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Water Quality Assessment of Chambal River by Using Multivariate Statistical Methods

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Abstract- The present investigation assessed the spatiotemporal variation in the surface water quality at 27 monitoring stations on the ChambalRiver with the aid of multivariate statistics, and categorized the river stretch from least to heavily polluted utilizing the Water Quality Index (WQI). The WQI unveiled a distinct pollution spectrum in the river, while cluster analysis (CA) grouped the stations according and water chemical similarities due to various stressors.A clear gradient of organic pollution and nutrient enrichment has been identified as the key drivers of the aquatic disturbance. WQI, CA, and PCA collectively provided an efficient framework for differentiating pollution levels and sources, underscoring the necessity of targeted monitoring and management to safeguard aquatic environments.

Keywords: Chambal River, Water Quality Index (WQI), Multivariate Statistical Analysis, Cluster Analysis (CA), Principal Component Analysis (PCA), Surface Water Quality, Spatiotemporal Variation.

I. INTRODUCTION

Though rivers store only about 2,000km3water globally yet they have an annual discharge of 45,500 km3/year (Oki and Kanae, 2006) and serve as one of the most important freshwater resources. Since time immemorial rivers have been used for domestic, industrial, and agricultural purposes along with means for waste disposal, transportation, and recreational activities (Boon et al. 1992).The growing human population along with rapid increase of industrialization and urbanization in the last few decades have caused a dramatic increase in the demand for river water, and concurrent significant deteriorations in water quality throughout the world (Chun et al 2001, Wong and Wong 2003)making rivers as one of the most endangered ecosystems of the world (Srivastava et al 2017).

These deteriorations have chiefly been attributed to anthropogenic activities such discharges of municipal and domestic wastes, industrial effluents and agricultural run-offs (Niemi et al. 1990). Regular monitoring of river water quality is indispensable for the formulation and implementation of conservation strategies. However, estimation of river water quality is quite complex owing to its control by several natural influences such as basin lithology, atmospheric inputs, climatic conditions and anthropogenic factors such as urbanization, industrialization and agricultural practices (Bricker and Jones,1995, Vega et al., 1998, Mandal et al 2010, Yu et al. 2010, Akhtar et al 2021).High spatial and temporal variations in rivers further augment the complexity of water quality determination (Deng et al 2021).This calls for long term monitoring programmes which may provide a reliable estimation of water quality.

However, the long-term monitoring programmes produce large data sets which are often difficult to analyse and interpret (Shin and Fong, 1999). Multivariate statistical techniques have aided in the meaningful representation and interpretation of complex data matrices ofwater quality (Zhang et al. 2011; Ajorlo et al. 2013; Garizi et al 2011).Multivariate statistical tools such as cluster analysis (CA), principal component analysis (PCA), factor analysis (FA) and discriminant analysis (DA) have enabled assignment of water samples to distinct groups, source apportionments, identifying spatial and temporal patterns (Wunderlin et al. 2001; Helena et al. 2000; Lee et al. 2001; Adam et al. 2001; Simeonov et al. 2003, 2004; Singh et al. 2004, 2005; Reghunath et al. 2002; Papatheodorou et al. 2007) and unravelling latent pollution sources (Han et al. 2009; Wong 2005; Kumarasamy et al. 2014; Pati et al. 2014; Thareja 2014; Wang et al. 2014; Khlil et al. 2014).These interpretations and analyses have significantly helped in river water quality estimation and formulation of management strategies.

Principal component analysis (PCA) and factor analysis (FA) has been frequently used for selection of water quality monitoring stations (Mavukkandy et al 2014). PCA was applied to identify pollution sources and discovered that anthropogenic pollutants are responsible for the high variation in the water quality (Han et al. 2009), identify latent factors or pollution sources(Wong 2015), assessment of the water quality of Ceyhan River (Tanriverdi et al. 2010).Details for mastering the arts of PCA and PFA are published elsewhere (Manly, 1986; Davis, 1986; Wackernagel, 1995; Tabachnick and Fidell, 2001).

CA was used to detect the similarity groups between the sampling sites. It was performed on the standardized data using Ward's method, with Euclidean distance. Spatial variances were also determined with CA using linkage distance (Wunderlin et al 2001; Simeonov et al. 2003; Kowalkowski et al. 2006).

India is the second most populated country in the world and comprises of approximately 17.5% of the world's population (Census 2011). The rapid growth of industrialization, urbanization, extensive agriculture, and rising energy demands have affected the physicochemical and biological attributes of the surface water bodies and has led to severe stress on the quality and quantity of water in India (Trivedi et al. 2008, Jain et al 2007, Li et al 2023). There are thirteen major river basins (area more than 20,000 square kilometre) in the country, which occupy 82.4% of total drainage basins, contribute eighty five percent of total surface flow and house eighty percent of the country's population (Gangwar 2013).As is the case with most developed countries, India also lacks well-implemented monitoring and remediation programs for rivers (Leung et al. 2013). About 70% rivers in India are polluted, which receive millionsof liters of domestic, industrial, and agricultural waste waters (Priyadarshi 2009, Jindal and Sharma 2011).

There is a heavy dearth of baseline water quality data for this highly important river. Most the available data is from short stretches with limited number of sites (Shivayogimath et al 2012). The present study records the water quality data for the entire stretch of Chambal Riverfor the first time. The present study was thus undertaken with the objective to (1) prepare a baseline water quality data which is presently unavailable for the entire stretch of Chambal River and (2) to establish water quality classes for different stretches of Chambal, a river which is highly significant from the view of biological diversity and hence assist in decision making for conservationists and water managers.

However, about 70% rivers in India are polluted (Jindal and Sharma 2011).The surface water quality is affected by both theanthropogenic activities and natural processes (Carpenter et al. 1998; Mokaya et al. 2004; Melina et al. 2005;Singh et al. 2005a).Today, about 14 major, 55 minor, and several hundred small rivers of India receive million litersof domestic, industrial, and agricultural wastewater (Priyadarshi 2009).

In river monitoring, it was frequent to face the problems of whether a variation of measured parameters should be attributed to pollution or to natural changes (temporal, climatic) changes in the river hydrology and how water quality varied in different human activities with similar natural changes. Also, it was necessary to determine which parameters or pollution sources were the most significant to describe such spatial and temporal variations (Ferrier et al. 2001, Alberto et al. 2001, Jonnalagadd and Mhere, 2001).

There are thirteen major river basins (area more than 20,000square kilometre) in the country, which occupy 82.4% of total drainage basins,contribute eighty five percent of total surface flow and house eighty percent of thecountry's population (Gangwar 2013). Major river basins are Brahmaputra, Ganga (including YamunaSub Basin), Indus (including Satluj and Beas Sub Basin), Godavari, Krishna,Mahanadi, Narmada, Cauvery, Brahmini (including Baitarni Sub Basin), Tapi, Mahi,Pennar and Sabarmati.Several physical and chemical studies have been carried out on Indian river such as Ganga (Bhutiani et al. 2016, Joshi et al. 2009), Yamuna (Sharma et al. 2016, Chadetrik et al. 2015, Kumar et al. 2016, Gupta et al. 2013, Bhardwaj et al. 2017), Narmada (Gupta et al. 2017, Bano et al. 2015, Barde et al. 2015) However, only few studies have been focused on Chambal river (Saksena et al. 2008, Rengaranjan et al. 2009, Gupta et al. 2011 and Jain 2012).

Chambal is one of the major tributary of the Yamuna River and one of the last remnant rivers in the greater Ganges River system, which has retained significant conservation values and it is considered as pollution-free (Hussain et al 2011) as compare to the other Indian rivers.It harbours the largest gharial(Gavialisgangeticus) population (Katdare et al,2011) and a high density of the Gangetic dolphin (Platanistagangetica).A total of 147 fish (32 families), 56 reptile (19 families), 308 bird (64 families) and 60 mammal (27 families) species are reported, including six Critically Endangered, 12 Endangered and 18 Vulnerable species, as categorised by the IUCN Red List of Threatened Species (Nair & Chaitanya, 2013).People along the river use water for many purposes. However, the surface water quality is deteriorating due to anthropogenic activities, industrialization, farming, transportation, urbanization, animal and human excretions and domestic wastes.

Pollution is caused when a change in the physical, chemical or biological condition in the environment affect quality of human life (Lowel and Thompson, 1992, Okoye et al. 2002). Industrial and municipal wastes are been continuously added to water bodies, hence affect the physiochemical quality of water making them unfit for use of livestock and other organisms (Dwivedi and Pandey, 2002). The extent of pollution is generally assessed by studying physical and chemical characteristics of the water bodies (Duran and Suicnz, 2007).

The objective of this study is to assess the present water quality through the analysis of selected water quality parameters like temperature, pH, EC, TDS, DO, BOD, COD, Nitrate, Silica, Cl, TP etc. In the present study, the efficiency of multivariate statistical techniques such as PCA, CA have been used to investigate Chambal River water quality and discriminate relative magnitude of anthropogenic and natural influences on the river water quality.

II. METHODOLOGY

Study area

The Chambal River is the largest tributary of the Yamuna River in Northern India and hence becomes a part of the greater Gangetic drainage system. The Chambal River is 960 km long perennial river which originates from the summit of Janapav hill of the Vindhyan range at an altitude of 854 m above the msl at 22° 27_ N and 75° 37_ E in Mhow, located in the state of Madhya Pradesh of Central India.Chambal Riverflows through three large states of Madhya Pradesh, Rajasthan and Uttar Pradesh. In the major part of its course, the Chambal River flows through badlands which are one of the most classic badlands in the world and comparable in their magnitude and extent only with the Dakota Big Badlands of North America (Joshi, 2014).

The Chambal basin is characterized by thorn forests, undulating floodplains, gullies and ravines(Gopal & Srivastava 2008). Evergreen riparian vegetation is completely absent, with only sparse ground cover along the severely eroded riverbanks and adjacent ravine lands (Hussain,1999). Chambal badlands have been associated with bandits for a very long period of time and some of the India's most notorious outlaws have operated from this region (Joshi, 2014). The Chambal is considered to be a pristine river which has retained significant conservation values (Hussain and Badola 2001).

Chambal river is a key repository of biological diversity where several globally threatened fauna still survive including six critically endangered, 12 endangered, and 18 vulnerable species, as categorized by the IUCN Red List of Threatened Species (Nair and Chaitanya 2013). These include the Gangetic River dolphin (Platanista gangeticagangetica), Gharial (Gavialis gangeticus) and the red-crowned roofed turtle, (Hardellathurjii). Considering the rich biological diversity of Chambal River the National Chambal Sanctuary (NCS) was established in 1978 by the Government of India to conserve the gharial and the unique Chambal ecosystem.

The NCS lies between 24°55' to 26°50' N and 75°34' to 79°18'E in Dholpur. It consists of the large arc described by the Chambal between JawaharSagar Dam in Rajasthan and the Chambal-Yamuna confluence in Uttar Pradesh. Over this arc, two stretches of the Chambal are protected as the National Chambal Sanctuary status - the upper sector, extending from JawaharSagar Dam to Kota Barrage, and the lower sector, extending from Keshoraipatan in Rajasthan to the Chambal-Yamuna confluence in Uttar Pradesh.

It might be noted here that the population of gharial had suffered a major blow in the year 2007-2008 when more than 112 gharials were found dead within a 60 to 70 km stretch of the Chambal River, which runs through Uttar Pradesh and Madhya Pradesh besides Rajasthan.

Material and Methods

The monitoring stations (Fig. 1) covered the twenty-seven sites along the river Chambal. Water quality measurements for 17 variables were measured in summer (Table 1) and winter season of 2023 (Table 2). In this study, 17 variables chosen are: temperature, pH, turbidity, total dissolved solids (TDS), electrical conductivity (EC), dissolved oxygen (DO), biochemical oxygen demand (BOD), chemical oxygen demand (COD), nitrate (NO3-), nitrite (NO2-), phosphate (PO4), silica (Si), chloride (Cl), total phosphorus (TP) and salt. Water samples were sampled and preserved in a labeled plastic bottle at each sampling sites for the measurement of physical and chemical parameters. These parameters were analyzed according to the standard procedures (APHA 1995, 2005).

The parameters such as temperature, pH, turbidity, TDS, EC, DO and salt were measured on sites using a multiparameter probe (Horiba U-23). The analysis of BOD and COD were performed in accordance with APHA (2005) guidelines. The analyses of NO3-, NO2-, PO4, silica, Cl, TP were conducted in the laboratory using UV/VIS double beam spectrophotometer (UV-1700).

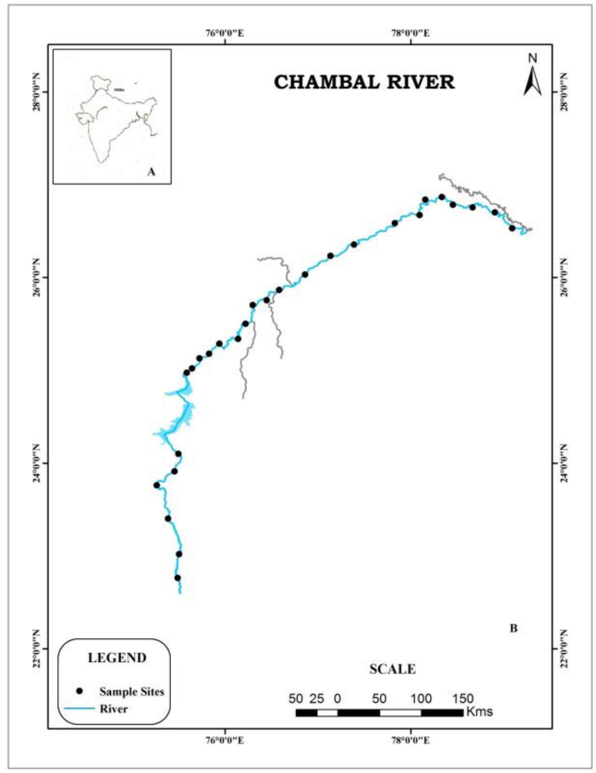

Fig.1: A. Location of Chambal River in India, B. Location of the selected sites of the Chambal River

Data Analysis

Multivariate analyses of the river water qualitydata sets were performed through correlation matrix, cluster analysis (CA), principal component analysis (PCA) (Wunderlin et al. 2001; Simeonov et al. 2003;Singh et al. 2004; Sundaray et al. 2006).Spearman correlation was carried out for 17 environmental variables of 27 sites and the data were processed using SPSS 17 statistical software.

The Spearman R coefficient was used to account for the non–normal distribution of measured water quality parameters.The Spearman R coefficient is a non–parametric measure of the correlation between variables. It is defined similarly to the Pearson correlation coefficient, but has been adapted for variables with non–normal distribution.Cluster analysis was applied to the river water quality data set with a view to group similar sampling sites together spread over the stretch. Hierarchical agglomerative cluster analysis is the most common approach that intuitively provides similar relationships between each sample and the entire data set (Mostafaei2014). In this study, hierarchical agglomerative cluster analysis was performed on the standardized data set by Ward's Method, using squared Euclidean distances to measure similarity.This method uses the analysis of variance approach to evaluate the distances between clusters,attempting to minimize the sum of squares of any two clusters that can be formed at each step (Sundaray 2009).

PCA was performed in this study to reveal the relationship between environmental variables and associated sampling sites using CANOCO software version 4.5. PCA provides information about the most meaningful parameters, which describe the entire data set and thereby allow the reduction of data with minimal loss of original information (Filik et al. 2008, Li et al. 2014).

Water Quality Index

Water Quality Index was calculated for all the sampling sites according to the National Sanitation Foundation Water Quality Index (NSF-WQI) and expressed mathematically as (Brown et al. 1970)

NSFWQI = ∑pi=1WiQi

Where Qi is the sub-index for ith water quality parameters, Wiis the weight associated with ith water quality parameter, and p is the number of water quality parameters. According to the NSFWQI, the water quality is classified as very bad, when the values range from 0-25, bad (25-50), medium (50-70), good (70-90) and excellent (90-100).

III. RESULTS

The mean and standard deviation of all physical and chemical parameters of two data sets (summer and winter 2023) at 27 sampling sites are given in Table 1 & 2. A total of 15 physicochemical variables were analyzed along the Chambal River. In this study, temperature at the sampling sites ranged from 30^{0}C to 38^{0}C in summer and 19^{0}C to 29^{0}C during winter season. The pH tended to be alkaline, varying from 7.3 to 8.95 in different season, with the maximum limit of 8.95 at S16. It was observed that the turbidity at sites of Group 1 (S1, S2 & S3) were quite high as compared to all sites in both the season. The DO varied from 5.7 mg/l in summer months to 8.9 mg/l during the winters. The BOD varied from 0.5 to 17 mg/l, while COD varied between 3.20 to 54.58 mg/l, with comparatively lower value in summer and higher during winter. Total dissolved solids varied from 0.20 to 0.50 mg/l. Chloride ion recorded the maximum values of 40.02, 40.69 and 40.42 mg/l for S13, S14 & S15 of Group 1 respectively. Phosphate and TP showed lower value in summer and higher during winter, ranging from 0.04 to 0.51 mg/l, 0.6 to 4.8 mg/l respectively.

Table 1: The mean values (S.D) with minimum and maximum values of measured environmental variables of selected sites during winter season 2023

.

Stations	Temp	pH	EC	TURB	TDS	DO	BOD	COD	nitrate	nitrite	PO_4	silica	Cl	TP	Salt
S1	28.87(1.82)	7.91(0.73)	0.79(0.05)	102.17(1.65)	0.53(0.01)	6.26 (0.19)	5.07(0.62)	11.85(6.85)	2.45 (0.67)	1.29(0.61)	0.46(0.01)	16.99(7.55)	31.97(2.74)	3.12(0.10)	0.36 (0.08)
S2	28.35(2.57)	7.83(0.38)	0.72 (0.01)	104.33 (8.96)	0.53 (0.01)	5.87 (0.47)	5.85 (0.92)	12.08(5.16)	1.97 (0.06)	1.29(0.24)	0.47(0.04)	15.09(5.93)	31.60(1.77)	3.31 0.18)	0.42 (0.02)
S3	29.59 (2.21)	8.07(0.38)	0.76 (0.07)	111.67 20.74)	0.51 (0.12)	5.74 (0.77)	5.86 (1.47)	12.65 5.47)	2.47 (0.50)	1.54 0.75)	0.40 0.03)	16.65 6.44)	32.14 1.47)	3.62 0.23)	0.37 (0.10)
S13	22.61 (0.41)	7.56(0.42)	0.76 (0.05)	77.26 (23.28)	0.52 (0.06)	5.73 (0.89)	15.59 3.52)	54.58(19.48)	1.03 (0.92)	0.71 0.56)	0.67 0.00)	8.86 (2.83)	40.02(3.51)	4.74(0.08)	0.41 (0.01)
S14	22.58 (0.73)	7.64 (0.41)	0.77 (0.12)	74.86 (21.16)	0.51 (0.01)	5.99 (1.35)	15.91(2.69)	51.49411.50)	1.26 (1.21)	0.64(0.48)	0.62(0.03)	8.98 (2.67)	40.69(3.83)	4.69(0.37)	0.41 (0.01)
S15	23.05 (0.35)	7.86 (0.96)	0.74 (0.07)	81.48 (25.01)	0.53 (0.01)	6.21 (1.21)	16.39(2.39)	30.77(37.86)	1.02 (0.81)	0.58(0.52)	0.60(0.06)	9.11 (2.48)	40.42(5.49)	4.61(0.57)	0.41 (0.02)
Max	29.59	8.07	0.79	111.67	0.53	6.26	16.39	54.58	2.47	1.54	0.67	16.99	40.69	4.74	0.42
Min	22.58	7.56	0.72	74.86	0.51	5.73	5.07	11.85	1.02	0.58	0.40	8.86	31.60	3.12	0.36
S4	23.77 (1.93)	7.57 (0.52)	0.51 (0.07)	21.70 (2.54)	0.30 (0.02)	7.56 (0.93)	1.81 (2.11)	4.70 (1.28)	2.22 (0.65)	1.25(1.00)	0.17(0.21)	10.57(5.75)	12.46(1.54)	1.54(0.36)	0.21 (0.01)
S5	24.15 (2.47)	7.73 (0.33)	0.53 (0.09)	22.45 (2.33)	0.31 (0.01)	7.29 (1.40)	2.25 (2.62)	5.29 (2.54)	1.94 (0.09)	0.71(0.39)	0.12(0.13)	9.86 (3.76)	13.15(1.48)	2.00(0.13)	0.21 (0.02)
S6	23.82 (1.81)	7.88 (0.03)	0.52 (0.05)	22.64 (1.78)	0.29 (0.01)	7.46 (0.99)	2.10 (2.41)	5.04 (2.60)	2.10 (0.77)	0.86(0.64)	0.19(0.22)	10.48(3.94)	12.95(1.44)	1.89(0.49)	0.17 (0.09)
S7	23.65 (2.32)	7.62 (0.04)	0.40 (0.14)	13.70 (9.04)	0.23 (0.04)	6.16 (0.37)	1.72 (1.78)	4.95 (0.50)	0.73 (0.40)	0.35(0.10)	0.22(0.09)	8.83 (2.72)	11.72(1.07)	2.69(0.18)	0.11 (0.01)
S8	23.49 (1.99)	7.67 (0.09)	0.44 (0.19)	14.90 (10.33)	0.22 (0.04)	6.48 (0.11)	1.74 (1.79)	5.36 (0.77)	0.72 (0.38)	0.28(0.07)	0.05(0.00)	9.09 (2.94)	11.60(1.46)	2.65(0.17)	0.11 (0.02)

S9	23.87 (1.16)	7.68 (0.06)	0.39 (0.11)	14.26 (9.25)	0.23 (0.04)	6.36 (0.37)	1.91 (2.00)	4.95 (1.07)	0.32 (0.30)	0.34(0.08)	0.12(0.10)	8.78 (2.66)	11.39(1.93)	2.47(0.66)	0.11 (0.02)
S10	23.87 (0.32)	7.66 (0.08)	0.34 (0.01)	9.18 (2.29)	0.16 (0.07)	6.68 (0.31)	2.42 (2.67)	6.36 (3.16)	3.93 (4.82)	2.78(3.75)	0.39(0.49)	7.86 (3.26)	14.70(3.16)	1.83(0.38)	0.27 (0.05)
S11	24.01 (0.16)	7.32 (0.51)	0.29 (0.09)	7.26 (0.49)	0.28 (0.15)	6.98 (0.26)	2.37 (2.60)	6.08 (2.85)	3.76 (4.63)	2.56(3.50)	0.51(0.66)	7.69 (3.16)	14.51(2.27)	1.63(0.49)	0.22 (0.02)
S12	24.78 (0.40)	7.76 (0.04)	0.37 (0.06)	7.14 (1.35)	0.24 (0.06)	7.33 (0.33)	2.74 (3.21)	6.59 (3.13)	3.90 (4.70)	3.11(4.24)	0.46(0.57)	8.22 (2.99)	15.22(3.10)	1.85(0.53)	0.29 (0.02)
Max	24.78	7.88	0.53	22.64	0.31	7.56	2.74	6.59	3.93	3.11	0.51	10.57	15.22	2.00	0.29
Min	23.49	7.32	0.29	7.14	0.16	6.16	1.72	4.70	0.32	0.28	0.05	7.69	11.39	1.54	0.11
S16	23.39 (0.15)	8.95 (0.00)	0.56 (0.02)	1.10 (1.41)	0.34 (0.03)	8.94 (0.00)	0.66 (0.56)	3.78 (2.30)	3.99 (0.61)	1.28(1.20)	0.04(0.00)	6.56 (1.74)	9.73 (1.74)	1.06(0.08)	0.30 (0.00)
S17	23.51 (0.35)	8.92 (0.05)	0.57 (0.01)	1.06 (1.32)	0.35 (0.02)	8.89 (0.18)	0.73 (0.70)	3.95 (2.62)	3.43 (0.46)	1.71(1.07)	0.04(0.01)	6.18 (0.59)	9.61 (1.17)	1.40(0.08)	0.36 (0.06)
S18	23.56 (0.66)	8.89 (0.05)	0.60 (0.01)	0.82 (1.00)	0.37 (0.02)	8.78 (0.18)	0.84 (0.72)	4.36 (2.47)	3.84 (1.18)	2.19(1.86)	0.04(0.01)	6.48 (1.93)	9.46 (1.87)	1.43(0.22)	0.32 (0.02)
S19	21.85 (1.06)	8.05 (0.09)	0.55 (0.03)	11.19 (1.54)	0.39 (0.03)	8.50 (0.26)	0.91 (0.89)	3.26 (1.52)	2.63 (0.47)	0.88(0.16)	0.17(0.19)	6.69 (2.46)	11.53(2.47)	2.02(0.04)	0.36 (0.06)
S20	21.73 (0.24)	8.03 (0.03)	0.51 (0.05)	10.12 (2.98)	0.40 (0.04)	7.67 (0.39)	0.63 (0.50)	3.05 (1.19)	2.42 (0.49)	1.01(0.21)	0.18(0.21)	6.53 (1.94)	11.76(3.15)	1.82(0.25)	0.32 (0.03)
S21	22.06 (0.90)	8.19 (0.72)	0.54 (0.00)	9.74 (2.60)	0.41 (0.02)	7.91 (0.28)	0.88 (0.83)	3.37 (1.15)	2.39 (0.20)	1.01(0.24)	0.21(0.24)	6.83 (2.56)	11.02(2.87)	1.86(0.18)	0.37 (0.04)
S22	20.20 (0.42)	8.01 (0.31)	0.59 (0.02)	13.27 (1.66)	0.34 (0.04)	7.11 (0.23)	1.25 (1.22)	4.45 (1.89)	5.75 (2.14)	3.32(2.09)	0.15(0.16)	7.92 (2.56)	10.15(1.58)	1.40(0.51)	0.31 (0.02)
S23	19.91 (1.40)	7.85 (0.31)	0.62 (0.00)	14.66 (0.23)	0.36 (0.05)	7.14 (0.01)	1.96 (2.23)	5.10 (2.38)	5.89 (1.75)	4.04(3.23)	0.16(0.18)	7.86 (2.67)	10.49(1.17)	1.50(0.54)	0.32 (0.03)
S24	20.65 (1.63)	8.11 (0.12)	0.63 (0.05)	13.98 (0.17)	0.39 (0.05)	7.20 (0.16)	1.70 (1.86)	4.82 (2.27)	6.13 (1.53)	3.52 3.25)	0.18 0.20)	8.05 (2.81)	10.97 0.70)	1.39 0.19)	0.31 (0.01)
S25	20.57 (4.71)	7.71 (0.68)	0.64 (0.02)	12.42 (8.63)	0.39 (0.01)	7.90 (0.46)	0.68 (0.75)	3.57 (2.10)	2.29 (0.09)	1.16(0.57)	0.13(0.12)	8.99 (2.91)	11.51(1.68)	2.01(0.08)	0.26 (0.09)
S26	21.02 (5.77)	7.98 (0.15)	0.63 (0.02)	12.19 (8.52)	2.32 (2.58)	7.64 (0.37)	0.65 (0.75)	3.62 (2.11)	2.30 (0.03)	0.73(0.00)	0.11(0.10)	8.88 (3.14)	10.94(1.80)	2.12(0.15)	0.33 (0.04)
S27	22.47 (3.29)	7.66 (0.35)	0.67 (0.07)	11.47 (7.63)	0.46 (0.11)	8.21 (0.99)	0.60 (0.60)	3.59 (1.82)	2.20 (0.15)	0.89(0.30)	0.10(0.08)	8.87 (3.30)	10.54(2.11)	2.08(0.33)	0.27 (0.10)
Max	23.56	8.95	0.67	14.66	2.32	8.94	1.96	5.10	6.13	4.04	0.21	8.99	11.76	2.12	0.37
Min	19.91	7.66	0.51	0.82	0.34	7.11	0.60	3.05	2.20	0.73	0.04	6.18	9.46	1.06	0.26

Table 2: The mean values (S.D) with minimum and maximum values of measured environmental variables of selected sites during summer season 2023.

Stations	Temp	pH	EC	TURB	TDS	DO	BOD	COD	nitrate	nitrite	PO4	silica	Cl	TP	Salt
S1	34.75 (5.16)	8.79(0.37)	0.75 (0.06)	50.50 (2.83)	0.50 (0.21)	6.24 (0.80)	8.00 (2.83)	14.00 (2.83)	0.25 (0.07)	0.14(0.06)	0.10(0.01)	0.90(0.01)	36.37(1.32)	3.02(0.13)	0.40 (0.00)
S2	34.75 (3.46)	8.31 (0.59)	0.70 (0.02)	49.15 (3.89)	0.47 (0.22)	6.07 (0.47)	8.49 (1.96)	14.00 (3.25)	0.24 (0.06)	0.17(0.03)	0.12(0.04)	0.91(0.01)	37.05(0.52)	2.93(0.40)	0.40 (0.00)
S3	35.40 (3.54)	8.52 (0.52)	0.69 (0.10)	49.80 (3.54)	0.49 (0.21)	5.83 (0.39)	8.90 (1.98)	14.35 (3.46)	0.27 (0.09)	0.19(0.01)	0.15(0.09)	0.95(0.06)	37.22(0.80)	3.13(1.12)	0.40 (0.00)
S13	31.93 (0.60)	8.82 (0.11)	0.76 (0.10)	49.30 (0.57)	0.44 (0.14)	7.68 (0.20)	10.50(2.12)	37.75 (2.90)	0.19 (0.01)	0.13(0.08)	0.10(0.00)	0.85(0.07)	44.63(5.97)	2.97(0.07)	0.40 (0.00)
S14	31.02 (0.16)	8.88 (0.31)	0.76 (0.08)	48.60 (2.12)	0.42 (0.13)	7.41 (0.42)	10.30(2.12)	36.50 (3.11)	0.18 (0.01)	0.12(0.07)	0.10(0.01)	0.90(0.11)	43.13(3.43)	2.99(0.20)	0.35 (0.07)
S15	32.18 (0.18)	8.42 (0.16)	0.73 (0.13)	48.35 (0.35)	0.43 (0.16)	7.39 (0.22)	10.58(2.57)	34.20 (4.38)	0.21 (0.02)	0.14(0.08)	0.10(0.01)	1.08(0.31)	44.41(4.97)	3.10(0.37)	0.40 (0.00)
Max	35.40	8.88	0.76	50.50	0.50	7.68	10.58	37.75	0.27	0.19	0.15	1.08	44.63	3.13	0.40
Min	31.02	8.31	0.69	48.35	0.42	5.83	8.00	14.00	0.18	0.12	0.10	0.85	36.37	2.93	0.35
S4	31.71 (1.14)	8.29 (0.37)	0.42 (0.02)	54.30 (1.41)	0.24 (0.03)	5.85 (0.88)	5.00 (1.41)	10.50 (2.12)	0.45 (0.07)	0.35(0.16)	0.09(0.01)	2.35(0.35)	15.27(1.33)	1.18(0.05)	0.20 (0.00)
S5	31.23 (1.88)	8.25 (0.24)	0.40 (0.00)	54.30 (0.42)	0.24 (0.04)	6.15 (0.71)	5.40 (1.27)	10.80 (0.99)	0.47 (0.12)	0.35(0.12)	0.08(0.01)	2.50(0.43)	15.81(1.46)	1.13(0.07)	0.20 (0.00)
S6	30.58 2.65)	8.10 (0.16)	0.40 (0.02)	53.40 (1.27)	0.23 (0.04)	6.06 (0.39)	5.40 (2.12)	10.55 (1.06)	0.46 (0.04)	0.30(0.13)	0.08(0.00)	2.37(0.18)	15.90(1.54)	1.04(0.04)	0.20 (0.00)
S7	30.97 (1.22)	8.48 (0.04)	0.34 (0.04)	16.50 (0.71)	0.21 (0.02)	8.69 (0.18)	3.50 (0.71)	10.50 (2.12)	0.25 (0.07)	0.18(0.01)	0.09(0.01)	1.95(0.08)	14.62(2.11)	1.67(0.16)	0.10 (0.00)
S8	30.74 (0.62)	8.26 (0.11)	0.29 (0.02)	16.25 (1.63)	0.23 (0.04)	8.49 (0.41)	3.70 (0.57)	10.30 (2.26)	0.26 (0.10)	0.19(0.02)	0.08(0.00)	2.19(0.30)	14.70(1.90)	1.51(0.11)	0.10 (0.00)
S9	30.36 (1.21)	8.19 (0.01)	0.33 (0.04)	16.70 (1.27)	0.21 (0.01)	8.40 (0.35)	4.05 (0.35)	10.65 (2.05)	0.26 (0.05)	0.21(0.02)	0.07(0.01)	2.25(0.36)	14.74(1.80)	1.34(0.16)	0.15 (0.07)
S10	37.60 (2.68)	8.59 (0.43)	0.38 (0.00)	18.70 (0.57)	0.25 (0.07)	7.44 (0.25)	4.50 (0.71)	14.00 (2.83)	0.45 (0.07)	0.40(0.03)	0.09(0.01)	1.00(0.01)	16.46(1.77)	1.83(1.19)	0.20 (0.00)
S11	36.50 (3.11)	5.92 (3.87)	0.34 (0.04)	18.10 (0.28)	0.20 (0.03)	7.55 (0.00)	4.49 (0.87)	13.95 (2.62)	0.46 (0.09)	0.39 (0.11	0.08(0.00)	0.70(0.41)	16.63(1.43)	1.94(1.19)	0.15 (0.07)
S12	36.45 (1.63)	8.25 (0.37)	0.36 (0.00)	18.80 (0.99)	0.21 (0.03)	7.47 (0.01)	4.85 (0.78)	14.30 (2.83)	0.50 (0.07)	0.40(0.15)	0.08(0.01)	1.05(0.06)	16.89(1.53)	1.89(1.34)	0.20 (0.00)
Max	37.60	8.59	0.42	54.30	0.25	8.69	5.40	14.30	0.50	0.40	0.09	2.50	16.89	1.94	0.20
Min	30.36	5.92	0.29	16.25	0.20	5.85	3.50	10.30	0.25	0.18	0.07	0.70	14.70	1.04	0.10
S16	33.50 (1.86)	8.37 (0.51)	0.71 (0.05)	9.05 (3.61)	0.44 (0.06)	8.40 (0.58)	3.50 (0.71)	14.00 (2.83)	0.45 (0.07)	0.39(0.14)	0.09(0.01)	1.50(0.14)	11.74(0.47)	0.69(0.07)	0.40 (0.00)
S17	32.71 (1.99)	8.36 (0.40)	0.66 (0.07)	8.95 (4.03)	0.42 (0.06)	8.44 (0.61)	3.49 (0.71)	13.60 (2.97)	0.50 (0.06)	0.37(0.23)	0.09(0.00)	1.65(0.36)	11.66(0.95)	0.70(0.11)	0.35 (0.07)
S18	32.84 (1.07)	8.35 (0.34)	0.69 (0.07)	8.85 (3.18)	0.43 (0.06)	8.40 (0.52)	3.63 (0.47)	14.15 (2.90)	0.48 (0.00)	0.36(0.13)	0.09(0.01)	1.76(0.48)	11.79(1.74)	0.68(0.19)	0.35 (0.07)
S19	33.10 (3.81)	8.65 (0.95)	0.72 (0.01)	20.00 (3.39)	0.41 (0.07)	6.98 (0.43)	3.35 (0.92)	9.00 (4.24)	0.21 (0.10)	0.16(0.03)	0.09(0.01)	1.95(0.06)	12.95 (1.1)	0.93(0.07)	0.30 (0.00)
S20	33.18 (2.80)	8.33 (0.93)	0.72 (0.01)	19.05 (3.46)	0.41 (0.08)	7.08 (0.42)	3.14 (1.18)	8.85 (4.31)	0.20 (0.13)	0.14(0.05)	0.08(0.00)	1.86(0.22)	13.45(0.94)	0.76(0.04)	0.30 (0.00)
S21	33.92 (2.28)	8.28 (0.71)	0.74 (0.00)	20.00 (2.97)	0.42 (0.13)	7.24 (0.32)	3.37 (1.09)	8.60 (4.53)	0.24 (0.09)	0.17(0.04)	0.09(0.01)	2.12(0.11)	13.30(0.52)	0.79(0.03)	0.35 (0.07)
S22	31.62(2.80)	8.13 (0.11)	0.58 (0.07)	19.25 (3.61)	0.34 (0.10)	7.14 (0.96)	3.00 (0.00)	8.50 (0.71)	0.65 (0.49)	0.37(0.12)	0.09(0.01)	2.00(0.28)	12.28(1.01)	0.86(0.08)	0.30 (0.00)
S23	31.77 (3.02)	8.03 (0.02)	0.56 (0.10)	18.65 (4.03)	0.33 (0.10)	7.03 (0.88)	3.05 (0.11)	8.05 (0.08)	0.67 (0.48)	0.60(0.40)	0.08(0.00)	1.86(0.64)	12.35(0.48)	0.85(0.08)	0.35 (0.07)
S24	31.11 (2.40)	7.96 (0.08)	0.54 (0.03)	18.50 (3.39)	0.33 (0.09)	7.15 (0.88)	3.11 (0.24)	8.82 (0.97)	0.66 (0.40)	0.33(0.02)	0.09(0.00)	2.18(0.40)	12.17(0.38)	0.82(0.09)	0.30 (0.00)
S25	38.33 (0.64)	7.84 (0.08)	0.74 (0.07)	13.30 (0.71)	0.41 (0.04)	7.01 (0.03)	4.50 (0.71)	14.50 (3.54)	0.48 (0.04)	0.31(0.21)	0.09(0.00)	2.15(0.08)	14.49(1.82)	0.68(0.09)	0.30 (0.00)

S26	36.73 (0.18)	7.71 (0.08)	0.71 (0.01)	12.20 (0.71)	0.38 (0.10)	7.08 (0.08)	4.44 (0.64)	14.50 (3.68)	0.45 (0.06)	0.27(0.18)	0.04(0.04)	2.09(0.13)	13.96(1.84)	0.61(0.15)	0.30 (0.14)
S27	37.05 (0.07)	7.67 (0.18)	0.62 (0.11)	12.65 (0.92)	0.38 (0.02)	6.94 (0.09)	4.37 (0.86)	14.35 (2.90)	0.45 (0.09)	0.28(0.23)	0.09(0.01)	2.18(0.18)	14.12(1.79)	0.72(0.10)	0.30 (0.14)
Max	38.33	8.65	0.74	20.00	0.44	8.44	4.50	14.50	0.67	0.60	0.09	2.18	14.49	0.93	0.40
Min	31.11	7.67	0.54	8.85	0.33	6.94	3.00	8.05	0.20	0.14	0.04	1.50	11.66	0.61	0.30

Statistical analysis

In order to test whether the data is normally distributed, we performed Kolmogorov-Smirnov (K-S) test. The results of K-S test showed that the data was not normally distributed. Then we performed Kruskal-Walis (Non-parametric ANOVA) test to determine the significant differences between two season data set. According to the results, most of the environmental variables were significantly correlated ($p < 0.05$) except EC, TDS, turbidity, DO and salt.

As the data were not normally distributed, the spearman's rank correlation was used to determine the relationship between environmental variables and associated sampling sites (Table 3&4), which is a non-parametric test of the degree of correlation (Shrestha and Kazama 2007). The correlation results in summer observation showed that BOD showed highly positive significant ($p<0.01$) with COD, PO4, Si, Cl and TP and highly negative significant with DO. Variables such as temperature, EC and TDS were non-significant with other variables. Similar relations have been found during the winter season.

Table 3: Spearman rank correlation between environmental variables and associated sites during winter season.

	Temp	pH	EC	Turb	TDS	DO	BOD	COD	Nitrate	Nitrite	Phos	Silica	Cl	TP	Salt
Temp	1														
pH	-0.206	1													
EC	-0.206	0.211	1												
Turb	0.233	-0.294	0.519**	1											
TDS	-0.232	0.276	0.866**	0.378	1										
DO	-0.365	0.513**	-0.235	-0.748**	-0.114	1									
BOD	0.543**	-0.408*	0.198	0.658**	0.076	-0.817**	1								
COD	0.546**	-0.443*	0.244	0.628**	0.063	-0.845**	0.948**	1							
NO_3	-0.213	0.514**	-0.059	-0.521**	-0.076	0.416*	-0.253	-0.258	1						
NO_2	-0.023	0.336	-0.007	-0.345	-0.062	0.210	-0.054	-0.049	0.910**	1					
Phos	0.293	-0.398*	0.192	0.478*	0.273	-0.705**	0.783**	0.681**	-0.164	-0.005	1				
Silica	0.408*	-0.382*	0.383*	0.854**	0.260	-0.569**	0.529**	0.533**	-0.536**	-0.335	0.342	1			
Cl	0.514**	-0.496**	0.173	0.633**	0.205	-0.731**	0.844**	0.772**	-0.419*	-0.264	0.858**	0.605**	1		
TP	0.271	-0.428*	0.425*	0.687**	0.429*	-0.681**	0.544**	0.540**	-0.759**	-0.662**	0.520**	0.645**	0.695**	1	
Salt	-0.136	0.373	0.716**	0.226	0.825**	-0.173	0.277	0.226	0.129	0.146	0.412*	-0.018	0.259	0.30	1

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Table 4: Spearman rank correlation between environmental variables and associated sites during summer season.

	Temp	pH	EC	Turb	TDS	DO	BOD	COD	Nitrate	Nitrite	Phos	Silica	Cl	TP	Salt
Temp	1														
pH	0.004	1													
EC	0.303	0.331	1												
Turb	-0.210	0.300	0.186	1											
TDS	0.311	**0.411***	**0.841****	0.130	1										
DO	-0.220	0.226	-0.230	**-0.633****	-0.204	1									
BOD	0.125	0.365	0.224	**0.537****	0.254	-0.279	1								
COD	**0.424***	0.271	**0.402***	-0.040	**0.402***	0.030	**0.753****	1							
NO_3	0.055	**-0.609****	**-0.470***	-0.347	-0.376	-0.019	**-0.390***	-0.258	1						
NO_2	0.174	**-0.410***	**-0.574****	-0.380	**-0.446***	0.122	-0.362	-0.232	**0.876****	1					
Phos	0.157	**0.583****	**0.580****	0.331	**0.748****	-0.178	**0.423***	**0.388***	**-0.394***	**-0.436***	1				
Silica	**-0.409***	**-0.709****	**-0.387***	-0.060	**-0.485***	-0.202	-0.347	**-0.470***	0.303	0.150	**-0.528****	1			
Cl	0.056	**0.424***	0.089	**0.631****	0.067	-0.222	**0.896****	**0.552****	**-0.492****	**-0.429***	0.349	**-0.422***	1		
TP	-0.135	**0.605****	-0.044	**0.630****	0.056	-0.078	**0.667****	0.262	**-0.454***	-0.373	**0.448***	**-0.513****	**0.869****	1	
Salt	0.266	0.331	**0.800****	0.151	**0.944****	-0.201	0.234	0.369	-0.244	-0.314	**0.699****	**-0.533****	0.073	0.087	1

** Correlation is significant at the 0.01 level (2-tailed).
*Correlation is significant at the 0.05 level (2-tailed).

PCA was applied on the normalized data to identify the influencing factors and to compare the patterns between environmental variables and associated sampling sites during summer and winter season (Fig. 2 and 3). 27 sampling sites and 15 environmental variables were used in this study. According to the summer PCA results, the first principal component (PC1) had an eigenvalue of 0.4625 which accounted for 46.25% of the total variance while the second component accounted for 62.56% (eigenvalue: 0.1631) of the total variance. The variables such as BOD, COD, PO4, Cl, TP and turbidity, along the PC1 contributed most to the variance and are associated with heavy pollution sites namely S1 to S3 and S13 to S15.

These variables had high positive loadings values, depicting a gradient of organic pollution and nutrients. Variables such as nitrate, nitrite, silica and DO has negative loading values along this axis. The PC2 axis differentiated the moderate (S4 to S12) and less pollution (S16 to S27) sites. The moderate polluted sites displayed more variance along PC2 axis.

The less polluted sites are associated with the vectors of nitrate, nitrite, silica and DO.In winter observations, the PC1 accounted for 48.67% and the PC2 accounted for 64.43% of the total variance in the data set. Like summer results, the variables such as BOD, COD, PO4, Cl, TP and turbidity along the PC1 are associated with the same sites but along the PC2 axis, the moderate and less polluted sites showed more variance from each other. Unlike summer results, the DO vector seemed to be quite significant and showed strong association with the less pollution sites along with nutrients such as nitrate and nitrite.

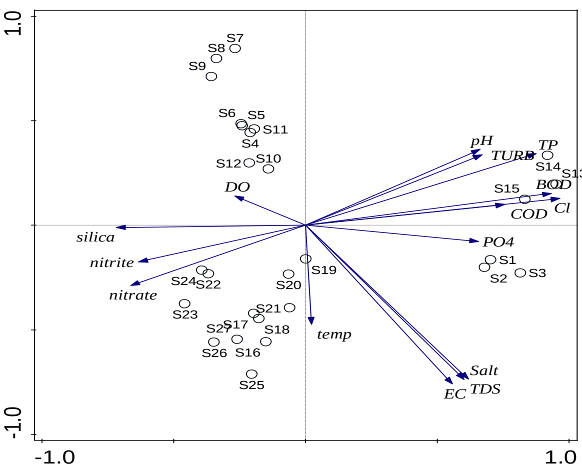

Fig. 2: Principal component analysis (PCA) carried out on physical and chemical variables of 27 sampling sites during summer (Only PC1 & PC2 depicted) from the River Chambal.

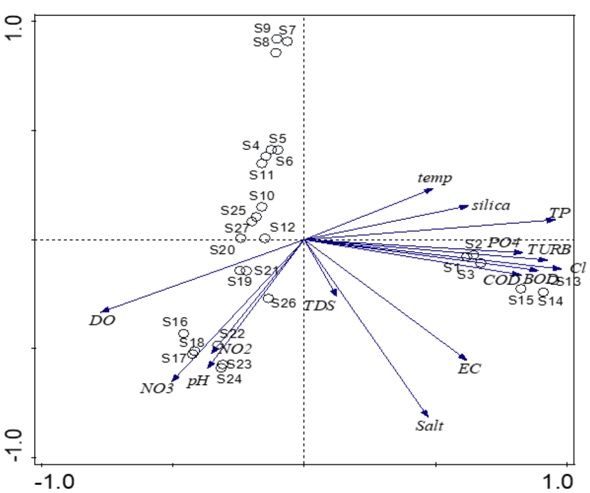

Fig.3: Principal component analysis (PCA) carried out on physical and chemical variables of 27 sampling sites during winter (Only PC1 & PC2 depicted) from the River Chambal.

Hierarchical agglomerative cluster analysis (CA) was applied to the river water quality data set to identify objects into groups/clusters, which once grouped, should exhibit within cluster homogeneity and between clusters heterogeneity (Awadallah and Yousry 2012; Guo et al. 2012) based on their differences or similarity (Angeler et al. 2007, Sánchez-Carrillo et al. 2007,Wang et al. 2014). In this study, the cluster analysis (CA) was used on standardized log-transformed data of two sets of summer and winter season. CA was performed using squared Euclidean distances as a measure of similarity (Ogwueleka 2015).

Based on the 15 variables, cluster analysis revealed a dendogram, in which 27 monitoring sites are grouped into distinct patterns of two main clusters: cluster 1 and cluster 2. According to the summer results (Fig. 4), cluster 1 i.e. Group 1 consists of 6 sites from S1 to S3 and S13 to S15, and is located in heavy pollution region. Cluster 2 (Group 2) can be further classified in two sub-groups: Group 2a and Group 2b. Group 2a consists of 12 sites (S4 to S12 and S19 to S21), could be considered as moderate pollution sites. Group 2b consists of 9 sites (S16 to S18 and S22 to S27), regarded as the less pollution sites. Similar pattern has been followed in winter season (Fig. 5). Group 1 in the winter season showed a similar composition among the sampling sites. However, the composition of Group 2a and Group 2b showed a different distribution of sampling sites.

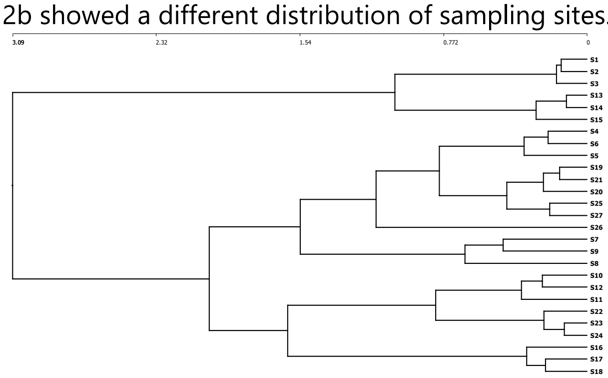

Fig. 4: Results of cluster analysis based on environmental variables sampled at 27 sampling sites during winter from the Chambal River.

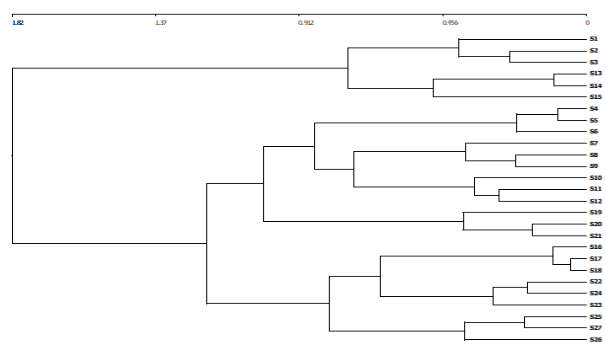

Fig. 5: Results of cluster analysis based on environmental variables sampled at 27 sampling sites during summer from the Chambal River.

The Water Quality Index for the selected environmental variables was calculated according to the NSF. Present values during the summer season indicated that WQI fall in the range of 73 to 87 which can be considered as “Good” water quality status of all the sampling sites. The results revealed that the Chambal River stretch from heavy pollution sites (S1 to S3 and S13 to S15) has “Medium” water quality status ranged from 54 to 67, while the rest of the sampling sites showed “Good” water quality status (ranged from 71 to 81).

Spatiotemporal variations of the selected environmental variables at all sampling sites during summer and winter season were illustrated by box and whiskers plots (Fig. 6). Variables such as BOD and COD showed high broad range or more variation during winter season at heavy pollution sites as compare to the moderate and less pollution sites. In contrast, DO have narrow range in winter season. Nitrate and nitrite showed similar pattern at all sites, indicating low values in summer and high values in winter.pH showed narrow range in both season

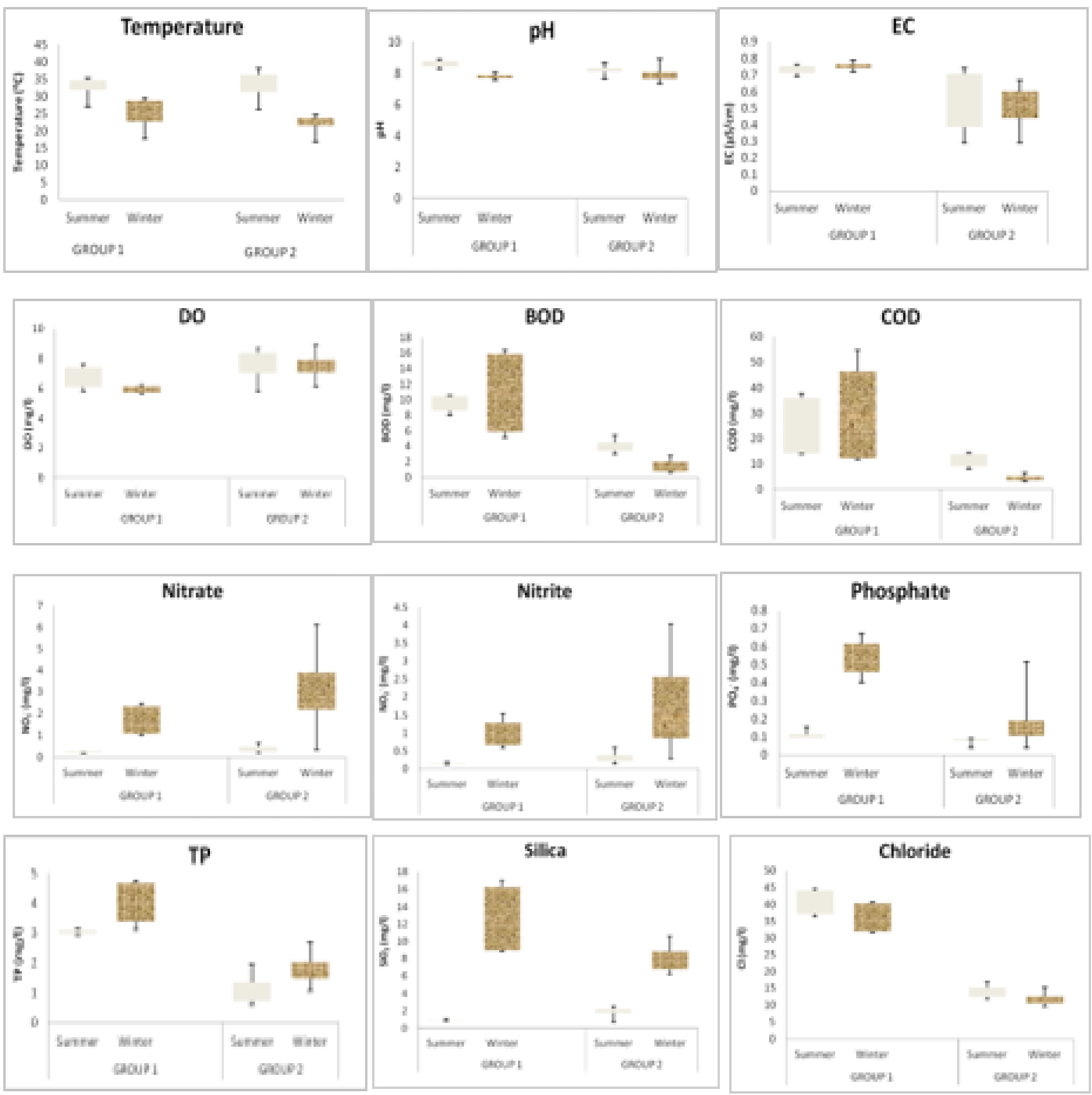

Fig. 6: Box plots of selected environmental variables for Group 1 and Group 2 of both seasons showing temporal variation.

IV. DISCUSSION

Descriptive statistical parameters such as mean, range (minimum and maximum) and standard deviation of water quality parameters collected in 2023 is summarized in Table 1 & 2. The analyzed water quality parameters depicted the variations in physico-chemical properties of Chambal River and categorized the sites into three group i.e. high pollution, moderate pollution and low pollution. The sites such as S1to S3 and S13 to S15 come under the high pollution range whereas sites from S4 to S12 and S16 to S27 covered moderate (9 sites) to low pollution (12 sites) region respectively. The study showed that all the sites exhibited a slight alkaline trend along the river.

The range of BOD and COD were high during winter season, which reflect anthropogenic influences at the sampling sites located in the urban area.Continuous discharge of sewage flow followed by industrial effluents carry organic and inorganic substances has led to increase the level of BOD and COD in the River (Singh 2001, Kanu et al 2011, Lemessa et al 2023). These parameters are indicators of organic pollution (Mustapha et al. 2013).

The effect of different seasons was also statistically analyzed within different environmental variables. The Kruskal-Wallistest revealed that most of the variables were significantly different ($p<0.05$), but few of them such as EC, TDS, turbidity, DO and salt were not significantly different ($p<0.05$).

PCA was conducted to determine the influencing variable that are important in assessing variations in river water quality (Shlens 2014, Juahir et al. 2011, Huang et al. 2010, Ouyang 2005). Nowadays,PCA is also used as an important technique for source apportionment in river water quality monitoring (Juahir et al. 2011;Huang et al. 2010; Shrestha and Kazama 2007).During the summer season, the PCA results suggested that along the PC1, the variables such as BOD, COD, PO4, turbidity and TP with high positive loadings explained for the organic pollution. The sites associated with this axis may receive domestic wastewater as well as a higher amounts of industrial effluents from Nagda and Kota.Similar strong positive loadings of these variables especially COD and BOD in PCs were observed in Cauvery River basin (Umamaheswari and Saravanan, 2009) and river Ganga at Varanasi (Kumari and Tripathi2014). However, PC2 displayed high loadings of variables such as NO3, NO2, silica. Most of the sites associated with PC2 axis are located in a less disturbed region or far from the urban sites in the PCA ordination on the lower left side of the biplot. The results of PCA during the winter season revealed that the variables such as Cl, TP, turbidity, BOD, PO4 and COD were positively associated respectively with high pollution sites along the PC1 axis whereas moderate and less polluted sites were associated with the environmental variables such as NO3, DO, pH and NO2 respectively.

Cluster analysis generated a dendrogram grouping the 27 sampling sites into two clusters (figure 4 & 5). Cluster 1 (6 sites) represented a heavy pollution region. All the sites were located in the major cities. These sites received wastewater from sources such as industries and urban source. Cluster 2 further subdivided into 2 groups, group 2a (12 sites) and group 2b (9 sites) corresponded to moderate level of pollution and relatively less pollution region respectively. These sites may receive primarily domestic wastewater from agricultural pollution.

Current study disclosed well defined degradation patterns across the Chambal River. The least polluted sites displayedbetter water quality, exhibiting relatively intact ecological state (Karr & Chu, 1999; Birk et al., 2012). In contrast, moderate pollution sites depicted transitional features, indicating early signs of ecological pressure (Bonada et al., 2006; Hering et al., 2010). Severe degradation consistent with advanced eutrophication and anthropogenic pressure can be delineated from high pollution sites,which were designated by poor water quality (Smith et al., 1999; Dodds & Smith, 2016).

Temporal variations observed in the water quality exhibits seasonal influences on the river health due to various natural and anthropogenic inputs, with higher deterioration experienced during summer and a relatively improved state in winter (Xu et al 2019).The use of multivariate techniques for deciphering river health patterns claimed a distinct gradient of pollution (Poikane et al., 2020; Miler & Brauns, 2020). Therefore, strengthening pollution control measures with management and conservation priorities and ascertaining restoration of the impacted sites are critical for safeguarding sustainable freshwater governance and averting irreversible ecological deterioration.

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