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Spatial Variations in the Benthic Diatom Flora and Its Diversity in the Highland-Plateau Rivers (Central India)

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Abstract: This study examines spatial distribution of benthic diatom communities from the rivers Chambal, Ken and Tons in Central India. Their floras consist of total 386 taxa, 110, 206 and 212 taxa in Chambal, Ken and Tons, respectively and are quite similar. Flora is highly similar within each river but varies among their corresponding sections (upper to mouth).Richness decreases gradually from source to mouth because substrate heterogeneity declines. Similarity in richness also declines in each river, but increases mildly amongst their corresponding sections, because substrate differs spatially. Alpha diversity is high and similar for the rivers. Species-rich genera are same. Elements of pristine conditions prevail in the flora. In light of these observations the benthic diatom communities are examined for the spatial distribution of flora and species diversity in the highland - plateau rivers Ken and Tons and Chambal. Studies will be useful to understand the regional patterns of diatom diversity and formulate reference conditions in these and other rivers of this region. The study will serve to assess the impacts of the proposed Ken-Betwa Link and climate change.

Keywords: Indian Peninsula, ecoregion, diatom, plateau rivers, Principal Component Analysis

I. INTRODUCTION

The freshwater biodiversity is distributed in a fundamentally different pattern from that in marine or terrestrial systems. Organisms on land or in the sea live in media that are more or less continuous over extensive regions and species adjust their ranges to some degree as climate or ecological conditions change. But freshwater habitats are relatively discontinuous, and many freshwater species do not disperse easily across the land barriers that separate river drainages into discrete units. The loss of biodiversity in an ecosystem has important implications, including diminished resistance and resilience to disturbance, system simplification, and loss of ecological integrity (WRI et al., 1992). In such ecosystems, monitoring and assessment using the resident biota provides both an integrative view of the effects of human influences and a rich variety of signals that can be used to diagnose the causes of degradation (Karr 2006). Biological assessment has thus been recommended for ecological assessment of such ecosystems as it is more reliable, relatively inexpensive and provides a synergistic and holistic approach (Chutter 1998). Various groups of organisms such as phytoplankton, zooplankton, macro invertebrates, periphyton, macrophytes and fish have been recognized as efficient biomonitors (Hering et al. 2006, Resh 2008, Hughes et al. 2012, Wu et al. 2014, Na et al. 2014). However, macro invertebrates and periphyton are the most recommended groups that can integrate the effects of multiple environmental stressors over time (Stevenson and Pan 1999, Kar and Chu 2000), thereby reflecting the ecological status of aquatic ecosystems. Amongst the periphytic communities, diatoms have been established as robust biomonitors and for long have been used for assessment of environmental conditions in streams and rivers (Stevenson et al. 2010). Diatoms constitute over 80% of the primary producers in the in the highland stream and river ecosystems (Nautiyal et al., 1997; 2004 a &b).

Little progress has been made to document the diatom flora, measures of species diversity and assemblages in the highland streams/rivers of India (Rout & Gaur 1994; Nautiyal 2001 & 2005; Nautiyal & Nautiyal 1999;Nautiyal et al., 2000;2004 a & b; Jüttner& Cox 2001; Nautiyal & Verma 2009;Verma&Nautiyal 2009). The interest is more recent because the uplands, like Himalaya have witnessed a lesser degree of human interference compared to Alps and other mountain chains and can serve as reference sites (Ormerod et al. 1994; Cantonati et al., 2001 &Nautiyal et al., 2004 b) and because increased developmental activities, consequent urbanization is affecting these rather pristine waters (Nautiyal et al., 1996&2000). The proposed Ken-Betwa Link (Bundelkhand region, Uttar Pradesh and Madhya Pradesh, NWDA 2006; Krueger et al., 2007) is one such contentious issue in the water starved Bundelkhand region (Central India). The Chambal River is also an intense issue because diatoms from this river have never been explored, though other rivers of the central highland region have received attention (Nautiyal and Nautiyal, 2014; Verma

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and Nautiyal, 2016; Nautiyal et al., 2017; Vermaet al., 2016). Both are important rivers in the lower section of the Yamuna river system in Central India.

Studies aiming to generate information on reference conditions are needed in the Peninsula and north-eastern parts of the country. In light of these observations the benthic diatom communities are examined for the spatial distribution of flora and species diversity in the highland - Plateau Rivers namely Chambal, Ken and Tons. Studies will be useful to understand the regional patterns of diatom diversity and formulate reference conditions in these and other rivers of this region.

II. METHODOLOGY

A. Study area

The Chambal River originates from the summit of Janapav hill of the Vindhyan range at an altitude of 854 m above the msl at $22^{0}27'$ N and $75^{0}37'$ E in Mhow, located in Madhya Pradesh of Central India. It flows through three large states of India namely Madhya Pradesh (M.P.), Rajasthan and Uttar Pradesh (U.P.) whereas Ken and Tons flow between $23^{o}30'$ to 26^{o}N latitude and $78^{o}30'$ to $82^{o}30'$E, longitude. Both the Rivers are located in a north-eastern part of the Bundelkh and plateau and Vindhya mountain ranges in the Central Highlands ecoregion located to north of the Tropic of Cancer between Narmada in the south and Gangetic Plains in the north. They are separated by smaller rivers (<100 km long) originating in the hills close to the Gangetic Plain. Both of them are ca. 300~350 km long. They find their source in the Kaimur series of the Upper Vindhyan range north of the river Narmada. The Ken flows northwards and joins the right bank of the Yamuna ca. 100 km before its confluence with the Ganga at Allahabad. The Tons lies to east of the Ken and flows in north-easterly direction to join the Ganga, nearly 50 km downstream of Allahabad. Both rivers flow from low to higher latitudes and cut across the plateau as they move towards the Plains. Upper sections of the Ken and Tons are about 20 km apart and the distance gradually increases (~150 km) towards their mouth sections. The Chambal River has three major tributaries namely the Parbati, Kali Sindh, and Banas rivers. Between 1960 and 1972 four multipurpose dams namely Gandhi Sagar, Jawahar Sagar, Ranapratap Sagar and Kota Barrage have been constructed on the upper reaches of Chambal River which have affected its flow considerably (Hussain and Choudhury 1992).

In order to decipher the spatial features of benthic diatom community one sampling station each was selected in the upper, middle, lower and mouth sections of the Ken and Tons (Figure 1) and four sites of National Chambal Sanctuary region of Chambal River (Figure 1). In each section the sampling station was selected on the ease of access by road. The geographical positions and physico-chemical characteristics of the rivers at these stations are presented in Table 1. Agriculture land use prevails on the river banks at all sampling locations, except patch of dry deciduous forest near Panna National Park in the Ken River. The area is largely rural. Urban areas include Banda, and Satna, located 2 to 10 km away respectively from the Ken and Tons in their middle section.

III. MATERIAL AND METHODS

Diatoms were collected from all the sampling sites of three rivers. Benthic diatom flora and communities were obtained by scraping 3 x 3 cm area of 4-5 palm sized stones (cobble) with a toothbrush following standard procedures (Kelly et al. 1998). All substrata were gently shaken and the resulting suspensions were pooled to form a single sample, which was then put in a labeled plastic bottle. All diatom samples were homogenized and fixed with 4% formaldehyde. In the laboratory, diatoms samples were first cleaned with hot HCl& $KMnO_4$ to remove organic coatings. The treated samples were repeatedly washed to remove all traces of acid and then cleaned with hydrogen peroxide. This method is based on Hasle (1978) and adapted by Round et al. (1990). It has been found suitable for cleaning diatom samples collected in India (Karthick et al. 2010).Diluted samples were mounted in Naphrax for examining the flora using standard literature (Hustedt 1985; Krammer& Lange-Bertalot 1986-1991; Gandhi 1998; Lange-Bertalot 2001; Krammer 2002; 2003; Werum& Lange Bertalot 2004;Metzeltin*et al.*, 2005). The identification and counting of taxa were carried out under a Light Microscope (Leica DM750) at a 100x magnification using immersion oil in accordance with CEN standards (2001). The samples and mounts are stored at the Amity Institute of Environmental Sciences, Amity University, Noida. In each sample 500-600 valves were counted for computing relative abundance, measures of diversity for the community within and among rivers using PAST v.2.03 and CAPS v. 4.0 (Hammer *et al.*, 2001;Seaby& Henderson 2007).

IV. RESULTS & DISCUSSION

A. Diatom communities: Spatial trends in richness and species diversity

The benthic diatom communities of the Chambal, Ken and Tons consists 110, 206 and 212 taxa (species, varieties, forms) respectively in their flora. The total flora of both rivers amounts to 276 taxa from 49 genera (Table 3).Though the flora is significantly similar in these rivers, but not highly similar as expected despite close proximity to each other, same terrain and

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ecoregion. Stanchevaet *al.*, (2007) also attributed high floristic similarity (0.737) among the Bulgarian rivers, it and Osum (length, 314 km, 189 km respectively; 1800 to 2030 m a.s.l., Balkan Range) to natural factors, such as similar geological characteristics and relief of the catchments of both rivers. Differences, in the flora of the Alaknanda (1 station 3 sites at 500 m a.s.l., 193 taxa, 23 genera, Nautiyal & Nautiyal, 1999 b) and Nagni Gad (4 stations from source to mouth 2000 to 400 m.a.s.l., 136 taxa, 25 genera, Verma & Nautiyal, 2009) that flow through lesser Himalaya, India shows that despite one geological entity they vary in total number of taxa because of their glacierfed and spring fed character and stream order which influence their flows.

Richness of total as well as individual flora from the Chambal, Ken and Tons sampled at 12 locations is considerably high compared with the total flora (114 taxa, 36 genera) from Bulgarian riversVit (98 taxa) and Osum(94 taxa) from 28 sites. The richness of the Ken and Tons is also higher than Nagni gad and a Plateau River Damodar (120 taxa, 22 genera, Nautiyal &Nautiyal, 1999 a), but is at par with Alaknanda-Ganga. Except Vit and Osum that are temperate rivers, rest are tropical to sub tropical, so richness cannot be merely attributed to location of the river in tropics and temperate, a geographical factor but also to primary and secondary factors (Begon*et al.*, 1990). This receives support from the observations on the diversity also. The diversity is higher in all region (H 5.561) and individual rivers the Ken and Tons (Table 2) compared with the Himalayan and Plateau rivers (Nautiyal*et al.*, 1996, 2004;Jüttner*et al.*, 1996;Rothfritz*et al.*, 1997; Nautiyal&Nautiyal, 1999 a & b). The Shannon diversity (H) of the Chambal River was found to be maximum at 2.316 (C2).The Shannon diversity > 4.0 have been reported from the River Indus, Pakistan (2.82-7.95 Ali *et al*., 2003); Shillong stream (1.6-4.1, Rout & Gaur, 1994); Himalaya and Alps (2.6 to 4.1, Cantonati*et al*., 2001). Each station contains 73% to 88% of river’s flora as the richness varies from 90 to 110 taxa in the Chambal, 151 to 182 taxa in the Ken and 156 to 186 taxa in the Tons. The richness is notably higher in the upper and middle stretch and declines in the lower and mouth stretch. A general longitudinal decline in the species richness and diversity is hence evident in these rivers (Table 2) attributed to reduction in substrate size and its heterogeneity from source to mouth. Besides reduction in particle size the alluvium deposited by the Ganga and Yamuna in mouth sections of the Ken and Tons also contributes to decline in substrate heterogeneity. The decrease in diversity also corresponds with declining the altitude of rivers. In the Himalaya Rivers’ the Shannon diversity increased longitudinally with decreasing altitude (Nautiyal*et al.*, 1997; Nautiyal*et al.,* 2004 a).

The longitudinal variation is minimalbecause58 to 70% of the flora is common from source to mouth and very few taxa are added along the course (compared with K1 16 new taxa occur at K2 and 4 taxa at K3). Similarly, some taxa are present at one station only causing decline downstream of its source. Hence, of 182 taxa at K1, 169, 155 and 136 taxa occur at K2, K3, and K4, respectively in the Ken and of 177 at taxa T1, 169, 136 and 128 taxa occur at T2, T3 and T4 in the Tons. The similarity decreases mildly from source to mouth resulting in low intra-river variation (Table 4).

B. Spatial distribution of floral elements

Detrended correspondence analysis (DCA) was performed on the diatom community data to determine the length of the gradient. The gradient length was less than 3 standard deviation units, which suggested the use of linear ordination techniques. Hence, PCA was used to determine the relationship between diatom assemblage composition and sampling sites using the software CANOCO version 4.5 (terBraak 1986).

A PCA was performed on the whole data set with respect to diatom assemblage composition and results obtained (Figure 2). The first four axes accounted for 76.44% of the total variability. The first and second principal axes together explained 54.00% of the total variation, which had an eigen value of 0.372 and 0.167 respectively. Species such as GPAR, ADCK, NCTE and NANT were positively associated with Tones sites which showed high loading values on axis 1 and negatively associated with Ken sites. Kens sites were dominated by the species such as NLIN, NROS, SULN, AMSC and NVIR, which showed high loading values on axis 2 whereas BVIT, NACI and SRUM were dominated by the Chambal River sites.

Brachysiravitrea was dominated by the Chambal River, followed by Nitzschiaacicularis, Syne drarumpens and Navicula cryptonella. The flora of the Ken (K) and Tons (T) were dominated by species and varieties of NaviculaBory(K 27, T 29 taxa), NitzschiaHassal (K 21, T 25 taxa) and Cymbella Agardh (K 21, T 20 taxa), followed by SynedraEhrenb, Gomphonema Ehrenb., Cymbopleura Krammer, AchnanthidiumKütz. andAmphora Ehrenberg having 8 to 15 taxa (Table 4). This is different from the Himalayan highlands where NaviculaBory (50 taxa), AchnanthidiumKütz. (49 taxa),Cymbella Agardh (39 taxa, includes Cymbopleura), NitzschiaHassal (28 taxa)are species rich genera (Nautiyal et al., 2004) and Bulgarian ranges where NitzschiaHassal (27 taxa), NaviculaBoryand Gomphonema Ehrenb (13 taxa each), are species rich (Stancheva et al., 2007).In the Damodar R. the species-rich genera areSynedraEhrenb., Gomphonema Ehrenb., Cymbella Agardh, Achnanthes Bory, Navicula Bory, NitzschiaHassal (Nautiyal&Nautiyal, 1999 a). Among some genera that occur either in the Ken or Tons, the genera Frustulia Rabenhorst, Gomphocymbelopsis and Mastogloia Thwaitesare exclusive in the Ken while AnomoeoneisPfitzer andBacillariaGmelin in the Tons.

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The species of these genera are not common in India compared with species of AulacoseiraThwaites, Achnanthes Bory, Stauroneis Ehrenberg, EpithemiaKützing, RhopalodiaO. Muller and HantzschiaGrunow (Table 3) that are well known from other parts of the country. Hence, former are truly exclusive compared to the latter that are relatively common.

In the Ken, the species-rich genera Nitzschia Hassal, SynedraEhrenb., Achnanthidium Kütz.and GomphonemaEhrenb. show decline in the number of taxa from the upper to mouth sections, NaviculaBory remain constant and Cymbella Agardh shows alternate decrease and increase. In the Tons NaviculaBory,Nitzschia Hassal,Synedra Ehrenb. And Gomphonema Ehrenb. show decrease while AchnanthidiumKütz. And Cymbella Agardh remain constant. Most of the taxa generally decline downstream of the upper section while few remain constant.

V. CONCLUSIONS

The study examines spatial distribution of benthic diatom flora, species richness and diversity among the Chambal, Ken and Tons rivers located in Central India. The region supports higher richness (276 taxa, 46 genera) compared to 110, 206 and 212 taxa in the Chambal, Ken and Tons, respectively, which are considerably similar, as 31 to 33% taxa are specific to respective rivers. Richness decreases gradually from source to mouth because substrate heterogeneity declines. Flora is highly similar within each river but varies among their corresponding upper, middle, lower and mouth sections, despite proximity of rivers. Similarity in richness declines downstream of source in each river, but increases mildly among them, though distance between these rivers increase progressively, attributed respectively to continuum and different substrates in corresponding sections, water quality being similar. Navicula Bory, Nitzschia Hassal and Cymbella Agardh are species rich genera in both rivers. Species richness of most genera decline downstream of the source.Genera representing pristine, oligotrophic water conditions prevail over high conductivity and brackish and pollution tolerant flora.

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Table 1Geographical co-ordinates of the sampling stations and Physical and chemical characteristics (minimum and maximum) at different stations of the Central Highlands region. (AT, Air temperature; WT Water temperature; pH; C1, Pinahat; C2, ; C3, Etawah; C4, ;K1, Shahnagar; K2, Panna; K3, Banda; K4, Chilla; T1, Amdara; T2, Maihar; T3, Satna; T4, Chakghat).

River	Ken River				Tons River					Chambal River		
Stations	K1	K2	K3	K4	T1	T2	T3	T4	C1	C2	C3	C4
Latitude(N)	23°59'28.92"	24°44'17.38"	25°28' 38.25"	25°46' 15.49"	24° 6'30.83"	24°16' 14.13"	24°33' 42.88"	25° 2'1.06"	26° 8'6.38"	24° 8'6.55"	26° 7'0.19"	26° 6'9.91"
Longitude(E)	80°18'1.77"	80° 0'41.16"	80°18' 51.62"	80°31' 36.99"	80°36'1 1.34"	80°48' 18.11"	80°54' 26.34"	81°43' 51.75"	78°33'86"	78°36' 77"	78°93' 51"	78°93' 66"
Altitude(m asl)	180	135	131	80	360	326	290	94	135	138	197	201
AT(^{0}C)	23-32	11.5-25	20-24.5	13.4-21.5	28-33	17-30	17.5-28	17-27	14-30	17-28	10-26	12-25
WT(^{0}C)	20.5-27	15-21.5	17-22	15-24.5	28-26.5	17-30	17.5-28	17-27	19-22	18-21	17.2-24	16.1-20
pH	7.2-7.5	7.0-7.2	7.2-7.5	7.2-7.5	7.2-7.6	7.0-7.6	7.4-7.6	7.4-7.6	7.4-8.9	7.8-8.3	7.5-8.2	7.4-8.2

Table 2Measures of species diversity in the Chambal, Ken and Tons rivers.

	Shannon H	Simpson 1-D
C1	2.229	0.894
C2	2.316	0.899
C3	2.255	0.895
C4	2.094	0.853
K1	5.048	0.992
K2	4.982	0.992
K3	4.853	0.99
K4	4.704	0.989
T1	5.01	0.992
T2	5.031	0.992
T3	4.799	0.99
T4	4.715	0.989

Table 3 Spatial variations in the number of species occurring in various genera recorded from the Plateau Rivers Ken and Tons.

	GENERA	Chambal	Ken	Tons
Thalassiosiraceae	Aulacoseira	1	1	
	Cyclotella	2	1	2
Fragilariaceae	Diatoma	1	2	4
	Fragilaria	1	1	2
	Staurosira	1	1	1
	Synedra	2	13	15
	Tabellaria	1	1	1

Eunotiaceae	Eunotia	3	3	4
Achnanthaceae	Achnanthes	1	1	
	Achnanthidium	8	8	11
	Planothidium	2	4	4
	Cocconeis	3	3	3
Naviculaceae	Amphora	5	10	8
	Anomoeoneis	1		1
	Brachysira	1	1	2
	Caloneis	3	5	5
	Cymbella	8	21	20
	Cymbopleura	8	12	10
	Diploneis	1	5	4
	Encyonema	2	4	4
	Frustulia		1	
	Gomphocymbelopsis	1	1	
	Gomphonema	6	2	3
	Gyrosigma	1	11	12
	Mastogloia	1	1	
	Navicula	12	27	29
	Naviculas. l.		3	3
	Adlafia		1	2
	Craticula	2	4	3
	Diadesmis	1	1	1
	Fallacia		1	2
	Geissleria	1	1	1
	Hippodonta		1	2
	Luticola	1	6	7
	Placoneis	2	2	2
	Sellaphora	3	5	5
	Neidium	1	2	2
	Pinnularia	2	3	3
	Stauroneis	1	2	
	Scoliopleura		1	
Epithemiaceae	Epithemia	2		1
	Rhopalodia	1		2
Bacillariaceae	Bacillaria	1		1
	Denticula	1	1	1
	Hantzschia	2	1	
	Nitzschia	12	21	25
Surirellaceae	Surirella	3	8	5
Total Genera		41	42	38
Total species		110	206	211

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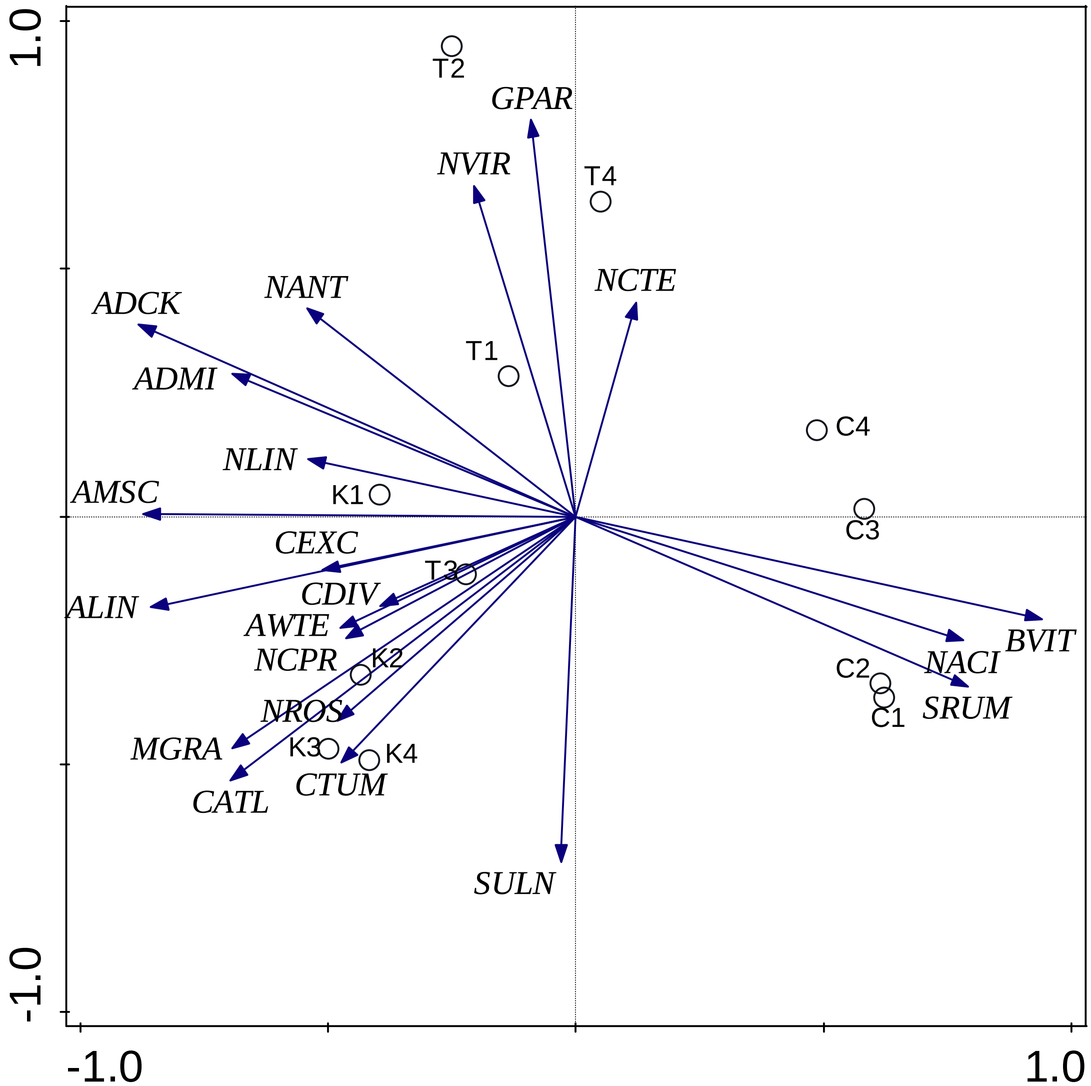

Figure 2: Principal Component Analysis (PCA) biplot showing the relationship between diatom composition assemblages and selected sampling sites recorded from the Chambal, Ken and Tons River. Acronyms are presented in Appendix I.

Appendix I
Summary of the results derived from Principal Component Analysis (PCA) applied on diatom assemblages and selected sampling sites.

	Axis 1	Axis 2	Axis 3	Axis 4
Eigen value	0.3725	0.1675	0.1285	0.0959
Explained variation (cumulative)	37.25	54.00	66.85	76.44

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Appendix Ii

CODE	SPECIES NAME
ADMI	Achnanthidiumminutissimum
AMSC	A. m. v. scotica
ADCK	Achnanthidiumchitrakootense
ALIN	Achnanthidiumlinearis
NCTE	Naviculacryptotenella
SULN	Synedra ulna
CDIV	Cymbelladiversa
AWTE	Amphora twentiana
NCPR	Naviculacapitatoradiata
CTUM	Cymbellatumida
CATL	Cymbellaaustralica
NANT	Naviculaantonii
CEXC	Cymbella excise
NROS	Navicularostellata
NLIN	Nitzschialinearis
GPAR	GomphonemaParvulum
MGRA	Melosira granulate
NVIR	Naviculaviridula
BVIT	Brachysiravitrea
SRUM	Synedrarumpens
NACI	Nitzschiaacicularis

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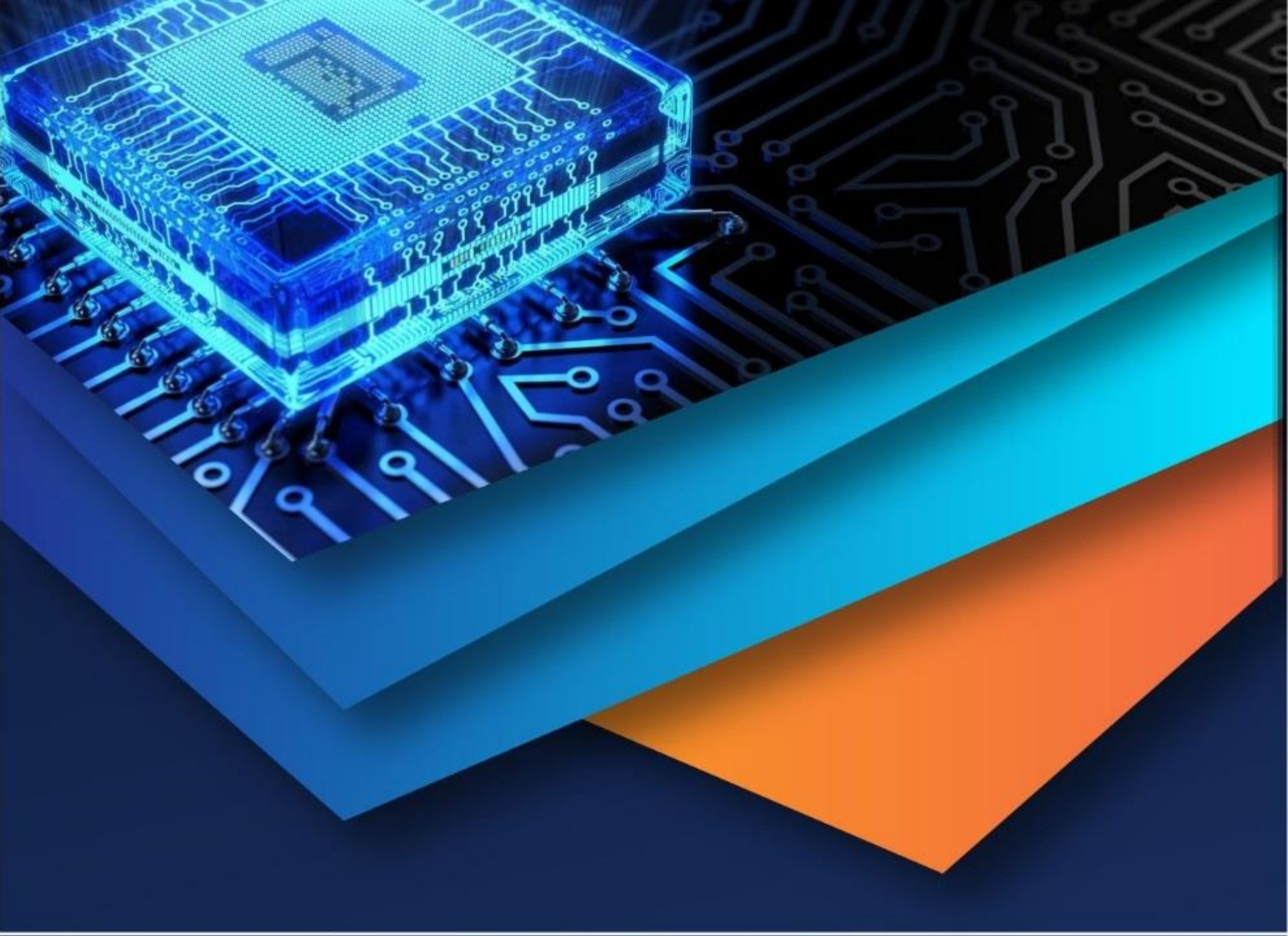

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