Study of ecology and interrelationship of parameters in two Ecologically Different Beels in Gangetic plain of West Bengal, India

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Abstract

Physical, chemical, and biological parameters of the Kole (Open type) and Suguna (Closed type) wetlands have been investigated from January 2011 to December 2013. These lakes are locally called as Baur.The work has been carried out for one and half year period from nov 2011- May2013 in different seasons viz. monsoon, post monsoon and premonsoon respectively in order to assess water quality parameters and diversity of biotic communities. The present article attempts to investigate the possible interrelationship among the physicochemical parameters and biotic communities of both the beels. During the investigation, zooplankton diversity was observed high in the wetland. Rotifers were the most dominant group followed by Cladocera, Copepoda, Protozoa and Ostracoda during the investigation. There is a high density of zooplankton in monsoon than compare to other seasons indicate good water quality and less pollution load in both beels. These investigations will be the basic guidelines for the researcher in the field of ecology of beels. The comparison of the ecological parameters of these two lakes is attempted in the present investigation. The study aim to investigate the diversity of biotic communities in relation to physico-chemical parameters of surface water in gangetic plain. Physico-chemical parameters of both the beels revealed well marked fluctuations with maxima and minima values of each parameter during specific months and analysis of biotic communities revealed seasonal variations with an increase during summer and a fall during winter and monsoon seasons.

Study of limnology and interrelationship of parameters in two Ecologically Different Beels in Gangetic plain of West Bengal, India

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Key Words: Open beel, Closed beel, Kole, Saguna, Ecology, Water quality, biotic communities, interrelationship.

INTRODUCTION

Wetlands are the creation of the river Ganges in the flood plain area. The physiographic and morphometric features of both the Beels are different from each other. The area and water level of the Kole Beel are fully dependent upon the water level of the river Ganga. During the summer season, the water level reaches a high level which drops down in the winter season. However, no study has been conducted on comparison of floodplain wetlands for physicochemical parameters and phytoplankton composition of Suguna and Kole floodplain wetlands of Garhwal Himalayas. Therefore, the present study aims to determine the influence of physicochemical parameters on the phytoplankton composition of both wetland ecosystems, which is prone to anthropogenic pressures.

Fishery, under modern scientific research, signifies the judicious exploitation of natural resources of water. The success of a fishery depends on the knowledge of the characteristics of water and soil. The floodplain lakes are considered as biologically sensitive areas as they have a vital bearing on the recruitment of population in the riverine ecosystem and provide excellent nursery grounds for several fish species besides a host of other fauna and flora. Most of the Beels of West Bengal are infested with macrophytes, which pose a problem in the operation of various fishing gear. These interfere in the productivity of the ecosystem also. The dewatering method is carried out during the month of December/January. After dewatering fish are easily caught by handpicking.

Phytoplankton is vital and important organisms which act as producer to the primary food supply in any aquatic ecosystem. They are the initial biological components from which the energy is transferred to higher organisms through the food chain (Tiwari and Chauhan, 2006; Saifullah et al., 2014). The physicochemical parameters are the major factors that control the dynamics and structure of the phytoplankton of the aquatic ecosystem (Hulyal and Kaliwal, 2009). Changes in physicochemical parameters of ecosystems have a substantial impact on the species that live within them. Seasonal variations in these parameters have an important role in the distribution, periodicity, and quantitative and qualitative composition of freshwater biota.

3.1 Selection of Study Sites:

3.1 Selection of Study Sites:

Three different locations were selected for a sampling of water and sediment- one in littoral and two in profoundly zone. Water was almost static during most parts of the year except monsoon season. In summer a vast area of the open lake was exposed and the land becomes agricultural land, which was again submerged during monsoon season.

Saguna *beel* is a closed system and the basin is solely dependent on rains for the water source. It is almost rectangular in shape with a water-spread area of 40 ha and lie between latitude 88° 4' E and longitude 22° 6' N and located at Kalyani district Nadia, West Bengal. The *beel* was a defunct watercourse, which earlier had a connection with the river Hooghly.

The Kole *beel*, an open system, is a shallow saucer-shaped basin of 6-kilometer in length having a total area of 81.6 ha. Kole *beel* lies between latitude 88° 7' E and longitude 23° 2' N and located at Samara Bazar, district Hooghly, West Bengal. The *beel* relates to the river Bhagirathi with the braided channel. The beel is having a moderate macrophyte infestation level. Variability is the principal feature of this floodplain wetland as it varies widely in contour from season to season depending on the water incursion. It is almost horseshoe shape covering an approximate area of 20 sq km. The depth varies from 8ft in winter to12 ft during monsoon. The climate is of tropical monsoon type. Annual rainfall varies between 1600 mm and 2050 mm.

3.2 Sampling methods:

3.2.1 Study Period

Sampling was performed for three years from September 2011 – February 2013 at the beels of West Bengal. During this period randomly two different floodplain wetlands from West Bengal were selected. Various different morphometric, abiotic, and biotic factors of beels from west Bengal were studied.

3.2.2 Frequency of Sampling

A sampling of core water quality parameters: Monthly

A sampling of soil quality parameters: Monthly

A sampling of Biotic Communities: Monthly

3.7. Statistical analysis

3.7.1 Descriptive statistics

PROC MEANS procedure of SAS® (SAS Institute, 2010) was used to estimate the descriptive statistics, *viz.* minimum, maximum, mean, standard error, and coefficient of variation for all parameters.

3.7.2 Analysis of variance

Analysis of variance (ANOVA) was used to discern significant differences among the parameters. PROC GLM procedure of SAS® (SAS Institute, 2010) was used which operates on both balanced and unbalanced designs. A significant source of variations was detected by GLM procedure. Boxplot of parameters were constructed by PROC GLM procedure of SAS® (SAS Institute, 2010) for parameters have shown distribution range of parameters (SAS Institute, 2010). ANOVA was performed to test differences of values obtained between months for all variables considered.

Result:

4.1 Air temperature

The air temperature has shown mean values of 26.1 °C and 27.5 °C for Saguna

and Kole wetland. The temperature has shown minimum and maximum values 21.1 °C (Jan 2012) and 34.5°C (May 2012) in open type and 21.3 °C (Jan 2013) and 29 °C (Oct 2012) in closed type. Then the analysis of variance revealed that there was a month-wise and wetland type-wise significant difference in air temperature (Table- 4.2.1 & 4.2.2). The Kole wetland has shown significantly higher values of air temperature in comparison with Saguna (Figure- 4.1.1).

4.2 WATER PHASE

4.2.1 Water temperature

The water temperature has shown mean values of 25.1 °C and 26.6°C for Saguna and Kole wetland during the study period. The pattern of temporal variation followed a similar trend in the two selected floodplain wetlands. The water temperature has shown minimum and maximum values 20.1 °C (Jan 2012) and 33.5°C (Oct 2012) in open type and 20.3°C (Jan 2012) and 28.1°C (Oct 2012) in closed type. The water gradually becomes warmer from February onwards with maximum temperature in July (table - 4.2.1 & 4.2.2). Then the analysis of variance revealed that there was a month-wise and wetland type-wise significant difference in water temperature (Table- 4.2.1 & 4.2.2). The Kole wetland has shown significantly higher values of water temperature in comparison with Saguna (Figure-4.2.1.1).

4.2.2 Water Depth

The depth has shown mean values of 2.83 m and 2.16 m for Saguna and Kole wetland. The depth has shown minimum and maximum values 1.33 m (June 2012) and 3.0 m (September 2012) in open type and 2.3 m (June 2012) and 3.3 m (September 2012) in closed type. Then the analysis of variance revealed that there was a month-wise and wetland type-wise significant difference in depth (Table - 4.2.1 & 4.2.2). The Kole wetland has shown significantly higher values of depth in comparison with Saguna (Figure-4.2.2.1).

Figure 1: Boxplot for air temp of the selected floodplain wetlands

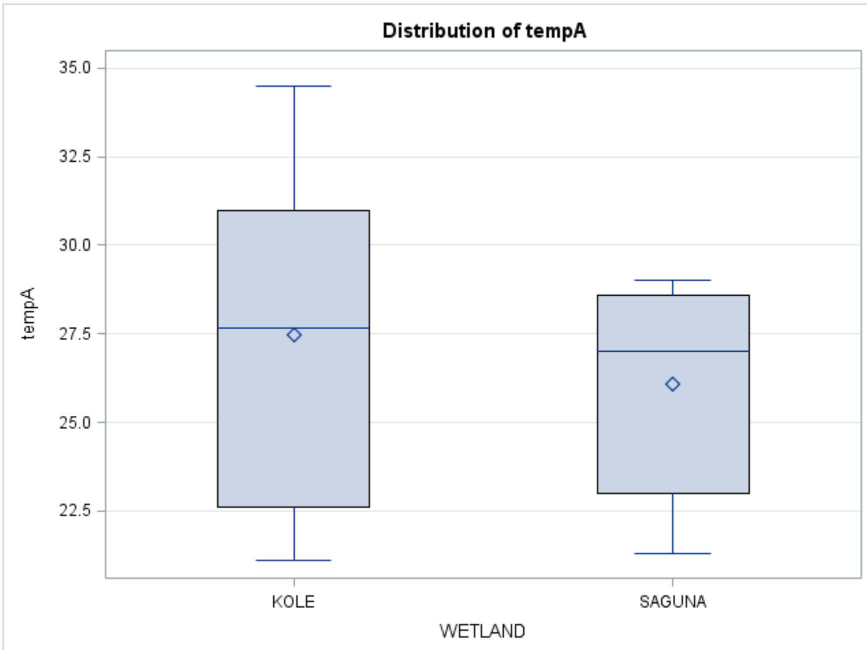

Figure 1: This is a caption

Figure 2: Monthly variation in air temperature between Saguna and Kole floodplain wetlands

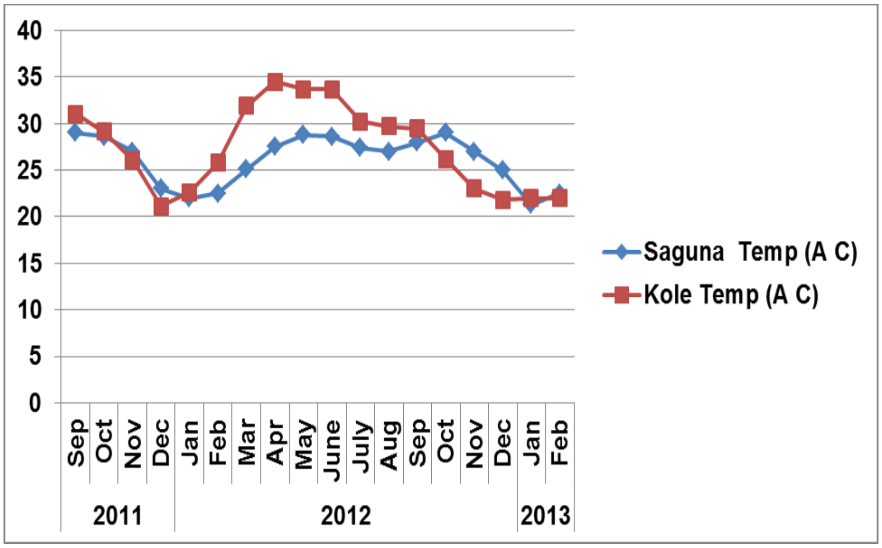

Figure 2: This is a caption

Figure 3 : Boxplot for water temp of the selected floodplain wetlands

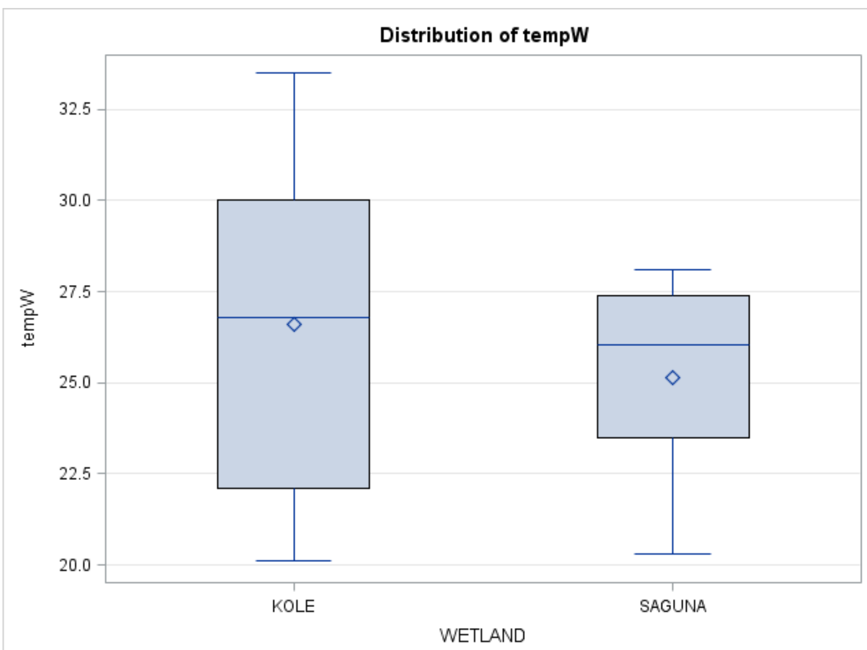

Figure 3: This is a caption

Figure 4: Monthly variation in water temperature between Saguna and Kole floodplain wetlands

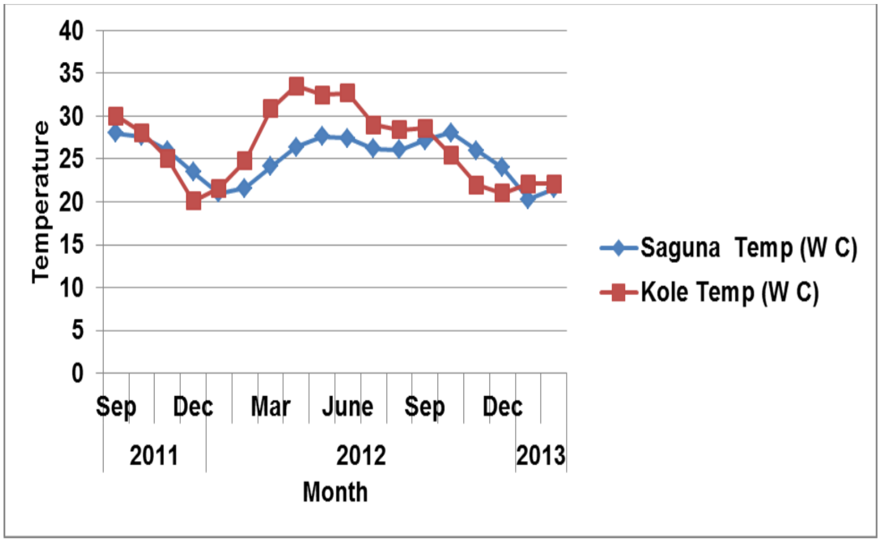

Figure 4: This is a caption

Figure 5: Boxplot for depth of the selected Floodplain wetlands

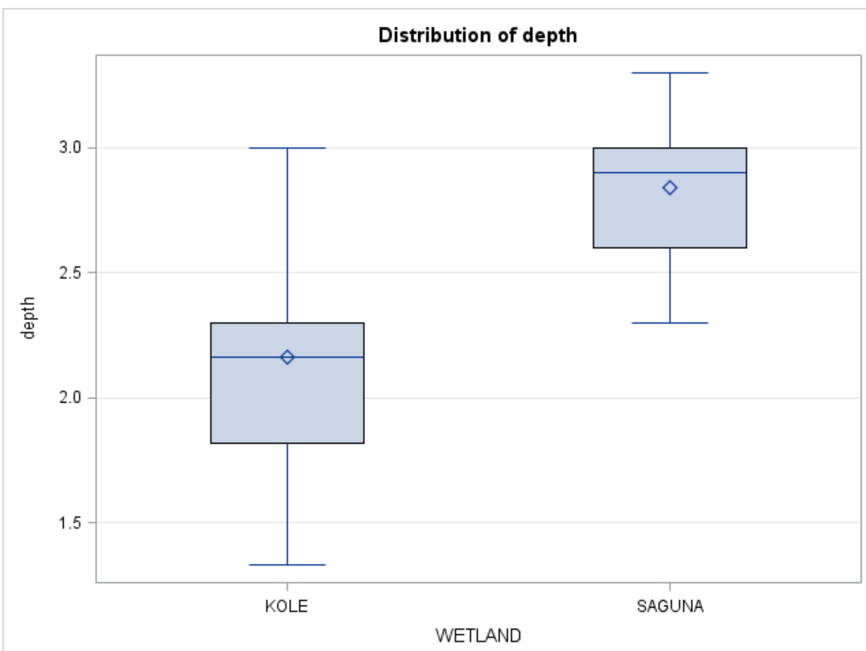

Figure 5: This is a caption

Figure 6 : Monthly variation in Depth between Saguna and Kole floodplain wetlands

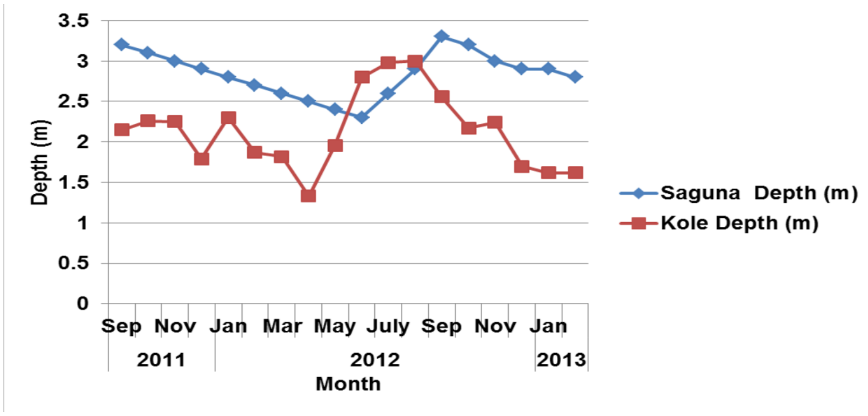

Figure 6: This is a c Monthly variation in Depth between Saguna and Kole floodplain wetlands

4.2.3 Transparency

The transparency has shown mean values of 1.9 m and 1.2 m for Saguna and Kole wetland. The transparency has shown minimum and maximum values 0.8 m and 2.0 m during the months August 2012, and February, 201 in open type and 1.4 m and 2.3 m during June 2012 and February 2012 in closed type. Then the analysis of variance revealed that there was a month-wise and wetland type-wise significant difference in transparency (Table- 4.2.1 & 4.2.2). The Saguna wetland has shown significantly higher values of transparency in comparison with Kole (Figure- 4.2.3.1).

4.2.4 Water coverage

The water coverage has shown mean values of 68.1% and 67.8 % for Saguna and Kole wetland. The water coverage has shown minimum and maximum values 45.7% (June 2012) and 95.7% (September 2012) in open type and 42% (June 2012) and 86 % (Oct 2012) in closed type. Then the analysis of variance revealed that there was a month-wise and wetland type-wise significant difference in water coverage (Table- 4.2.1 & 4.2.2). The Saguna wetland has shown significantly higher values of water coverage in comparison with Kole (Figure- 4.2.4.1).

4.2.5 Water reaction (pH):

The pH has shown mean values of 8 and 7.9 for Saguna and Kole wetland. The pH has shown minimum and maximum values 7.5(August 2012) and 8.4 (March 2012) during the months of in open type and 7.6(August 2012) and 8.6 (March 2012) during the months in closed type. Then the analysis of variance revealed that there was a month-wise and wetland type-wise significant difference in pH (Table-4.2.1 & 4.2.2). The Saguna wetland has shown significantly higher values of Specific conductivity in comparison with Kole (Figure-4.2.5.1).

Figure 7 : Boxplot for transparency of the selected floodplain wetlands

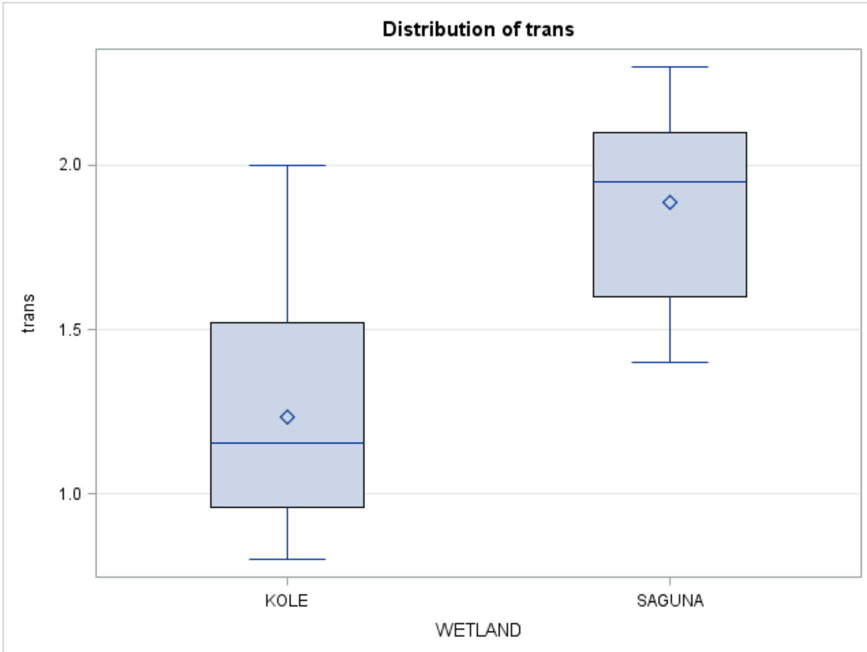

Figure 7: This is a caption

Figure 8 : Monthly variation in transparency between Saguna and Kole floodplain wetlands

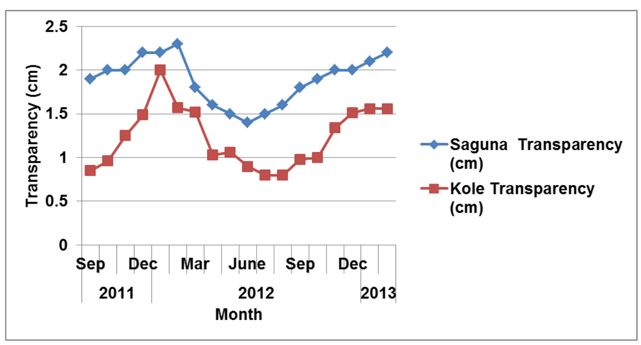

Figure 8: This is a caption

Figure 9 : Boxplot for water cover of the selected floodplain wetlands

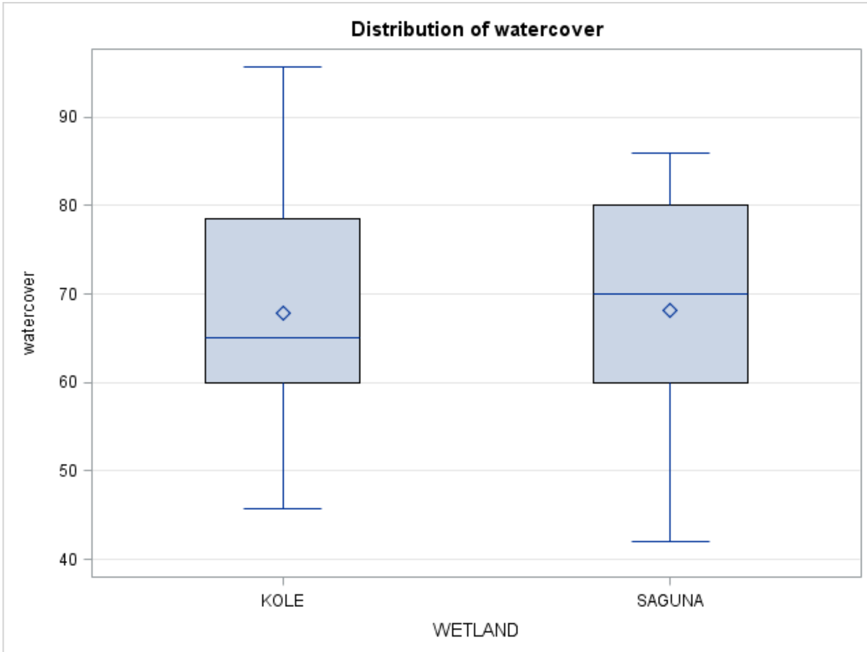

Figure 9: This is a caption

Figure 10: Monthly variation in water coverage area between Saguna and Kole floodplain wetlands

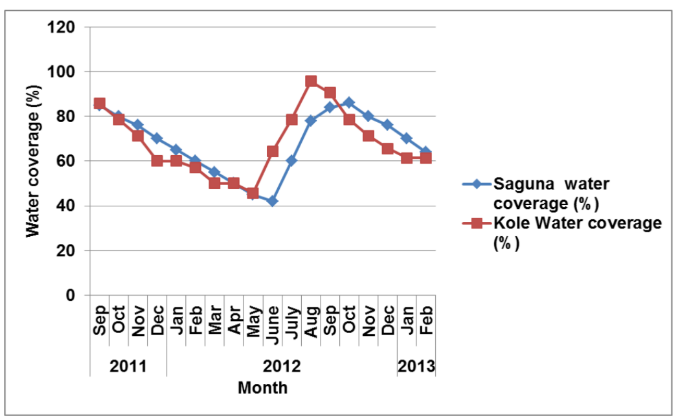

Figure 10: This is a caption

Figure 11: Boxplot for pH of the selected floodplain wetlands

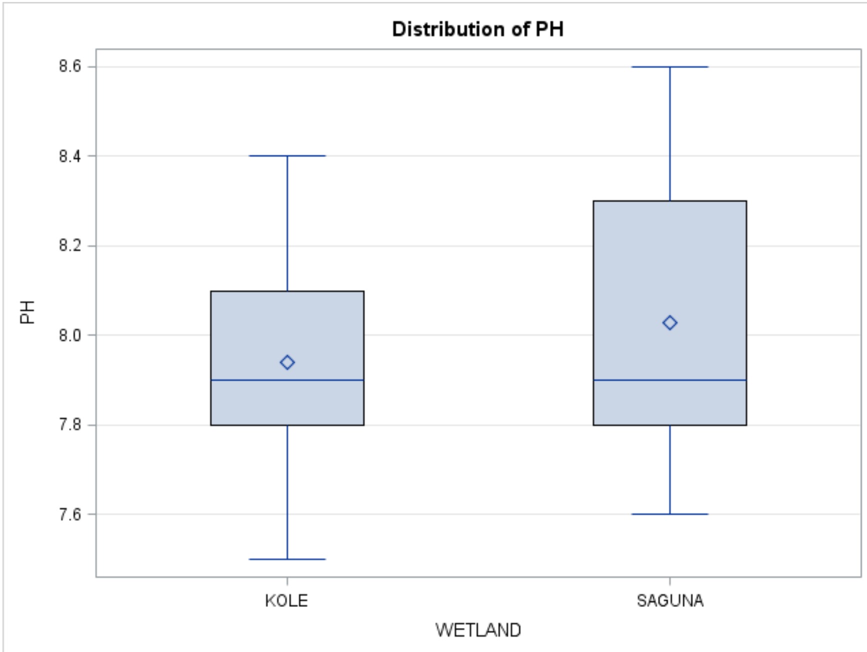

Figure 11: This is a caption

Figure 12 : Monthly variation in pH between Saguna and Kole floodplain wetlands

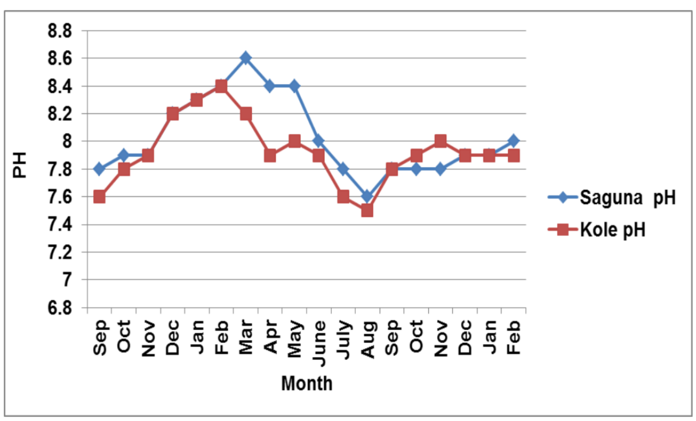

Figure 12: This is a caption

4.2.6 Free CO2

The Free CO2 has shown mean values of 1.1 ppm and 1.3 ppm for Saguna and Kole wetland. The Free CO2 has shown minimum and maximum values 0 (Dec 2011 and Jan 2012, Dec 2012 and Jan 2013) and 3.5 ppm (August 2012) in open type and 0 (September 2011 and February 2012) and 3 ppm (June 2012) in closed type. Then the analysis of variance revealed that there was a month-wise and wetland type-wise significant difference in Free CO2 (Table-4.2.1 & 4.2.2). The Kole wetland has shown significantly higher values of Free CO2 in comparison with Saguna (Figure-4.2.6.1.).

4.2.7 Total alkalinity

The Total alkalinity has shown mean values of 1.3 ppm and 145.2 ppm for Saguna and Kole wetland. The Total alkalinity has shown minimum and maximum values 130 ppm (Sept 2012 and 165 ppm (June 2012) in open type and 84 ppm (Dec 2011) and 125 ppm (June) months in closed type. Then the analysis of variance revealed that there was a month-wise and wetland type-wise significant difference in Total alkalinity (Table-4.2.1 & 4.2.2). The Kole wetland has shown significantly higher values of Total alkalinity in comparison with Saguna (Figure- 4.2.7.1).

4.2.8 Total hardness:

The Total hardness has shown mean values of 105.3 ppm and ppm for Saguna and Kole wetland. The Total hardness has shown minimum and maximum values 134 ppm (Sept 2011) and 165 ppm (June 2012) in open type and 87 ppm (Sept 2011) and 132 ppm (June 2012) in closed type. Then the analysis of variance revealed that there was a month-wise and wetland type-wise significant difference in Total hardness (Table-4.2.1 & 4.2.2). The Kole wetland has shown significantly higher values of Total hardness in comparison with Saguna (Figure-4.2.8.1).

Figure 13: Boxplot for Free CO_2 of the selected floodplain wetlands

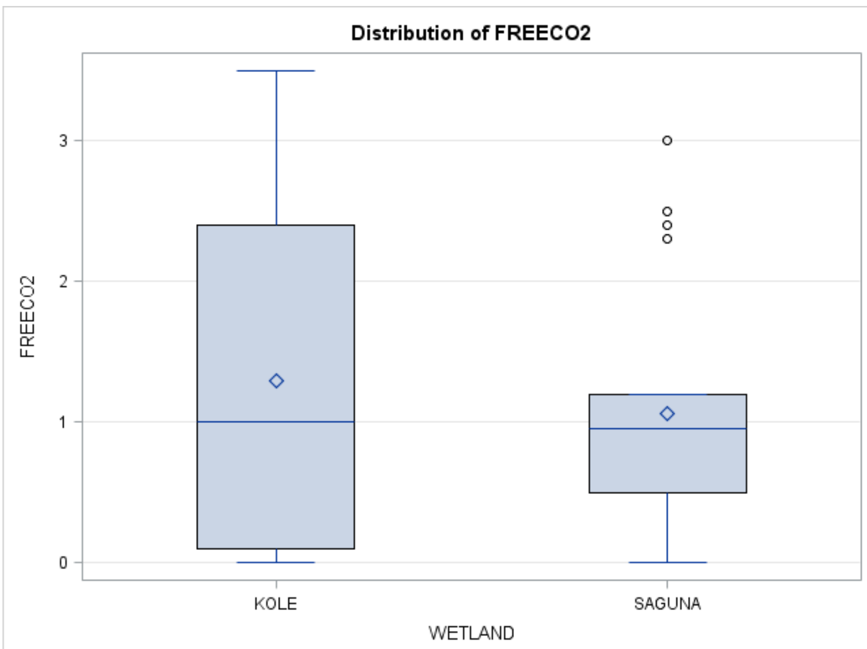

Figure 13: This is a caption

Figure 14 : Monthly variation in Free CO_2 between Saguna and Kole floodplain wetlands

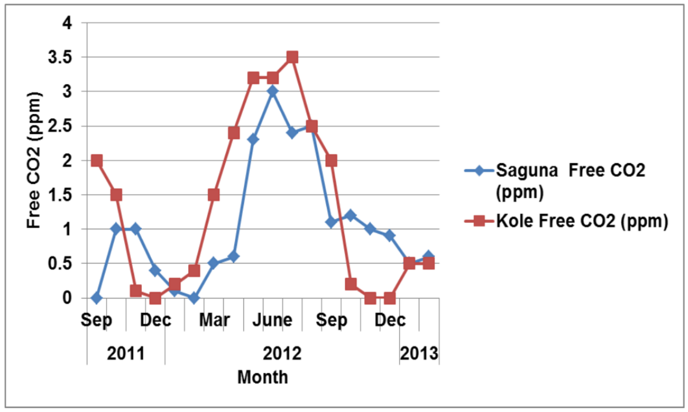

Figure 14: This is a caption

Figure 15 : Boxplot for Total alkalinity of the selected floodplain wetlands

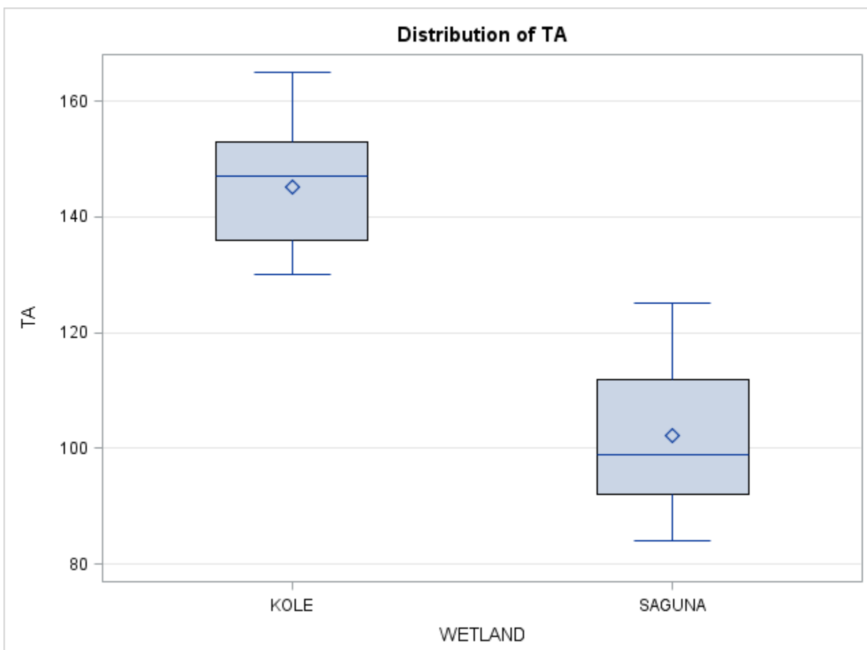

Figure 15: This is a caption

Figure 16 : Monthly variation in Total alkalinity between Saguna and Kole floodplain wetlands

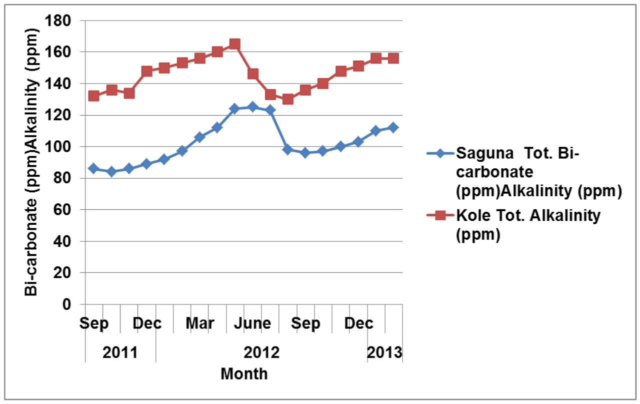

Figure 16: This is a caption

Figure 17 : Boxplot for total hardness of the selected floodplain wetlands

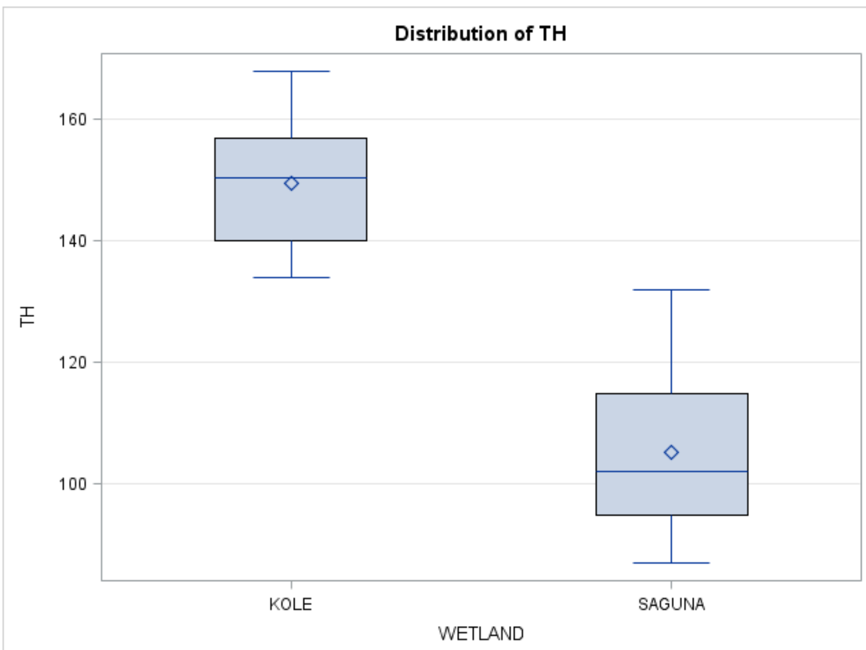

Figure 17: This is a caption

Figure 18 : Monthly variation in Total hardness between Saguna and Kole floodplain wetlands

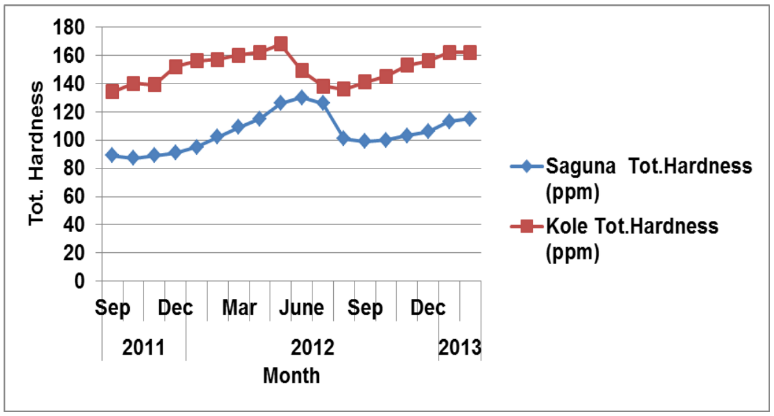

Figure 18: This is a caption

4.2.8 Specific conductivity

The pattern of seasonal variation in respect of specific conductivity in the studied beels showed relatively higher values in summer, while low in the monsoon. The Specific conductivity has shown mean values of 263.7 µS/cm and 472.3 µS/cm for Saguna and Kole wetland. The Specific conductivity has shown minimum and maximum values 412 µS/cm (Sept 2012) and 590 µS/cm (May 2012) in open type and 222 µS/cm (Sept 2012) and 340 µS/cm (June 2012) during the months in closed type. Then the analysis of variance revealed that there was a month-wise and wetland type-wise significant difference in Specific conductivity (Table-4.2.1 & 4.2.2). The Kole wetland has shown significantly higher values of Specific conductivity in comparison with Saguna (Figure - 4.2.8.1).

4.2.9 Dissolved oxygen:

The Dissolved oxygen has shown mean values of 7.5 ppm and 7.7 ppm for Saguna and Kole wetland. The Dissolved oxygen has shown minimum and maximum values 6.9 ppm (August 2012) and 8.4 ppm (Dec 2011 and Jan 2012) in open type and 6.4 ppm (August 2012) and 8.3 ppm (February 2012) in closed type. Then the analysis of variance revealed that there was a month-wise and wetland type-wise significant difference in Dissolved oxygen (Table-4.2.1 & 4.2.2). The Kole wetland has shown significantly higher values of Dissolved oxygen in comparison with Saguna (Figure - 4.2.9.1.).

4.2.10 Calcium:

The calcium has shown mean values of 39.7 ppm and 34.8 ppm for Saguna and Kole wetland. The calcium has shown minimum and maximum values 26 ppm (Sept 2011) and 42 ppm (May 2012) in open type and 33.6 ppm (Sept 2011) and 48 ppm (May 2012) in closed type. Then the analysis of variance revealed that there was a month-wise and wetland type-wise significant difference in calcium (Table-4.2.1 & 4.2.2). The Saguna wetland has shown significantly higher values of Total hardness in comparison with Kole (Figure - 4.2.10.1).

Figure 19 : Boxplot for Specific conductivity of the selected floodplain wetlands

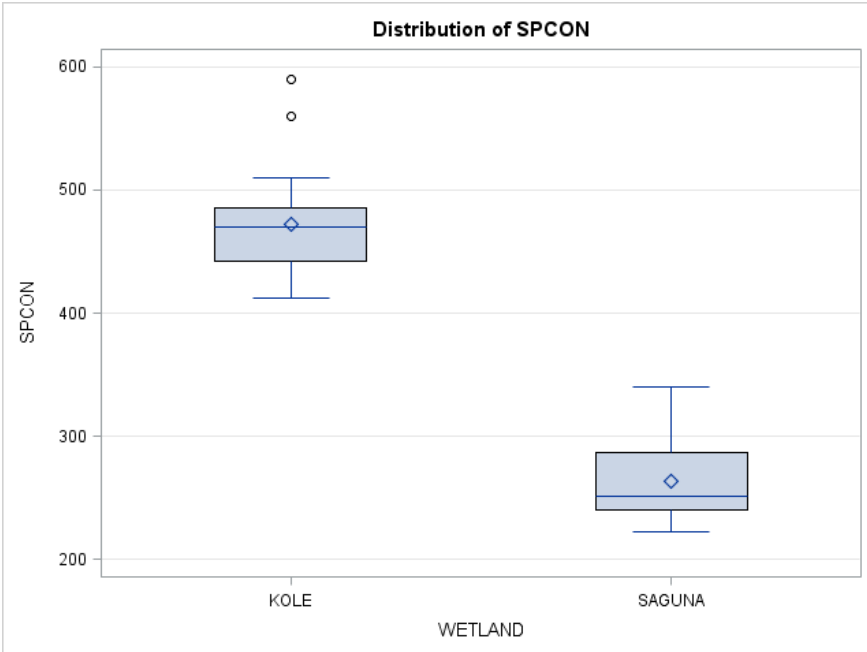

Figure 19: This is a caption

Figure 20 : Monthly variation in specific conductivity between Saguna and Kole floodplain wetlands

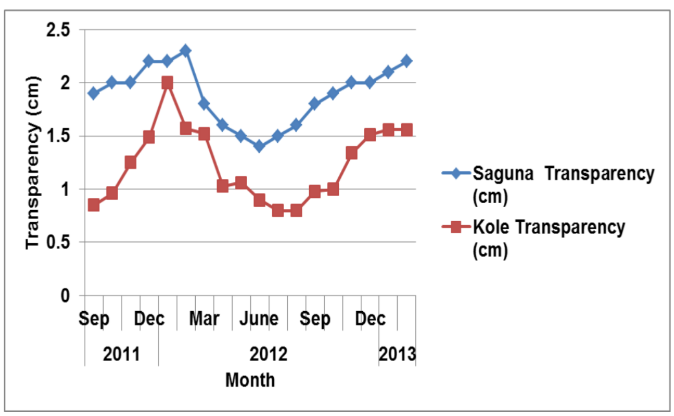

Figure 20: This is a caption

Figure 21: Boxplot for Dissolved oxygen of the selected floodplain wetlands

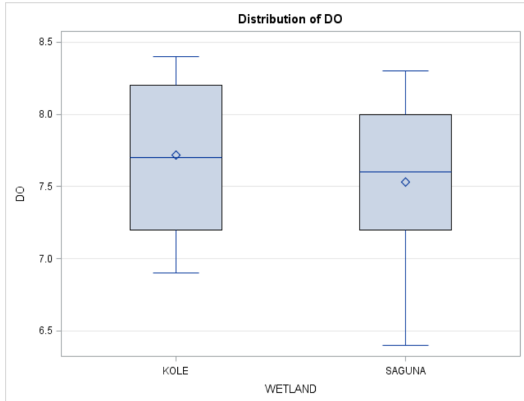

Figure 21: This is a caption

Figure 22: Monthly variation in dissolved oxygen between Saguna and Kole floodplain wetlands

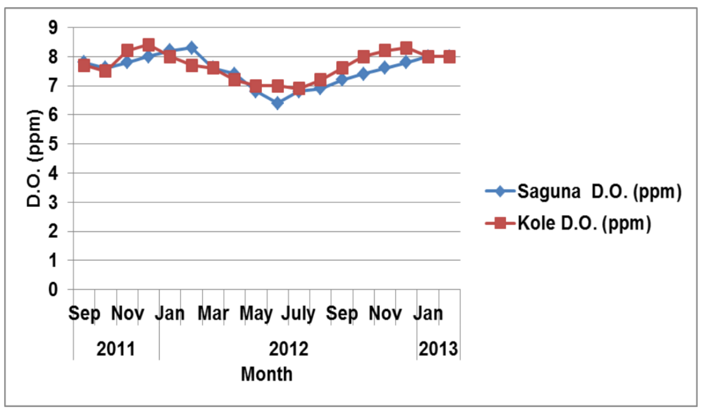

Figure 22: This is a caption

Figure 23: Boxplot for calcium of the selected floodplain wetlands

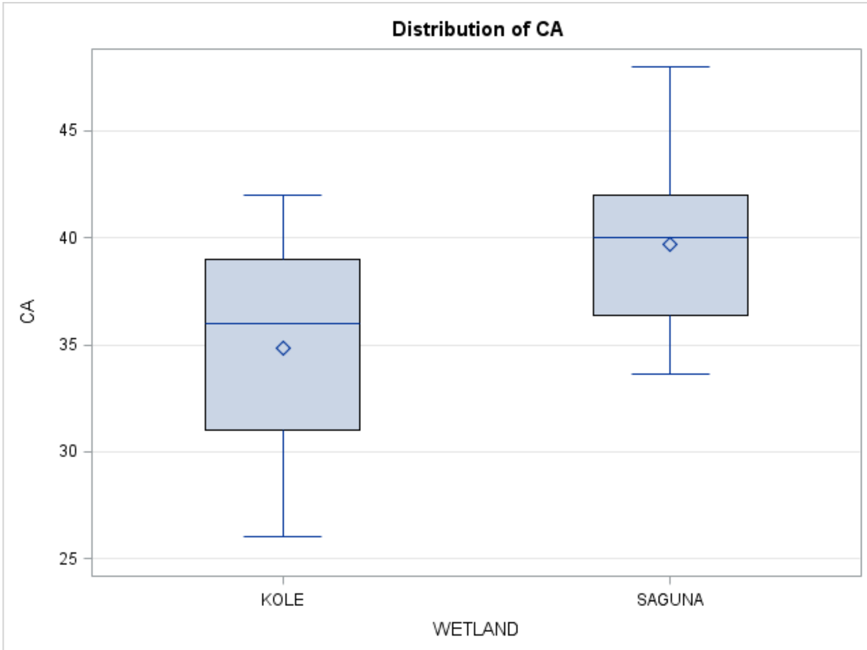

Figure 23: This is a caption

Figure 24: Monthly variation in Calcium between Saguna and Kole floodplain wetlands

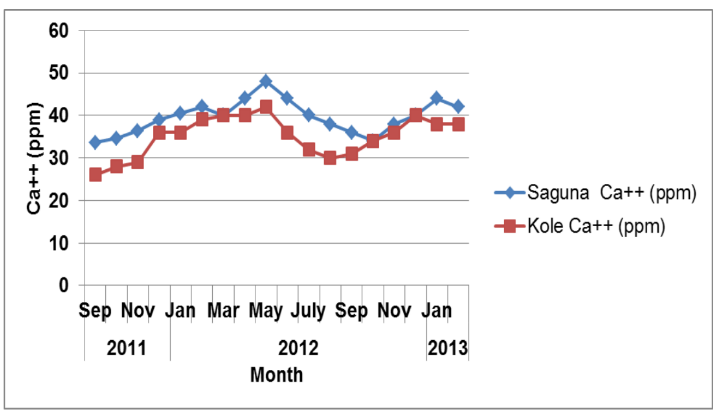

Figure 24: This is a caption

4.2.11 Magnesium:

The magnesium has shown mean values of 1.9 ppm and 15.3 ppm for Saguna and Kole wetland. The magnesium has shown minimum and maximum values 13.74 ppm (Jan of 2013) and 17.58 ppm (October of 2011) in open type and 0.24 ppm (Nov of 2011) and 6.318 ppm (July of 2012) in closed type. Then the analysis of variance revealed that there was a month-wise and wetland type-wise significant difference in magnesium (Table- 4.2.1 & 4.2.2). The Kole wetland has shown significantly higher values of magnesium in comparison with Saguna (Figure-4.2.11.1).

4.2.12 Nitrate-Nitrogen:

The Nitrate has shown mean values of 98.4 ppm and 105.6 ppm for Saguna and Kole wetland. The Nitrate has shown minimum and maximum values 22 ppm (April 2012) and 225 ppm (August 2012) in open type and 40 ppm (May 2012) and 220 ppm (August 2012) in closed type. Then the analysis of variance revealed that there was a month-wise and wetland type-wise significant difference in Nitrate (Table-4.2.1 & 4.2.2). The Kole wetland has shown significantly higher values of Nitrate in comparison with Saguna (Figure- 4.2.12.1).

4.2.13 Phosphate-phosphorus:

The phosphorus has shown mean values of 143 ppm and 99 ppm for Saguna and Kole wetland. The phosphorus has shown minimum and maximum values 28 ppm (May 2012) and 220 ppm September 2012) in open type and 20 ppm (May 2012) and 360 ppm (September 2012) in closed type. Phosphate-phosphorus exhibited irregular variation during the study period showing many peaks and troughs. However, both the beels exhibited a more or less similar trend of temporal variation even though minor deviations were observed. Then the analysis of variance revealed that there was a month-wise and wetland type-wise significant difference in phosphorus (Table-4.2.1 & 4.2.2). The Kole wetland has shown significantly higher values of phosphorus in comparison with Saguna (Figure 4.2.13.1).

Figure 25: Boxplot for Magnesium of the selected floodplain wetlands

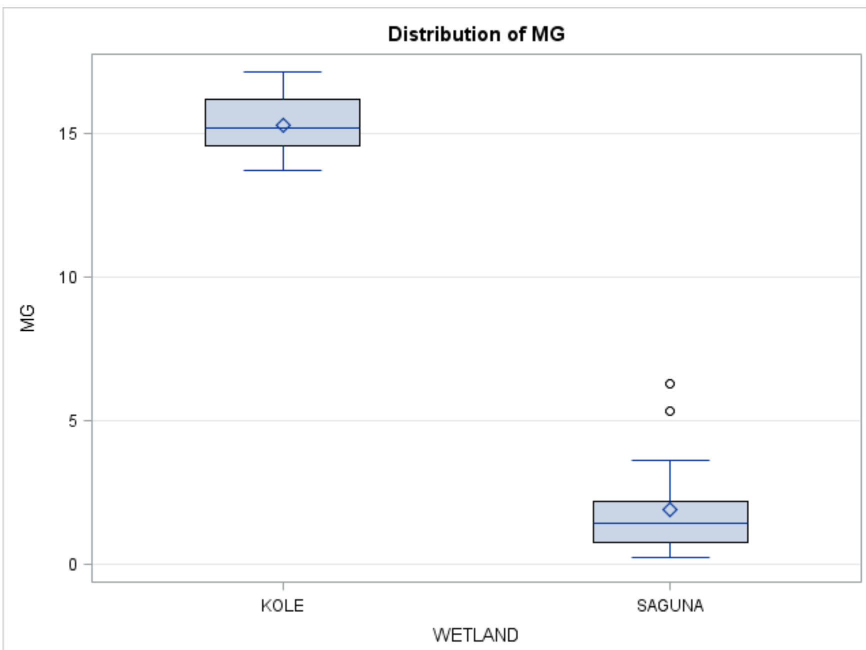

Figure 25: This is a caption

Figure 26: Monthly variation in Magnesium between Saguna and Kole floodplain wetlands

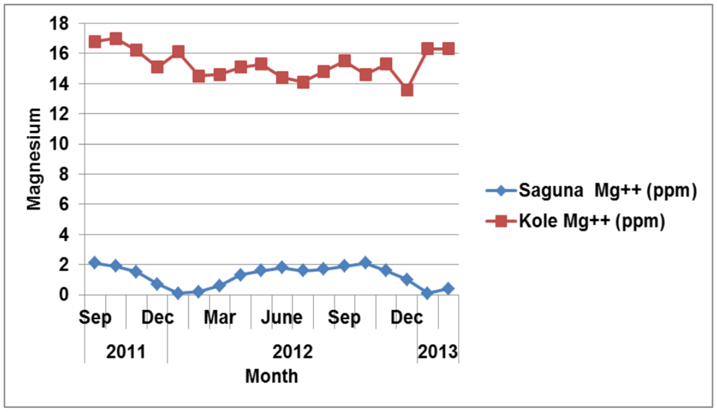

Figure 26: This is a caption

Figure 27: Boxplot for Nitrate of the selected floodplain wetlands

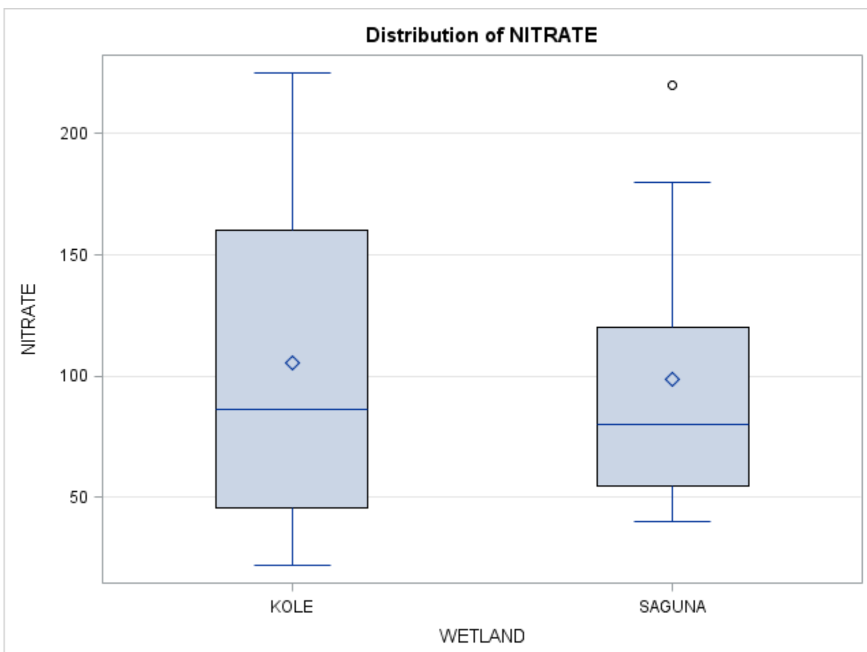

Figure 27: This is a caption

Figure 28: Monthly variation in Nitrate between Saguna and Kole floodplain wetlands

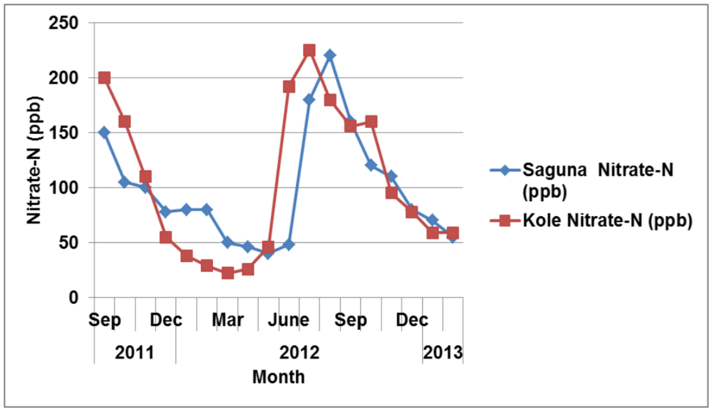

Figure 28: This is a caption

Figure 29: Boxplot for phosphate-phosphorous of the selected floodplain wetlands

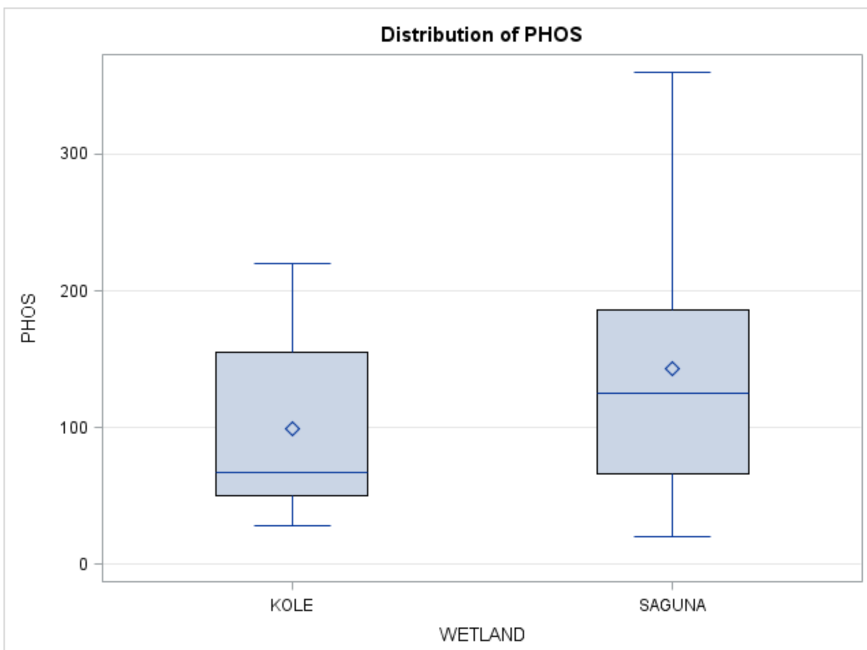

Figure 29: This is a caption

Figure 30: Monthly variation in Phosphate-P between Saguna and Kole floodplain wetlands

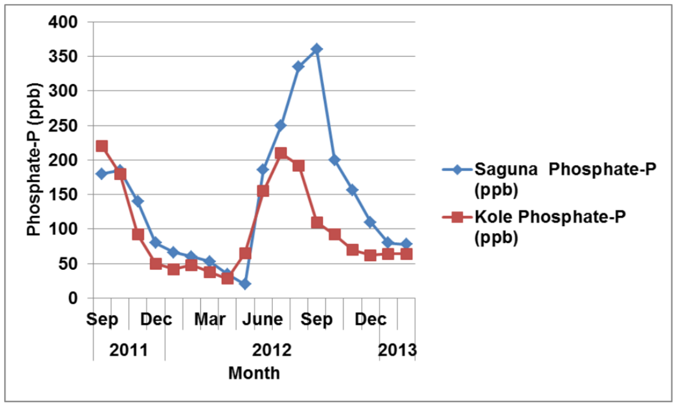

Figure 30: This is a caption

4.2.14 Chloride

The chloride has shown mean values of 20 ppm and 34 ppm for Saguna and Kole wetland. The chloride has shown minimum and maximum values 26.5 ppm (Sept 2012) and 39.5 ppm (March 2012) in open type and 9.23 ppm (Sept 2012) and 24.4 ppm (June 2012) in closed type. Then the analysis of variance revealed that there was a month-wise and wetland type-wise significant difference in chloride (Table-4.2.1 & 4.2.2). The Kole wetland has shown significantly higher values of chloride in comparison with Saguna (Figure-4.2.14.1).

4.2.15 Silicate-silica

The distribution of silicate-silica of water showed distinct seasonal variation. Both the beels exhibited more or less similar variation patterns. The silica has shown mean values of 7.1 ppm and 7.0 ppm for Saguna and Kole wetland. The silica has shown minimum and maximum values 4 (May. 2012) and 10.1 ppm (September 2011) in open type and 4 ppm (May 2012) and 10.8 ppm (August, September 2012) in closed type. Then the analysis of variance revealed that there was a month-wise and wetland type-wise significant difference in silica (Table-4.2.1 & 4.2.2). The Kole wetland has shown significantly higher values of silica in comparison with Saguna (Figure-4.2.15.1).

Figure 31: Boxplot for Chlorides of the selected floodplain wetlands

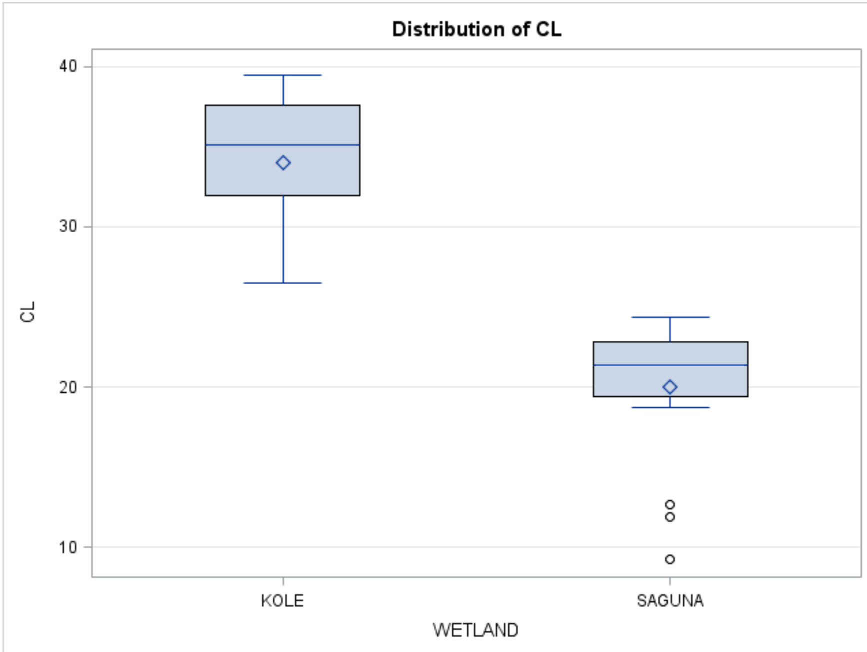

Figure 31: This is a caption

Figure 32: Monthly variation in Chloride between Saguna and Kole floodplain wetlands

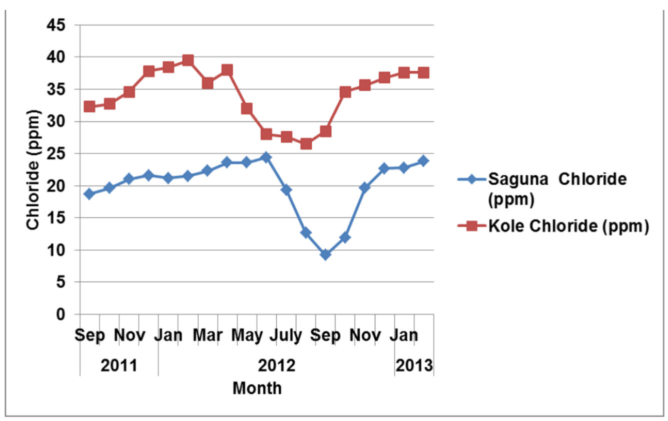

Figure 32: This is a caption

Figure33 : Boxplot for Silica of the selected floodplain wetlands

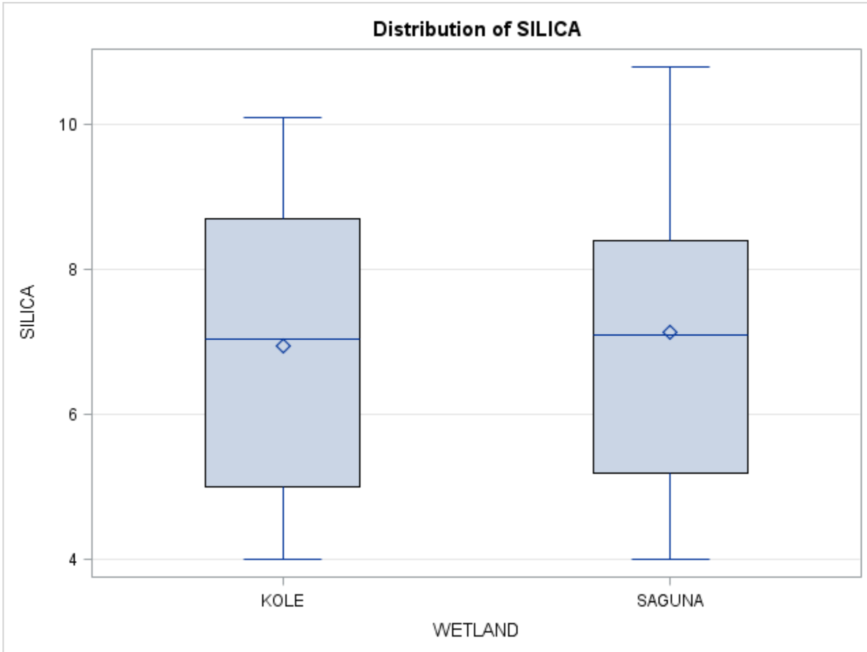

Figure 33: This is a caption

Figure 34: Monthly variation in Silicate-Silica between Saguna and Kole floodplain wetlands

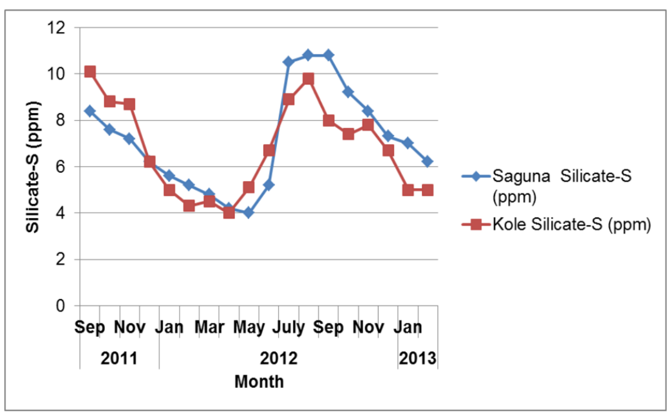

Figure 34: This is a caption

Table 4.2.1: Descriptive statistics of Water quality parameters data of Saguna

Parameters	Mean	SE	SD
Transparency (m)	1.9	0.06	0.27
Water coverage(%)	68.1	3.26	13.81
Macrophyte coverage (%)	5.0	0.67	2.85
Depth(m)	2.8	0.07	0.28
Temp (Air) °C	26.1	0.64	2.70

Temp (Water) °C	25.1	0.61	2.60
Water reaction(pH)	8.0	0.07	0.28
Specific conductivity (µS/cm)	263.7	8.35	35.41
Dissolved oxygen (ppm)	7.5	0.13	0.53
Free Carbon di Oxide (ppm)	1.1	0.21	0.90
Total Alkalinity (ppm)	1.3	0.97	4.12
Total Hardness (ppm)	105.3	3.20	13.57
Calcium (ppm)	39.7	0.93	3.93
Magnesium(ppm)	1.9	0.39	1.64
Chloride (ppm)	20.0	1.03	4.37
Nitrate – N (ppm)	98.4	11.95	50.71
Phosphate-phosphorus (ppm)	143.0	23.21	98.45
Silicate-silica (ppm)	7.1	0.52	2.19

Table 4.2.2: Descriptive statistics of water quality parameters of Kole

Parameters	Mean	SE	SD
Transparency (m)	1.2	0.1	0.3
Water coverage(%)	0.6	0.04	0.2
Macrophyte coverage (%)	0.4	0.03	0.1
Depth(m)	60.9	2.3	9.8
Temp (Air) °C	34.9	2.6	11.0
Temp (Water) °C	0.02	0.001	0.004
Water reaction(pH)	67.8	3.2	13.7
Specific conductivity (µS/cm)	16.2	1.2	5.0
Dissolved oxygen (ppm)	2.2	0.1	0.5
Free Carbon di Oxide (ppm)	27.5	1.1	4.6
Total Alkalinity (ppm)	26.6	1.0	4.4
Total Hardness (ppm)	7.9	0.1	0.2
Calcium (ppm)	472.3	11.0	46.5
Magnesium(ppm)	7.7	0.1	0.5
Chloride (ppm)	1.3	0.3	1.3
Nitrate – N (ppm)	145.2	2.5	10.5
Phosphate-phosphorus (ppm)	149.6	2.4	10.3
Silicate-silica (ppm)	34.8	1.1	4.7

4.3 SOIL QUALITY

4.3.1 Soil texture

The soil texture in the two beels is given in the table. It can be seen that the soil of the two selected beels Saguna and Kole contains a high percentage of sand which is about 60 – 65 %.

Soil texture showed moderate spatial variations in the selected Floodplain wetlands. The beels did not show much temporal variation in soil texture. The soil texture of the Kole indicated a shift from sandy-clay to more silty-clay, as receiving humus originated from massive stands of aquatic weeds.

4.3.2 Sand

The sand has shown mean values of 71.7 % and 64.2% for Saguna and Kole wetland. The sand has shown minimum and maximum values of 61% (Sept, October, Nov, Dec of 2011 and Jan, Feb, March, and Apr of 2012) and 68% (Sept, Oct, Nov and Dec of 2012 and Jan & Feb of 2013) in open type and 69% (Sept 2013) and 73 (Oct, Nov & Dec of 2012 and Jan & Feb of 2013) in closed type. Then the analysis of variance revealed that there was a month-wise and wetland type-wise significant difference in the sand (Table- 4.3.1 & 4.3.2). The Saguna wetland has shown significantly higher values of sand in comparison with Kole (Figure-4.3.1.1).

4.3.3 Silt

The silt has shown mean values of 9.9 % and 21.2 % for Saguna and Kole wetland. The silt has shown minimum and maximum values of 17 % (Oct, Nov, Dec 2012 and Jan, Feb 2013)) and 25 % (Sept, Oct, Nov & Dec of 2011 and Jan, Feb, March & April of 2012) in open type and 9% (Sept, Oct, Nov, Dec 2012 and Jan, Feb 2013) and 14 % (August 2012) in closed type. Then the analysis of variance revealed that there was a month-wise and wetland type-wise significant difference in silt (Table- 4.3.1 & 4.3.2). The Saguna wetland has shown significantly higher values of silt in comparison with Kole (Figure-4.3.2.1).

Figure 35: Boxplot for Sand of the selected floodplain wetlands

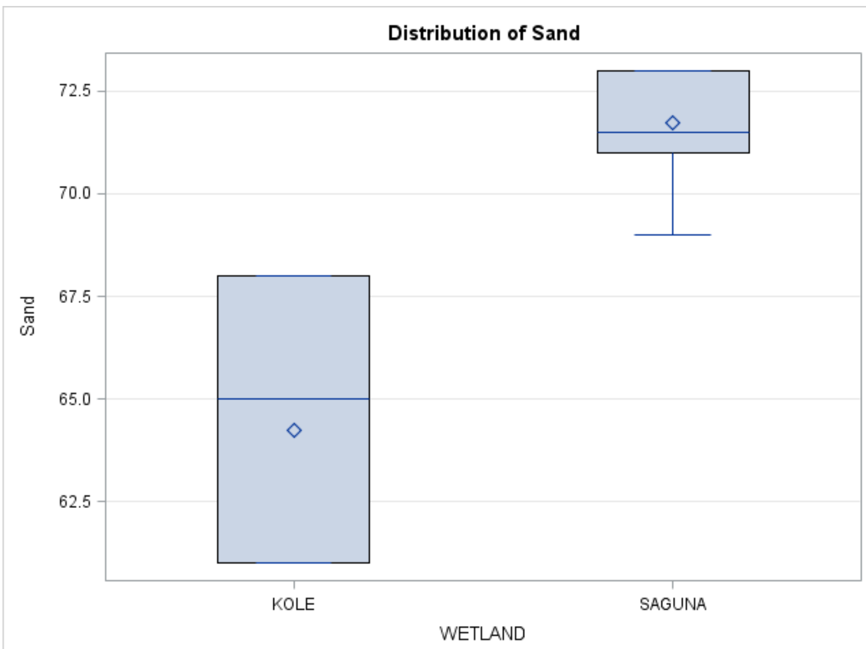

Figure 35: This is a caption

Figure 36: Monthly variation in sand (%) between Saguna and Kole floodplain wetlands

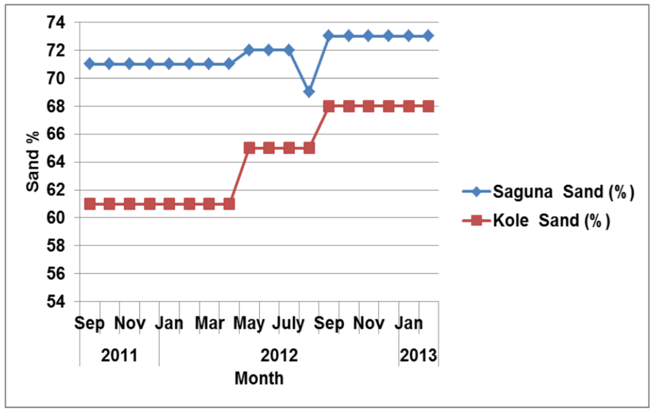

Figure 36: This is a caption

Figure 37: Boxplot for silt of the selected floodplain wetlands

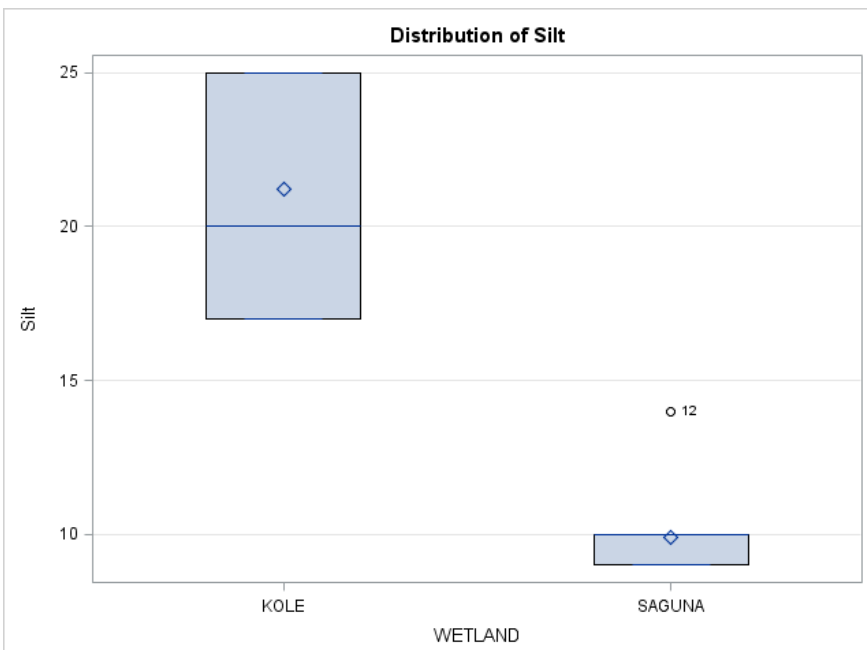

Figure 37: This is a caption

Figure 38: Monthly variation in silt (%) between Saguna and Kole floodplain wetlands

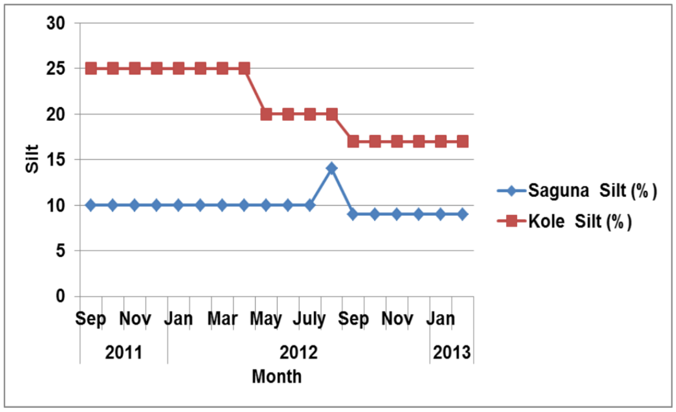

Figure 38: This is a caption

4.3.4 Clay

The clay has shown mean values of 18.4 % and 14.6% for Saguna and Kole wetland. The clay has shown minimum and maximum values 14 % (Sept to April, 2012) and 15% (may to Feb, 2013) in open type and 17 % and 19 % during the months in closed type. Then the analysis of variance revealed that there was a month wise and wetland type wise significant difference in clay (Table- 4.3.1 & 4.3.2). The Saguna wetland has shown significantly higher values of clay in comparison with Kole (Figure - 4.3.3.1).

4.3.5 Soil pH

The soil pH has shown mean values of 7.4 and 7.5 for Saguna and Kole wetland. The soil pH has shown minimum and maximum values 7.1(August 2012) and 7.8 (February 2012) in open type and 7.1 (September, 2012) and 7.8 (June, 2012) in closed type. Then the analysis of variance revealed that there was a month-wise and wetland type-wise significant difference in soil pH (Table- 4.3.1 & 4.3.2). The Saguna wetland has shown significantly higher values of soil pH in comparison with Kole (Figure-4.3.4.1). The soil pH exhibited hardly any seasonality with minor higher values during the monsoon and lower values during summer in two selected beel. The trend of temporal variation was more or less similar in both the beels.

4.3.6 Organic carbon

The organic carbon content of soil underwent irregular temporal variation during the study period. The soil organic carbon has shown mean values of 2.1% and 0.6 % in Saguna and Kole and wetland. The soil organic carbon has shown minimum and maximum values 0.48% (April 2012) and 0.74% (September 2011) in open type and 0.6 % (July 2012) and 3.9 % (September 2011) in closed type. Then the analysis of variance revealed that there was a month-wise and wetland type-wise significant difference in soil organic carbon (Table- 4.3.1 & 4.3.2). The Saguna wetland has shown significantly higher values of soil organic carbon in comparison with Kole (Figure-4.3.5.1).

Figure 39: Boxplot for clay of the selected floodplain wetlands

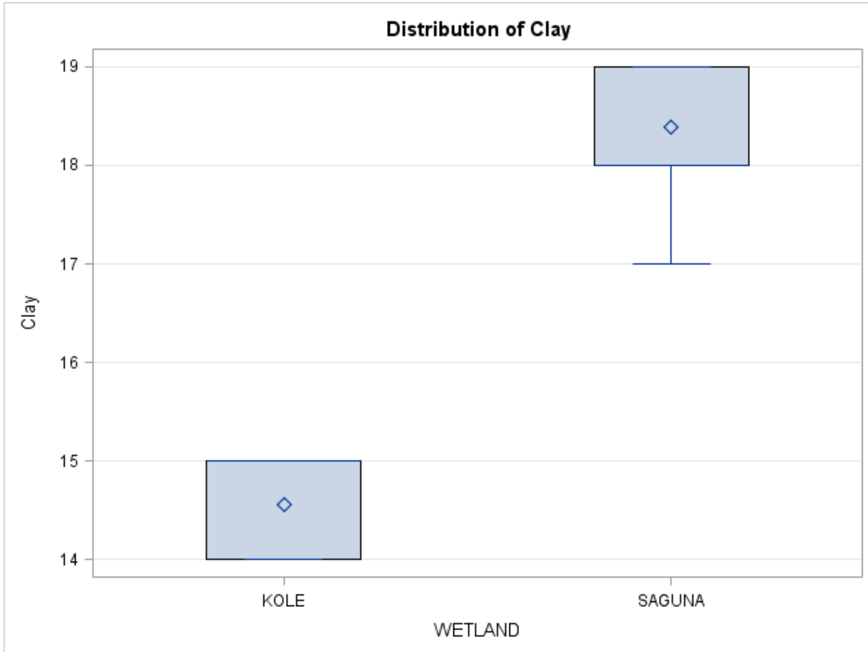

Figure 39: This is a caption

Figure 40: Monthly variation in clay (%) between Saguna and Kole floodplain wetlands

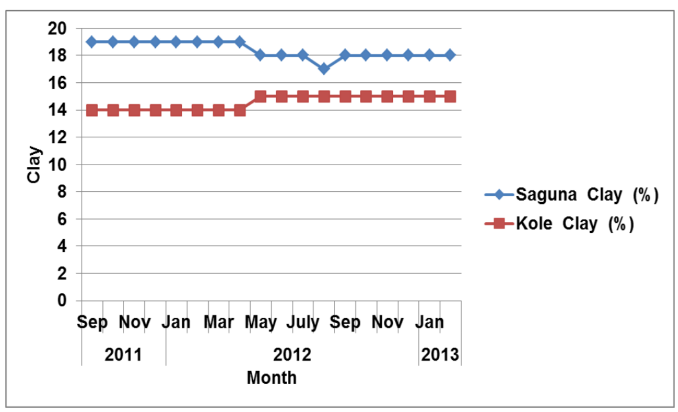

Figure 40: This is a caption

Figure 41: Boxplot for soil pH of the selected floodplain wetlands

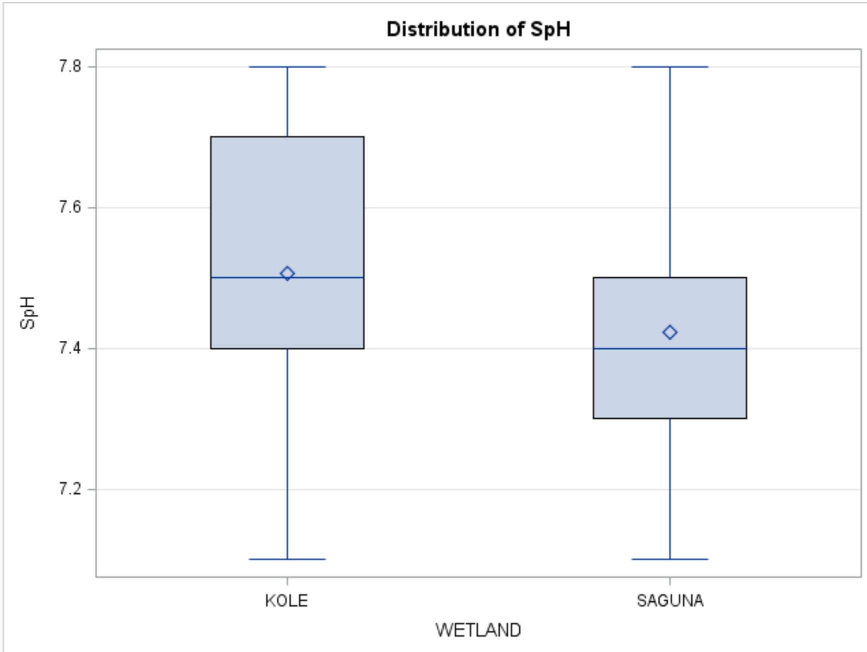

Figure 41: This is a caption

Figure 42: Monthly variation in soil pH between Saguna and Kole floodplain wetlands

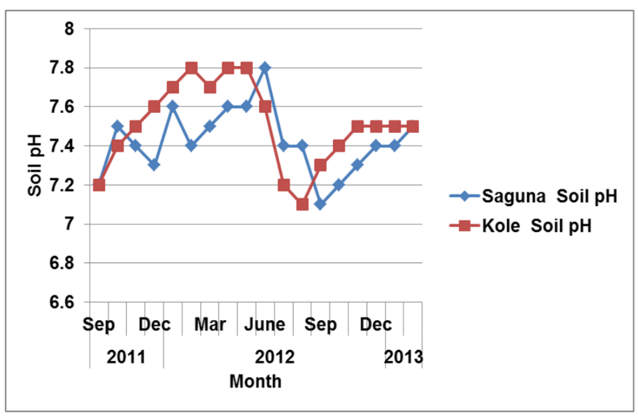

Figure 42: This is a caption

Figure 43: Boxplot for organic carbon in soil of the selected floodplain wetlands

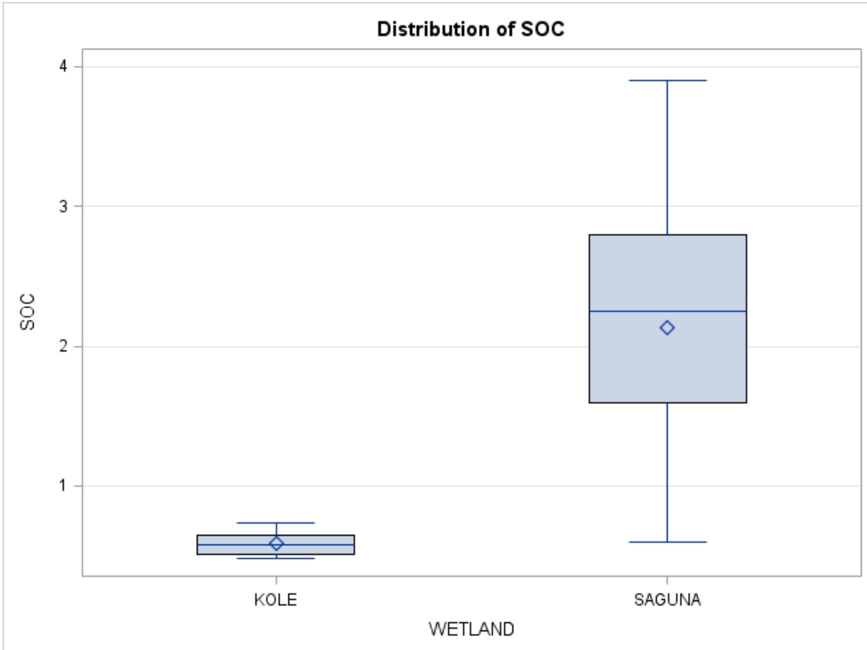

Figure 43: This is a caption

Figure 44: Monthly variation in organic carbon in soil between Saguna and Kole floodplain wetlands

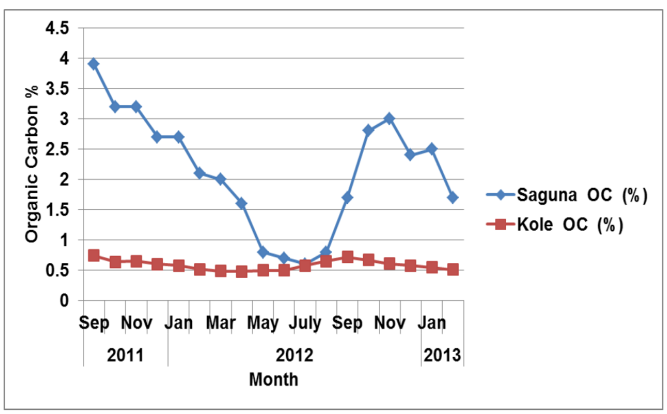

Figure 44: This is a caption

4.3.6 Available nitrogen

The soil available nitrogen has shown mean values of 22.6 mg/100g and 26.8 mg/100g for Saguna and Kole wetland. The soil available nitrogen has shown minimum and maximum values 20 mg/100g (June, 12) and 33 mg/100g (September, 11) in open type and 18 mg/100g (Jan & Feb of 13) and 28 mg/100g (Sept, 11 and Sept, 12) in closed type. Then the analysis of variance revealed that there was a month wise and wetland type wise significant difference in soil available nitrogen (Table- 4.3.1 & 4.3.2). The Kole wetland has shown significantly higher values of soil available nitrogen in comparison with Saguna (Figure - 4.3.6.1).

4.3.7 Available phosphorus

In temporal variation pattern showed considerable differences between the beels. The soil available phosphorus has shown mean values of 0.4 mg/100g of soil and 0.3 mg/100gof soil for Saguna and Kole wetland. The soil available phosphorus has shown minimum and maximum values 0.21 mg/100gof soil (January, 2013) and 0.46 mg/100gof soil (September, 2012) during the months of in open type and 0.24 mg/100gof soil (Jan, 11 and March, 12 and Jan, 13) and 0.58 (September, 2011) in closed type. Then the analysis of variance revealed that there was a month wise and wetland type wise significant difference in soil available phosphorus (Table- 4.3.1 & 4.3.2). The Saguna wetland has shown significantly higher values of soil available phosphorus in comparison with Kole (Figure-4.3.7.1).

Figure 45: Boxplot for Available nitrogen of the selected floodplain wetlands

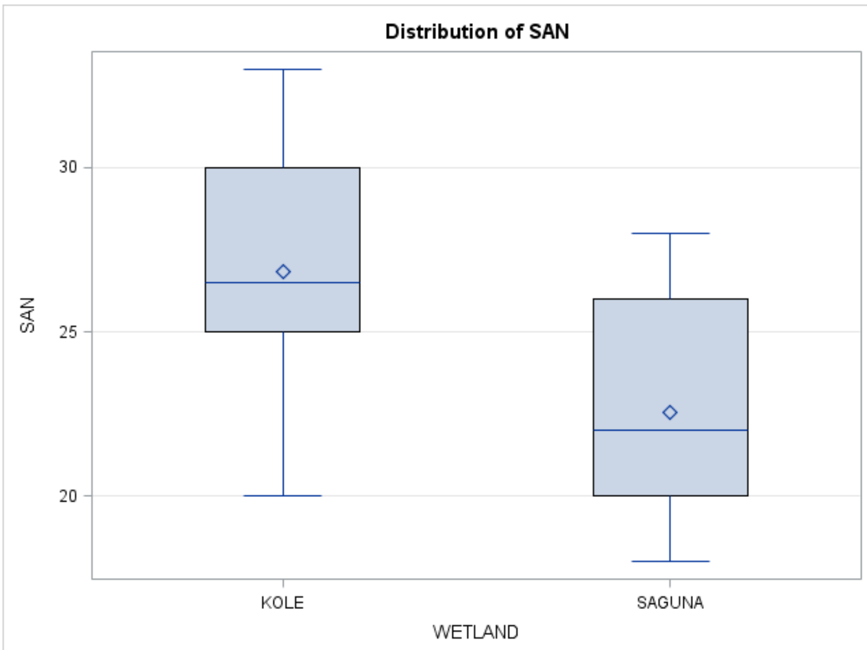

Figure 45: This is a caption

Figure 46: Monthly variation in available Nitrogen in soil between Saguna and Kole floodplain wetlands

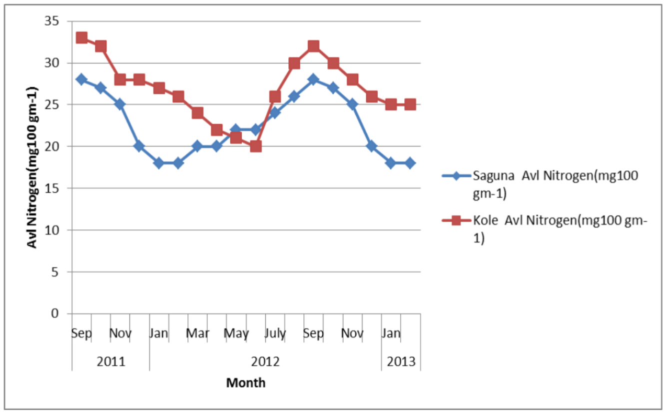

Figure 46: This is a caption

Figure 47: Boxplot for available phosphorous of soil of the selected floodplain wetlands

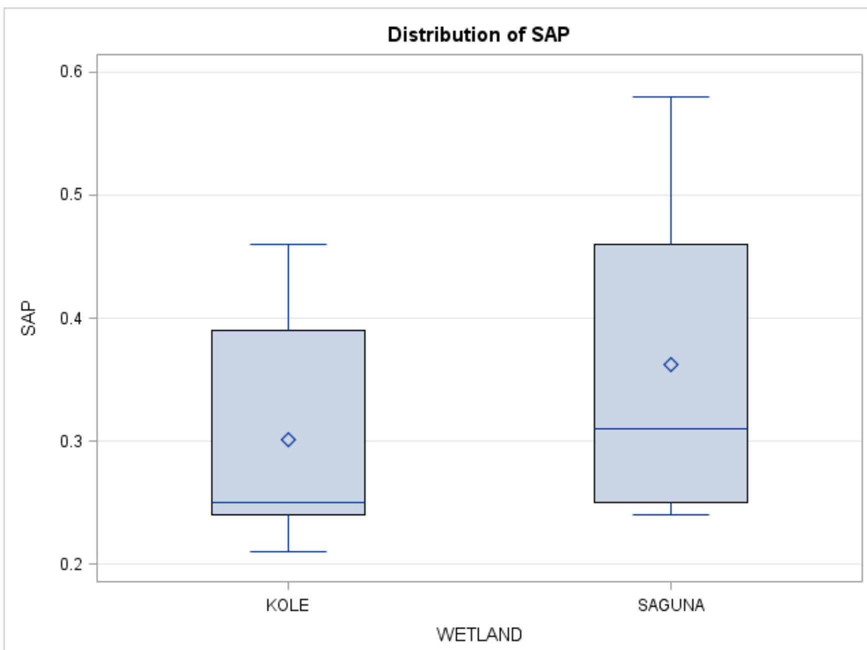

Figure 47: This is a caption

Figure 48: Monthly variation in available Phosphrous in soil between Saguna and Kole floodplain wetlands

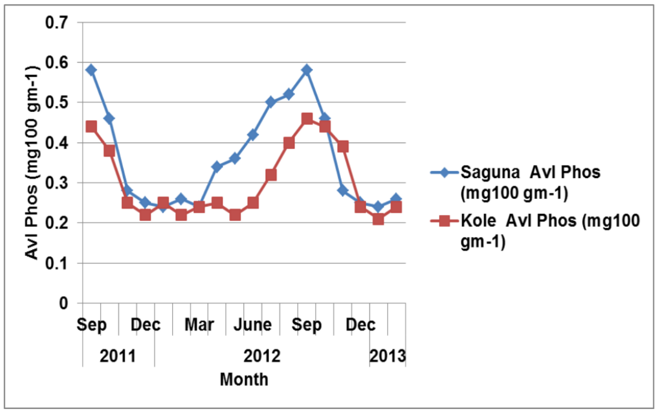

Figure 48: This is a caption

Table 4.3.1 Descriptive statistics of soil quality parameter data of Saguna

Parameters	Mean	SE	SD
Sand (%)	71.7	0.27	1.13
Silt (%)	9.9	0.27	1.13
Clay (%)	18.4	0.14	0.61
Soil pH	7.4	0.04	0.17
Soil Organic carbon	2.1	0.23	0.97
Soil Available Phosphorus	0.4	0.03	0.13
Soil available nitrogen	22.6	0.88	3.71

Table 4.3:2 Descriptive statistics of soil quality parameter data of Kole

Parameters	Mean	SE	SD
Sand	64.2	0.7	3.2
Silt	21.2	0.9	3.7
Clay	14.6	0.1	0.5
SpH	7.5	0.1	0.2
Soil Organic carbon	0.6	0.02	0.1
Soil Available Phosphorus	0.3	0.02	0.1
Soil available nitrogen	26.8	0.9	3.7

4.4 BIOTIC COMMUNITIES

4.4.1 Plankton

The order of month-wise abundance of plankton in Saguna beel was November>October>March>February>January>April>December> July>September>August>June.

The order of month-wise abundance Kole beel was December>August> November> April >October >July >March> February> May> January >September> June. Phytoplankton contributed 73.0 % and 61.8 % to total plankton population in Saguna and Kole Beel respectively.

4.4.1.1 Phytoplankton

The phytoplankton has shown mean values of 1543.2 numbers/l and 1052 numbers/l for Saguna and Kole wetland. The phytoplankton has shown minimum and maximum values 570 numbers/l (August 2012) and 1476 numbers/l (September 2012) in open type and 763 numbers/l (August 2012) and 1952 numbers/l (September 2011) in closed type. Then the analysis of variance revealed that there was a month-wise and wetland type-wise significant difference in phytoplankton (Table- 4.4.1.1). The Saguna wetland has shown significantly higher values of phytoplankton in comparison with Kole.

The trend of abundance followed a sequence of Bacillariophyceae>Chlorophyceae>Euglenophyceae>Dinophyceae>Xanthophy during 2011-13.

In general, there is a gradual decline in the abundance of phytoplankton during the monsoon, however, the concentration increase from post-monsoon to winter. A total of 64 species of phytoplankton (13 species of Myxophyceae, 24 species of Chlorophyceae, 18 species of Bacillariophyceae, 2 species of Euglenophyceae, 1 species of Dinophyceae, and 2 species of Xanthophyceae) were recorded from the selected beels.

Among the various groups of phytoplankton, Bacillariophyceae remained the most dominant group (35.35 % on an average) followed by Myxophyceae (26.24%), Chlorophyceae (22.15 %), and Dinophyceae (8.78 %) in Saguna beel.

In Kole beel, Bacillariophyceae (29.92 %), Chlorophyceae was the most dominant group (22.7 %), Euglenoida (9.26 %), and Dinophyceae (7.4 %).

The number of phytoplankton genera occurring in Saguna beel was higher (52) than that in Saguna beel (45 genera). The group Bacillariophyceae was represented by 20 genera (19 in Saguna and 14 in Kole beel) out of which *Fragillaria spp.*, *Melosira spp.* and *Navicula spp.* were the most dominant ones. Chlorophyceae was represented by 20 genera (14 in Saguna beel and 17 in Kole beel) of which *Spirogyra spp. Pediastrum spp.* and *Mougeotia spp.* were commonly encountered. Out of 10 genera representing Myxophyceae (9 in Saguna and 6 in Kole beel), *Microcystis spp.*, *Anabaena spp.* and *Oscilatoria spp.* were fairly common. Desmids were represented by 11 genera (10 in Saguna beel and 6 in Kole beel), out of which *Cosmarium spp.* and *Staurastrum spp.* were the most dominant ones. The group Euglenoida, represented by *Euglena spp.* and *Phacus spp.*, occurred only in Kole beel.

Table 4.4.1.1: Diversity of phytoplankton in selected beels (floodplain wetlands) of west Bengal

Myxophyceae	*Pandorina morum* (S,K)
Anabaena spiroides (S,K)	*Pediastrum duplex* (S,K)
Aphanocapsa roeseana (S,K)	*Scenedesmus obliqumus* (S,K)
Aphanothece pallida (S,K)	*Spirogyra maxima* (S,K)
Chroococcus minutus (S,K)	*Staurasterum orbiculare (S)*
Cylindrospermum sp (S,K)	*Stigoclonium sp* (S,K)
Gleocapsa sp (S,K)	*Tetraedon sp (SK)*
Gloeotrichia echinulat (S,K)	*Tetraspora gelatinosa (S)*
Lyngbya birgei (S,K)	*Ulothrix zonata* (S,K)
Merismopedia minima (S,K)	*Westella botryoides (K)*
Microcystis aeruginosa (S,K)	*Volvox areus* (S,K)
Nostoc linckia (S,K)	Bacillariophyceae
Oscillatoria rubescens (S,K)	*Amphora coffeaeformis* (S,K)
Phormidium inundatum (S,K)	Cyclotella *meneginiyana* (S,K)
Rivullaria aquatica (K)	*Cymbella lanceolata (S)*
Spirulina princeps (S,K)	*Eunotia pectinalis (S)*
Actinasrtum gracillinum (S,K)	*Fragillaria brevistriata (S)*
Eudorina elegans (S,K)	*Gomphonema lanceolatum* (S,K)
Ankistrodesmus falcatus (S,K)	*Gyrosigma acuminatum* (S,K)

Asterococcus limneticus (S,K)	*Melosira granulate* (S,K)
Characium augustum (K)	*Navicula radiosa* (S,K)
Chlorella vulgaris (S,K)	*Nitzschia sigmoidia* (S,K)
Chlorococcum infusionum (S)	*Pinnularia major* (S,K)
Cladophora sp (S,K)	*Rhopalodia gibba* (S,K)
Closterium parvulum (S,K)	*Surirella sp* (S,K)
Cosmerium bengalicum (S,K)	*Synedra capitata* (S,K)
Crucigenia quadrata (S,K)	Euglenophyceae
Dictyosphaerium pulchellum (S)	*Euglena viridis (S)*
Euastrum spinulosum (S,K)	*Phacus caudate* (S,K)
Hydrodiction idium (S,K)	*Dinophyceae*
Micrasterius agardh (S,K)	*Ceratium macroceros (S)*
Mougeotia genuflexa (S,K)	Xanthophyceae
Oedogonium australe (S,K)	*Botrydium granulatum* (S,K)
Oocystis crassa (S)	*Tribonema vulgare (K)*

S=Saguna Floodplain wetland, K= Kole Floodplain wetland

4.4.1.1.1 Myxophyceae

The phytoplankton has shown mean values of 404.5 numbers/l and 295.7 numbers/l for Saguna and Kole wetland. The phytoplankton has shown minimum and maximum values 187 numbers/l (Nov 2011) and 459 numbers/l (December 2012) during the months of in open type and 197 numbers/l (July 2012) and 605 numbers/l (January 2012) during the months in closed type. Then the analysis of variance revealed that there was a month-wise and wetland type-wise significant difference in phytoplankton (Table- 4.4.1.1.1 & 4.4.1.1.2). The Saguna wetland has shown significantly higher values of phytoplankton comparison with Kole (Figure-4.4.1.1.1.1).

4.4.1.1.2 Chlorophyceae

The Chlorophyceae has shown mean values of 355.1 numbers/l and 243.7 numbers/l for Saguna and Kole wetland. The Chlorophyceae has shown minimum and maximum values 92 numbers/l (July 2012) and 514 numbers/l (September 2012) in open type and 117 numbers/l (July 2012) and 775 numbers/l (September 2011) in closed type. Then the analysis of variance revealed that there was a month-wise and wetland type-wise significant difference in Chlorophyceae (Table- 4.4.1.1.2 & 4.4.1.1.3). The Saguna wetland has shown significantly higher values of Chlorophyceae in comparison with Kole (Figure- 4.4.1.1.2.1).

4.4.1.1.3 Bacillariophyceae

The Bacillariophyceae has shown mean values of 529.8 numbers/l and 316.5 numbers/l for Saguna and Kole wetland. The Bacillariophyceae has shown minimum and maximum values 120 numbers/l (July 2012) and 461 numbers/l (January 2013) in open type and 324 numbers/l (September 2012) and 703 numbers/l (December 2011) in closed type. Then the analysis of variance revealed that there was a month-wise and wetland type-wise significant difference in Bacillariophyceae (Table- 4.4.1.1.2 & 4.4.1.1.3). The Saguna wetland has shown significantly higher values of Bacillariophyceae in comparison with Kole (Figure- 4.4.1.1.3.1).

4.4.1.1.4 Euglenoida

The Euglenoida has shown mean values of 131.4 numbers/l and 93.6 numbers/l for Saguna and Kole wetland. The Euglenoida has shown minimum and maximum values 24 (August 2012) and 188 numbers/l (April 2012) in open type and 47 numbers/l (September 2012) and 259 numbers/l (May 2012) in closed type. Then the analysis of variance revealed that there was a month-wise and wetland type-wise significant difference in Euglenoida (Table- 4.4.1.1.2 & 4.4.1.1.3). The Saguna wetland has shown significantly higher values of Euglenoida in comparison with Kole (Figure-4.4.1.1.4.1).

4.4.1.1.5 Dinophyceae

The Dinophyceae has shown mean values of 83.6 numbers/l and 78.6 numbers/l for Saguna and Kole wetland. The Dinophyceae has shown minimum and maximum values 26 numbers/l (August 2012) and 163 numbers/l (December 2011) in open type and 22 numbers/l (August 2012) and 164 numbers/l (December 2011) in closed type. Then the analysis of variance revealed that there was a month-wise and wetland type-wise significant difference in Dinophyceae (Table-4.4.1.1.2 & 4.4.1.1.3). The Kole wetland has shown significantly higher values of Dinophyceae in comparison with Saguna (Figure-4.4.1.1.5.1).

4.4.1.1.6 Xanthophyceae

The Xanthophyceae has shown mean values of 38.8 numbers/l and 23.9 numbers/l for Saguna and Kole wetland. The Xanthophyceae has shown minimum and maximum values 9 numbers/l (January 2013) and 63 numbers/l (September 2011) in open type and 7 numbers/l (August 2012) and 100 numbers/l (September 2011) in closed type. Then the analysis of variance revealed that there was a month-wise and wetland type-wise significant difference in Xanthophyceae (Table- 4.4.1.1.2 & 4.4.1.1.3). The Saguna wetland has shown significantly higher values of Xanthophyceae in comparison with Kole (Figure-4.4.1.1.6.1).

Figure 49: Boxplot for Myxophyceae of the selected floodplain wetlands

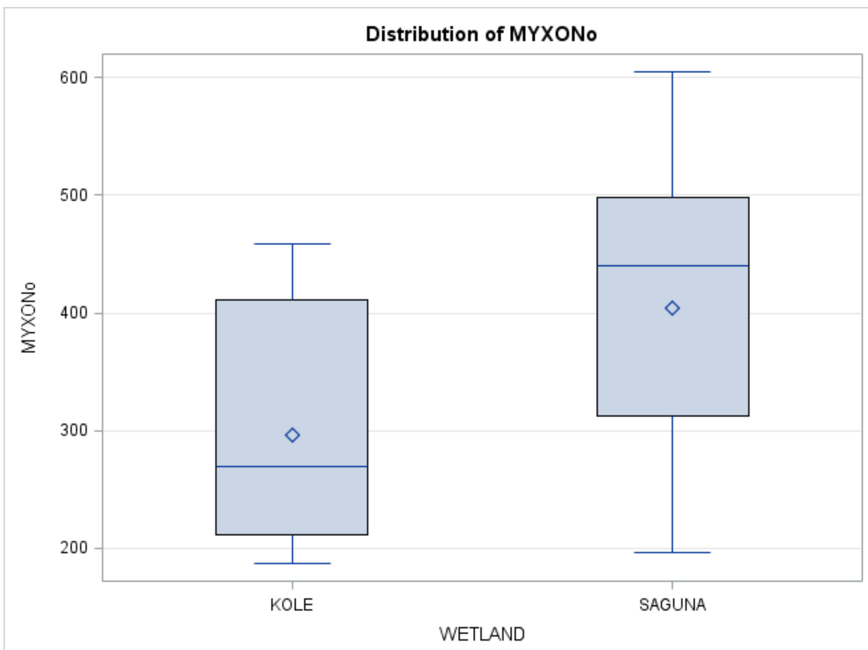

Figure 49: This is a caption

Figure 50: Monthly variation in numbers of Myxophyceae between Saguna and Kole floodplain wetlands

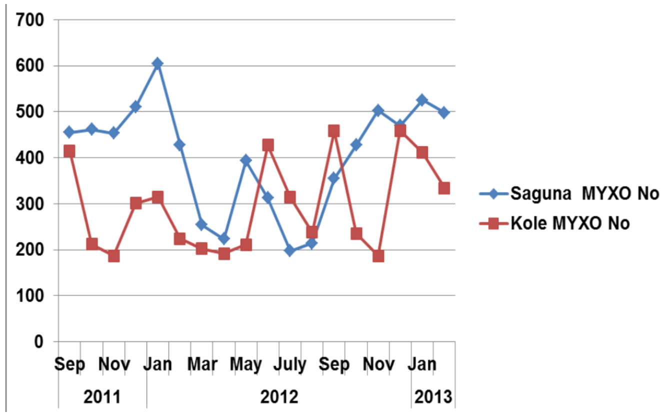

Figure 50: This is a caption

Figure 51: Boxplot for Chlorophyceae of the selected floodplain wetlands

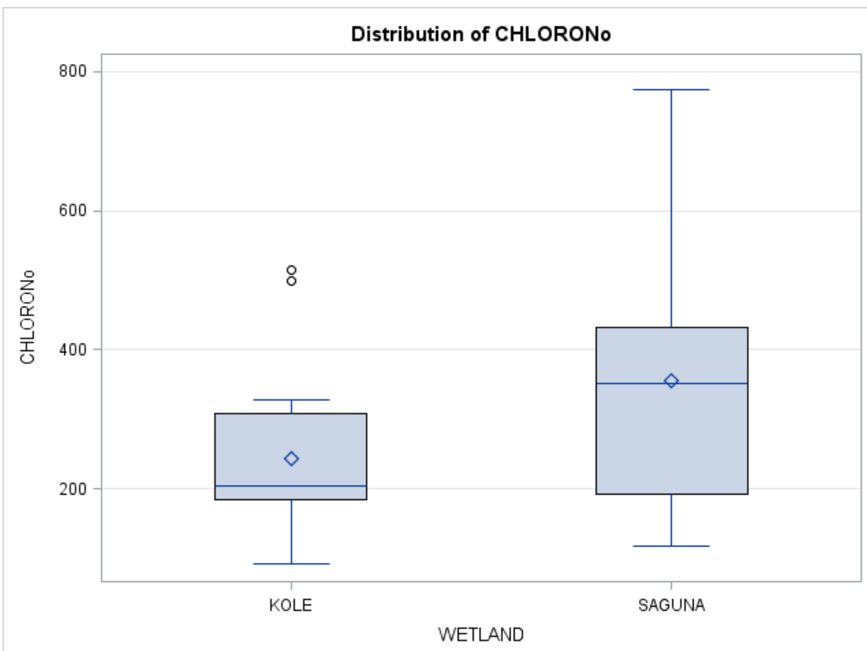

Figure 51: This is a caption

Figure52: Monthly variation in numbers of Chlorophyceae between Saguna and Kole floodplain wetlands

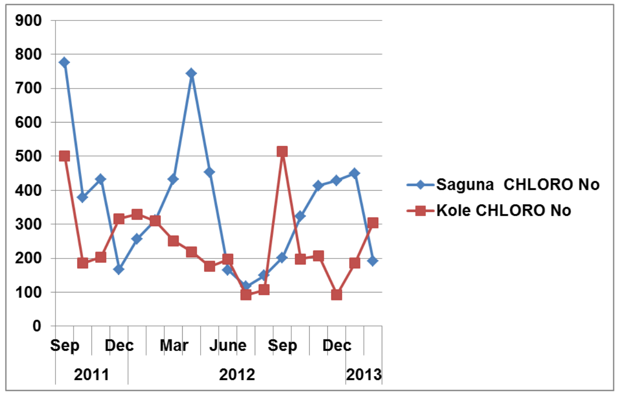

Figure 52: This is a caption

Figure 53: Boxplot for Bacillariophyceae of the selected floodplain wetlands

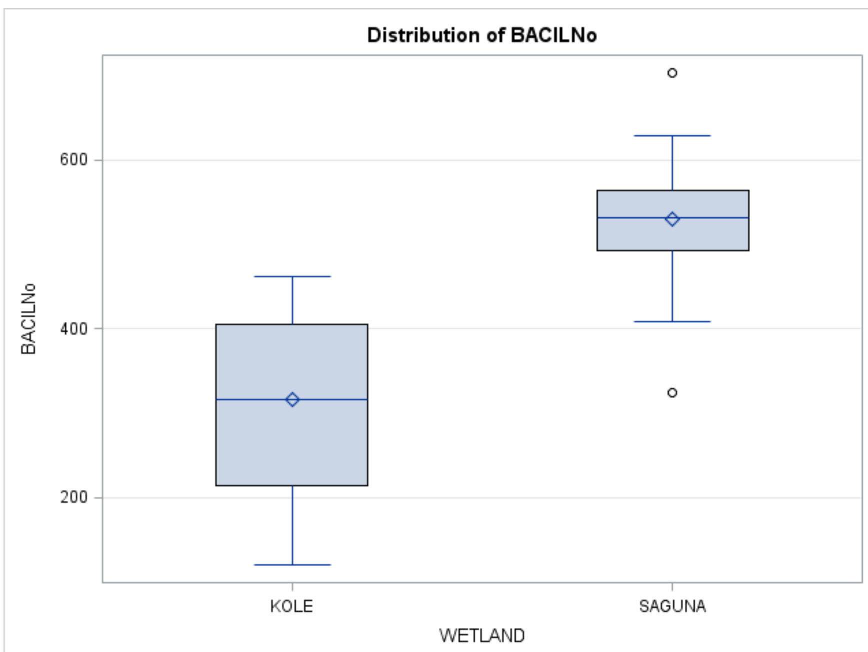

Figure 53: This is a caption

Figure 54: Monthly variation in numbers Bacillariophyceae between Saguna and Kole floodplain wetlands

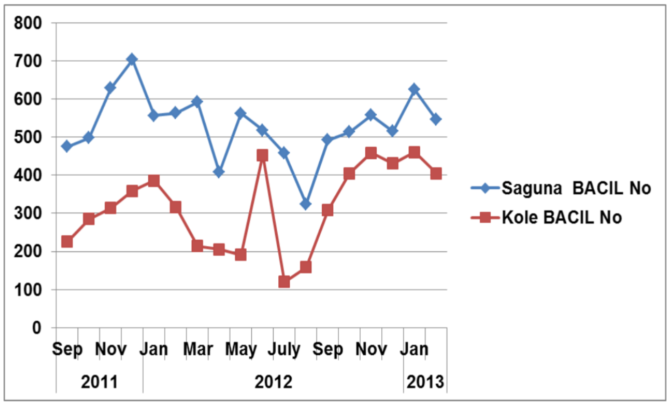

Figure 54: This is a caption

Figure 55: Boxplot for Euglenoida of the selected floodplain wetlands

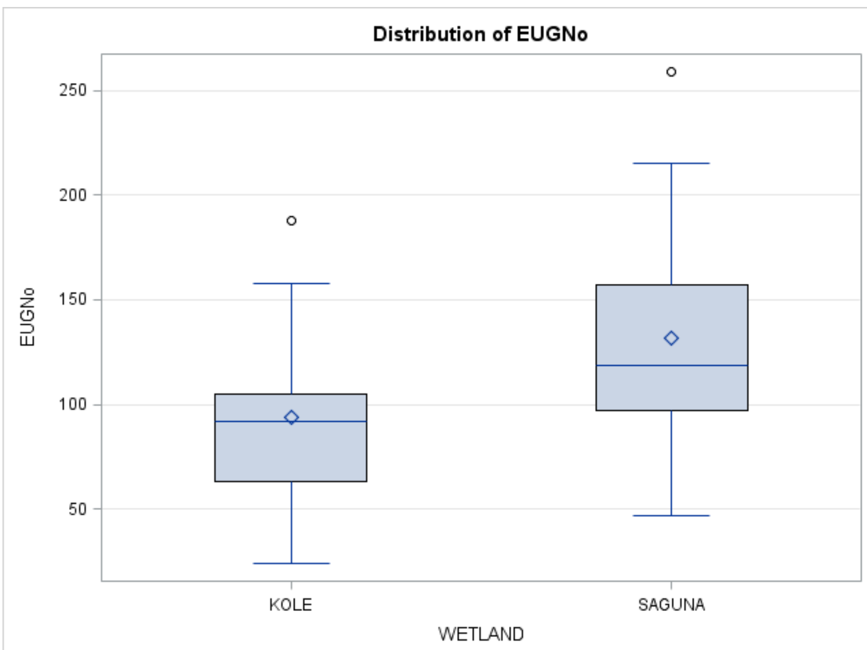

Figure 55: This is a caption

Figure 56: Monthly variation in numbers of Euglenoida between Saguna and Kole floodplain wetlands

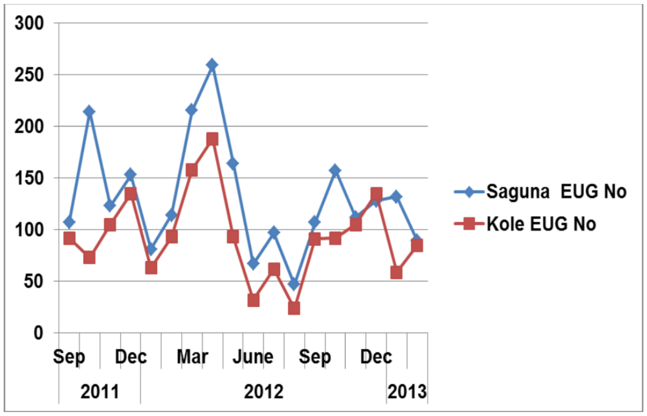

Figure 56: This is a caption

Figure 57: Boxplot for Dinophyceae of the selected floodplain wetlands

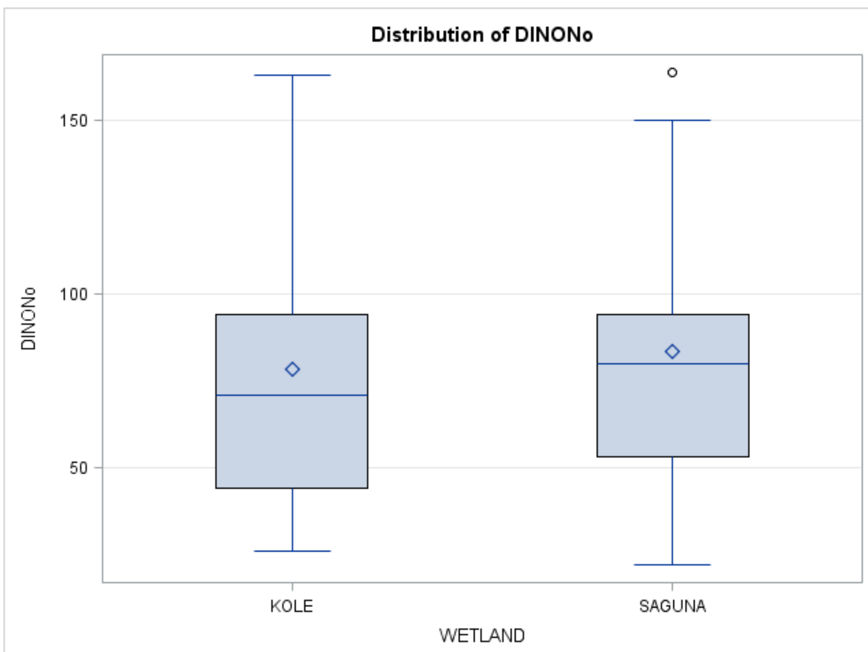

Figure 57: This is a caption

Figure 58: Monthly variation in numbers of Dinophyceae between Saguna and Kole floodplain wetlands

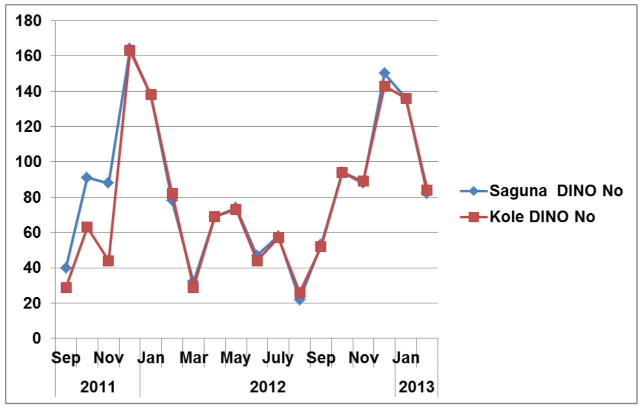

Figure 58: This is a caption

Figure 59: Boxplot for Xanthophyceae of the selected floodplain wetlands

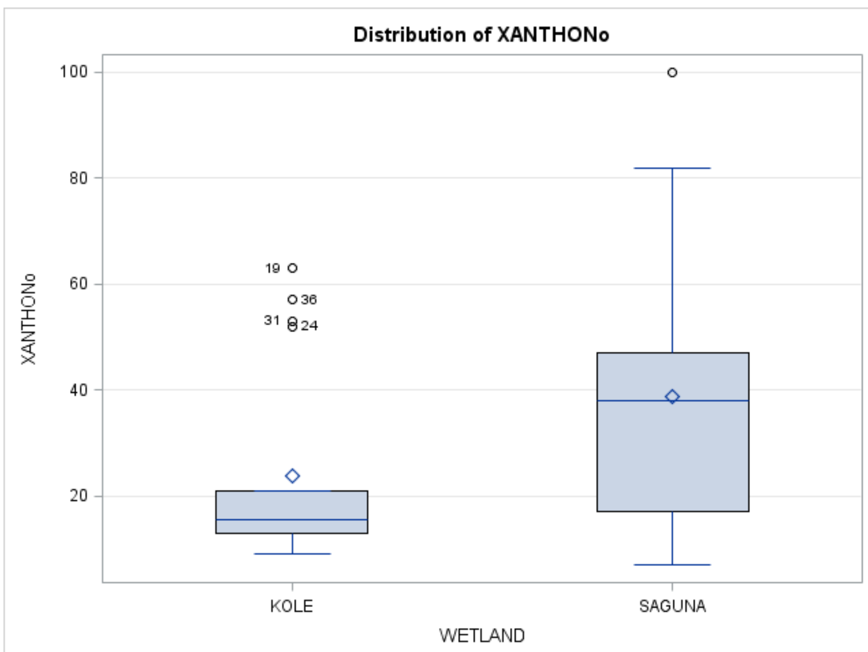

Figure 59: This is a caption

Figure 60: Monthly variation in numbers/l of xanthophyceae between Saguna and Kole floodplain wetlands

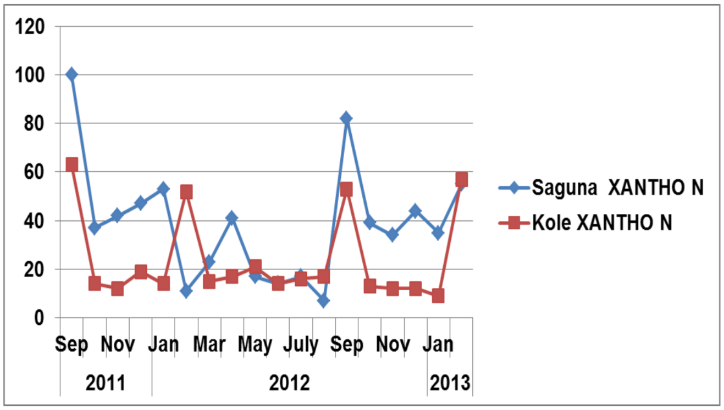

Figure 60: This is a caption

Table 4.4.1.1.2: Descriptive statistics of Phytoplankton data of Saguna

Sl. No.	Parameters	Mean	SE	SD
1.	Total Plankton NO	1849.6	92.36	391.85
2.	Phytoplankton No	1543.2	75.90	322.01
3.	Myxophyceae No	404.5	28.23	119.75
4.	Chlorophyceae No	355.1	44.29	187.89
5.	Bacillariophyceae No	529.8	20.22	85.80
6.	Euglenoida No	131.4	12.91	54.78
7.	Dinophyceae No	83.6	9.64	40.88
8.	Xanthophyceae No	38.8	5.67	24.04

Table 4.4.1.1.3: Descriptive statistics of Phytoplankton data of Kole

Sl. No.	Parameters	Mean	SE	SD
1.	Total Plankton NO	1111.8	56.4	239.3
2.	Phytoplankton No	1052.0	60.4	256.1
3.	Myxophyceae No	295.7	23.5	99.8
4.	Chlorophyceae No	243.7	28.2	119.6
5.	Bacillariophyceae No	316.5	26.0	110.3
6.	Euglenoida No	93.6	9.7	41.3
7.	Dinophyceae No	78.6	9.9	42.1
8.	Xanthophyceae No	23.9	4.3	18.1

4.4.17. 1 Phytoplankton and Physico-chemical parameters of water

Table 4.4.17.1 Eigen values and proportion of explained variation in the factor analysis on the selected physico chemical parameters of water and phytoplankton.

Preliminary Eigenvalues: Total = 4279.38205
Average = 171.175282

1
2
3

The factor analysis on selected physico-chemical parameters and phytoplankton was carried out to identify the significant factors with proportional loadings of variables on them. The analysis along with the varimax rotation procedure revealed that there were 3 significant factors (Eigen value>1) which together explained 96.38% of the total variation in the data (Table 4.4.17.1). However, the first factor with high positive loadings of macrophytes, specific conductivity, total alkalinity, total hardness, magnesium, chloride and negative loadings of transparency, depth, Myxophyceae and Bacillariophyceae explained 71.83% of the variation in the data (Table 4.4.17.2). The second factor was loaded positively with air temperature, water temperature, gross primary production and free carbon dioxide and negatively loaded with dissolved oxygen and Dinophyceae which explained 16.99% of the total variation in the data (Table 4.4.17.2). The third factor was positively loaded with calcium and pH and negatively loaded with silica, phosphate and nitrate which explained 7.56% of the total variation. This reveals the positive there is a correlation relation between the variables loaded positively or negatively and there is a definite negative correlation between the positively loaded variables and negatively loaded variables. The variables heavily loaded on the different factors were identified using the scratching procedure (Hatcher, 2003). Thus, the first factor was efficient in discriminating the wetland types. The variables loaded positively loaded on the first factor were high in the Kole wetland in comparison with Saguna. The clear depiction of this statement is given in Figure. 4.4.17.1 -4.4.17.2.

Figure. 4.4.17.1 The wetland-wise score plot of the second factor against the first factor generated in the factor analysis of selected physicochemical parameters of water and phytoplankton.

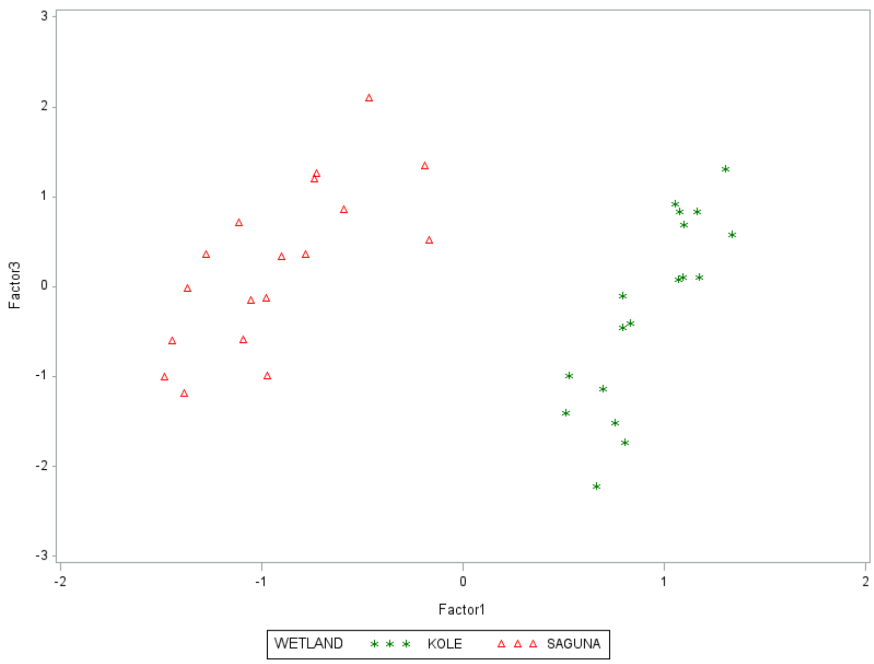

Figure 61: This is a caption

Figure. 4.4.17.2 The wetland wise score plot of the third factor against the first factor generated in the factor analysis of selected physico chemical parameters of water and phytoplankton.

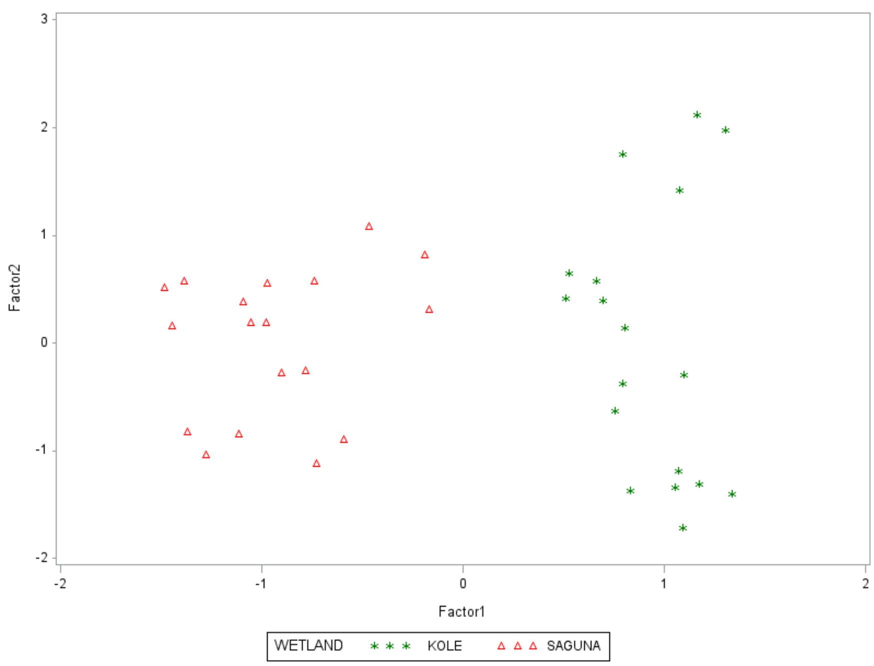

Figure 62: This is a caption

Table 4.4.17.2 Rotated factor pattern observed in the factor analysis of selected physico chemical parameters of water and phytoplankton.

Parameters	Factor1	Factor2	Factor3
Transparency	-0.7017	-0.4478	0.31333
Macrophyte	0.87143	0.18589	0.138
GPP	0.40429	0.68929	-0.105
Depth	-0.8019	0.06775	-0.3206
Temperature Air	0.15256	0.96619	-0.2078
Temperature water	0.1579	0.95837	-0.22
PH	-0.0628	-0.2439	0.59378
Specific Conductivity	0.95786	0.11606	0.03816
Dissolved Oxygen	0.07583	-0.7876	-0.1271
Free Carbon di Oxide	0.14952	0.78231	-0.0031
Total alkalinity	0.98091	0.07382	0.17784
Total hardness	0.98338	0.05654	0.16938
Calcium	-0.273	0.03185	0.96149
Magnesium	0.96307	0.00975	-0.2559
Chloride	0.89217	-0.1968	0.07475
Nitrate	-0.1012	0.19196	-0.6983
Phosphorus	-0.3385	0.26711	-0.5203
Silicate-Silica	-0.1772	-0.0109	-0.722
Myxophyceae No	-0.5183	-0.2095	0.05798
Chlorophyceae No	-0.39	0.0096	-0.0712
Bacillariophyceae No	-0.6934	-0.3417	0.29035
Euglenophyceae	-0.3613	0.00448	0.15882
Dinophyceae	-0.0782	-0.5758	0.18231
Xanthophyceae	-0.4207	-0.0565	-0.2691

Figure. 4.4.17.3 The wetland wise score plot of the third factor against the second factor generated in the factor analysis of selected physico-chemical parameters of water and phytoplankton.

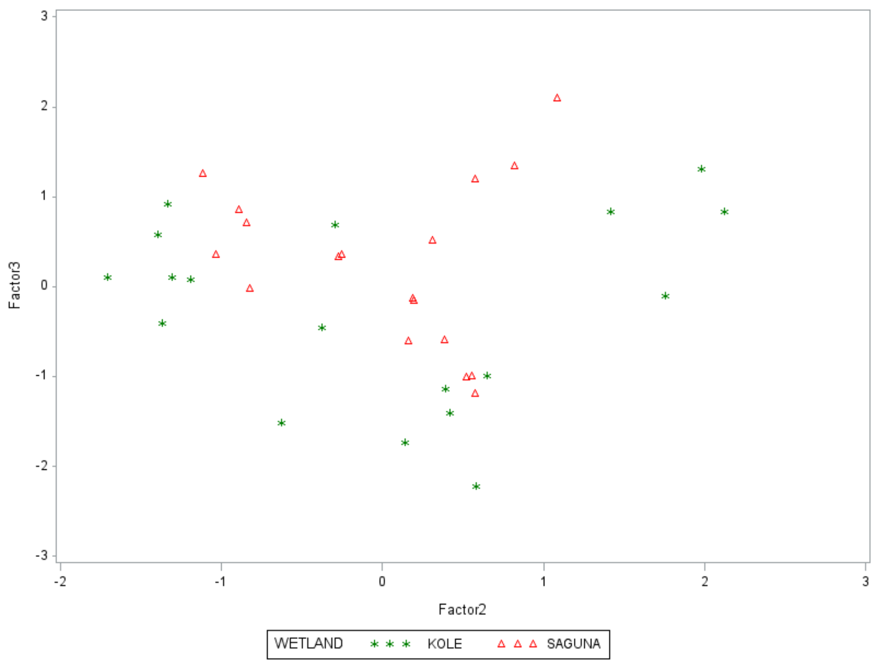

Figure 63: This is a caption

DISCUSSION

The lakes called *beels s* or *baors* in West Bengal are the components of the Gangetic floodplain wetland system and constitute an important resource for inland fisheries of the State. The investigated *beels* systems are the representatives of typical open and closed types of water bodies: One closed water body (Saguna), in the district of Nadia, West Bengal and the second one, open water (Kole) connected with the Hooghly River in the district of Hooghly.

Dissolved oxygen is an important environmental parameter that decides ecological health of a stream and protects aquatic life (Chang, 2002).

High dissolved oxygen was recorded during winter season at all the sites. It may be due to high photosynthetic rate of phytoplankton communities in clear water that results in higher values of dissolved oxygen (Sharma and Rathore, 2000; Ravindra et al., 2003).

Higher dissolved oxygen in winter season and lower oxygen in monsoon were also recorded in Haraz River in Iran (Pejman et al., 2009), many rivers of Gangetic plain, India (Rani et al., 2011) and several rivers of the Central Himalayas including the Chandrabhaga River (Sharma et al., 2007) and the Tons River (Sharma et al., 2009).

The presence of limestone rocks results in higher pH (Ormerod et al., 1990). Alkaline water promotes high primary productivity (Kumar and Prabhahar, 2012). The water of Baldi stream was alkaline in nature throughout the study period.

Similar findings were reported by Liu et al. (2010).

5.1 WATER QUALITY CHARACTERISTICS

5.1.1 Physical Attributes

5. 1.1.1 Depth

In morphometry of lake most frequently used terms are maximum depth and length of the shoreline. Certain European limnologists reveal that average depth is the factor that determines whether a lake is eutrophic or oligotrophic, computing average depth as the quotient of the volume of the lake over the area of the lake. In the present study, the *beels s* by differences in topography, hydrodynamics, contour, age, and catchment characteristics showed ecological and production variation.

Owing to the topographical features, the fluctuations in the water column are within an annual range of 4.0 - 6.0 m in the *beels* systems, and of two *beels*, Saguna is comparatively deeper. The seasonal fluctuations in the water column were conspicuous and mostly dependent on the replenishment resources and volume.

The Saguna is dependent on catchment run-off for depth replenishment. In Kole, the riverine ingress serves as water filler.

As indicated from the seasonal water column of the *beels ecosystems* these are shallow water bodies and can be classified as the littoral lake with a gradual slope and depth not exceeding 6 meters. Mukhopadhyay (1997a) indicated that the majority of the *beel*s s in West Bengal are vulnerable to high water level fluctuations.

Low rainfall causes water balance problems for the closed *beel*.

Sugunan *et al.*, (2000) report in that shallow *beel*, the whole water body gets heated up rapidly, thereby increasing the impact of chemical and biochemical reactions. Dey (1981) indicated shallow *beel* also facilitates dense growth of rooted aquatic macrophytes which compete for nutrients and space with Phytoplankters and are not part of the autotrophic food chain.

In the selected *beel*, the inflow of surface water carrying a heavy load of inorganic and organic materials washed down from the catchments following pre-monsoon showers might have caused a steep reduction in Secchi depth during March-April. Considerable lowering of Secchi depth in June and September may be attributed to the inflow of surface run-off floodwater into the *beel*s s following heavy monsoon showers, experienced during these periods. Marked lowering of the Secchi depth was observed at Saguna *beel*s during the period of September-October was apparently due to the effects of jute retting at these places. It also indicated poor plankton populations throughout the year in this macrophyte-infested beel. The depth of the Secchi disc fluctuated widely (0.23 m to 1.45 m) and showed irregular Spatio-temporal variations in the selected *beel*s. Even though the penetration of solar radiation in natural waters is a function of the angle of light falling on the water surface, the geographical positions of the water body, presence of dissolved and particulate materials, and other interfering factors will affect the rate of penetration during different times of the year.

5. 1.1.1 Transparency

Transparency is an important limiting factor in the productivity of a water body. It varies greatly with the nature of the basin, degree of exposure, nature of inflow and sediment, etc. Water bodies with clay bottom are likely to have high turbidity while, rock basins, and those with sand, gravel, and humus predominance to have low turbidity (Nath, 1997). Other factors affecting transparency are suspended clay and silt, particulate organic matter, dispersed planktonic organism, and pigments produced by the decomposition of organic matter (Kielhorn, 1952; McCombic, 1953; Bamforth, 1958; Michael, 1969). Excessive turbidity has a pronounced effect in confining daily heat gains to the surface layer of water (Smith, 1934). In the present study, the *beels* varied in respect of water transparency mostly influenced by the growth of planktonic organisms and suspended organic matter.

The transparency in general was more during monsoon due to the dilution effect of the replenished volume of water. In the present study, the two selected *beel*s were found to have low transparency during the summer period (particularly May- June), which is attributed to the wind action and phytoplankton bloom. Various workers have also reported similar seasonal fluctuations in lake water transparency (Jermolajev, 1958; Michael, 1969; Kumar, 1985; Nath, 1999). Aquatic organisms vary widely in their relation to the different degrees of turbidity. Without a doubt, many organisms smother in the prolonged condition of very high turbidity (Needham and Lloyd, 1930; Nath, 2001).

5. 1.1.3 Flow

The Kole *beel,* which possesses a riverine connection, is victimized adversely forwards input-output ratio due to continuous water exchange.

While this adversely affects the biological productivity of the ecosystem, it helps in delaying the eutrophication process. Rapid water renewal also helps in breaking the thermal stratification, if any, in deep *beels s*, which is beneficial for nutrient recycling and gaseous exchange. At the same time, continuous water flow does not allow the plankton species to stabilize, resulting in lower plankton density and primary production rates in such *beel*s. Besides, a rapid increase in water levels during monsoon months causes death and decay of submerged and marginal macrophytes in all the *beels s*, which is beneficial for recycling nutrients locked up as macrophyte biomass. In the present study, the flow pattern in the *beel*s eco-systems varied depending on the geo-morphometric and hydrology of the individuals. The open *beels* Kole was under flowing condition due to the ingress and egress of the river flood while. The closed *beels* Saguna experienced waves and feeble current due to the wind actions throughout the year. However, these closed *beels s* were also receiving localized flowing conditions at the receiving points of catchment run-off during the rainy days. Welch (1948

) mentioned the works of various workers reporting what appeared to be physiological effects of turbulence, such as suspension of growth in certain algae, acceleration of movements in *Oscillatoria*, alteration in the number of mass in *Daphnia,* and decrease in locomotion and ingestion in *Paramoecium.*

5. 1.1.4 Temperature

Temperature is a universally accepted density-independent factor shaping the biotic communities to a large extent, as it has a pronounced effect on chemical and biological processes (Prasad, 1956). The monthly fluctuation of water temperature in ambient water largely depends on the changes in the solar radiation. Water temperature plays an important role in influencing the productivity of water bodies. It varies widely depending on the climatic condition of the place where the water bodies are located and it also undergoes wide diurnal fluctuation. Banerjea (1967) stated that of all the physical factors, the temperature is most essential for photosynthetic activity which in turn is basic to productivity. No other single factor has been linked with so many direct effects. In the present study, the temperature of the surface water ranged from 19.5 to 33.5 0C, with little variation among the *beels eco*-systems. The minimum temperature recorded during winter was lower by 8.3 to 12.0 0C in comparison to the maximum recorded in the summer season. Though not much deep, the *beels s* irrespective of open or closed were thermally stratified. The variation in surface water temperature was maximum in the winter spell when the water was least distributed and the temperature fluctuation within the day was also maximum. The prevalence of such thermoclines conditions in the small tropical lake of some Asian countries (Java, Sumatra, and elsewhere) has been reported by Ruttner, (1931). Kumar (1985) recorded stratified temperature in a *beel*s eco-system of Nadia district in West Bengal.

Dwivedi and Chonder (1977) observed moderate stratification of temperature in Keetham-lake U. P. William and Murdococh (1966) reported that when the temperature was high, production was high in Beafort Channel. Macan (1950; 1961) has shown several ways in which temperature can affect the growth of freshwater animals. In the investigated *beels* ecosystems, the water temperature closely followed the atmosphere temperature (Tables -4. 2.1 & 4. 2.2). Variation in water temperature was quite distinct during different seasons throughout the study. Bhowmik (1988) reported that maximum and minimum temperature in *beels* and *baors* of West Bengal varied from 17.5 to 32.0 0C which conforms with the present study.

The more significant effect of higher temperature is the increased rate of biochemical activity of the microbes so that the release of nutrients by decomposition of organic matter at the bottom is more at higher temperature with the consequent increase in the nutrient status of water (Ganapati, 1956). Rai and Dutta Munshi (1979) have also reported that the presence of macrophytes profoundly influences water temperature. The present study also confirms the same. According to Banerjea (1967); Jhingran (1989) in water bodies with high organic contents in bottom mud, large-scale mortality takes place in summer months especially after a shower or cold wind.

This happens due to overturn of thermally stratified layers so that the bottom layer of the anaerobic decomposition zone with reducing gases, distributes itself throughout the volume of water and even the relatively oxygen-rich surface layer of water suffers oxygen depletion. In the present study, no such incidence was observed in the *beels ecosystems.* The water quality profile of wetlands of West Bengal as recorded by CIFRI, in Bulletin no. 103 ranged between 20.0 ° C to 35.4 ° C. Thus the present findings are in agreement with the earlier findings of CIFRI, Barrackpore in the selected water bodies of West Bengal.

5.2 CHEMICAL ATTRIBUTES

5.2.1 Dissolved oxygen

Of all the chemical parameters, dissolved oxygen is considered a prime important factor for regulating the metabolic process of plant and animal communities as well as indicating the water quality. Hutchinson (1957) has remarked that a series of oxygen determinations along with knowledge of turbidity and color of water could provide more information about the nature of water than any other chemical data. The *beels* waters receive oxygen mainly from two sources; by absorption from the atmosphere at surface level and intense photosynthetic activity of all the chlorophyll bearing lives within the *beels s* eco-systems. The addition of atmospheric oxygen to the *beel*s s depends on many factors such as temperature, water movement, wind velocity, etc. The prime life-bearing gas in aquatic media was within the moderate range of 6.4 to 10.8 ppm (Tables 4. 2.1 & 4. 2.2).

Phenomenally, the *beels* waters were more oxygenated during the photoperiod compared to the non-photoperiod of the day. Similar diurnal variation in oxygen content of lake water has been reported by various workers (Hutchinson, 1957; Bhowmick,1968) and the ill effects of complete deoxygenation on fish survival have also been recorded by (Moore, 1950). In the present investigation, the reflection of temperature and photosynthetic-respiration relationship and dissolved oxygen showed stratified distribution in the water column of the *beel*s ecosystems. The surface water was more oxygenated compared to the bottom and the difference in oxygen concentrations between the surface and bottom was maximum in the closed and comparatively deeper *beels* Saguna. The difference in oxygen concentration was also related to the seasonal variation; showing the maximum in monsoon (1.1 to 3.0 ppm) followed winter (0.4 to 2.7 ppm) and summer (0.2 to 2.6 ppm).

The reason for the maximum stratification of oxygen in monsoon may be attributed to the high rate of surface mixing of atmospheric oxygen due to the showering of a raindrop (Banerjea, 1967). It is interesting to mention that the higher concentration of oxygen in the surface water during monsoon was always not in confirmation with the high plankton density whereas Das and Srivastava, (1956) reported that the phytoplankton peak corresponds to the high oxygen values while zooplankton peaks are associated with low oxygen values. Oxygen content observed to be poor during the period of the high temperature such as the summer season (Bhowmik, 1968; 1988; Sugunan *et al.*, 2000) conforms with the present study. The DO values in the bottom layer of the *beels s* indicate discrepancy and depletion of oxygen characteristic of eutrophic waters; reading as low as 0.2 ppm were recorded during the early morning of summer. Kumar, (1985) also reported a similar observation. Dehadrai (1972) reported oxygen depletion in shallow eutrophic waters as a common feature in swamps of North Bihar. There is considerable loss of oxygen at the soil water interphase due to the accumulation of organic matter. Gas bubbles arising from the sediments remove oxygen from the water. Mainly caused by the concurrence of calm hot weather with the massive organic aggregate, the dissolved oxygen has been reported to be alarmingly low level in eutrophic water (Dehadrai, 1972). The short and long-term variations in dissolved oxygen in lakes give a good measure of their trophic state (Goswami, 1985).

Oligotrophic waters show variation from saturation, while eutrophic ones may range from virtual to 250 percent saturation.

The dissolved oxygen content of water fluctuated widely in Kole *beel*s (5.34-12.14 ppm). According to Boyd (1982), fish do not feed or grow well when dissolved oxygen concentration remains continuously below 4 or 5 ppm. The oxygen levels recorded during the present investigation were above this critical level in both the *beel*s s. Comparatively, lower dissolved oxygen levels recorded in Kole *beel*s may be attributed to the extensive growth of water hyacinth covering the surface area for diffusion/wind action. Wide fluctuations in dissolved oxygen content of water in the *beel*s s might be due to dense aquatic vegetation, shallow water depth, and intense fishing activities at times (Yadava *et al.*, 1987). Dissolved oxygen was inversely related to water temperature (r=0.778).

5.2.2 Water reaction pH

The pH negative log of hydrogen-ion concentration controls the chemical state of nutrients in the water bodies. Changes in pH influence important plant nutrients such as phosphate, ammonia, iron, and trace metals. pH below 4 or 5 severely restricts species diversity and above 10.0 indicates an extreme eutrophic environment. In lakes, pH is regarded important as (I) limiting and (ii) as an index of general environmental conditions. In the present investigation, the hydrogen-ion concentration in surface water of the *beel*s s was 8.0 and above except on few occasions.

The seasonal influence on pH value was not highly significant. However, pH at the bottom of the water column was marginally different with decreased concentration of hydrogen ion. The observed pH as 8.0 and above has been recorded to be productive by various workers (Hutchinson, 1957; Banerjea,1967).

The pH values of water in the afternoon are almost always higher than those in the morning due to the photosynthesis and respiratory activities of various organisms in the water (Michael, 1969).

It generally tends to maintain a nearly constant value throughout the year and the seasonal fluctuation is narrow (Michael, 1969). Several workers (Chakravarty *et al.*, 1959; David *et al.*, 1969) have, however, reported the highest pH values during summer and lowest during monsoon (Chakravarty *et. al.*, 1959; David *et al.*, 1969). A slightly alkaline water pH was optimum not only for the fish but also fish food organisms. Thus, Michael (1969) observed that when pH ranged between 7.3 and 8.4 the water provided optimum conditions for the growth of plankton. It is important to note that there is some evidence of different species of a taxonomic group having an individual pH range. The present study bears the agreement of alkaline pH with the study of Bhowmik (1988) where the pH value of the *beels s* and *baors* of West Bengal was recorded between 6.8 and 9.1.

pH is one of the most important characteristics regulating the life process and nutrient availability in the water body, particularly in floodplain wetlands with alternate drying and flooding. The pH of water has a significant role in the survival of aquatic plants. The fluctuation in pH of the water was influenced by the acidic character of the basin soil and the dense aquatic vegetation (Yadava *et al.*, 1987) as well as by the inflowing surface run-off/floodwater. A sharp decline was observed in the pH of *beel*s water during May-June, which was probably due to the inflow of considerable organic matter from the catchment along with surface run-off/floodwater, coupled with the mixing of bottom water rich in organic matter and their subsequent decomposition. According to Swingle (1967), water having a pH range of 6.5 to 9.0 as recorded before daybreak is the most suitable for fish production. Banerjea (1967) observed a neutral condition of pH (6.5 to 7.5) to be the most favorable for fish production in ponds. The pH level equivalent to the dividing line between soft water and hard waters and according to this pond waters having a total hardness of 15 ppm or above is satisfactory for the growth of fish. Based on the average hardness levels, Kole *beel*s and Saguna *beel*s can be considered as soft water and hard water *beel*s s respectively. According to Jhingran (1991), soft water lakes are generally poorer about their aquatic fauna and flora and usually contain less living matter per unit area than hard water lakes. However, although the total mass of organisms is greater in hard water lakes, medium lakes hold a greater variety of living organisms.

5.2.3 Alkalinity

Since total alkalinity values are the resultant of the entire biological and chemical process taking place in the water body, as such it is also taken as a rough index of productivity of the water body (Laal, 1981). Alkalinity or acid combining capacity of natural freshwater bodies is mainly caused by carbonate and bicarbonate of calcium and magnesium, calcium being the major constituent. These along with dissolved carbon dioxide in water form an equilibrium system, which is of primary importance in the ecology of the environment. In a natural water body, the total alkalinity values are inversely related to the water level. In the present investigation, the alkalinity of the *beels* waters was observed to be within the product range.

The high alkalinity of the *beels* water was because of the presence of salts generated through the death and decay of the macrophytes, benthic organisms, and also the plankton. The high alkalinity value was recorded in *beels s* infested with a high density of macrophyte-associated fauna and benthic biomass. Sugunan *et al.*, (2000) reported similar observations.

5.2.4 Free CO2

Free CO2 plays an important role in influencing the productivity of the water bodies. Its content in a water body varies widely depending on the amount and nature of biological activity in the water. Many workers have studied the fluctuations of free CO2 of water in ponds and lakes at different places and during different seasons in a year as well as at different hours in a day and observed a range of 17 to 39 ppm in lakes at Lucknow (Das and Srivastava, 1956; 1965), from nil to 10 ppm water body at Kalyani (Bhowmick, 1968), and from 0.4 to 15 ppm in a water body at Burdwan. CO2 is necessary for photosynthesis, free CO2 content may sharply go up, and may even disappear. Thus, free CO2 was absent in Amaravathy reservoir, Madras (Sreenivasan, 1964), and in Ramgarh lake, U. P. during certain periods. Such absence of free CO2 in water was found to be related to the presence of heavy phytoplankton populations (Michael, 1969). In some cases, the absence of free CO2 in water may also be due to a reaction with carbonate present in large quantities in the water. In the present study, free CO2 content in surface water of the *beel*s s was always below detection levels and the gas was examined to be present at the bottom layers in moderate to low concentration. The pronounce absence of the free CO*2* at the subsurface level of the water was in confirmation of the observation made by Reid (1961), who reported that at pH 8 and above the free CO*2* is usually absent. The available free CO*2* in the column water was indicative of photosynthetic activities and bio-respiration in the environment.

Free CO2 in the water occurs due to respiration of the biotic communities thriving therein, decomposition of organic matters, and also due to infiltration through the soil. Carbon dioxide is an important component of the buffering system, influencing the concentrations of carbonates and bicarbonates in the water. An inverse correlation between F-CO2 and dissolved oxygen was observed by Das and Shrivastava (1956); Michael (1969). The higher levels of free CO2 observed during summer might be due to the decomposition of organic matter (Chakravarty *et al.*, 1959).

Fishes can tolerate a high concentration of F-CO2, although they avoid levels as low as 5 ppm. Most fish species will survive waters containing up to 60 ppm (Hart, 1944). In the selected *beel*s s, dissolved F-CO2 concentrations fluctuated widely (undetectable to 18.59 ppm) but remained well within the tolerable range. The highest concentrations of F-CO2 recorded in May at most stations indicate its influx through rainwater in the form of carbonic acid (Chakravorty *et al.*, 1959) as well as decomposition of organic matter brought in by surface runoff.

Considerably, the higher concentration of F-CO2 recorded at Kole *beel*s and Saguna *beel*s during the period of September-October was apparently due to the effect of jute retting at these places. F-CO2 had a significant inverse relation with the pH of water (r=-0.761). A similar inverse relationship between these parameters was observed by many workers in lakes (Gonzalves and Joshi, 1946) and *beel*s s (Goswami, 1985).

5.2.5 Specific conductivity

The total contribution of dissolved solids is considered as a useful parameter in describing the chemical density as a fitness factor and as a general increase of edaphic relationship that contributes to the productivity of water. The specific conductance of water is a measure of the resistance of a solution to electrical flow, which declines with increasing ion content (Wetzel, 2001). The temperature of the electrolyte affects ionic velocities as conductance increases about 2% per degree centigrade (Wetzel, 2001). It reflects the nutrient status of a water body and the distribution of macrophytes (Crowder, *et al.*, 1977). The specific conductivity values recorded from these lakes were in an acceptable range.

According to Welch, (1948), the other things being equal, the richer a body of electrolytes the greater its biological productivity.

All the ecosystems under investigation maintained moderate to high specific conductivity of water and the values were, by and large, higher during dry seasons, summer and winter, whereas comparatively low in the monsoon spell of the year. Among the two ecosystems, the specific conductivity of water was comparatively higher in Kole whereas the same was comparatively lower in Saguna.

This disparity in specific conductance values was in the order of production potentialities and other related parameters of respective water bodies. It has been reported an optimum range as 250 - 400 µS/cm and opined that specific conductivity above 400 µS/cm does not limit or favor productivity.

Specific conductivity indicates the total concentration of the solid constituents of the natural waters. It ranges from 58.2 to 128.0 µ S/cm in Kole *beel*s. It had a significant positive correlation with total alkalinity (r=0.762) and total hardness (0.707), which is natural since all these three parameters are related to the sum of the total ions, cations, and anions respectively. These parameters followed a similar pattern of seasonal fluctuation, with minimal values recorded during April-May. Their levels sharply declined during the monsoon season, reaching the lowest levels in September.

specific conductivity had a significant direct correlation with organic carbon (0.809) and available phosphorus in soils (0.898), suggesting that the water quality variable was directly influenced by soil fertility.

5.2.6 Chloride Content

Chloride concentrations of the selected *beel*s s (12.8- 29.4 ppm) were slightly lower than those of other *beel*s s of the lower Ganges zone (Sugunan and Bhattacharjya, 2000). The levels of chloride in the range of 31-50 ppm are considered ideal for freshwater fish culture. Chloride exhibited distinct seasonal variations and recorded comparatively higher levels in Saguna *beel*. The highest chloride content recorded in May was probably due to land washing brought into the *beel* by surface runoff during pre-monsoon showers. The chloride content gradually declined during the monsoon season because of dilution.

5.2.7 Nitrate-Nitrogen

As constituents of protein, nitrogen occupies a highly important place in an aquatic ecosystem.

Nitrate unlike ammonia, phosphate, or metal ions, moves freely through the soil along with subsurface water. It is the most highly oxidized form of nitrogen and is usually the most abundant form of combined inorganic nitrogen in lakes and streams. Many investigators have monitored the fluctuation of nitrate content in water bodies at different places and during different seasons in a year and observed a direct relationship between nitrate and phytoplankton population (Chakrabarti *et al.*, 1959; Bhowmick, 1968; Saha *et al.*, 1971). In the present investigation, the values of water-soluble nitrate varied from system to system and with seasonal changes. The level of the nutrient was 0.3 - 1.5 ppm in Kole, while, it was comparatively higher in the range of 0.8 to 1.3 ppm in Saguna (Tables - 4. 2.1 & 4. 2.2.). By and large, the systems were comparatively richer in nitrate value during the summer and winter seasons, while the monsoon concentration of the nutrient was comparatively lower because of the dilution effect. The fluctuation trend in nitrate level indicated mesotrophic to the eutrophic condition of the *beel*s s (Goldman and Horne, 1983). The nitrate contents in the studied *beels* were within the productive range (Banerjea, 1967) and optimal for the growth of plankton which is in agreement with the study.

In the aquatic environment, nitrogen is present in the combined forms of ammonia, nitrite, nitrate, urea, and dissolved organic compounds. Nitrate levels remain almost constant in an oligotrophic lake, fall to zero in eutrophic lakes, and do not become limiting in mesotrophic lakes. According to Jhingran (1991), the values of dissolved organic nitrogen below 0.1 ppm may be considered as indicative of poor productivity, those in the range of 0.1 to 0.2 ppm of average productivity, and those above 0.2 ppm as favorable for productive ponds. Goldman and Horne (1983) noted that the nitrate level usually found in natural water bodies is up to 1 ppm and is not harmful.

Nitrate-nitrogen concentrations ranged from 22 to 225 ppb (average 105.6 ppb) in Kole *beel*s and from 40 to 220 ppb (Average 98.4 ppb) in Saguna *beel*s, which were within the desirable limits for fish production. The marked increase in nitrate-nitrogen levels observed during April and June was probably due to rain washings from catchment while the minor peak observed in September may be attributed to floodwater inflow. Comparatively higher average nitrate-nitrogen levels recorded in Kole *beel*s indicate that it is more productive.

5.2.8 phosphate-phosphorus

Ecologically phosphorus is the most critical single nutrient in the maintenance of aquatic productivity. The main supply of phosphorus in the water body comes from the leaching of soils of the catchment area by rains (Swingle, 1947; Heron, 1961). Primary production of the water body is a function of water-soluble inorganic phosphorus when the concentrations of other essential nutrients are in their optimum range. In the present study, the phosphate values were much lower compared to the nitrate values in all the *beels* ecosystems. The level of phosphate was 20 to 360 ppb in Saguna. Kole which is an open system recorded a lower level of phosphate 28 to 220 ppb compared to the other system. The summer concentration of this nutrient was always higher compared to other seasons. The minimum level of phosphate was recorded in the monsoon season in all the *beels* ecosystems. The phosphate cycle of the *beels s* was in correlation with the dissolved oxygen and known to play important role in controlling the rate of phosphorus release from the sediment to the photic zone (Munawar, 1970; Goldman, 1972). The phosphate values classified from (i) 0 to 0.02 ppm as low productive,(ii) 0.02 to 0.05 ppm as fairly productive, (iii) 0.05 to 0.1 ppm as good, and (iv) 0.1 to 0.2 ppm as very good productive by Moyle, (1946) it suggests that the *beel*s s under investigation might be rated as fair to good products in respect of the phosphate contents.

In a natural setting, the characteristics of floodplain wetlands are influenced by the annual cycle of flood and the resulting periodic incursion of river water (Junk *et al.*, 1989). Variation in frequency and duration of river inputs or connectivity is a major distinguishing factor among the water bodies (Hamilton and Lewis, 1990; Amoros, 1991). In the present investigation, the lakes received a considerable amount of nutrients from the catchment run-off during monsoon months, which is being reflected during the post-monsoon period. Such ingress of surface runoff along with that of the allochthonous organic matter and nutrients were responsible for the higher levels of organic carbon, available nitrogen, and phosphorus in sediment.

Phosphate-phosphorus exhibited an irregular fluctuating pattern of seasonal variation in the present study, which may be related to the cycle of the utilization of this important nutrient element by the primary producers. The peak phosphate levels recorded in July may be partly due to the leaching of soils of the catchment by rain and/or floodwater, which is one of the main sources of phosphorus in natural waters. Such high levels of nutrients recorded during the period of the first flood/high water level (including high nitrate-nitrogen levels recorded in June) may also be attributed to the death and decomposition of submerged macrophytes and their subsequent mineralization.

Melack and Fisher (1990) observed that during less water, nutrient concentrations increased due to sediment resuspension in floodwater lakes of Central Amazonia. Hamilton and Lewis (1987) attributed the nutrient enrichment during low water to turbulence from wind action and sediment resuspension. Boneto *et al.*, (1984) attributed it to hypolimnetic anoxic condition and release of nutrients from the sediment.

5.2.9 Silicate

The reactive silicate is probably the only form available for planktonic growth. The silica cycle is very different from the cycle of nitrogen, phosphorus, and other nutrients. Although silica is a common mineral largely on the earth's surface, the silicate concentration in freshwater is not generally high; it ranges between nil and 7.5 ppm (Hutchinson, 1957). Many workers (Bhowmick, 1968) have observed a direct relationship between silicate content and diatom population in the water body. In the present observation, the silicate concentration in the *beels* waters did not show much variation. The concentration of the element was maximum during summer in Saguna (4 – 10.8 ppm) followed by winter in Kole (4 – 10.8 ppm) Tables - 4. 2.1 & 4. 2.2). The monsoon concentration of silicate was low in two *beels* systems. However, the silicate level in the *beel* was observed to be much above the limiting concentration of 0.5 ppm and was favorable for planktonic production (Bhowmick, 1968).

The importance of silicate-silica in the production of diatoms is well recognized. However, in the present investigation, a significant direct relationship between the two parameters could not be established. Silicate-silica had a significant direct relation (r=0.668) with rainfall, indicating rain-induced surface runoff/floodwater to be the primary source of these nutrients in the *beel*s.

Further, with the sudden rise in water level and turbidity, the submerged macrophytes like *Hydrilla verticillata*, which grow abundantly in the *beel*s s, decay and release nutrients to the water. A similar phenomenon was observed by Furch (1984) in Amazonian 'Varzea' (flood plain) lakes and a floodplain lake of Sao Paulo, Brazil.

5.3 SEDIMENT CHARACTERISTICS

5.3.1 Physical attributes

5.3.1.1 Soil texture

The bottom soil composition of a lake is the resultant contribution of various factors and for this reason, great variation exists. Even within a restricted area, two lakes may differ significantly in bottom type and bottom associated feature also. Eventually, a large number of lakes have been studied in respect of their development and evaluation of the basin together with a succession of biologically different associations of organisms. The *beels* ecosystems under investigation have geological similarity to a great extent since these water bodies constitute the components of the same Gangetic floodplain wetlands. By virtue, these are closed to each other in respect of their bottom, the texture being alluvial and possessing a moderate percentage of silt and clay which on the other hand, is symbolic for rich productivity support to hold-up waters (Tables - 4.3.1 & 4.3.2).

The basin, as it is exposed to sedimentation through varying processes and different sources is never static and permanent. The modification of shore water line and depth is inherent in lakes as a result of dynamics operating within the lake and processes outside the lake. The lakes' understudy though not in totality but some characteristics that have shown the differences in composition.

The soil composition of a lake or *beel*s is due to the contribution of various factors, which even within a restricted area may differ significantly in bottom type and bottom associated features between two *beel*s. As the investigated water bodies of the *beel*s s constitute the component of the same Gangetic floodplain wetlands they have geological similarity to a great extent. They have a high percentage of sand (87-93 %). As the *beel* Kole contains a moderate percentage of silt and clay, the texture is alluvial which is a symbol for rich productivity. However, the *beel* Kole understudy shows some variation, as the open *beel* have a comparatively high percentage (14%) of clay than the closed ones.

5.3.2 Chemical attributes

5.3.2.1 *Soil pH*

The pH of bottom soil influences the chemical composition of the water and hence, the productivity of the aquatic system. The soil pH was always acidic to neutral.

This is indicative of the productive nature of the system, which has also been reflected in the present study.

Banerjea (1967) believed that the soil reaction in the neutral range (pH 6.5 to 7.5), was most favorable, whereas, that in the moderately acid (pH 5.5 to 6.5) or in moderately alkaline (pH 7.5 to 8.5) average in terms of productivity. In the present study, the pH values recorded in the soil (6.0 - 7.0) were thus indicative of high productivity in the investigated *beels s,* which confirms the study.

Saguna *beel*s recorded marginally higher soil pH as well as a considerably lower level of organic carbon, available nitrogen, and available phosphorus than Kole *beel*s, which suggests gradual accumulation of organic matter and nutrients in the later over the years. The prevailing hydrological regimes of Kole *beel*s like heavy infestation by water hyacinth and reduced water exchange/mixing due to river regulation presents favorable conditions for nutrients lacking in bottom sediments.

Soils of Saguna *beel*s had comparatively higher pH levels (overall average 7.9) than that of Kole *beel*s (7.7). Further, the range of variation in soil pH was wider (7.5 to 8.1). The soil pH in the two *beel*s s was neutral. Das (2000) working on the *beel*s s of West Bengal has reported a similar pH of soil.

5.3.2.2 Organic carbon

Organic carbon acts as a source of energy for the microbes responsible for various biochemical processes besides releasing nutrients including some trace elements in the aquatic system. Organic carbon is an integral part of a certain chemical compound. When the level of organic carbon was estimated in the *beels system*, it distinctly showed a difference in its content from one system to the other and with the change of seasons. In the present study, the Kole, which is an open system and exposed to river flushing, had incredibly low (0.48 – 0.72%) organic carbon.

The highest level of organic carbon was recorded in the sediment of Saguna (0.6 to 3.9%), which is a closed system with a high macrophyte-infested water body. A high level of organic carbon was always recorded during the summer season for all the *beels* systems under study.

The fluctuation of organic carbon in an aquatic system with the change of places and during different seasons has been reported by various workers (Bhowmick, 1968). The observed organic carbon level in the *beel*s was towards the higher side and within the unconducive range (Banerjea, 1967). The seasonal fluctuation indicated a definite pattern of peaks of organic carbon as observed by Bhowmick (1968). Kumar (1985) reported a similar observation where organic carbon values ranged from 3.8 to 4.8 % in *beels* located at Kalyani. A high level of organic carbon was always recorded during winter for all the *beel* systems under study due to the lowering of decomposition rated rate of organic matter by microbes in winter.

Organic carbon in sediment considerably exhibited Spatio-temporal variations in the selected wetlands of West Bengal. In Saguna wetland it ranged from 3.9 to 7.9 % while in Kole it was 1.2- 3.1 % respectively during the period under investigation (2011-13). It has been reported that soil with an organic carbon content of 1.5 to 2.5 % or above is considered productive (Moyle, 1946; Banerjea, 1967). Thus the wetlands could be considered productive.

5.3.2.3 Available nitrogen

Nitrogen in the aquatic system is present in mostly inorganic form, the fraction present as amino acids, peptides, and easily decomposable proteins are called available nitrogen. In the present study, available nitrogen in the *beels sediment* was varying in concentrations. The nitrate and available phosphorus are considered to be limiting factors, being the primary nutrient for ecosystem functions (Carney *et al.*, 1993 and Brown, 1981). Saguna has a lower value (18 - 28 mg/100g of soil) and Kole has a higher value (21- 33 mg/100g of soil) (Tables - 4.3.1 & 4.3.2). The nitrogen levels in *beel*s s were within the range of favorable productivity (Banerjea, 1967).

5.3.2.4 Available phosphorus

The available phosphorus in the bottom is considered to be the most critical element in productivity and to be more important than total phosphate (Jhingran, 1977). Because of the fact PO4 -3 ion in soil form soluble compound with iron and aluminum and with calcium under alkaline condition, renders the phosphate ion unavailable to the water phase. Available phosphorus content in the sediment was much low in compared to available nitrogen. It is well documented that in shallow lakes, aquatic macrophytes act as a sink for nutrients, both nitrate (N) and Phosphorus (P), during their growth phase withdrawing up to 60% of N & P from the sediment and after their decomposition releases them back to the water as well as to the sediment (Donk *et al.*, 1993). Available phosphorus content in sediment phase in the selected wetlands fluctuated to the range from 0.24 to 0.58 mg/100 g (Saguna wetlands); from 0.24 to 0.48 mg/100g (Kole wetlands).

Soil having available phosphorus less than 0.5 ppm is poorly productive; between 0.5 and 1.0 ppm moderately productive and higher than 100 ppm highly productive, which indicates that the *beels s* under investigation were in medium to the high productive range. Sugunan *et al.*, (2000) reported that in contrast to other nutrient parameters, available phosphorus values were lowest in closed and weed-choked *beels s* (traces to 3.18 mg/100 g of soil), higher in closed but moderately weed-infested *beels s* (traces to 7.6 mg /100 g of soil), and highest in open one (traces to 10.08 mg /100 g of soil). This observation is based on the study made on a large number of *beels s* of West Bengal and eventually, the present observation is, by and large, in agreement with the findings and indicative of productive.

5.4.1 Biotic communities

5.4.1.1 Planktonic structure

The plankton population in the *beel*s systems was diverse in respect of species and population density. From the 2 systems, 62 species of plankters belonging to 51 genera and 29 families were identified. The closed systems harbored the plankton population with more families (Saguna: 21). In the open system, the number of families was restricted to 20 in Kole (Table).

Dominance in respect of species under *Chlorophyceae* was in the system Saguna. The species under the group *Cyanophyceae* were almost in equal number in the two ecosystems. *Bacillariophyceae* was represented by the maximum number of species in Saguna while Kole lower number of species under this group. The total number of species of zooplankton was maximum in Kole (15) and minimum in Saguna (6).

Among the phytoplanktonic group, *Chlorophyceae* constituted a comparatively higher percentage in Saguna (38.0 - 41.0%). The percentage of *Cyanophyceae* population was comparatively high in Kole (88.0 - 89.0%). The percentage contribution by the *Bacillariophyceae* was maximum in Saguna (6.0-8.0%) and minimum in Kole (1.0-3.7%). The *Dianophyceae* population were recorded in Kole (0.0 - 3.0%) and Saguna (0.5 - 2.2%). Among the zooplankton, *Copepods* contributed comparatively in higher percentage in Saguna (26.0 - 62.0%) and Kole (32.6 - 60.0%). The minimum percentage of *Copepods* in the zooplankton population was recorded in Saguna (7.69 - 15.30%). *Cladocerans* were present in Kole and Saguna only and the percentage contribution by this group of zooplankton in the respective systems were 7.69 to 13.46 and 0.37 to 4.04. *Ostracods* were encountered in Saguna (2.25 to 5.86%) and Kole (2.25 to 23.07%). The dominance of *Rotifers* was in Kole (52.02 - 70.97%) followed by Kole (23.07 - 50.0%). Protozoans were encountered in Saguna (3.04 to 5.17%) and Kole (16.21 to 92.33%). Sugunan *et al.*,(2000) observed population of phyto and zooplankton in flood plain wetlands of West Bengal at a lower level during the southwest monsoon which increased thereafter when the environment becomes stable and the plankton population established utilizing inorganic nutrients and organic matter brought in by the incoming flood or run-off water. Thus, they recorded the plankton population during winter (25 to 4,658 u/l) whereas in summer it was manyfold higher 281 to 40,836 u/l. In the present observation, the plankton population was recorded more during summer in Saguna, whereas it was higher during winter in Kole. Bhowmik (1988) also recorded maximum plankton population during summer season predominated by phytoplankton whereas during winter predominated by zooplankton. Jha (1997) recorded a higher plankton population in the closed type of flood plain lakes in Bihar which conforms with the present study.

5.4.1.1 Species diversity

The stability of the ecosystem can be studied by comparing the species diversity of different communities

(Sugunan, 1989). The study revealed the maximum species diversity in Saguna, which is a closed water body. The system Kole had comparatively lower species diversity (Tables – 4.4.8.1 to 4.4.8.7).

In Saguna the values indicate uniform species diversity in the system during the period of investigation. This indicates that the winter season with favorable temperature, dissolved oxygen, and other Physico-chemical parameters besides the solar penetration augmented the species diversity in all the systems irrespectively of open or closed systems. Similar observations were encountered by Beaver *et al.*, (1989). Sugunan *et al.*, (2000) reported that diversity indices in respect of zooplankters in different *beel*s s of South and North Bengal have shown many variations.

5.4.1.2 Similarity coefficient

The similarity was most significant between the seasons in Saguna followed by Kole. When comparing the relationship of the planktonic population between the seasons the correlation was very significant. As a whole, the relative values (Table - 4.4.8.1 to 4.4.8.7) confirmed that the closed systems are more similar while open systems differ in planktonic structure depending on the replenishment mechanism and also nutrient supply from autochthonous and allochthonous sources.

The overview of the findings indicated the impact of sediment characteristics like organic carbon, available nitrogen, and available phosphorus and Physico-chemical properties of the water like depth, temperature, water flow, free carbon dioxide, dissolved oxygen, pH, alkalinity, nitrate, phosphate, and silicate with plankton population of the *beels* ecosystems. The correlation is drawn between water and sediment characteristic and plankton population indicated the best of the same between the plankton and dissolved oxygen in Saguna, $r = 0.6154$; with nitrate in Kole, $r = 0.5740$ and silicate in Kole, $r = 0.6537$; Saguna, $r = 0.5574$ and Kole, $r = 0.5328$ (Table 4.4.16.1 to 4.4.16.12).

Similar correlation between the plankton and sediment nutrient levels indicated soil nitrate to bear close impact on planktonic growth in Saguna, (r = 0.5080; p<0.01) and Kole, ($r = 0.5198$) and phosphorus in Kole,($r = 0.5010$). Banik *et al.*, (1994) also made similar attempt to correlate rotifers with the limnological parameters and observed temperature(r=-0.9795), dissolved oxygen (r =0.8686), pH (r=-0.6954), bicarbonate (r = 0.6501) and phosphate phosphorus (r=0.983) showing significant correlation with the occurrence of total rotifers (Table - 4.4.16.1 to 4.4.16.12).

In Greek, the plankton population means wandering. In aquatic ecosystems, the plankton comprises those microscopic aquatic florae and fauna, which drift along with the water and move along with the wind action. The autotrophs carrying the photosynthetic pigments (chlorophyll) make use of the rich inorganic nutrients available in the lake ecosystem and synthesize organic matter which comes under phytoplankton, while zooplankton includes the microscopic animalcules assembled from different classes or groups. Functionally, these two broad groups are different from each other. Besides fixing physical energy in the form of chemical energy the phytoplankton also served as food for the primary consumers in the food chain system.

Plankton forms the base of the ecological pyramid together with aquatic macrophytes. On the other hand, zooplankton feeds on the phytoplankton as well as on the huge reserve of organic matter (detritus). Thus zooplankton is the secondary producer or primary consumer, linking phytoplankton and detritus with biotic communities occupying higher trophic levels. Zooplanktons play a vital role in making efficient use of dead and living organic matter in lakes. Both the phytoplankton and zooplankton are natural food for several planktivorous fish species, thereby supporting a considerable portion of fish yield from the lakes. It was reported that a direct relationship between plankton production and fish yield. Thus, plankton productivity can be used as a dynamic biological correlate for the assessment of fish yield (Almazan and Boyd, 1978).

The *beel*s s under the present study recorded poor production of plankton, with the average total plankton population being 863 and 623 µ l-1 in Kole and Saguna *beel*s respectively. *Beel* Kole in West Bengal is generally characterized by the poor concentration of plankton but consists of a diverse assemblage of nearly all major taxonomic groups (Lahon, 1983; Goswami, 1985; Yadava, 1987; Sugunan and Bhattacharjya, 2000), even though different plankton has different environmental requirements. The prevalence of low plankton density corroborates the findings of Sinha, *et al.*, 1992; Dutta Munshi and Singh 1993, 1995; Bhowmik 1985; Siddiqui and Ahamed 1995; Baruah, *et al.*, (1993).

The utilization of nutrients by a profuse growth of macro vegetation resulted in poor phytoplankton in the *beel* (Yadava *et al.*, 1987). In the present study, seasonal variation of the total plankton population showed three to four peaks. several Physico-chemical, biological, and environmental circumstances acting simultaneously should be taken into consideration while studying the fluctuations of the plankton population. The biological processes are so complex that no single ecological factor can be identified to be responsible for the growth and production of the plankton community.

Lahon (1983), Goswami (1985), Yadava (1987) reported the dominance of phytoplankton in *beel*s. Phytoplankton dominated the total plankton population in both Kole *beel*s (73 %) and Saguna *beel*s (68 %). According to Boyd (1971), macrophytes rapidly absorb nutrients for their growth and retain them for a longer period, while nutrients used up by phytoplankton are recycled rapidly as their life span is short, usually two weeks or less. In general, however, the numerical abundance of phytoplankton was invariably poor in the wetlands of West Bengal, a typical case of macrophyte-dominated ecosystems. The primary reason could be attributed to the low concentration of nitrate and phosphate in the ambient water, a manifestation of greater dominance of macrophytes thereby locking the nutrients. The wetlands exhibited strong competition between the macrophytes and phytoplankton in respect to sunlight and nutrients (N: P), influencing the abundance and quality of phytoplankton from one system to another (Wetzel, 2001). Macrophytes being the dominant autotrophs might have used the available nutrients, sunlight more efficiently, as such grow rapidly, almost shadowing the proliferation of phytoplankton (Boyd, 1971). The wetland specific abundance and fluctuation of phytoplankton are as under:

The average phytoplankton population of Saguna wetland ranged from 1349.23 no./l – 1546.25 no./l. The trend of abundance followed a sequence of Bacillariophyceae (35.32 %)>Myxophyceae (27.25 %)>Chlorophyceae (21.08%)> Euglenophyceae (9.24%)>Dinophyceae (5.08%)>Xanthophyceae (2.03%) during 2011-13. The dominance of Bacillariophyceae in Saguna wetland corroborates with the findings of CIFRI, 2000(Bull No. 103).

Kole wetland indicated a community structure of phytoplankton in the range of 1024.17 no./l – 1168.00 no./l. The qualitative texture of the community structure was almost similar to other wetlands, such as Bacillariophyceae (34.10 %)> Myxophyceae (30.52%) > Chlorophyceae (20.72%) > Euglenophyceae (7.45%) > Dinophyceae (5.84%) > Xanthophyceae (1.66%) during 2011-13. The present finding though indicated a similar community structure but the community size was relatively small as compared to the findings of Sugunan and Mukhopadhyaya (1995).

The utilization pattern of nutrients in both the wetlands indicated a similar trend wherein bulk of the nutrients was used by macrophytes, leading to the poor abundance of phytoplankton (Yadava, *et al.*, 1987). Sinha and Sharma (1996a, 1996b) also observed that, in Kawartal wetland, Begusarai, Bihar, macrophytes used to consume the bulk of the nutrients directly from the sediments. Heavy infestation of macrophytes, especially free-floating ones, in both the wetlands understudy in West Bengal, was one of the significant factors for the poor abundance and diversity of phytoplankton.

Several Physico-chemical, biological, and environmental factors, acting simultaneously, should be taken into consideration while studying plankton. Byars (1960) observed that temperature is the factor determining the seasonal distribution of aquatic organisms in general and phytoplankton.

In the present study greater abundance of phytoplankton in wetlands of West Bengal was generally coincided with a relatively high-temperature regime like Saguna (May, September, January), Kole (December and May). In the case of Saguna and Kole wetlands, however, the low temperature of winter also favored the proliferation of certain groups of phytoplankton leading to maxima. It was evident that higher temperature was not only the single factor for greater abundance, but it also depends on the requirement of temperature by different groups of phytoplankton.

Increased production of phytoplankton with a higher concentration of dissolved oxygen has been reported by several workers (Alikunhi *et al.*, 1955; Das and Srivastava, 1956; Moitra and Bhattacharjee, 1965; Saha *et al.*, 1971). During the present investigation, however, no such co-relationship could be established. Reid (1961) stated that the solubility of oxygen in water increases when lowering the temperature. Higher rates of carbon dioxide during monsoon indicate its influence through rainwater in the form of carbonic acid.

It is a fact that the proliferation of phytoplankton is generally inhabited in macrophyte-dominated water bodies, thereby leading to a decrease in photosynthesis. In tropical lakes, the total biomass of phytoplankton and primary productivity are often high as compared to temperate lakes (Wetzel 2001). The abrupt change in biotic communities like wind-induced vertical mixing; nutrients loading through surface runoff in monsoon and increased turbidity are more frequent in a tropical lake than in temperate lakes (Talling, 1986; Lewis, 1978a, 1978b, 1996; Melack, 1979). Nutrient enrichment commonly leads to an increase in concentrations of total P and Total N, but not Silica, which is necessary for diatom production.

Cairns (1956) investigated the optimum temperature range (15-30 ˚C) as the most favorable for the growth of diatoms. In the present study, increased growth of blue-green algae was recorded in Saguna (24-31 ˚C) associated with a sizeable population of diatoms in relatively high water temperature. Despite the high-temperature range (26-35.5 ˚C) in Kole, Bacillariophyceae was not the dominant group among the phytoplankton community.

Imevore (1967) could not correlate seasonal variation in plankton with temperature. Increased production of phytoplankton is generally associated with higher values of dissolved oxygen (Alikunhi *et al.*, 1955; Das and Srivastava, 1956; Moitra and Bhattacharjya, 1965; Saha *et al.*, 1971). Since the phytoplankton population fluctuated considerably during the present study, no such relationship could be observed. However, the dissolved oxygen content of water was comparatively higher in December and August, which were periods of primary and secondary peaks in phytoplankton abundance.

The importance of nutrients in the growth and abundance of phytoplankton is well recognized. Phosphate plays a regulatory role in the growth and abundance of plankton besides the penetration of sunlight, which had a direct bearing. However, no significant relation was obtained between phosphate and phytoplankton population in the present study. According to Alikunhi (1993), silicon is related to phytoplankton productivity.

In the present case, phytoplankton abundance was inversely related to rainfall, which is logical, because periods of higher rainfall were associated with higher allochthonous turbidity and relatively unstable geographical conditions hindering the colonization of phytoplankton.

Kole *beel* supported a higher number of phytoplankton taxa than Saguna *beel* probably because of higher macrophytes growth and diverse ecological conditions (both lotic and lentic) prevailing in this open *beel*. The phytoplankton community structure observed in Kole *beel*s Bacillariophyceae>Chlorophyceae>Myxophyceae>Desmidiaceae) in respect of relative abundance showed the dominance of Bacillariophyceae, which is in occurrence with the trend reported by Yadava (1987a) in open *beel*s s. On the other hand, the dominance of Chlorophyceae was observed in Saguna *beel*s (Chloorophyceae>Bacillariophyceae>Myxophyceae>Euglenophyceae>Desmidiaceae) conforms with the observation made in other closed *beel*s s of the valley (Lahon, 1983; Goswami, 1985; Acharjee, 1997). The Chlorophyceae, which is the most successful competitor in waters exposed to the penetration of sunlight, was commonly represented by *Spirogyra spp., Pediastrum spp.,* and *Mougotia spp.* Dominance may be due to the reduction in old vegetation strands after annual decomposition bearing higher exposed areas for light penetration (Acharjee, 1997). Bacillariophyceae, which was the most dominant group in Kole *beel*s was dominated by *Fragillaria spp.*, *Melosira spp.* and *Navicula spp.* in the present study, Bacillariophyceae occurred in all the months (Shetty *et al.*, 1961); Yadava, 1987a; Acharjee, 1997). Myxophyceae was the third most dominant group in the *beel*s s and was commonly represented by *Microcystis spp.*, *Anabaena spp.*, and *Oscillatoria spp.*

The above finding is in agreement with that of Dhir *beel* (Yadava, 1987a), which indicates utilization of silicon in the water body due to the fast depletion of desmid biomass. Since the maximal abundance of diatoms was recorded during November- December, temperature did not seem to have played an important role in their seasonal variation. Optimum alkalinity range for blue-green algae to be 50 to 110 ppm. In the present study, the peak biomass of Myxophyceae corresponded to a lower range of temperature (23.5-26.1 °C) and total alkalinity (30.08-68.36 ppm).

Rawson (1956) reported a higher population of desmids in oligotrophic lakes. Similarly, an increase in the abundance of Cyanophyceae has been related to eutrophication. The presence of blue-green algal species like *Anabaena spp.* and *Microcystis spp.* in the *beel*s s indicated their eutrophic nature. According to Rawson (1956), desmids were characteristic of oligotrophy. The desmids contributed only 10% and 8.6% of total phytoplankton abundance in Kole *beel*s and Saguna *beel*s respectively, which suggests that both the *beel*s are gradually advancing towards eutrophy. Kutkuhn (1958) stated that that , the eutrophic existence of a water body is indicated by Myxophyceae, Chlorococcales, Euglenoids, and Bacillariophyceae Centrales. (Kutkuhn, n.d.)

During the present study 73 species of phytoplankton (15 species of Myxophyceae, 30 species of Chlorophyceae, 23 species of Bacillariophyceae, 2 species of Euglenophyceae, 1 species of Dinophyceae, and 2 species of Xanthophyceae) were recorded from both the wetlands. Representation of *Mougetia sp.*, *Pediastrum sp.* and *Scenedesmus sp.* was substantial to abundant in the plankton samples of the wetlands, especially from the closed ones, indicating their eutrophic nature (Hutchinson, 1987).

The zooplankton community, which is a vital link in the aquatic food chain, is influenced by many Physico-chemical and biological factors. Temperature is considered as one of the determining factors in the seasonal distribution of the zooplankton population (Byars, 1960). But in the present study, no such relationship was observed. Similar observations were made from the floodplain lakes of India (Singh, 2000). The seasonal variation of the zooplankton population closely followed that of phytoplankton. According to Wright (1961), the abundance of zooplankton is chiefly dependent on the abundance of phytoplankton. In the present study, the major peak was observed in December when the abundance of phytoplankton was not always the highest. Zooplankton population had an exceedingly high direct correlation with phytoplankton abundance (r=0.978) in the present study, which further corroborates the above facts.

Apart from temperature and food availability, the zooplankton density is also related to the chemical properties of water (Unni, 1971). The present study revealed a poor population of zooplankton in Kole *beel* although phytoplankton was rich in this *beel*. Similar observations were made by Lahon (1983), Goswami (1985), Yadava, *et al.*, (1987). However, Kole *beel* supported a considerably higher zooplankton population, contributing to 38.2 % of the total plankton population despite having a poor phytoplankton population. The zooplankton population derived a part of their food from the organic detritus in addition to phytoplankton in these heavy macrophytes-infested *beel*s.

The zooplankton community structure in Kole *beel* showed the dominance of copepods (Copepoda>Rotifera>Cladocera), which is a common feature in the *beel*s s of Ganges Valley On the other hand, the dominance of rotifers observed in Saguna *beel* (Rotifer>Copepoda>Protozoa> Cladocera) was agreeable with the trend reported from other closed *beel*s of the lower Ganges Valley. A gradual decline was observed in the percentage contribution of copepods to the total plankton population from October onwards in Saguna *beel*, which may be related to the prediction pressure from the sizeable number of catla (*Catla catla*) fry stocked in these *beel*s during September.

Food of Juvenile catla (2-10 cm) overwhelmingly comprised crustaceans (80%) and in adults also they were the most dominant food group (45%). Copepods, though present throughout the year, did not show any regular periodicity. Chen (1965) and Yadava (1987a) reported the affinity of copepod populations towards warm water. Ganapati and Rao (1954) observed temperature to be the controlling factor in the seasonal variation of copepods. The irregular periodicity observed in the present study indicated no definite relationship with water temperature. Mathew (1975) and Singh (2000) observed that copepod production depended on the availability of food supply.

Rotifers have a versatile capacity to survive in different environments as some of them feed on various phytoplanktons, some feed on detritus and bacteria, while some others have been described as raptorial predators (Singh, 2000). Such high adaptive nature of this group favored its dominance of the zooplankton community in Saguna *beel*. The predominance of rotifers is a common feature of Indian freshwaters (George, 1966; Michael, 1969; Lahon, 1983). The relative abundance of rotifers in the *beels* s under the present study may be attributed to the infestation of macrophytes and the high accumulation of organic nutrients due to their annual decomposition. Peak rotifer abundance occurred during November-December in the present study. George (1966) and Singh (2000) recorded maximum production of rotifers during the summer season. Among the rotifers, the loricate forms like *Brachionus spp.* and *Keratella spp.* were predominant. Michael (1966) and Singh (2000) have made similar observations. The peak biomass of protozoans was recorded during November-December in the present study. Thus, a temperature range of 23.5 to 26.1 °C seemed to favor their growth, which lies within the optimum temperature range for the growth of protozoans (Pennak, 1953).

Various workers (Wright, 1961; Michael, 1966) have suggested that the density of cladocerans is primarily determined by the food supply. In the present study, their peak population coincided with periods of rich phytoplankton, which conforms with the above observation.

5.4.1.3 Periphyton

Periphyton assemblage is known to be controlled from the "top-down" by a fish grazer interaction, and/or from "bottom-up" by nutrient and light availability. Each lake is unique concerning the presence, type, abundance of fish, grazing invertebrates, periphyton, macrophytes, nutrients, and clarity of the water. Periphyton is composed of attached plants and animals embedded in a "mucopolysaccharide matrix". But these organisms have a significant role in the food chain of an aquatic ecosystem. The abundance of periphyton in the wetlands was estimated at 390 nos/cm2 (Saguna) and 503 nos/cm2 (Kole).

The community structure of the periphytic organism in the wetlands of West Bengal was recorded as Bacillariophyceae > Myxophyceae > Chlorophyceae>Miscellaneous Algae>Protozoa>Rotifers.

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