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Article

Assessment of Metal Contamination with Seasonal Variation in Sediments of Narmada River (India) Using Pollution Indices

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Abstract: This study aimed to assess the presence of metal contamination in the sediments of the Narmada River by considering seasonal variations. In this context, samples were gathered from six stations along the river in 2021–22. To assess the various metals including Li, Na, Mg, Al, Ca, Fe, Cu, Zn, Co, and Ni by utilizing ICP-MS. Sediment contamination was assessed by utilizing indices like contamination factor (CF), pollution load index (PLI), geo-accumulation factor (Igeo), and enrichment factor (EF). The observed order of metals concentration revealed that metals Fe>Al>Mg>Ca>Na>Cu>Zn>Co>Ni>Li. The seasonal variation reveals metals Al, Fe, Cu, Zn, and Ni exhibit the highest concentrations during the monsoon and metals Li and Co, the highest concentration in the post-monsoon, while metals Na, Mg, and Ca, exhibit their peak concentration during the pre-monsoon. The findings from CF, PLI, Igeo, and EF indicate that there were low to moderate contaminations, metal pollution exists, uncontaminated to moderate contaminations, and minor enrichment. The cluster analysis revealed the source of contamination was anthropogenic, marine, and fertilizer activities. Additionally, Correlation matrix was employed to establish connections between metals. The findings of this research are to understand the metal contamination and potential carcinogenicity in the sediment of Narmada River.

Keywords: seasonal variation; contamination factor; pollution load index; geo-accumulation index; enrichment factor; Narmada River

1. Introduction

In recent years, the escalating presence of metal contamination in aquatic ecosystems has raised significant concerns due to its toxicity, pervasiveness, and accumulation. This issue has garnered substantial attention and awareness, underscoring the growing need for immediate action. The main sources of metal contamination in river sediments are untreated domestic wastewater, agricultural fertilizer and pesticides, industrial discharge, and natural activities [1–3]. The aqueous phase and river sediments get a distribution of metal that is released into a river system throughout its conveyance by point or nonpoint sources [4]. Due to the combined effects of adsorption, hydrolysis, co-precipitation, and fine particles, most unbound metal ions do not persist within the solution and instead accumulate in large quantities in sediments [5]. When harmful and persistent chemical pollutants with slow decomposition rates are discharged into the river water, sediments act as a top pollutant key store for such contaminants. River sediments serve as habitats for diverse aquatic animals and plants, playing a crucial ecological role in the aquatic environment while also serving as reservoirs for pollutants. This can lead to the accumulation of metal residues, potentially posing health risks if these contaminants enter the human food chain. In aquatic systems, Sediments serve the dual role of potential secondary sources and transporters of pollutants. The retention of metals in river sediments has the capacity to perpetual future pollutant. Hence, it is imperative to conduct comprehensive research on sediment quality to assess the potential threat posed by metal contamination and the associated carcinogenic risks [6–11]. Sediment contamination assessment studies have been utilized globally during the past few decades [6,11–18]. Metals are categorized

based on their source of origin into three primary groups: anthropogenic metals (Li, Cu, Zn, Co, Ni), crustal metals (Al and Fe), and marine-related metals (Na, Ca, Mg) [19].

Correlation and Cluster analysis have gained widespread recognition as valuable tools for identifying, classifying, and understanding the relationships among sources of pollutants [2,16,20].

Narmada River is an important river in India and This was the first in-depth study on metal. The report was finished using routine sampling over two years at six sample stations. ICP-MS was applied for the determination of metal concentration and Method 3050B was applied for calculation. Hence, the main aim of this research is to investigate the concentration of metal with seasonal variation in the sediment of the Narmada River.

2. Materials and Methods

2.1. Study area

The Narmada River ranks as the fifth-longest river in the Indian subcontinent and it is called the lifeline of Madhya Pradesh. Over time, numerous small towns and large cities have flourished along their banks. Unfortunately, due to various human activities, such as the discharge of domestic, dairy industrial waste and natural drainage, the river's water quality has deteriorated significantly. Therefore, it is essential to analyse the quality of sediments. For this, six sampling stations were selected in such a way as to cover Jabalpur city (Figure 1). The first sampling station is Jamtaraghat which is close to the Pariyat tributary and dairy industries. The second, third, and fourth sampling stations are Gwarighat, Tilwaraghat, and Bhedaghat. These are close to urban areas. The fifth and sixth sampling stations are Ghugharaghat and Parmatghat. They are close to agricultural and rural areas. The distance between the first four sampling stations is 5 km each and fourth to fifth and fifth to sixth are 10 km and 15 km respectively. As such a stretch of 40 km has been taken for this study.

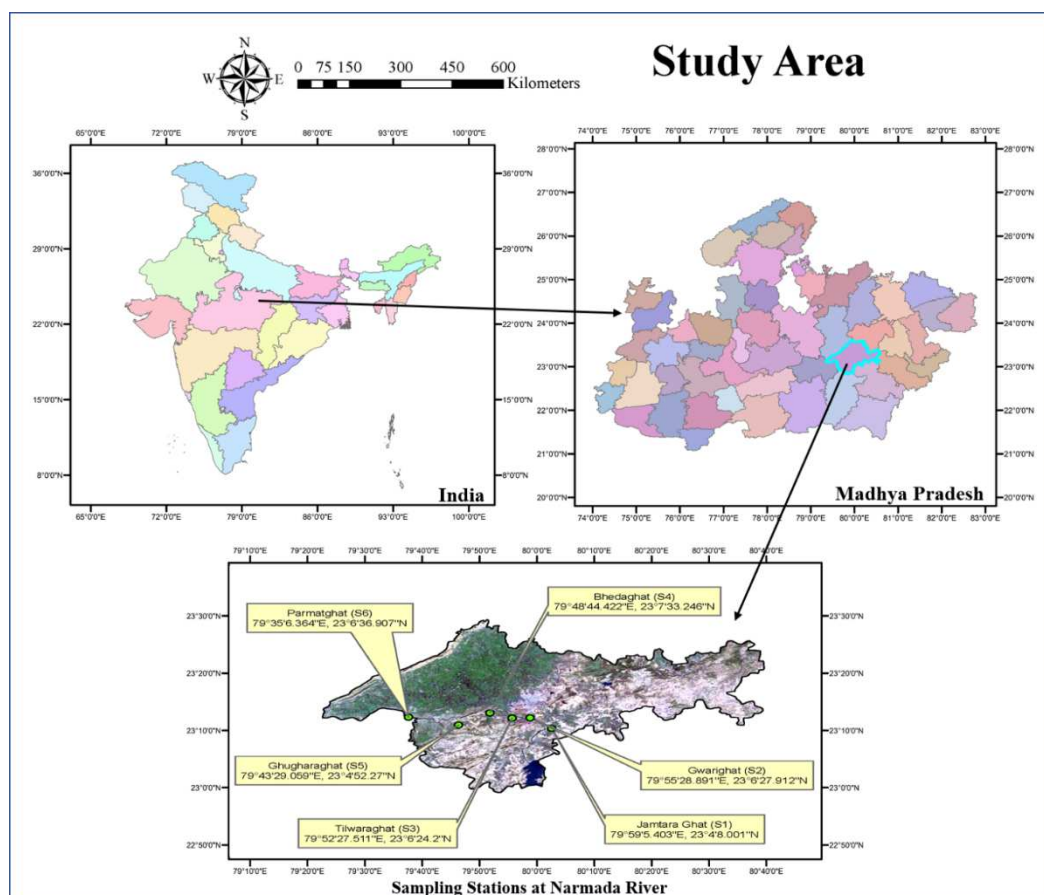


Figure 1. Study area and sampling Point Location along the Narmada River.

2.2. Sample Collection and Instrumental Analysis

Samples of sediment were gathered from sampling sites over four distinct phases: firstly, May (Pre-monsoon); secondly, July (monsoon); thirdly September (Post- monsoon) and fourthly January (Winter) during the year 2021-22. The samples were collected from six stations of four composite samples each weighing approximately 200 g. After sampling, samples were immediately enclosed within uncontaminated polyethylene bags and transported to the laboratory, where they were stored at a temperature of 4°C. In preparation for analysis, the samples underwent an air-drying process. Subsequently, plant fragments and stones were eliminated by sieving the dried sample through a 2 mm mesh. The analytical procedure was followed to EPA protocol 3050B, involving acid digestion for sediments, sludges, and soils. This method utilizes a combination of hydrogen peroxide and nitric acid for complete metal digestion. The next step involved utilizing ICP-MS (Inductively Coupled Plasma-Mass Spectrometry) to ascertain the concentration of metals within the sediment samples.

2.3. Analysis of Sediment Contamination

In the explication of geochemical data, the selection of background value is crucial. Many authors have utilized the average shale value as a reference background value [13,16,21]. However, due to the absence of data regarding background values for the Narmada River sediment and the enclosed area under investigation. Consequently, this study adopts a meticulous approach and computes background values by averaging the metal concentrations in uncontaminated sediments within the study region [1,5,20]

2.3.1. Contamination factor (CF)

CF is expressed as $CF = (\text{Sediment Metal Concentration}) / (\text{Background value of the metal})$.

Following the classification by Hakanson (1980), CF values are interpreted as follows: $CF < 1$ indicates low contamination; $1 < CF < 3$ suggests moderate contamination; $3 < CF < 6$ implies considerable contamination.

2.3.2. Pollution load Index (PLI)

PLI is expressed as: $PLI = (\text{Product of contamination})^{1/n}$

When PLI exceeds 1, it signifies the presence of metal pollution. Conversely, If PLI is less than 1, there is no evidence of metal pollution.

2.3.2. Geo-accumulation index (I_{geo})

I_{geo} is determined using the formula $I_{geo} = \log_2 \frac{C_n}{1.5B_n}$

C_n and B_n represent measured concentration and geochemical background values. Constant 1.5 is applied to account for possible variations in the background value. I_{geo} values correspond to different contamination classes: Class 0 ($I_{geo} \leq 0$) indicates Uncontaminated status; Class 1 ($0 < I_{geo} < 1$) signifies uncontaminated to moderately contaminated; Class 2 ($1 < I_{geo} < 2$) represents moderate contaminated; Class 3 ($2 < I_{geo} < 3$) denotes moderately to heavily contaminated.

2.3.3. Enrichment factor (EF)

The EF is defined as: $EF = [(\text{Metal/Fe}) \text{ sample}] / [(\text{Metal/Fe}) \text{ background}]$

Fe serves as the reference element for geochemical normalization., The interpretation of EF values is as follows: $EF < 1$ implies no enrichment; < 3 indicates minor enrichment; 3-5 suggests moderate enrichment; 5-10 implies moderately severe enrichment; 10-25 signifies severe enrichment.

3. Results and Discussion

3.1. Metal contamination

The findings concerning metal concentrations (Table 1) reveal a range across different stations and seasons. Li concentration ranged between 0.034 to 0.077 mg kg⁻¹, with station third exhibiting the highest concentration during the post-monsoon season and station six having the lowest concentration during the monsoon season. Na concentrations ranged between 16.426 to 32.383 mg kg⁻¹, with station first registering the highest concentration during the pre-monsoon season and station six recording the lowest concentration during the monsoon season. Similarly, Mg concentrations varied from 77.459 to 167.286 mg kg⁻¹, with station fourth having the highest pre-monsoon concentration and station six the lowest during the monsoon. Al concentration spanned from 229.937 to 479.472 mg kg⁻¹, with the first station exhibiting the greatest concentration during monsoon season, while station six had the lowest concentration during the pre-monsoon season. Ca concentrations ranged between 13.231 to 39.912 mg kg⁻¹, with station first registering the highest concentration during the pre-monsoon season and station fifth recording the lowest concentration during the monsoon season. Fe concentrations varied between 309.682 to 1133.822 mg kg⁻¹, with station first exhibiting the highest concentration in the monsoon season and station six having the lowest concentration in the pre-monsoon season. Cu concentrations spanned from 0.842 to 2.965 mg kg⁻¹, with the third station having the highest during the monsoon and station six displaying the lowest during the pre-monsoon. Zn concentrations varied between 0.686 and 2.09 mg kg⁻¹, with station third exhibiting the highest concentration during the monsoon and station fifth recording the lowest before the monsoon. Co concentrations spanned from 0.548 to 1.387 mg kg⁻¹, peaking at station third in the post-monsoon and being lowest at station six during the monsoon. Ni concentrations spanned from 0.323 to 0.953 mg kg⁻¹, with station third displaying the highest concentration during the monsoon and station fifth recording the lowest during the pre-monsoon.

During the monsoon season, the interaction between agricultural runoff and river water led to an increase in the concentrations of Cu, Zn, and Ni due to their presence in fertilizers and pesticides.

In the post-monsoon season, higher human activities contributed to elevated concentrations of Li and Co. The pre-monsoon period witnessed increased concentrations of Na, Mg, and Ca due to higher evaporation rates during summer.

The spatial distribution patterns indicated that the station first exhibited higher concentrations of Na, Al, Ca, and Fe owing to geological and marine influences. Station fourth had elevated Mg concentrations due to the presence of marble rock sections. Human and agricultural activities lead to increased concentrations of Li, Cu, Zn, Co, and Ni at station third. Notably, the concentration hierarchy was Fe > Al > Mg > Ca > Na > Cu > Zn > Co > Ni > Li.

Regarding seasonal variations, the distribution of the metals followed the order of monsoon > post-monsoon > winter > pre-monsoon for Al, Fe, Cu, Zn, and Ni. Conversely, Li and Co showed a distribution pattern of post-monsoon > winter > pre-monsoon > monsoon, while Na, Mg, and Ca demonstrated a distribution sequence of pre-monsoon > post-monsoon > winter > monsoon. Two of the analysed metals, Co and Ni, possess carcinogenic potential. However, their concentrations remained below the acceptable limit, indicating no cancer risk.

Table 1. Concentration of various metals at all studies stations in the sediments of Narmada River.

S. No.	Seasons	Metal Concentration (mg kg ⁻¹)									
		Li	Na	Mg	Al	Ca	Fe	Cu	Zn	Co	Ni
S-1	Pre-Monsoon	0.048	32.383	140.741	341.852	39.912	739.951	1.103	0.693	1.151	0.456
	Monsoon	0.039	21.962	108.641	479.472	25.873	1133.822	2.263	1.457	0.965	0.796
	Post-Monsoon	0.056	26.218	128.862	386.637	32.872	989.549	1.492	0.879	1.262	0.573
	Winter	0.051	28.983	133.264	352.916	33.648	762.161	1.166	0.795	1.183	0.475
	Average value	0.049	27.387	127.877	390.219	33.076	906.371	1.506	0.956	1.140	0.575
S-2	Pre-Monsoon	0.057	31.752	142.467	332.852	36.647	718.246	1.410	0.728	1.172	0.509
	Monsoon	0.043	21.484	113.646	463.173	21.527	1076.161	2.353	1.691	0.976	0.892
	Post-Monsoon	0.069	25.017	135.757	372.374	30.982	972.076	1.583	1.05	1.326	0.616
	Winter	0.061	28.674	137.442	345.751	31.473	732.807	1.506	0.899	1.273	0.568
	Average value	0.058	26.732	132.328	378.538	30.157	874.823	1.713	1.092	1.187	0.646

S-3	Pre-Monsoon	0.068	29.738	152.262	313.786	34.342	703.972	1.924	1.085	1.176	0.535
	Monsoon	0.052	20.141	122.528	443.284	19.638	1099.291	2.965	2.09	0.983	0.953
	Post-Monsoon	0.077	23.41	144.742	357.438	28.347	956.752	2.179	1.383	1.387	0.692
	Winter	0.071	27.374	146.472	330.264	29.793	716.992	1.968	1.126	1.281	0.572
	Average value	0.067	25.166	141.501	361.193	28.030	869.252	2.259	1.421	1.207	0.688
	Pre-Monsoon	0.065	25.895	167.286	287.732	32.842	581.862	1.472	0.998	1.130	0.390
	Monsoon	0.050	18.462	137.866	425.683	16.749	982.653	2.526	1.922	0.951	0.614
	Post-Monsoon	0.072	22.173	158.742	352.693	26.476	754.528	1.843	1.294	1.295	0.501
	Winter	0.067	24.021	161.573	302.744	27.638	590.372	1.511	1.094	1.247	0.414
	Average value	0.064	22.638	156.367	342.213	25.926	727.354	1.838	1.327	1.156	0.480
S-5	Pre-Monsoon	0.047	22.946	104.451	233.739	25.852	415.795	0.969	0.686	0.779	0.323
	Monsoon	0.036	16.894	89.741	364.153	13.231	911.658	1.972	1.556	0.597	0.593
	Post-Monsoon	0.054	18.688	96.065	312.753	18.887	666.926	1.262	0.828	0.852	0.390

	Winter	0.050	20.458	100.231	247.025	20.236	432.897	0.993	0.718	0.811	0.349
	Average										
	value	0.047	19.747	97.622	289.418	19.552	606.819	1.299	0.947	0.760	0.414
	Pre-										
	Monsoon	0.046	22.863	94.052	229.937	26.998	309.682	0.842	0.706	0.727	0.332
	Monsoon	0.034	16.426	77.459	358.583	15.098	799.854	1.882	1.562	0.548	0.598
	Post-										
S-6	Monsoon	0.053	18.219	84.362	309.482	19.931	628.874	1.212	0.922	0.896	0.396
	Winter	0.050	20.316	89.984	242.219	22.626	327.215	0.869	0.714	0.844	0.354
	Average										
	value	0.046	19.456	86.464	285.055	21.163	516.406	1.201	0.976	0.754	0.420

3.2. Analysis of Pollution Indices

In Table 2, The average value of CF was 1.306, ranging between 0.833 and 2.172. The lowest CF value was observed at station sixth for metal Mg and the highest CF value was recorded at station third during the monsoon season for metal Cu. The findings of the CF indicate that there was low contamination to moderate contamination.

Regarding the PLI, its average value was 1.296, with a range spanning from 1.012 to 1.531. The lowest PLI value was detected at the sixth station, while the highest was observed at the third station. The PLI results indicate a spectrum from no metal pollution to the presence of pollution.

Table 2. Contamination factor and Pollution load index of all studies stations in Sediments of Narmada River.

S. No.	Contamination factor										PLI
	Li	Na	Mg	Al	Ca	Fe	Cu	Zn	Co	Ni	
S-1	1.244	1.330	1.232	1.356	1.696	1.504	1.448	1.059	1.508	1.459	1.373
S-2	1.474	1.298	1.274	1.316	1.546	1.452	1.647	1.209	1.570	1.640	1.435
S-3	1.718	1.222	1.363	1.255	1.437	1.442	2.172	1.574	1.596	1.746	1.531

S-4	1.628	1.099	1.506	1.189	1.329	1.207	1.767	1.470	1.529	1.218	1.379
S-5	1.199	0.959	0.940	1.006	1.002	1.007	1.249	1.049	1.005	1.050	1.043
S-6	1.173	0.945	0.833	0.991	1.085	0.857	1.155	1.081	0.997	1.066	1.012
Ave. Value	1.406	1.142	1.191	1.185	1.349	1.245	1.573	1.240	1.368	1.363	1.296
Max. Value	1.718	1.330	1.506	1.356	1.696	1.504	2.172	1.574	1.596	1.746	1.531
Min. Value	1.173	0.945	0.833	0.991	1.002	0.857	1.155	1.049	0.997	1.050	1.012

In Table 3, the average I_{geo} value was -0.229, ranging from -0.849 to 0.534. The lowest I_{geo} value was observed at station sixth for metal Mg, while the highest was found at the third station for Cu. These findings suggest a range of uncontaminated to moderate classes of metals.

Table 3. Geo-accumulation index (I_{geo}) of all studies stations in the Sediments of Narmada River.

S. No.	Geo-accumulation index									
	Li	Na	Mg	Al	Ca	Fe	Cu	Zn	Co	Ni
S-1	-0.270	-0.174	-0.284	-0.145	0.177	0.004	-0.051	-0.503	0.008	-0.040
S-2	-0.025	-0.208	-0.235	-0.189	0.044	-0.047	0.135	-0.311	0.066	0.129
S-3	0.196	-0.296	-0.138	-0.257	-0.062	-0.057	0.534	0.069	0.090	0.219
S-4	0.118	-0.448	0.006	-0.335	-0.175	-0.314	0.237	-0.030	0.027	-0.301
S-5	-0.323	-0.645	-0.674	-0.577	-0.582	-0.575	-0.264	-0.516	-0.578	-0.514
S-6	-0.355	-0.667	-0.849	-0.598	-0.467	-0.808	-0.377	-0.473	-0.589	-0.493

Ave. Value	-0.110	-0.406	-0.362	-0.350	-0.178	-0.300	0.036	-0.294	-0.163	-0.167
Max. Value	0.196	-0.174	0.006	-0.145	0.177	0.004	0.534	0.069	0.090	0.219
Min. Value	-0.355	-0.667	-0.849	-0.598	-0.582	-0.808	-0.377	-0.516	-0.589	-0.514

In Table 4, the average value of EF was 1.062. ranging from 0.704 to 1.506. The lowest EF value was detected at station first for metal Zn, and the highest was recorded at station third for metal Cu. The EF results indicate a range from no enrichment to minor enrichment.

Table 4. Enrichment factor (EF) of all studies stations in Sediments of Narmada River.

S. No.	Enrichment factor									
	Li	Na	Mg	Al	Ca	Fe	Cu	Zn	Co	Ni
S-1	0.827	0.884	0.819	0.902	1.127	1.000	0.963	0.704	1.003	0.970
S-2	1.016	0.894	0.878	0.906	1.065	1.000	1.135	0.833	1.081	1.130
S-3	1.191	0.847	0.945	0.870	0.996	1.000	1.506	1.091	1.107	1.211
S-4	1.349	0.911	1.248	0.985	1.101	1.000	1.464	1.218	1.267	1.009
S-5	1.191	0.952	0.934	0.999	0.995	1.000	1.240	1.042	0.998	1.043
S-6	1.369	1.103	0.972	1.156	1.266	1.000	1.348	1.261	1.164	1.244
Ave. Value	1.157	0.932	0.966	0.970	1.092	1.000	1.276	1.025	1.103	1.101
Max. Value	1.369	1.103	1.248	1.156	1.266	1.000	1.506	1.261	1.267	1.244
Min. Value	0.827	0.847	0.819	0.870	0.995	1.000	0.963	0.704	0.998	0.970

A comparison of the metal concentration in sediment from the Narmada River and other selected rivers is shown in Table 5. The maximum concentration of the Narmada River was very low to

comparisons to other selected rivers for Fe, Al, Cu, Zn, Co, and Ni. Additionally, concentrations of Li, Na, and Ca were not measured in the other selected rivers. Furthermore, the concentration of metals in the Narmada River sediment remained below permissible limits.

Table 5. Metal content comparison with selected other rivers.

Name of		Maximum Concentration (mg kg ⁻¹)									Referen
River	Li	Na	Mg	Al	Ca	Fe	Cu	Zn	Co	Ni	ces
Narmada River	0.08	32.38	167.29	479.47	39.91	1133.82	2.97	2.09	1.39	0.95	This study
Huafei River	-	-	-	-	-	-	866.90	4206.97	-	101.35	[22]
Nile River	-	-	-	-	-	50814	49.52	166.56	29.85	62.74	[23]
Weihe River	-	-	-	-	-	-	69.34	143.64	-	62.38	[7]
Old Brahma putra	-	-	-	90000	-	-	6.20	52.7	4.10	12.8	[2]
Yinma River	-	-	-	-	-	-	23.80	151.15	-	25.06	[24]
Swarna mukhi River	-	-	-	-	-	23296	108.3	40.93	7.22	6	[10]

Zarrin-												
Gol	-	-	785.96	2923.86	-	13751.04	-	32.68	8.79	12.39	[25]	
River												
Liaohe												
River	-	-	-	-	-	-	17.82	50.24	-	17.73	[26]	
Halda												
River	-	-	-	9316.83	-	-	5.90	79.58	4.92	15.97	[27]	
River												
Ganga	-	-	-	-	-	31988.6	29.8	67.8	-	26.7	[28]	
Brisbane												
River	-	-	-	-	-	-	29	106.6	-	15.3	[29]	
Le'an												
River	-	-	-	-	-	-	1428.4	1280.11	-	44.36	[8]	
Meghna												
River	-	-	-	-	-	-	-	79.02	-	76.1	[30]	
Arvind												
River	-	-	-	-	-	-	22.5	-	26.81	64.5	[31]	
Jialu												
River	-	-	-	-	-	-	107.61	210		80.26	[32]	
Langat												
River	-	-	-	-	-	-	14.84	74.70	-	8.25	[33]	

Pearl	-	-	-	-	-	-	-	189.49	-	-	[34]
River											
Euphrat	-	-	-	-	-	2249.5	18.9	48.0	-	67.1	[12]
es, River											
Kabini	-	-	-	-	-	1855.7	161.03	191	-	280.32	[35]
River											
Tigris	-	-	-	-	-	-	5075.6	2396.6	389.8	288.0	[20]
River											
River Po	-	-	-	-	-	-	90.1	645	-	161	[36]
Gediz	-	-	-	-	-	18233	56	72	25	51	[37]
river											
Tinto	-	-	-	-	-	-	2700	5280	42	36	[38]
River											
Gomti	-	-	-	-	-	19305.5	245.33	343.47	-	76.08	[39]
River											
Shing											
Mun	-	-	-	114	-	-	1.66	2.2	-	-	[18]
River											

3.3. Correlation coefficient

A correlation matrix was applied to establish the relationship regarding the common source among the metals in the sediment of the Narmada River (Bhuyan et al., 2019a; Islam et al., 2015; Varol, 2011).The Person correlation coefficient values are provided in Table 6. Notably, the calculated correlation coefficient indicates robust linear associations between certain metal pairs. For instance, a notably strong linear relationship was observed between Na and Mg (0.927), Na and Ca (.982), Al and Fe (0.998) as well as Li and Co (0.876), Cu and Zn (0.986), Cu and Ni (0.998), Zn and Ni (0.979). These Correlation outcomes offer insights into the common sources of these metals. The finding

suggests that marine metals, lithogenic sources, and anthropogenic activities are likely caused by the presence of these metals in the sediment.

Table 6. Correlation matrix of metals in sediments.

	Li	Na	Mg	Al	Ca	Fe	Cu	Zn	Co	Ni
Li	1									
Na	0.620	1								
Mg	0.366	0.927	1							
Al	-0.955	-0.584	-0.262	1						
Ca	0.697	0.982	0.842	-0.702	1					
Fe	-0.969	-0.573	-0.259	0.998	-0.687	1				
Cu	-0.923	-0.416	-0.073	0.981	-0.552	0.982	1			
Zn	-0.956	-0.563	-0.240	1.000	-0.683	0.999	0.986	1		
Co	0.876	0.824	0.725	-0.736	0.812	-0.756	-0.631	-0.729	1	
Ni	-0.900	-0.389	-0.038	0.974	-0.533	0.973	0.998	0.979	-0.589	1

3.4. Cluster analysis (CA)

CA was employed to identify similar characteristic sources of contamination among the various parameters through the use of a dendrogram [40–43] shown in Figure 2. From the outcome of the dendrogram; three clusters have found; Cluster 1 encompasses Li and Co; these parameters are attributed to anthropogenic activities. Cluster 2 comprises Na, Ca, and Mg, originating from marine metals activities. Finally, Cluster 3 includes Al, Zn, Fe, Cu, and Ni, stemming from agricultural fertilizers and natural earth sources.

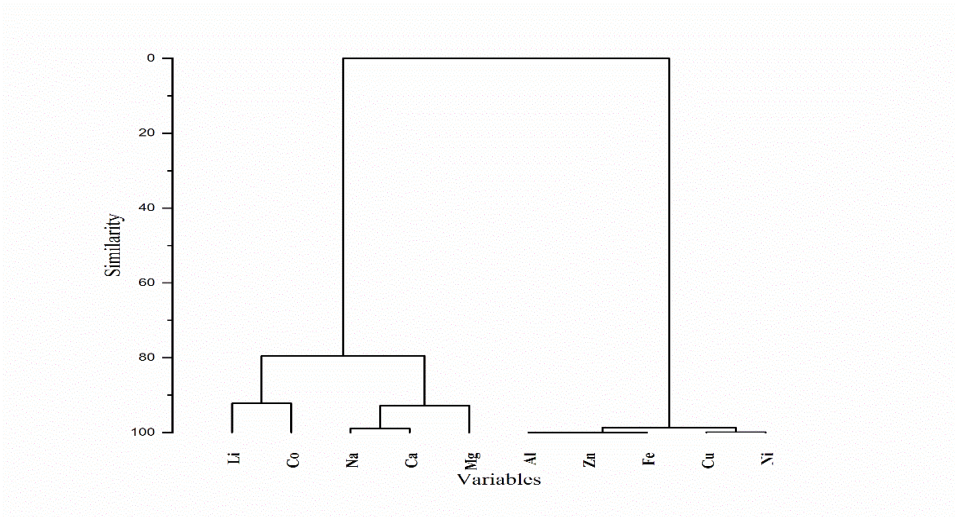


Figure 2. Dendrogram showing clustering of the analysed parameters.

4. Conclusions

The main aim of this investigation was to assess the presence and concentrations of various metals (Li, Na, Mg, Al, Ca, Fe, Cu, Zn, Co, and Ni) within the sedimentary deposits of the Narmada River. The concentration of these metals was within the permissible limit. The observed trends in metal distribution throughout the different seasons exhibited distinguishable patterns. Notably, during the monsoon season, there was an elevated concertation of metals Al, Fe, Cu, Zn, and Ni, with post-monsoon, winter, and summer seasons following in descending order of concentration. Conversely, metals like Na, Mg, and Ca demonstrated higher concentrations during the pre-monsoon period, succeeded by winter, post-monsoon, and monsoon seasons. Moreover, metals Li and Co exhibited greater concentrations in the post-monsoon season, succeeded by winter, pre-monsoon, and monsoon. Upon assessment of Co and Ni concentrations, it was determined that the sediment samples did not pose a carcinogenic risk. Pollution indices, when applied to the results, indicated that the sediment quality ranged from unpolluted to minimally polluted. The sources of contamination were identified as being associated with human activities, natural crustal processes, and marine-derived metal inputs. Notably, this study holds significance as the first of its kind focused on the Narmada River. However, it’s important to acknowledge that the study was conducted using a limited number of samples. The finding of this research establishes a foundational dataset for prospective studies and contributes valuable insights to the formulation of strategies for effective river basin management.

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