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Spatio-Temporal Analysis of Water Quality Trends in the Middle Stretch of the River Damodar

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ABSTRACT

This study focused on assessing the spatial and temporal variation of water quality trends in the middle stretch of the river Damodar. River water samples were collected from twelve different sites and analysed for various physico-chemical parameters for the assessment of water quality trends. Experimental results showed that the pH ranged from 7.0–8.53, with electrical conductivity 180–710 µS/cm. The value of cationic components (mg/l) viz., Ca^{2+}, Mg^{2+}, Na^{+} and K^{+} ranged from 12.346–30.467, 5.417–18.995, 9.425–42.962 and 1.814–12.75 respectively. The value of anionic components (mg/l) viz., SO_4^{2-}, Cl^{-}, NO_3^{-} ranged from 8.273– 40.935, 4.786–24.698 and 0.045–3.282 respectively. Water chemistry of the area reflects geochemical influences, aided by industrial and other anthropogenic impacts. From the study it was observed that the values of most of the parameters at all sites were least during the monsoon, when the flow volume increased greatly due to the surface runoff. The concentration of studied heavy metals was higher at the upstream of the study area which might be due to disposal of solid waste and wastewater generated from industrial activities. The study revealed that the analyzed physicochemical parameters along with heavy metals exhibited wide range of fluctuations at different locations. The changes in water quality trends in the study area were due to seasonal effects and catchment characteristics.

Keywords: Damodar River, Hydrochemistry, Spatio-Temporal Variation, Water Quality, Heavy Metal

I. INTRODUCTION

Spatial and temporal variability in water chemistry in rivers is directly related to different factors like the natural processes [1] and anthropogenic activities [2,3]. Natural processes influencing the hydrochemistry include precipitation, weathering of rocks, and sediment transport, whereas anthropogenic activities include industrial development and urbanization in the catchment area. Various industrial activities have continuously introduced pollutants into the riverine environment and many authors have attempted to assess the chemical behavior of heavy metals and potentially toxic inorganic substances in the river system (4-14). Runoff and drainage from various nonpoint sources like agricultural fields are the major sources of nitrogen (N) and phosphorus (P) to river waters which can cause eutrophication [15-18]. According to Allan and Flecker, (1993) [19], the land use is one of the most important factors to determine the water quality which also influences aquatic resources. Contamination by different types of toxic elements through industrial discharges into the river is one of the major causes of environmental problems in the river system. The study area receives mining and industrial effluents from the collieries and industries. A Huge amount of agricultural runoff is also received by the river in the study site.

The Damodar is an important peninsular Indian river, serves as a variety of purposes including drinking, agriculture and industrial needs. Industries like coke oven plants, sponge iron industries, and several coal washeries discharge their heavy metal containing effluents directly or indirectly into the upper and middle stretch of the river at different points. Heavy metals may enter into the riverine ecosystem through the indiscreet disposal of chemical and metal wastes from industrial, agricultural and mining activities and from various natural sources also. The distribution of heavy metals and toxic chemicals and their effects on the aquatic/riverine environment have been studied by various researchers [20-22]. The heavy metals in aquatic ecosystems are considered as serious pollutants due to their environmental persistence, toxicity and ability to be incorporated into food chains [23, 24]. The objectives of the present study are: (1) to assess the trends of water quality on the spatial and temporal basis and (2) to detect heavy metal distributions and the changes in the water quality characteristics.

II. METHODS AND MATERIAL

Collection of river water samples

Surface water was sampled for physicochemical analysis on a seasonal basis (premonsoon, monsoon and postmonsoon) from the river Damodar (Fig.1). River water samples were collected from twelve different sites and prepared for the analysis for various physicochemical parameters. Water was stored in high grade plastic bottles of 1-Lit capacity and all the sample bottles were stored in ice boxes and brought to the laboratory for further analysis. Analytical grade (AR) reagents and distilled water were used throughout the experiment.

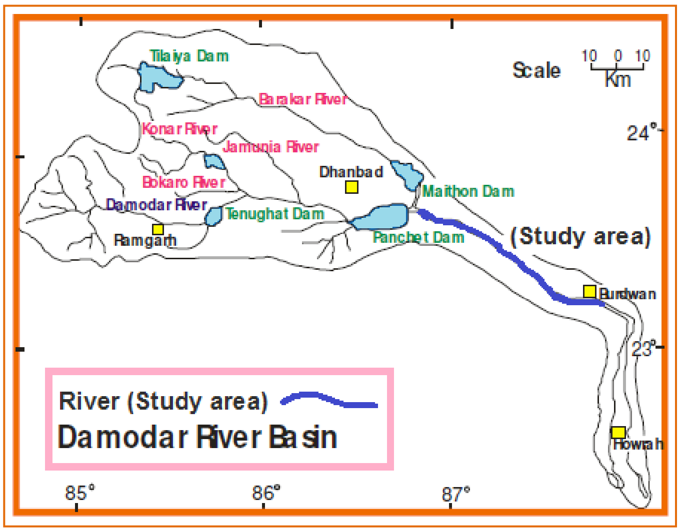

Figure 1. Location map of the Damodar River showing study area

Chemical analysis

Various physicochemical parameters like pH, electrical conductivity (EC), total dissolved solids (TDS), total hardness (TH), calcium (Ca^{2+}), magnesium (Mg^{2+}), sodium (Na^+), potassium (K^+), sulphate (SO_4^{2-}), chloride (Cl^-), nitrate (NO_3^-), lead (Pb), iron (Fe) and manganese (Mn), were determined following the methods of APHA (1998) [2]. Electrical conductivity (EC), TDS and pH values were measured in the field using a portable conductivity-pH meter. Calcium (Ca^{2+}) and magnesium (Mg^{2+}) were determined using the titrimetric method. Sulfate measured by $BaCl_2$ method using spectrophotometer, nitrate analysis was carried out using spectrophotometer; sodium (Na^+) and potassium (K^+) was analyzed using flame photometer. Chloride (Cl) concentration was measured by $AgNO_3$ titration method. For heavy metals, 500 ml river water samples were acidified with the HNO_3 and preserved separately. The concentration of heavymetals in river water was estimated by Atomic Absorption Spectrophotometer (GBC Avanta).

III. RESULT AND DISCUSSION

Hydrochemical characteristics of the river water in the study area are summarized in Table 1-3. The analytical results including pH, cationic and anionic components along the River Damodar are presented in Figure 2 to 5 The pH value of the river water in the study area ranged from 7.0 to 8.53, indicating neutral to alkaline type of river water. Water having pH value beyond the normal range may cause the nutritional imbalance. Electrical conductivity (EC), in river water varied between 180–710 µS/cm in premonsoon, 180–290 µS/cm in monsoon and 190–310 µS/cm in postmonsoon season. Electrical conductivity and Na^+ play significant roles in the suitability of water for irrigation. The high level of electrical conductivity at the site S5 is mainly attributed to industrial waste discharge in this region. TDS in river water varied between 118.33–459.76 mg/l in premonsoon, 108.45–190.25 mg/l in monsoon and 127.32–199.65 mg/l in postmonsoon season. Total dissolved solid (TDS) in river water indicates the nature of the water quality or salinity. The values of electrical conductivity and TDS decrease during monsoon season as compared to premonsoon and postmonsoon season.

Discharge of untreated industrial and municipal wastewater and agricultural activities containing toxic substances into aquatic environment resulting water pollution and causes degradation of water making them unsuitable for drinking, agriculture, and aquatic life [25, 26]. The average value of cationic components like Ca^{2+} (20.568±3.605 mg/l), Mg^{2+} (11.011±3.270 mg/l), Na^+ (18.422±8.735 mg/l) and K^+ (6.025±2.562 mg/l) was higher in premonsoon season than the other seasons. One of the main reasons for the abundance of calcium and magnesium in water is its natural occurrence in the earth's crust. Average Ca^{2+}, Mg^{2+}, Na^{+} and K^{+} was lower in the monsoon season due to diluting effect and higher during premonsoon season reflecting the concentrating effect. Water chemistry related to total hardness, Ca^{2+}, Mg^{2+}, Na^{+} and K^{+} of the study area reflected geochemical influences. Rivers play an important role in human development and are important natural potential sources, received wide attention due to the need to understand the quality and chemistry of water, which is a cumulative reflection of precipitation, weathering processes, the geology of the catchment area, and anthropogenic activities. The study revealed that the analyzed physicochemical parameters along with heavy metals exhibited a wide range of fluctuations at different locations.

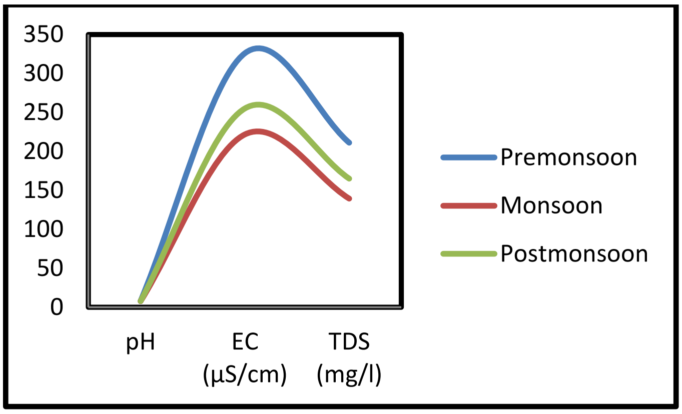

Figure 2. Distribution of pH, EC and TDS in river water

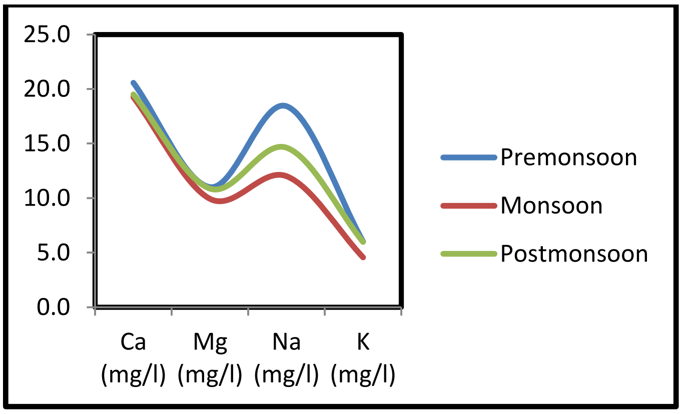

Figure 3. Distribution of Ca^{2+}, Mg^{2+}, Na^{+} and K^{+} in river water

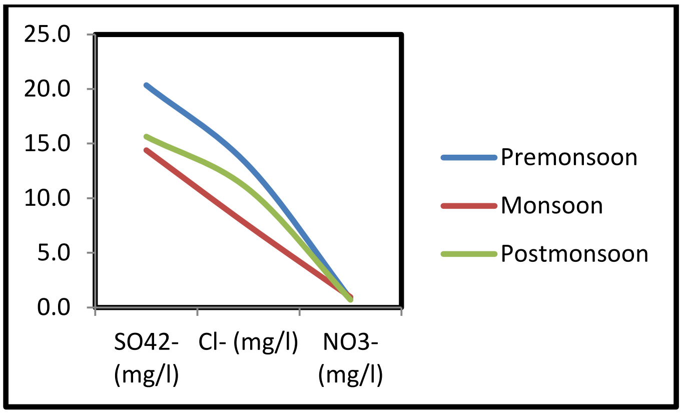

Figure 4. Distribution of SO_4^{2-}, Cl^{-} and NO_3^{-} in river water

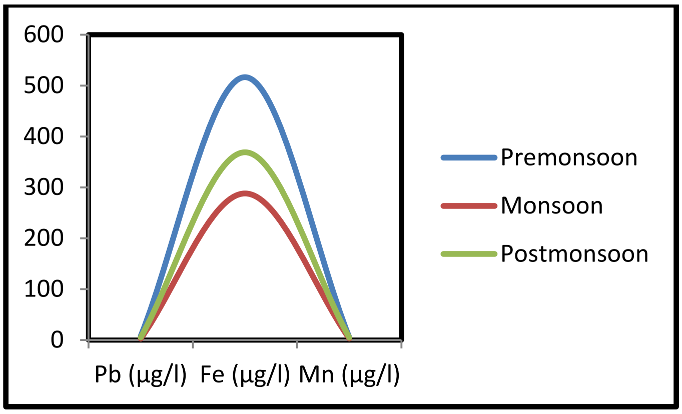

Figure 5. Distribution of Pb, Fe and Mn in river water

Nitrogen is planted nutrient, an essential constituent of proteins which stimulates crop growth. The concentration of nitrate in the river water ranged from 0.779±0.406 mg/l in premonsoon, 0.955±0.789 mg/l in monsoon and 0.704±0.261 mg/l in postmonsoon season. The values of nitrate increased during monsoon season as compared to other nonmonsoon seasons. Nitrates are the major components of agricultural fertilizers commonly used by farmers in the surrounding area. These fertilizers may be leached into the study area leading to increased concentration of nitrates [27]. The concentration of nitrate is higher near the downstream of the study area which is may be due runoff from the agricultural field. The average value of sulphate (SO_4^{2-}), is 20.349 mg/l in premonsoon, 14.396 mg/l in monsoon and 15.641 mg/l in postmonsoon with the standard deviation 9.599, 6.074 and 5.985 respectively. The average value of chloride (Cl^{-}), is 12.992 mg/l in premonsoon, 7.504 mg/l in monsoon and 10.838 mg/l in post monsoon with the standard deviation 4.856, 1.742

and 4.769 respectively. The concentration of SO_4^{2-}, Cl^- along with heavy metals is higher at the site S5 of the study area which is may be due to the disposal of solid waste along with wastewater from industrial sites.

Heavy metals discharged into the river system by various sources during their transportation are distributed between the aqueous phase and bed sediments [28, 29]. Iron (Fe) concentration in the study area varied between 516.2±514.1 µg/l in premonsoon, 287.8±185.9 µg/l in monsoon and 368.7±344.2 µg/l during postmonsoon seasons. Lead (Pb) concentration in the study area varied between 7.421±5.729 µg/l in premonsoon, 2.536±2.820 µg/l in monsoon and 4.820±4.991 µg/l during postmonsoon seasons. The lead (Pb) concentrations the river water were within the limit though in some sites of the studied river is marginally exceeded the standard drinking water quality guideline (0.01 mg/l) suggested by WHO (2006) [30]. The increase in the lead (Pb) concentration in the river water may be due to the direct discharge from different industrial sources and atmospheric inflow of dust containing car exhausts. Manganese (Mn) concentration in the study area varied between 4.765±4.737 µg/l in premonsoon, 2.784±2.514 µg/l in monsoon and 4.438±5.836 µg/l during postmonsoon seasons. The manganese (Mn) concentrations in the river water were below the standard drinking water quality guideline (0.4 mg/l) suggested by WHO (2006) [30]. The concentration of dissolved metals in the study area showed decreased values in the monsoon season as compared to nonmonsoon seasons, which is perhaps due to the dilution effect of the rain fall. The concentration of studied heavy metals was higher at the upstream of the study area which might be due to disposal of solid waste and wastewater generated from industrial activities.

Table 1. Physico-chemical characteristics of the Damodar river water in pre-monsoon season

	pH	EC	TDS	TH	Ca	Mg	Na	K	SO42-	Cl-	NO3-	Fe	Pb	Mn
S1	7.49	240	156.12	88	19.934	10.328	14.65	3.257	11.786	7.258	0.562	562	12.306	1.355
S2	7.82	220	147.96	104	14.526	7.888	12.857	5.774	12.245	10.973	0.511	352	10.109	2.664
S3	8.22	250	158.69	96	22.490	13.08	12.835	5.38	35.788	17.95	0.964	125	10.841	15.42
S4	7.94	500	319.65	112	17.658	18.245	12.964	3.375	16.885	14.175	0.953	1054	12.084	0.354
S5	7.25	710	459.76	108	15.155	6.185	42.962	3.037	40.935	24.698	0.291	1962	18.562	3.451
S6	8.41	540	346.97	76	26.652	14.126	24.895	11.23	21.750	15.070	0.872	357	1.145	6.892
S7	7.85	380	252.45	48	19.775	8.068	22.825	9.725	18.239	12.763	0.749	325	0.00	12.45
S8	7.46	220	138.37	56	22.877	8.559	15.275	5.332	16.314	11.998	0.324	279	6.896	2.452
S9	7.46	230	150.75	76	23.554	11.787	16.29	7.525	20.302	9.461	0.577	154	9.340	2.450
S10	7.64	250	159.35	96	23.387	10.831	17.785	7.442	24.792	8.543	1.760	334	3.321	5.468
S11	8.53	190	118.33	116	21.931	12.501	11.30	4.443	16.876	14.456	0.625	395	0.977	3.968
S12	8.42	180	124.35	112	18.873	10.528	16.425	5.774	8.273	8.561	1.162	296	3.469	0.245
Mi	7.2	180	118.3	48	14.52	6.185	11.30	3.03	8.273	7.258	0.29	125	0.00	0.24

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Max	8.53	710	459.76	116	26.652	18.245	42.962	11.23	40.935	24.698	1.760	1962	18.56	15.42
Ave	7.87	325.8	211.10	90.67	20.568	11.011	18.422	6.025	20.349	12.992	0.779	516.2	7.421	4.765
SD	0.43	169.7	109.25	22.46	3.6050	3.270	8.735	2.562	9.599	4.856	0.406	514.1	5.729	4.737

Units: EC in µS/cm; Fe, Pb and Mn in µg/l; other physicochemical parameters are in mg/l

Table 2. Physico-chemical characteristics of the Damodar river water in monsoon season

	pH	EC	TDS	TH	Ca	Mg	Na	K	SO42-	Cl-	NO3-	Fe	Pb	Mn
S1	7.79	220	137.43	80	17.845	11.053	18.56	4.339	14.246	4.786	0.752	146	4.428	2.634
S2	7.67	240	149.58	40	17.958	9.499	11.465	4.524	14.71	8.112	0.734	265	3.60	3.647
S3	7.86	200	122.32	76	16.80	9.032	12.125	5.571	10.524	6.703	0.827	347	6.373	0.862
S4	7.45	260	158.97	112	24.830	8.826	9.658	4.257	9.657	9.348	0.045	514	2.549	2.876
S5	7.00	290	190.25	76	30.467	10.952	10.429	4.159	28.185	9.603	3.282	722	8.865	8.968
S6	7.56	230	152.76	92	18.547	10.254	12.548	5.321	9.326	8.247	0.776	247	0.00	1.512
S7	7.46	230	147.86	100	19.868	9.741	10.347	3.285	10.254	5.637	0.792	163	0.00	1.324
S8	7.78	220	143.00	32	18.852	10.327	11.248	2.475	18.752	9.324	0.786	357	1.445	0.987
S9	7.56	210	127.43	112	17.760	7.084	12.964	4.638	9.637	8.762	0.854	345	0.00	1.147
S10	7.63	190	108.45	72	18.848	14.226	14.542	8.23	22.935	5.070	1.101	147	0.862	6.492
S11	7.78	170	114.37	36	12.346	9.458	9.425	3.039	14.673	6.186	0.364	77	1.826	1.481
S12	8.47	190	119.67	116	16.842	8.754	10.786	4.96	9.854	8.267	1.142	124	0.484	1.475
Min	7.00	180	108.45	32	12.346	7.084	9.425	2.475	9.326	4.786	0.045	77	0.00	0.862
Max	8.47	290	190.25	116	30.467	14.226	18.56	8.23	28.185	9.603	3.282	722	8.865	8.968
Ave	7.67	221.7	139.3	78.67	19.247	9.934	12.00	4.567	14.396	7.504	0.955	287.8	2.536	2.784
SD	0.34	32.9	22.9	29.85	4.507	1.731	2.529	1.472	6.074	1.742	0.789	185.9	2.820	2.514

Units: EC in µS/cm; Fe, Pb and Mn in µg/l; other physicochemical parameters are in mg/l

Table 3. Physico-chemical characteristics of the Damodar river water in post-monsoon season

	pH	EC	TDS	TH	Ca	Mg	Na	K	SO42-	Cl-	NO3-	Fe	Pb	Mn
S1	7.86	250	159.45	120	21.398	10.612	14.375	3.834	17.584	8.497	0.562	246	4.157	5.754
S2	7.98	230	152.46	100	18.811	8.688	9.870	5.414	13.234	9.457	0.786	154	7.423	0.219
S3	7.66	250	155.46	80	17.911	7.928	15.975	3.375	12.990	8.974	0.964	254	0.712	0.527
S4	8.37	270	168.33	100	19.246	12.795	13.025	7.917	11.887	17.501	0.953	786	11.543	3.785
S5	7.00	310	199.65	104	19.324	16.35	11.70	7.446	32.596	23.025	1.162	1228	15.808	17.96
S6	7.86	240	162.45	56	21.147	18.995	21.775	4.055	17.234	11.504	0.878	652	5.837	2.428
S7	7.27	290	187.35	72	18.254	12.14	11.70	12.75	15.575	8.118	0.749	298	1.566	0.324
S8	7.38	300	195	112	19.865	9.758	15.325	3.037	16.761	7.946	0.324	147	1.926	1.755
S9	8.39	290	188.5	64	14.381	10.361	22.912	2.808	8.946	8.928	0.577	95	7.444	0.786
S10	7.48	240	153.74	76	26.452	8.837	14.047	1.814	16.667	11.487	0.291	178	0.00	2.578
S11	8.25	200	130	32	18.467	5.417	11.924	4.899	11.373	6.536	0.625	263	0.984	2.349
S12	8.41	190	127.32	108	18.786	8.550	12.819	4.424	12.64	8.077	0.579	124	0.44	14.786
Min	7.00	190	127.32	32	14.381	5.417	9.870	1.814	8.946	6.536	0.291	95	0.00	0.219
Max	8.41	310	199.65	120	26.452	18.995	22.912	12.75	32.596	23.025	1.162	1228	15.808	17.96
Ave	7.83	255.0	165.0	85.33	19.504	10.869	14.621	5.148	15.641	10.838	0.704	368.7	4.820	4.438
SD	0.48	38.3	23.8	26.39	2.816	3.761	3.993	2.993	5.985	4.769	0.261	344.2	4.991	5.836

Units: EC in μS/cm; Fe, Pb and Mn in μg/l; other physicochemical parameters are in mg/l

IV. CONCLUSION

The elemental concentrations in river waters were different during three investigation periods; the concentrations were higher during the pre-monsoon season than the monsoon season and the postmonsoon season is characterized by intermediate values. Water chemistry of the study area reflected geochemical influences, aided by industrial and other anthropogenic impacts. The study revealed that the analyzed physicochemical parameters along with heavy metals exhibited wide range of fluctuations at different locations. Seasonal variation in electrical conductivity (EC) indicates an increase in concentration of major ions in the non-monsoon seasons. The concentration of SO_4^{2-}, Cl^- along with heavy metals were higher at the upstream of the study area which is may be due the disposal of solid waste along with wastewater from industrial sites. However, the monsoon values of nitrate in the downstream of the study area were increased, which may be due to the surface runoff from the surrounding agricultural fields which were cultivated during the monsoons. The changes in water quality trends in the study area were due to seasonal effects and catchment characteristics.

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