CHAPTER 5

RESULTS AND DISCUSSION ON WATER QUALITY ANALYSIS

Two sets of trials were conducted to artificially replicate the lake eutrophication scenario as illustrated in table 3. In the 1^{st} trial two concrete bedded tanks were used and tests for water quality parameters pH, TDS, EC, BOD, DO, turbidity, TN, TP, SD, temp were periodically monitored. To validate the findings of the 1^{st} trial, a 2^{nd} trial was conducted with a concrete tank and one artificial pond. In the 2^{nd} set-up, in addition to the water quality parameters investigated in the 1^{st} trial, another important parameter Chl-a was also monitored in regular interval of time. The results and discussion on experimental investigations carried out for water quality analysis on the artificially simulated eutrophied lakes have been presented in this chapter.

5.1 RESULTS AND DISCUSSION FROM 1^{ST} TRIAL

Eutrophication process was recreated effectively with periodic application of waste water to the studied artificial lakes. As major cause of contamination of most urban and rural surface water bodies in Assam is due to domestic and agricultural runoffs, the waste water applied to the studied lakes had been gathered from pond highly contaminated from domestic effluents all throughout the period. The average pH, EC, TDS, and turbidity values of the applied waste water were 7.54, 689.80 µS/cm, 344.71 ppm and 178.65 NTU respectively. The nutrient concentration of the applied waste water was high with average TN and TP concentrations of 0.48 mg/L and 2.79 mg/L respectively. The laboratory examinations were done for around eight and nine months' time span from March to December' 2018 for Tank 1 and Tank 2 respectively and at that point total degradation of water quality had been noticed. The water quality in both the artificial lakes deteriorated significantly during the final stage of experimentation as compared to initial condition as evident from Figure 5.1.

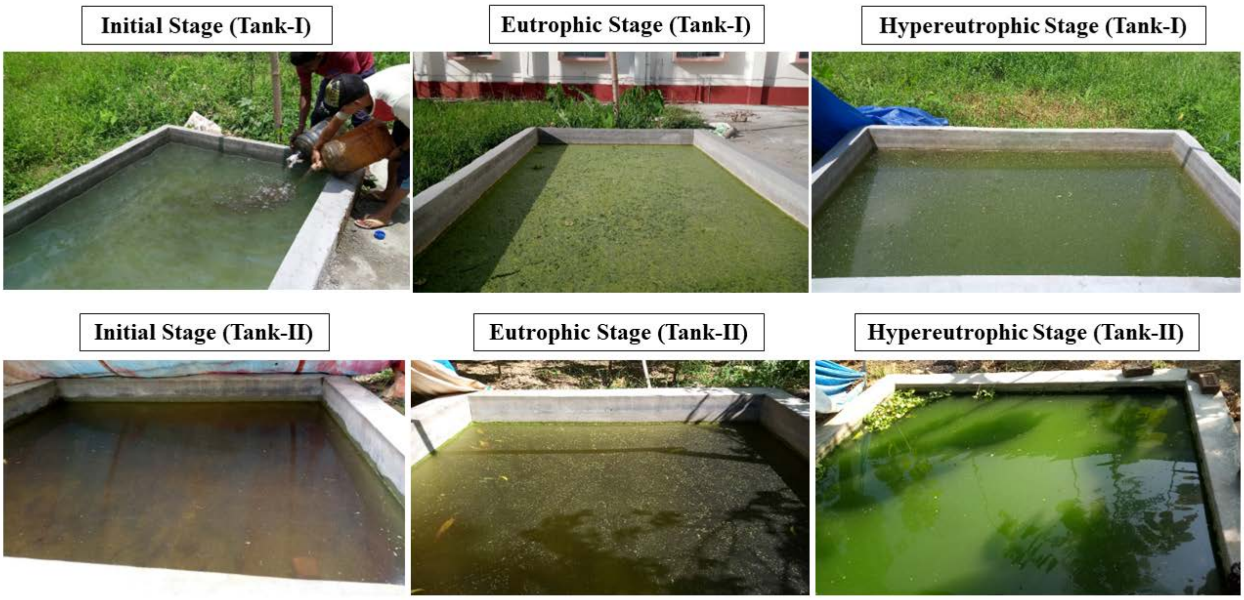

Figure 5.1: Water quality deterioration in the studied prototype lakes (Trial 1)

5.1.1 Water quality analysis

Over the studied period, the effects of eutrophication were prominent in the artificial lakes with increased algal growth, high turbidity, and hypoxia. The variation of the desired water quality parameters investigated in the studied artificial lakes have been presented from Fig. 5.2 to Fig. 5.11. It was observed that because of continuous increase in the nutrient concentration, a favorable condition for occurrence of eutrophication was initiated in the lakes and as a result the water quality parameters changed significantly.

5.1.1.1 pH

The pH values of both the prototype lakes were found to show an increasing trend in general with time as evident from Figure 5.2. For Tank 1, it was seen that pH value changed from a minimum value of 7.78 during the initial clear water state to maximum of 10.32 during highly eutrophic state. Similarly, pH value was found to change from 7.36 upto 9.92 in case of Tank 2 during the period of investigation. This change in pH values for both the investigated lakes can be attributed to the occurrence of algal bloom as a result of nutrient enrichment. During photosynthesis of algae during day time CO_2 is used up and O_2 is released which may result in increase of pH. During the hypereutrophic stages of the lakes, it was seen that the pH values were more or less stagnant and showed decreasing trends as a result of O_2 uptake in the process of decomposition of organic matter.

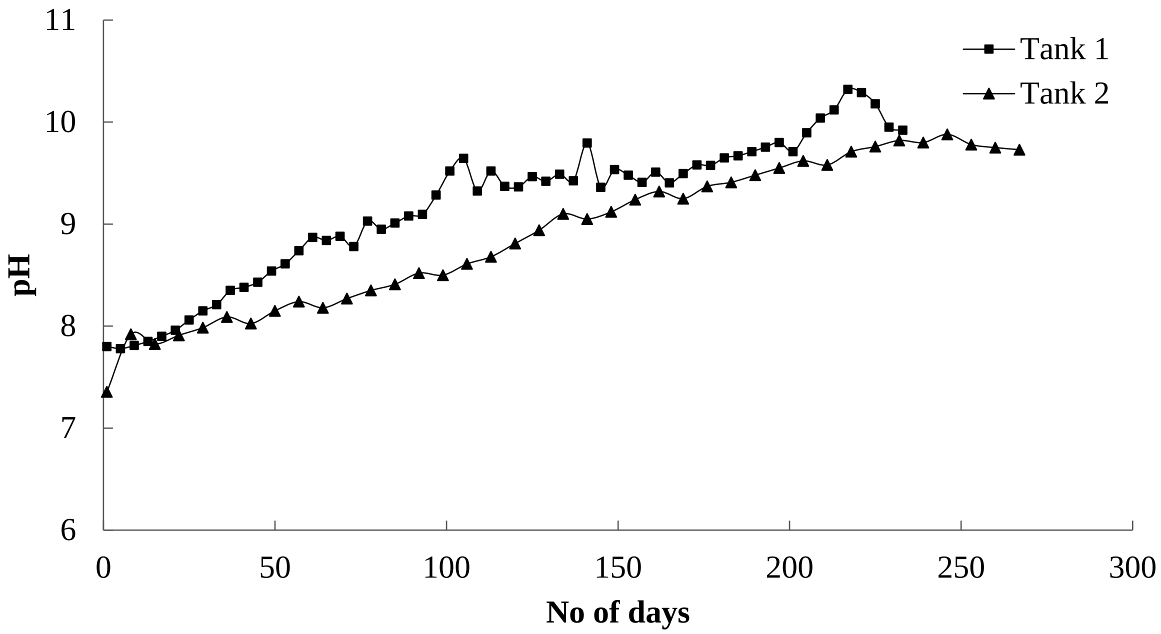

Figure 5.2: Variation of pH with time (Trial 1)

5.1.1.2 EC and TDS

EC and TDS of water samples were found to change gradually in the studied lakes in due course of time. As both EC and TDS are highly correlated, they showed similar increasing trend during the period of investigation as shown in Figure 5.3 and Figure 5.4 respectively. The EC values were initially 238 µS/cm and 164 µS/cm for Tank 1 and Tank 2 respectively and changed upto 795 µS/cm and 460 µS/cm respectively during final stages of investigation. The TDS values also increased from 119 ppm to 456 ppm for Tank 1 and from 80 ppm to 264 ppm for Tank 2 during the process of water quality deterioration in the investigated lakes. The increase in EC and TDS of water is mainly due to nutrient enrichment specially with N and P that contributes to the elevated levels of dissolved solids. Moreover, during the process of algal decomposition, organic matter may release ions to water which can contribute to increase in EC and TDS. The extent of change of EC and TDS may depend on several factors like degree of eutrophication, temperature, pH, species composition etc. and so changes can vary from one lake to another. In case of Tank 1, it was seen that the variation of EC and TDS were more rapid compared with Tank 2 during the eutrophic stage. This can be due to the fact that the algal bloom or extent of eutrophication observed in case of Tank 1 was higher than the Tank 2.

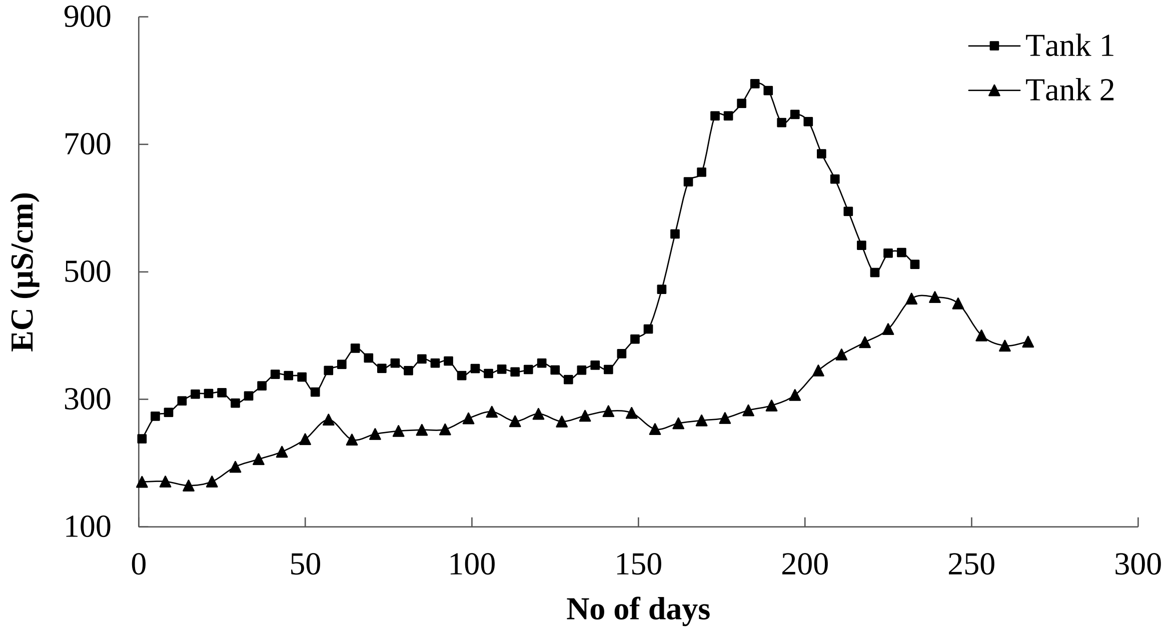

Figure 5.3: Variation of EC with time (Trial 1)

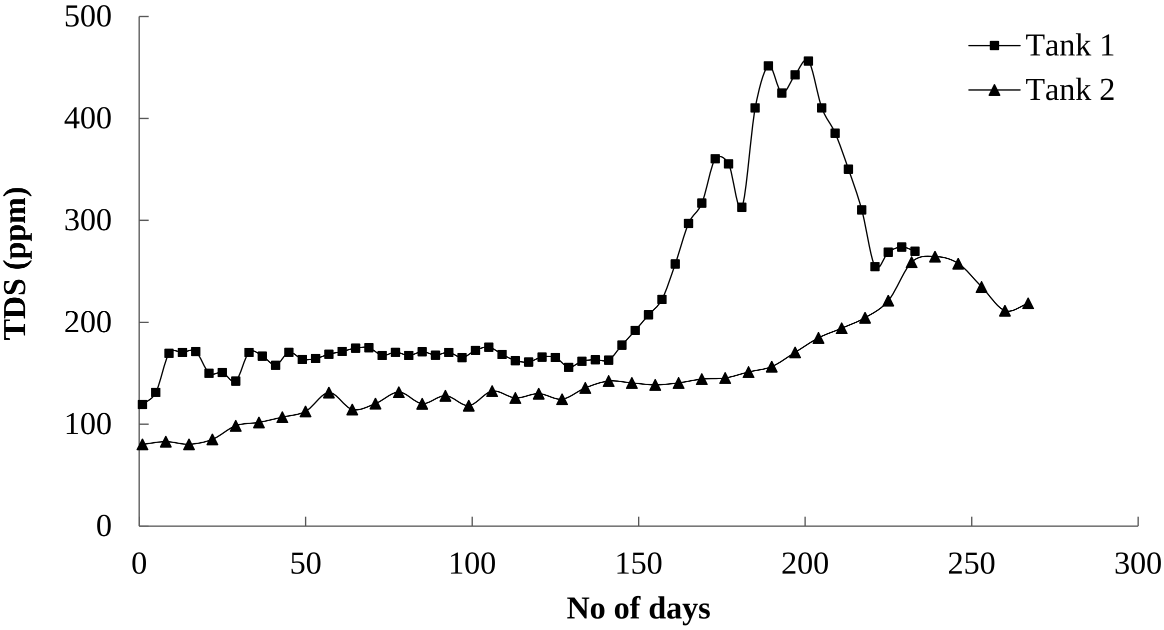

Figure 5.4: Variation of TDS with time (Trial 1)

5.1.1.3 DO

DO is one of the most important indicator parameters of lake eutrophication and gradual decrease of DO levels was quite indicative of change of trophic status of the investigated lakes during the studied period. Figure 5.5 below shows that DO values were initially 6.70 mg/L and 6.20 mg/L respectively for Tank 1 and Tank 2 and finally it reached a minimum value of 3.40 mg/L and 4.50 mg/L respectively. It can be inferred that both the lakes have transitioned from an initial clear water stage to a hypereutrophic stage. This reduction in DO levels is mainly due to the utilization of oxygen by the bacteria and other microorganisms for decomposition process of algal biomass and organic matter. It was seen that during the initial periods of nutrient enrichment, the DO levels were not constantly decreasing rather fluctuating and after occurrence of high algal blooms from around 100 days period, DO was decreasing gradually. This fluctuation can be attributed to the fact that during initial period, high influx of nutrients promotes rapid algal and plant biomass growth and they undergo photosynthesis producing oxygen as a byproduct. So, during daylight hours there may be an increase in oxygen levels as a result of photosynthesis activity during the initial growth period.

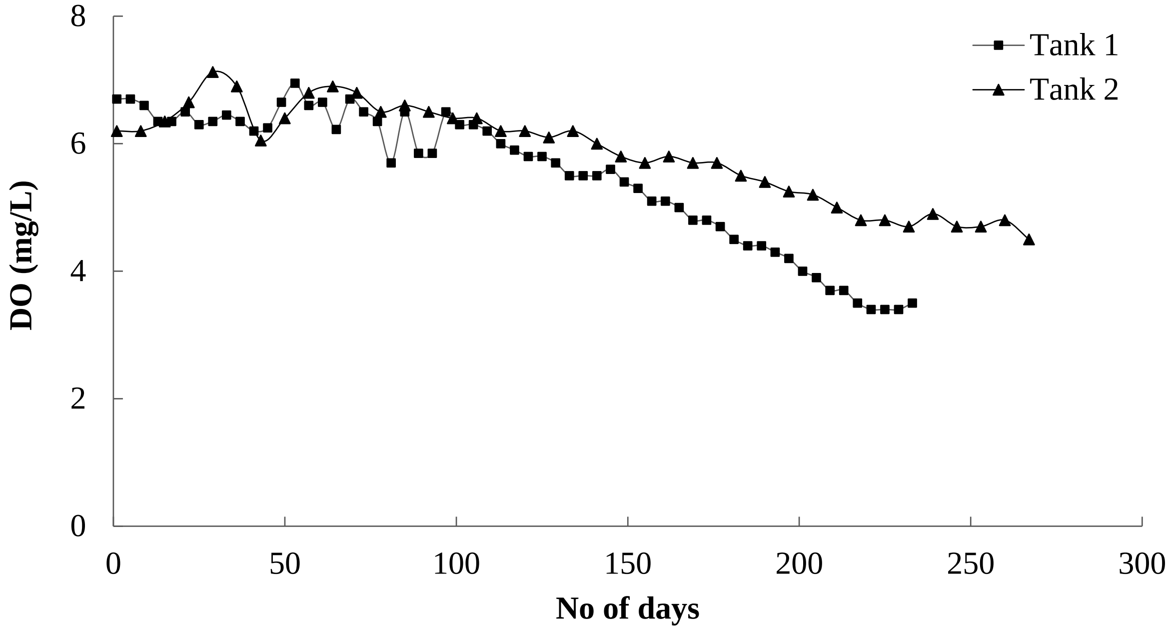

Figure 5.5: Variation of DO with time (Trial 1)

5.1.1.4 SD

Due to continuous application of nutrients to the artificial lakes algal or cyanobacterial bloom was observed. These organisms can scatter and absorb light, making it difficult for light to penetrate through water and thus making it turbid and cloudy. When algae die and decompose, it can further decrease SD due to increased turbidity from suspended organic matter. So, during the process of trophic status change of the studied artificial lakes, the SD values were found to decrease considerably as shown in Figure 5.6. It was observed that the SD, from an initial value of 65 cm decreased upto 18 cm for Tank 1. Similarly for Tank 2, SD value changed from 74 cm to a minimum of 14 cm in due course of time.

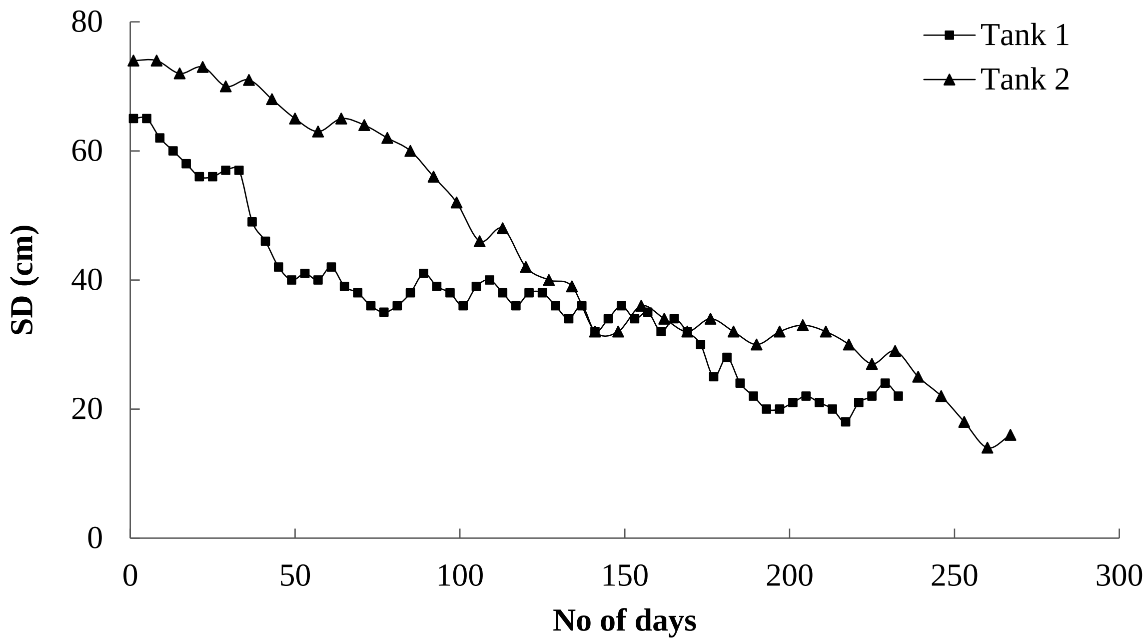

Figure 5.6: Variation of SD with time (Trial 1)

5.1.1.5 TN and TP

With gradual application of nutrient rich waste water to the lakes the TN and TP concentrations were found to increase significantly. TN and TP are the key elements responsible for excessive algal growth leading to eutrophication of water bodies. So increased concentrations of these elements favoured the growth of algae and resulted in eutrophication of the studied artificial lakes. The variations of TN and TP are presented with Figure 5.7 and Figure 5.8 respectively. The concentrations of TN and TP in both the lakes were 0 initially as clear filtered water was used during the starting of experimental set-up. Thereafter concentrations of these elements started increasing and for TN reached maximum values of 1.64 mg/L and 1.97 mg/L for Tank 1 and Tank 2 water respectively. For TP maximum concentrations were 2.15 mg/L and 2.41 mg/L respectively for Tank 1 and Tank 2 during the hypereutrophic stage.

From the Figures it can be observed that for TP concentration, the increasing trend is more or less consistent throughout the study period. However, during the initial stage of nutrient enrichment, the increase in TN concentrations were slightly slower compared to later stages. This may be due to the fact that during the initial growth period of algae or other aquatic plants large amounts of nutrients are used particularly nitrogen for the present set-up of the experimental investigation.

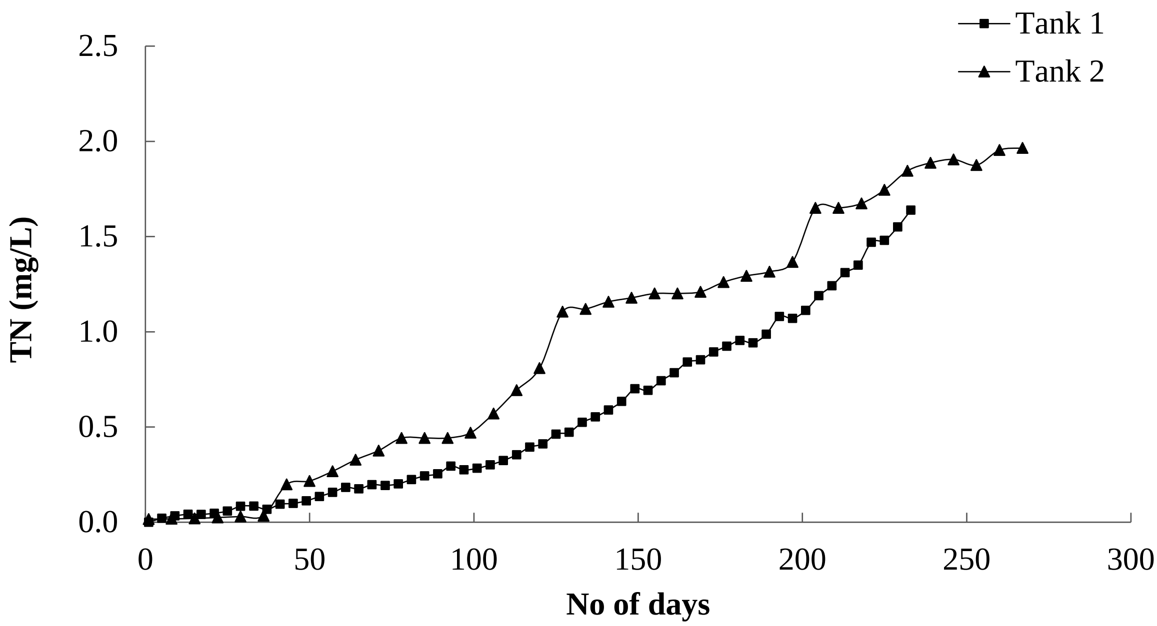

Figure 5.7: Variation of TN with time (Trial 1)

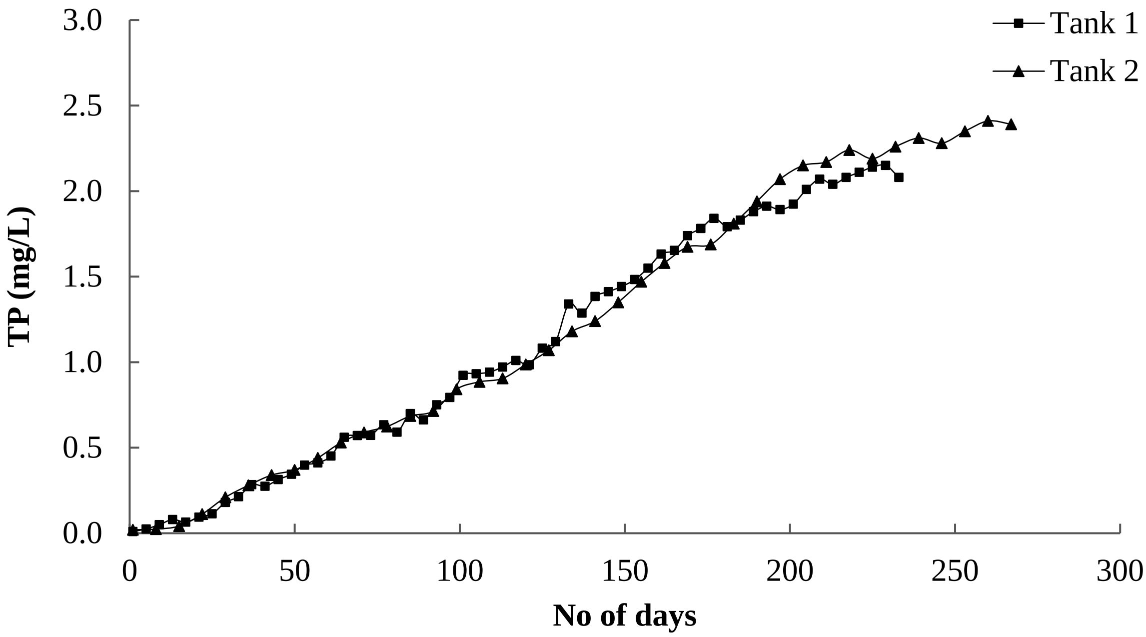

Figure 5.8: Variation of TP with time (Trial 1)

5.1.1.6 BOD

The effect of nutrient enrichment on BOD levels of the studied artificial lakes have been presented with Figure 5.9. It was observed that BOD levels increased considerably during the eutrophied stage of the lakes. For Tank 1 it was seen that from around 100 days to 200 days period BOD values were high. Similarly for Tank 2 from around 100 days to 230 days interval higher values of BOD was reported. During these periods the lakes were in eutrophic to hypereutrophic state and organic matter content was high due to death of algae and other aquatic plants. As a result, more oxygen is used by bacteria and microorganisms to decompose the organic matter leading to higher BOD values. During the final stages when the lakes were hypereutrophic and anoxic conditions prevailed, the BOD growth rate decreased.

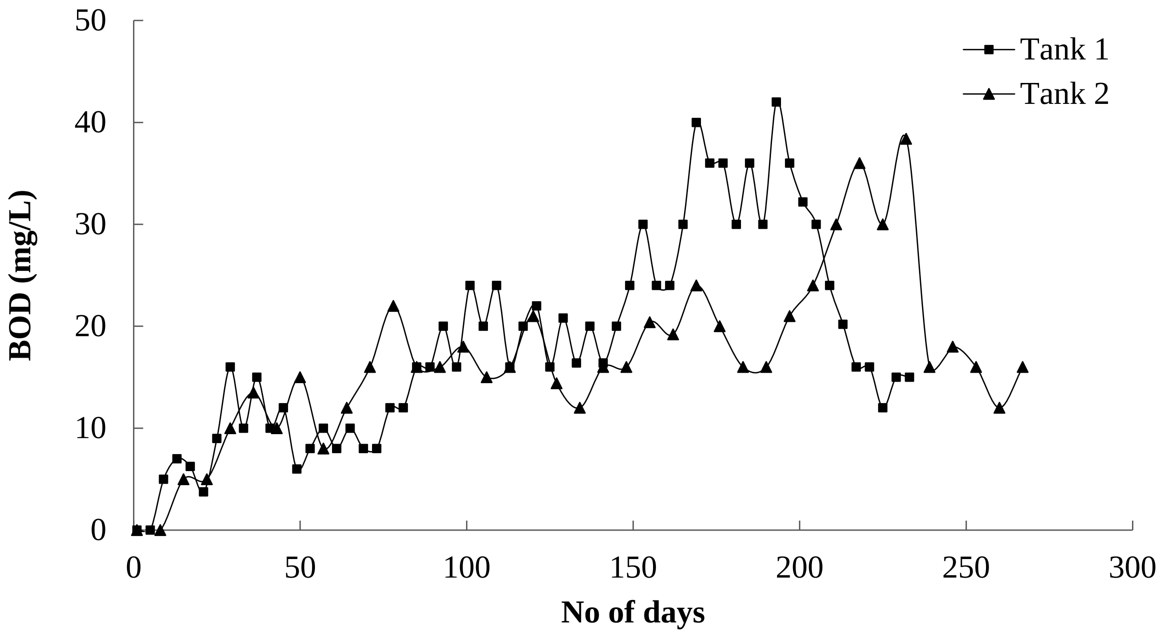

Figure 5.9: Variation of BOD with time (Trial 1)

5.1.1.7 Turbidity

The variation of turbidity of the lake water has been presented with Figure 5.10. The turbidity of the lakes increased significantly with time implying water quality deterioration as a result of eutrophication. As both turbidity and SD are highly correlated and are associated with water transparency and dissolved solids, increase in turbidity is supported by the fact that SD decreased with time. Maximum turbidity values of 65.40 NTU and 45.80 NTU was observed for Tank 1 and Tank 2 respectively. Compared with Tank 1, turbidity values of Tank 2 was slightly lower. This can be attributed to the fact that the water volume of Tank 2 was higher in comparison with the volume of Tank 1.

5.1.1.8 Temperature

As temperature may have a significant role in different biochemical and physio-chemical processes associated with eutrophication like metabolic rates, algal growth, nutrient availability for aquatic plants, oxygen dissolution etc., ambient water temperature was monitored throughout the study period. The temperature variations during the study period is presented with Figure 5.11. Throughout the experimental investigation period the water temperature was found to be within 25° to 36°.

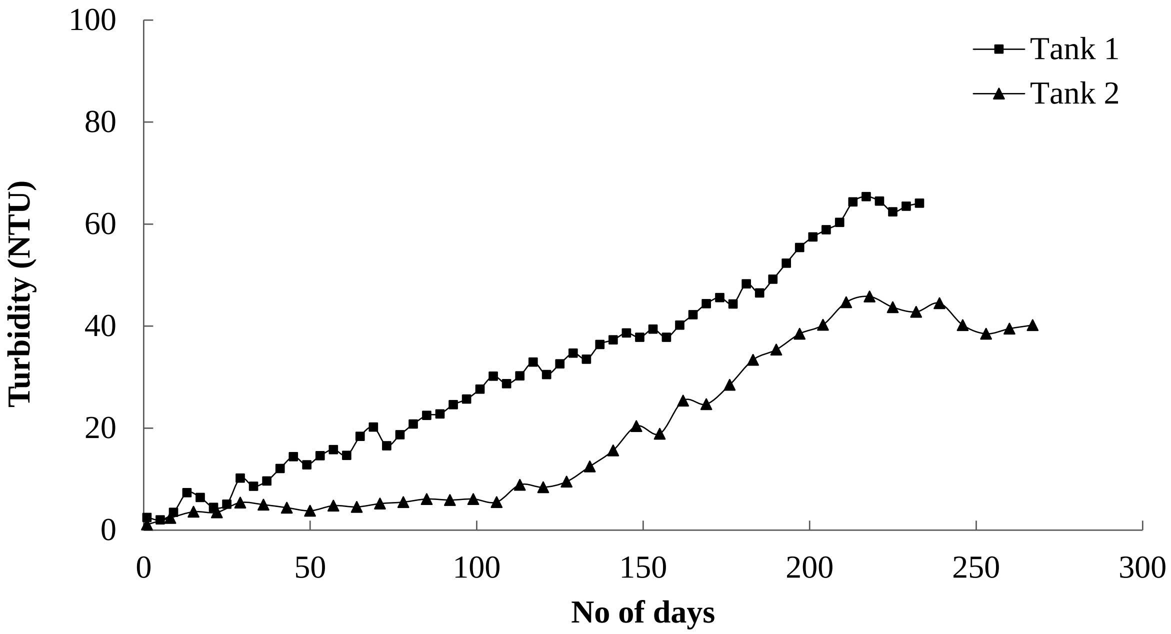

Figure 5.10: Variation of turbidity with time (Trial 1)

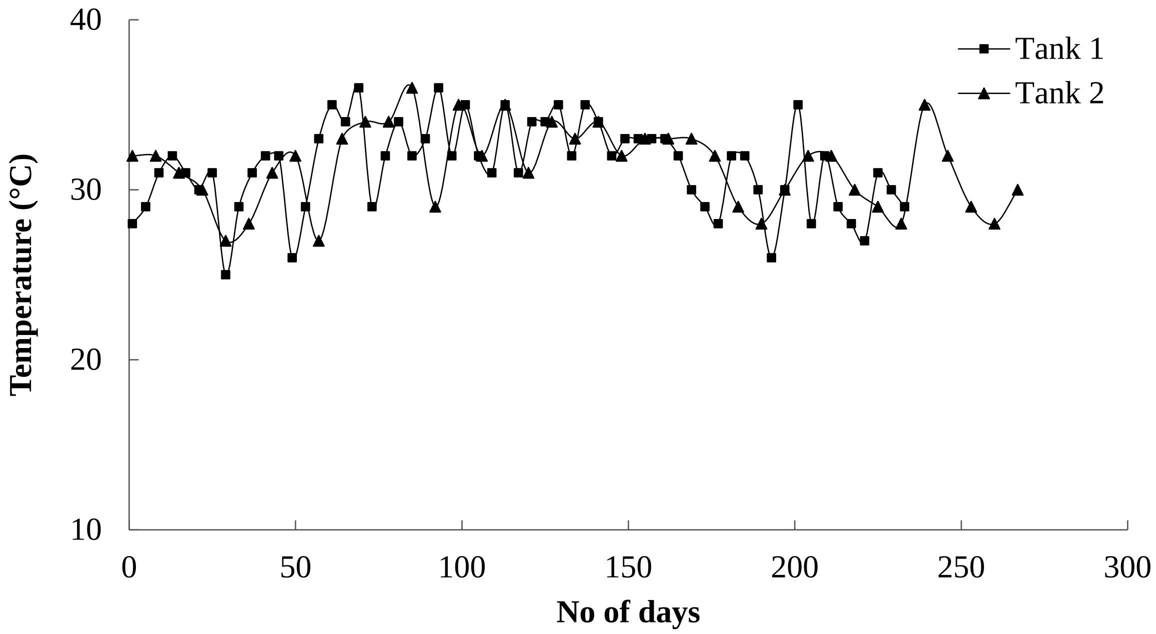

Figure 5.11: Variation of Temperature during period of investigation (Trial 1)

5.1.1.9 Statistical summary

It is evident from the above discussion that with gradual application of waste water to the artificial lakes, the trophic state of the lakes changed from a clear water oligotrophic to hypereutrophic state. A total of 98 samples were analysed from the prototype lakes for model training. The investigated water quality parameters showed significant changes during the process of eutrophication. The statistical summary of experimental investigation in terms of maximum, minimum, average, and standard deviation for different physio-chemical properties of water samples collected during the study period from the prototype lakes were calculated and are presented with Table 5.1. The investigated dataset were used for calculation of TSI of the studied artificial lakes and thereafter data-driven models were trained and tested for DO and SD prediction in eutrophic lakes of Assam.

Table 5.1: Statistical summary of investigated water quality variables (Trial 1)

	pH	EC (μS/cm)	TDS (ppm)	Turb (NTU)	TN (mg/L)	TP (mg/L)	Temp (°C)	BOD (mg/L)	DO (mg/L)	SD (cm)
Max	10.32	795.00	456.32	65.40	1.97	2.41	36.00	42.00	7.13	74.00
Min	7.36	164.80	80.23	1.10	0.00	0.01	25.00	0.00	3.40	14.00
Avg	9.06	380.57	195.27	26.99	0.71	1.14	31.40	17.63	5.64	40.00
St. Dev.	0.71	153.93	87.60	18.72	0.59	0.75	2.49	9.29	0.96	15.44

* Turb= Turbidity, Max= Maximum, Min= Minimum, St Dev.= Standard Deviation, Avg=Average

5.1.2 TSI Evaluation

To legitimize event of eutrophication in the examined prototype lakes scientifically, the experimental dataset was utilized for trophic status assessment as per convention proposed via Carlson [20]. For determination of Carlson trophic status (TSI), SD and TP values of the studied lakes were utilized as per equations 1 and 3. The maximum, minimum and average values of TSI based on TP and SD values for the investigated artificial lakes are presented in Table 5.2. The concentration of TP during the initial period of investigation was quite low (0.01 mg/L) and water was transparent upto the full depth of the lakes. For this condition, TSI value was assessed as less than 40 indicating that the studied lakes were in the oligotrophic state. With gradual application of nutrients to the artificial lakes, the water quality of the lakes deteriorated considerably with higher TP concentration and lower SD values. In this condition, calculated value of TSI was well in excess of 70 both for TP and SD standards inferring that lake water quality had changed to a hypereutrophic stage from a freshwater stage. As such, the lake eutrophication phenomenon was replicated in controlled environment successfully and thereafter investigated dataset were used for model development.

Table 5.2: Calculated TSI values of studied artificial lakes (Trial 1)

	TSI_{TP}			**TSI_{SD}**		
	Min^m	Max^m	Avg.	Min^m	Max^m	Avg.
Tank 1	37.37	114.86	104.90	<40	84.74	74.39
Tank 2	37.37	116.51	106.94	<40	88.37	71.61

5.1.3 Evaluation of correlation coefficient

To check the linear relationship between the investigated water quality parameters, correlation coefficient matrix analysis was performed and the results are presented with Table 5.3. Considering correlation coefficient of 0.5 as threshold value based on previous research [118, 146], it was observed that the linear dependency between two investigated parameters were generally poor. Significant relationship was observed only between EC and TDS with correlation coefficient value of 0.84. This strong positive correlation may be due to the ions dissolved in water that conduct electricity. The target eutrophication indicator parameters DO, SD, TN, and TP also had no significant correlation with other parameters. This poor linear correlation among the water quality parameters may be due to several factors such as multifactorial influences of ecological systems, species interaction, threshold effect in ecological relationships, uncertainty etc. So, for the presented work linear correlation may not sufficiently represent true association among variables.

Table 5.3: Correlation coefficient matrix of water quality variables (Trial 1)

	pH	EC	TDS	Turb	TN	TP	Temp	BOD	DO	SD
pH	1.00									
EC	0.54	1.00								
TDS	0.56	0.84	1.00							
Turb	0.35	0.49	0.41	1.00						
TN	-0.41	-0.26	-0.24	-0.25	1.00					
TP	-0.50	0.30	0.33	-0.01	0.22	1.00				
Temp	0.09	-0.09	-0.11	-0.03	0.06	-0.16	1.00			
BOD	-0.15	0.50	0.53	0.24	0.03	0.49	-0.18	1.00		
DO	0.21	-0.58	-0.54	-0.49	-0.42	-0.47	0.19	-0.44	1.00	
SD	-0.41	-0.52	-0.48	-0.59	-0.17	-0.29	0.14	-0.43	0.31	1.00

5.2 RESULTS AND DISCUSSION FROM 2ND TRIAL

To ascertain the effect of nutrient enrichment on water quality parameters as obtained from the 1st trial, a second set of experimental investigation was conducted. In the 2nd trial Tank 1 and Tank 3 were used to simulate the process of eutrophication. During this trial, the concrete tank and the artificial pond was used to check any variations in the process of eutrophication occurring under controlled environment and natural condition.

5.2.1 Water quality analysis

With periodic addition of waste water from the same source as in 1st trial to the considered artificial prototype lakes, eutrophication process was replicated in the 2nd trial also. The experimental investigations were carried out for around nine months period from February to November’ 2019 for Tank 1 and for eleven months period from February’ 2019 to January’ 2020 for Tank 3. For both the studied lakes, algal bloom was observed due to nutrient enrichment, more significantly after around three months’ time and thereafter complete deterioration of water quality has been observed with heavy algal growth and subsequent degradation for both the studied artificial lakes as evident from Figure 5.12.

In addition to all the water quality parameters examined during the 1st trial, Chl-a concentrations were also monitored during the 2nd trial. The effect of nutrient enrichment on the investigated parameters were prominent and significant changes have been observed during the study period. The trends of variation of pH, EC, TDS, DO, BOD, TN, TP, turbidity, and SD were similar to findings of 1st trial. The pH values increased gradually for both the lakes as presented with Figure 5.13. From initial values of 7.75 and 7.40, pH reached maximum values of 10.14 and 9.45 during hypereutrophic states of the Tank 1 and Tank 3 respectively. The EC and TDS values also showed an increasing trend and the results are presented with Figure 5.14 and Figure 5.15 respectively. BOD of the lake water also increased significantly during the process of eutrophication and it is presented with Figure 5.16. In between 100 to 250 days of investigation for Tank 1, major change in BOD values were observed when the algal growth and decomposition process was at peak. Similarly for Tank 3, major changes in BOD values were observed in between around 100 to 280 days of investigation.

Figure 5.17 below illustrates the variation of DO concentrations for the investigated prototype lakes. The DO concentrations reduced considerably due to eutrophication in both the artificial lakes. DO values reduced to as low as 1.80 mg/L and 2.30 mg/L for Tank 1 and Tank 3 respectively indicating highly anoxic conditions during the hypereutrophic state. The variation of turbidity has been presented with Figure 5.18 and it was seen that turbidity gradually increased due to eutrophication in the lakes. The change in nutrient concentrations in the lake water has been presented with Figure 5.19 and Figure 5.20 for TN and TP respectively. Both TN and TP concentrations increased gradually due to application of waste water to the lakes. Unlike the results of 1st trial, growth rate of concentration in both TN and TP were slightly slow during initial phases of experimentation. SD showed a gradual decreasing trend similar to results of 1st trial for both Tank 1 and Tank 3 as illustrated in Figure 5.21. Figure 5.22 presents the variation of ambient water temperature throughout the study period.

Chl-a is one of the most important indicator parameters of lake eutrophication and its variations during the study period has been presented with Figure 5.23. Initially Chl-a concentrations were 0 for both the lakes and thereafter with continuous nutrient loading with N and P, gradual algal growth was observed leading to increasing Chl-a concentrations. During algal bloom period Chl-a concentrations increased considerably reaching maximum value of 249.88 µg/L and 188.35 µg/L for Tank 1 and Tank 3 respectively. This higher Chl-a concentration justifies the water quality deterioration in the investigated artificial lakes in terms of decreased DO levels, higher turbidity, increased nutrient levels and higher TDS concentrations. During final stages of investigation, the growth rate of Chl-a was found to decrease indicating that the algal decomposition rate was higher than algal growth rate and the lakes have obtained hypereutrophic stage.

It was observed that the variation of water quality parameters were similar for the Tank 1 and Tank 3. However, the time required to reach hypereutrophic state for Tank 1 was lesser compared to Tank 3. It was evident as eutrophication was allowed to occur in controlled environment in case of Tank 1 but eutrophication was allowed to take place in a natural way for Tank 3 which was an artificial pond. Due to factors like interaction of bed materials with pond water, sediment mixing, nutrient deposition or release from pond surface etc. slight variations were observed for the nutrient enrichment rate, Chl-a growth rate and other parameters compared with Tank 1. Around 100 and 150 day observations, visible changes in water quality parameters were observed in case of Tank 3 particularly for pH, DO, turbidity, TN, and TP values due to dilution of water as a result of heavy rainfall.

Figure 5.12: Water quality deterioration in the studied prototype lakes (trial 2)

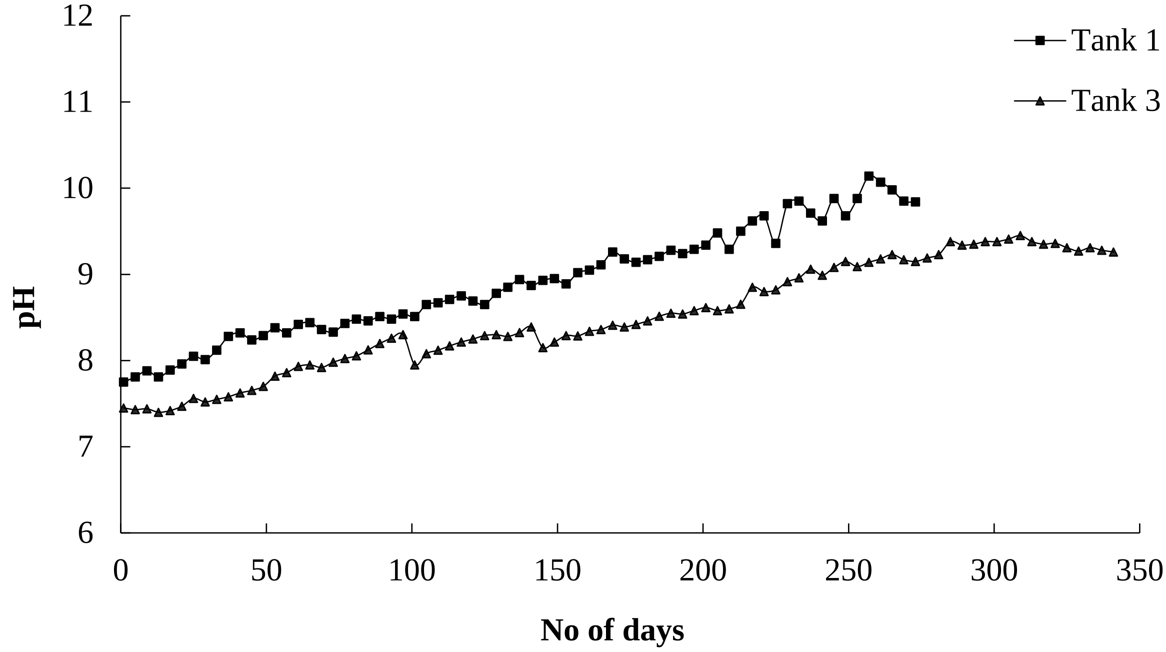

Figure 5.13: Variation of pH with time (Trial 2)

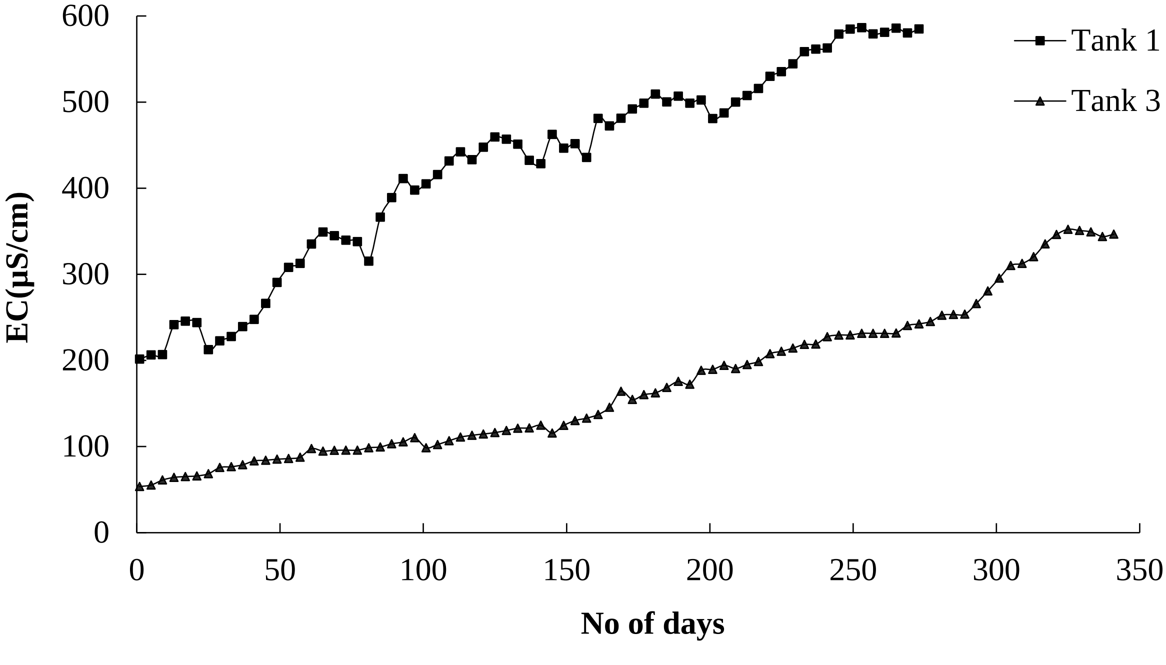

Figure 5.14: Variation of EC with time (Trial 2)

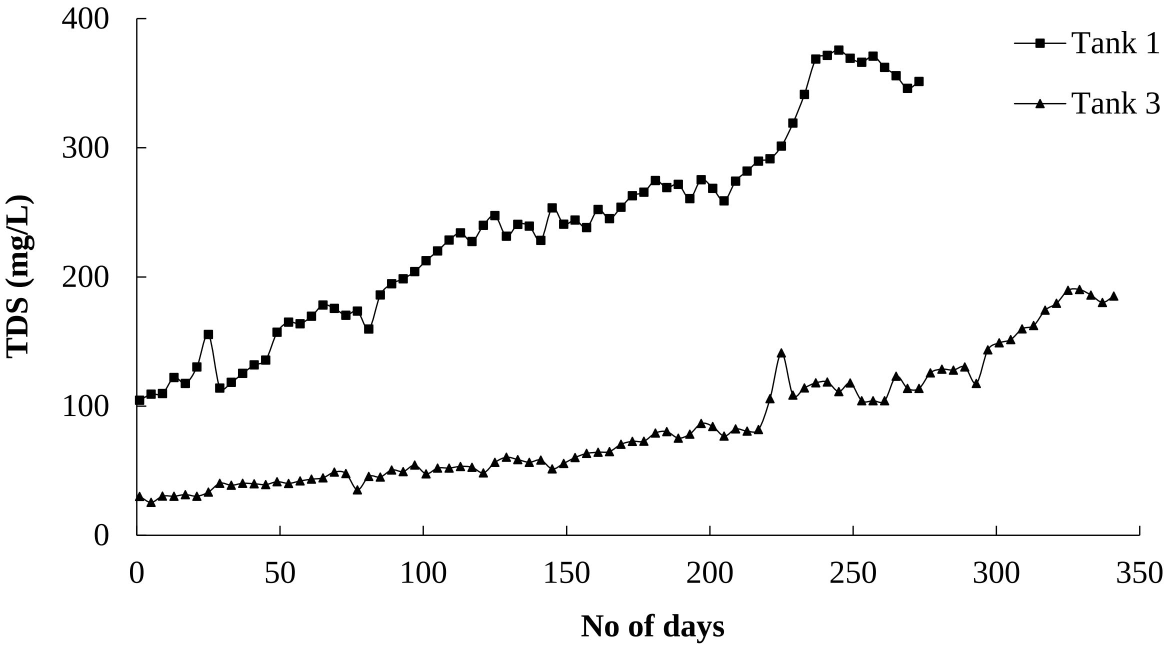

Figure 5.15: Variation of TDS with time (Trial 2)

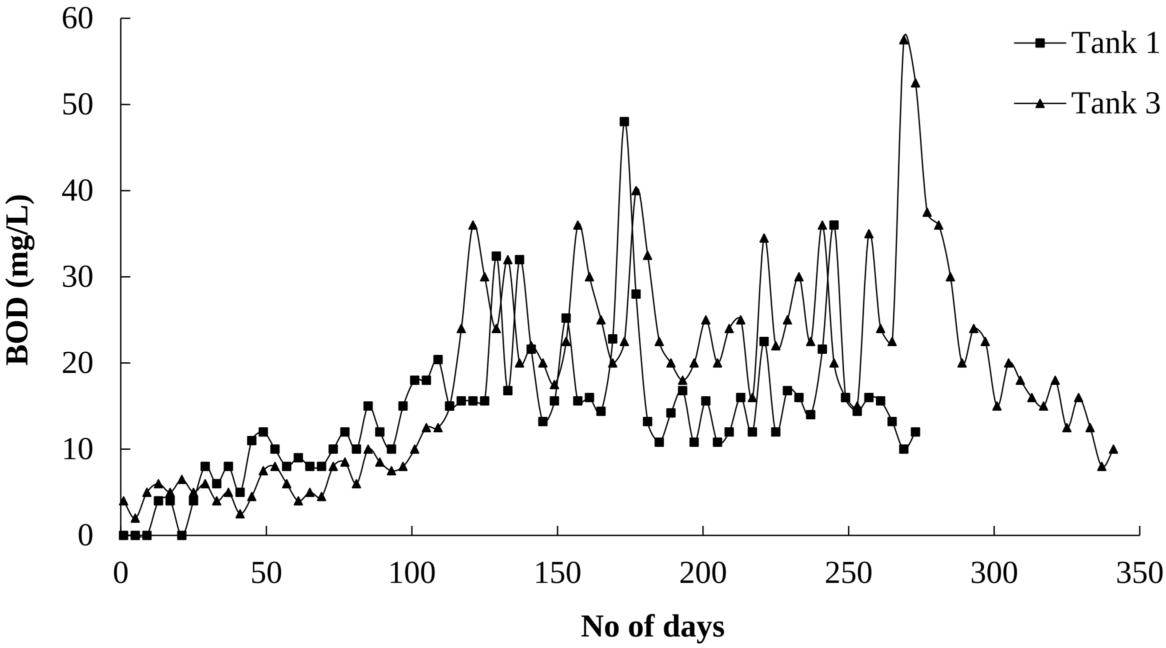

Figure 5.16: Variation of BOD with time (Trial 2)

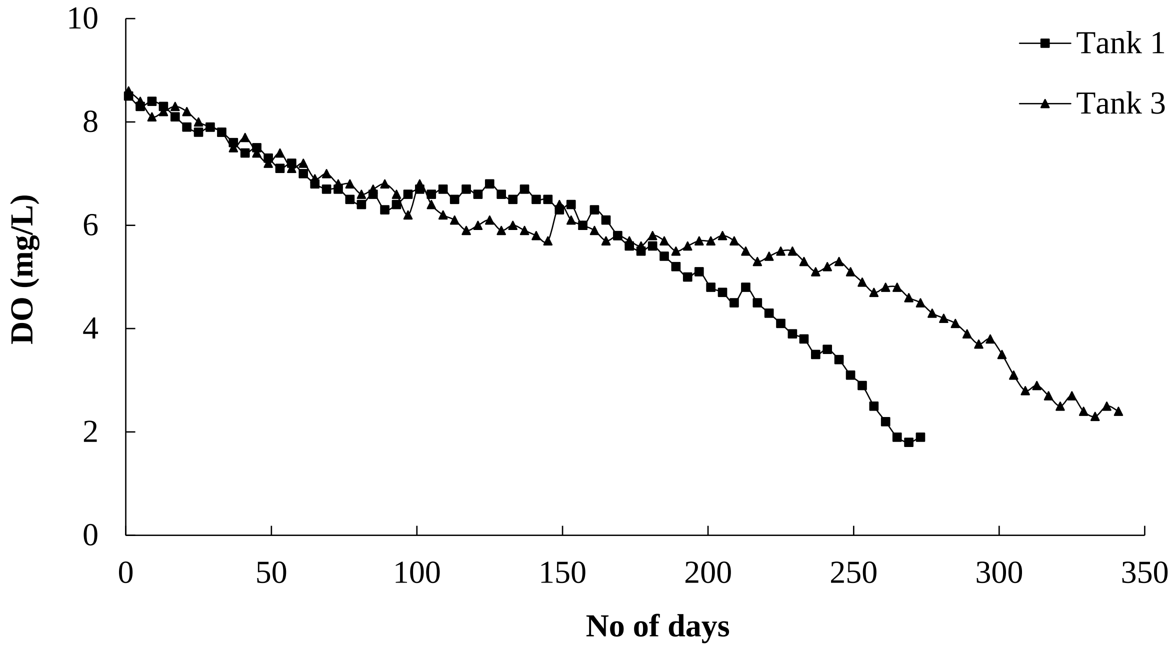

Figure 5.17: Variation of DO with time (Trial 2)

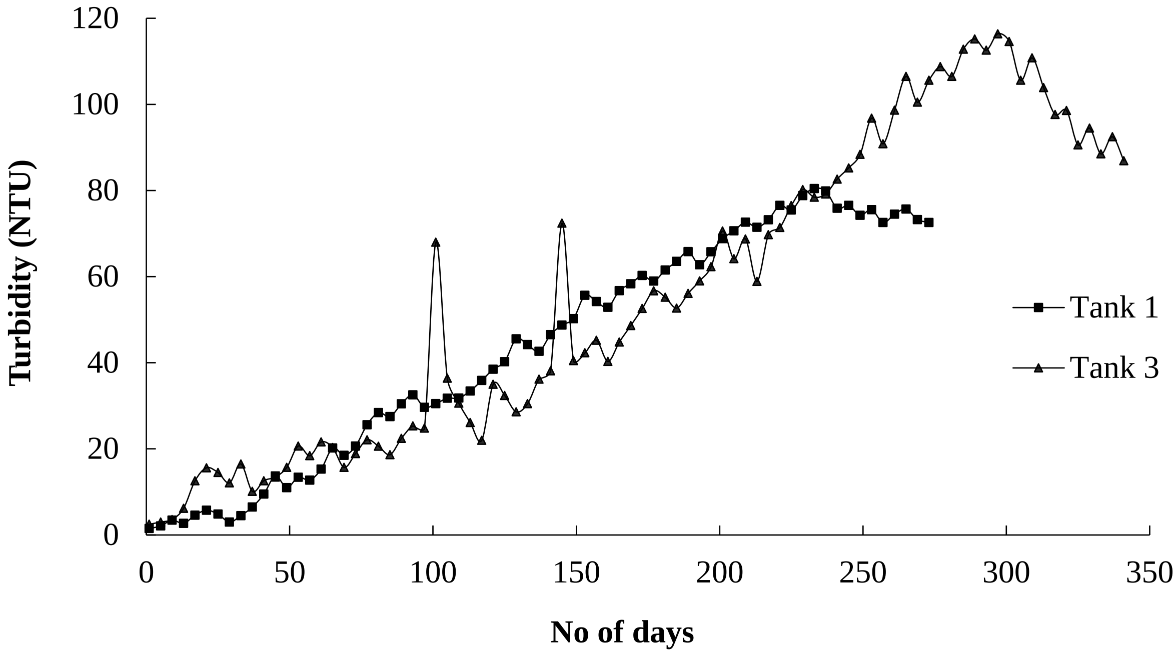

Figure 5.18: Variation of turbidity with time (Trial 2)

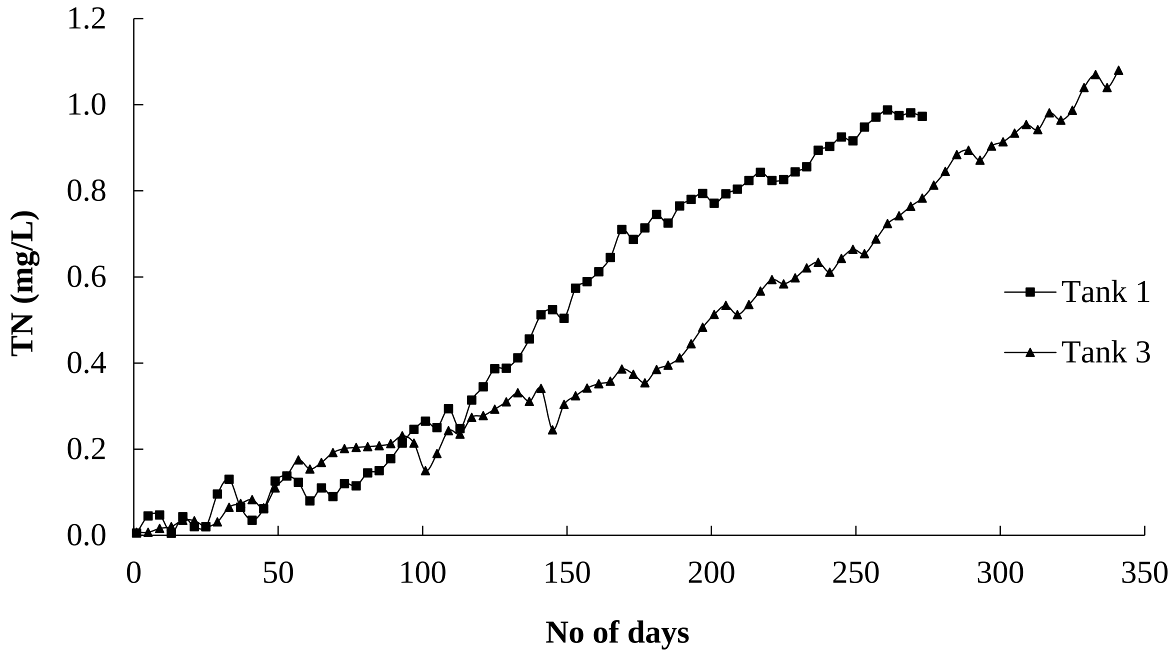

Figure 5.19: Variation of TN with time (Trial 2)

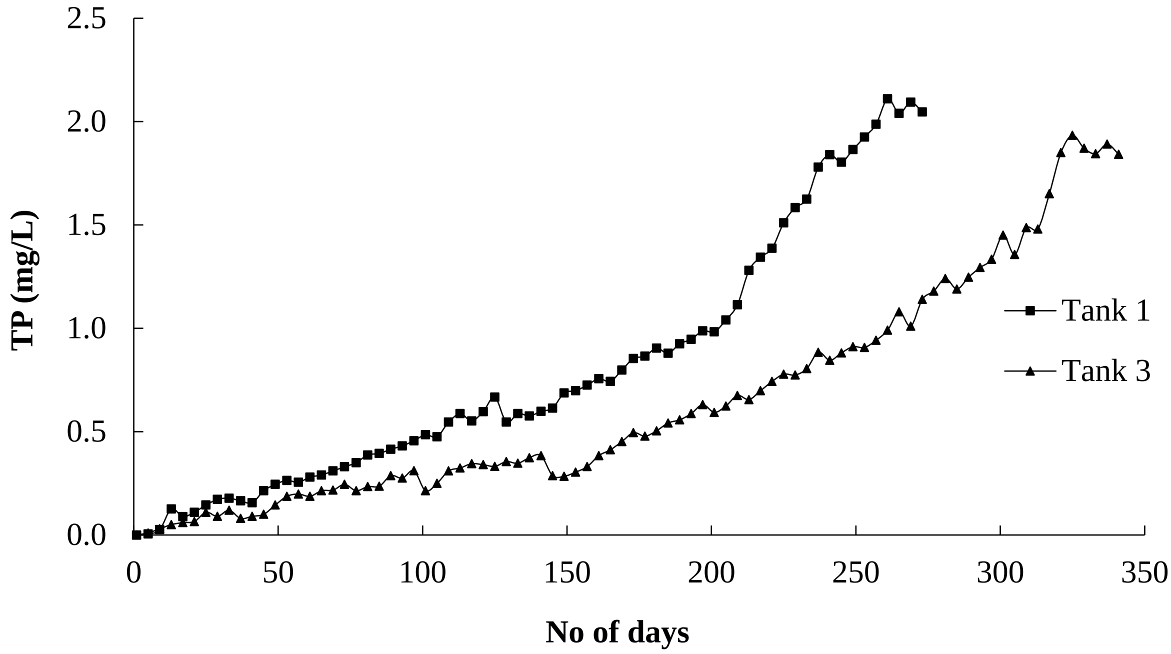

Figure 5.20: Variation of TP with time (Trial 2)

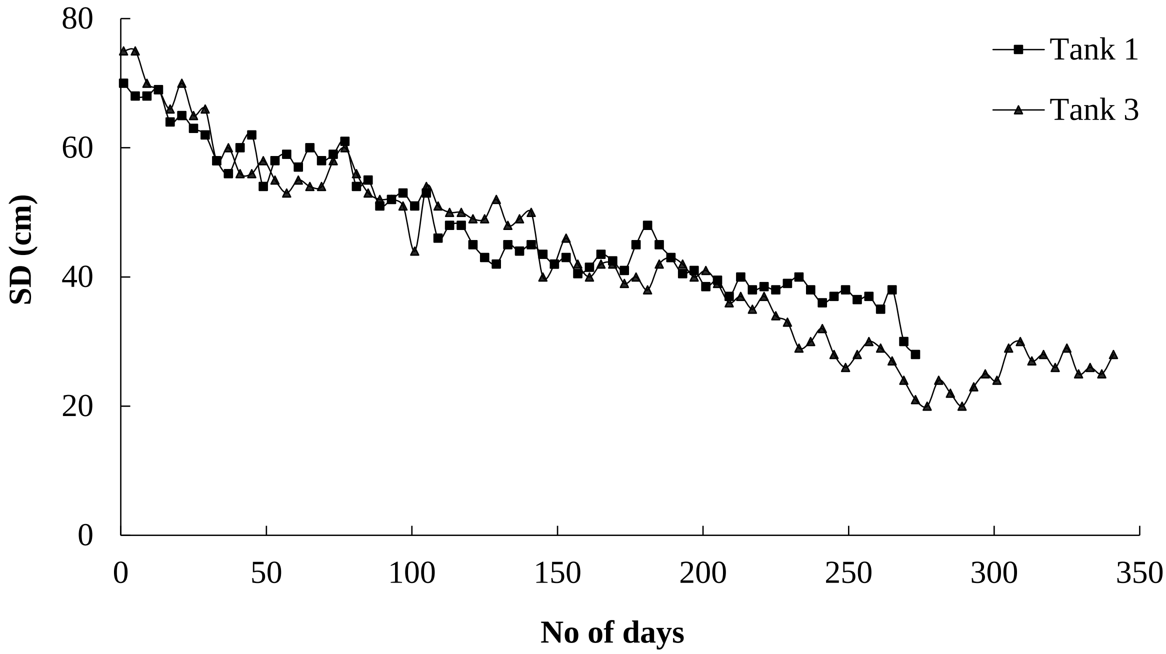

Figure 5.21: Variation of SD with time (Trial 2)

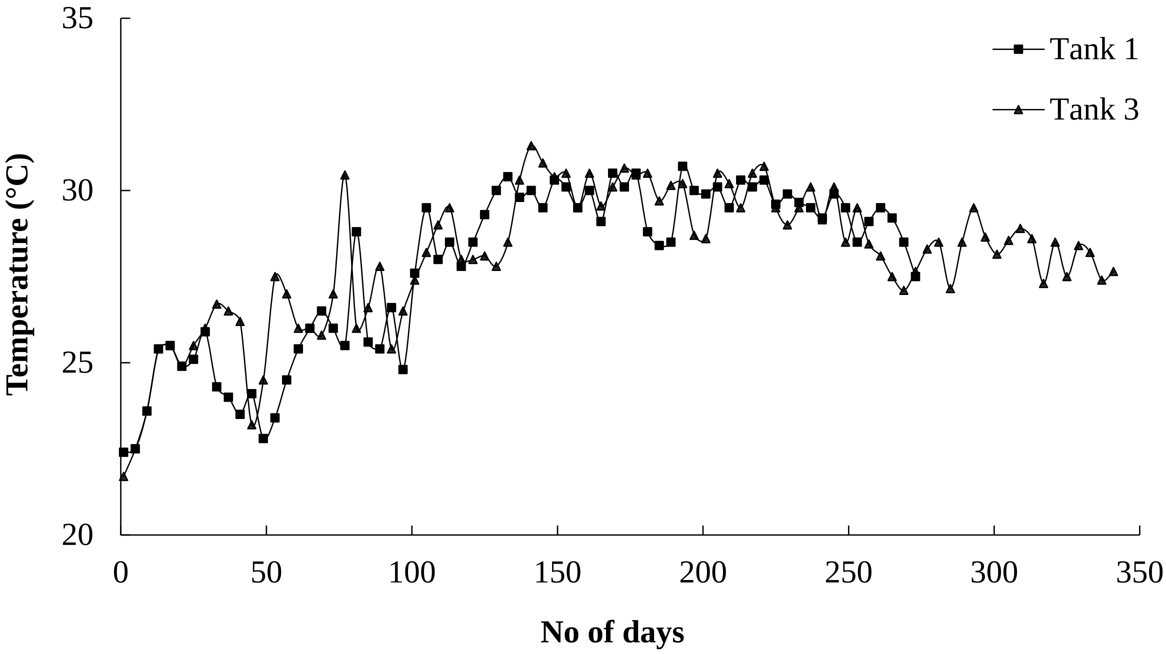

Figure 5.22: Variation of temperature with time (Trial 2)

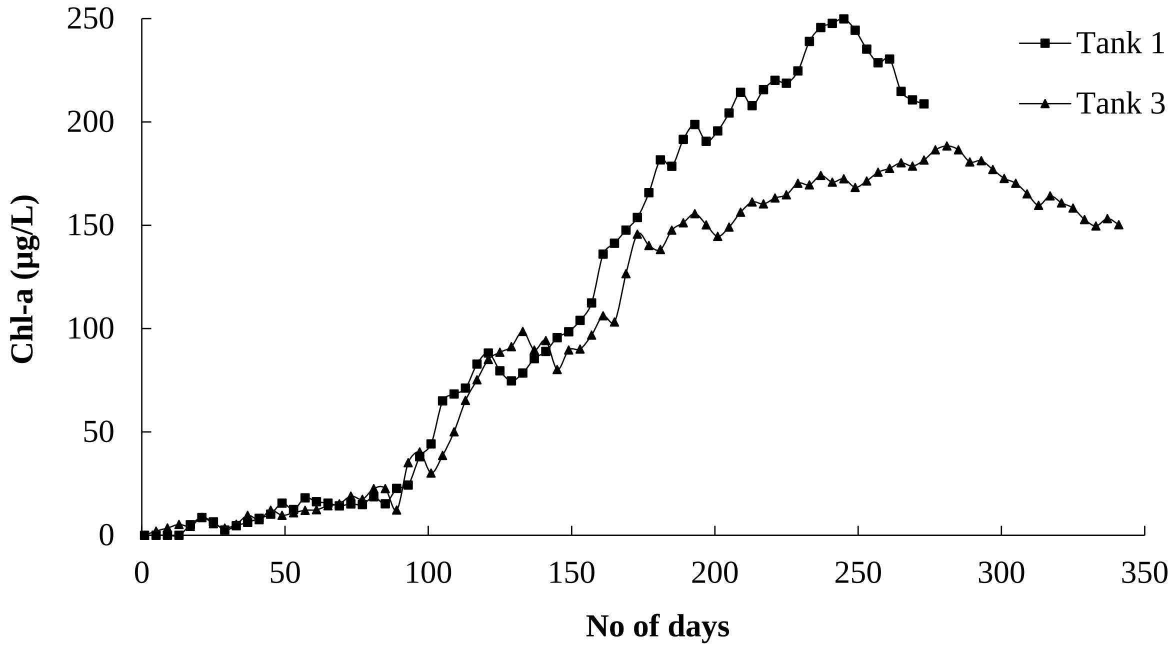

Figure 5.23: Variation of Chl-a with time (Trial 2)

From the above results and discussion, it was evident that in the 2nd trial also the eutrophication process was successfully replicated with continuous addition of nutrient rich waste water to the considered artificial lakes. In total, 69 and 86 numbers of samples were analysed during the 2nd trial with Tank 1 and Tank 3 respectively. Table 5.4 shows the statistical summary of the results obtained during the experimental investigation in terms of maximum, minimum, average, and standard deviation values of water quality parameters. Considering the data range of investigated parameters, it was seen that the standard deviation of the parameters were generally high indicating that greater variability and uncertainty was associated with the dataset. So, use of sophisticated machine learning approaches was done in the post processing to deal with data variability and uncertainty.

5.2.2 TSI Evaluation

For TSI calculation, the average and maximum values of Chl-a and TP were used as per equation 2 and 3 respectively. TSI based on SD was calculated considering average and minimum value as per equation 1. TSI values were determined for each parameter individually and then mean value was considered for trophic status evaluation. The TSI values obtained for the considered artificial lakes are presented in

Table 5.5. In the initial period of investigation lower concentration of TP (0 mg/L) and Chl-a (0 µg/L) was observed in the lakes and SD value was not obtained as the water was completely transparent to the full lake depth. Corresponding to this condition minimum value of TSI was obtained as less than 40 for TP, Chl-a and SD consideration indicating that the studied lakes were initially at oligotrophic stage. However, during progressive deterioration of water quality maximum values of TP, Chl-a and minimum value of SD were recorded and for that condition calculated maximum value of TSI was obtained as more than 70 for the three considered criteria. This indicated that the studied lakes had reached hypereutrophic stage and at that point the experimental investigation was terminated and evaluated dataset were used for development of data-driven models for DO, SD and Chl-a prediction.

Table 5.4: Statistical summary of the experimental investigation on the studied artificial lakes (Trial 2)

		Tank 1				**Tank 3**			
	Waste water quality	Max	Min	Avg.	St. Dev.	Max	Min	Avg.	St. Dev.
pH	7.34	10.14	7.75	8.90	0.64	9.45	7.40	8.50	0.63
EC (µS/cm)	703.80	586.40	201.50	423.85	117.14	352.32	53.60	172.33	86.21
TDS (mg/L)	344.70	375.65	104.50	234.67	77.79	190.23	25.47	84.37	46.14
BOD (mg/L)	30.00	48.00	0.00	14.16	8.23	57.50	2.00	18.43	11.46
DO (mg/L)	6.10	8.50	1.80	5.84	1.72	8.60	2.30	5.65	1.58
Turb (NTU)	215.30	80.45	1.50	43.52	26.33	116.40	2.50	56.16	35.41
TN (mg/L)	0.48	0.99	0.01	0.47	0.34	1.08	0.01	0.45	0.32
TP (mg/L)	2.79	2.11	0.00	0.79	0.61	1.93	0.00	0.65	0.53
SD (cm)	--	70.00	28.00	47.94	10.34	75.00	20.00	42.42	14.38
$Temp^r$ (°C)	--	30.70	22.40	27.79	2.45	31.30	21.70	28.09	2.00
Chl-a (µg/L)	24.52	249.88	0.00	108.30	89.87	188.35	0.00	103.35	68.14

*Max = Maximum, Min = Minimum, Avg. = Average, St. Dev. = Standard deviation

5.2.3 Evaluation of correlation coefficient

Pearson linear correlation coefficient among the investigated water quality parameters was evaluated and the results are presented with Table 5.6 and Table 5.7 for

Tank 1 and Tank 3 respectively. Similar to 1st trial, linear correlation was not found to be strong among water quality parameters. Eutrophication indicator parameter DO was found to be negatively correlated with other parameters except for SD. pH, EC, TP, and Chl-a was found to be having relatively higher correlation (more than 0.5) compared to other parameters. Apart from DO, SD was also negatively correlated with other investigated parameters. Positive correlation between DO and SD was evident as both the parameters decreased considerably due to eutrophication in the lakes. Correlation coefficient value of SD with other parameters were found to be small. Chl-a was found to be negatively correlated with DO and SD because with gradual increase in algal content in the lakes both DO and SD decreased. With other water quality parameters Chl-a was positively correlated for the considered lakes. In case of Chl-a, compared to other parameters DO, TN and TP were found to have relatively higher correlation.

Table 5.5: Trophic status estimation results of investigated lakes (Trial 2)

	TSI (SD)		**TSI (Chl-a)**		**TSI (TP)**		**TSI_{MEAN}**		**Remarks**
	Max^m	Avg.	Max^m	Avg.	Max^m	Avg.	Max^m	Avg.	
Tank 1	78.37	70.61	84.72	76.52	114.59	100.50	92.56	82.54	Hypereutrophic
Tank 3	83.22	72.37	81.95	76.06	113.34	97.50	92.84	76.06	Hypereutrophic

Table 5.6: Correlation coefficient matrix of water quality variables for Tank-1 (Trial 2)

	pH	EC	TDS	BOD	DO	Turb	TN	TP	SD	Temp	Chl-a
pH	1.00										
EC	0.45	1.00									
TDS	0.47	0.77	1.00								
BOD	0.49	0.57	0.51	1.00							
DO	-0.55	-0.52	-0.47	-0.34	1.00						
Turb	0.27	0.57	0.55	0.32	-0.29	1.00					
TN	0.37	0.14	0.15	0.27	-0.41	0.18	1.00				
TP	0.26	0.20	0.16	0.36	-0.51	0.29	0.53	1.00			
SD	-0.43	-0.45	-0.39	-0.28	0.16	-0.54	-0.33	-0.36	1.00		
Temp	0.17	0.23	0.26	0.05	-0.22	0.14	0.09	0.14	-0.28	1.00	
Chl-a	0.46	0.32	0.34	0.13	-0.63	0.47	0.58	0.53	-0.49	0.26	1.00

Table 5.7: Correlation coefficient matrix of water quality variables for Tank-3 (Trial 2)

	pH	EC	TDS	BOD	DO	Turb	TN	TP	SD	Temp	Chl-a
pH	1.00										
EC	0.25	1.00									
TDS	0.32	0.69	1.00								
BOD	0.14	0.08	0.13	1.00							
DO	-0.44	-0.37	-0.35	-0.22	1.00						
Turb	0.15	0.31	0.28	0.14	-0.28	1.00					
TN	0.37	0.49	0.47	0.24	-0.47	0.54	1.00				
TP	0.22	0.39	0.38	0.12	-0.56	0.28	0.48	1.00			
SD	-0.46	-0.41	-0.36	-0.26	0.47	-0.46	-0.23	-0.26	1.00		
Temp	0.09	0.17	0.11	0.34	-0.15	0.31	0.20	0.19	-0.26	1.00	
Chl-a	0.53	0.45	0.38	0.39	-0.53	0.41	0.68	0.59	-0.48	0.12	1.00

5.3 SUMMARY OF EXPERIMENTAL OBSERVATIONS

From the results and discussion of the experimental investigation conducted on the artificial prototype lakes following conclusions can be drawn:

i. Lake eutrophication process was successfully replicated with periodic application of waste water to artificially constructed prototype lakes.
ii. Significant changes have been observed in water quality of the studied lakes during the process of eutrophication.
iii. pH, EC, TDS, and BOD of the lakes increased considerably during the period of investigation.
iv. Water transparency and clarity deteriorated significantly during the process of eutrophication as reflected in decreasing SD and higher turbidity values.
v. Due to nutrient enrichment the concentrations of TN and TP increased gradually in the lakes.
vi. The nutrient enrichment in the lakes favored the growth of algae and as such concentrations of Chl-a in water increased significantly.

vii. The eutrophication process resulted in anoxic conditions in the studied lakes and DO concentrations decreased considerably during the final stages of investigation.

viii. The investigated water quality parameters were found to exhibit similar trends of variations for both types of prototype lakes i.e., the concrete bedded Tank and artificial pond. However, eutrophication process was found to continue for longer duration of time in the artificial pond. During both 1st and 2nd trial, complete deterioration of water quality has been observed for concrete bedded tanks in between 230 to 270 days' time period. In case of the artificial pond (Tank 3), hypereutrophic stage was achieved in around a period of 350 days.

ix. The occurrence of eutrophication in the studied lakes was mathematically verified with TSI. TSI values indicated clearly that the investigated lakes changed their trophic status from initial oligotrophic to final hypereutrophic state due to nutrient enrichment.

x. The linear correlation among investigated water quality parameters were found to be generally poor as reflected by smaller correlation coefficient values between parameters.