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EVALUATION OF WATER QUALITY USING WATER QUALITY INDEX OF PIT LAKES, RANIGANJ COAL FIELD AREA, WEST BENGAL, INDIA

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ABSTRACT: The present study was conducted to monitor the status of water quality and to determine the water quality index (WQI) of ten pit-lakes of Andal block under Raniganj coal field, West Bengal, India for three successive seasons from 2016 to 2018. This paper deals with the study of ten physicochemical parameters such as pH, total conductivity, total hardness, total Chloride, total alkalinity, phosphate phosphorus, nitrate nitrogen, total dissolved solids, dissolved oxygen and biological oxygen demand which influence overall water quality. The WQI of these ten pit-lakes varies seasonally. In pre-monsoon season it ranges from 44.11 -191.97, in monsoon it shows highest values and ranges from106.45- 214.69 whereas in after-monsoon it ranges from 25.72-350.48. The results indicate that almost all the pit-lakes shows poor to unsuitable water quality. Therefore, proper treatment of water of these pit-lakes is needed before any use.

KEYWORDS: Water quality, Pit-lakes, Physicochemical parameters, Water quality index.

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1. INTRODUCTION

Water is the prime and vital natural resource for every life entity in the globe, maintaining a perfect ecological balance between economical and various developmental activities. Remembering this pristine and scarce resource for maintain life cycle, it would be a matter of immense concern. In recent decades pressure of population increase, unplanned urbanization and industrialization and agricultural activities demands huge quantity of water. The main source of water is surface water and ground waters but these water resources are under scanner of environmental concern which is continuously reported by several researcher and policy maker [1]. Therefore, to maintain the ecological health of water bodies and resources, regular and proper monitoring of water quality is necessary. Water Resource is deteriorating day by day because of several reasons, mainly due to rapid civilization and the day is not so far when recent water resources tend to be insufficient to mitigate the future water demand. So to overcome the challenge an alternative water resources are essential and one of the best and potential choice is the conversion of different mine void into pit lakes as a water resources in a sustainable way. In this paper ten selected pit-lakes of Andal block under Raniganj coal field area are taken as study area and the water quality index is assessed seasonally during 2016-2018 to examine and evaluate the recent water quality status and more importantly to prepare framework for proper management and conservation. Water quality index is widely accepted approach to highlight the water quality information to the public domain as well as provide base line idea about the suitability of water for different activities. Fundamentally WQI is calculated mathematically from different test results and gives a single value. Therefore WQI is applied to represent a complex water quality data in a simpler and under stable form [2]. There are different water quality indices have been structured all over the world, such as, US National Sanitation Foundation Water Quality Index (NSFWQI), Canadian Council of Ministers of the Environment Water Quality Index (CCMEWQI), British Columbia Water Quality Index (BCWQI), and Oregon Water Quality Index (OWQI) [3, 4, 5]. Horton [6] was probably the pioneer to formulate water quality index and after various researcher developed their own water quality index [7, 8, 9]. Among them, water quality index, formulated by Brown et al, 1970 is widely used [10]. In India, Bhargava is thought to be the pioneer in water quality index study [11]. In this study we used the weighted arithmetic index method formulated by Brown et al, 1970 [10].

2. MATERIALS AND METHODS

Study Area

Raniganj Coalfield (RCF) is the mother of coal mine in India and is spread over different district of West Bengal (Burdwan, Birbhum, Bankura and Purulia) as well as at Dhanbad district in Jharkhand also. For the present investigation ten pit-lakes of Andal block under RCF has been selected. Figure 1 and table 1 represents the detailed location of the study area.

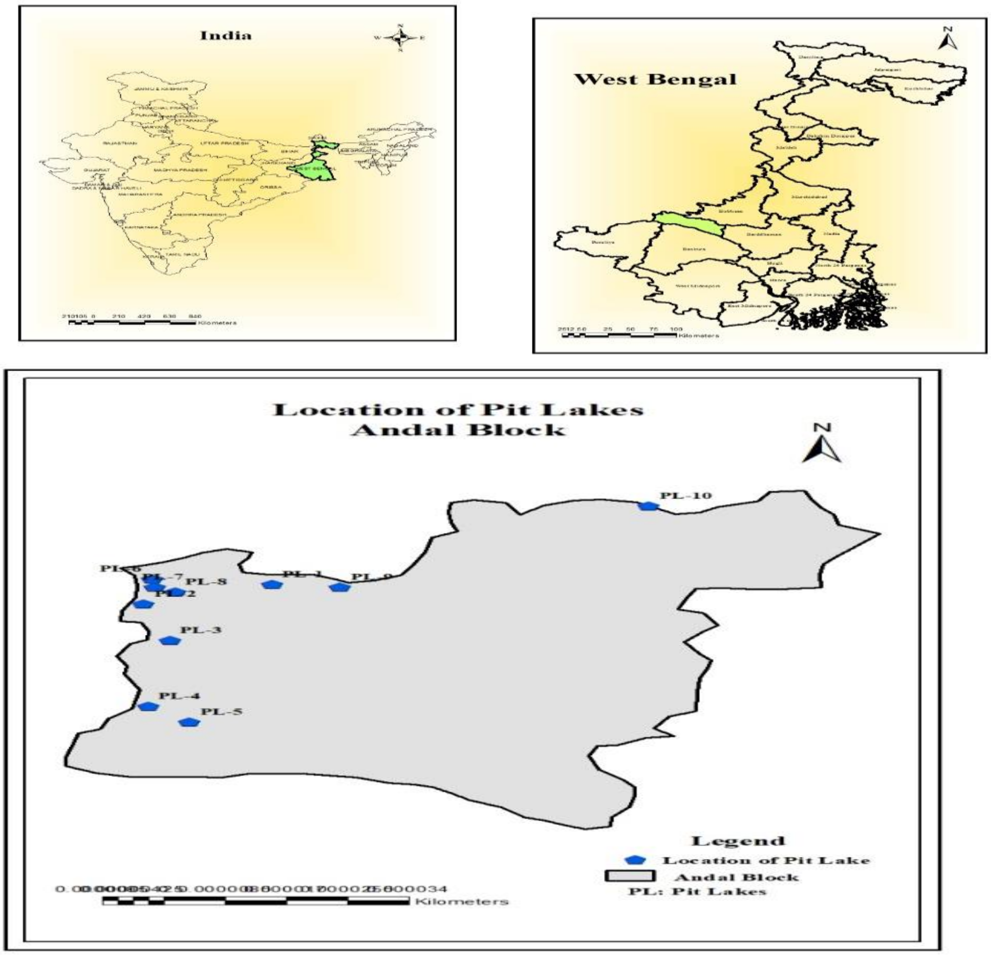


Figure 1: Location map of the study area

Table 1: Details of selected pit-lakes in Raniganj Coal Field (RCF), West Bengal, India.

Sl. No.	NAME OF THE PIT LAKE	MINE AREA	BLOCK	DIVISION	LONGITUDE	LATITUDE
1	JAMBAD	KAJORA	ANDAL	DURGAPUR	23^{0}38′56.5″N	87^{0}10′30.7″E
2	WESTERN KAJORA	KAJORA	ANDAL	DURGAPUR	23°37'37.58"N	87° 6'4.96"E
3	ATEWAL	KAJORA	ANDAL	DURGAPUR	23°36'31.07"N	87° 8'36.00"E
4	KHADANKALI	KAJORA	ANDAL	DURGAPUR	23^{0}35´48.7´´N	87^{0}9´54.9´´E
5	BABUISOL SIB MANDIR	KAJORA	ANDAL	DURGAPUR	23^{0}35´51.7´´N	87^{0}10´18.6´´E
6	SANKARPUR	BANKOLA	ANDAL	DURGAPUR	23^{0}40´12.1´´N	87^{0}14´13.6´´E
7	REAL KAJORA	KAJORA	ANDAL	DURGAPUR	23^{0}38'2.3"N	87^{0}11'9.6"E
8	DHADARDIHI 1	KAJORA	ANDAL	DURGAPUR	23^{0}37′36″N	87^{0}9′38.7″E
9	DHADARDIHI 2	KAJORA	ANDAL	DURGAPUR	23^{0}37′57.1″N	87^{0}9′51.3″E
10	DHADARDIHI 3	KAJORA	ANDAL	DURGAPUR	23^{0}38′1.9″N	87^{0}9′53.5″E

Water samples were collected from ten pit-lake in Andal block under Raniganj coal field following standard guidelines during pre-monsoon (PM), monsoon (M) and After-monsoon (AM) season over a period of three years (2016-2018). Standard methods were followed to analyze different physico-chemical parameters of the water samples of selected pit-lakes [12]. A set of ten most commonly used water quality parameters namely pH, electrical conductivity (EC), total dissolved solid (TDS), chloride, total alkalinity (TA), total hardness (TH), nitrate nitrogen, phosphate phosphorous, dissolved oxygen (DO) and biochemical oxygen demand (BOD) were taken to generate water quality index (WQI).

Calculation of WQI

WQI was calculated using the weighted arithmetic index method [10]. The equation is: **WQI=** $\sum QnWn / \sum Wn$ (Qn is the quality rating of nth water quality parameter and Wn is the unit weight of nth water quality parameter). Qn was calculated by the equation: Qn= 100 [(Vn -Vi) / (Vs -Vi)]; where Vn is the actual amount of nth parameter present;Vi is the ideal value of the parameter [Vi = 0, except for pH (Vi = 7) and DO (Vi = 14.6 mg/l)], Vs is the standard permissible value for the nth water quality parameter (table 3).Unit weight (Wn) was determined by the formula: Wn = k/Vs; k is the constant of proportionality and was calculated following the equation: k = [1/$\sum$ 1/Vs = 1, 2, . . .n] (table 3).

Statistical Analysis

Minitab statistical package was utilized for the statistical analysis of water analysis results. Correlation analysis was done by Microsoft excel and PCA was performed to explain the observed variance in the data. Also PCA attempts to explain the correlation between the observations in terms of the underlying factors, which are not directly observable [13]. Principal component analysis (PCA) is used as an important multivariate statistical tools to reduce large number of data sets in lot of excellent studies [14, 15, 16, 17, 18, 19, 20, 21].

3. RESULTS AND DISCUSSION

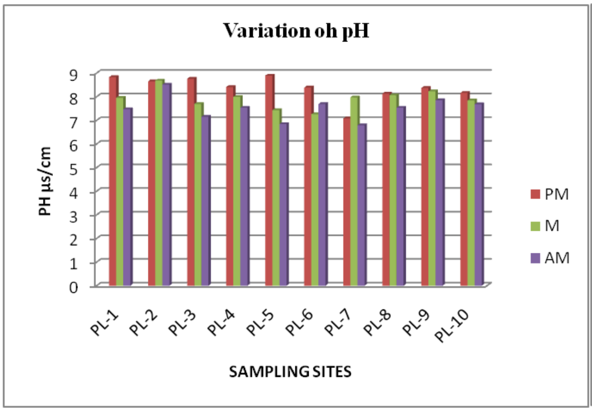
The statistical summary of the selected water quality parameters at various sampling sites are presented in Table 2.

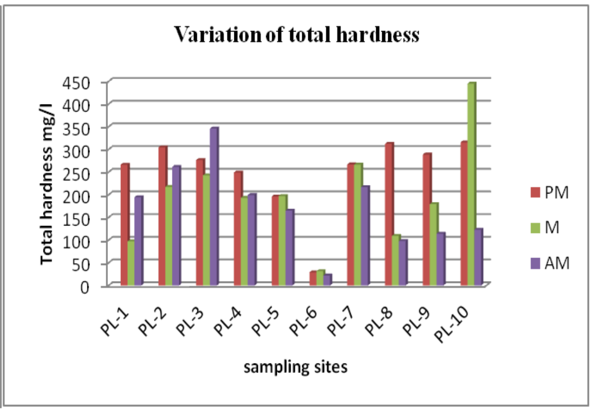
Table 2: Statistical representation of water quality parameters of different pit lake

Pit lakes	PH	TH	TC	ALK	CHL	PHOS	NITRO	TDS	DO	BOD
PL 1	8.09± 0.61	186.1± 70.83	448.50 ±1.92	33.33± 8.10	53.98± 8.27	0.78± 0.39	1.40± 0.38	290.4± 69.18	4.28± 0.58	1.88± 0.26
PL 2	8.61± 0.58	261.1± 38.31	449.7± 2.63	23.80± 8.95	37.80± 11.02	2.39± 0.65	2.72± 1.39	348± 75.85	4.12± 0.41	1.99± 0.22
PL 3	7.87± 0.72	288.5± 44.86	419.6± 72.09	25.5± 6.37	23.65± 9.48	0.92± 0.71	1.23± 0.43	243.6± 59.01	3.91± 0.33	2.06± 0.37
PL 4	7.98± 0.68	214± 26.70	386.2± 66.07	22.67± 5.29	39.55± 13.63	2.54± 1.24	1.58± 0.21	237.2± 62.08	4.7± 0.55	2.08± 0.37
PL 5	7.72± 0.92	176.08 ±30.42	349.42 ±49.03	25.67± 5.14	35.35± 15.45	2.99±1 .67	1.16±0 .73	233.17 ±29.95	5.36±0 .29	2.43±0 .29
PL 6	7.78± 0.62	27.5± 6.14	332± 67.24	28.5± 4.72	43.99± 17.86	1.80±0 .28	0.84±0 .33	262.25 ±40.15	4.63±0 .48	2.43±0 .09
PL 7	7.28± 0.53	250.08 ±25.22	141.5± 0.99	27.75± 15.12	46.64± 23.72	2.23±1 .12	1.89±1 .13	197.87 ±175.7 3	4.75±0 .33	2.33±0 .26
PL 8	7.91± 0.40	173.33 ±103.0 5	395.33 ±85.44	26.75± 10.56	42.09± 10.87	0.88±0 .37	2.09±1 .31	250.67 ±12.41	4.42±0 .36	2.34±0 .14
PL 9	8.15± 0.27	194.17 ±75.33	478.08 ±32.17	24.83± 5.97	37.36± 1.34	0.97±0 .58	2.03±1 .19	250.51 ±4.87	4.69±0 .31	2.53±0 .19
PL 10	7.89± 0.25	184.5± 96.86	391.58 ±99.11	28.08± 6.29	38.43± 2.15	1.13±0 .54	2.5±2. 29	253.83 ±2.79	4.74±0 .34	2.63±0 .18

TH- total hardness, TC- total conductivity, ALK- alkalinity, CHL- Chloride, PHOS- phosphate phosphorous, NITRO- nitrate nitrogen, TDS- Total dissolved solids, DO- dissolved oxygen, BOD- biological oxygen demand.

The variation of different water quality parameters at different pit-lakes during the study period are represented in figure 2. The average pH values of different pit-lakes are ranges from 7.28-8.61 which is near to the BIS prescribed limits. Electrical conductivity is capacity of conducting electric current. Electrical conductivity is a directly related with the dissolved salts present in the water [22]. Digital conductivity meter is used to measure electrical conductivity and the results were expressed in microsiemen/centimeter. Observed EC values for the water samples of selected 10 pit-lakes are ranged between 141.58 to 478.08 µS/cm. TDS directly measure total dissolved particles in a water and BIS desirable limit is 500 mg/l. The concentration of TDS for the water samples ranged from 197.87 mg/l to 348 mg/l which were also match the range of desirable limit. Calcium and magnesium are the principal cations which brings hardness. Basically the total hardness of water is dependent on the amount of calcium and magnesium ions and shows proportion relation [23, 24] Total hardness of the sampling sites is ranges from 27.5 to 288.5 mg/l. Chloride is considered as an important WQ parameter. The chloride and nitrate nitrogen content in water comes mainly from natural sources, industrial effluents and sewage systems [25]. The average chloride concentration of the water samples are between 23.65 to 53.98 mg/l which is within the desirable limit of BIS (250 mg/l). Nitrate-nitrogen content of different pit-lakes was ranges from 0.84 to 2.72 mg/l. The amount of dissolved oxygen in water is dependent on different chemical and microbiological processes. Besides salinity and temperature is also potential factor [26]. Optimum range of DO for good water qualities is within of 4–6 mg/l and DO concentration below this optimum range is expected to be polluted. The mean values of DO of the water samples are ranges from 3.91 to 5.36 mg/l. Biochemical oxygen demand (BOD) represent the amount of oxygen needed for aerobic microorganisms to degrade different organics present in a water [27] and hence BOD acts as an indicator of organic pollution where higher values of BOD indicates higher levels of organic pollution [28]. Present analysis revealed the mean BOD values ranges from 1.88 to 2.63 mg/l. Alkalinity is used to measure the capacity of water to neutralize acid [29]. The mean concentration of alkalinity in water samples of selected pit-lakes are ranges from 22.67 to 33.33 mg/l which is under the BIS prescribed limit of 120 mg/l. The concentrations of phosphate phosphorous in different pit-lakes are ranges from 0.78 to 2.99 mg/l.





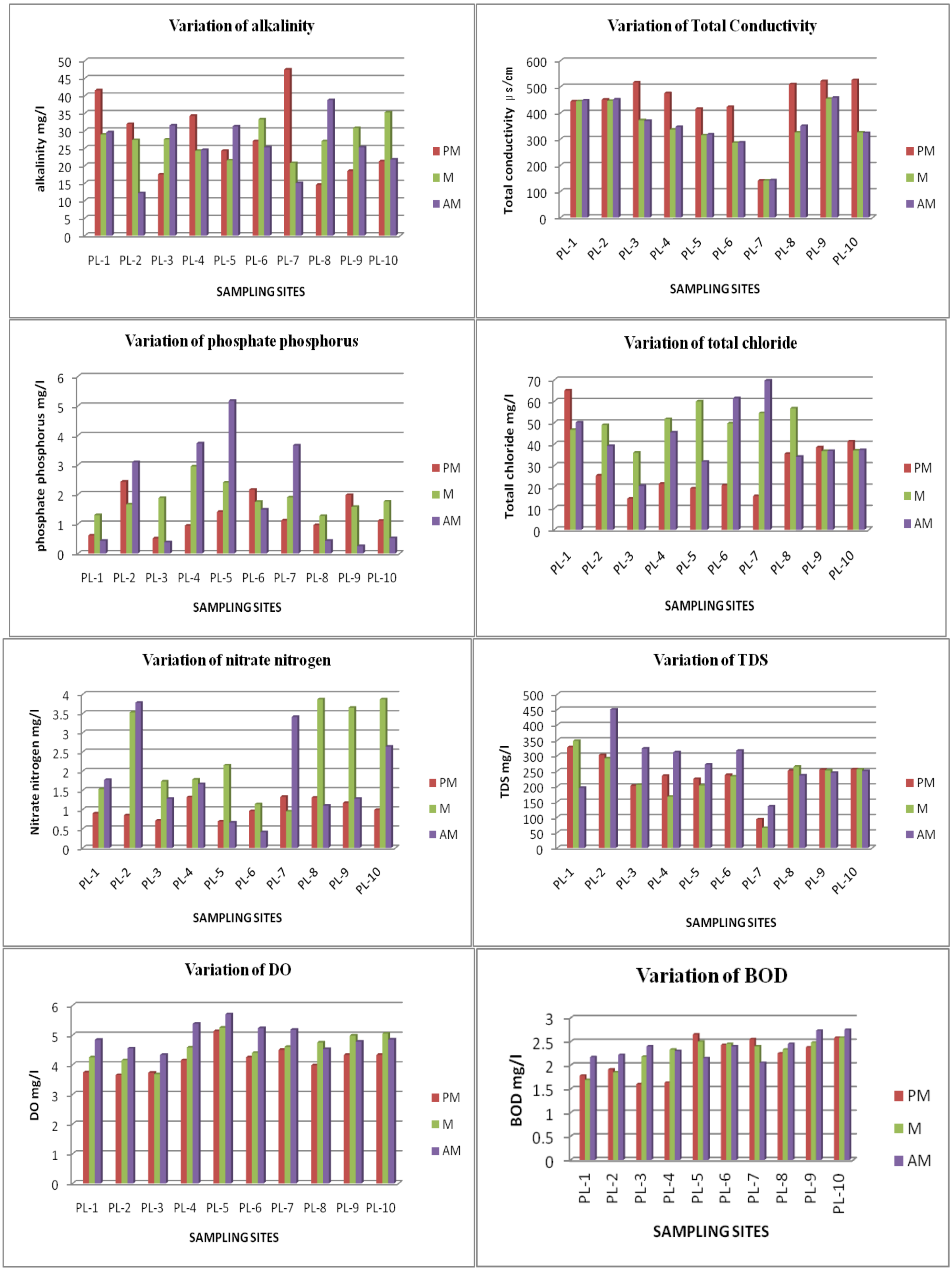


Figure 2: Variation of physicochemical parameters in the study sites.

Season wise observed values of different physicochemical parameters and the corresponding WQI values are presented in tabular form (table 4 to 13). Table 3 represents the standard value of drinking water quality and the unit weights assigned to each parameter used for calculating the WQI. Maximum weight, i.e., 0.641 and 0.128 are assigned to phosphate, DO and BOD respectively, indicates their importance and impact on overall water quality index. Our study showed that most of the sampling sites are fall under very poor and unsuitable water category. The WQI analysis unveiled the fact that pit-lake 5 is the most polluted sites in all seasons (table 15 and figure 3).

Table 3: Relative weights (Wn) and standard value (Vs) of the parameters used for WQI determination

Sl. No.	Parameters	Standard value(Vs)	Unit weight (Wn)
1	pH	6.5-8.5	0.075
2	TH	300	0.0021
3	TC	300	0.0021
4	ALK	120	0.0053
5	TDS	500	0.0012
6	DO	5	0.1282
7	BOD	5	0.1282
8	CHL	250	0.0026
9	PHOS	1.00	0.641
10	NITRO	45	0.0142

Table 4: Calculation of WQI at PL-1

Parameter	**PM**				**M**				**AM**			
	Vn	Qn	Wn	QnWn	Vn	Qn	Wn	QnWn	Vn	Qn	Wn	QnWn
PH	8.83	122	0.075	9.15	7.95	63.3	0.075	4.748	7.47	31.3	0.075	2.348
TH	266.33	88.8	0.002	0.178	97.37	32.5	0.002	0.065	194.67	64.9	0.002	0.129
TC	444.33	148.1	0.002	0.296	445.14	148.4	0.002	0.297	448	149.3	0.002	0.0299
ALK	41.56	34.6	0.005	0.173	28.89	24.1	0.005	0.121	29.55	24.6	0.005	0.123
CL	65.08	26	0.003	0.078	46.69	18.7	0.003	0.056	50.16	20.1	0.003	0.060
PO4	0.61	61	0.641	39.10	1.30	130	0.641	83.33	0.43	43	0.641	27.563
N2	0.90	2	0.014	0.028	1.53	3.4	0.014	0.048	1.77	3.9	0.014	0.055
DO	3.74	113.1	0.128	14.477	4.25	107.8	0.128	13.798	4.84	101.7	0.128	13.018
BOD	1.78	35.6	0.128	4.557	1.69	33.8	0.128	13.798	2.17	43.4	0.128	5.555
TDS	327.67	65.5	0.001	0.066	348.42	69.7	0.001	0.069	195.18	39	0.001	0.039
∑WnQn= 68.103					∑WnQn= 116.33				∑WnQn= 48.92			
∑Wn=0.999					∑Wn=0.999				∑Wn=0.999			
(WQI)= ∑WnQn/ ΣWn= 68.17					(WQI)=∑WnQn/ ΣWn= 116.44				(WQI)= ∑WnQn/ ΣWn= 48.96			

Table 5: Calculation of WQI at PL-2

Parameter	PM				M				AM			
	Vn	Qn	Wn	QnWn	Vn	Qn	Wn	QnWn	Vn	Qn	Wn	QnWn
PH	8.65	110	0.075	8.25	8.68	112	0.075	8.4	8.51	100.7	0.075	7.553
TH	304.5	101.5	0.002	0.203	217.44	72.5	0.002	0.014	261.47	87.2	0.002	0.174
TC	451	150.3	0.002	0.3006	446.5	148.8	0.002	0.296	451.75	150.6	0.002	0.301
ALK	31.92	26.6	0.005	0.133	27.34	22.8	0.005	0.114	12.15	10.1	0.005	0.051
CL	25.32	10.1	0.003	0.030	48.95	19.6	0.003	0.059	39.14	15.7	0.003	0.047
PO4	2.43	24.3	0.641	15.576	1.66	166	0.641	106.406	3.09	309	0.641	198.069
N2	0.85	1.9	0.014	0.027	3.53	7.8	0.014	0.109	3.78	8.4	0.014	0.118
DO	3.65	114.1	0.128	14.605	4.15	108.9	0.128	13.939	4.55	104.7	0.128	13.402
BOD	1.91	38.2	0.128	4.889	1.85	37	0.128	4.736	2.22	44.4	0.128	5.683
TDS	302.25	60.5	0.001	0.061	291.25	58.3	0.001	0.058	450.5	90.1	0.001	0.090
∑WnQn=44.07					∑WnQn=134.13				∑WnQn=225.49			
∑Wn=0.999					∑Wn=0.999				∑Wn=0.999			
(WQI)= ∑WnQn/ ΣWn= 44.11					(WQI)= ∑WnQn/ ΣWn= 134.26				(WQI)= ∑WnQn/ ΣWn= 225.72			

Table 6: Calculation of WQI at PL-3

Parameter	PM				M				AM			
	Vn	Qn	Wn	nWn	Vn	Qn	Wn	QnWn	Vn	Qn	Wn	QnWn
PH	8.76	117.3	0.075	8.7975	7.69	46	0.075	3.45	7.15	10	0.075	0.75
TH	276.5	92.2	0.002	0.1844	243	81	0.002	0.162	346	115.3	0.002	0.2306
TC	517.25	172.4	0.002	0.3448	372.25	124.1	0.002	0.2482	369.5	123.2	0.002	0.2464
ALK	17.5	14.6	0.005	0.073	27.5	22.9	0.005	0.1145	31.5	26.3	0.005	0.1315
CL	14.49	5.8	0.003	0.0174	35.97	14.4	0.003	0.0432	20.48	8.2	0.003	0.0246
PO4	0.51	51	0.641	32.691	1.88	188	0.641	120.508	0.38	38	0.641	24.358
N2	0.71	1.6	0.014	0.0224	1.73	3.8	0.014	0.0532	1.28	2.8	0.014	0.0392
DO	3.73	114.1	0.128	14.6048	3.68	113.8	0.128	14.5664	4.33	106.9	0.128	13.6832
BOD	1.6	32	0.128	4.096	2.18	43.6	0.128	5.5808	2.4	48	0.128	6.144
TDS	202.25	40.5	0.001	0.0405	205.25	41.1	0.001	0.0411	323.5	64.7	0.001	0.0647
∑WnQn=60.87					∑WnQn=144.77				∑WnQn=45.67			
∑Wn=0.999					∑Wn=0.999				∑Wn=0.999			
(WQI)= ∑WnQn/ ΣWn= 60.93					(WQI)= ∑WnQn/ ΣWn= 144.91				(WQI)= ∑WnQn/ ΣWn= 45.72			

Table 7: Calculation of WQI at PL-4

Parameter	PM				M				AM			
	Vn	Qn	Wn	QnWn	Vn	Qn	Wn	QnWn	Vn	Qn	Wn	QnWn
PH	8.41	94	0.075	7.05	7.99	66	0.075	4.95	7.53	35.3	0.075	2.6475
TH	249.25	86	0.002	0.172	193.25	64.4	0.002	0.1288	199.5	66.5	0.002	0.133
TC	475.5	158.5	0.002	0.317	336.5	112.2	0.002	0.2244	346.75	115.6	0.002	0.2312
ALK	34.25	28.5	0.005	0.1425	24.25	20.2	0.005	0.101	24.5	20.4	0.005	0.102
CL	21.48	8.6	0.003	0.0258	51.71	20.7	0.003	0.0621	45.46	22.7	0.003	0.0681
PO4	0.94	94	0.641	60.254	2.95	295	0.641	189.095	3.73	373	0.641	239.093
N2	1.32	2.9	0.014	0.0406	1.78	39.6	0.014	0.5544	1.66	3.7	0.014	0.0518
DO	4.15	108.9	0.128	13.9392	4.58	104.4	0.128	13.3632	5.38	96	0.128	12.288
BOD	1.63	32.6	0.128	4.1728	2.33	46.6	0.128	5.9648	2.3	46	0.128	5.888
TDS	234.75	46.9	0.001	0.0469	166.75	33.8	0.001	0.0338	311.25	62.3	0.001	0.0623
∑WnQn= 86.161					∑WnQn=214.48				∑WnQn=260.565			
∑Wn=0.999					∑Wn=0.999				∑Wn=0.999			
(WQI)= ∑WnQn/ ΣWn= 86.25					(WQI)= ∑WnQn/ ΣWn= 214.69				(WQI)= ∑WnQn/ ΣWn= 260.83			

Table 8: Calculation of WQI at PL-5

Parameter	PM				M				AM			
	Vn	Qn	Wn	QnWn	Vn	Qn	Wn	QnWn	Vn	Qn	Wn	QnWn
PH	8.89	106	0.075	7.95	7.43	28.7	0.075	2.1525	6.84	10.7	0.075	0.8025
TH	196	65.3	0.002	0.1306	197.25	65.6	0.002	0.1312	165	55	0.002	0.11
TC	415.75	138.6	0.002	0.2772	314.75	104.9	0.002	0.2098	317.75	105.9	0.002	0.2118
ALK	24.25	20.2	0.005	0.101	21.5	17.9	0.005	0.0895	31.25	26	0.005	0.13
CL	19.29	7.7	0.003	0.0231	59.97	23.9	0.003	0.0717	31.79	12.7	0.003	0.0381
PO4	1.41	141	0.641	90.381	2.4	240	0.641	153.84	5.17	517	0.641	331.397
N2	0.69	105	0.014	1.47	2.15	4.8	0.014	0.0672	0.66	1.5	0.014	0.021
DO	5.13	98.6	0.128	12.6208	5.25	97.4	0.128	12.4672	5.7	92.7	0.128	11.8656
BOD	2.65	53	0.128	6.784	2.5	50	0.128	6.4	2.15	43	0.128	5.504
TDS	224.5	44.9	0.001	0.0449	203.25	40.7	0.001	0.0407	271.15	54.4	0.001	0.0544
∑WnQn=119.78					∑WnQn= 175.47				∑WnQn= 350.13			
∑Wn=0.999					∑Wn=0.999				∑Wn=0.999			
(WQI)= ∑WnQn/ ΣWn= 191.97					(WQI)= ∑WnQn/ ΣWn= 175.64				(WQI)= ∑WnQn/ ΣWn= 350.48			

Table 9: Calculation of WQI at PL-6

Parameter	PM				M				AM			
	Vn	Qn	Wn	QnWn	Vn	Qn	Wn	QnWn	Vn	Qn	Wn	QnWn
PH	8.39	92.7	0.075	6.9525	7.26	17.3	0.075	1.2975	7.69	46	0.075	3.45
TH	29	9.7	0.002	0.0194	31.5	10.5	0.002	0.021	22	7.3	0.002	0.0146
TC	423	141	0.002	0.282	285.75	95.3	0.002	0.1906	287.25	95.8	0.002	0.1916
ALK	27	22.5	0.005	0.1125	33.25	27.7	0.005	0.1385	25.25	21.0	0.005	0.105
CL	20.79	8.3	0.003	0.0249	49.73	19.9	0.003	0.0597	61.46	24.6	0.003	0.0738
PO4	2.16	216	0.641	138.456	1.75	175	0.641	112.175	1.49	149	0.641	95.509
N2	0.96	2.1	0.014	0.0294	1.14	20.5	0.014	0.287	0.41	0.9	0.014	0.0126
DO	4.25	107.8	0.128	13.7984	4.4	106.3	0.128	13.6064	5.23	97.6	0.128	12.4928
BOD	2.43	48.6	0.128	6.2208	2.45	49	0.128	6.272	2.4	48	0.128	6.144
TDS	237.5	47.5	0.001	0.0475	232.75	46.5	0.001	0.0465	316.5	63.3	0.001	0.0633
∑WnQn= 165.94					∑WnQn= 134.09				∑WnQn= 118.056			
∑Wn=0.999					∑Wn=0.999				∑Wn=0.999			
(WQI)= ∑WnQn/ ΣWn= 166.11					(WQI)= ∑WnQn/ ΣWn= 134.22				(WQI)= ∑WnQn/ ΣWn= 118.17			

Table 10: Calculation of WQI at PL-7

Parameter	PM				M				AM			
	Vn	Qn	Wn	QnWn	Vn	Qn	Wn	QnWn	Vn	Qn	Wn	QnWn
PH	7.08	5.3	0.075	0.3975	7.97	64.7	0.075	4.8525	6.79	14	0.075	1.05
TH	267	89	0.002	0.178	266.5	88.8	0.002	0.1776	216.75	72.3	0.002	0.1446
TC	141	47	0.002	0.094	141.25	47.1	0.002	0.0942	142.5	47.5	0.002	0.095
ALK	47.5	39.6	0.005	0.198	20.75	17.3	0.005	0.0865	15	12.5	0.005	0.0625
CL	15.74	6.3	0.003	0.0189	54.49	21.8	0.003	0.0654	69.69	27.9	0.003	0.0837
PO4	1.12	112	0.641	71.792	1.90	190	0.641	121.79	3.66	366	0.641	234.606
N2	1.33	2.9	0.014	0.0406	0.95	2.1	0.014	0.0294	3.41	7.6	0.014	0.1064
DO	4.5	105.2	0.128	13.4656	4.6	104.2	0.128	13.3376	5.18	98.1	0.128	12.5568
BOD	2.55	51	0.128	6.528	2.4	48	0.128	6.144	2.05	41	0.128	5.248
TDS	93.25	18.7	0.001	0.0187	65.11	13.0	0.001	0.013	135.25	27.1	0.001	0.0271
∑WnQn=92.73					∑WnQn=146.59				∑WnQn=253.98			
∑Wn=0.999					∑Wn=0.999				∑Wn=0.999			
(WQI)= ∑WnQn/ ΣWn= 92.82					(WQI)= ∑WnQn/ ΣWn= 146.74				(WQI)= ∑WnQn/ ΣWn= 254.23			

Table 11: Calculation of WQI at PL-8

Parameter	PM				M				AM			
	V_n	Q_n	Wn	Q_nW_n	V_n	Q_n	Wn	Q_nW_n	V_n	Q_n	Wn	Q_nW_n
PH	8.13	75.3	0.075	5.6475	8.06	70.7	0.075	5.3025	7.53	35.3	0.075	2.6475
TH	312.5	104.2	0.002	0.2084	109.5	36.5	0.002	0.073	98	32.7	0.002	0.0654
TC	510	170	0.002	0.34	325.25	108.4	0.002	0.2168	350.75	116.9	0.002	0.2338
ALK	14.5	12.1	0.005	0.0605	27	22.5	0.005	0.1125	38.75	32.3	0.005	0.1615
CL	35.48	14.2	0.003	0.0426	56.74	22.7	0.003	0.0681	34.07	13.6	0.003	0.0408
PO4	0.96	96	0.641	61.536	1.27	127	0.641	81.407	0.43	4.3	0.641	2.7563
N2	1.31	2.9	0.014	0.0406	3.87	8.6	0.014	0.1204	1.1	2.4	0.014	0.0336
DO	3.98	110.6	0.128	14.1568	4.75	102.6	0.128	13.1328	4.53	104.9	0.128	13.4272
BOD	2.25	45	0.128	5.76	2.33	46.6	0.128	5.9648	2.45	49	0.128	6.272
TDS	251.75	50.4	0.001	0.0504	264.5	52.9	0.001	0.0529	235.75	47.2	0.001	0.0472
∑WnQn=87.84					∑WnQn=106.45				∑WnQn=25.69			
∑Wn=0.999					∑Wn=0.999				∑Wn=0.999			
(WQI)= ∑WnQn/ ΣWn= 87.93					(WQI)= ∑WnQn/ ΣWn= 106.55				(WQI)= ∑WnQn/ ΣWn= 25.72			

Table 12: Calculation of WQI at PL-9

Parameter	PM				M				AM			
	Vn	Qn	Wn	QnWn	Vn	Qn	Wn	QnWn	Vn	Qn	Wn	QnWn
PH	8.37	91.3	0.075	6.8475	8.23	82	0.075	6.15	7.85	56.7	0.075	4.2525
TH	288.75	96.3	0.002	0.1926	179.5	59.8	0.002	0.1196	114.25	38.1	0.002	0.0762
TC	521.5	173.8	0.002	0.3476	454.5	151.5	0.002	0.303	458.25	152.8	0.002	0.3056
ALK	18.5	15.4	0.005	0.077	30.75	25.6	0.005	0.128	25.25	29.4	0.005	0.147
CL	38.49	15.4	0.003	0.0462	36.75	14.7	0.003	0.0441	36.83	14.7	0.003	0.0441
PO4	1.98	118	0.641	75.638	1.58	158	0.641	101.278	0.25	25	0.641	16.025
N2	1.17	2.6	0.014	0.0364	3.65	8.1	0.014	0.1134	1.28	2.8	0.014	0.0392
DO	4.33	106.9	0.128	13.6832	4.98	100.2	0.128	12.8256	4.78	102.3	0.128	13.0944
BOD	2.38	47.6	0.128	6.0928	2.48	49.6	0.128	6.3488	2.73	54.6	0.128	6.9888
TDS	254.75	50.9	0.001	0.0509	252.5	50.5	0.001	0.0505	244.25	48.9	0.001	0.0489
∑WnQn=103.01					∑WnQn=127.36				∑WnQn=41.02			
∑Wn=0.999					∑Wn=0.999				∑Wn=0.999			
(WQI)= ∑WnQn/ ΣWn= 103.11					(WQI)= ∑WnQn/ ΣWn= 127.49				(WQI)= ∑WnQn/ ΣWn= 41.06			

Table 13: Calculation of WQI at PL-10

Parameter	PM				M				AM			
	Vn	Qn	Wn	QnWn	Vn	Qn	Wn	QnWn	Vn	Qn	Wn	QnWn
PH	8.16	77.3	0.075	5.7975	7.84	55.3	0.075	4.1475	7.68	45.3	0.075	3.3975
TH	315.5	105.2	0.002	0.2104	445	38.3	0.002	0.0766	123	41	0.002	0.082
TC	525.75	175.3	0.002	0.3506	325.5	108.5	0.002	0.217	323.5	107.8	0.002	0.2156
ALK	21.25	18.1	0.005	0.0905	35.25	29.4	0.005	0.147	21.75	18.1	0.005	0.0905
CL	41.22	16.5	0.003	0.0495	37.01	14.8	0.003	0.0444	37.22	14.9	0.003	0.0447
PO4	1.11	111	0.641	71.151	1.76	176	0.641	112.816	0.52	52	0.641	33.332
N2	0.99	2.2	0.014	0.0308	3.87	8.6	0.014	0.1204	2.64	5.9	0.014	0.0826
DO	4.33	106.9	0.128	13.6832	5.05	99.5	0.128	12.736	4.85	101.6	0.128	13.0048
BOD	2.58	51.6	0.128	6.6048	2.58	51.6	0.128	6.6048	2.75	55	0.128	7.04
TDS	255.75	51.2	0.001	0.0512	255.5	51.1	0.001	0.0511	250.25	50.1	0.001	0.0501
	∑WnQn=98.02				ΣWn Qn=136.96				∑WnQn=57.34			
	∑Wn=0.999				∑Wn=0.999				∑Wn=0.999			
	(WQI)= ∑WnQn/ ΣWn= 98.12				(WQI)= ∑WnQn/∑Wn= 137.09				(WQI)= ∑WnQn/ ΣWn= 57.39			

Table 14: WQI range and status of the water sample [10]

WQI	Water quality status	Possible usage
0-25	Excellent	Drinking, irrigation and industrial
26-50	Good	Drinking, irrigation and industrial
51-75	Poor	Irrigation and industrial
76-100	Very poor	Irrigation
Above 100	Unsuitable for fish culture and drinking	Treatment is needed before any use

Table 15: Summary of WQI of the Pit-lakes

Sampling station	PM		M		AM	
	WQI	WQS	WQI	WQS	WQI	WQS
PL-1	68.17	POOR	116.44	UNSUITABLE	48.96	GOOD
PL-2	44.11	GOOD	134.26	UNSUITABLE	225.72	UNSUITABLE
PL-3	60.93	POOR	144.91	UNSUITABLE	45.72	GOOD
PL-4	86.25	VERY POOR	214.69	UNSUITABLE	260.83	UNSUITABLE
PL-5	191.97	UNSUITABLE	175.64	UNSUITABLE	350.48	UNSUITABLE
PL-6	166.11	UNSUITABLE	134.22	UNSUITABLE	118.17	UNSUITABLE
PL-7	92.82	VERY POOR	146.74	UNSUITABLE	254.23	UNSUITABLE
PL-8	87.84	VERY POOR	106.45	UNSUITABLE	25.72	GOOD
PL-9	103.11	UNSUITABLE	127.49	UNSUITABLE	41.06	GOOD
PL-10	98.12	VERY POOR	137.09	UNSUITABLE	57.39	POOR

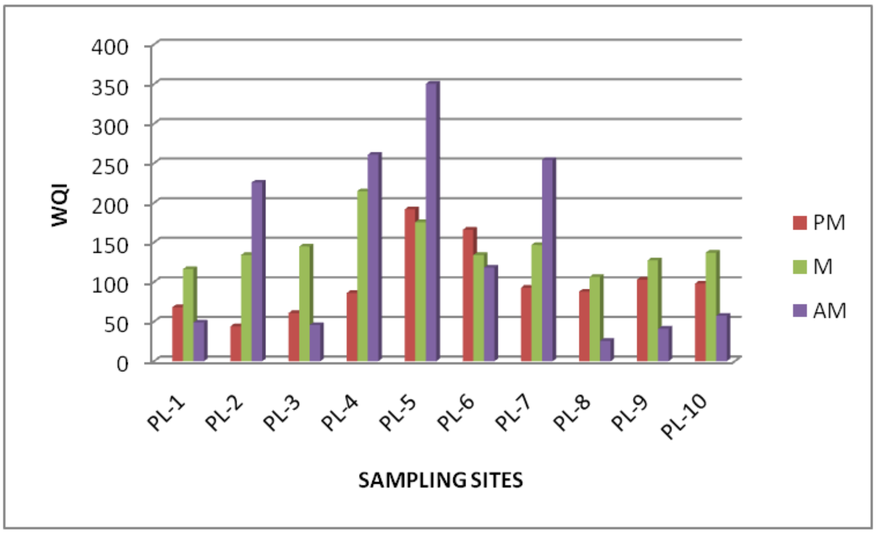


Figure 3: WQI status in different study sites.

Correlation coefficient analysis among the chemical parameters of selected ten pit-lakes shows significant relationships among the variables (Table 16). pH shows positive correlation with TC and TDS. TC is also positively correlated with TDS. Positive correlation is also exhibited between ALK and CHL and DO with BOD.

Table 16: **Correlation matrix of water quality parameters of studied pit-lakes**

	ph	Total hardness	Total conductivity	Alkalinity	Chloride	phosphate	nitrogen	TDS	DO	BOD
ph	1									
Total hardness	0.151448	1								
Total conductiv	0.847968	0.045821844	1							
Alkalinity	-0.24544	-0.352880518	-0.114182077	1						
Chloride	-0.1161	-0.4041447	-0.255143024	0.666958	1					
phosphate	-0.13601	0.017876631	-0.429091878	-0.47739	-0.05149	1				
nitrogen	0.44323	0.440621512	0.176615396	-0.25534	0.008811	-0.097058825	1			
TDS	0.897313	0.023314676	0.64261585	0.030555	0.085588	-0.081828355	0.376358	1		
DO	-0.46809	-0.387456421	-0.392086978	-0.07954	0.157446	0.546961419	-0.18154	-0.51386	1	
BOD	-0.39808	-0.437279752	-0.241690427	-0.08218	-0.11912	-0.015252719	0.103088	-0.46592	0.638127	1

Principal component Principal component analysis was performed to extract the most crucial factors regulating the water quality. The first principal component accounts for 36.10% of total variance. The variables that correlate the most with the first principal component (PC1) are DO (0.339) and BOD (0.305) (table 17). These two variables show positive correlation with the first principal component. The first five principal components describe 94.20% of the variation in the data. Therefore these components are good contributor of the water hydrology. Figure 4 highlights the loading plot of first two principal components. DO and BOD has positive loadings on first component whereas PH, TC and TDS have negative loadings on first components. ALK and CHL have large negative loadings on second component

Table 17: Loadings of 10 experimental variables on principal components for selected pit lakes Eigen analysis of the Correlation Matrix

Eigenvalue	**3.6100**	**2.1336**	**1.3833**	**1.2159**	**1.0734**	**0.3490**	**0.2154**	**0.0171**	**0.0023**	**0.0000**
Proportion	0.361	0.213	0.138	0.122	0.107	0.035	0.022	0.002	0.000	0.000
Cumulative	0.361	0.574	0.713	0.834	0.942	0.977	0.998	1.000	1.000	1.000

Eigenvectors

Variable	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8	PC9	PC10
PH	-0.479	0.017	0.326	-0.114	-0.055	0.086	-0.078	0.373	0.341	-0.616
TC	-0.415	-0.056	0.303	0.251	-0.263	0.509	-0.095	-0.257	0.178	0.484
TH	-0.217	0.360	-0.520	-0.025	0.296	0.450	0.225	0.430	-0.023	0.163
ALK	0.084	-0.626	-0.136	0.025	0.123	0.184	0.627	-0.135	0.327	-0.125
CHL	0.108	-0.504	0.082	-0.419	0.347	0.165	-0.493	0.297	0.021	0.269
PHOS	0.179	0.370	0.146	-0.662	-0.133	-0.059	0.221	-0.110	0.480	0.245
NITRO	-0.239	0.186	0.170	0.015	0.792	-0.084	-0.024	-0.487	0.056	-0.065
TDS	-0.437	-0.138	0.271	-0.282	-0.012	-0.284	0.436	0.164	-0.528	0.244
DO	0.399	0.136	0.411	-0.136	0.038	0.590	0.149	-0.064	-0.425	-0.278
BOD	0.305	0.111	0.462	0.460	0.242	-0.173	0.192	0.472	0.225	0.266

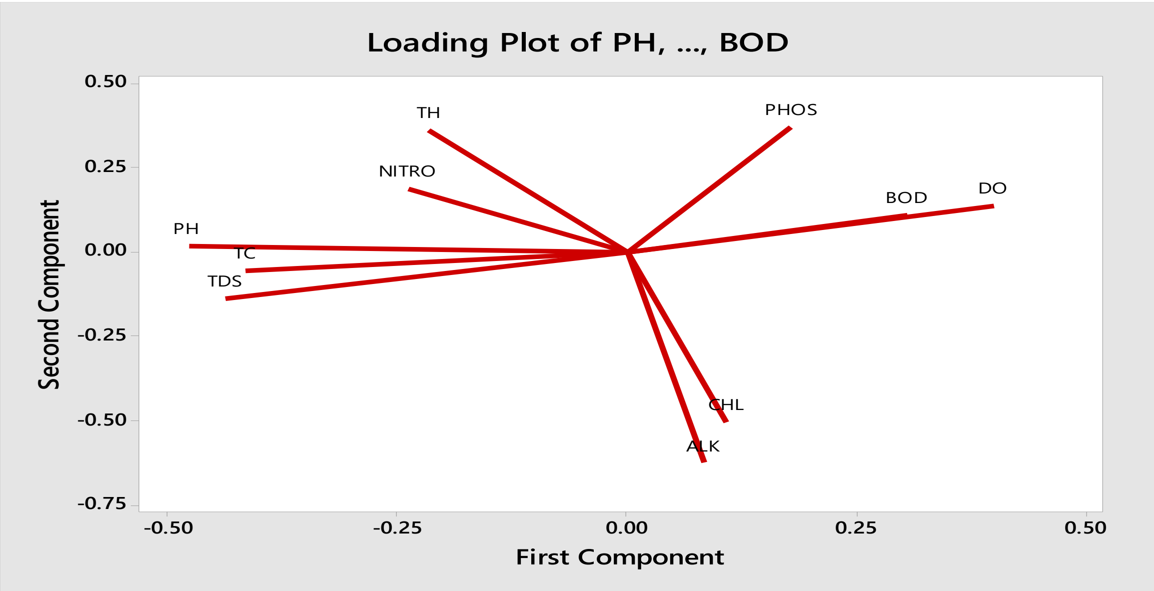


Figure 4: Loading plot of different physicochemical parameters

4. CONCLUSION

Water quality monitoring is an important criterion to match the demand and supply of water for different purposes. Supply of sufficient freshwater to mitigate the needs of society is considered to be integral part of sustainable environmental management [30, 31]. For this purpose, various indices regarding water quality have been used to transform different water quality parameters into a single value which is simple and easy to interprets water quality index is generated by combination of different physicochemical parameters [32, 33]. The present findings stated that there is a significant difference in the physicochemical parameters of pit lake water bodies among different season and over all study indicate that the health condition of most pit lakes are significantly inferior. Based on the WQI, all the pit lakes are unsuitable for use in the monsoon season. The outcomes of this investigation might contribute in management policies of these huge water bodies. This study can also be useful to evolve strategies for an ecological restoration, conservation and management.

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CONFLICT OF INTEREST

The authors declare no conflict of interest

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