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Annual and seasonal variations in hydrochemistry and nutrient dynamics of two irrigation reservoirs of central Gujarat, India

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Abstract

This study reports the annual and seasonal changes in water quality of two reservoirs inundated with Narmada river water in Vadodara district, Gujarat, India. Surface water samples were collected on seasonal basis from February 2009 to January 2011 and were analyzed for 15 water quality parameters. Most significant parameters which contributed in annual and seasonal variations were assessed by Principal Components/Factor Analysis (PCA/FA) which identified three factors with86.11% and 80.56% of the total variance of the sampled data at TIR and JIR respectively. Results of this study demonstrate that the water quality of wetlands has a direct and close association with the surrounding environment.

Keywords: Irrigation reservoirs, water quality, physico-chemical parameters, annual variations, seasonal variations, PCA/FA.

Introduction

Freshwater bodies represent approximately 30% of the global surface area, despite their extensive loss in some countries[1]. Many of these are built for irrigation, flood protection and water supply[2,3] which play an important role in environmental niche formation. Ponds and shallow reservoirs are exceptionally rich in terms of biodiversity [4,5]and recently have been recognized as important habitats for the same[6]. In comparison to ponds, small reservoirs are larger and thus temporarily more stable. They are also valuable in protecting surface water quality in agricultural landscapes as their hydrocoenoses help in sanitizing polluted waters that drain into such reservoirs from the surroundings. The effects of water chemistry on biodiversity have been extensively studied[7-11] and studies have suggested the relative importance of other environmental variables such as hydrology[12], food availability[13], nutrient enrichment, fish[14] and land use[15] as well.

In recent years the assessment of water for its quality has become a critical issue; especially due its recognition as scarce resource for the future[16,17,18,19].Water quality monitoring is a helpful tool to evaluate the impacts of pollution sources and also ensures the effective management and protection of aquatic life that the water body supports[20].Moreover, the changes in the key physical and chemical parameters at landscape scale are known to affect the food web at primary and secondary production levels eventually altering the corresponding aquatic community and ecosystem attributes such as species richness, distribution, dispersal and biodiversity[21].

Thus, water quality serves as an important indicator for characterizing the effects of land use on these water bodies, and their management and conservation as well. The seasonal changes in the environment with anthropogenic pressures change the quality of water bodies, especially in the semi-arid zone where such changes are pronounced[7]. The water level in these reservoirs changes seasonally each year and can vary dramatically over longer periods. Particular water quality parameters are considered as indicators of specific anthropogenic stressors, such as nitrogen (N) and phosphorous (P) for agricultural run-off, and chloride (Cl^-) for pollution[22]. Carbon and nitrogen are significant parameters due to their high content in all dissolved organic matter.

India is facing a serious predicament of natural resource scarcity especially that of water in view of population growth and economic development[23]. Water, a major natural resource and a basic human need, needs appropriate management for its quality. Due to considerable development of industry and agriculture the aquatic ecosystems have become perceptibly altered in several aspects in recent years and as such they are exposed to local incongruity as well[24]. Hence monitoring of water quality becomes the prime element that can direct the proper management and conservation of such ecosystems. Further, it also becomes necessary to understand the influence of seasonal variations on the quality of water in the surrounding water bodies. Therefore our study includes evaluation of two reservoirs in the semi-arid zone of Central Gujarat, India which originally were monsoon dependent but since turn of the century have been inundated with water from Narmada, the fifth longest river of India.A previous study on the water quality of these reservoirs was carried out in 2005-2007 when the inundation from Narmada had just started[7,25]. Before inundation these were seasonal wetlands with short hydroperiods and low human movements. After almost a decade of inundation, human activities around both the reservoirs have increased noticeably. Thus, the present study was undertaken to understand the influence of environmental changes and influence of Narmada inundation on the hydrochemical properties of water of the two different reservoirs situated in the semi-arid zone of Gujarat, India. The aim of our study was to investigate the influence of seasons and role of Narmada inundation on the physico-chemical characteristics of water at these reservoirs.

Materials and methods

Study sites: Timbi Irrigation Reservoir (TIR- 22°18' 49" N to 22°18' 53 " N longitude and 73°17' 11" E to 73°17' 22" E latitude) is located about 10 kilometers East of Vadodara city. This reservoir was constructed by His Highness Shrimant Maharaja Sir Sayajirao Gaekwad III of erstwhile State of Baroda in 1947-48 near village Shripor Timbi of Waghodia Taluka, District Vadodara. With an area of about 41 hectares, the water from this reservoir is supplied to agricultural fields of eight villages surrounding Shripor Timbi village. It has an earthen dam which has a periphery of approximately 5 kilometers. Due to urban expansion, usage of water for irrigation purposes and other activities like washing clothes, etc. the reservoir is now under threat. As the city is expanding and people are moving out of the city limits, many residential areas and education campuses are coming up in the area which are likely to produce undesirable impacts in the serene area surrounding the reservoir. The second irrigation reservoir *i.e.* Jawla Irrigation Reservoir (JIR -22^o 33' 21" N to 22^o 33' 25" N and 73^o 14' 22" E to 73^o 14' 28" E) is located a kilometer away on the South-West side of Savli town and East side of Jawla village. In recent years anthropogenic activities have increased around JIR due to development of a residential area for translocated villages due to Narmada dam. JIR is totally surrounded by the agricultural fields. It has a temple on earthen dam of 2 kilometers which marks the western boundary. Both of these monsoon dependent reservoirs are now inundated with Narmada water.

Sampling and chemical analysis: Water samples were collected monthly for two consecutive years from February 2009 to March 2011. At each reservoir, 6 surface water samples of 1 litre each were collected as replicates using bottles that were pre-rinsed with sample water. The samples were analysed for 15 parameters that include water temperature (WT), water cover (WC), pH, dissolved oxygen (DO), free carbon dioxide (CO_2), acidity (Acidity), total alkalinity (T-Alk), Kjeldahl nitrogen (KN), nitrate nitrogen (NO_3–N), nitrite nitrogen (NO_2–N), total phosphorus (TP), inorganic phosphates (PO_4–P), chloride (Cl), salinity and sulphates (SO_4). Water temperature (ºC) and water cover were measured on the field itself. Dissolved oxygen was fixed on field and brought to the laboratory with sample water for further analysis. The samples were kept in refrigeration (4ºC) until chemical analysis was carried out.To analyze physico-chemical parameters standard methods[26-28] were used. All of the water quality parameters were expressed in milligrams per litre (mg/1), except WT (°C), pH and water cover (%). For analyzing seasonal variations, data was divided for four seasons as summer (March to May), monsoon (June to August), post-monsoon (September to November) and winter (December to February).

Data analysis: Total 3 visits were made per season at both the water bodies, amounting to 24 visits per site in two years. t-test and Analysis of variance (ANOVA) were performed to analyse the significant annual and seasonal differences ($p<0.05$) respectively using Graph Pad Prism 5 software and Microsoft Excel. Relationships among the considered variables were tested using Pearson's correlation with statistical significance ($p<0.05$) (Table-3 and 4) using SPSS 19.0 software (IBM Co. Ltd, USA).

Multivariate analysis of the water quality data structure was performed using PCA/FA techniques (using XLSTAT)[13,17-19,29,30,32,33]. Standardisation of the experimental data was carried out before PCA and FA was applied[17,31,34].

Table-1: Loadings of experimental variables (15) on the first three rotated PCs for complete data set of TIR

Variables	VF1	VF2	VF3
KN	0.984*	-0.098	-0.151
TP	-0.136	-0.503	0.854*
IP	0.905*	0.405	0.131
NO_2	0.348	0.916*	0.200
NO_3	0.994*	-0.109	-0.018
SO_4	-0.127	0.976*	0.178
DO	-0.239	0.943*	-0.231
CL	0.150	0.989*	-0.007
Salinity	0.150	0.989*	-0.008
Acidity	-0.060	0.826*	-0.560
TA	0.984*	0.088	-0.156
Free CO_2	-0.983*	-0.069	-0.171
pH	0.795*	-0.591	0.139
WT	0.093	0.360	0.928*
WC	-0.987*	-0.153	-0.048

Values marked * indicate significance levels $p<0.05$.

Table-2: Loadings of experimental variables (15) on the first three rotated PCs for complete data set of JIR

Variables	VF1	VF2	VF3
KN	0.954*	0.108	0.281
TP	0.515	0.852*	-0.097
IP	-0.109	0.972*	-0.206
NO_2	-0.897*	-0.115	-0.426
NO_3	0.275	0.955*	0.114
SO_4	0.018	0.998*	0.068
DO	0.059	-0.781*	0.621
Cl	0.949*	-0.037	-0.313
Salinity	0.949*	-0.037	-0.313
Acidity	0.223	0.214	-0.951*
TA	-0.931*	-0.176	0.321
Free CO_2	-0.331	-0.585	0.740*
pH	-0.006	0.198	0.980*
WT	-0.710*	0.700	-0.076
WC	0.894*	0.261	-0.364

Values marked * indicate significance levels p<0.05

Table-3: Correlation matrix for physico-chemical characteristics of water at TIR.

Para-meter	Acidity	Cl	CO_2	DO	TA	IP	KN	NO_3	NO_2	pH	Salinity	SO_4	WT	TP	WC
Acidity	1.000														
Cl	0.399**	1.000													
CO2	0.363**	0.106	1.000												
DO	0.014	0.127	-0.374**	1.000											
TA	0.454**	0.201*	0.186	-0.258*	1.000										
IP	0.339**	0.235*	0.297**	-0.030	0.219*	1.000									
KN	0.279**	0.293**	0.154	0.265*	0.081	0.072	1.000								
NO3	0.313**	0.197	0.614**	-0.409**	0.188	0.270*	0.450**	1.000							
NO2	0.372**	0.258	0.142	-0.047	0.245*	0.037	0.056	0.000	1.000						
pH	0.087	-0.284**	0.348**	-0.232*	-0.157	0.120	0.169	0.269*	-0.103	1.000					
Salinity	0.399**	1.000**	0.106	0.127	0.201*	0.235*	0.293**	0.197	0.258*	-0.284**	1.000				
SO4	0.394**	0.225	0.301**	-0.252*	0.291*	0.349**	0.505**	0.508**	0.119	0.282*	0.225	1.000			
WT	0.272	0.177	0.495*	-0.569**	-0.102	0.236	0.192	0.306	0.061	0.283	0.177	0.238	1.000		
TP	0.146	0.139	0.022	0.220*	0.323**	0.115	-0.006	-0.142	0.209*	-0.384**	0.139	-0.256*	-0.383	1.000	
WC	0.160	0.152	-0.516*	0.534**	0.148	0.015	0.216	-0.156	-0.034	-0.306	0.152	0.360	-0.070	-0.380	1.000

Values with * are different from 0 with a significance level alpha=0.05

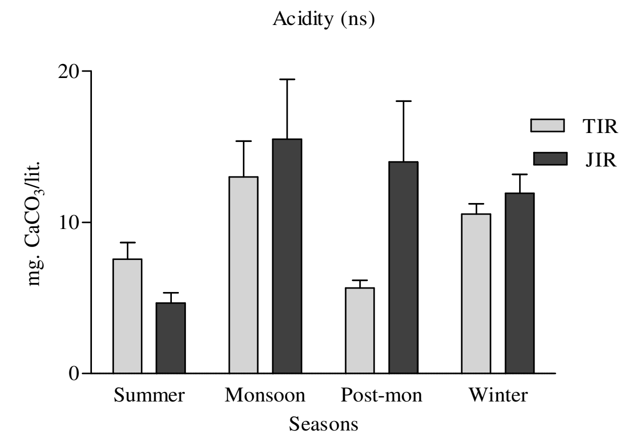
Table-4: Correlation matrix for physico-chemical characteristics of water at JIR.

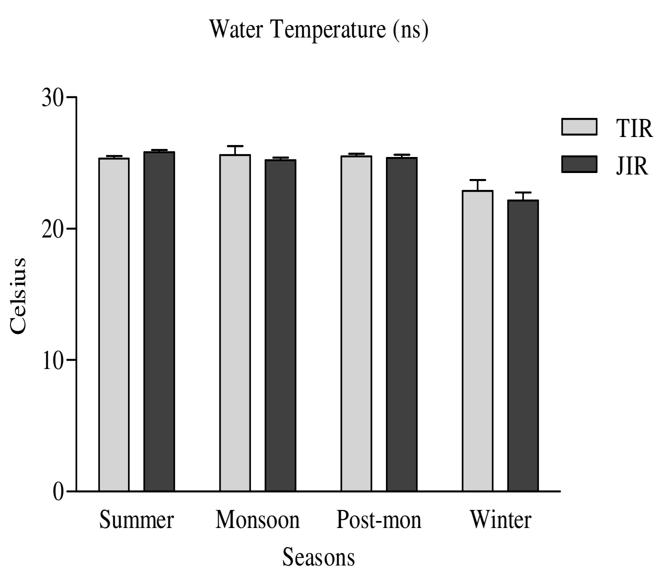
Para-meter	Acidity	Cl	CO_2	DO	TA	IP	KN	NO_3	NO_2	pH	Salinity	SO_4	WT	TP	WC
Acidity	1.000														
Cl	-0.344**	1.000													
CO2	0.283*	-0.075	1.000												
DO	-0.147	0.169	-0.338**	1.000											
TA	0.290*	0.009	0.476**	-0.153	1.000										
IP	-0.222	0.151	-0.037	0.242*	-0.019	1.000									
KN	0.099	0.083	-0.037	0.138	-0.119	-0.133	1.000								
NO3	0.055	0.055	0.037	-0.265*	0.231	-0.116	-0.101	1.000							
NO2	0.595**	-0.193	0.078	-0.087	0.323**	-0.095	-0.075	0.121	1.000						
pH	-0.075	0.018	-0.280*	-0.062	0.010	0.020	-0.113	-0.076	0.052	1.000					
Salinity	-0.344**	1.000**	-0.075	0.169	0.009	0.151	0.083	0.055	-0.193	0.018	1.000				
SO4	0.045	0.192	0.002	0.174	0.235*	-0.055	0.028	-0.073	0.373**	0.136	0.192	1.000			
WT	0.122	-0.383	-0.107	0.239	-0.289	0.011	0.133	0.596**	0.118	-0.348	-0.383	-0.030	1.000		
TP	-0.045	-0.133	0.007	0.314**	-0.166	-0.045	0.155	-0.333*	-0.211	-0.162	-0.133	-0.250*	-0.417	1.000	
WC	-0.221	0.765**	0.308	0.015	0.683**	0.083	-0.459*	-0.256	-0.046	0.298	0.765**	0.307	-0.234	-0.202	1.000

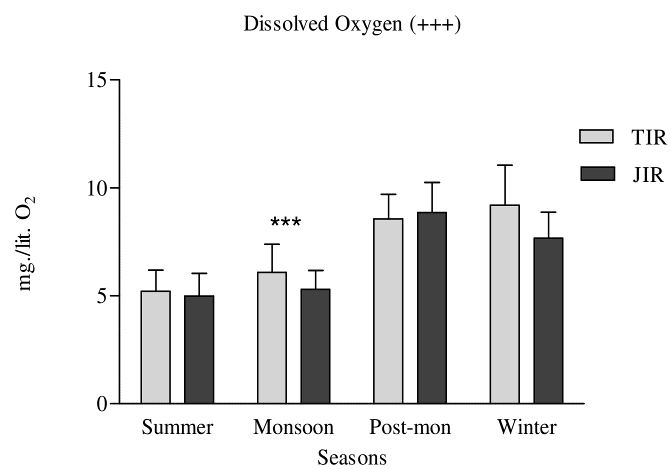
Values with * are different from 0 with a significance level alpha=0.05

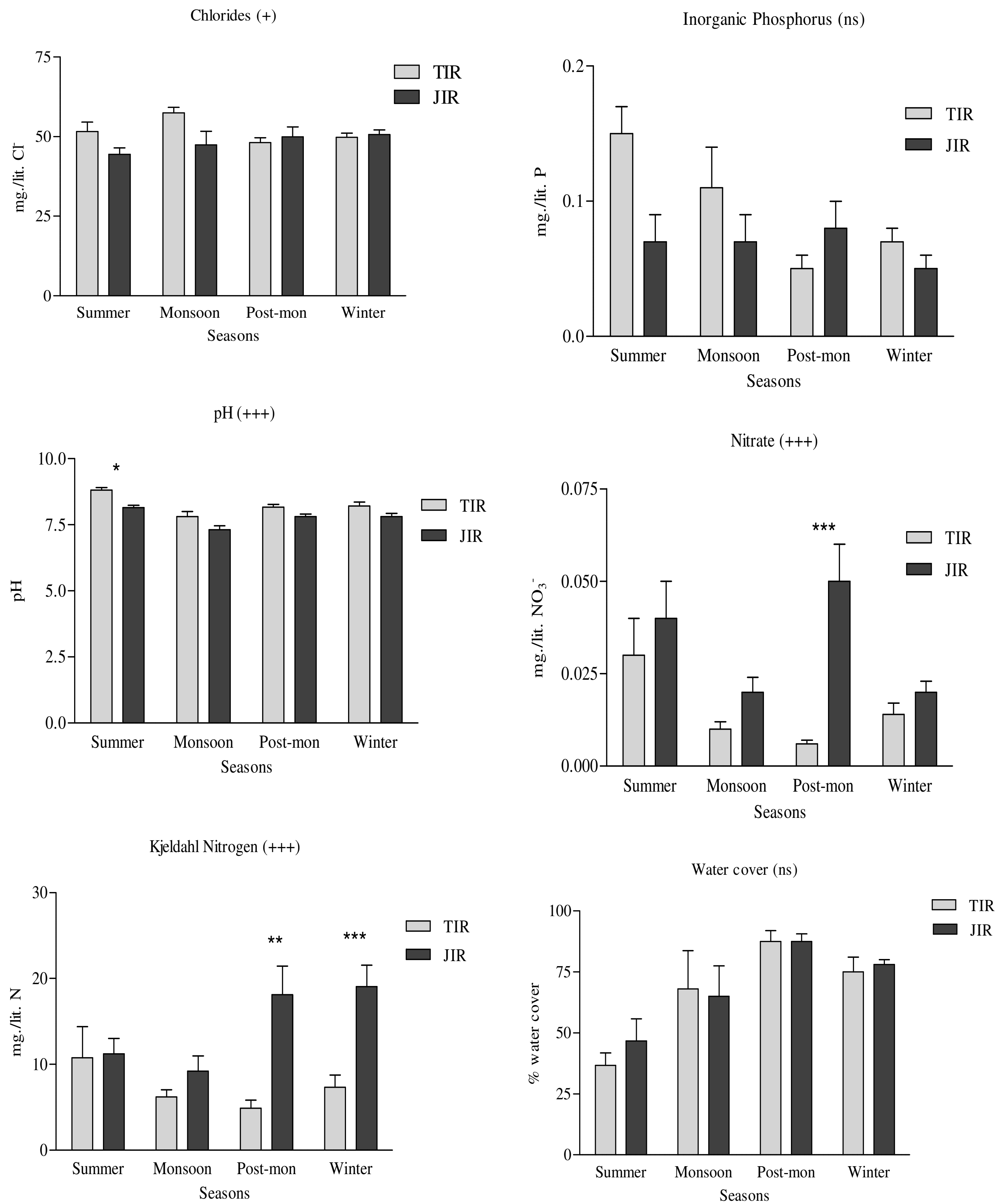
Results and discussion

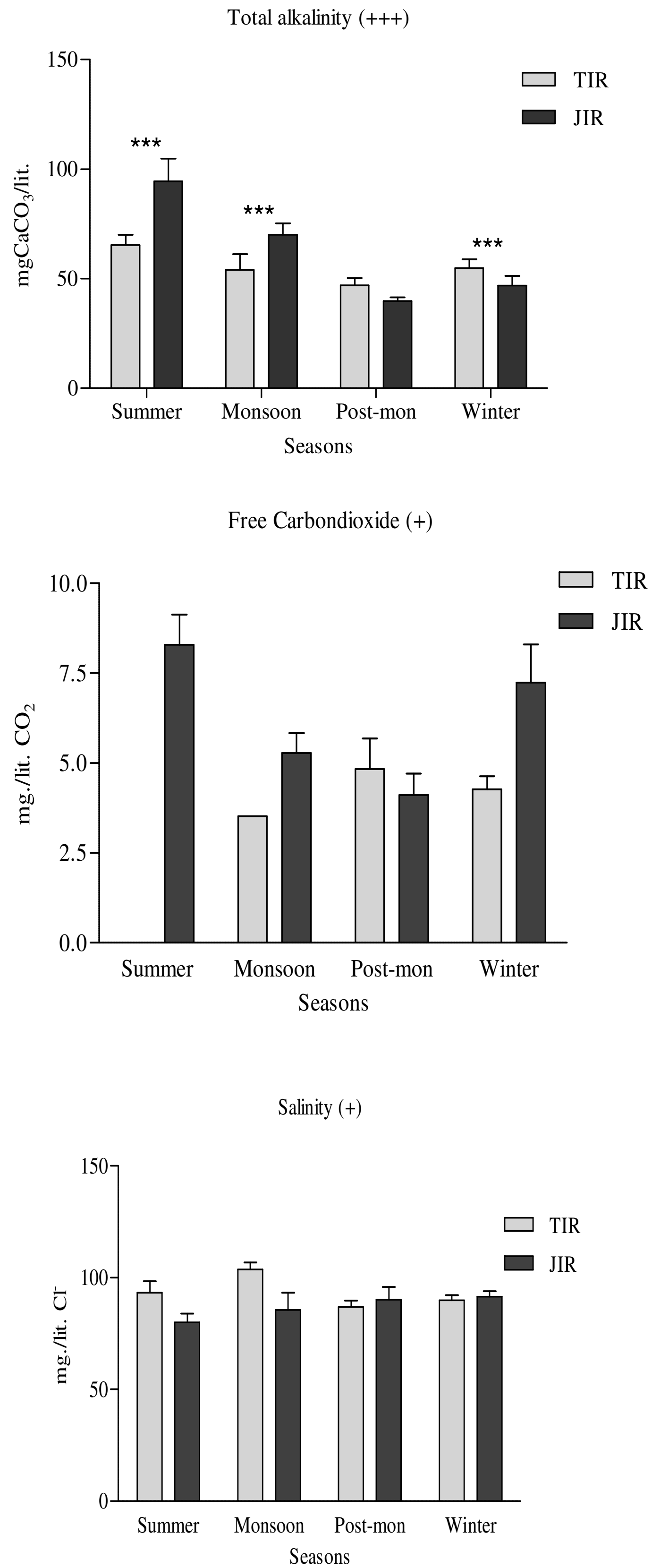
The basic statistics for all of the water quality parameters measured during the sampling period of two years at two reservoirs are summarized in Figure-1. Most water quality parameters except water temperature, water cover, acidity and inorganic phosphates showed significant annual variations ($p<0.05$). However, seasonal differences were noted for total alkalinity, dissolved oxygen, pH, sulphates, Kjeldahl nitrogen, total phosphates, nitrites and nitrates during various seasons.

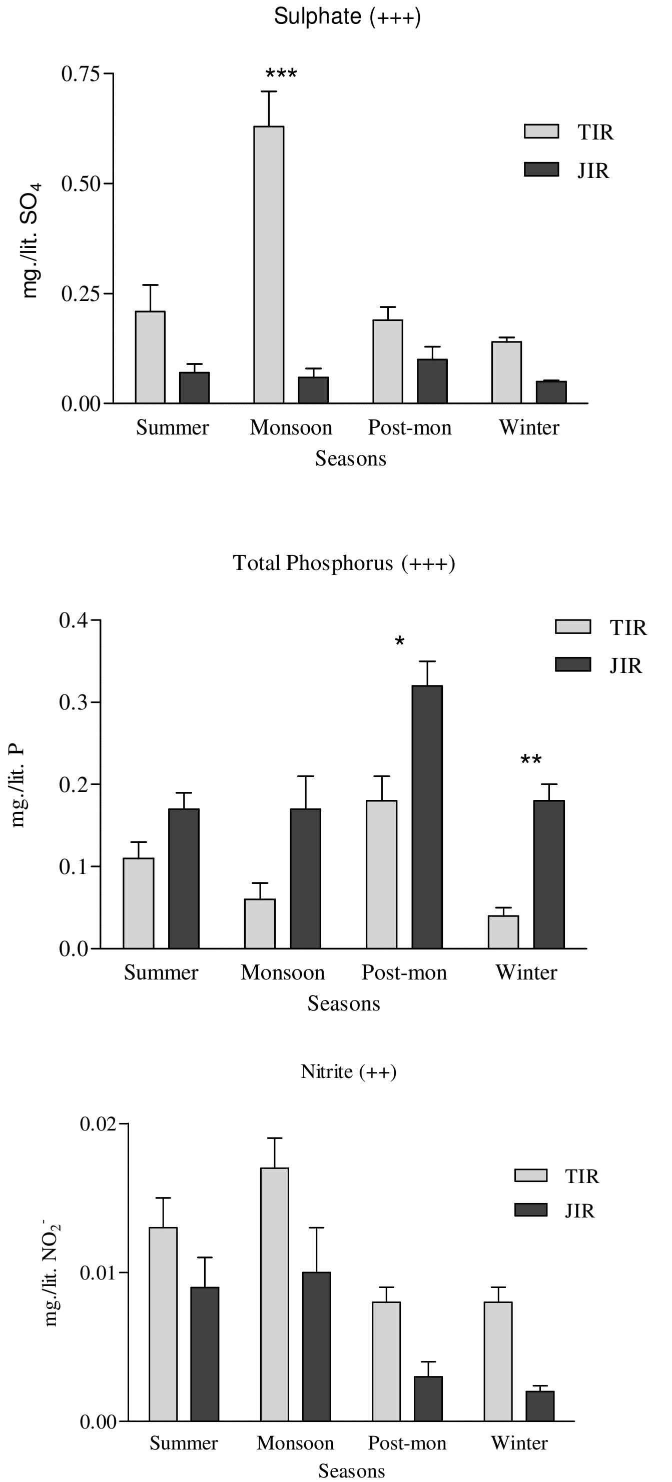







Chlorides (+)
TIR
JIR
mg./lit. Cl⁻
75
50
25
0
Summer
Monsoon
Post-mon
Winter
Seasons
Inorganic Phosphorus (ns)
TIR
JIR
mg./lit. P
0.2
0.1
0.0
Summer
Monsoon
Post-mon
Winter
Seasons
pH (+++)
*
TIR
JIR
pH
10.0
7.5
5.0
2.5
0.0
Summer
Monsoon
Post-mon
Winter
Seasons
Nitrate (+++)
***
TIR
JIR
mg./lit. NO3⁻
0.075
0.050
0.025
0.000
Summer
Monsoon
Post-mon
Winter
Seasons
Kjeldahl Nitrogen (+++)
**
***
TIR
JIR
mg./lit. N
30
20
10
0
Summer
Monsoon
Post-mon
Winter
Seasons
Water cover (ns)
TIR
JIR
% water cover
100
75
50
25
0
Summer
Monsoon
Post-mon
Winter
Seasons





+ denotes significance (P< 0.05) obtained for annual variations.
* denotes significance (P< 0.05) obtained for seasonal variations.

Figure-1: Annual and seasonal variations in water quality in TIR and JIR from 2009-2011.

The parameters correlated for the two sites can be taken as representing the major source of seasonal variations in water quality of the reservoirs[35]. In the present study, the water quality parameters (Table-3 and 4) evaluated through this correlations matrix showed that concentrations of few parameters (e.g. water surface temperature, pH, chlorides, salinity) only change to a limited extent, while others (e.g. SO_4, nitrogen, PO_4, NO_2, NO_3, acidity, alkalinity, CO_2) are probably strongly influenced by the water level fluctuations and sediment-water interactions during various seasons.

Annual patterns in water quality: We hypothesized that there would be minimal variability in the water quality of the two reservoirs since both Timbi and Jawla aremerely 25 kilometers apart. However the studies indicated contradictory results. As opposed to the hypothesis, the results specified an influence of the surroundings on the spatial variability of both the reservoirs.

The major differences were noted in the nutrient concentrations (SO_4, KN, NO_3-N, NO_2 and TP). KN, NO_3-N and TP were higher at JIR which may be attributed to the cattle bathing in the reservoir as well as grazing in the catchment area. Extremely active phosphate anions (PO_4^{3-}) are mobilized through precipitation of cations of Ca^{2+}, Mg^{2+}, Fe^{3+} and Al^{3+} depending on the properties of soil. These are forms of phosphorus that are highly insoluble and not available to plants[36].

Occurrences of Nitrite (NO^{2-}), an intermediate in oxidation/reduction process of ammonia and nitrates and ordinarily not found in high concentrations in surface waters, indicates the efficiency of biological processes such as nitrification, denitrification or biological nutrient removal[37]. In the present study the differences in the nitrate and nitrite levels in the two reservoirs indicates that these biological processes take place depending on the available microclimatic conditions influenced by overall climatic conditions. However, sulphates were significantly higher at TIR.

Accumulation of ions occurs in the deeper water during summer stagnation[38]. They are constituents of TDS and known to form salts with sodium, potassium, magnesium and other cations[39].

Seasonal patterns in water quality: Several studies have reported regarding water cover in lakes and reservoirs to be maximum during post-monsoon when streams continue to bring water[7,9,10]. After a period of three years this remained true for both the reservoirs.

As the reservoirs are inundated with Narmada water under the same schedules water is received at same time but the draining time depends on the cropping patterns in the area, resulting in differences in the water cover. Alkalinity was significantly lower during post-monsoon, which was largely due to the dilution by precipitation. DO exhibit strong seasonal variability (Figure-1) probably a result from photosynthetic and respiratory processes, contamination caused by hydrology[40,41] and chemical processes, including sulfur oxidation by bacterial activity[41].Further the oxygen deficit during summer is a characteristic feature of a productive wetland[42,43]. This was observed in the present study at both the reservoirs. Absence of carbon dioxide in TIR surface water during summer could be attributed to the early morning hours when the samples were collected and probably due to scanty vegetation[7].

Lower contents of N (NO_3-N and NO_2), P and high levels of DO (Figure-1) in the post-monsoon and winter indicated improved water quality at TIR. However at JIR, the KN concentration increased significantly during post-monsoon and winter in comparison to the wet season. Even the nitrate levels showed a significant difference when the wet season and post-monsoon as well as winter were compared. Deshkar[7] observed high levels of nitrates during monsoon at TIR, and two other water bodies where no specific conclusion could be made however at larger reservoir she studied similar results were obtained. Higher concentration of nitrates observed in the present study during summer could be because of the possible concentration of nitrogen in the water body.

The consistently higher nitrate-nitrogen concentrations during the wet seasons are assumed to increase due to input from the drainage basin[44]. Minimum concentrations of nitrates as well as nitrites were observed during winter as was also noted by Rathod[45].The average concentrations of total phosphorus were higher inpost-monsoon compared to summer at both the reservoirs. This may be due to inputs through rainwater surface runoff, which carry more nutrients into the reservoirs probably used by planktons which flourish in summer[7,45].

Principal component analysis/Factor analysis (PCA/FA): PCA/FA performed to compare the compositional pattern between the water samples and to identify the factors influencing each one (Table-1 and 2; Figure 2) revealed three PCs with eigen values of >1 explained about 86.11% of the total variance in the water quality data set at TIR while 80.56% at JIR. At TIR, the first PC accounting for 45.2% of the total variance was correlated (loading>0.70) with KN, IP, NO_2, NO_3, TA, CO_2 and WC. The second PC accounting for 40.91% of total variance was correlated with SO_4, DO, Cl, Salinity and acidity, whereas, the third correlated with only TP and WT.

At the second reservoir JIR, the first PC with a total variance of 48.17% was correlated (loading>0.70) with TP, Cl, salinity, TA, CO_2 and WC. The second PC (32.39% of total variance) was correlated with IP, WT, SO_4 and DO, whereas, the third correlated with acidity and pH.

A scree plot used to identify the number of PCs to be retained to comprehend the underlying data structure as described by Vega[33] identified three varifactors (VFs). The corresponding varifactors (VFs), and loadings for the variables are presented in Table 1 and 2. VF coefficients having a correlation greater than 0.7 were considered significant (strong).

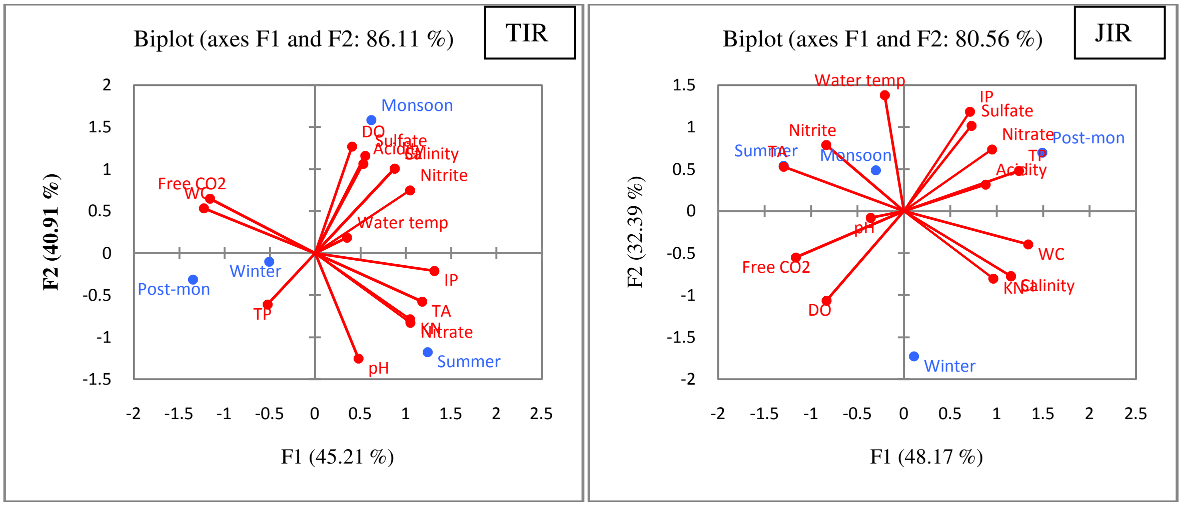


Figure-2: PCA correlation biplot for the study conducted during 2009-2011 at TIR and JIR.

Varifactor (VF) 1 at TIR, which explained 43.89% of the total variance, had strong positive loadings (>0.70) on KN, IP, NO_3, TA and pH which can be inferred as a major nutrients and mineral components of the surface water of TIR. The free CO_2concentrationshowed a strong negative loading with VF1in surface water at TIR which explains its summer decline. Use of CO_2in photosynthetic activities and warmer temperatures are known to lower the CO_2 levels in surface water while accumulation of same in deeper water occurs due to thermal stratification[38]. This is also expected to increase the pH of surface water in summer. The second VF accounting for 41.81% of total variance was correlated with NO_2, SO_4, DO, Cl, salinity and acidity, whereas, the third VF correlated with TP and WT. VF2 and VF3 represents the effects of surface runoff.

At JIR, the first VF accounting for 41.35% of the total variance correlated positively (loading>0.70) with KN, Cl, salinity and WC but negatively with NO_2, TA, WT. This VF points to variations in natural ionic salts in the basin from soil weathering and runoff. The second VF accounting for 34.88% of total variance was positively correlated with TP, IP, NO_3, SO_4 and negatively with DO, whereas, the third correlated positively with CO_2 and pH but negatively with acidity. VF2 indicates the effects of runoffwith nutrients. Fertilizers and manure which contribute to high levels of soil nitrates and phosphorus are commonly used in the area. Suspended particles from these tend to have adsorbed nutrients[30]. Agricultural runoff probably carries more suspended solids with nitrate and phosphorus into the reservoirs during precipitation. A negative correlation between temperature and dissolved oxygen is a natural process because the solubility of oxygen in water decreases with increasing temperature[29].

The results from the PCA/FA suggested that most of the variations in water quality are explained by the soluble salts, physical parameters and nutrients. However, FA served as a means to identify those parameters that had the greatest contribution to seasonal variations in the water quality of reservoirs. A similar approach has been used based on PCA/ FA for the evaluation of variations in water quality[17,19,46,47].

Correlation analysis: The data were combined to calculate the correlation matrix of the 15 analyzed variables (Table-3 and 4). As they are affected simultaneously by annual and seasonal variations, the correlation coefficients should be interpreted with caution. High and positive correlations were observed between water cover, free CO_2, nitrate, sulphates and Kjeldahl nitrogen (r=0.505 to 0.614), which are responsible for water mineralization at TIR while at JIR majority of the variables correlated strongly with water cover indicating the importance of water levels at the reservoir. Acidity of water was most significantly and positively correlated with chlorides, carbondioxide, nitrites at TIR. As expected, DO at TIR was negatively correlated with temperature because the solubility of oxygen in water decreases with increasing temperature.

Conclusion

These parameters were basically affected due to the seasonal fluctuations in the climatic conditions, water level, inundation from Narmada, anthropogenic pressure *etc*. At the two reservoirs in the subtropics although overall weather is comparatively warmer, fluctuation in temperature and humidity (rain) are observed. The inundation from Narmada River during the study influenced the water level probably changing the chemistry of water. However at JIR presence of emergent vegetation all throughout the year showed the impacts on the chemistry of water. The physical and chemical properties of freshwater body are characteristic of the climatic, geochemical, geomorphological conditions as well as anthropogenic activities. The physico-chemical properties of water affect the biota present therein.

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