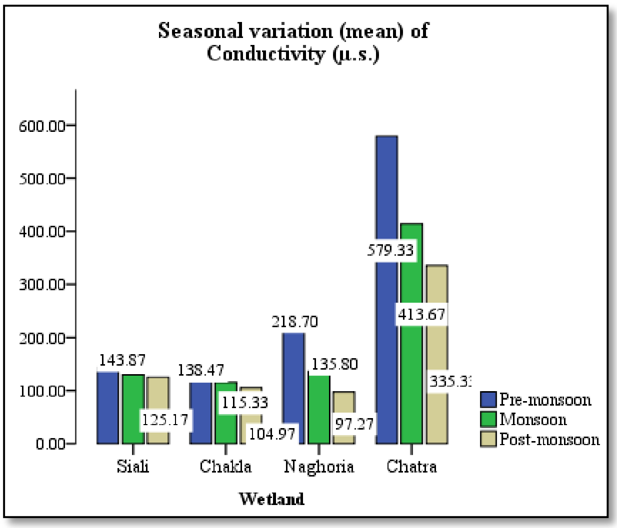


(a)

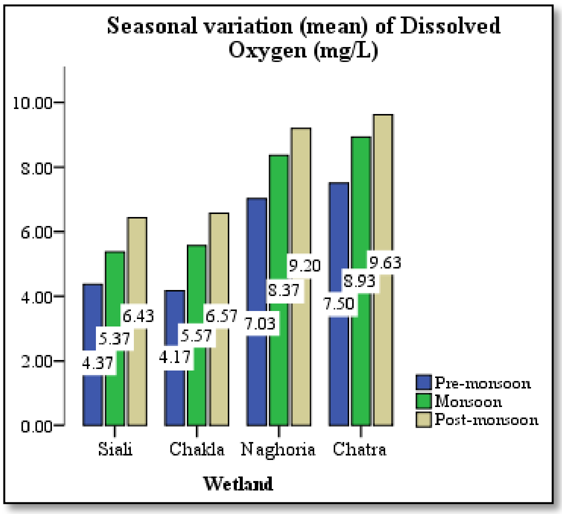


(b)

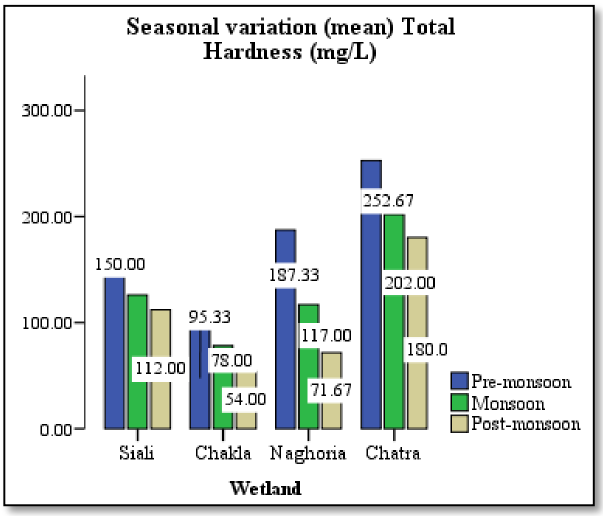
Figure 4.2: *Seasonal variations of Chemical water quality parameters between selected wetlands*



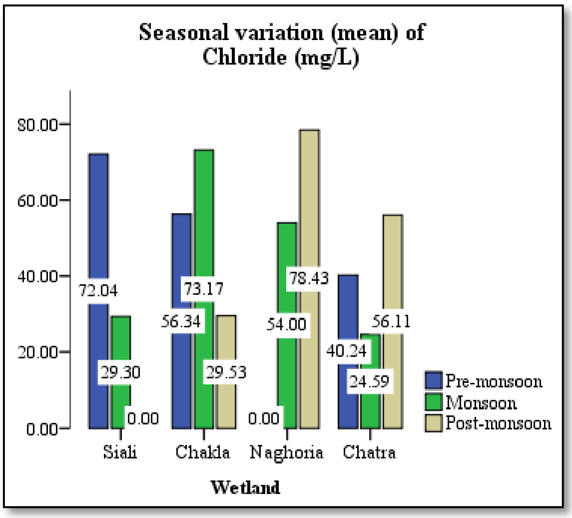
(c)



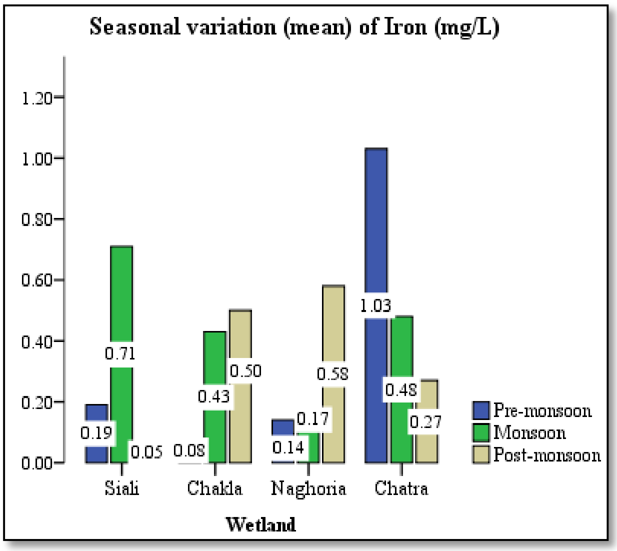
(d)



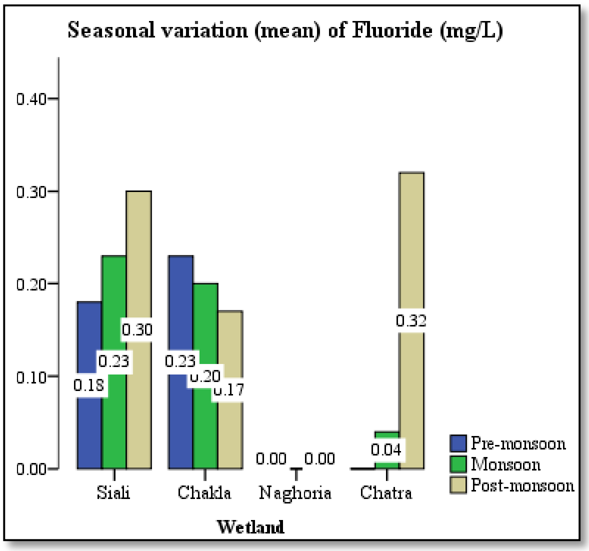
(e)



(f)

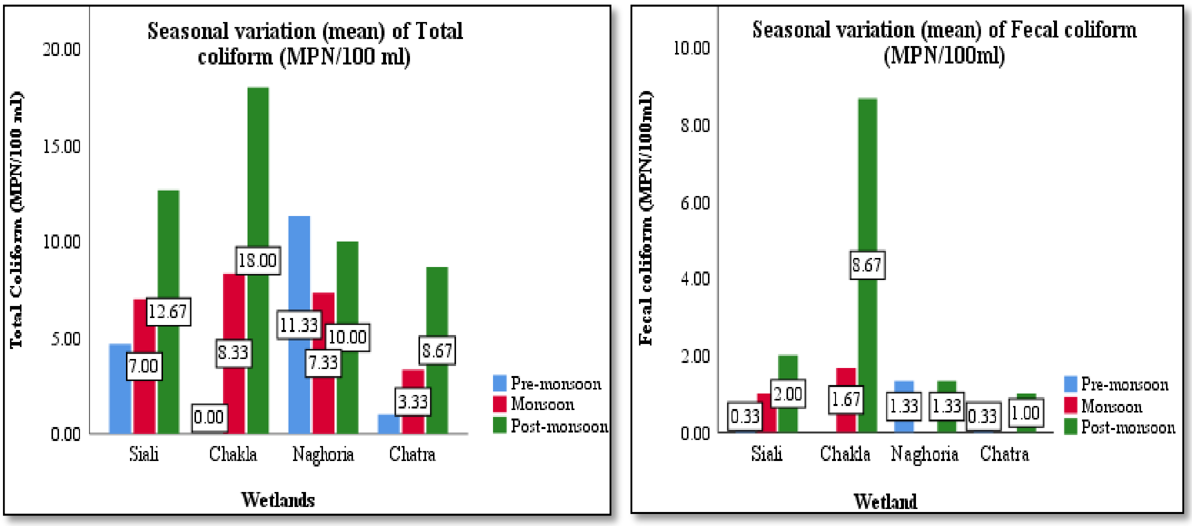


(g)



(h)

Figure 4.2 *Seasonal variations of Chemical water quality parameters between selected wetlands*



(a) (b)

Figure 4.3 *Seasonal variations of Bacteriological water quality parameters between selected wetlands*

4.3.3 Naghoria wetland

4.3.3.1 Wetland hydrology:

The hydrology of the Naghoria wetland area is a typical representation of river bed hydrological characteristic. The main support of its drainage is rain water, along with the river water of Kalindri. Sometimes these channels are continuous or partially dissected, somewhere existing as waterlogged channels and somewhere it is captured by inhabitants for the agricultural and settlement purposes. Therefore this wetland is uniquely characterized by the continuous wet and dry courses. The water level is recorded lowest (< 2 meter) during pre-monsoon, from March to end of May, which indicates the dry phase of summer. Water level is at its maximum (> 3 meter) during monsoon, from the end of June to October, as the surface run-off from the vast catchment area enters into the channel by Kalindri River and Nurpur connection via Nurpur barrage from Ganga River *(Map 4.6)*. On the basis of field study and information, taken from Phulbaria and Uttar Lakshipur Gram Panchayat, it is observed that this cut-off channel experiences fluctuation in the water spread area especially during pre-monsoon and monsoon months. Naghoria wetland is almost perennial by nature and apart from its huge surface area; the hydrology of the Naghoria is partially dependent on the ground water regime. Direction of the ground water flow is almost same as the general slope and water table seems to be very close (< 3 m). The excess water drains through Kalindri to Mahananda River. The field study reveals that, Naghoria wetland is capable to store 0.5

meter water as extra amount during the monsoon months (July to September), which is amounted to volume 6,772,784 m^3 of water. Being a cut-off of River Kalindri, Nagoria wetland is potential to store excess water from wetland catchment in order to reduce down the flood peak as well as recharge the ground water. Moreover, the dynamic water storage of this perennial cut-off is recorded 1.2 meter during the study, in which 0.9 meter gets evaporated *(Pal, 2017)*. Out of the remaining portion (0.3 meter) of dynamic wetland water storage, major portion (approximately 60 %) gets infiltrated and acts as ground water reservoir for further usage especially during pre-monsoon.

4.3.3.2 Physico-chemical and bacteriological parameters:

4.3.3.2.1 Physical parameters:

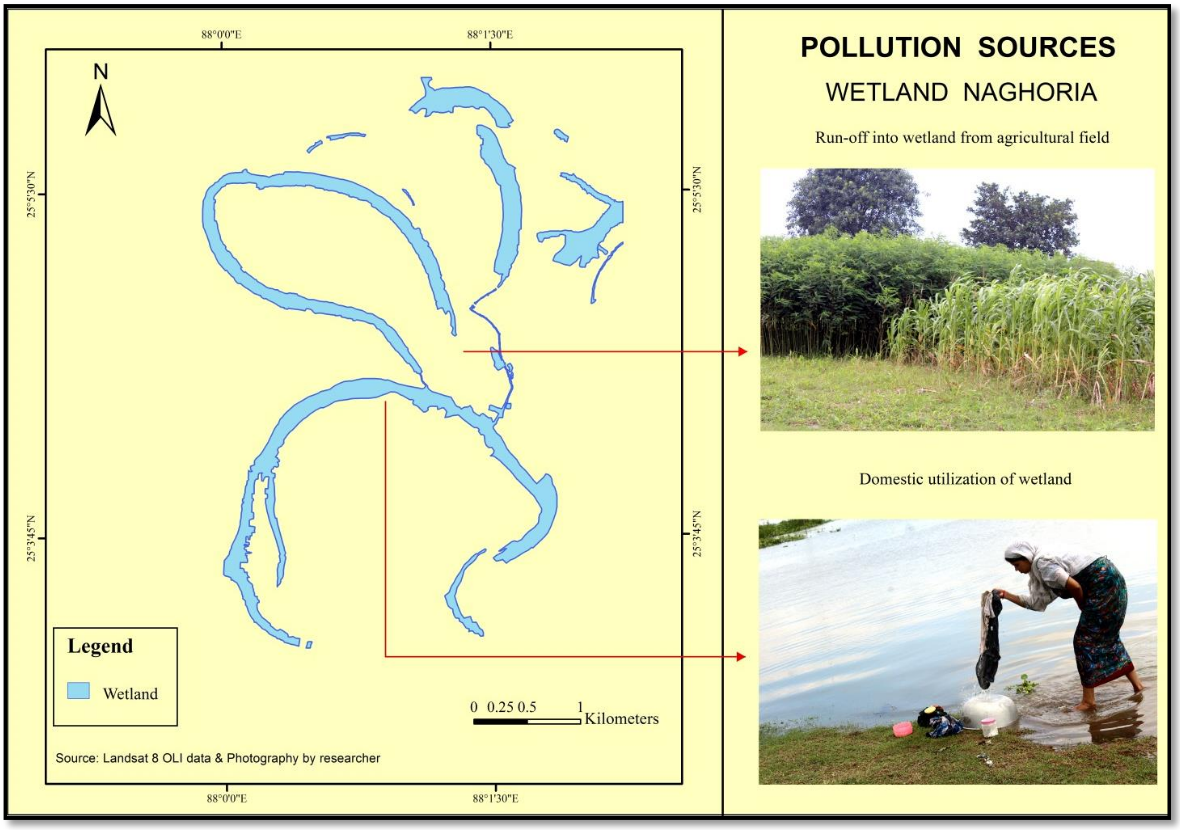
Naghoria wetland records ***water temperature*** between 24.4°C ($\bar{X}$=24.57; σ=0.21) to 32.7°C ($\bar{X}$=32.23; σ=0.40) during the entire study period. Maximum water temperature is recorded in pre-monsoon (32.70°C), followed by monsoon (27.47°C) and minimum during post-monsoon (24.40°C) *(Figure 4.1a)*.

Naghoria wetland records moderate to high ***turbidity*** ranges from 1.72 N.T.U. ($\bar{X}$=2.24; σ=0.46) to 5.75 N.T.U. ($\bar{X}$=5.26; σ=0.43) throughout the study period. The obtained turbidity is high during monsoon (5.75 N.T.U.) and found above the permissible limit in Naghoria wetland, whereas, lowest turbidity is recorded in pre-monsoon (1.7N.T.U.) *(Table 4.4) (Figure 4.1 a and b)*.

4.3.3.2.2 Chemical parameters:

The water ***pH*** ranges from 6.89 ($\bar{X}$=7.06; σ=0.15) to 7.78 ($\bar{X}$=7.65, σ=0.11) throughout the study period. The pre-monsoon (7.78) indicates the water to be slightly alkaline, which substantiates the growth of algae in this wetland. The record depicts a gradual decline of pH during monsoon (7.51) and post-monsoon (6.89) period, which influence the luxuriant growth of emergent macrophytes *(Table 4.4) (Figure 4.2 a) (Map 4.5)*.

The value of ***conductivity*** is recorded to be fluctuating as well as ranges from 77.6 µ.s. ($\bar{X}$=97.27; σ=26.65) to 264 µ.s. ($\bar{X}$=218.7; σ=39.63) throughout the study period. Naghoria wetland shows a marked seasonal change in conductivity, with maximum record during pre-monsoon (264.20µ.s.) which decline successively during monsoon (135.80µ.s.) and post-monsoon (77.60µ.s.) season *(Table 4.4) (Figure 4.2c)*.



Map 4.5: *Agricultural and domestic sewage inflow into Naghoria wetland*

Total dissolved solid displays a significant range of variation across all the seasons from 38.5 ppm ($\bar{X}$=47.3; σ=13.38) to 104.1 ppm. ($\bar{X}$=99.77; σ=4.04). Comparatively higher dissolved solids in Naghoria wetland during pre-monsoon (104.10ppm) is attributed to the presence of high concentration of major cations and anions in wetland water *(Map 4.5)*. Monsoon (76.30ppm) and post-monsoon (38.50ppm) record drastic drop of dissolved solid within wetland *(Table 4.4) (Figure 4.2b).*

Table 4.4 Statistical result on physic-chemical and bacteriological parameters of Naghoria wetland

Parameters	Pre-monsoon			Monsoon			Post-monsoon		
	Mean		Std. Deviation	Mean		Std. Deviation	Mean		Std. Deviation
	Statistic	Std. Error	Statistic	Statistic	Std. Error	Statistic	Statistic	Std. Error	Statistic
Water temperature	32.23	0.23	0.40	27.47	0.27	0.46	24.57	0.12	0.21
pH	7.65	0.065	0.11	7.51	0.00	0.00	7.06	0.09	0.15
Conductivity	218.70	22.88	39.63	135.80	21.73	37.64	97.27	15.39	26.65
Total dissolved solid	99.77	2.33	4.04	76.97	0.67	1.15	47.30	7.73	13.38
Turbidity	2.24	0.27	0.46	5.26	0.25	0.43	3.74	0.12	0.22
Total hardness	187.33	4.67	8.08	117.00	10.50	18.19	71.67	7.96	13.79
Dissolved oxygen	7.03	0.03	0.06	8.37	0.09	0.15	9.20	0.10	0.17
Chloride	0.00	0.00	0.00	0.00	0.00	0.00	24.59	2.33	4.04
Iron	0.05	.007	.012	0.14	0.017	0.029	0.48	0.12	0.21
Fluoride	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Arsenic	0.06	0.01	0.01	0.00	0.00	0.00	0.02	0.003	0.004
Total coliform	11.33	0.67	1.15	7.33	0.33	0.58	10.00	1.00	1.74
Fecal coliform	1.33	0.33	0.58	0.00	0.00	0.00	1.33	0.67	1.15

Source: *1. Water sample collected from field study*

2. Water sample tested by P.H.E. Department, under Malda Polytechnic, Govt. of West Bengal.

The ***dissolved oxygen*** in Naghoria wetland records an average concentration, ranging between 7 mg/L ($\bar{X}$=7.03; σ=0.06) to 9.3 mg/L ($\bar{X}$=9.20; σ=0.17). Maximum dissolved oxygen concentration is recorded during post-monsoon (9.30mg/l), whereas relatively lower concentration is recorded in pre-monsoon (7.00mg/L) *(Table 4.4) (Figure 4.2d)*, which may be caused due to the abundance of floating vegetation and pit formation in this cut-off meander.

Total hardness records significant fluctuations ranging between 56 mg/L ($\bar{X}$=71.67; σ=13.79) to 196 mg/L ($\bar{X}$=187.33; σ=8.08) throughout the study period. Its peak value is recorded during pre-monsoon (196mg/L), followed by monsoon (117mg/L) and post-monsoon (56mg/L) season *(Table 4.4) (Figure 4.2e)*. So the hardness status of Naghoria wetland is in the mid-way between hard and soft water and can be termed as normal water and therefore is suitable for the macrophytes and fish cultivation.

In Naghoria wetland ***chloride*** content is recorded very less with a little trace during post-monsoon amounting 26.92 mg/L ($\bar{X}$=24.59, σ=4.04) *(Figure 4.2f).*

Iron and ***arsenic*** components are recorded insignificant throughout the year, ranging from 0.04 mg/L ($\bar{X}$=0.05; σ=0.01) to 0.6 mg/L ($\bar{X}$=0.48; σ=0.21) and 0 to 0.07 mg/L ($\bar{X}$=0.06; σ=0.01) respectively in this water body. ***Fluoride*** content is also below the detectable limit throughout the year. ***Manganese*** and ***nitrates*** are recorded below the detectable limit. The nitrate content in the ground and surface water is normally low, but can reach at high levels due to agricultural run-off and contamination of human and animal waste into this water body *(Map 4.5)*.

4.3.3.2.3 Bacteriological parameters:

The bacteriological analysis of wetland water reveals the profound presence of both the total and fecal coliform round the year in this cut-off. ***Total coliform*** ranges from 7 MPN ($\bar{X}$=7.33; σ=0.58) to 12 MPN ($\bar{X}$=11.33; σ=1.15) per 100 ml water with maximum concentration during pre-monsoon season (12MPN/100ml).

Fecal coliform records only 2 MPN per 100 ml water. The result shows gradual decline in both the coliform counts during the monsoon and post-monsoon seasons *(Table 4.4) (Figure 4.3 a&b)*. The fecal coliform contamination is comparatively less, which would otherwise pose threat to the fishing and other purposes in this wetland ecosystem. The high prevalence of coliform within wetland water suggests a chronic problem and potential health risk especially to those populations, who use this water resource for different purposes.

4.3.4 Chatra wetland

4.3.4.1 Wetland hydrology:

The main support of the drainage of Chatra wetland is surface runoff, along with the consistent supply of municipal sewage flow. This peri-urban wetland is also rain fed and receives substantial amount of water round the year. The extent of water in this wetland fluctuates throughout the entire study time, and records significantly high during monsoon and post- monsoon season. The water level is recorded 2 to 3 meter in several pockets of this wetland, whereas maximum water depth is recorded > 3.0 meter during monsoon, followed by post-monsoon season *(Map 4.6)*. This wetland is particularly valuable in flood regulation as it holds 2.8 meter of excess water during monsoon period as per the field study, which is amounted to volume 9,620,318 m^3 and releases the flood water gradually in a desynchronized manner as well as moderates the peak discharge. The process of water retention and detention act as a very effective tool to regularize the ground water level. In the present study, the dynamic water storage of Chatra wetland is recorded 1.7 meter, including 0.9 meter of water to get evaporated *(Pal, 2017)*. Out of the remaining portion (0.8 meter), approximately 60 % of dynamic wetland water storage gets infiltrated as ground water reservoir and enable high water table by discharging gradually the water during lean period (pre-monsoon season).

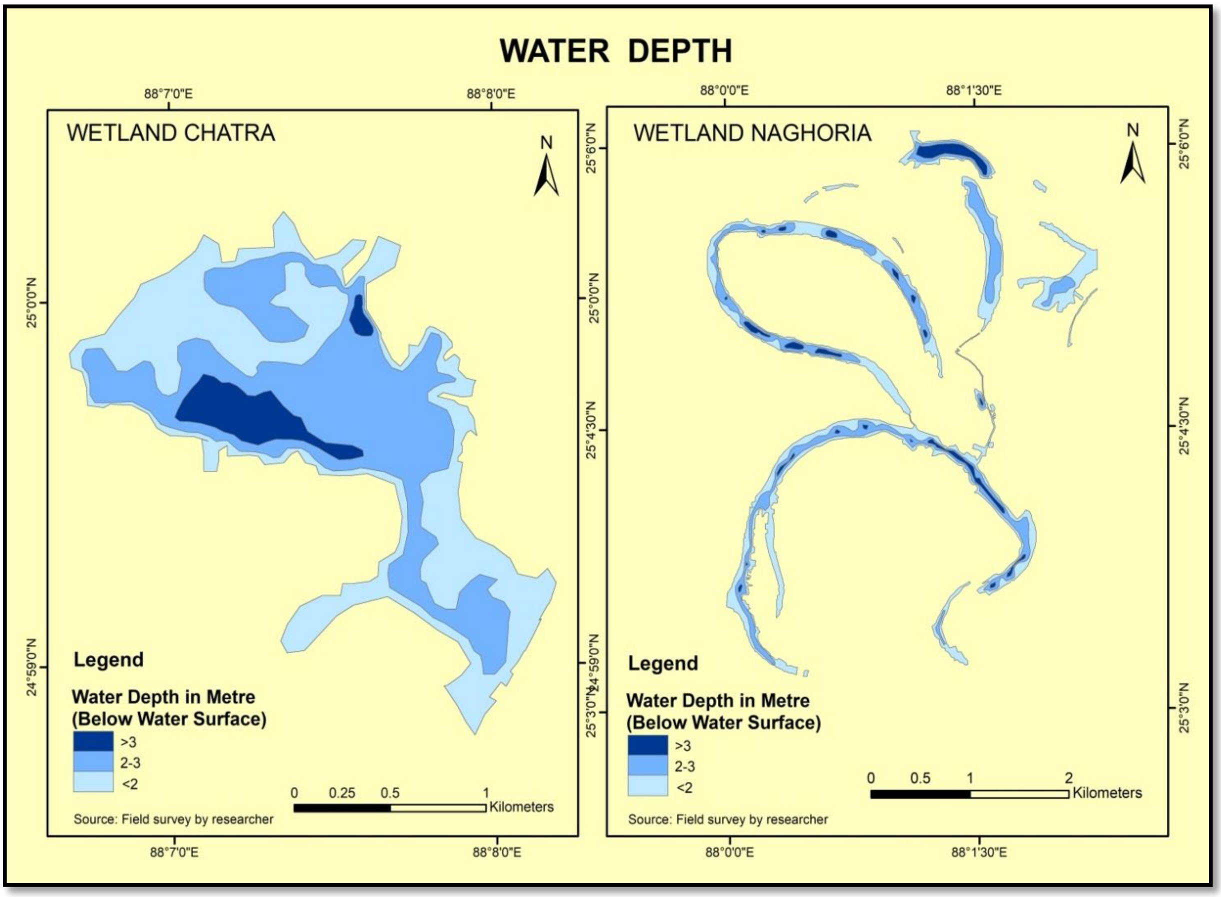
4.3.4.2 Physico-chemical and bacteriological parameters:

4.3.4.2.1 Physical parameters:

In the present study, ***water temperature*** is recorded between 25°C ($\bar{X}$=24.83; σ=0.29) to 32.9°C ($\bar{X}$=32.47; σ=0.45) throughout the study period. Maximum temperature is recorded in pre-monsoon (32.90°C), followed by monsoon (28.83°C) and post-monsoon (24.50°C) *(Table 4.5) (Figure 4.1 a)*. Being shallow water body, Chatra wetland is euphotic throughout and is a region of active photosynthesis process, as it contains a considerable population of the phytoplankton.

Chatra wetland records fluctuating ***turbidity*** ranges from 2.26 N.T.U. (X=3.22; σ=0.94) to 7.67 N.T.U. (X=7.38; σ=0.43) throughout the study. Monsoon (7.67N.T.U.) shows maximum record of turbidity, which exceeds the permissible limit (BIS & APHA). Post-monsoon (4.83N.T.U.) and pre-monsoon (2.26N.T.U.) successively record sharp decline in water turbidity *(Figure 4.1b)*. High turbidity in this peri-urban wetland is caused due to large accumulation of sewage water along with the organic pollutants from the adjacent English

Bazar Municipality *(Map 4.7)*. The increasing trend in turbidity by organic pollutants results into eutrophication.



Map 4.6: *Water depth of wetland Naghoria and Chatra in meter (below water surface)*

4.3.4.2.2 Chemical parameters:

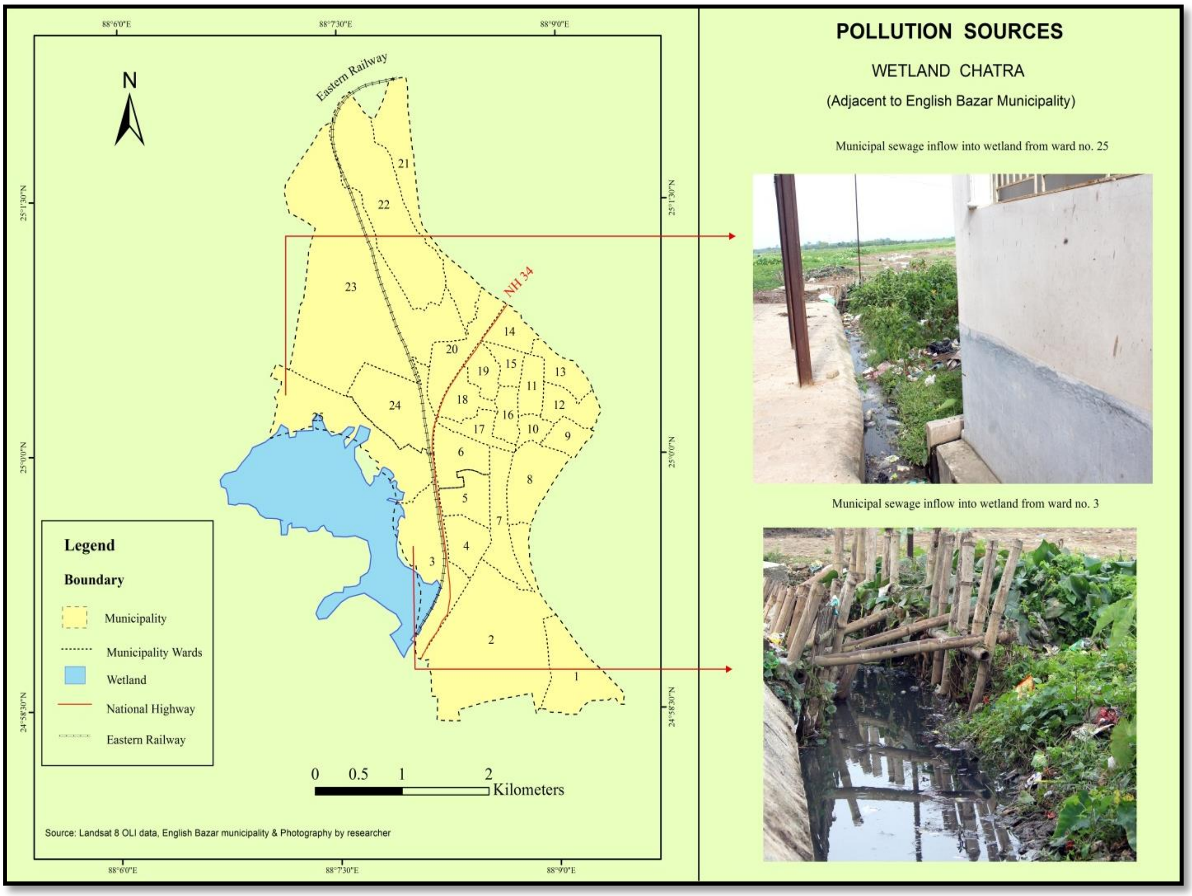
Wetland water ***pH*** ranges from 7.13 ($\bar{X}$=7.17; σ=0.06) to 8.67 ($\bar{X}$=8.24; σ=0.45) throughout the study period. The highest value of pH during pre-monsoon (8.67) reveals that the wetland water is normal to alkaline, associated with the high photosynthetic activity, which eventually substantiates excessive algal growth in wetland water. The recorded pH gradually declines during the monsoon (7.60) and post-monsoon (7.13) *(Table 4.5) (Figure 4.2 a)*, which is attributed to decomposition of carbonaceous materials, entering into the water body from surrounding agricultural field (north-west, west, south-west).

Conductivity in Chatra wetland is recorded highly fluctuating, which ranges between 330 µ.s. ($\bar{X}$=335.33; σ=4.73) to 593 µ.s. ($\bar{X}$=579.33; σ=13.05) *(Table 4.5) (Figure 4.2c)*. Pre-monsoon (593µ.s.) records maximum value of conductivity, which may be caused due to large ionic concentration, pollution status especially from domestic and municipal effluents and sewage and other organic matters from the peripheral localities into this water body. Monsoon (413.67µ.s.) followed by post-monsoon (330µ.s.) record sharp drop of conductivity in this peri-urban wetland *(Map 4.7)*.

Total dissolved solids also records a fluctuating concentration between 169 ppm (X=180.33; σ=14.01) to 298 ppm (X=293.33; σ=4.16) during the entire study period in Chatra wetland. Maximum dissolved solid is recorded during pre-monsoon (298ppm), followed by monsoon (248ppm) and minimum during post-monsoon (169ppm) *(Table 4.5) (Figure 4.2b)*. Primary sources of TDS into receiving wetland are agricultural runoff, domestic sewage, leaching of soil contamination and point source water pollution discharge in the form of municipal sewage from the adjacent municipal wards *(Map 4.7)*. Consequently, high concentration of dissolved solids increases the nutrient status of water body and ultimately results into immense potential of eutrophication. High level of TDS determines disturbances in the ecological balance and suffocation in the aquatic fauna.

The ***dissolved oxygen*** is found within 7.2 mg/L (X=7.50; σ=0.26) to 9.7 mg/L (X=9.63; σ=0.12) throughout the study period, with maximum concentration during post-monsoon (9.70mg/L) *(Table 4.5) (Figure 4.2d)*. The disposal of domestic and municipal sewage as well as other oxygen demanding waste reduces the dissolved oxygen concentration in the receiving peri-urban wetland, which is profoundly observed during pre-monsoon (7.20mg/L) period. Oxygen content of the bottom layer is compared to the surface, which indicates the eutrophic nature of the wetland ecosystem *(Chatrath, 1992)*.

In the present study, ***total hardness*** is recorded between 169 mg/L (X=180; σ=14.18) to 264 mg/L (X=252.67; σ=10.26). The peak value of hardness is recorded during pre-monsoon (264.00mg/L) period, which may be resulted from the sewage outflow from adjacent town into this peri-urban water body *(Table 4.5) (Figure 4.2e)*.



Map 4.7: *Municipal sewage inflow into Chatra wetland from adjacent wards*

Chloride concentration in Chatra wetland is more or less same across all the seasons, which records 53 mg/L (X=54; σ=1.74) to 56.34 mg/L (X=56.34; σ=0) during the entire study period. The relatively high concentration of chloride is recorded during pre-monsoon (56.34mg/L), which may be an index of pollution of animal origin and there is a direct correlation between chloride concentration and pollution levels *(Table 4.5) (Figure 4.2f)*.

The ***iron*** content in the wetland water ranges from 0.07 mg/L (X=0.01; σ=0.08) to 0.39 mg/L (X=0.27; σ=0.12) with maximum record during post-monsoon (0.39mg/L) whereas, minimum during pre-monsoon (0.07mg/L). The ***fluoride*** content is recorded negligible, with a little trace during post-monsoon (0.32 mg/L). ***Nitrate, arsenic, manganese*** contents are considerably low and found below detectable limit across all seasons in Chatra wetland.

Table 4.5 Statistical result on physic-chemical and bacteriological parameters of Chatra wetland

Parameters	Pre-monsoon			Monsoon			Post-monsoon		
	Mean		Std. Deviation	Mean		Std. Deviation	Mean		Std. Deviation
	Statistic	Std. Error	Statistic	Statistic	Std. Error	Statistic	Statistic	Std. Error	Statistic
Water temperature	32.47	0.26	0.45	28.83	0.17	0.29	24.83	0.17	0.29
pH	8.24	0.26	0.45	7.60	0.18	0.318	7.17	0.03	0.06
Conductivity	579.33	7.54	13.05	413.67	3.22	5.58	335.33	2.73	4.73
Total dissolved solid	293.33	2.40	4.16	248.00	1.53	2.65	180.33	8.09	14.01
Turbidity	3.22	0.54	0.94	7.38	0.25	0.43	5.40	0.29	0.50
Total hardness	252.67	5.93	10.26	202.00	6.00	10.39	180.00	8.19	14.18
Dissolved oxygen	7.50	0.15	0.26	8.93	0.03	0.058	9.63	0.067	0.12
Chloride	56.34	0.00	0.00	54.00	1.00	1.74	56.11	0.00	0.00
Iron	0.08	0.007	0.012	0.17	0.04	0.07	0.27	0.07	0.12
Fluoride	0.00	0.00	0.00	0.04	0.043	0.08	0.32	0.00	0.00
Arsenic	.0027	0.003	0.005	0.00	0.00	0.00	0.00	0.00	0.00
Total coliform	1.00	0.58	1.00	3.33	0.88	1.53	8.67	0.67	1.15
Fecal coliform	0.00	0.00	0.00	0.00	0.00	0.00	1.00	1.00	1.73

Source: *1. Water sample collected from field study*

2. Water sample tested by P.H.E. Department, under Malda Polytechnic, Govt. of West Bengal.

4.3.4.2.3. Bacteriological parameters:

In the context of bacteriological analysis, the laboratory test shows that the total and fecal coliform, are less in quantity in comparison with other three wetlands under case study. Average ***total coliform*** count ranges between 0 to 10 MPN (X=8.67; σ=1.15) per 100 ml water with highest record during post-monsoon (10MPN/100ml), whereas minimum during pre-monsoon (2MPN/100ml) period *(Table 4.5) (Figure 4.3a)*.

Fecal coliform is recorded insignificant (3MPN/100ml) throughout the entire water sample collection period *(Table 4.5) (Figure 4.3 b)*.

As per the field observation, Chatra wetland, being peri-urban, receives direct sewage inflow through 9 sewerages under ward no. 3 and 13 sewerages under ward no. 25, connected with several networks of sub-drains along the south-west boundary of adjacent English Bazar municipality. Few number of municipal sewerages from ward no. 23 and 24 along north-west boundary got outfall into this lowland. The water sample test *(Appendix-8)* covering three seasons (pre-monsoon, monsoon and post-monsoon) in consecutive 3 years (2015-18) record most of the water quality parameters to be restricted within permissible range, except water pH, conductivity, dissolved solid and water hardness, as proposed by BIS (2012) and APHA (2017), which is attributed to the filtering effect of Chatra wetland, acting as a *'kidney of landscape'*. The wetland and associated macrophytes (especially the water hyacinth) and microorganisms slow down the surface water flow, as well as allow the suspended particles (sediments and nutrients) to drop down to ground level and maintain the water quality round the year. This peri-urban wetland of Malda district is proved to be potential to treat regular inflow of waste water through several inlets from the adjacent localities.

4.4 Analysis of variance (ANOVA) of wetland water quality parameters:

The physical, chemical and bacteriological parameters of collected water sample from the selected wetlands have been interpreted. The study reveals that the wetlands record an identical trend of selected physico-chemical and bacteriological characteristics of wetland water with a distinct seasonal variation throughout the entire study period, which represent the ecological status of wetlands in Malda district. The variation of different physical, chemical and bacteriological parameters between the wetlands and the seasons has been computed by one way Anova, which is displayed from table 4.6 (a & b) to 4.18 (a & b).

4.4.1. Physical parameters:

4.4.1.1. Water temperature:

In the present study, the physical parameter of water temperature is recorded maximum during pre-monsoon, followed by monsoon and post-monsoon. The maximum water temperature is attributed to intense solar radiation, long day time exposure, high atmospheric temperature and low water level. This work is in accordance with early workers *(Akhtar et al., 2018)* in water bodies of Varanasi; *(Dattatreya et al., 2018)* in South-east coast, India; *(Alam et al., 2015)* in the Beels of Bangladesh.

Table 4.6 (a) Output of Water temperature between wetlands by Multiple Comparisons Test

	Sum of Squares	df	Mean Square	F	P value
Between Groups	9.036	3	3.012	.276	.842
Within Groups	349.047	32	10.908		
Total	358.082	35			

(I) Wetlands	(J) Wetlands	Mean Difference (I-J)	Std. Error	P value	95% Confidence Interval	
					Lower Bound	Upper Bound
Siali	Chakla	.88889	1.55690	.940	-3.3293	5.1071
	Naghoria	.11111	1.55690	1.000	-4.1071	4.3293
	Chatra	-.51111	1.55690	.988	-4.7293	3.7071
Chakla	Siali	-.88889	1.55690	.940	-5.1071	3.3293
	Naghoria	-.77778	1.55690	.959	-4.9960	3.4404
	Chatra	-1.40000	1.55690	.805	-5.6182	2.8182
Naghoria	Siali	-.11111	1.55690	1.000	-4.3293	4.1071
	Chakla	.77778	1.55690	.959	-3.4404	4.9960
	Chatra	-.62222	1.55690	.978	-4.8404	3.5960
Chatra	Siali	.51111	1.55690	.988	-3.7071	4.7293
	Chakla	1.40000	1.55690	.805	-2.8182	5.6182
	Naghoria	.62222	1.55690	.978	-3.5960	4.8404

Statistical analysis shows no significant variation of water temperature between the wetlands (F=0.28) where, p value > α value (significance level at 0.05 in two-tailed test) at 95% confidence level. The wetlands, under more or less uniform physiography record an identical trend in water temperature, corresponding with atmospheric temperature. Statistical analysis shows significant ($p<0.05$) variation of water temperature between the seasons (F=343.73) where, p value < α value. Table 4.6 (a) & (b) are self-explanatory.

Table 4.6 (b) Output of Water temperatures between seasons by Multiple Comparisons Test

	Sum of Squares	df	Mean Square	F	P value
Between Groups	341.681	2	170.840	343.729	.000
Within Groups	16.402	33	.497		
Total	358.082	35			

(I) Seasons	(J) Seasons	Mean Difference (I-J)	Std. Error	P value	95% Confidence Interval	
					Lower Bound	Upper Bound
Pre-monsoon	Monsoon	4.00000*	.28781	.000	3.2938	4.7062
	Post-monsoon	7.54167*	.28781	.000	6.8354	8.2479
Monsoon	Pre-monsoon	-4.00000*	.28781	.000	-4.7062	-3.2938
	Post-monsoon	3.54167*	.28781	.000	2.8354	4.2479
Post-monsoon	Pre-monsoon	-7.54167*	.28781	.000	-8.2479	-6.8354
	Monsoon	-3.54167*	.28781	.000	-4.2479	-2.8354

**. The mean difference is significant at the 0.05 level.*

4.4.1.2. Turbidity:

In the present study, high accumulations of sewage water in conjunction with organic load have resulted into high turbidity during monsoon and successively record sharp decline during post-monsoon and pre-monsoon. Low turbidity may be recorded due to trapping of turbidity particles by the underwater hydrophytes in the wetlands *(Vankar et al., 2018)*. This study is in accordance with early workers in the wetlands of Jorhat, Assam *(Lodh et al., 2014)* and Central Gujarat *(Vankar et al., 2018)*.

Table 4.7 (a) Output of Turbidity between wetland by Multiple Comparisons Test

	Sum of Squares	df	Mean Square	F	P value
Between Groups	30.847	3	10.282	5.396	.004
Within Groups	60.975	32	1.905		
Total	91.821	35			

(I) Wetlands	(J) Wetlands	Mean Difference (I-J)	Std. Error	P value	95% Confidence Interval Lower Bound	Upper Bound
Siali	Chakla	-2.07556*	.65072	.016	-3.8386	-.3125
	Naghoria	-.34889	.65072	.950	-2.1119	1.4141
	Chatra	-1.93778*	.65072	.027	-3.7008	-.1747
Chakla	Siali	2.07556*	.65072	.016	.3125	3.8386
	Naghoria	1.72667	.65072	.057	-.0364	3.4897
	Chatra	.13778	.65072	.997	-1.6253	1.9008
Naghoria	Siali	.34889	.65072	.950	-1.4141	2.1119
	Chakla	-1.72667	.65072	.057	-3.4897	.0364
	Chatra	-1.58889	.65072	.089	-3.3519	.1741
Chatra	Siali	1.93778*	.65072	.027	.1747	3.7008
	Chakla	-.13778	.65072	.997	-1.9008	1.6253
	Naghoria	1.58889	.65072	.089	-.1741	3.3519

**. The mean difference is significant at the 0.05 level.*

Statistical analysis shows significant ($p<0.05$) variation in water turbidity between wetlands ($F=5.40$) where, the p value < α value (significance level at 0.05 in two-tailed test) at 95% confidence level. Siali wetland makes significant variation with Chakla and Chatra wetland. It may be caused that, Chatra wetland, being a peri-urban water body, receives large accumulation of sewage water along with the organic pollutants from the adjacent wards under English Bazar municipality. ANOVA also shows significant ($p<0.05$) variation between the surveyed seasons ($F=20.82$) as, the p value < α value *(Table 4.7 (a) & (b))*.

Table 4.7 (b) Output of Turbidity between seasons by Multiple Comparisons Test

	Sum of Squares	df	Mean Square	F	P value
Between Groups	51.220	2	25.610	20.815	.000
Within Groups	40.601	33	1.230		
Total	91.821	35			

(I) Seasons	(J) Seasons	Mean Difference (I-J)	Std. Error	P value	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
Pre-monsoon	Monsoon	-2.92083*	.45283	.000	-4.0320	-1.8097
	Post-monsoon	-1.52417*	.45283	.005	-2.6353	-.4130
Monsoon	Pre-monsoon	2.92083*	.45283	.000	1.8097	4.0320
	Post-monsoon	1.39667*	.45283	.011	.2855	2.5078
Post-monsoon	Pre-monsoon	1.52417*	.45283	.005	.4130	2.6353
	Monsoon	-1.39667*	.45283	.011	-2.5078	-.2855

**. The mean difference is significant at the 0.05 level.*

4.4.2 Chemical parameters:

4.4.2.1 Water pH:

Water pH as a chemical water quality parameter is recorded maximum during pre-monsoon, followed by monsoon and post-monsoon in the wetlands. The pre-monsoon peak may be attributed to active photosynthesis and high decomposition activities. The lower level of pH during monsoon and post-monsoon may be attributed to addition of surface run-off into wetland water and decomposition of organic matter. This study in Malda district is found similar with early observers in the wetlands of Jorhat, Assam *(Abujam et al., 2012)*; in Sagar wetland, Madhya Pradesh *(Choudhary & Ahi, 2015);* in Karnataka *(Majagi, 2014);* in water bodies, U.P. *(Maurya & Singh, 2016)*.

Table 4.8 (a) Output of Water pH between wetland by Multiple Comparisons Test

	Sum of Squares	df	Mean Square	F	P value
Between Groups	.764	3	.255	2.042	.128
Within Groups	3.992	32	.125		
Total	4.757	35			

(I) Wetlands	(J) Wetlands	Mean Difference (I-J)	Std. Error	P value	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
Siali	Chakla	.08111	.16651	.961	-.3700	.5322
	Naghoria	-.04444	.16651	.993	-.4956	.4067
	Chatra	-.30778	.16651	.270	-.7589	.1434
Chakla	Siali	-.08111	.16651	.961	-.5322	.3700
	Naghoria	-.12556	.16651	.874	-.5767	.3256
	Chatra	-.38889	.16651	.111	-.8400	.0622
Naghoria	Siali	.04444	.16651	.993	-.4067	.4956
	Chakla	.12556	.16651	.874	-.3256	.5767
	Chatra	-.26333	.16651	.403	-.7145	.1878
Chatra	Siali	.30778	.16651	.270	-.1434	.7589
	Chakla	.38889	.16651	.111	-.0622	.8400
	Naghoria	.26333	.16651	.403	-.1878	.7145

In the present study, the statistical analysis shows no significant ($p>0.05$) variation of water pH between the wetlands ($F=2.04$) where, p value > α (significance level at 0.05 in two-tailed test) at 95% confidence level. All the selected wetlands maintain an identical record of pH. Conversely, analysis of variance shows significant ($p<0.05$) variation of water pH between the seasons ($F=19.78$) where, the p value < α value. *(Table 4.8 (a) & (b)).*

Table 4.8 (b) Output of Water pH between seasons by Multiple Comparisons Test

	Sum of Squares	df	Mean Square	F	P value
Between Groups	2.593	2	1.297	19.783	.000
Within Groups	2.163	33	.066		
Total	4.757	35			

(I) Seasons	(J) Seasons	Mean Difference (I-J)	Std. Error	P value	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
Pre-monsoon	Monsoon	.27833*	.10452	.031	.0219	.5348
	Post-monsoon	.65500*	.10452	.000	.3985	.9115
Monsoon	Pre-monsoon	-.27833*	.10452	.031	-.5348	-.0219
	Post-monsoon	.37667*	.10452	.003	.1202	.6331
Post-monsoon	Pre-monsoon	-.65500*	.10452	.000	-.9115	-.3985
	Monsoon	-.37667*	.10452	.003	-.6331	-.1202

**. The mean difference is significant at the 0.05 level.*

4.4.2.2 Conductivity:

In the present study, the conductivity is recorded highest during pre-monsoon and relatively lower during post-monsoon seasons in the case studies. High conductivity during pre-monsoon may be caused due to large ionic concentration by addition of domestic sewage into wetlands. Highest concentration of conductivity may also be associated with decreasing fresh water flow and increasing evaporation rate by intense sunlight. Conversely, the lower concentration of conductivity may be caused due to influx of monsoon water into wetlands as well as flushing out of dissolved ion. This observation reveals similarity by the early workers in Kuttanad wetland ecosystem, Kerala *(Sylas, 2010)*; in the urban lakes, Bangalore *(Ramachandra et al., 2014)*; in Rudrasagar wetland, Tripura *(Abir, 2014);* in Surila taal, U.P. *(Maurya & Singh, 2016).*

Table 4.9 (a) Output of Conductivity between wetland by Multiple Comparisons Test

	Sum of Squares	df	Mean Square	F	P value
Between Groups	646379.499	3	215459.833	54.120	.000
Within Groups	127396.953	32	3981.155		
Total	773776.452	35			

(I) Wetlands	(J) Wetlands	Mean Difference (I-J)	Std. Error	P value	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
Siali	Chakla	13.34444	29.74392	.969	-67.2426	93.9315
	Naghoria	-17.65556	29.74392	.933	-98.2426	62.9315
	Chatra	-309.84444*	29.74392	.000	-390.4315	-229.2574
Chakla	Siali	-13.34444	29.74392	.969	-93.9315	67.2426
	Naghoria	-31.00000	29.74392	.726	-111.5870	49.5870
	Chatra	-323.18889*	29.74392	.000	-403.7759	-242.6018
Naghoria	Siali	17.65556	29.74392	.933	-62.9315	98.2426
	Chakla	31.00000	29.74392	.726	-49.5870	111.5870
	Chatra	-292.18889*	29.74392	.000	-372.7759	-211.6018
Chatra	Siali	309.84444*	29.74392	.000	229.2574	390.4315
	Chakla	323.18889*	29.74392	.000	242.6018	403.7759
	Naghoria	292.18889*	29.74392	.000	211.6018	372.7759

**. The mean difference is significant at the 0.05 level.*

ANOVA shows significant ($p<0.05$) variation in water conductivity between the wetlands ($F=54.12$), where the p value < α value (significance level at 0.05 in two-tailed test) at 95% confidence level. Chatra wetland records significant variation with Siali, Chakla and Naghoria wetland. This may be caused that, Chatra wetland receives highly toxic municipal sewage along with agricultural and domestic effluents comparing with other three wetlands, which only receive agricultural and organic waste and it creates a variation between the wetlands. On the contrary, no significant ($p>0.05$) variation is found between the seasons ($F=1.60$) where, the p value > α value. This indicates almost all the seasons identically record the concentration of conductivity within wetlands. Table 4.9 (a) & (b) are self-explanatory.

Table 4.9 (b) Output of Conductivity between seasons by Multiple Comparisons Test

	Sum of Squares	df	Mean Square	F	P value
Between Groups	68369.817	2	34184.909	1.599	.217
Within Groups	705406.635	33	21375.959		
Total	773776.452	35			

(I) Seasons	(J) Seasons	Mean Difference (I-J)	Std. Error	P value	95% Confidence Interval Lower Bound	Upper Bound
Pre-monsoon	Monsoon	71.45000	59.68802	.463	-75.0121	217.9121
	Post-monsoon	104.40833	59.68802	.202	-42.0538	250.8705
Monsoon	Pre-monsoon	-71.45000	59.68802	.463	-217.9121	75.0121
	Post-monsoon	32.95833	59.68802	.846	-113.5038	179.4205
Post-monsoon	Pre-monsoon	-104.40833	59.68802	.202	-250.8705	42.0538
	Monsoon	-32.95833	59.68802	.846	-179.4205	113.5038

4.4.2.3 Total dissolved solid:

In the present study, the total dissolved solid in wetland water records maximum during pre-monsoon due to additional organic and inorganic waste into wetlands from the peripheral locality. Water dissolved solid substantially declines during monsoon and post-monsoon in the wetlands due to influx of monsoon water. The present work is in accordance with the early workers in Bibi Lake, Ahmedabad *(Qureshimatva & Solanki, 2015)*; in Gujarat *(Sonal et al., 2010);* in Chandlodia Lake, Ahmedabad, Gujarat *(Qureshimatva et al., 2015);* in the fresh water pond of Central India *(Yadav et al., 2013)*.

Table 4.10 (a) Output of Dissolved solid between wetland by Multiple Comparisons Test

	Sum of Squares	df	Mean Square	F	P value
Between Groups	204222.601	3	68074.200	84.890	.000
Within Groups	25661.109	32	801.910		
Total	229883.710	35			

(I) Wetlands	(J) Wetlands	Mean Difference (I-J)	Std. Error	P value	95% Confidence Interval Lower Bound	Upper Bound
Siali	Chakla	9.74444	13.34924	.884	-26.4235	45.9124
	Naghoria	-6.45556	13.34924	.962	-42.6235	29.7124
	Chatra	-172.33333*	13.34924	.000	-208.5012	-136.1654

Chakla	Siali	-9.74444	13.34924	.884	-45.9124	26.4235
	Naghoria	-16.20000	13.34924	.623	-52.3679	19.9679
	Chatra	-182.07778*	13.34924	.000	-218.2457	-145.9099
Naghoria	Siali	6.45556	13.34924	.962	-29.7124	42.6235
	Chakla	16.20000	13.34924	.623	-19.9679	52.3679
	Chatra	-165.87778*	13.34924	.000	-202.0457	-129.7099
Chatra	Siali	172.33333*	13.34924	.000	136.1654	208.5012
	Chakla	182.07778*	13.34924	.000	145.9099	218.2457
	Naghoria	165.87778*	13.34924	.000	129.7099	202.0457

**. The mean difference is significant at the 0.05 level.*

Statistical analysis shows significant ($p<0.05$) variation in water dissolved solid between the wetlands ($F=84.89$), where the p value < α (significance level at 0.05 in two-tailed) at 95% confidence level. Between the wetlands, Chatra wetland with Siali, Chakla and Naghoria wetland record significant variation, which may be caused by the following lines: The primary sources of dissolved solid into receiving wetlands of Siali, Chakla and Naghoria are agricultural runoff and domestic sewage. But the peri-urban wetland of Chatra regularly receives the point source discharge in the form of municipal sewage from the adjacent wards, which has made a substantial variation with other three water bodies under case study. No significant variation ($p>0.05$) in the dissolved solid is found between the seasons ($F=1.16$) where, the p value > α value. This result has indicated an identical record of tds throughout the seasons. Table 4.10 (a) & (b) are self-explanatory.

Table 4.10 (b) Output of Dissolved solid between seasons by Multiple Comparisons Test

	Sum of Squares	df	Mean Square	F	P value
Between Groups	15148.402	2	7574.201	1.164	.325
Within Groups	214735.308	33	6507.131		
Total	229883.710	35			

(I) Seasons	(J) Seasons	Mean Difference (I-J)	Std. Error	P value	95% Confidence Interval Lower Bound	Upper Bound
Pre-monsoon	Monsoon	22.25833	32.93208	.779	-58.5502	103.0669
	Post-monsoon	50.14167	32.93208	.294	-30.6669	130.9502
Monsoon	Pre-monsoon	-22.25833	32.93208	.779	-103.0669	58.5502
	Post-monsoon	27.88333	32.93208	.677	-52.9252	108.6919
Post-monsoon	Pre-monsoon	-50.14167	32.93208	.294	-130.9502	30.6669
	Monsoon	-27.88333	32.93208	.677	-108.6919	52.9252

4.4.2.4 Total hardness:

In the present study, total hardness in wetland water is recorded maximum during pre-monsoon due to domestic and municipal sewage inflow, when the water level is low whereas, minimum concentration is recorded during monsoon and post-monsoon due to additional influx of run-off into wetlands. This work is supported by several workers in inland wetlands of Gujarat *(Sonal et al., 2010)*; in the wetlands of Karnataka *(Majagi, 2014)*; in the fresh water lake of central India *(Yadav et al., 2013)*; beels of Bangladesh *(Alam et al., 2015)*; in Chandlodia Lake of Gujarat *(Verma et al., 2012);* in water bodies of Madhya Pradesh *(Choudhary & Ahi, 2015).*

Table 4.11 (a) Output of Total hardness between wetland by Multiple Comparisons Test

	Sum of Squares	df	Mean Square	F	P value
Between Groups	85433.222	3	28477.741	24.919	.000
Within Groups	36569.778	32	1142.806		
Total	122003.000	35			

(I) Wetlands	(J) Wetlands	Mean Difference (I-J)	Std. Error	P value	95% Confidence Interval Lower Bound	Upper Bound
Siali	Chakla	53.556*	15.936	.010	10.38	96.73
	Naghoria	4.000	15.936	.994	-39.18	47.18
	Chatra	-82.222*	15.936	.000	-125.40	-39.05
Chakla	Siali	-53.556*	15.936	.010	-96.73	-10.38
	Naghoria	-49.556*	15.936	.019	-92.73	-6.38
	Chatra	-135.778*	15.936	.000	-178.95	-92.60
Naghoria	Siali	-4.000	15.936	.994	-47.18	39.18
	Chakla	49.556*	15.936	.019	6.38	92.73
	Chatra	-86.222*	15.936	.000	-129.40	-43.05
Chatra	Siali	82.222*	15.936	.000	39.05	125.40
	Chakla	135.778*	15.936	.000	92.60	178.95
	Naghoria	86.222*	15.936	.000	43.05	129.40

**. The mean difference is significant at the 0.05 level.*

Statistical analysis shows significant ($p<0.05$) variation in water hardness between the wetlands ($F=24.92$) where, the p value < α value (significance level at 0.05 in two-tailed test) at 95% confidence level. Between the case studies, Chatra wetland with Siali, Naghoria and Chakla wetland; and Chakla wetland with Siali and Naghoria wetland record significant variations. The regular addition as well as accumulation of sewage from the resident localities and municipalities with presence of high content of calcium and magnesium makes Chatra wetland significantly variable with other water bodies. ANOVA shows marked and significant ($p<0.05$) variation between the seasons ($F=4.75$) of pre-monsoon with post-monsoon where, the p value < α value. *(Table 4.11 (a) & (b))*.

Table 4.11 (b) Output of Total hardness between seasons by Multiple Comparisons Test

	Sum of Squares	df	Mean Square	F	P value
Between Groups	27273.167	2	13636.583	4.750	.015
Within Groups	94729.833	33	2870.601		
Total	122003.000	35			

(I) Seasons	(J) Seasons	Mean Difference (I-J)	Std. Error	P value	95% Confidence Interval Lower Bound	Upper Bound
Pre-monsoon	Monsoon	40.583	21.873	.168	-13.09	94.26
	Post-monsoon	66.917*	21.873	.012	13.24	120.59
Monsoon	Pre-monsoon	-40.583	21.873	.168	-94.26	13.09
	Post-monsoon	26.333	21.873	.459	-27.34	80.01
Post-monsoon	Pre-monsoon	-66.917*	21.873	.012	-120.59	-13.24
	Monsoon	-26.333	21.873	.459	-80.01	27.34

**. The mean difference is significant at the 0.05 level.*

4.4.2.5 Dissolved oxygen:

In the present study, the wetlands record highest concentration of dissolved oxygen during post-monsoon, due to increased solubility of oxygen content because of low atmospheric as well as water temperature *(Maurya & Singh, 2016)*. Lowest concentration of do is observed in pre-monsoon because of increasing water temperature corresponding with atmospheric temperature and high microbial activity, heavy organic load in the form of oxygen demanding waste. This work is in accordance with early workers in East Kolkata Wetland *(Roy et al., 2016)*; in Surila taal, Uttar Pradesh *(Maurya & Singh, 2016)*; in Satajan wetland, Assam *(Hazarika, 2013)*; in wetlands of Mid-westernghat region *(Pramod et al., 2011)*.

Statistical analysis shows significant ($p<0.05$) variation of dissolved oxygen between the wetlands ($F=28.50$) where, the p value < α value (significance level at 0.05 in two tailed test) at 95% confidence level. Significant ($p<0.05$) variation of dissolved oxygen is recorded between Siali and Chakla wetland with Chatra and Naghoria wetland. As the high concentration of do is good for aquatic health of an ecosystem, it is quite unnatural that the wetlands, regularly receive domestic and municipal sewage, record high concentration of do rather than those water bodies receive only agricultural and domestic discharge. But the study consistently records this trend consecutively for three years. Therefore, further research and investigation can be done. However, significant ($p<0.05$) variation is also recorded between the seasons ($F=5.58$) of pre-monsoon and post-monsoon *(Table no. 4.12 (a) & (b))*.

Table 4.12 (a) Output of Dissolved oxygen between wetland by Multiple Comparisons Test

	Sum of Squares	df	Mean Square	F	P value
Between Groups	83.894	3	27.965	28.501	.000
Within Groups	31.398	32	.981		
Total	115.292	35			

(I) Wetlands	(J) Wetlands	Mean Difference (I-J)	Std. Error	P value	95% Confidence Interval	
					Lower Bound	Upper Bound
Siali	Chakla	-.04444	.46695	1.000	-1.3096	1.2207
	Naghoria	-2.81111*	.46695	.000	-4.0762	-1.5460
	Chatra	-3.30000*	.46695	.000	-4.5651	-2.0349
Chakla	Siali	.04444	.46695	1.000	-1.2207	1.3096
	Naghoria	-2.76667*	.46695	.000	-4.0318	-1.5015
	Chatra	-3.25556*	.46695	.000	-4.5207	-1.9904
Naghoria	Siali	2.81111*	.46695	.000	1.5460	4.0762
	Chakla	2.76667*	.46695	.000	1.5015	4.0318
	Chatra	-.48889	.46695	.723	-1.7540	.7762
Chatra	Siali	3.30000*	.46695	.000	2.0349	4.5651
	Chakla	3.25556*	.46695	.000	1.9904	4.5207
	Naghoria	.48889	.46695	.723	-.7762	1.7540

**. The mean difference is significant at the 0.05 level.*

Table 4.12 (b) Output of Dissolved oxygen between seasons by Multiple Comparisons Test

	Sum of Squares	df	Mean Square	F	P value
Between Groups	29.127	2	14.564	5.578	.008
Within Groups	86.165	33	2.611		
Total	115.292	35			

(I) Seasons	(J) Seasons	Mean Difference (I-J)	Std. Error	P value	95% Confidence Interval	
					Lower Bound	Upper Bound
Pre-monsoon	Monsoon	-1.29167	.65968	.139	-2.9104	.3271
	Post-monsoon	-2.19167*	.65968	.006	-3.8104	-.5729
Monsoon	Pre-monsoon	1.29167	.65968	.139	-.3271	2.9104
	Post-monsoon	-.90000	.65968	.371	-2.5187	.7187
Post-monsoon	Pre-monsoon	2.19167*	.65968	.006	.5729	3.8104
	Monsoon	.90000	.65968	.371	-.7187	2.5187

**. The mean difference is significant at the 0.05 level.*

4.4.2.6 Iron:

In the present study, iron content record maximum concentration during post-monsoon, followed by pre-monsoon and monsoon. This result is found similar by early workers in the wetlands of westernghat regions *(Pramod et al., 2011)*.

Table 4.13 (a) Output of Iron content between wetland by Multiple Comparisons Test

	Sum of Squares	df	Mean Square	F	P value
Between Groups	1.820	3	.607	12.783	.000
Within Groups	1.519	32	.047		
Total	3.338	35			

(I) Wetlands	(J) Wetlands	Mean Difference (I-J)	Std. Error	P value	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
Siali	Chakla	-.35111*	.10269	.009	-.6293	-.0729
	Naghoria	.17333	.10269	.346	-.1049	.4516
	Chatra	.22222	.10269	.155	-.0560	.5005
Chakla	Siali	.35111*	.10269	.009	.0729	.6293
	Naghoria	.52444*	.10269	.000	.2462	.8027
	Chatra	.57333*	.10269	.000	.2951	.8516
Naghoria	Siali	-.17333	.10269	.346	-.4516	.1049
	Chakla	-.52444*	.10269	.000	-.8027	-.2462
	Chatra	.04889	.10269	.964	-.2293	.3271
Chatra	Siali	-.22222	.10269	.155	-.5005	.0560
	Chakla	-.57333*	.10269	.000	-.8516	-.2951
	Naghoria	-.04889	.10269	.964	-.3271	.2293

**. The mean difference is significant at the 0.05 level.*

Statistical analysis shows significant ($p<0.05$) variation of iron content in water between the wetlands ($F=12.78$) where, the p value < α (significance level at 0.05 in two-tailed test) at 95% confidence level. Iron content variation may be caused due to solid waste disposal without treatment into wetlands especially from those, adjacent to municipal boundary. ANOVA shows significant variation between the seasons ($F=4.92$) of post-monsoon with pre-monsoon and monsoon. Table 4.13 (a) & (b) are self-explanatory.

Table 4.13 (b) Output of Iron content between seasons by Multiple Comparisons Test

	Sum of Squares	df	Mean Square	F	P value
Between Groups	.767	2	.384	4.924	.013
Within Groups	2.571	33	.078		
Total	3.338	35			

(I) Seasons	(J) Seasons	Mean Difference (I-J)	Std. Error	P value	95% Confidence Interval Lower Bound	Upper Bound
Pre-monsoon	Monsoon	-.05000	.11395	.900	-.3296	.2296
	Post-monsoon	-.33167*	.11395	.017	-.6113	-.0520
Monsoon	Pre-monsoon	.05000	.11395	.900	-.2296	.3296
	Post-monsoon	-.28167*	.11395	.048	-.5613	-.0020
Post-monsoon	Pre-monsoon	.33167*	.11395	.017	.0520	.6113
	Monsoon	.28167*	.11395	.048	.0020	.5613

**. The mean difference is significant at the 0.05 level.*

4.4.2.7 Chloride:

In the present study, chloride content is recorded highest during post-monsoon and is maintained up to pre-monsoon. The high level of chloride in water may be caused due to high accumulation of organic load through run-off inflow during monsoon. Relatively low level of chloride content in wetland is attributed to maximum evaporation of water during pre-monsoon. This study is in conformity with early workers in Orai pond, U.P. *(Yadav et al., 2013)*; in Pune, Maharashtra *(Yadav & Yadav, 2017)*; in Sagar Lake, M.P. *(Choudhary & Ahi, 2015)*; in Central Gujarat *(Vankar et al., 2018)*.

Table 4.14 (a) Output of Chloride content between wetland by Multiple Comparisons Test

	Sum of Squares	df	Mean Square	F	P value
Between Groups	22154.886	3	7384.962	146.898	.000
Within Groups	1608.726	32	50.273		
Total	23763.611	35			

(I) Wetlands	(J) Wetlands	Mean Difference (I-J)	Std. Error	P value	95% Confidence Interval Lower Bound	Upper Bound
Siali	Chakla	41.52000*	3.34241	.000	32.4642	50.5758
	Naghoria	66.35000*	3.34241	.000	57.2942	75.4058
	Chatra	19.06222*	3.34241	.000	10.0064	28.1180
Chakla	Siali	-41.52000*	3.34241	.000	-50.5758	-32.4642
	Naghoria	24.83000*	3.34241	.000	15.7742	33.8858
	Chatra	-22.45778*	3.34241	.000	-31.5136	-13.4020
Naghoria	Siali	-66.35000*	3.34241	.000	-75.4058	-57.2942
	Chakla	-24.83000*	3.34241	.000	-33.8858	-15.7742
	Chatra	-47.28778*	3.34241	.000	-56.3436	-38.2320
Chatra	Siali	-19.06222*	3.34241	.000	-28.1180	-10.0064
	Chakla	22.45778*	3.34241	.000	13.4020	31.5136
	Naghoria	47.28778*	3.34241	.000	38.2320	56.3436

**. The mean difference is significant at the 0.05 level.*

Statistical analysis shows significant ($p<0.05$) variation in chloride content between the wetlands ($F=146.90$) where, the p value < α value (significance level at 0.05 in two-tailed test) at 95% confidence level. The variations between wetlands are attributed to natural contaminants and pollutants by frequent run-off into the wetlands *(Parashar et al., 2008)*. No significant ($p>0.05$) variation is recorded between the seasons ($F=0.57$), where the p value > α value *(Table 4.14(a) & (b))*.

Table 4.14(b) Output of Chloride content between seasons by Multiple Comparisons Test

	Sum of Squares	df	Mean Square	F	P value
Between Groups	787.231	2	393.616	.565	.574
Within Groups	22976.380	33	696.254		
Total	23763.611	35			

(I) Seasons	(J) Seasons	Mean Difference (I-J)	Std. Error	P value	95% Confidence Interval Lower Bound	Upper Bound
Pre-monsoon	Monsoon	-.17250	10.77229	1.000	-26.6055	26.2605
	Post-monsoon	-10.00500	10.77229	.626	-36.4380	16.4280
Monsoon	Pre-monsoon	.17250	10.77229	1.000	-26.2605	26.6055
	Post-monsoon	-9.83250	10.77229	.636	-36.2655	16.6005
Post-monsoon	Pre-monsoon	10.00500	10.77229	.626	-16.4280	36.4380
	Monsoon	9.83250	10.77229	.636	-16.6005	36.2655

4.4.2.8 Fluoride:

In the present study, fluoride content records very negligible throughout the study period. Statistical analysis shows significant ($p<0.05$) variation of fluoride content between the wetlands ($F=14.07$) where, the p value < α value (significance level at 0.05 in two-tailed test) at 95% confidence level. The wetlands, located adjacent to Malda town, record fluoride content below detectable limit. No significant variation of fluoride concentration is recorded between the seasons ($F=2.32$) where, the p value > α value. Table 4.15 (a) & (b) are self-explanatory.

Table 4.15 (a) Output of Fluoride content between wetland by Multiple Comparisons Test

	Sum of Squares	df	Mean Square	F	P value.
Between Groups	.294	3	.098	14.071	.000
Within Groups	.223	32	.007		
Total	.516	35			

(I) Wetlands	(J) Wetlands	Mean Difference (I-J)	Std. Error	P value	95% Confidence Interval Lower Bound	Upper Bound
Siali	Chakla	.03889	.03932	.757	-.0676	.1454
	Naghoria	.23667*	.03932	.000	.1301	.3432
	Chatra	.11556*	.03932	.029	.0090	.2221

Chakla	Siali	-.03889	.03932	.757	-.1454	.0676
	Naghoria	.19778*	.03932	.000	.0912	.3043
	Chatra	.07667	.03932	.228	-.0299	.1832
Naghoria	Siali	-.23667*	.03932	.000	-.3432	-.1301
	Chakla	-.19778*	.03932	.000	-.3043	-.0912
	Chatra	-.12111*	.03932	.021	-.2276	-.0146
Chatra	Siali	-.11556*	.03932	.029	-.2221	-.0090
	Chakla	-.07667	.03932	.228	-.1832	.0299
	Naghoria	.12111*	.03932	.021	.0146	.2276

**. The mean difference is significant at the 0.05 level.*

Table 4.15 (b) Output of Fluoride content between seasons by Multiple Comparisons Test

	Sum of Squares	df	Mean Square	F	P value
Between Groups	.064	2	.032	2.321	.114
Within Groups	.453	33	.014		
Total	.516	35			

(I) Seasons	(J) Seasons	Mean Difference (I-J)	Std. Error	P value	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
Pre-monsoon	Monsoon	-.01750	.04782	.929	-.1348	.0998
	Post-monsoon	-.09667	.04782	.123	-.2140	.0207
Monsoon	Pre-monsoon	.01750	.04782	.929	-.0998	.1348
	Post-monsoon	-.07917	.04782	.237	-.1965	.0382
Post-monsoon	Pre-monsoon	.09667	.04782	.123	-.0207	.2140
	Monsoon	.07917	.04782	.237	-.0382	.1965

4.4.2.9 Arsenic:

Arsenic content is recorded negligible in all the case studies with small presence during pre-monsoon throughout the entire study period. This work is in accordance with early workers *(Chakraborty et al., 2007)* in the aquifers of English Bazar block, Malda district. Statistical analysis shows significant ($p<0.05$) variation of arsenic content between the wetlands ($F=5.22$) where, the p value < α value (significance level at 0.05 in two-tailed test) at 95% confidence level. The peri-urban wetland, located adjacent to municipal area, record arsenic content below detectable limit throughout the study period, which makes significant variation with other wetlands. Analysis of variance shows significant variation between the seasons ($F=4.62$), especially between pre-monsoon and monsoon *(Table 4.16 (a) & (b))*.

Table 4.16 (a) Output of Arsenic content between wetland by Multiple Comparisons Test

	Sum of Squares	df	Mean Square	F	P value
Between Groups	.003	3	.001	5.215	.005
Within Groups	.007	32	.000		
Total	.010	35			

(I) Wetlands	(J) Wetlands	Mean Difference (I-J)	Std. Error	P value	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
Siali	Chakla	.004333	.006952	.924	-.01450	.02317
	Naghoria	-.017556	.006952	.075	-.03639	.00128
	Chatra	.007667	.006952	.690	-.01117	.02650
Chakla	Siali	-.004333	.006952	.924	-.02317	.01450
	Naghoria	-.021889*	.006952	.018	-.04072	-.00305
	Chatra	.003333	.006952	.963	-.01550	.02217
Naghoria	Siali	.017556	.006952	.075	-.00128	.03639
	Chakla	.021889*	.006952	.018	.00305	.04072
	Chatra	.025222*	.006952	.005	.00639	.04406
Chatra	Siali	-.007667	.006952	.690	-.02650	.01117
	Chakla	-.003333	.006952	.963	-.02217	.01550
	Naghoria	-.025222*	.006952	.005	-.04406	-.00639

**. The mean difference is significant at the 0.05 level.*

Table 4.16 (b) Output of Arsenic content between seasons by Multiple Comparisons Test

	Sum of Squares	df	Mean Square	F	P value
Between Groups	.002	2	.001	4.618	.017
Within Groups	.008	33	.000		
Total	.010	35			

(I) Seasons	(J) Seasons	Mean Difference (I-J)	Std. Error	P value	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
Pre-monsoon	Monsoon	.019417*	.006394	.013	.00373	.03511
	Post-monsoon	.009000	.006394	.349	-.00669	.02469
Monsoon	Pre-monsoon	-.019417*	.006394	.013	-.03511	-.00373
	Post-monsoon	-.010417	.006394	.248	-.02611	.00527
Post-monsoon	Pre-monsoon	-.009000	.006394	.349	-.02469	.00669
	Monsoon	.010417	.006394	.248	-.00527	.02611

**. The mean difference is significant at the 0.05 level.*

4.4.3 Bacteriological parameters:

4.4.3.1 Total coliform:

The total and fecal coliform indicates the bacterial contamination of wetland water in Malda district. In the case studies, maximum total coliform count is recorded during post-monsoon period and is maintained up to pre-monsoon. This result is in accordance with early workers in Kerala *(Jalal & Sanalkumar, 2012)*. The land run-off, full of chemical fertilizers and pesticides from peripheral agricultural field during monsoon and regular influx of domestic sewage throughout all the season are found responsible for relatively high coliform count.

Table 4.17 (a) Output of Total coliform count between wetland by Multiple Comparisons Test

	Sum of Squares	df	Mean Square	F	P value
Between Groups	144.972	3	48.324	2.099	.120
Within Groups	736.667	32	23.021		
Total	881.639	35			

(I) Wetlands	(J) Wetlands	Mean Difference (I-J)	Std. Error	P value	95% Confidence Interval	
					Lower Bound	Upper Bound
Siali	Chakla	-.667	2.262	.991	-6.79	5.46
	Naghoria	-1.444	2.262	.919	-7.57	4.68
	Chatra	3.778	2.262	.356	-2.35	9.91
Chakla	Siali	.667	2.262	.991	-5.46	6.79
	Naghoria	-.778	2.262	.986	-6.91	5.35
	Chatra	4.444	2.262	.222	-1.68	10.57
Naghoria	Siali	1.444	2.262	.919	-4.68	7.57
	Chakla	.778	2.262	.986	-5.35	6.91
	Chatra	5.222	2.262	.117	-.91	11.35
Chatra	Siali	-3.778	2.262	.356	-9.91	2.35
	Chakla	-4.444	2.262	.222	-10.57	1.68
	Naghoria	-5.222	2.262	.117	-11.35	.91

Statistical analysis shows no significant variation of total coliform count between the wetlands (F=2.10) where, the p value > α value (significance level at 0.05 in two-tailed test) at 95% confidence level. The wetlands, which regularly encounter the wetland-catchment interactions through intensive anthropogenic activities, should record a vulnerable coliform count especially after the monsoon run-off. But, in present study, coliform count record is not that much vulnerable as expected. It is a positive indication especially from the ecological perspective of wetland ecosystem and at the same time it reveals an enormous scope for further study. The statistical analysis shows significant ($p<0.05$) variation in coliform count between the seasons (F=14.86), where the p value < α value (significance level at 0.05 in two-tailed test) at 95% confidence level. Table 4.17 (a) & (b) are self-explanatory.

Table 4.17 (b) Output of Total coliform counts between seasons by Multiple Comparisons Test

	Sum of Squares	df	Mean Square	F	P value
Between Groups	417.722	2	208.861	14.857	.000
Within Groups	463.917	33	14.058		
Total	881.639	35			

(I) Seasons	(J) Seasons	Mean Difference (I-J)	Std. Error	P value	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
Pre-monsoon	Monsoon	-2.250	1.531	.318	-6.01	1.51
	Post-monsoon	-8.083*	1.531	.000	-11.84	-4.33
Monsoon	Pre-monsoon	2.250	1.531	.318	-1.51	6.01
	Post-monsoon	-5.833*	1.531	.002	-9.59	-2.08
Post-monsoon	Pre-monsoon	8.083*	1.531	.000	4.33	11.84
	Monsoon	5.833*	1.531	.002	2.08	9.59

**. The mean difference is significant at the 0.05 level.*

4.4.3.2 Fecal coliform:

Similar with total coliform, the fecal coliform shows maximum count during post-monsoon in the wetland sites. Similar observation is made by early worker in Kuttanad wetland, Kerala *(Sylas, 2010)*. Analysis of variance shows significant ($p<0.05$) variation in fecal coliform count between the wetlands ($F=4.39$), where the p value < α value (significance level at 0.05 in two-tailed test) at 95% confidence level. Chakla wetland records significant variation in fecal coliform count with other case studies, which is attributed to maximum open defecation problem around Chakla wetland as well as polluted water inflow from peripheral settlers. ANOVA shows significant ($p<0.05$) variation in fecal coliform count also between the seasons ($F=6.31$) which, may be caused by increased land run-off during monsoon and post-monsoon, and eventually results into high growth of bacterial population *(Sylas, 2010)*. Furthermore, domestic wastes from the surrounding villages and nearby municipal wards are also responsible for the bacterial contamination in these wetlands *(Irrinki & Irrinki, 2006-07)*. Table 4.18 (a) & (b) are self-explanatory.

Table 4.18 (a) Output of Fecal coliform count between wetland by Multiple Comparisons Test

	Sum of Squares	df	Mean Square	F	P value
Between Groups	59.222	3	19.741	4.394	.011
Within Groups	143.778	32	4.493		
Total	203.000	35			

(I) Wetlands	(J) Wetlands	Mean Difference (I-J)	Std. Error	P value	95% Confidence Interval	
					Lower Bound	Upper Bound
Siali	Chakla	-2.556	.999	.070	-5.26	.15
	Naghoria	.222	.999	.996	-2.49	2.93
	Chatra	.778	.999	.864	-1.93	3.49
Chakla	Siali	2.556	.999	.070	-.15	5.26
	Naghoria	2.778*	.999	.043	.07	5.49
	Chatra	3.333*	.999	.011	.63	6.04
Naghoria	Siali	-.222	.999	.996	-2.93	2.49
	Chakla	-2.778*	.999	.043	-5.49	-.07
	Chatra	.556	.999	.944	-2.15	3.26
Chatra	Siali	-.778	.999	.864	-3.49	1.93
	Chakla	-3.333*	.999	.011	-6.04	-.63
	Naghoria	-.556	.999	.944	-3.26	2.15

**. The mean difference is significant at the 0.05 level.*

Table 4.18 (b) Output of Fecal coliform counts between wetland by Multiple Comparisons Test

	Sum of Squares	df	Mean Square	F	P value
Between Groups	56.167	2	28.083	6.312	.005
Within Groups	146.833	33	4.449		
Total	203.000	35			

(I) Seasons	(J) Seasons	Mean Difference (I-J)	Std. Error	P value	95% Confidence Interval	
					Lower Bound	Upper Bound
Pre-monsoon	Monsoon	-.417	.861	.879	-2.53	1.70
	Post-monsoon	-2.833*	.861	.007	-4.95	-.72
Monsoon	Pre-monsoon	.417	.861	.879	-1.70	2.53
	Post-monsoon	-2.417*	.861	.022	-4.53	-.30
Post-monsoon	Pre-monsoon	2.833*	.861	.007	.72	4.95
	Monsoon	2.417*	.861	.022	.30	4.53

**. The mean difference is significant at the 0.05 level.*

4.5 Correlation matrix of wetland water quality parameters:

The observation on the wetland water quality parameters are analyzed with Pearson's product moment correlation coefficient in order to know the relationship between different parameters and their impact on other water quality parameters, which is displayed in Table 4.19.

In the present study, all the wetlands under case study record similar trend where the ***water temperature*** shows highly significant ($p<0.01$) positive correlation with water pH ($r=0.766$) *(Figure 4.4a)*, total hardness ($r=0.593$) *(Figure 4.4b)* at 0.01 significance level and significant ($p<0.05$) positive correlation with conductivity ($r=0.407$) *(Figure 4.6a)* and dissolved solid ($r=0.371$) *(Figure 4.6b)* at 0.05 significance level. Water temperature shows highly significant ($p<0.05$) negative correlation with iron ($r=-0.513$), total coliform ($r=-0.677$) *(Figure 4.5 a)* and fecal coliform ($r=-0.534$) *(Figure 4.5b)*; and significant negative correlation with dissolved oxygen ($r=-0.396$) *(Figure 4.7 a)*, turbidity *(Figure 4.7b)* and fluoride ($r=-0.355$). Statistical analysis shows that water temperature records non-significant ($p>0.05$) positive correlation with arsenic and negative correlation with chloride within the wetland water.

Wetland water ***pH*** shows highly significant ($p<0.01$) positive correlation with water temperature ($r=0.861$) *(Figure 4.4 a)*, conductivity ($r=0.652$) *(Figure 4.4c)*, dissolved solid ($r=0.619$) *(Figure 4.4d)* and total hardness ($r=0.685$) *(Figure 4.4e)* at 0.01 significance level. Water pH records highly significant ($p<0.05$) negative correlation with iron ($r=-0.576$), fluoride ($r=-0.431$), total coliform ($r=-0.619$) *(Figure 4.5c)* and fecal coliform *(Figure 4.5d).* Water pH records non-significant ($p>0.05$) positive correlation with turbidity, dissolved oxygen, arsenic whereas negative correlation with chloride.

Conductivity of wetland water shows highly significant ($p<0.01$) positive correlation with pH ($r=0.652$), total dissolved solid ($r=0.986$) *(Figure 4.4 f)* and total hardness ($r=0.886$) *(Figure 4.4g)* at 0.01 significance level. Conductivity records highly significant negative correlation with iron ($r=-0.501$) and total coliform ($r=-0.474$). Water conductivity records significant ($p<0.05$) positive correlation with dissolved oxygen ($r=0.413$) *(Figure 4.6 c)* at 0.05 significance level and negative correlation with fecal coliform ($r=-0.342$). Statistical analysis reveals that conductivity has non-significant ($p>0.05$) positive correlation with turbidity and chloride; and negative correlation with arsenic and fluoride.

Table 4.19 Correlation Matrix between water quality parameters of selected wetlands

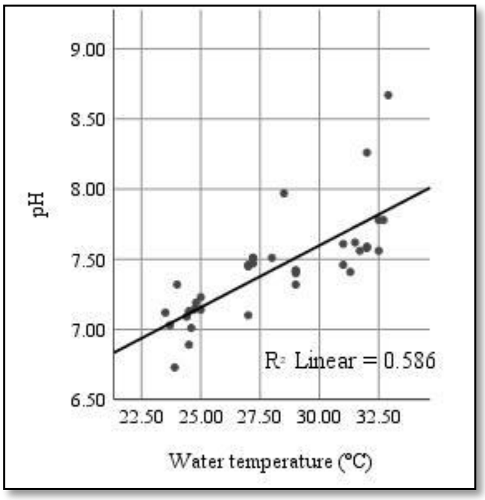
	WT	pH	Cond	TDS	Turbidity	TH	DO	Iron	Arsenic	Cl	Fluoride	TC	FC
WT	1	.766**	.407*	.371*	-.414*	.593**	-.396*	-.513**	.251	-.087	-.355*	-.677**	-.534**
pH		1	.652**	.619**	-.169	.685**	-.088	-.576**	.015	-.028	-.431**	-.619**	-.519**
Cond			1	.986**	.074	.886**	.413*	-.501**	-.122	.197	-.296	-.474**	-.342*
TDS				1	.159	.871**	.447**	-.508**	-.184	.217	-.290	-.492**	-.351*
Turbidity					1	-.191	.296	.219	-.562**	-.052	.111	.031	.175
TH						1	.286	-.722**	.112	.196	-.278	-.491**	-.513**
DO							1	-.312	.003	-.233	-.374*	.171	-.077
Iron								1	-.187	.103	.419*	.454**	.720**
Arsenic									1	-.406*	-.346*	.382*	.129
Cl										1	.578**	-.119	-.016
Fluoride											1	.138	.183
TC												1	.795**
FC													1

**. Correlation is significant at 0.01 level (2-tailed).

*. Correlation is significant at 0.05 level (2-tailed).

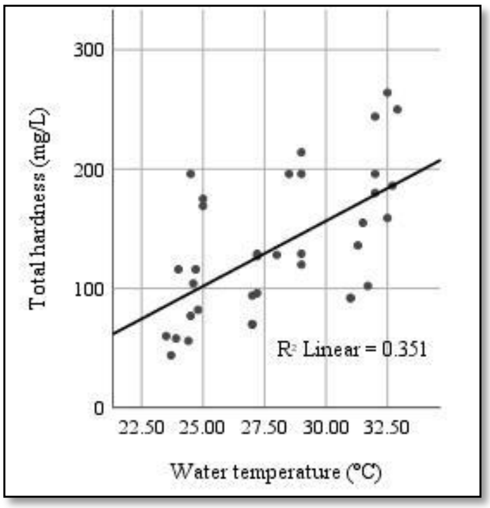
WT=Water temperature, Cond= Conductivity, TDS= Total dissolved solids, TH= Total hardness, DO= Dissolved oxygen, Cl= Chloride, TC= Total coliform, FC= Fecal colifrom.

Relation between Water temperature and pH



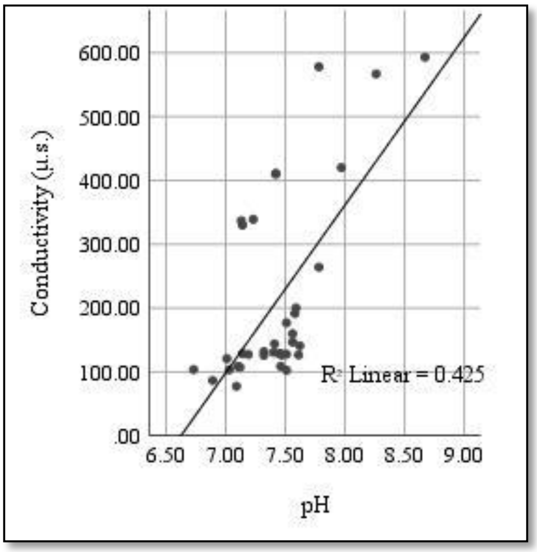
(a)

Relation between Water temperature and Total hardness



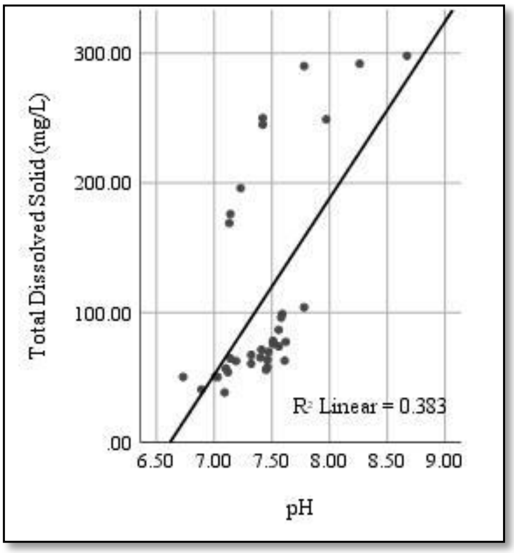
(b)

Relation between pH and Conductivity



(c)

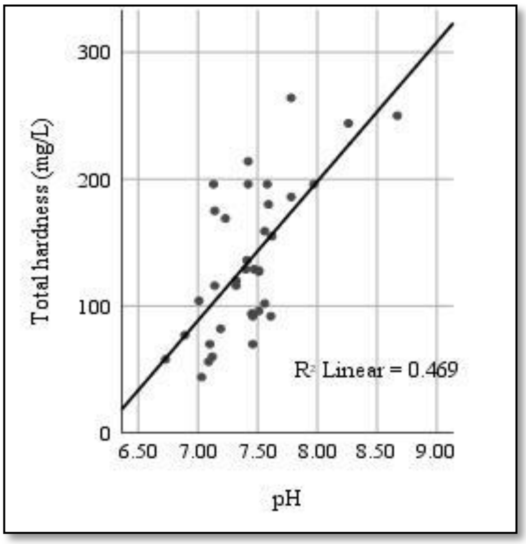
Relation between pH and Total dissolved solid



(d)

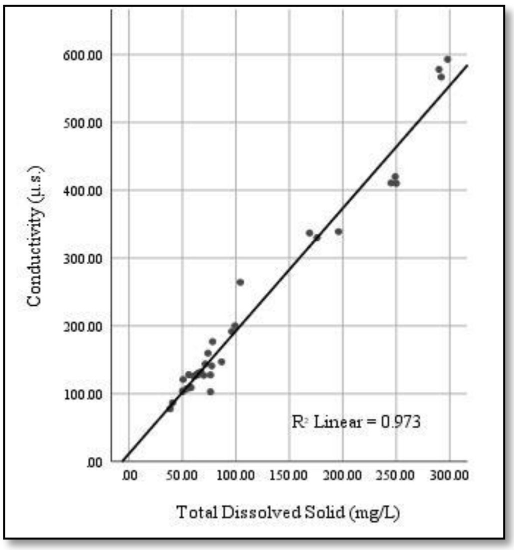
Figure 4.4: *Highly significant (p<0.01) positive correlation between wetland water quality parameters*

Relation between pH and Total hardness



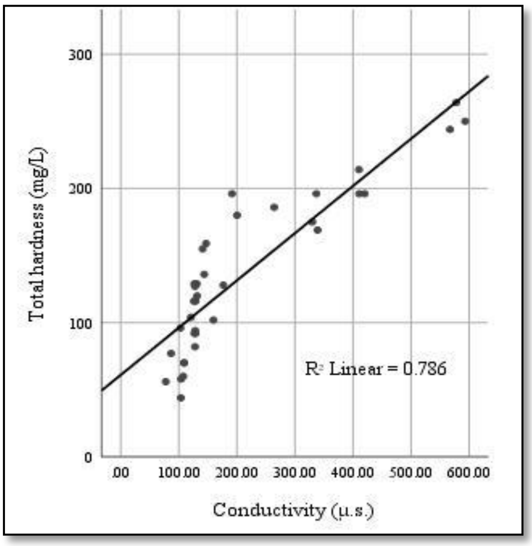
(e)

Relation between Total dissolved solid and Conductivity



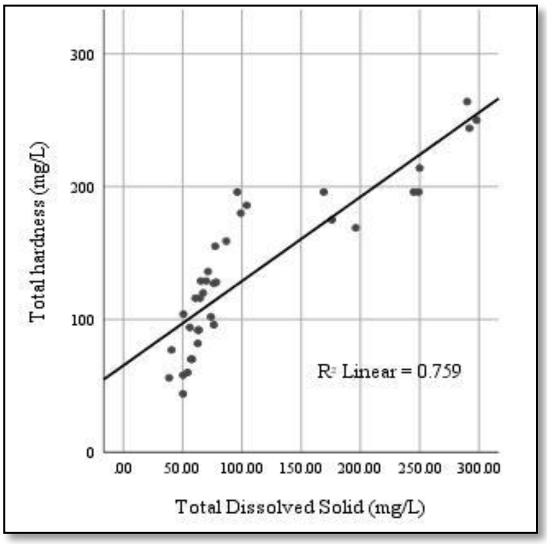
(f)

Relation between Conductivity and Total hardness



(g)

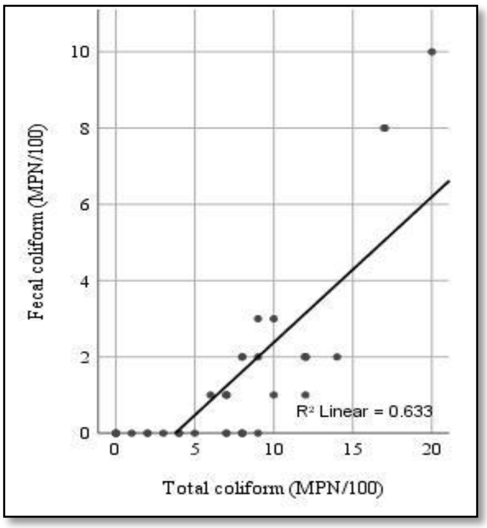
Relation between Total dissolved solid and Total hardness



(h)

Figure 4.4: *Highly significant ($p<0.01$) positive correlation between wetland water quality parameters*

Relation between Total coliform and Fecal coliform



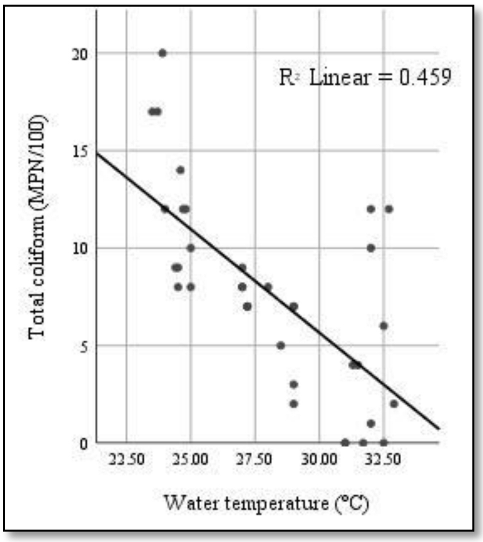
(i)

Figure 4.4: *Highly significant (p<0.01) positive correlation between wetland water quality parameters*

In the present study, ***total dissolved solid*** within wetland water shows highly significant ($p<0.01$) positive correlation with water pH ($r=0.619$), conductivity ($r=0.986$), total hardness ($r=0.886$) *(Figure 4.4 h)* at 0.01 significance level and dissolved oxygen ($r=0.447$). Dissolved solid record highly significant ($p<0.01$) negative correlation with iron ($r=-0.508$) and total coliform ($r=-0.492$); whereas significant ($p<0.05$) negative correlation with fecal coliform ($r=-0.351$). Dissolved solid within wetlands record non-significant ($p>0.05$) positive correlation with turbidity, and chloride and negative correlation with fluoride and arsenic.

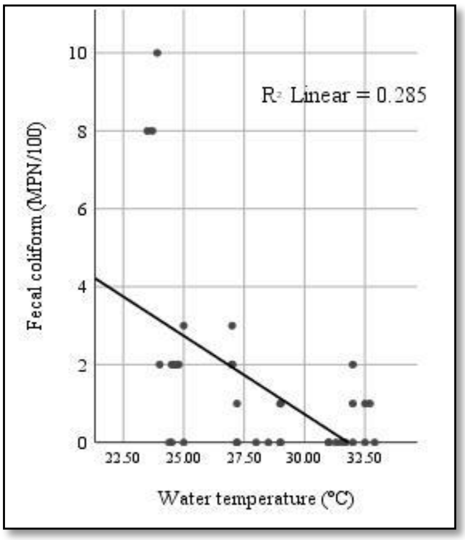
Turbidity shows highly significant ($p<0.01$) negative correlation with arsenic ($r=-0.562$) at 0.01 significance level and significant ($p<0.05$) negative correlation with water temperature ($r=-0.414$) at 0.05 significance level. Turbidity record non-significant ($p>0.05$) positive correlation with water conductivity, dissolved solid, dissolved oxygen, iron, fluoride, total and fecal coliform; and negative correlation with hardness, pH and chloride.

Relation between Water temperature and Total coliform



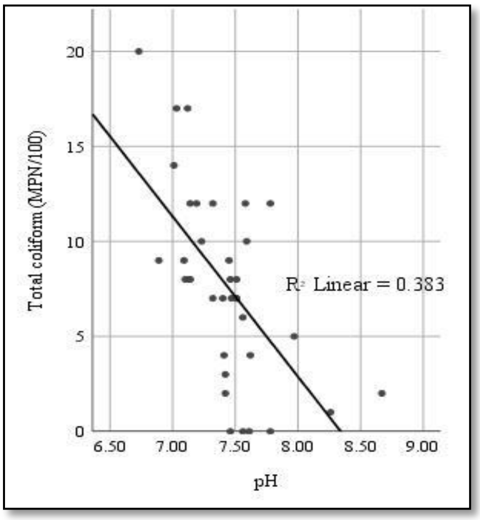
(a)

Relation between Water temperature and Fecal coliform



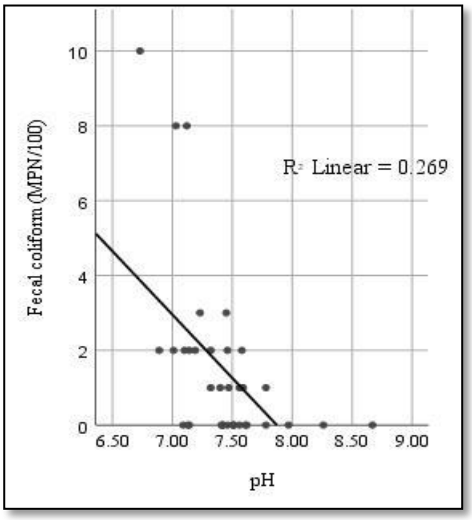
(b)

Relation between pH and Total coliform



(c)

Relation between pH and Fecal coliform



(d)

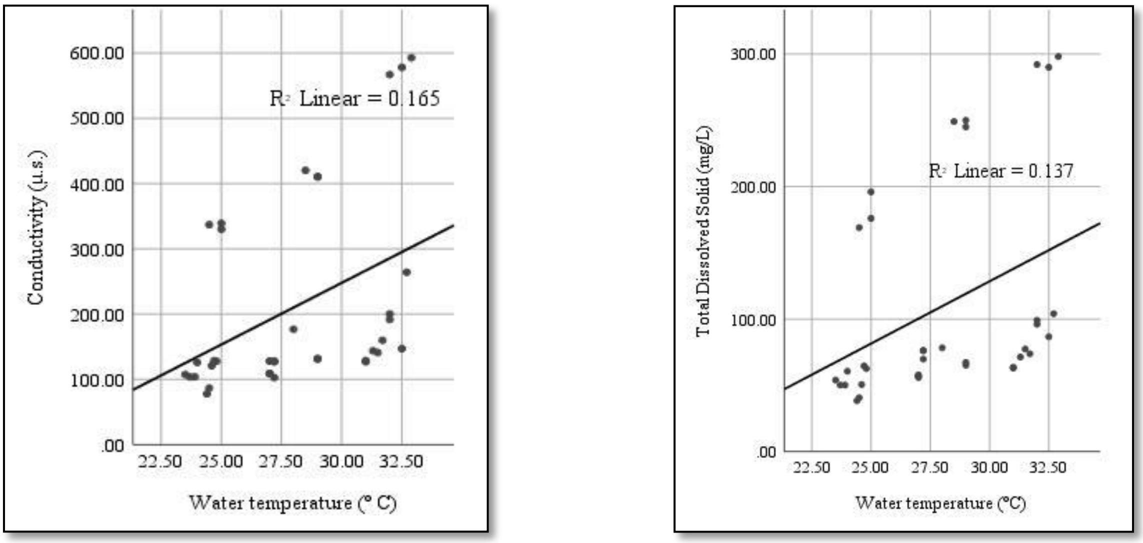
Figure 4.5: *Highly Significant (p<0.01) Negative Correlation between water quality parameters*

Statistical analysis records ***total hardness*** to have highly significant (p<0.01) positive correlation with water temperature (r=0.593), pH (r=0.685), conductivity (r=0.886) and dissolved solid (r=0.881) and negative correlation with iron (r=-0.722), total coliform (r=-0.491) and fecal coliform (r=-0.513) at 0.01 significance level. Total hardness shows non-significant (P>0.05) positive correlation with dissolved oxygen, arsenic, chloride; and negative correlation with turbidity and fluoride.

In the present study, ***dissolved oxygen*** shows highly significant (p<0.01) positive correlation with dissolved solid (r=0.441) at 0.01 significance level. Significant (p<0.05) positive correlation of do with conductivity (r=0.413) and negative correlation with water temperature (r=-0.396) and fluoride (r=-0.374) has been recorded at 0.05 significance level. Dissolved oxygen records non-significant (p>0.05) positive correlation with turbidity, hardness, arsenic and total coliform, whereas negative correlation with iron, chloride and fecal coliform.

The wetlands record ***iron*** content to have highly significant (p<0.01) positive correlation with total coliform (r=0.454) and fecal coliform (r=0.720); and negative correlation with water temperature (r=-0.513), pH (r=-0.576), conductivity (r=-0.501), dissolved solid (r=-0.508) and hardness (r=-0.722) at 0.01 significance level. Iron content records significant (p<0.05) positive correlation with fluoride (r=0.419) and non-significant (p>0.05) positive correlation with turbidity and chloride; and negative correlation with dissolved oxygen and arsenic.

Relation between Water temperature and Conductivity **Relation between Water temperature and Dissolved solid**

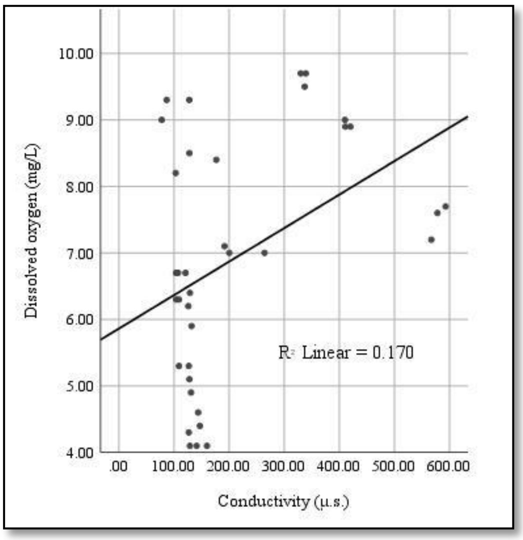


(a) (b)

Figure 4.6: *Significant (p<0.05) Positive Correlation between water quality parameters*

In the present study, ***arsenic*** content records highly significant (p<0.01) negative correlation with turbidity (r=-0.562) at 0.01 significance level. Arsenic records significant (p<0.05) positive correlation with total coliform (r=0.382) and negative correlation with chloride (r=-0.406) and fluoride (r=-0.346) at 0.05 significance level. Arsenic in the wetland water records non-significant (p>0.05) positive correlation with water temperature, pH, hardness and dissolved oxygen; whereas records negative correlation with conductivity, tds and iron.

Relation between Conductivity and Dissolved oxygen



(c)

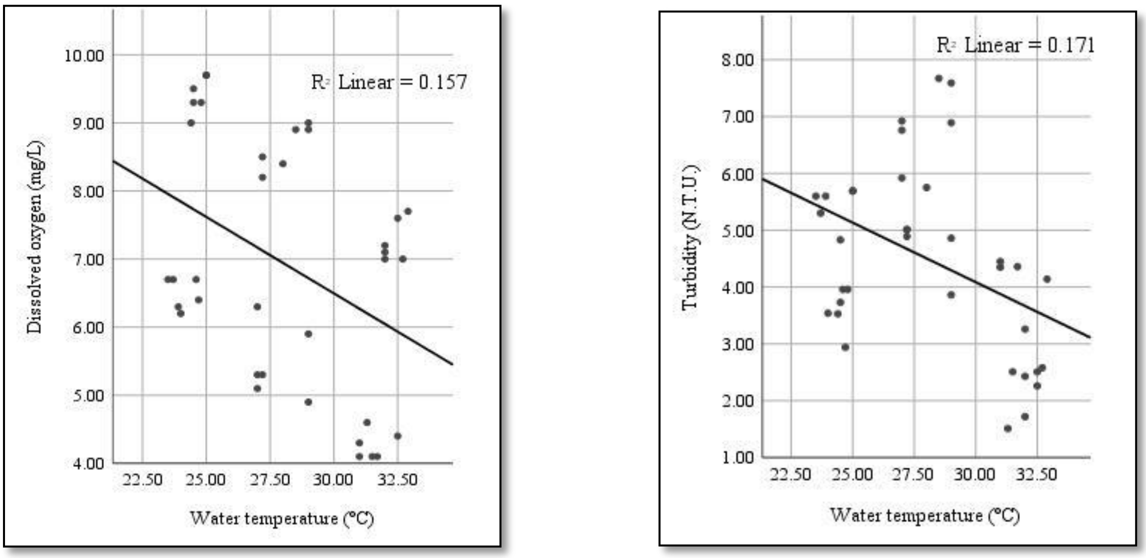
Figure 4.6: *Significant (p<0.05) Positive Correlation between water quality parameters*

Chloride content in wetland water records highly significant (p<0.01) positive correlation with fluoride (r=0.578) and significant (p<0.05) negative correlation with arsenic (r=-0.406). Chloride has non-significant (p>0.05) positive correlation with conductivity, tds, hardness and iron whereas, negative correlation with temperature, pH, turbidity, do, total and fecal coliform.

In the present study, ***fluoride*** content records highly significant (p<0.01) positive correlation with chloride (r=0.578) and negative correlation with pH (r=-0.431). Fluoride records significant (p<0.05) positive correlation with iron (r=0.419) and negative correlation with temperature (r=-0.355), pH (r=-0.431), do (r=-0.374) and arsenic (r=-0.346). Fluoride has non-significant (p>0.05) positive correlation with turbidity, total and fecal coliform, whereas negative correlation with conductivity, tds and total hardness.

Statistical result shows that bacteriological parameters are also correlated with physic-chemical parameters of water quality. ***Total coliform*** shows highly significant (p<0.01) positive correlation with iron (r=0.454) and fecal coliform (r=0.795) (*Fig 4.4 i)* at 0.01 significance level and negative correlation with pH (r=0.731). Total coliform records significant (p<0.05) negative correlation with temperature (r=-0.677), pH (r=-0.619), conductivity (r=-0.474, tds (r=-0.492) and hardness (r=-0.491) at 0.05 significance level. Total coliform count in wetland water shows significant (p<0.05) positive correlation with arsenic (r=0.382) whereas, non-significant (p>0.05) positive correlation with turbidity, dissolved oxygen, fluoride and negative correlation with chloride content.

Relation between Water temperature and Dissolved oxygen **Relation between Water temperature and Turbidity**



(a) (b)

Figure 4.7: *Significant ($p<0.05$) Negative Correlation between water quality parameters*

According to Statistical analysis ***fecal coliform*** shows highly significant ($p<0.01$) positive correlation with iron (r=0.720) and total coliform (r=0.796) and negative correlation with temperature (r=-0.534), pH (r=-0.519) and total hardness (r=-0.513). Fecal coliform shows non-significant ($p>0.05$) positive correlation with turbidity, fluoride and arsenic and negative correlation with dissolved oxygen and chloride of wetland water.

4.6 Conclusion:

In the present study, the physico-chemical as well as bacteriological characteristics of water have been tested and analyzed in case of four wetlands, viz, Siali, Chakla, Naghoria and Chatra, as a representation of entire wetland resource of Malda district . The year round seasonal variation of physico-chemical and bacteriological parameters of these wetlands provide a vivid picture of the ecological status of wetlands under study area. Based on the findings, overall water qualities of the wetlands in Malda district are found within the permissible limit especially for biological species which indicates the prevalence of desirable quality of water. At the same time, wetlands, which are subject to agricultural and municipal sewage inflow from peripheral area, exhibits high concentration of dissolved solid, total hardness, turbidity and conductivity and are found to exceed the desirable limits to some extent. After a detail study on physico-chemical and bacteriological water quality parameters, it reveals that the wetlands within the rural periphery receive land run-off from adjacent agricultural field, whereas the peri-urban water body is contaminated by municipal and domestic effluents discharge into wetland without any discrimination. Therefore, the wetlands encounter several challenges in the form of ever increasing concentration of dissolved solid, conductivity and water hardness especially when the water availability is low during the pre-monsoon period. The high organic components substantially promote the proliferation of pathogenic and bacterial population (coliform bacteria) in wetland water as well as minimize the dissolved oxygen content. So an appropriate conservative measure would be necessary to resolve the existing eutrophication level of these wetlands. The present study urges the need for restoration of the wetland in Malda district in order to ensure the sustainability of a healthy natural ecosystem.

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