CHAPTER 5

RESULTS AND DISCUSSION

5.1 Physico – chemical Parameters and Trace Metal Analysis

The retrieved values of different Physico - chemical parameters for Thol wetland during the study period i.e. for the year 2015-2016, 2016-2017 and 2017-2018 is as per **Annexure –I, II and III** respectively. The range and the mean values along with the standard deviation of various physico-chemical parameters is calculated and thus found is summarized as mentioned in **Table no. 5.1**. The Spatio-temporal variation of various Physico-chemical parameters during the study period is presented in the form of series of graphs at **Fig. 5.1**. Additional parameters i.e. Heavy Metals Cadmium (Cd), Copper (Cu), Iron (Fe), Lead (Pb), Manganese (Mn), Nickel (Ni), Hexavalent Chromium (Cr^{+6}), Total Chromium (Total Cr) and Zinc (Zn) were analyzed on ICPMS during the year 2016-2017 and 2017-2018 and are found to be as per **Annexure –IV and V** respectively.

Temperature (Ambient): Temp (A) is found to range from 28 - 36 ^{o}C, 21.5 - 36 ^{o}C and 20.5 - 38.5^{o}C during the first, second and third year respectively with overall mean value of 30.3 ± 0.65 ^{o}C. In the present study, the Temp (A) at Thol wetland was found maximum (38.5 ^{o}C) during the summer season of the year 2017 -2018 at Location 1 and minimum value (20.5 ^{o}C) was obtained during the winter season of the year 2017-2018 at Location 1 (**Annexure –I, II and III**). During the study period, Temp (A) showed high significant positive relationship with Temp (W), TKN and NO_2-N and it showed high significant negative relationship with Cond, TDS, PO_4, Ca, Mg, Na, %Na, SAR and SO_4 **(Table. 5.3**).

Table no. 5.1: Summary of Physico-Chemical Parameters of Thol Wetland During the Study Period (Year 2015 – Year 2018)

Parameters		First Year		Second Year		Third Year		Overall of Mean Values	
	Unit	Range	Mean ± SD	Range	Mean ± SD	Range	Mean ± SD	Range	Mean ± SD
Temperature (Ambient)	Centigrade	28 - 36	31.3 ± 2.5	21.5 - 36	30.0 ± 3.2	20.5 - 38.5	30.3 ± 4.2	30.0 - 31.3	30.3 ± 0.65
Temperature (Water)	Centigrade	19 - 32	27.0 ± 3.0	18 - 35	26.3 ± 4.3	17.5 - 30.8	26.8 ± 3.5	26.3 - 27.3	26.8 ± 0.53
pH	pH	7.39 - 9.39	8.32 ± 0.62	7.20 - 9.65	8.27 ± 0.75	7.27 - 8.39	7.90 ± 0.29	7.90 - 8.32	8.17 ± 0.23
Colour	Hazen	5 - 80	28.3 ± 22.75	5 - 100	37.2 ± 33.5	10 - 45	22.8 ± 8.3	22.8 – 37.2	29.4 ± 7.29
Turbidity	NTU	1.5 - 190	34.5 ± 57.21	2 - 320.6	50.6 ± 86.2	7.4 - 67	24.5 ± 13.7	24.5 - 50.6	36.5 ± 13.16
Conductivity	µs/cm	209 - 880	364 ± 205	194 - 947	372 ± 220	264 - 528	367 ± 68	364 - 372	368 ± 4.08
Total Solids	mg/L	166 - 980	322 ± 240	98 - 1260	332 ± 330	148 - 358	252 ± 55	252 - 332	302 ± 43.88
Total Dissolved Solids	mg/L	134 - 580	219 ± 124	90 - 700	225 ± 172	130 - 302	220 ± 44	219 - 225	221 ± 3.37
Total Suspended Solids	mg/L	32 - 440	103 ±1 21	8 - 560	107 ± 162	6 - 84	31 ± 22	31 - 107	80 ± 42.47
Ammonical Nitrogen	mg/L	0.10 - 2.98	1.12 ± 0.82	0.28 - 3.08	1.04 ± 0.85	0.20 - 1.82	0.68 ± 0.51	0.68 - 1.12	0.95 ± 0.23
Total Kjeldahl Nitrogen	mg/L	11.20 - 31.56	19.86 ± 5.57	0.56 - 31.64	8.39 ± 9.29	0.31 - 3.11	1.31 ± 1.00	1.31 - 19.86	9.85 ± 9.36
Nitrate (NO_3-N)	mg/L	0.040 - 1.919	0.269 ± 0.430	0.076 - 0.370	0.192 ± 0.074	0.068 - 0.232	0.113 ± 0.042	0.113 - 0.269	0.191 ± 0.08
Nitrite	µg/l	0.009 - 0.390	0.096 ± 0.088	0.000 - 0.133	0.060 ± 0.042	0.01 - 0.108	0.039 ± 0.024	0.039 - 0.096	0.065 ± 0.03
Phosphate	mg/L	0.000 - 0.090	0.024 ± 0.024	0.000 - 0.295	0.063 ± 0.086	0.000 - 0.309	0.091 ± 0.102	0.024 - 0.091	0.059 ± 0.03
Alkalinity as $CaCO_3$	mg/L	80 - 136	102 ± 16.92	80 - 152	108.4 ± 19.5	74 - 144	115 ± 18	102 - 115	108 ± 6.22
Total Hardness as $CaCO_3$	mg/L	40 - 116	74.89 ± 21.28	60 - 116	84.3 ± 16.4	62 - 123	93 ± 16	74.89 - 93.00	83.98 ± 8.95
Calcium	mg/L	11.8 - 24.34	16.43 ± 3.99	12.82 - 32.64	20.71 ± 5.58	16.03 - 32.00	23.72 ± 4.47	16.43 - 23.72	20.29 ± 3.66
Magnesium	mg/L	2.43 - 10.17	7.19 ± 2.27	3.04 - 14.59	7.98 ± 2.97	3.16 - 12.88	8.15 ± 2.09	7.19 - 8.15	7.77 ± 0.51
Sodium	mg/L	16.7 - 103	31.93 ± 23.67	21.33 - 119	42.69 ± 25.24	21.74 – 65.0	39.80 ± 10.76	31.93 - 42.96	38.14 ± 5.57
Potassium	mg/L	1.00 - 4.80	2.98 ± 1.19	0.00 - 8.20	3.68 ± 2.39	3.00 - 11.99	5.68 ± 2.95	2.98 - 5.68	4.11 ±1.40
% Sodium	%	30.37 - 71.92	45.06 ± 11.95	34.88 - 70.5	48.47 ± 10.26	36.29 - 61.42	46.04 ± 6.08	45.06 - 48.47	46.52 ± 1.75
SAR	milimole/L	0.86 - 4.93	1.64 ± 1.10	1.03 - 4.86	2.00 ± 1.05	1.2 - 2.85	1.79 ± 0.46	1.64 - 2.00	1.81 ± 0.18
Fluoride	mg/L	0.00 - 1.00	0.319 ± 0.303	0.00 - 1.30	0.46 ± 0.35	0.00 - 0.41	0.24 ± 0.11	0.24 - 0.46	0.339 ± 0.11
Dissolved Oxygen	mg/L	4.55 - 14.68	10.10 ± 2.64	4.77 – 15.97	10.70 ± 3.64	1.93 - 13.7	6.74 ± 3.04	6.74 - 10.70	9.18 ± 2.13
Chemical Oxygen Demand	mg/L	40 - 480	147 ± 124	21 - 577	139 ± 166	18 - 116	59 ± 23.55	59 - 147	115 ± 48.74
BOD (3 days 27^oC)	mg/L	10 - 168	43 ± 44	8 - 201	49 ± 58	6 - 31	17 ± 6.76	17 - 49	37 ± 16.92
Chloride as Cl^-	mg/L	19 - 120	44 ± 27	12 - 148	43 ± 33	29 - 97	65 ± 17.94	43 - 63	50 ± 11.39
Sulphate	mg/L	8 - 67	22 ± 15	8 - 92	24 ± 19	11 - 34	25 ± 6.80	22 - 25	24 ± 1.79
Total Organic Carbon	mg/L	4.7 - 101.2	34.7 ± 26.6	8.2 - 116.0	38.1 ± 31.0	3.5 - 33.2	15.86 ± 8.84	15.86 - 38.1	29.6 ± 11.99

Table no. 5.2: Various Standard Values Prescribed for Physico Chemical Parameters

Parameters	Unit	FAO Guidelines (1985): irrigation water (Usual range)	BIS Standards (2002): Designated Use Class E (Max Values)	Drinking Water Standards IS 10500:2012#	CPCB Discharge Standards for Inland Surface Water⁂
Temperature (Ambient)	Centigrade	-	-	-	-
Temperature (Water)	Centigrade	-	-	-	-
pH	pH	6.0 – 8.5	6.5 -8.5	6.5 -8.5	5.5 – 9.0
Colour	Hazen	-	-	5 (15)	-
Turbidity	NTU	-	-	1 (5)	-
Conductivity	µs/cm	0 – 3000	2250	-	-
Total Solids	mg/L	-	-	-	-
Total Dissolved Solids	mg/L	0 – 2000	-	500 (2000)	-
Total Suspended Solids	mg/L	-	-	-	100 (200)
Ammonical Nitrogen	mg/L	-	-	0.5	50
Total Kjeldahl Nitrogen	mg/L	-	-	-	100
Nitrate (NO_3-N)	mg/L	0 – 10	-	45	10
Nitrite	µg/l	-	-	-	-
Phosphate	mg/L	0 – 2	-	-	5.0
Alkalinity as $CaCO_3$	mg/L	200	-	200 (600)	-
Total Hardness as $CaCO_3$	mg/L	712*	-	200 (600)	-
Calcium	mg/L	0 – 400	-	75 (200)	-
Magnesium	mg/L	0 – 61	-	30 (100)	-
Sodium	mg/L	0 – 920	-	-	-
Potassium	mg/L	0 – 2	-	-	-
% Sodium	%	-	60	-	-
SAR	milimole/L	0 – 15	26	-	-
Fluoride	mg/L	1.5*	-	1 (1.5)	2.0
Dissolved Oxygen	mg/L	-	-	-	-
Chemical Oxygen Demand	mg/L	-	-	-	-
BOD (3 days 27°C)	mg/L	-	-	-	30 (100)
Chloride as Cl^-	mg/L	0 – 1065	600	250 (1000)	250
Sulphate	mg/L	0 – 960	1000	200 (400)	-
Total Organic Carbon	mg/L	-	-	-	-

*****Values as suggested by Directorate of Water Management, ICAR, 2014. **#**Permissible limits are shown in brackets. ⁂ Values for Land of irrigation are sown in bracket

Table 5.3 Correlation Matrix among the Physico-Chemical Parameters of Thol Wetland During March 2015 – Feb 2018

	Temp (A)	*Temp (W)*	*pH*	*Colour*	*Turbid*	*Cond*	*TS*	*TDS*	*TSS*	*NH_3 - N*	*TKN*	*Nitrate*	*Nitrite*	*PO_4*	*Alk*	*TH*	*Ca*	*Mg*	*Na*	*K*	*% Na*	*SAR*	*F*	*DO*	*COD*	*BOD*	*Cl*	*SO_4*	*TOC*
Temp (A)	1.000																												
Temp (W)	**0.961**	1.000																											
pH	0.353	0.082	1.000																										
Colour	-0.394	-0.631	0.721	1.000																									
Turbid	-0.397	-0.634	0.719	**1.000**	1.000																								
Cond	**-0.926**	**-0.994**	0.026	0.711	0.714	1.000																							
TS	0.139	-0.139	**0.976**	**0.856**	**0.854**	0.245	1.000																						
TDS	**-0.785**	**-0.925**	0.303	**0.878**	**0.880**	**0.961**	0.504	1.000																					
TSS	0.207	-0.070	**0.988**	**0.818**	**0.816**	0.177	**0.998**	0.443	1.000																				
NH_3-N	0.406	0.139	**0.998**	0.680	0.677	-0.032	**0.961**	0.247	**0.978**	1.000																			
TKN	**0.786**	0.585	**0.856**	0.260	0.256	-0.494	0.722	-0.234	**0.768**	**0.884**	1.000																		
Nitrate	0.697	0.473	**0.917**	0.384	0.381	-0.376	**0.807**	-0.104	**0.846**	**0.938**	**0.991**	1.000																	
Nitrite	**0.804**	0.609	**0.840**	0.230	0.227	-0.520	0.701	-0.263	0.748	**0.870**	**1.000**	**0.987**	1.000																
PO_4	**-0.766**	-0.559	**-0.872**	-0.290	-0.286	0.467	-0.743	0.203	**-0.788**	**-0.899**	**-1.000**	**-0.995**	**-0.998**	1.000															
Alk	-0.703	-0.481	**-0.913**	-0.376	-0.373	0.384	**-0.801**	0.112	**-0.841**	**-0.935**	**-0.992**	**-1.000**	**-0.988**	**0.996**	1.000														
TH	-0.720	-0.501	**-0.903**	-0.355	-0.351	0.405	**-0.787**	0.135	**-0.828**	**-0.927**	**-0.995**	**-0.999**	**-0.992**	**0.998**	**1.000**	1.000													
Ca	**-0.768**	-0.562	**-0.870**	-0.287	-0.283	0.469	-0.741	0.206	**-0.786**	**-0.897**	**-1.000**	**-0.995**	**-0.998**	**1.000**	**0.996**	**0.997**	1.000												
Mg	**-0.903**	**-0.750**	-0.720	-0.039	-0.035	0.675	-0.550	0.444	-0.607	**-0.759**	**-0.975**	**-0.937**	**-0.981**	**0.968**	**0.940**	**0.948**	**0.968**	1.000											
Na	**-1.000**	**-0.959**	-0.361	0.385	0.389	**0.923**	-0.148	**0.779**	-0.216	-0.414	**-0.791**	-0.704	**-0.809**	**0.772**	0.710	0.726	**0.773**	**0.907**	1.000										
K	-0.482	-0.223	**-0.990**	-0.615	-0.612	0.117	**-0.934**	-0.164	**-0.957**	**-0.996**	**-0.921**	**-0.964**	**-0.909**	**0.933**	**0.962**	**0.955**	**0.932**	**0.812**	0.490	1.000									
% Na	**-0.881**	**-0.977**	0.133	**0.782**	**0.784**	**0.994**	0.347	**0.985**	0.281	0.075	-0.399	-0.274	-0.426	0.370	0.283	0.305	0.372	0.592	**0.876**	0.010	1.000								
SAR	**-0.933**	**-0.996**	0.009	0.699	0.702	**1.000**	0.228	**0.956**	0.160	-0.049	-0.509	-0.392	-0.535	0.482	0.399	0.421	0.485	0.688	**0.929**	0.134	**0.992**	1.000							
F	-0.419	-0.652	0.702	**1.000**	**1.000**	0.730	**0.841**	**0.891**	**0.802**	0.660	0.233	0.359	0.204	-0.264	-0.351	-0.329	-0.261	-0.012	0.410	-0.594	**0.799**	**0.718**	1.000						
DO	0.110	-0.168	**0.969**	**0.870**	**0.868**	0.273	**1.000**	0.529	**0.995**	**0.953**	0.701	**0.789**	0.680	-0.724	**-0.784**	**-0.769**	-0.722	-0.526	-0.119	**-0.924**	0.374	0.256	**0.857**	1.000					
COD	0.332	0.059	**1.000**	0.737	0.734	0.048	**0.980**	0.324	**0.992**	**0.997**	**0.844**	**0.908**	**0.828**	**-0.861**	**-0.904**	**-0.894**	**-0.859**	-0.704	-0.340	**-0.986**	0.155	0.031	0.718	**0.974**	1.000				
BOD	0.069	-0.208	**0.958**	**0.890**	**0.888**	0.312	**0.998**	0.564	**0.990**	**0.940**	0.671	**0.763**	0.649	-0.695	**-0.758**	-0.742	-0.692	-0.490	-0.078	**-0.907**	0.412	0.296	**0.877**	**0.999**	**0.964**	1.000			
Cl	-0.220	0.056	**-0.990**	**-0.810**	**-0.808**	-0.163	**-0.997**	-0.431	**-1.000**	**-0.981**	**-0.777**	**-0.853**	**-0.757**	**0.796**	**0.848**	**0.836**	**0.794**	0.618	0.230	**0.961**	-0.268	-0.146	**-0.794**	**-0.994**	**-0.993**	**-0.988**	1.000		
SO_4	**-0.866**	-0.695	**-0.773**	-0.118	-0.115	0.614	-0.615	0.371	-0.668	**-0.808**	**-0.990**	**-0.962**	**-0.994**	**0.985**	**0.964**	**0.970**	**0.985**	**0.997**	**0.871**	**0.856**	0.526	0.627	-0.091	-0.592	**-0.759**	-0.558	0.678	1.000	
TOC	0.106	-0.172	**0.968**	**0.872**	**0.871**	0.277	**0.999**	0.533	**0.995**	**0.952**	0.699	**0.787**	0.677	-0.721	**-0.781**	**-0.767**	-0.719	-0.522	-0.115	**-0.922**	0.378	0.260	**0.859**	**1.000**	**0.973**	**0.999**	**-0.993**	-0.589	1.000

High Correlation Values $r \geq 0.750$ are highlighted.

Temp (A) = Temperature (Ambient), Temp (W) = Temperature (Water), Turbid = Turbidity, Cond = Conductivity, TS = Total Solids, TDS Total Dissolved Solids, TSS = Total Suspended Solids, NH_3–N = Ammonical Nitrogen, TKN = Total Kjeldahl Nitrogen, Nitrate = Nitrate (NO_3-N), PO_4 = Phosphate, Alk = Alkalinity as $CaCO_3$, TH = Total Hardness as $CaCO_3$, Ca = Calcium, Mg = Magnesium, Na = Sodium, K = Potassium, % Na = % Sodium, SAR = Sodium Absorption Ratio, F = Fluoride, DO = Dissolved Oxygen, COD = Chemical Oxygen Demand, BOD = BOD (3 days 27^{o}C), Cl = Chloride as Cl^-, SO_4 = Sulphate and TOC = Total Organic Carbon

Temperature (Water): Temp (W) is found to range from 19 - 32 ^{o}C, 18 - 35 ^{o}C and 17.5 - 30.8^{o}C during the first, second and third year respectively with overall mean value of 26.8 ± 0.53 ^{o}C (**Table 5.1**). During the study, the Temp (W) of Thol wetland was found maximum (35 ^{o}C) during the summer season of the year 2016 -2017 at Location 3 and minimum value (17.5 ^{o}C) was obtained during the winter season of the year 2017-2018 at Location 1 (**Annexure –I, II and III**). During the study period, Temp (W) showed significant negative relationship with Cond, TDS, Na, %Na, and SAR (**Table. 5.3**).

pH: pH indicates the hydrogen ion concentration [H^{+}] in water and it reflects acidity or alkalinity. During the study period, the range of pH was found to be 7.39 - 9.39, 7.20 - 9.65 and 7.27 - 8.39 for the first, second and third year respectively with overall mean value of 8.17 ± 0.23 (**Table 5.1**). The maximum pH (9.65) and minimum pH (7.2) recorded was during summer season in the year 2016 - 2017 at location 2 and location 3 respectively (**Annexure –I, II and III**). The pH of water during the study period shows high significant positive relationship with TS, TSS, NH_3-N, TKN, NO_3-N, NO_2-N, DO, BOD, COD, and TOC and high significant negative correlation with PO_4, Alk, TH, Ca, K, Cl^{-} and SO_4 (**Table. 5.3**).

Turbidity: Turbidity impairs the light penetration in the water column. It results from various suspended particles mainly of clay, organisms like plankton and algae. These suspended particles absorb more light resulting in rise of the water temperature. During the first two years, turbidity revealed a wide variation with a range of 1.5 - 90 NTU and 2 - 320.6 NTU; whereas during the third year, turbidity range was found to be 7.4 – 67 NTU and with overall mean value of 36.5 ± 13.16 NTU (**Table 5.4**). During the study

period, the turbidity was found maximum during the summer season in the year 2016-2017 at Location -3 and minimum turbidity was found during winter in the year 2015-2016 at Location 1 (**Annexure –I, II and III**). The Turbidity of water during the study period shows high significant positive relationship with TS, TSS, TDS, %Na, F, DO, BOD and TOC and high significant negative correlation with Chloride (**Table. 5.3**).

Conductivity: Electrical conductivity (EC) is the ability of a water sample to carry an electric current. EC values of Thol wetland were in the range of 209 - 880 µs/cm, 194 - 947 µs/cm and 264 - 528 µs/cm for the first, second and third year respectively with overall mean value of 368 ± 4.08 µs/cm (**Table 5.1**). Seasonal variations of the present investigations revealed that EC was high during summer seasons and low during winter seasons (**Annexure –I, II and III**). In the present study EC showed high significant positive correlation with TDS, Na, %Na, and SAR (**Table. 5.3**).

Total Solids: TS ranges from 166 - 980 mg/L, 98 - 1260 mg/L and 148 - 358 mg/L during the first, second and third year respectively with overall mean value of 302 ± 43.88 mg/L (**Table 5.1**). During the study, the total solids of Thol wetland was found maximum (1260 mg/L) during the summer season of the year 2016 -2017 at Location 2 and minimum value (98 mg/L) was obtained during the monsoon season of the year 2016 -2017 at Location 1 (**Annexure –I, II and III**). During the study period, total solids showed high significant positive relationship with TDS, TSS, Nitrate, F, DO, COD, BOD and TOC and it showed high significant negative relationship with Alk, TH, K and Cl^- (**Table. 5.3**).

Total Dissolved Solids: Total dissolved solids collectively measures all inorganic and organic substances present in water. TDS displayed a wide range of variations with

range of 134 - 580 mg/L, 90 - 700 mg/L and 130 - 302 mg/L during the first, second and third year respectively with overall mean value of 221 ± 3.37 mg/L (**Table 5.1**). The total dissolved solids of Thol wetland was found maximum (700 mg/L) during the summer season of the year 2016 -2017 at Location 2 and least TDS (90 mg/L) was obtained during the monsoon season of the year 2016 -2017 at Location 1 (**Annexure – I, II and III**). The TDS of water during the study period shows high significant positive relationship with Na, % Na, SAR and F (**Table. 5.3**).

Total Suspended Solids : TSS ranges from 32 - 440 mg/L, 8 - 560 mg/L and 6 - 84 mg/L during the first, second and third year respectively with overall mean value of 80 ± 42.47 mg/L (**Table 5.1**). In the present investigation, the total suspended solids of Thol wetland was found maximum (560 mg/L) during the summer season of the year 2016-2017 at Location 2 and minimum value (6 mg/L) was obtained during the summer season of the year 2017 -2018 at Location 2 and Location 3 (**Annexure –I, II and III**). During the study period, total suspended solids showed high significant positive relationship with NH_3-N, TKN, Nitrate, F, DO, COD, BOD and TOC and it showed high significant negative relationship with PO_4, Alk, TH, Ca, K and Cl^- (**Table. 5.3**).

Ammonical Nitrogen : NH_3-N varies between 0.10 - 2.98 mg/L, 0.28 - 3.08 mg/L and 0.20 - 1.82 mg/L during the first, second and third year respectively with overall mean value of 0.95 ± 0.23 mg/L (**Table 5.1**). In the present investigation, NH_3-N value of Thol wetland was found maximum (3.08 mg/L) during the summer season of the year 2016 -2017 at Location 3 and minimum value (0.10 mg/L) was obtained during the winter season of the year 2015 - 2016 at Location 3 (**Annexure –I, II and III**). During

the study period, NH_3-N showed high significant positive correlation with, TKN, Nitrate, Nitrite, DO, COD, BOD and TOC and it showed high significant negative relationship with PO_4, Alk, TH, Ca, Mg, K and Cl^- and SO_4 **(Table. 5.3**).

Total Kjeldahl Nitrogen : TKN varies between 11.20 - 31.56 mg/L, 0.56 - 31.64 mg/L and 0.31 - 3.11 mg/L during the first, second and third year respectively with overall mean value of 9.85 ± 9.36 mg/L (**Table 5.1**). The TKN value of Thol wetland was found maximum (31.64 mg/L) during the summer season of the year 2016 -2017 at Location 3 and minimum value (0.31 mg/L) was obtained during the summer season of the year 2017 - 2018 at Location 1 (**Annexure –I, II and III**). During the study period, TKN showed high significant positive correlation with Nitrate, Nitrite and COD and it showed high significant negative relationship with PO_4, Alk, TH, Ca, Mg, Na, K and Cl^- and SO_4 **(Table. 5.3**).

Nitrate (NO_3-N): Nitrate is the most stable form of nitrogen. Its main sources are Fertilizers, decomposing plant and animal matter. High nitrate concentration can result in algal blooms and eutrophication in an aquatic ecosystem. NO_3-N ranged between 0.040 - 1.919 mg/L, 0.076 - 0.370 mg/L and 0.068 - 0.232 mg/L during the first, second and third year respectively with overall mean value of 0.191 ± 0.08 mg/L (**Table 5.1**). During the present study, the NO_3-N of Thol wetland was recorded maximum (1.919 mg/L) during the summer season of the year 2016 -2017 at Location 1 and minimum value (0.040 mg/L) was obtained during the monsoon and winter seasons of the year 2015 -2016 at Location 3 (**Annexure –I, II and III**). During the study period, NO_3-N shows high significant positive correlation with NO_2-N, DO,

COD BOD and TOC and it showed high significant negative relationship with PO_4, Alk, TH, Ca, Mg, K, Cl^- and SO_4 **(Table. 5.3).**

Nitrite (NO_2-N): Nitrite is an intermediate of microbial driven nitrification process which results into oxidation of NH_4^+ to NO_3^- ($NH_4^+ \rightarrow NO_2^- \rightarrow NO_3^-$). During the present study, NO_2-N ranged between 0.009 – 0.390 mg/L, 0.000 - 0.130 mg/L and 0.010 - 0.108 mg/L during the first, second and third year respectively with overall mean value of 0.065 ± 0.03 mg/L (**Table 5.1**). During the present study, both the maximum (0.390 mg/L) and minimum (0.009 mg/L) values for NO_2-N of Thol wetland was recorded during the winter season of the year 2015 -2016 at Location 1 (**Annexure –I, II and III**). During the study period, NO_2-N shows high significant positive correlation with COD and it showed high significant negative relationship with PO_4, Alk, TH, Ca, Mg, K, Cl^- and SO_4 **(Table. 5.3).**

Phosphate: Present study displayed that phosphate ranges between 0.000-0.090 mg/L, 0.000–0.295 mg/L and 0.000-0.309 mg/L during the first, second and third year respectively with overall mean value of 0.059 ± 0.03 mg/L (**Table 5.1**). During the present study, the PO_4 of Thol wetland was recorded maximum (0.309 mg/L) during the monsoon season of the year 2017 -2018 at Location 3 and the values shows a declining trend during winter and post summer periods (**Annexure –I, II and III**). During the study period, PO_4 shows high significant positive correlation with Alk, TH, Ca, Mg, K, Cl^- and SO_4 and high negative correlation with COD **(Table. 5.3).**

Total Alkalinity as $CaCO_3$: Total alkalinity is imparted mainly by bicarbonate, carbonate and hydroxide present in the water. The CO_2 - HCO_3 - CO_3 equilibrium mechanism is the major buffering system in aquatic bodies. Total alkalinity was found

in the range of 80 - 136 mg/L, 80 - 152 mg/L, and 74 - 144 mg/L during the first, second and third year of study period respectively with the overall mean value of 108 ± 6.22 mg/L (**Table 5.1**). The highest value (152 mg/L) is obtained during the summer month of the year 2016-2017 and the lowest (74 mg/L) in the monsoon month of the year 2017-2018 (**Annexure –I, II and III**). It is observed that total alkalinity shows high significant negative correlation with TH, Ca, Mg, K, Cl^- and SO_4 and high negative correlation with DO, COD, BOD and TOC **(Table. 5.3).**

Total Hardness as $CaCO_3$: TH ranges from 40 - 116 mg/L, 60 – 116 mg/L and 62 - 123 mg/L during the first, second and third year respectively with overall mean value of 83.98 ± 8.95 mg/L (**Table 5.1**). During the study period, total hardness of Thol wetland was found maximum (123 mg/L) during the monsoon season of the year 2017-2018 at Location 1 and minimum value (40 mg/L) was obtained during the summer season of the year 2015-2016 at Location 2 and Location 3 (**Annexure –I, II and III**). During the study period, total hardness showed high significant positive relationship with Ca, Mg, K, Cl^- and SO_4 and it showed high significant negative relationship with DO,COD and TOC **(Table. 5.3).**

Calcium: Calcium ranges from 11.8 - 24.34 mg/L, 12.82 - 32.64 mg/L and 16.03 - 32.00 mg/L during the first, second and third year respectively with overall mean value of 20.29 ± 3.66 mg/L (**Table 5.1**). In the present study, the Ca value of Thol wetland was found maximum (32.64 mg/L) during the summer season of the year 2016-2017 at Location 2 and minimum value (11.8 mg/L) was obtained during the monsoon season of the year 2015-2016 at Location 3 (**Annexure –I, II and III**). During the study

period, Ca showed high significant positive relationship with Mg, Na, K, Cl^- and SO_4 and it showed high significant negative relationship with COD **(Table. 5.3).**

Magnesium: Magnesium ranges from 2.43 - 10.17 mg/L, 3.04 - 14.59 mg/L and 3.16 - 12.88 mg/L during the first, second and third year respectively with overall mean value of 7.77 ± 0.51 mg/L (**Table 5.1**). During the study, the magnesium value of Thol wetland was found maximum (14.59 mg/L) during the summer season of the year 2016-2017 at Location 1 and minimum value (2.43 mg/L) was obtained during the summer season of the year 2015-2016 at Location 2 and Location 3 (**Annexure –I, II and III**). During the study period, Mg showed high significant positive relationship with Na, K and SO_4 **(Table. 5.3).**

Sodium: Sodium ranges from 16.7 - 103 mg/L, 21.33 - 119 mg/L and 21.74 - 65 mg/L during the first, second and third year respectively with overall mean value of 38.14 ± 5.57 mg/L (**Table 5.1**). In the present study, the value of Na found maximum (119 mg/L) during the summer season of the year 2016 - 2017 at Location 2 and minimum value (16.7 mg/L) was obtained during the monsoon season of the year 2015 - 2016 at Location 1 (**Annexure –I, II and III**). During the study period, Na showed high significant positive relationship with % Na, SAR, and SO_4 **(Table. 5.3).**

Potassium: Potassium ranges from 1.0 - 4.8 mg/L, 0.0 - 8.2 mg/L and 3 - 11.99 mg/L during the first, second and third year respectively with overall mean value of 4.11 ±1.40 mg/L (**Table 5.1**). During the study period, K was found maximum (11.99 mg/L) during the summer season of the year 2017 - 2018 at Location 3 and minimum value (1.0 mg/L) was obtained during the winter season of the year 2015 -2016 at Location 1, Location 2 and Location 3 (**Annexure –I, II and III**). During the study period, K

showed high significant positive relationship with Cl^- and SO_4 and it showed high significant negative relationship with DO, COD, BOD and TOC **(Table. 5.3).**

% Sodium: Sodium ranges from 30.37 - 71.92, 34.88 - 70.5 and 36.29 - 61.42 during the first, second and third year respectively with overall mean value of 46.52 ± 1.75 (**Table 5.1**). During the study, %Na in Thol wetland was found maximum (71.92) during the summer season of the year 2015 - 2016 at Location 2 and minimum value (30.37) was obtained during the winter season of the year 2015 - 2016 at Location 1 (**Annexure –I, II and III**). During the study period, %Na showed high significant positive relationship with SAR and F **(Table. 5.3).**

Sodium Absorption Ratio: SAR ranges from 0.86 - 4.93 milimole/L, 1.03 - 4.86 milimole/L and 1.2 - 2.85 milimole/L during the first, second and third year respectively with overall mean value of 1.81 ± 0.18 milimole/L (**Table 5.1**). SAR of Thol wetland was found maximum (4.93 mg/L) during the summer season of the year 2015 - 2016 at Location 2 and minimum value (0.86 mg/L) was obtained during the monsoon of the year 2015 - 2016 at Location 1 (**Annexure –I, II and III**).

Fluoride: Fluoride ranges from 0.00 - 1.00 mg/L, 0.00 - 1.3 mg/L and 0.00 - 0.41 mg/L during the first, second and third year respectively with overall mean value of 0.339 ± 0.11 mg/L (**Table 5.1**). In the present study, the Fluoride of Thol wetland was found maximum (1.3 mg/L) during the summer season of the year 2016 - 2017 at Location 2. Fluoride was not detected on several occasions during the study period (**Annexure –I, II and III**). Fluoride showed high significant positive relationship with DO, BOD and TOC and it showed high significant negative relationship with Cl^- **(Table. 5.3).**

Dissolved Oxygen: Dissolved Oxygen is one of the best indicators for evaluating the health of a water body. DO ranges between 4.55 - 14.68 mg/L, 4.77 - 15.97 mg/L and 1.93 - 13.7 mg/L during the first, second and third year respectively with the overall mean value of 9.18 ± 2.13 mg/L (**Table 5.1**). The highest value (15.97 mg/L) of DO was found in the summer month of the year 2016 - 2017 at location 2 and the lowest (1.93 mg/L) in the monsoon month of the year 2017 - 2018 at location 1 (**Annexure – I, II and III**). During the study period, dissolved oxygen of Thol wetland shows high significant positive correlation with BOD, COD and TOC and high significant negative relation with Cl^- **(Table. 5.3).**

Chemical Oxygen Demand (COD): COD is an indicator of non-biodegradable oxygen demanding matter present in an aquatic body. In the present study, COD was found in the range of 40 - 480 mg/L, 21 - 577 mg/L and 18 - 116 mg/L during the first, second and third year respectively with the overall mean value of 115 ± 48.74 mg/L (**Table 5.1**). The maximum value (577 mg/L) is obtained during the summer month of the year 2016 - 2017 at location 3 and the lowest value (18 mg/L) in the summer month of the year 2017 - 2018 at location 2 (**Annexure –I, II and III**). COD showed highly significant positive correlation with BOD and TOC and highly significant negative correlation with Cl^- and SO_4 **(Table. 5.3).**

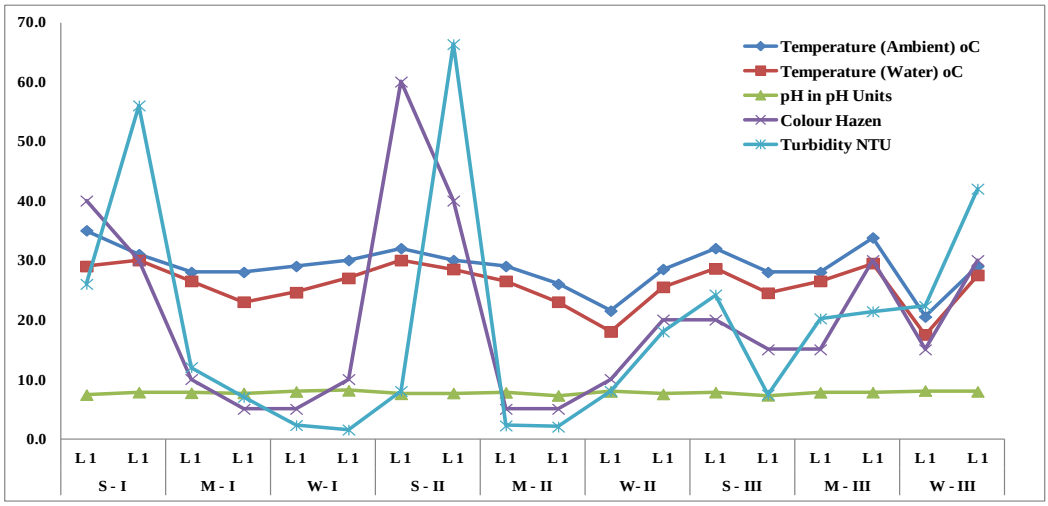
Biochemical Oxygen Demand (BOD - 3 days 27^{o}C): BOD is an indicator of the degradable components of an aquatic body. BOD was found in the range of 10 - 168 mg/L, 8 - 201 mg/L and 6 - 31 mg/L during the first, second and third year with the overall mean value of 37 ± 16.92 mg/L (**Table 5.1**). The maximum value (201 mg/L) is obtained during the summer month of the year 2016 - 2017 at location 3 and the lowest

value (6 mg/L) in the (post) summer of the year 2017 -2018 at location 2 (**Annexure – I, II and III**). BOD showed highly significant positive correlation with TOC and significant negative correlation with Cl^- **(Table. 5.3).**

Chloride (Cl^-): Chloride occurs naturally in all types of water because of its high solubility. Its presence in freshwater indicates the level of sewage pollution. During the study period, Chloride ranged between 19 - 120 mg/L, 12 - 148 mg/L and 29 - 97 mg/L during the first, second and third year respectively with the overall mean value of 50 ± 11.39 mg/L (**Table 5.1**). The maximum value (148 mg/L) is found in the summer month of the year 2016-2017 at location 2 and the minimum value (12 mg/L) is found in the monsoon month of the year 2016 - 2017 at location 1 (**Annexure –I, II and III**). Cl^- showed highly significant negative correlation with TOC **(Table. 5.3).**

Sulphate: Sulphate ranges from 8 - 67 mg/L, 8 – 92 mg/L and 11 - 34 mg/L during the first, second and third year respectively with overall mean value of 24 ± 1.79 mg/L (**Table 5.1**). In the present study, sulphate value of Thol wetland was found maximum (92 mg/L) during the summer season of the year 2016 - 2017 at Location 2 and minimum value (8 mg/L) was obtained during the monsoon season of the years 2016 - 2017 and 2017 - 2018 at Location 1 (**Annexure –I, II and III**).

Total Organic Carbon: TOC ranges from 4.7 - 101.2 mg/L, 8.2 - 116 mg/L and 3.5 - 33.2 mg/L during the first, second and third year respectively with overall mean value of 29.6 ± 11.99 mg/L (**Table 5.1**). In the present study, the TOC value of Thol wetland was found maximum (116 mg/L) during the summer season of the year 2016-2017 at Location 2 and minimum value (3.5 mg/L) was obtained during the summer season of the year 2017 - 2018 at Location 2 (**Annexure –I, II and III**).



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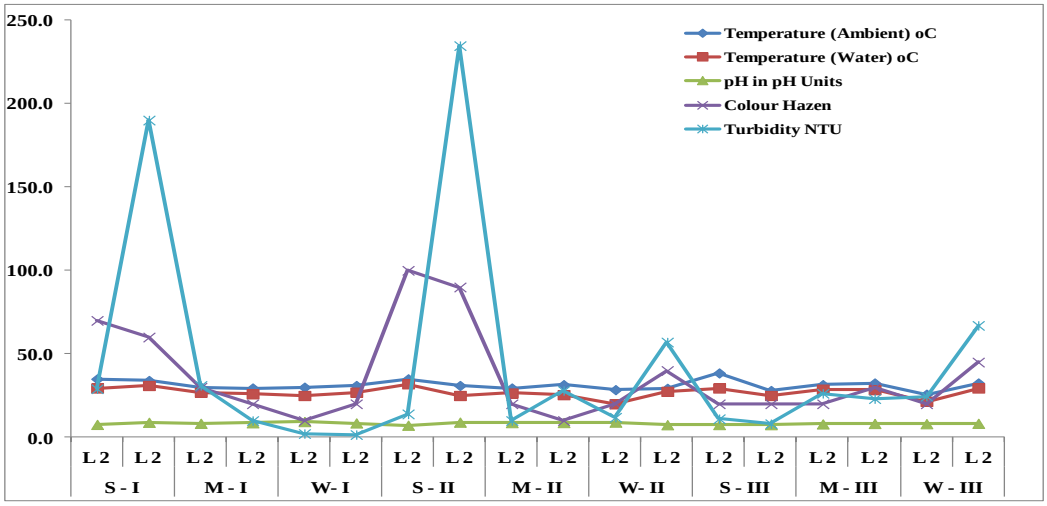

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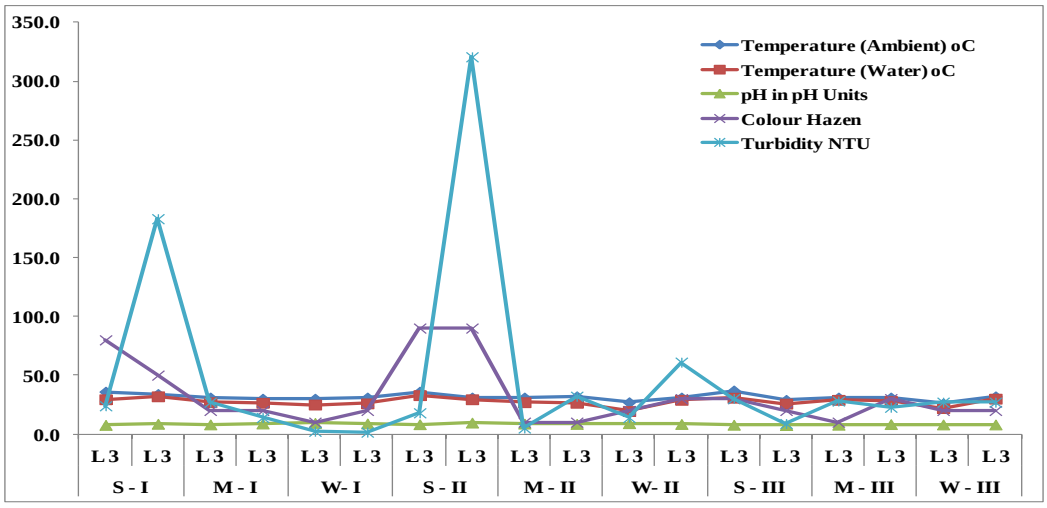

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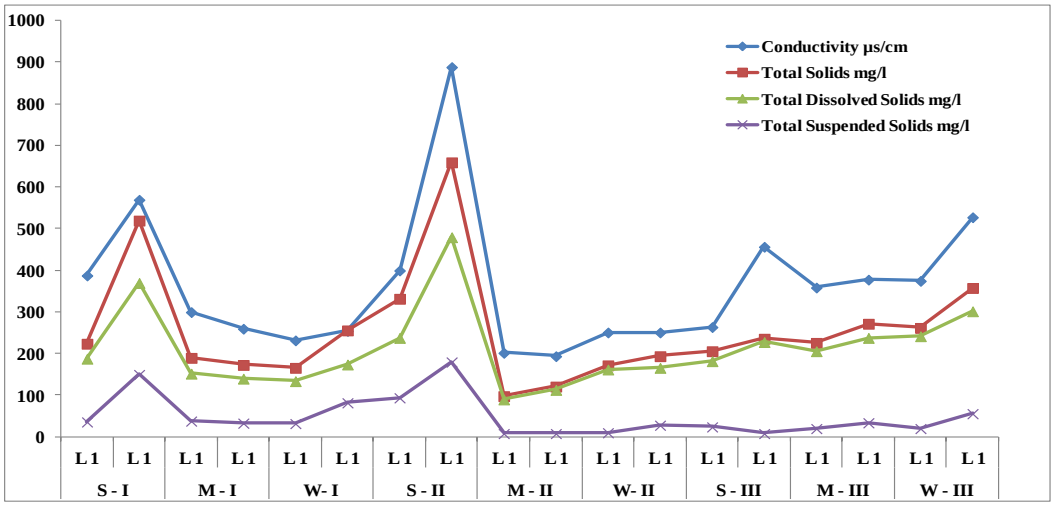

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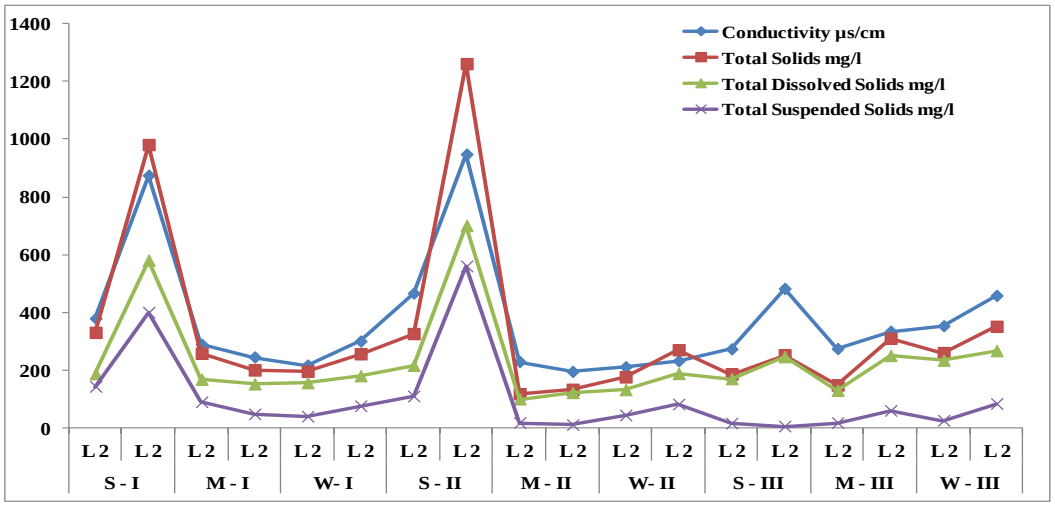

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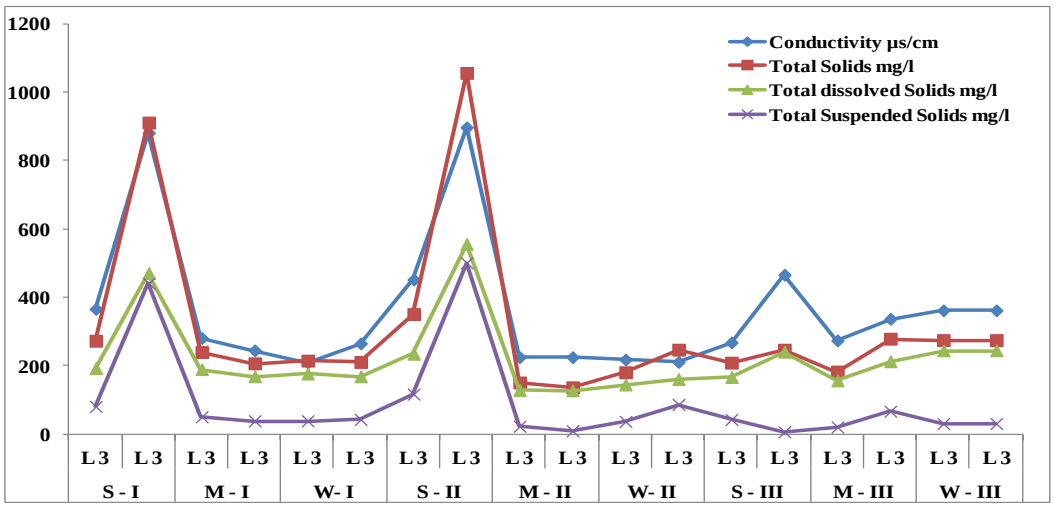

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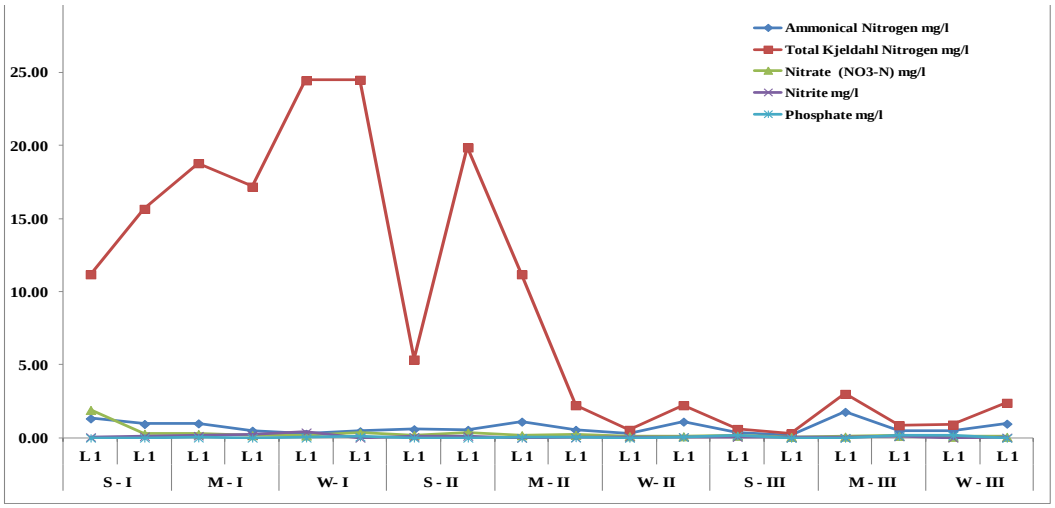

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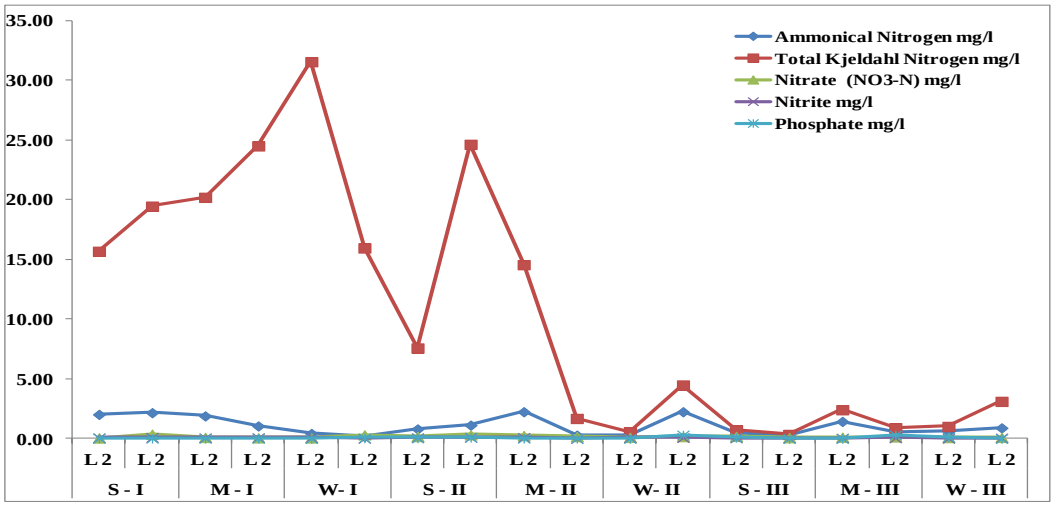

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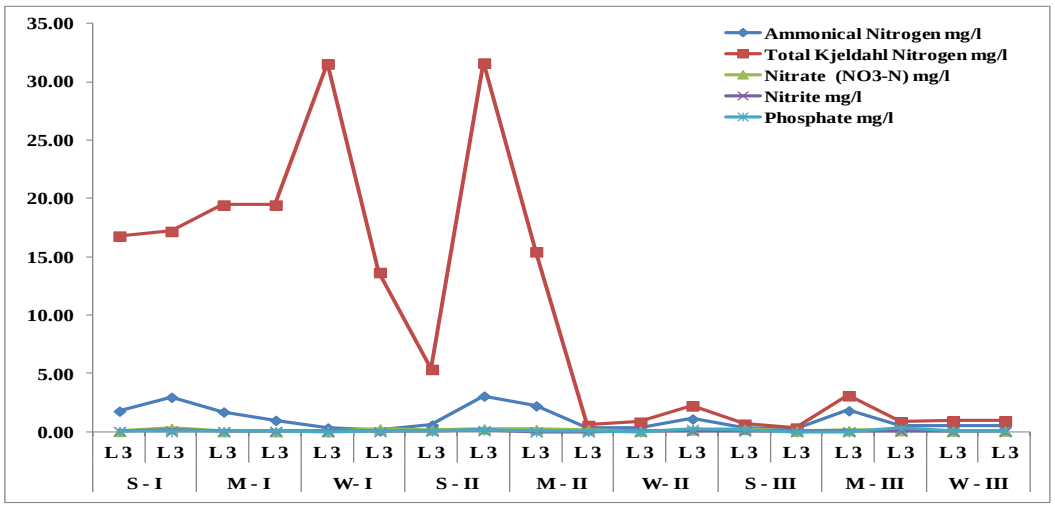

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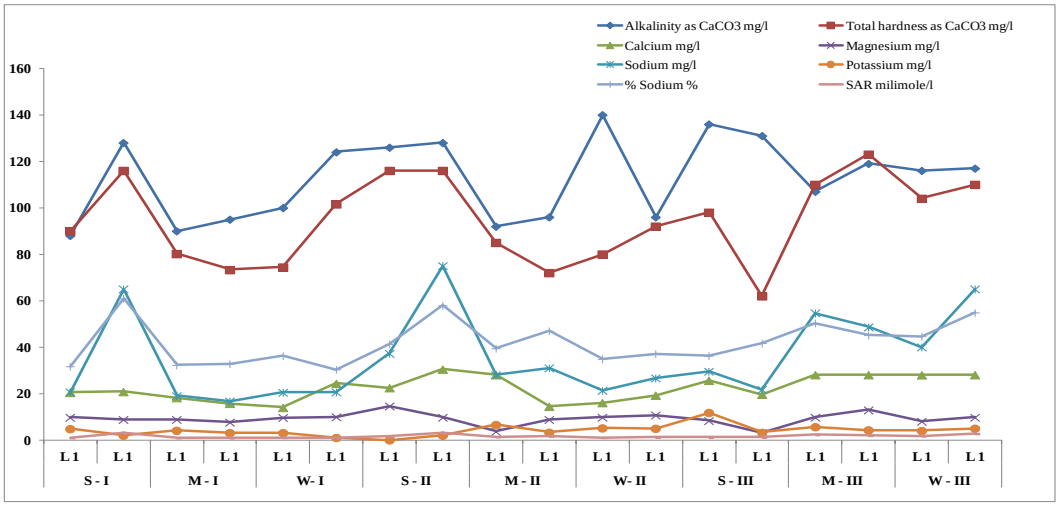

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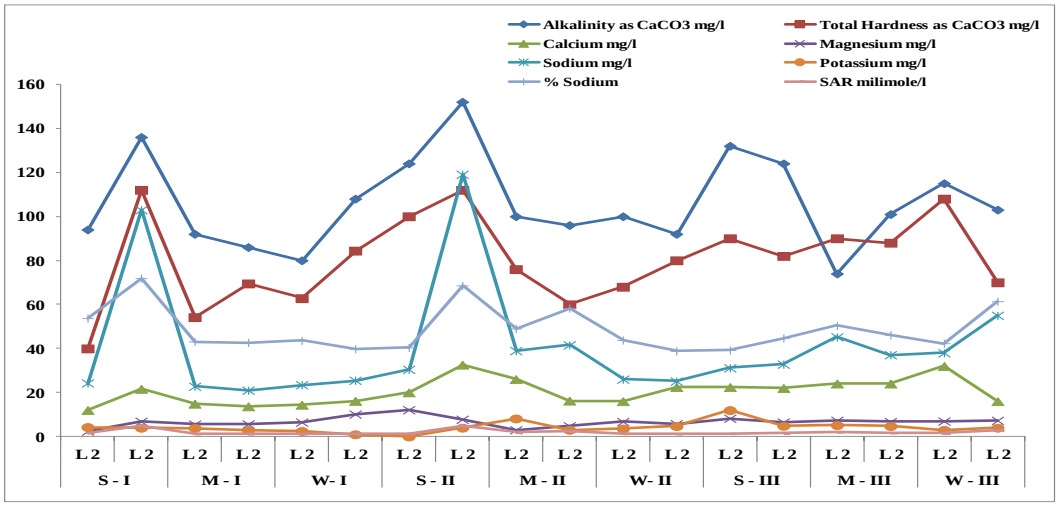

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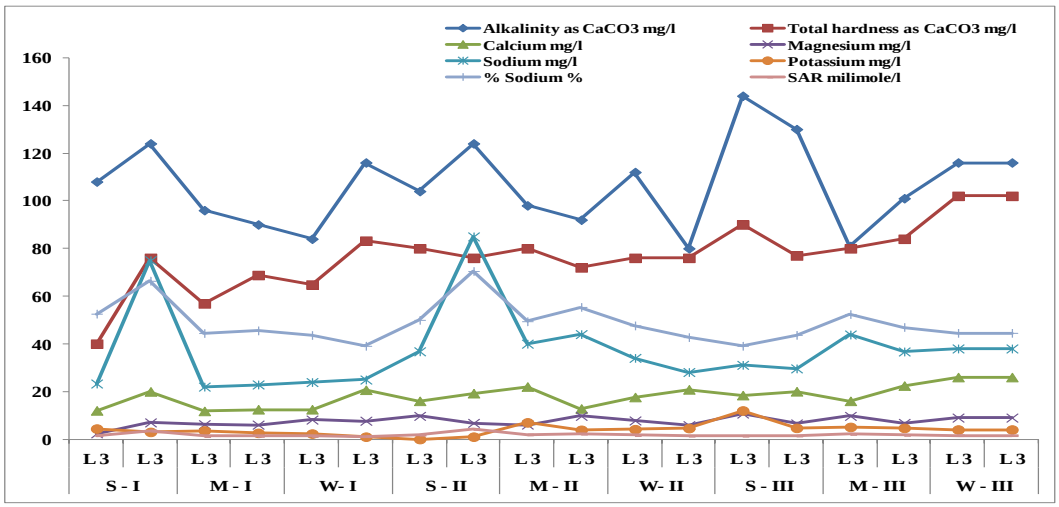

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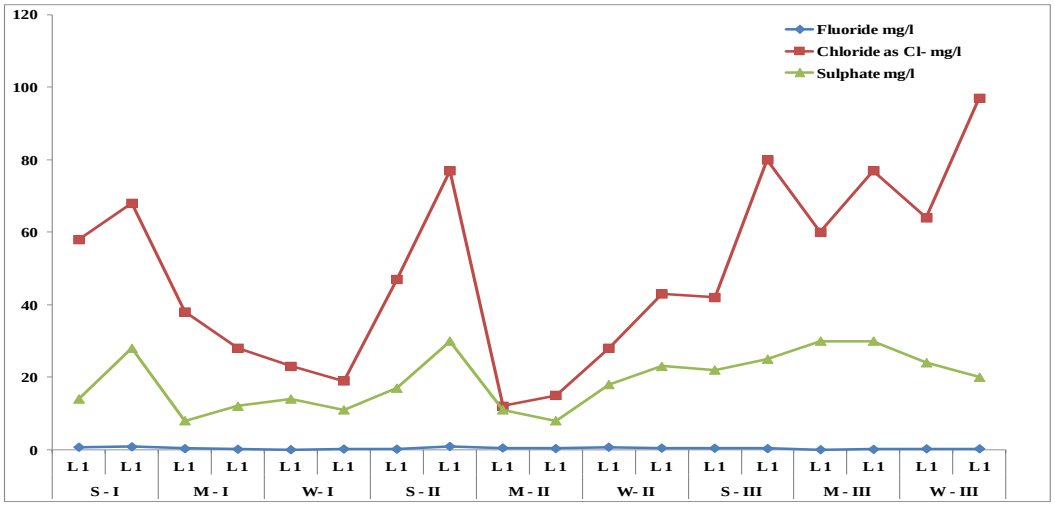

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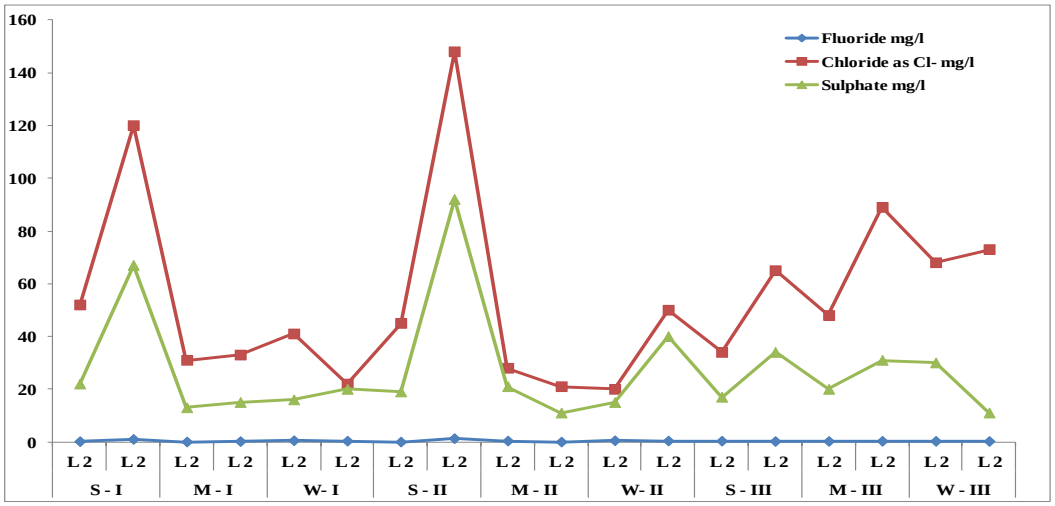

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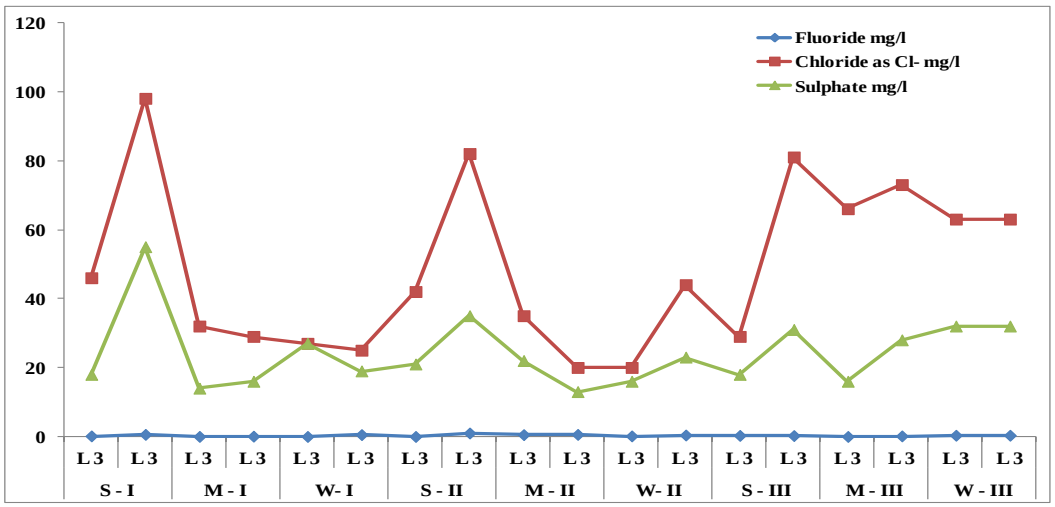

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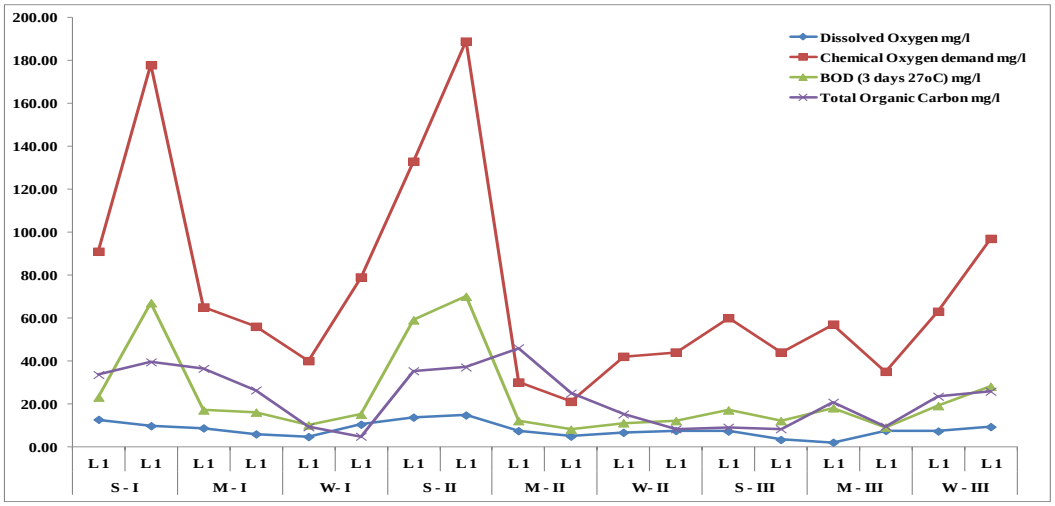

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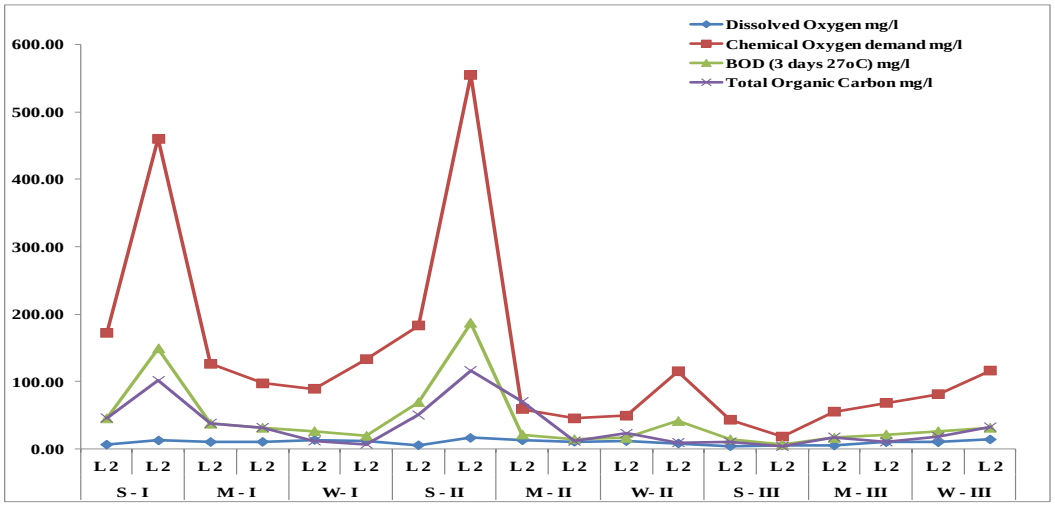

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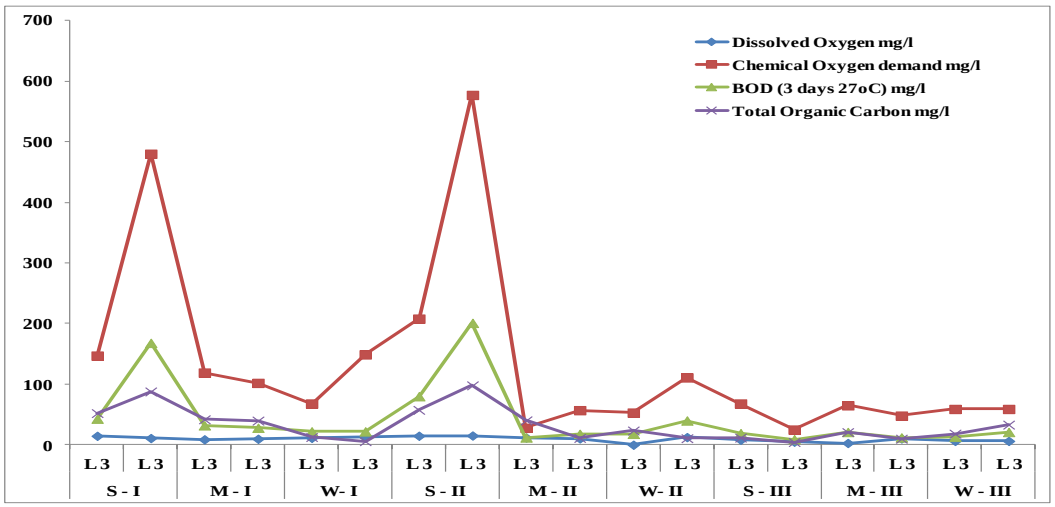

Location -3

Fig. 5.1: Spatio - Temporal Variation of Various Physico-Chemical Parameters During the Study Period

The obtained values of Physico-chemical parameters found during the study period are compared with FAO guidelines for irrigation water (Raychaudhari et al., 2014), Drinking water specifications (IS 10500:2012) and CPCB standards for inland surface waters. It is revealed that except for the Phosphate and Total Hardness, the ranges of values for Thol wetland for various parameters are also in accordance with the findings by Jessicca *et. al.* (2011) for Thol wetland. Detailed comparison also reveals that the ranges of parameters values obtained during the present study are wider than those found by Jessicca *et. al*. (2011) for Thol wetland and this is because all three seasons were covered for a period of three years during the present study.

It is evident that the overall mean values of the water quality parameters like Colour, Turbidity, K and Na crosses the 'limits' on several instances especially during the summer seasons at Location 2 and Location 3. The BOD and COD values are also found to cross the CPCB standards. The comparative high values of COD and BOD are indicators of accumulation of organic matter in wetland water (**Annexure –I, II and III; Table 5.1)**. This is mainly imparted by organic detritus in the form of dried leaves, twigs, flowers etc. falling from the surrounding trees and shrubs into the wetland water. The water column also had a greenish hue due to phytoplankton growth indicating organic content. These investigations are also in close conformity with the finding of Parikh and Mankodi, (2011) when common parameters under the studies are considered. The DO of Thol wetland was high in summer seasons and comparatively lower during monsoon and winter seasons. This can be attributed to the higher photosynthetic activity surpassing the respiration rate.

5.2 Water Quality Index

Water Quality Index helps us to reveal the fact that whether the quality of wetland is deteriorating, improving or remains steady. WQI of Thol Wetland was established from important and relevant physicochemical parameters. The parameters considered for calculation of WQI of Thol wetland for irrigation usage were pH, Conductivity, Total Dissolved Solids, Nitrate (NO_3-N), Phosphate, Alkalinity as $CaCO_3$, Total hardness as $CaCO_3$, Sodium, Potassium, Calcium, Magnesium, % Sodium, SAR, Fluoride, Chloride as Cl^- and Sulphate. Using the described methodology, prescribed irrigation water guidelines/criteria values and respective weight assigned, the WQI of Thol Wetland was calculated (**Table 4.2 and Table 5.4 & 5.5**) for all three seasons and all three locations considering the average retrieved values of Physico-chemical parameters for the year 2015 - 2016, 2016 - 2017 and 2017 - 2018 (**Annexure –I, II and III**). The Spatio-temporal water quality indices thus found are summarized as (**Table 5.6**).

WQI values for different seasons during the study period are found to be 50.97, 41.17 and 29.55 for summer, monsoon and winter seasons in the year 2015-16; 31.67, 58.64 for summer, monsoon and winter seasons in the year 2016-17 and 81.39, 56.46 and 50.14 for summer, monsoon and winter seasons in the year 2017-18 respectively. Whereas the WQI values found at different locations of Thol wetland are 39.93, 42.23 and 39.52 for Location 1, Location 2 and Location 3 in the year 2015-16; 46.48, 49.79 and 46.03 for Location 1, Location 2 and Location 3 in the year 2016-17 and 62.79, 62.24 and 62.79 for Location 1, Location 2 and Location 3 in the year 2017-18.

Table no. 5.4: Calculation of WQI of Thol Wetland During Monsoon Season*

Parameter	Average Observed Values (Concentration Ci)	Standard Values (Si)	Weight (wi)	Relative Weight (Wi)	Quality Rating Scale (Qi)	Sub Index (SIi)
pH	8.23	7.0	1	0.0323	117.55	3.79
Conductivity	269.67	3000	4	0.1290	8.99	1.16
Total Dissolved Solids	161.50	2000	4	0.1290	8.08	1.04
Nitrate (NO_3-N)	0.115	10	3	0.0968	1.15	0.11
Phosphate	0.015	2	1	0.0323	0.75	0.02
Alkalinity as $CaCO_3$	91.50	200	1	0.0323	45.75	1.48
Total Hardness as $CaCO_3$	67.15	712	1	0.0323	9.43	0.30
Sodium	20.73	920	1	0.0323	2.25	0.07
Potassium	3.37	2	5	0.1613	168.33	27.15
Calcium	14.46	400	1	0.0323	3.62	0.12
Magnesium	6.67	61	2	0.0645	10.93	0.71
% Sodium	40.12	60	2	0.0645	66.87	4.31
SAR	1.12	15	2	0.0645	7.47	0.48
Fluoride	0.12	1.5	1	0.0323	8.17	0.26
Chloride	31.83	1065	1	0.0323	2.99	0.10
Sulphate	13.00	960	1	0.0323	1.35	0.04
					WQI	**41.15**

*Similarly, the WQI was calculated for the winter and summer seasons and also for three different locations by considering the observed yearly average values of concerned Physico-chemical parameters.

Table no.5.5: Location wise WQI of Thol Wetland During 2015-2016

Parameter	Unit	Location 1	Location 2	Location 3	Average
pH	in pH Units	7.77	8.60	8.61	8.32
Conductivity	µS/cm	334.12	383.98	373.62	363.91
Total Dissolved Solids	mg/L	193.00	237.17	227.17	219.11
Nitrate (NO3-N)	mg/L	0.53	0.15	0.12	0.27
Phosphate	mg/L	0.03	0.02	0.02	0.02
Alkalinity as CaCO3	mg/L	104.17	99.33	103.00	102.17
Total Hardness as CaCO3	mg/L	89.25	70.48	64.95	74.89
Sodium	mg/L	27.08	36.69	32.01	31.93
Potassium	mg/L	3.02	3.10	2.82	2.98
Calcium	mg/L	18.89	15.48	14.91	16.43
Magnesium	mg/L	9.08	6.22	6.26	7.19
% Sodium	%	37.40	48.44	49.31	45.05
SAR	me/l	1.27	1.91	1.72	1.63
Fluoride	mg/L	0.35	0.37	0.23	0.32
Chloride	mg/L	39.00	49.83	42.83	43.89
Sulphate	mg/L	14.50	25.50	24.83	21.61
	WQI	**39.93**	**42.23**	**39.52**	**40.56**

Table no. 5.6 Summary of Spatio-Temporal WQI of Thol Wetland

	Year 2015-16	Year 2016-17	Year 2017-18	Average WQI
Summer	50.97	31.67	81.39	54.68
Monsoon	41.17	58.64	56.46	52.09
Winter	29.55	51.79	50.14	43.83
Average WQI	**40.56**	**47.37**	**62.66**	**50.20**
Location 1	39.93	46.38	62.79	49.7
Location 2	42.23	49.79	62.24	51.42
Location 3	39.44	46.03	62.79	49.42
Average WQI	**40.53**	**47.40**	**62.61**	**50.18**

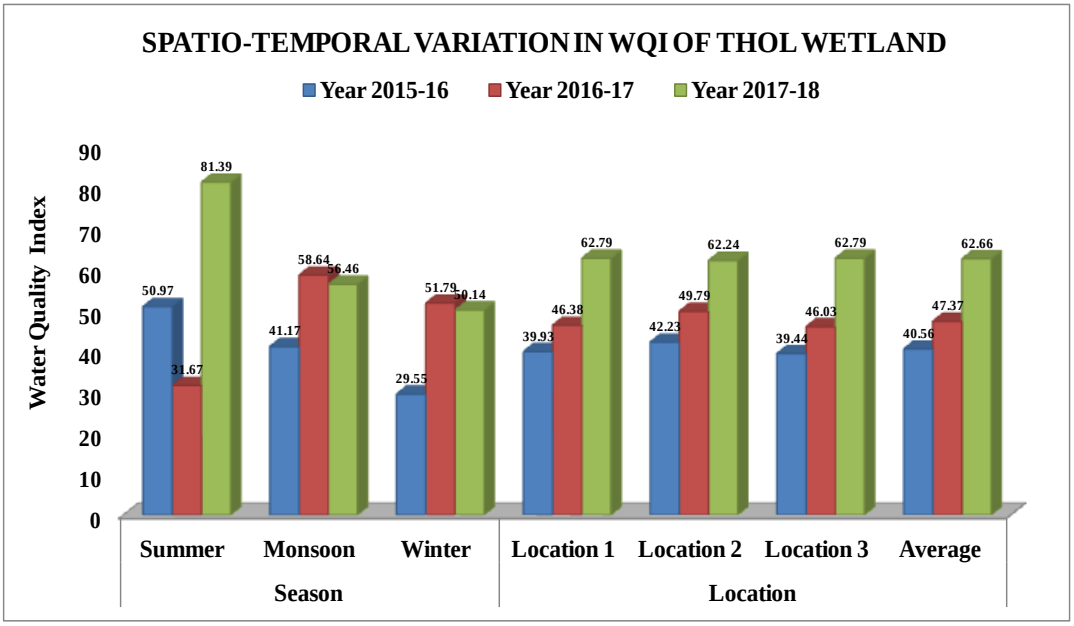

Fig.5.2 Seasonal and Temporal Pattern of Water Quality Index of Thol Wetland During the Year 2015-2018.

respectively against the average WQI value of 40.55, 47.5 and 62.61 for the Year 2015-2016, 2016-2017 and 2017-2018 respectively (**Fig.5.2**). The overall average aggregate WQI for Thol Wetland is found to be 50.18 for the study period. The WQI value during monsoon and winter seasons of the year 2015-16 and summer season of the year 2016-17 being < 50, water quality is found to be excellent for irrigation purpose. All other WQI seasonal values are falling between 50 - 150; the water quality

is classified as good for irrigation purpose. Whereas, for all three locations during the year 2015-16 and 2016-17, the WQI values being <50, the water quality is found to be excellent for irrigation purpose. However, during the third year of the study the WQI values ranges between 50 - 150 and therefore the water quality is classified as good. The average season WQI for the study period reveals that the water quality in winter season is Excellent and during monsoon and summer it is good for irrigation purpose. The average Location wise WQI for the study period reveals that the quality at Location 1 and Location 3 is excellent and at Location 2 it is found to be good for irrigation purpose.

Moreover, the water quality of Thol wetland shows SAR (Abdul et al., 2010; Anant, 2012 and Ramkrishnaiah et al., 2009) value below 10 and average Electrical Conductivity (Abul et,al., 2010) value below 1500 µS/cm at all locations and also throughout all seasons of the study period. These values thus indicate the hazard class to be low. The average value of various physico chemical parameters of Thol wetland water (**Annexure –I, II and III; Table 5.1**) reveals comparatively higher values of Total Dissolved Solids and Total Hardness during summer seasons which may be due to low water level and high rate of decomposition and evaporation thus concentrating the salts. This is also reflected by a comparative higher seasonal value of WQI in summer season of respective year. The WQI thus developed is a simple tool yet very useful for the water quality assessment and it can be used by all concerned for maintaining good health of the Thol wetland. Generally water is considered unsuitable for irrigation if TDS is above 1000 ppm. (Zwart & Trivedi, 1994). When water in high sodium is applied to soils, some of the sodium is taken up by the clay which in

exchange gives up calcium and magnesium. This process is called base change. As a result, the physical characteristics of the soils are altered. Clay that carries a good excess of calcium and magnesium ions has a good structure and permeability. If it takes up sodium, it becomes sticky and slick when wet and has a very low permeability. When dry it shrinks into hard clods which are difficult to break. High concentration sodium salts develops alkaline soil in which little or no vegetation can grow (Zwart & Trivedi, 1994). When the retrieved average values of Conductivity and SAR are compared with the reference values (**Table 4.4**), the Thol wetland water falls under 'moderately saline', its suitability for irrigation is found to be 'safe under practically all conditions', its Hazard level to be 'most probably safe' and the irrigation water classification based on hazardous effect is found to be 'Low'. These findings are in with consonance with the WQI value found during the present study.

5.3 Trace Metal Analysis

The retrieved values of different Trace metals for Thol wetland during the study period i.e. for the year 2016-2017 and 2017-2018 is as per **Annexure –IV and V** respectively. Based on the retrieved average values, the Spatio-Temporal variation in Trace metals concentration for Thol Wetland during the year 2016-2018 is placed in **Table no. 5.7** and the mean concentration and standard deviation of trace metals in Thol wetland water during the study period is placed in **Table no. 5.8.** In our study, the highest concentration among all of metals was that of iron with range of 0.000-0.941 mg/L and 0.000-0.800 mg/L for the Year II and Year III respectively with mean concentration of 0.236 ± 0.0982 mg/L. Manganese and Hexavalent Chromium were not detected during

Table no. 5.7: Spatio-Temporal variation in Trace Metals of Thol Wetland During Year 2016-2018 (Average Values in mg/L)

Parameters	Year 2016-17			Year 2017-18			Year 2016-17			Year 2017-18		
	Summer	Monsoon	Winter	Summer	Monsoon	Winter	Location 1	Location 2	Location 3	Location 1	Location 2	Location 3
Cadmium	0.000	0.000	0.001	0.000	0.063	0.000	0.000	0.000	0.000	0.022	0.022	0.019
Copper	0.037	0.006	0.003	0.004	0.004	0.020	0.018	0.014	0.012	0.008	0.318	0.002
Iron	0.701	0.073	0.141	0.015	0.023	0.461	0.243	0.373	0.300	0.119	0.931	0.283
Lead	0.000	0.002	0.001	0.000	0.000	0.031	0.002	0.000	0.001	0.000	0.031	0.000
Manganese	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Nickel	0.005	0.001	0.002	0.001	0.001	0.023	0.003	0.002	0.003	0.000	0.024	0.000
Hexavalent Chromium	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Total Chromium	0.000	0.001	0.002	0.000	0.000	0.139	0.001	0.001	0.001	0.005	0.134	0.000
Zinc	0.065	0.010	0.003	0.000	0.001	0.124	0.031	0.020	0.028	0.029	0.085	0.011

Table no. 5.8: Summary of Trace Metal Analysis of Thol Wetland for During Year 2016-2018 (Values in mg/L)

Parameters	Second Year		Third Year		Overall Values	Drinking Water Specifications (BIS 10500 : 2012)* mg/L	CPCB Effluent Discharge Standards for Inland Surface Water mg/L
	Range	Mean ± SD	Range	Mean ± SD	Mean ± SD		
Cadmium	0.000-0.001	0.0002 ± 0.0004	0.000-0.131	0.021 ± 0.0482	0.011 ± 0.0147	0.003	2.0
Copper	0.000-0.082	0.0148 ± 0.0273	0.000-0.093	0.009 ± 0.0221	0.012 ± 0.0038	0.050 (1.5)	3.0
Iron	0.000-0.941	0.3053 ± 0.3524	0.000-0.800	0.166 ± 0.2806	0.236 ± 0.0982	1.00	30
Lead	0.000-0.009	0.0008 ± 0.0021	0.000-0.185	0.010 ± 0.0436	0.006 ± 0.0068	0.010	0.1
Manganese	0.000-0.000	0.0000 ± 0.0000	0.000-0.000	0.000 ± 0.0000	0.000 ± 0.0000	0.100 (0.3)	2.0
Nickel	0.000-0.012	0.0026 ± 0.0035	0.000-0.140	0.008 ± 0.0329	0.005 ± 0.0039	0.020	3.0
Hexavalent Chromium	0.000-0.000	0.0000 ± 0.0000	0.000-0.000	0.000 ± 0.0000	0.000 ± 0.0000	0.100	0.1
Total Chromium	0.000-0.003	0.0008 ± 0.0011	0.000-0.801	0.046 ± 0.1885	0.024 ± 0.0321	0.05	2.0
Zinc	0.000-0.112	0.0260 ± 0.0326	0.000-0.427	0.042 ± 0.1055	0.034 ± 0.0110	5.00	5.0

* Acceptable Limits and the values in parenthesis indicate Permissible Limits in absence of alternate source.

the study period. The concentration trend for trace metals is established as Fe > Zn > Cu >Ni > Pb = TCr > Cd > Mn = Cr^{+6} for the Year II and as Fe > TCr > Zn > Cd > Pb > Cu > Ni > Mn = Cr^{+6} for the Year III where as the overall trend is Fe > Zn > TCr > Cu > Cd > Pb > Ni > Mn = Cr^{+6}. The general pattern for total trace metal load shows Year III > Year II.

When compared with the Drinking Water Specifications (BIS: 10500 2012) and with CPCB Discharge Standards for Inland Surface Waters (**Table 5.8**), it is found that the mean concentration of Copper, Iron, Lead, Manganese, Nickel, Hexavalent Chromium, Total Chromium and Zinc were lower than the 'limits' prescribed by both BIS and CPCB. Only the mean value of Cadmium is found to be little higher than the BIS threshold, however it is still at a safe level when compared with the prescribed CPCB Standards. It is to be noted that the surface water of Thol wetland is released for irrigation purpose and no instances of drinking by human was observed. The overall safe trace metal concentration in water matrix can be attributed to the field observations revealing that the wetland is located considerably distant and little disturbances from industries or dense human habitations. Moreover, the wetland is also receiving fresh water from Narmada river canal apart from the rain water.

5.4 Primary Production and Photosynthesis Respiration Ratio

The Gross Primary Production and Photosynthesis Ratio found during the study period along with the important field conditions and observations are put-up at **Annexure -IX.** The Spatio-Temporal variation in GPP was analyzed and the summary for the same is placed at **Table no. 5.9.**

Table no. 5.9 Summary of Spatio-Temporal GPP of Thol Wetland

	Year 2015-16	Year 2016-17	Year 2017-18	Average GPP
Summer	11.24	10.17	8.74	**10.05**
Monsoon	3.38	1.76	1.82	**2.32**
Winter	6.64	2.35	4.99	**4.66**
Average GPP	**7.09**	**4.76**	**5.18**	**5.68**
Location 1	6.7	4.65	4.95	**5.43**
Location 3	7.48	4.87	5.42	**5.92**
Average GPP	**7.09**	**4.76**	**5.19**	**5.68**

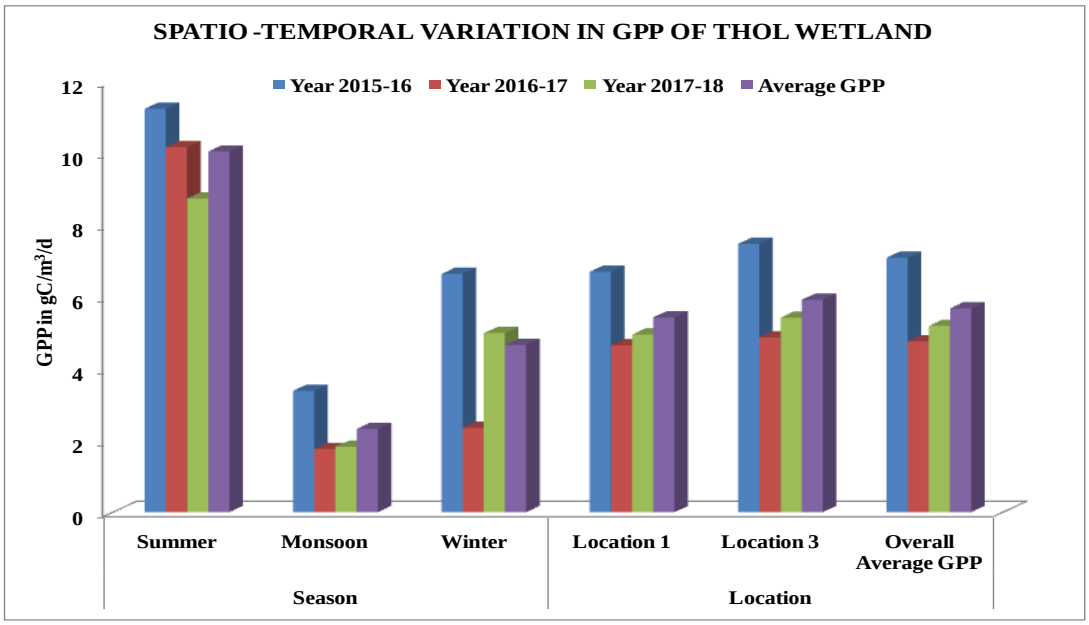

Fig.5.3 Seasonal and Temporal Pattern in GPP of Thol Wetland during 2015-2018.

It is found that the total daily productivity (Gross Primary Productivity - GPP) of Thol Wetland was maximum (12.45 g C/m^3/d) in summer season at Location 1 in the year 2016-2017 (**Annexure -IX**).and the minimum (0.3 g C/m^3/d) in monsoon season at Location 1 in the year 2016-2017 (**Annexure -IX**) against the overall average value of 5.68 g C/m^3/d during the study period (**Table no. 5.9, Fig. 5.3**). Moreover, it is revealed that to the yearly primary production, summer season

contributes about 53%, winter 31% and monsoon 16% during the year 2015-2016; summer 71%, winter 17% and monsoon 12% during the year 2016-2017 and summer 56%, winter 32% and monsoon 12% during the year 2017-2018 (**Fig. 5.4**) against the overall average contribution value of summer season 59%, winter 27% and monsoon 14%. Therefore, the season wise GPP trend is established as summer > winter > monsoon.

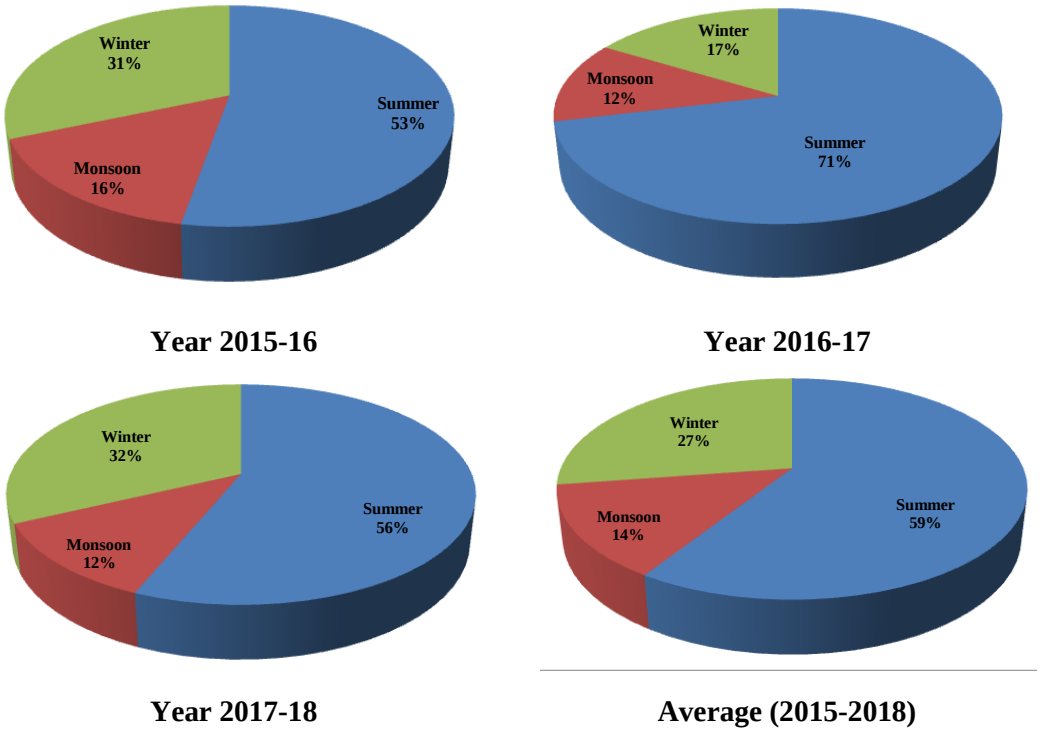

Fig.5.4 Seasonal Contribution to GPP in Thol Wetland

For location 1, the GPP ranged between 0.3 g C/m^3/d to 12.45 g C/m^3/d (**Annexure -IX**) against the average value of 5.43 g C/m^3/d during the study period (**Table no. 5.9, Fig. 5.3**). Whereas for location 3, the GPP ranged between 2.78 g C/m^3/d to 10.88 g C/m^3/d (**Annexure -IX**) against the average value of

5.92 g C/m^3/d during the study period (**Table no. 5.9, Fig. 5.3**). The Location wise GPP trend is established as Location 3 > Location 1 for the study period.

The Spatio-Temporal variation in Photosynthesis – Respiration (P/R) Ratio was also analyzed and the summary for the same is placed at **Table no. 5.10** as below.

Table no. 5.10 Summary of Spatio-Temporal P/R Ratio of Thol Wetland

	Year 2015-16	Year 2016-17	Year 2017-18	Average P/R
Summer	0.55	1.28	0.74	**0.86**
Monsoon	0.46	0.24	0.73	**0.48**
Winter	1.10	1.35	1.86	**1.44**
Average P/R	**0.70**	**0.96**	**1.11**	**0.92**
Location 1	0.93	1.12	0.61	**0.89**
Location 3	0.48	0.79	1.61	**0.96**
Average P/R	**0.71**	**0.96**	**1.11**	**0.92**

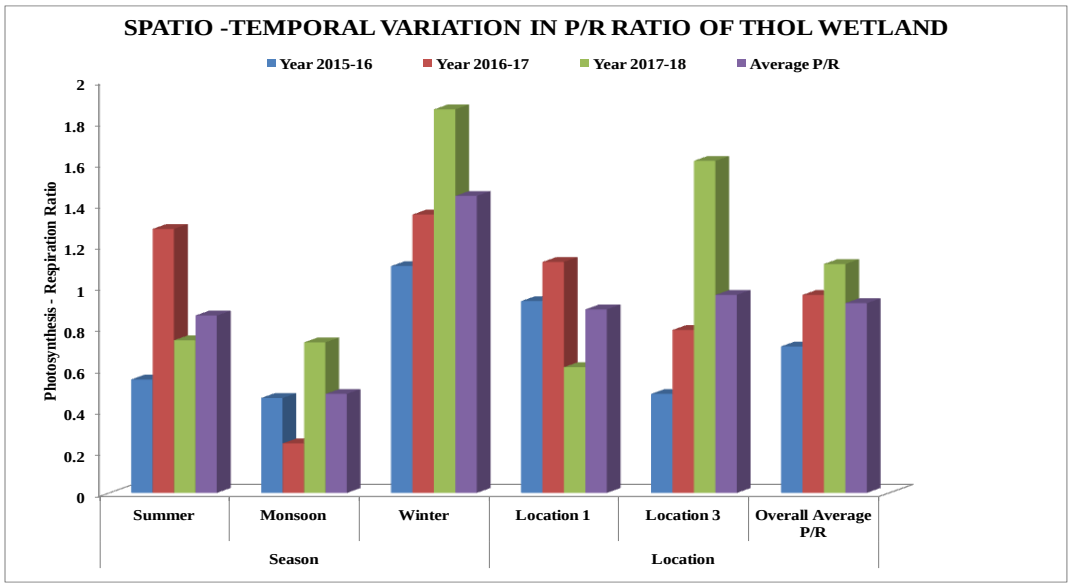

Fig.5.5 Seasonal and Temporal Pattern in P/R Ratio of Thol Wetland during 2015-2018.

It is found that the P/R Ratio of Thol Wetland was maximum (3.032) in winter season at Location 3 in the year 2017-2018 (**Annexure -IX**) and the minimum

(0.032) in monsoon season at Location 1 in the year 2016 - 2017 (**Annexure -IX**) against the overall average value of 0.92 during the study period (**Table no. 5.10, Fig. 5.5**). For location 1, the P/R Ratio ranged between 0.032 to 2.061 (**Annexure - IX**) against the average value of 0.89 during the study period (**Table no. 5.10, Fig. 5.5**), whereas for location 3, the P/R Ratio ranged between 0.388 to 3.032 (**Annexure -IX**) against the average value of 0.96 during the study period (**Table no. 5.10, Fig. 5.5**). The Location wise P/R Ratio trend is established as Location 3 > Location 1 for the study period.

The linear trend line is plotted for Gross Primary Production and Photosynthesis Respiration Ratio to comprehend the seasonal trend. Linear regression model was generated for these two parameters where seasons were taken on the X axis and quantitative value of parameters on Y axis. The regression equation is depicted as component on each graph (**Fig. 5.6 and 5.7**).

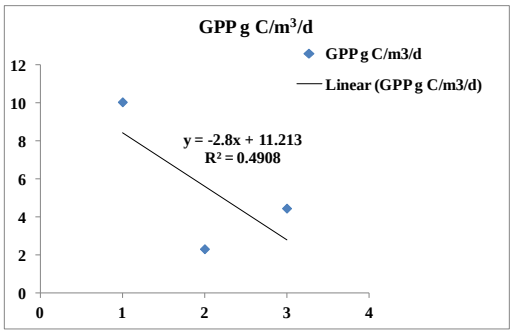

Fig. 5.6 Linear Regression for Gross Primary Production (Average Values)

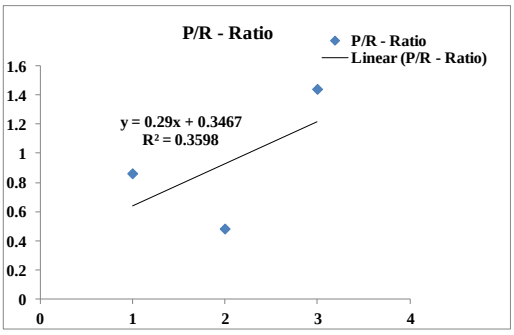

Fig. 5.7 Linear Regression for P/R Ratio (Average Values)

Field observations during the study period revealed that the Wetland water is enriched by organic detritus. Aquatic birds were also found grazing and swimming in water and taking rest near the water edges. With monsoon season setting, the surrounding flora starts getting revived and flourish. There was also a

populous growth of emergent aquatic weed lotus – Nelumbo lucifera at this location 1 (**Plate 5.1 A to C**). The big leaves of Nelumbo shades the water keeping it cool and thus allowing for more dissolved oxygen. The plant also provides shelter for small aquatic creatures, which in turn attract predator birds.

Plate 5.1 A to C:
A. Profulus Growth of *Nelumbo lucifera* (kamal kakadi)
B. Dried and Dead *Nelumbo lucifera* during Extreme Summer
C. *Nelumbo lucifera* in Surrounding Waters at Location 1

The seasonal pattern of dissolved oxygen during the in situ experiment shows that during the summer the values remains comparatively higher which is probably due to rich phytoplankton growth.

Moreover, there exists a relationship between Gross Production (P) and Total Community Respiration (R), where P/R = 1 indicates a steady-state community and if the P/R is greater or less than 1 then organic matter either accumulates or is depleted respectively (Zwart and Trivedi, 1994). During the in situ measurements, the Photosynthesis Respiration Ratio is found to be greater than 1 during winter season for all three years of the study period and in summer season during the year 2016-2017. Moreover, the P/R values are >1 for L1 during the year 2016 - 2017 and for L3 in the year 2017 - 2018. This indicates that there is an accumulation of organic matter in Thol Wetland during these months and at

respective locations. These findings were also substantiated by the fact that (i) organic detritus in the form of dried leaves, twigs, flowers etc. falling from the surrounding trees and shrubs (ii) deposition and dissolution of Birds excreta, Cattle dung and droppings into the wetland waters and (iii) the water column visually appeared greenish due to lush phytoplankton growth indicating high organic content. However during monsoon season, the Photosynthesis Respiration ratio is found to be less than 1 indicating that Respiration activity is more than the Photosynthesis the reasons being organic content gets diluted during the monsoon season as well as the rapid depletion of organic content by the primary consumers. It is interesting to note that the average P/R value trend during the study period is found to be Year III > Year II > Year I indicating the trend of accumulation of organic matter in the Thol wetland. However the overall average P/R value is 0.92 indicating that the wetland is striving towards a steady state community.

5.5 Biological Assessments

Biomonitoring: The number of Benthic Macro invertebrates families falling into different taxonomic groups and the calculated Saprobic Score found for Location L1 and Location L2 along with the abundancy scale during the study period is placed at **Annexure VI**. In all 20 different families falling across 7 taxonomic groups/orders were encountered (**Annexure VI**). The number of families found in each taxonomic order is depicted in the following graph (**Fig.5.8**). The minimum and maximum number of families encountered at Location 1 is 8 and 16 respectively and for Location 2 the minimum and maximum values are 7 and 12 respectively. The family level seasonal diversity trend of Benthic

Macroinvertebrates is found as winter > monsoon > summer at both the Location 1 and Location 2 whereas the family level diversity trend of Benthic Macroinvertebrates during the study period is found as Year III > Year II > Year I.

The overall diversity score was found to be ranging from 0.5 - 0.71 and the BMWP Score was found to be ranging from 4.38 – 5.63 during the study period. For Location 1 and Location 2 the diversity score ranged from 0.52 - 0.69 and the BMWP Score ranged from 5.00 - 5.63. Similarly, for Summer season, Monsoon season and Winter season the diversity score was found to be ranging from 0.53 - 0.59, 0.50 - 0.71, 0.59 - 0.69 and the BMWP Score was found to be ranging from 4.38 - 5.33, 4.78 - 5.63, 4.44 - 5.57 respectively (**Annexure VI**).

The substrate composition in the wetland at sampling locations approximately comprised of Gravels (20%), Sand (35%) and Grasses, algae & other submerged vegetation (55%).

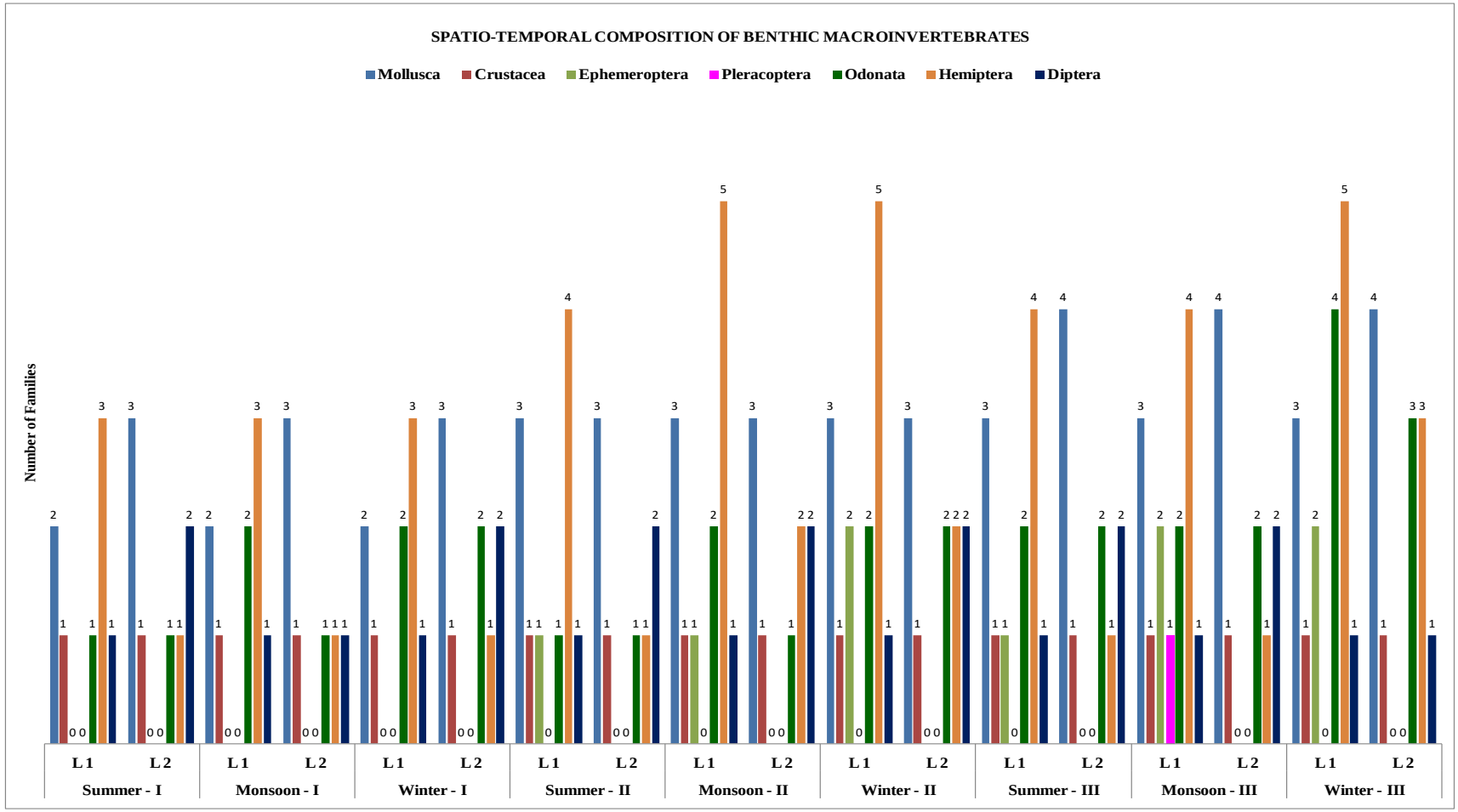

Fig. 5.8 Graph – Location and Season Wise Composition of Benthic Macroinvertebrates at Thol Wetland During the Study Period

A. Indicative Collection of Benthic Macroinvertebtrates

B. Gomphidae

C. Lestidae

D. Belastomatidae

E. Lymnedae

F. Thiaridae

G. Planorbidae

H. Viviparidae

I. Chironomidae

J. Atydae

K. Ranatrinidae

L. Nepidae

M. Hydrometridae and Gerridae Swimming on Water Surface

Plates 5.2 (A to M): Some of the Benthic Macroinvertebrates Found During the Study Period

Table 5.11: Season wise and Location wise Variation of Saprobic Score and Diversity Score and Integrated Water Quality of Thol Wetland During 2015-2018

Season	Location	Saprobic Score	Diversity Score	Water Quality	Water Quality Class	Indicator Colour
Summer I	L1	5.00	0.58	Moderate Pollution	C	Green
	L2	4.38	0.55	Moderate Pollution	C	Green
Monsoon I	L1	5.33	0.61	Moderate Pollution	C	Green
	L2	4.71	0.61	Moderate Pollution	C	Green
Winter I	L1	5.33	0.52	Moderate Pollution	C	Green
	L2	4.78	0.50	Moderate Pollution	C	Green
Summer II	L1	5.09	0.56	Moderate Pollution	C	Green
	L2	4.38	0.50	Moderate Pollution	C	Green
Monsoon II	L1	5.31	0.69	Moderate Pollution	C	Green
	L2	4.44	0.59	Moderate Pollution	C	Green
Winter II	L1	5.43	0.65	Moderate Pollution	C	Green
	L2	4.80	0.71	Moderate Pollution	C	Green
Summer III	L1	5.33	0.59	Moderate Pollution	C	Green
	L2	4.90	0.53	Moderate Pollution	C	Green
Monsoon III	L1	5.57	0.63	Moderate Pollution	C	Green
	L2	4.90	0.60	Moderate Pollution	C	Green
Winter III	L1	5.63	0.66	Moderate Pollution	C	Green
	L2	5.25	0.63	Moderate Pollution	C	Green
Average		**5.03**	**0.59**	**Moderate Pollution**	**C**	**Green**

The Saprobic Score ranges from 4.38 – 5.33, 4.38 – 5.43 and 4.90 – 5.63 during the first, second and third year respectively with overall average value of 5.03; whereas, the Diversity Score ranges from 0.50 – 0.61, 0.50 – 0.71 and 0.53 – 0.66 with overall average value of 0.59 (**Table 5.11**). These values when compared with the BWQC (Biological Water Quality Criteria) developed by Central Pollution Control Board (**Table 4.5**), collectively indicate that the water quality of Thol wetland at both the locations during the study period is 'Moderately Polluted' (**Table 5.11**). The Integrated water quality of Thol wetland is observed to be 'Moderately Polluted' owing to comparatively high organic content. The results of Physico-chemical analysis are in consonance with the BWQC developed by CPCB. Therefore the use of Biomonitoring for water quality assessment using Benthic Macro-invertebrates can be used as a complementary method along with the regular Physico-chemical analysis for comprehensive water quality monitoring.

5.6 Sediment Quality

The values of different Sediment quality parameters for Thol wetland during the study period i.e. for the year 2016-2017 and 2017-2018 is as per **Annexure –VII and VIII** respectively. Based on the average values, the Spatio -Temporal variation in Sediment Quality of Thol Wetland is placed at **Table 5.12**. Moreover, the range and the mean values along with the standard deviation of these Physico-chemical parameters is calculated and thus found is summarized as mentioned in **Table 5.13**.

Sediment Colour: The overall visual colour of Thol Sediment appears light brown – blackish brown – blackish. Moreover, for most of the times, the general feel of the Thol sediment in the field is found to be smooth and bit greasy indicating organic sediment. The bottom sediment when exposed during the summer shows almost 5 cm deep cracks and very thin patchy film of white salt deposition (**Plate 4.6**).

Bulk Density: It is the weight of the soil in a given volume. It is an indicator of soil compaction. A compact soil has higher value of bulk density. Organic soil has a lower value of bulk density. It also affects water holding capacity of the soil. During the study period, the range of Bulk density was found to be 1.26 - 1.48 mg/m^3 and 1.25 - 1.47 mg/m^3 for the second and third year respectively with overall mean value of 1.37 ± 0.01 mg/m^3 (**Table 5.13**).

pH: The soil pH is a measure of the negative logarithm of the hydrogen ion concentration of the sediment solution. It is thus a measure of acidity or alkalinity of the sediment. Nutrient availability and microbial activity are favoured by a soil pH range of 5.5 – 8.0 (DoAC, MoA, 2011; GEMI, 2016). During the study period, the range of pH was found to be 6.66 -8.22 and 6.38 - 8.58 for the second and third year respectively with overall mean value of 7.56 ± 0.07 (**Table 5.13**). The maximum pH (8.58) recorded was during monsoon season in the year 2017 – 2018 at location 1 whereas minimum pH (6.38) recorded was during summer season at location 2 in the same year (**Annexure –VII and VIII**).

Table no. 5.12: Spatio -Temporal variation in Sediment Quality of Thol Wetland Year 2016-2018 (Average Values)

Sr. No.	Parameters	Unit	Year 2016-17			Year 2017-18			Year 2016-17		Year 2017-18	
			Summer	Monsoon	Winter	Summer	Monsoon	Winter	Location 1	Location 2	Location 1	Location 2
1	pH	pH Units	7.57	7.43	7.53	7.26	8.06	7.50	7.71	7.31	7.99	7.22
2	Conductivity	µs/cm	389.00	230.55	345.75	290.20	215.48	485.43	269.37	374.17	185.07	475.67
3	Total Kjeldahl Nitrogen	%	0.17	0.12	0.26	0.24	0.13	0.20	0.11	0.25	0.07	0.30
4	Available Nitrogen	%	0.85	0.44	0.77	0.41	0.42	1.51	0.61	0.76	0.33	1.23
5	Available Phosphorous	kg/hectare	13.36	42.50	4.01	10.43	6.36	24.93	20.72	19.19	13.13	14.68
6	Organic Carbon	%	0.23	0.57	1.02	1.10	0.95	1.57	0.40	0.82	0.65	1.77
7	Organic Matter	%	0.39	0.99	1.76	1.90	1.64	2.70	0.68	1.41	1.11	3.04
8	Bulk Density	mg/m^3	1.32	1.40	1.36	1.36	1.40	1.37	1.36	1.36	1.38	1.37

Table no. 5.13: Summary of Sediment Quality of Thol Wetland Year 2016-2018 (Average Values)

Sr. No.	Parameters	Unit	Second Year		Third Year		Overall of Mean Values
			Range	Mean ± SD	Range	Mean ± SD	Mean ± SD
1	pH	pH Units	6.66 -8.22	7.51 ± 0.45	6.38 - 8.58	7.60 ± 0.62	7.56 ± 0.07
2	Conductivity	µs/cm	177.2 - 517.0	321.8 ± 118.40	84.8 - 1227	330.4 ± 304.02	326.07 ± 6.08
3	Total Kjeldahl Nitrogen	%	0.04 - 0.62	0.18 ± 0.15	0.03 - 0.62	0.19 ± 0.19	0.18 ± 0.002
4	Available Nitrogen	%	0.33 - 1.40	0.69 ± 0.39	0.14 - 3.73	0.78 ± 1.01	0.73 ± 0.07
5	Available Phosphorous	kg/hectare	0.50 - 64.10	19.95 ± 22.18	1.47 - 49.17	13.90 ± 16.18	16.93 ± 4.28
6	Organic Carbon	%	0.18 - 1.57	0.61 ± 0.49	0.2 - 2.74	1.21 ± 0.78	0.91 ± 0.43
7	Organic Matter	%	0.30 - 2.71	1.04 ± 0.85	0.34 - 4.72	2.08 ± 1.34	1.56 ± 0.73
8	Bulk Density	mg/m^3	1.26 - 1.48	1.36 ± 0.07	1.25 - 1.47	1.38 ± 0.08	1.37 ± 0.01

Conductivity: The salt content in sediment is measured in terms of electrical conductivity (EC). During the study period, the range of conductivity was found to be 177.2 – 517 µs/cm and 84.8 – 1227 µs/cm for the second and third year respectively with overall mean value of 326.07 ± 6.08 (**Table 5.13**). The maximum conductivity (1227 µs/cm) recorded was during winter season in the year 2017 - 2018 at location 2, whereas the minimum conductivity (84.8 µs/cm) recorded was during summer season in the same year at location 1 (**Annexure – VII and VIII**).

Table 5.14: General Interpretation of EC values for Soil

Soil	EC (µS/cm)	Total Salt Content (%)	Crop Reaction
Salt free	0 - 2000	< 0.15	Salinity effect negligible, except for more sensitive crops
Slightly saline	4000 - 8000	0.15 - 0.35	Yield of many crops restricted
Moderately saline	8000 - 15000	0.35 - 0.65	Only tolerant crops yield satisfactorily
Highly saline	> 15000	> 0.65	Only very tolerant crops yield satisfactorily

Source: Department of Agriculture & Cooperation Ministry of Agriculture, (2011)

The retrieved values for conductivity of Thol Wetland sediment when compared with the reference values available in **Table 5.14**, reveals that the sediment is salt free with salt content < 0.15% for all the locations and for all the seasons under consideration of the present study.

Organic Carbon and Organic Matter: It is generally assumed that on an average Organic Matter (OM) contains about 58% Organic Carbon (DoAC, MoA, 2011). The OM consists of living organisms, dead plant and animal residues. It is also the most chemically active portion of the soil and serves as a reservoir for various essential elements. It contributes to cation exchange capacity and buffers

the soil, supplies Nitrogen, Phosphorous, Sulphur and other secondary and micro nutrients for plant growth. It holds cations and anions and releases them slowly. It chealates micronutrients such as Zn, Mn, and Cu making them easily available to plant roots. Accumulation of organic matter occurs when the deposition rate is faster than the decomposition rate and the deposition formed is called peat (DoAC, MoA, 2011; GEMI, 2016). Looking to the site conditions and field observations, the remains of herbaceous plants, shrubs, trees and to some extent remains (faecal material) of aquatic birds and animals mainly contributes to the peat formation. Therefore, the peat here in this case is mainly of Herbaceous – Woody Peat type. The sediment texture during the study felt to be grainy – smooth and greasy indicating mineralizing stage with high organic content. During the study period, the range of Organic matter was found to be 0.3 –2.71% and 0.34 – 4.72% for the second and third year respectively with overall mean value of 1.56 ± 0.73 (**Table 5.13**). The maximum OM (4.72 %) recorded was during winter season in the year 2017 - 2018 at location 2, whereas the minimum OM (0.34%) recorded was during summer season in the year 2016 - 2017 at location 1 (**Annexure –VII and VIII**). The trend for overall % of Organic Carbon and Organic Matter is found to be L2 > L1 indicating the tendency of Thol wetland to accumulate the Organic matter towards the lower gradient i.e. the Western and South –West portion of the wetland from where the water is discharged for irrigation.