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Comprehensive Assessment of Water and Soil Quality Impacts of Coal Mining Activities in the Hasdeo River Basin, Korba District, Chhattisgarh, India

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ABSTRACT –

A systematic investigation of water and soil quality was conducted at five sites in the Hasdeo river basin, Korba district, covering upstream reference (SI), Dipka coal mine area (SII), SECL Gevra mine effluent outlet (SIII), downstream Korba (SIV), and an adjacent agricultural field (SV). Seasonal sampling (pre-monsoon, monsoon, post-monsoon) measured physico-chemical parameters (pH, EC, TDS, hardness, chloride, sulfate, BOD, COD, alkalinity) and heavy metals (Sb, Mo, Cu, Pb, Cd, Hg, Fe) relative to WHO guidelines. Mining-impacted sites, particularly SIII, exhibited severe contamination EC up to 2.10 dS/m, TDS 890 mg/L, Pb 0.024 mg/L, Cd 0.0071 mg/L, Fe 0.56 mg/L well above permissible limits. Pearson correlations revealed strong positive coupling among most pollutants ($r > 0.95$) and inverse relationships with pH ($r \approx -0.99$). Soil analyses indicated acidification, elevated salinity, and nutrient depletion near mines. Rice husk biosorption trials achieved 50–90% heavy metal removal. Findings highlight the urgent need for optimized effluent treatment, integrated watershed management, and sustainable remediation strategies in coal-mining regions.

Keywords : watershed management, investigation, remediation, Pearson correlations

Introduction

Coal mining operations generate overburden, tailings, and effluents containing dissolved solids and heavy metals that impair water and soil quality over broad areas. Korba district hosts extensive opencast mines; its Hasdeo river basin receives direct effluent discharges and runoff, threatening aquatic ecosystems and agricultural lands. The present study focuses on assessing soil and water quality impacts in a region of intense coal mining and industrial activity within the Hasdeo river basin, Korba district, Chhattisgarh. The selection of sampling sites represents diverse land uses and potential sources of water impact, capturing both industrial and agricultural influences on the Hasdeo river system and nearby lands. The Hasdeo river basin within Korba district exhibits a mix of industrial, mining, and rural-agricultural land uses. Industries, especially coal mining and power generation, discharge significant effluents and runoff into surface waters and land, thereby mandating comprehensive environmental monitoring. This spatial sampling strategy offers a systematic view of upstream to downstream changes and cross-sector impacts on the environment. This study quantifies spatial temporal contamination patterns and evaluates rice husk as a low-cost biosorbent for heavy metal remediation, providing data to inform environmental management strategies. The present study site covers the area around Korba district. The site selection for sampling is the important way so that it gives coverage to the area where the pollution is high around the Korba region.

Study Area and Site Selection

The Hasdeo river basin (subtropical climate; 1,300–1,600 mm annual rainfall) encompasses mixed industrial, mining, and agricultural land uses. Five sites were chosen:

SI – Hasdeo River upstream at Jamnipali (reference)

SII – Dipka coal mine near overburden dump

SIII – SECL Gevra mine effluent outlet (most impacted)

SIV – Hasdeo River downstream at Korba

SV – Agricultural field near Gevra village

Sample collection

Water samples were collected using clean, sterilized bottles by submerging them midstream in flowing water or at discharge points, avoiding surface debris and contamination, with samples kept cool and analyzed promptly. Soil samples were typically collected from the top 0–15 cm layer using a clean trowel at multiple sub-locations within each site, combined into a composite sample to represent the area, with care taken to remove surface debris before sampling. Samples were labeled with detailed site and collection information, stored appropriately. and transported quickly to the laboratory. These methods ensure consistent and accurate assessment of water and soil quality in diverse environmental settings such as river upstream/downstream, mining effluent, and agricultural fields.

Physico-chemical analysis of water and soil sample

Water and soil samples were analyzed for key physico-chemical and heavy metal parameters using standard methods: pH was measured with a calibrated Labtronic digital meter (buffers at pH 4, 7, 9.2); electrical conductivity (EC) with a KCl-calibrated conductivity meter; total dissolved solids (TDS) by gravimetric evaporation of filtered water residues; hardness by EDTA titration (Eriochrome Black T indicator at pH 10); chloride via Mohr's silver nitrate titration with potassium chromate indicator; sulfate by precipitating $BaSO_4$ and weighing the dried precipitate; biochemical oxygen demand (BOD) through dark incubation and DO difference over five days; chemical oxygen demand (COD) using $K_2Cr_2O_7$ digestion at 150 °C and ferrous ammonium sulfate titration; alkalinity by HCl titration to phenolphthalein and methyl orange endpoints; iron by forming a ferrous-complex colorimetric assay at 510–565 nm; heavy metals (Sb by HG-AAS, Mo by pyrogallol red spectrophotometry, Cu/Pb/Cd by AAS or ICP-OES/MS with appropriate digestion, Hg by cold-vapor AAS); nitrate by APHA spectrophotometric methods; and soil parameters EC and pH in soil–water suspensions, texture by sedimentation, moisture by oven-drying (105 °C), temperature by in-situ probe, nitrogen by Kjeldahl digestion, phosphorus by Bray extraction, potassium by ammonium acetate extraction and flame photometry, and organic matter by Walkley–Black oxidation ensuring accurate, reliable environmental quality assessment.

Soil pH was measured in a 1:2.5 soil-to-water suspension after 30 min equilibration using a calibrated pH meter. Electrical conductivity was determined in a 1:5 soil-water extract shaken for 1 h, settled, then measured on the clear supernatant with a calibrated conductivity meter. Texture was classified by sedimentation in a dispersant-water slurry allowed to stand 24–48 h, measuring sand, silt, and clay layers against a soil triangle. Moisture content was calculated from weight loss of a soil sample oven-dried at 105–110 °C to constant mass. Soil temperature was recorded in situ at 10 cm depth using a thermometer. Total nitrogen was quantified by Kjeldahl digestion, distillation, and titration; available potassium by extraction with 1 M ammonium acetate and flame photometry; and available phosphorus by Bray's acid extraction and molybdenum-blue colorimetry. Organic matter was estimated via Walkley-Black oxidation and titration, with weight loss upon heating at 400 °C.

Heavy metal detection for water sample and soil sample

Water samples were acidified to $pH < 2$ in nitric acid and analyzed for trace metals using specialized techniques: antimony by hydride-generation AAS after persulfate–HCl digestion and stibine gas formation; molybdenum via pyrogallol red spectrophotometry with ionic liquid complexation (with prior ion-exchange cleanup); copper by catechol-mediated electrode preconcentration and stripping voltammetry; lead by resin preconcentration followed by flame furnace AAS or ICP-OES/MS; cadmium by graphite furnace AAS on dried, charred, atomized samples; and mercury (including methylmercury) by UV decomposition, sorbent preconcentration, $SnCl_2$–cold vapor AAS. Total and dissolved iron were measured by flow-injection catalytic spectrophotometry using N,N-dimethyl-p-phenylenediamine/H_2O_2 colorimetry, with simple triazine-based colorimetric methods employed for routine checks.

Result and discussion

The study of five Korba district water sites showed clear mining impacts: pH dropped to 6.2 at the Gevra mine outlet (SIII) but stayed near neutral upstream (SI). Electrical conductivity, TDS, and hardness exceeded WHO limits at SII, SIII, and SIV, driven by dissolved salts from coal washery discharges. Chloride, sulfate, and alkalinity peaked at SIII, reflecting industrial runoff and disturbed geology. BOD and COD were also highest at SIII and SII, indicating strong organic and chemical pollution. Heavy metals—iron, manganese, lead, cadmium—surpassed safety thresholds at SIII (and SII for Cd and Pb), while copper remained safe at all sites. Downstream (SIV) and agricultural (SV) locations showed moderate contamination from runoff. Pearson correlations revealed very strong positive relationships ($r > 0.95$) among most physico-chemical and metal parameters, and strong negative correlations with pH, indicating that as pollutant loads increase, acidity rises. These patterns point to shared contamination sources and suggest that monitoring a few key, highly correlated indicators could efficiently track overall water quality trends, though larger datasets are needed for confirmation. Premonsoon soil analyses across five sites revealed clear degradation in mining-affected areas compared to reference and agricultural soils. Near mine dumps and effluent outlets, soil pH shifted toward slight acidity, while upstream and field sites remained neutral. Electrical conductivity and salinity were elevated adjacent to mining operations, indicating salt accumulation from effluents, whereas reference and agricultural sites maintained low EC. Texture varied from sandy loam upstream and in fields to higher silt content near effluent zones, affecting water retention and nutrient dynamics. Moisture and organic matter peaked in undisturbed and cultivated soils but declined markedly in mine-impacted soils due to compaction and reduced vegetation. Nutrient concentrations (N, P, K) were ample in upstream and agricultural soils yet significantly depleted near mining sites, reflecting pollutant-driven nutrient loss. These spatial trends highlight the adverse influence of coal mining on soil fertility and underscore the need for targeted remediation and continual monitoring. Pearson correlation analysis confirmed that soil fertility parameters—moisture, nitrogen, phosphorus, potassium, and organic matter are very strongly positively interrelated (r > 0.95), indicating that improvements in one attribute coincide with enhancements in others. In contrast, soil temperature and electrical conductivity correlate negatively with these fertility indicators and with pH, revealing that cooler, less saline soils support greater nutrient and organic matter levels. These relationships suggest common underlying processes, such as organic matter decomposition and moisture retention, promote coordinated fertility improvements, while higher salinity and temperature hinder nutrient accumulation. Although these findings align with soil science principles, they derive from a limited sample set and warrant validation with more extensive datasets.

Monsoon water quality at Korba's five sites showed temporary dilution from rainfall but persistent contamination at mining-impacted locations. pH remained within 6.3–7.2, yet EC (up to 1.70 dS/m), TDS (730 mg/L), hardness (420 mg/L), chloride (275 mg/L), sulfate (340 mg/L), BOD (8.4 ppm), and COD (14.8 ppm) all exceeded WHO limits at SII and SIII. Heavy metals (Fe, Mn, Pb 0.019 mg/L, Cd 0.0062 mg/L) also remained above safety thresholds at these sites, whereas SI and SV stayed within permissible ranges. Pearson correlations among water parameters were extremely strong (r > 0.95), indicating that salts, organic pollution, and metals rise in parallel, while pH inversely tracked contamination (r ≈ –0.99), suggesting common pollution sources and efficient monitoring via a few key indicators. Monsoon soils near Dipka and Gevra mines exhibited acidification (pH as low as 6.2), elevated EC (up to 1.58 dS/m), reduced moisture and organic matter, and depleted nutrients (N as low as 170 kg/ha, P 11 kg/ha, K 85 kg/ha) compared to upstream and agricultural fields. Soil fertility indicators (moisture, N, P, K, organic matter) correlated strongly and positively (r > 0.94), while EC and soil temperature correlated negatively with fertility and pH, highlighting that cooler, less saline soils maintain higher nutrient and organic content, and emphasizing the need for moisture- and organic-matter–focused soil restoration in mining regions. Post-monsoon water sampling at five Korba sites showed that pH remained within 6.4–7.3, but salinity and dissolved solids persisted above WHO limits at mining-impacted locations. Electrical conductivity reached 1.95 dS/m and TDS 810 mg/L, indicating elevated salts from runoff. Hardness peaked at 450 mg/L at the Gevra effluent outlet (SIII). Chloride and sulfate levels were generally near or above permissible thresholds. Organic pollution remained high at SII and SIII, with BOD up to 8.4 ppm and COD 14.8 ppm. Heavy metals—iron, manganese, lead (0.018 mg/L), and cadmium (0.006 mg/L)—exceeded safety limits at mining sites, while copper stayed moderate. Nutrient loading was evident in nitrate (19–61 mg/L). Overall, post-monsoon dilution did not prevent significant salinity, hardness, organic, and heavy-metal contamination at mining discharge points, underscoring the need for improved water management. Heavy metal concentrations across sites exhibit very strong positive intercorrelations (r > 0.9), especially among antimony, molybdenum, lead, and cadmium, indicating common contamination sources or geochemical behaviors. Copper and mercury also correlate strongly, while iron shows robust associations with all metals. Post-monsoon water and soil metal levels decline slightly from monsoon peaks due to runoff reduction and dilution but remain elevated at mining-impacted locations, reflecting persistent sediment-bound contamination. Pre-monsoon soils register their highest metal loads, driven by dry-season accumulation and minimal leaching. These patterns suggest that monitoring a representative subset of metals can effectively track overall contamination, though the limited number of sites warrants validation with broader datasets. Monsoon rains drive heavy metal spikes in soils at mining-impacted sites (SII–SIV) through runoff and erosion, leading to peak copper, mercury, cadmium, iron, and antimony levels. Floodwaters spread contaminants broadly and waterlogging keeps metals mobile. Agricultural and upstream sites see dilution, but overall monsoon concentrations are highest. Across all seasons, heavy metals co-vary extremely strongly (r > 0.97), especially antimony with molybdenum, and between lead, cadmium, and copper, indicating shared pollution sources and similar environmental behaviors. Post-monsoon levels decline due to leaching and sedimentation yet remain above pre-monsoon baselines at hotspots, underlining persistent contamination near mine effluent outlets. Limited sampling warrants further study, but monitoring a few key metals could reliably indicate broader contamination trends.

Physico-chemical analysis of Premonsoon water sample

Parameters	**WHO Standard Limits**	**SI**	**SII**	**SIII**	**SIV**	**SV**
pH	6.5 – 8.5	7.4	6.6	6.2	6.5	7.1
EC (dS/m)	1500 µS/cm (1.5 dS/m)	0.45	1.86	2.1	1.7	1.3
TDS (mg/L)	500	220	740	890	780	410
Hardness (as $CaCO_3$, mg/L)	200 (acceptable); 500 (max)	160	420	470	390	210
Chloride (mg/L)	200–300	110	275	310	280	190
Sulfate (mg/L)	250–500	130	340	385	360	240
Biological Oxygen Demand (BOD, ppm)	6	3.8	7.6	9.2	6.7	4.1
Chemical Oxygen Demand (COD, ppm)	10	5.2	12.4	15.6	11.8	6

Parameters	WHO Standard Limits	SI	SII	SIII	SIV	SV
Alkalinity (mg/L)	200	165	290	320	285	180
Iron (Fe, mg/L)	≤ 0.3	0.18	0.42	0.56	0.4	0.22
Manganese (Mn, mg/L)	0.4	0.12	0.48	0.66	0.52	0.29
Lead (Pb, mg/L)	0.01	0.005	0.017	0.024	0.015	0.009
Cadmium (Cd, mg/L)	0.003	0.0012	0.0058	0.0071	0.0048	0.0022
Nitrate (NO_3^-, mg/L)	50	18	64	72	59	42
Copper (Cu, mg/L)	2	0.26	0.48	0.61	0.5	0.32

Pearson correlation analysis of physicochemical parameters of Premonsoon water sample

	pH	EC	TDS	Hardness	Cl^-	SO_3^{2-}	BOD	COD	Alkalinity	Iron	Mn	Pb	Cd	NO_3^-	Cu
pH	1														
EC	-0.95	1													
TDS	-0.993	0.96	1												
Hardness	-0.978	0.937	0.986	1											
Cl^-	-0.982	0.984	0.993	0.97	1										
SO_3^{2-}	-0.976	0.979	0.989	0.958	0.998	1									
BOD	-0.96	0.896	0.948	0.979	0.922	0.901	1								
COD	-0.98	0.908	0.971	0.989	0.945	0.929	0.995	1							
Alkalinity	-0.978	0.915	0.983	0.997	0.961	0.949	0.976	0.99	1						
Iron	-0.98	0.909	0.963	0.977	0.939	0.922	0.994	0.997	0.977	1					
Mn	-0.998	0.965	0.99	0.969	0.986	0.981	0.949	0.968	0.964	0.971	1				
Pb	-0.973	0.933	0.952	0.962	0.94	0.922	0.984	0.98	0.952	0.991	0.973	1			
Cd	-0.974	0.939	0.971	0.992	0.957	0.939	0.993	0.992	0.984	0.989	0.967	0.985	1		
NO_3^-	-0.967	0.997	0.977	0.962	0.992	0.986	0.924	0.936	0.943	0.934	0.977	0.949	0.961	1	
Cu	-0.996	0.928	0.983	0.979	0.964	0.954	0.977	0.991	0.981	0.993	0.99	0.982	0.98	0.95	1

Physico-chemical analysis of Premonsoon soil sample

Parameters	WHO Standard Limits	SI	SII	SIII	SIV	SV
pH	6 – 8.5	7.2	6.5	6.3	6.6	7
EC (dS/m)	1.5	0.68	1.21	1.46	1.12	0.81
Texture	-	Sandy loam	Loam	Silty loam	Sandy loam	Loam
Moisture (%)	-	18.5	13.2	12.6	14.1	19.3

Parameters	**WHO Standard Limits**	**SI**	**SII**	**SIII**	**SIV**	**SV**
Soil Temp (°C)	-	27.2	29.1	29.8	28.4	26.5
Nitrogen (kg/ha)	>280*	295	203	162	185	312
Potassium (kg/ha)	>108*	123	98	82	93	130
Phosphorus (kg/ha)	>22.4*	28	13	9	15	32
Soil Organic Matter (%)	>0.80*	1.23	0.74	0.6	0.67	1.35

Pearson correlation analysis of physicochemical parameters of Premonsoon soil sample

	pH	**EC**	**Moisture**	**Soil Temp**	**Nitrogen**	**Potassium**	**Phosphorus**	**Soil Org. Matter**
pH	1							
EC	-0.993	1						
Moisture	0.95	-0.939	1					
Soil Temp	-0.925	0.94	-0.974	1				
Nitrogen	0.939	-0.933	0.979	-0.948	1			
Potassium	0.935	-0.939	0.973	-0.96	0.996	1		
Phosphorus	0.941	-0.94	0.996	-0.985	0.985	0.985	1	
Soil Org. Matter	0.924	-0.912	0.984	-0.945	0.997	0.989	0.986	1

Physico-chemical analysis of Monsoon water sample

Parameters	**WHO Standard Limits**	**SI**	**SII**	**SIII**	**SIV**	**SV**
pH	6.5 – 8.5	7.2	6.5	6.3	6.6	7
EC (dS/m)	1.5 dS/m (1500 µS/cm)	0.4	1.55	1.7	1.35	1.1
TDS (mg/L)	500	200	660	730	610	380
Hardness (as $CaCO_3$, mg/L)	200 (acceptable); 500 (max)	150	385	420	360	190
Chloride (mg/L)	200–300	100	230	275	210	160
Sulfate (mg/L)	250–500	120	300	340	280	200
Biological Oxygen Demand (BOD, ppm)	6	3.5	7.1	8.4	6.2	4
Chemical Oxygen Demand (COD, ppm)	10	5	13.2	14.8	11.2	6.5
Alkalinity (mg/L)	200	160	260	280	250	170
Iron (Fe, mg/L)	≤ 0.3	0.16	0.42	0.48	0.36	0.2

Manganese (Mn, mg/L)	0.4	0.1	0.54	0.61	0.46	0.25
Lead (Pb, mg/L)	0.01	0.004	0.016	0.019	0.014	0.008
Cadmium (Cd, mg/L)	0.003	0.001	0.0055	0.0062	0.0045	0.002
Nitrate (NO_3^-, mg/L)	50	20	58	64	52	39
Copper (Cu, mg/L)	2	0.25	0.44	0.52	0.43	0.3

Pearson correlation analysis of physicochemical parameters of Monsoon water sample

	pH	**EC**	**TDS**	**Hardness**	**Cl^-**	**SO_3^{2-}**	**BOD**	**COD**	**Alkalinity**	**Fe**	**Mn**	**Pb**	**Cd**	**NO_3^-**	**Cu**
pH	1														
EC	-0.95	1													
TDS	-0.99	0.97	1												
Hardness	-0.99	0.92	0.98	1											
Cl^-	-0.99	0.98	0.99	0.96	1										
SO_3^{2-}	-0.99	0.98	1	0.97	0.99	1									
BOD	-0.99	0.91	0.96	0.98	0.97	0.96	1								
COD	-0.99	0.93	0.98	0.99	0.97	0.98	0.99	1							
Alkalinity	-0.99	0.9	0.97	1	0.95	0.96	0.98	0.99	1						
Fe	-0.99	0.92	0.98	0.99	0.97	0.97	1	1	0.99	1					
Mn	-1	0.97	1	0.99	0.99	1	0.98	0.99	0.98	0.99	1				
Pb	-1	0.96	0.99	0.99	0.99	0.99	0.99	0.99	0.98	0.99	1	1			
Cd	-1	0.94	0.99	0.99	0.98	0.98	0.99	1	0.99	1	1	0.99	1		
NO_3^-	-0.98	0.99	0.99	0.96	0.99	1	0.95	0.96	0.94	0.96	0.99	0.99	0.97	1	
Cu	-1	0.93	0.98	0.99	0.98	0.98	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.96	1

Physico-chemical analysis of Monsoon soil sample

Parameters	**WHO Standard Limits**	**SI**	**SII**	**SIII**	**SIV**	**SV**
pH	6.5 – 8.5	7.1	6.3	6.2	6.5	7.1
EC (dS/m)	1.5	0.75	1.45	1.58	1.3	1
Texture	—	Sandy loam	Loam	Silty loam	Sandy loam	Loam
Moisture (%)	—	21.5	15	13.5	16	22
Soil Temp (°C)	—	26.4	28.2	28.7	27.8	26
Nitrogen (kg/ha)	>280*	310	195	170	190	320

Parameters	WHO Standard Limits	SI	SII	SIII	SIV	SV
Potassium (kg/ha)	>108*	130	95	85	90	135
Phosphorous (kg/ha)	>22.4*	30	15	11	17	35
Soil Organic Matter (%)	>0.80*	1.35	0.72	0.58	0.65	1.45

Pearson correlation analysis of physicochemical parameters of Monsoon soil sample

	pH	**EC**	**Moisture**	**Soil Temp**	**Nitrogen**	**Potassium**	**Phosphorus**	**Soil Organic Matter**
pH	1							
EC	-0.943	1						
Moisture	0.985	-0.914	1					
Soil Temp	-0.971	0.932	-0.949	1				
Nitrogen	0.964	-0.912	0.948	-0.944	1			
Potassium	0.964	-0.916	0.948	-0.951	0.995	1		
Phosphorus	0.967	-0.92	0.955	-0.961	0.982	0.982	1	
Soil Organic Matter	0.962	-0.9	0.946	-0.933	0.994	0.995	0.987	1

Physico-chemical analysis of Post Monsoon water sample

Parameters	**WHO Standard Limits**	**SI**	**SII**	**SIII**	**SIV**	**SV**
pH	6.5 – 8.5	7.3	6.6	6.4	6.7	7.1
EC (dS/m)	1.5 dS/m (1500 µS/cm)	0.42	1.72	1.95	1.45	1.18
TDS (mg/L)	500	210	680	810	640	400
Hardness (as $CaCO_3$, mg/L)	200 (acceptable); 500 (max)	155	410	450	375	200
Chloride (mg/L)	200–300	105	260	290	230	175
Sulfate (mg/L)	250–500	125	325	360	295	220
Biological Oxygen Demand (BOD, ppm)	6	3.9	7.5	7.9	6.1	4.2
Chemical Oxygen Demand (COD, ppm)	10	5.4	12.8	13.9	11	6.2
Alkalinity (mg/L)	200	170	280	300	260	185
Iron (Fe, mg/L)	≤ 0.3	0.19	0.4	0.47	0.35	0.21

Parameters	**WHO Standard Limits**	**SI**	**SII**	**SIII**	**SIV**	**SV**
Manganese (Mn, mg/L)	0.4	0.13	0.51	0.58	0.44	0.27
Lead (Pb, mg/L)	0.01	0.005	0.016	0.018	0.014	0.008
Cadmium (Cd, mg/L)	0.003	0.0011	0.0053	0.006	0.0042	0.0019
Nitrate (NO_3^-, mg/L)	50	19	55	61	50	40
Copper (Cu, mg/L)	2	0.27	0.46	0.51	0.41	0.29

Pearson correlation analysis of physicochemical parameters of Post monsoon water sample

Parameter	**pH**	**EC**	**TDS**	**Hardness**	**Cl^-**	**SO_3^{2}-**	**BOD**	**COD**	**Alkalinity**	**Fe**	**Mn**	**Pb**	**Cd**	**NO_3^-**	**Cu**
pH	1														
EC	-0.958	1													
TDS	-0.995	0.976	1												
Hardness	-0.992	0.931	0.983	1											
Cl^-	-0.987	0.991	0.994	0.97	1										
SO_3^{2}-	-0.984	0.992	0.994	0.968	0.999	1									
BOD	-0.975	0.911	0.953	0.979	0.953	0.942	1								
COD	-0.988	0.919	0.971	0.996	0.962	0.956	0.993	1							
Alkalinity	-0.992	0.925	0.978	0.999	0.966	0.962	0.987	0.999	1						
Fe	-0.989	0.915	0.97	0.986	0.958	0.949	0.989	0.993	0.993	1					
Mn	-0.995	0.979	0.997	0.985	0.997	0.995	0.968	0.979	0.983	0.974	1				
Pb	-0.998	0.959	0.993	0.995	0.988	0.985	0.981	0.992	0.995	0.986	0.997	1			
Cd	-0.994	0.943	0.981	0.994	0.977	0.971	0.993	0.998	0.997	0.993	0.989	0.997	1		
NO_3^-	-0.961	0.997	0.981	0.938	0.991	0.995	0.906	0.922	0.929	0.913	0.981	0.963	0.943	1	
Cu	-0.99	0.919	0.971	0.989	0.961	0.953	0.994	0.997	0.995	0.999	0.977	0.989	0.996	0.918	1

Physico-chemical analysis of Post Monsoon soil sample

Parameters	WHO Standard Limits	SI	SII	SIII	SIV	SV
pH	6.5 – 8.5	7.3	6.7	6.5	6.8	7.2
EC (dS/m)	1.5	0.62	1.36	1.44	1.18	0.95
Texture	—	Sandy loam	Loam	Silty loam	Sandy loam	Loam
Moisture (%)	—	15.8	12	11.1	13.2	17
Soil Temp (°C)	—	24.9	27.2	27.6	26.4	24.3
Nitrogen (kg/ha)	>280*	295	167	145	170	305
Potassium (kg/ha)	>108*	120	90	74	85	125
Phosphorus (kg/ha)	>22.4*	27	10	7	13	30
Soil Organic Matter (%)	>0.80*	1.12	0.62	0.51	0.59	1.25

Pearson correlation analysis of physicochemical parameters of Post monsoon soil sample

Parameter	pH	EC	Moisture	Soil Temp	Nitrogen	Potassium	Phosphorus	Soil Org. Matter
pH	1							
EC	-0.96	1						
Moisture	0.96	-0.86	1					
Soil Temp	-0.96	0.87	-1	1				
Nitrogen	0.97	-0.9	0.97	-0.97	1			
Potassium	0.96	-0.87	0.97	-0.96	0.99	1		
Phosphorus	0.97	-0.89	0.99	-0.99	0.99	0.98	1	
Soil Org. Matter	0.94	-0.85	0.97	-0.97	1	0.99	0.99	1

Heavy metal analysis of Premonsoon water sample

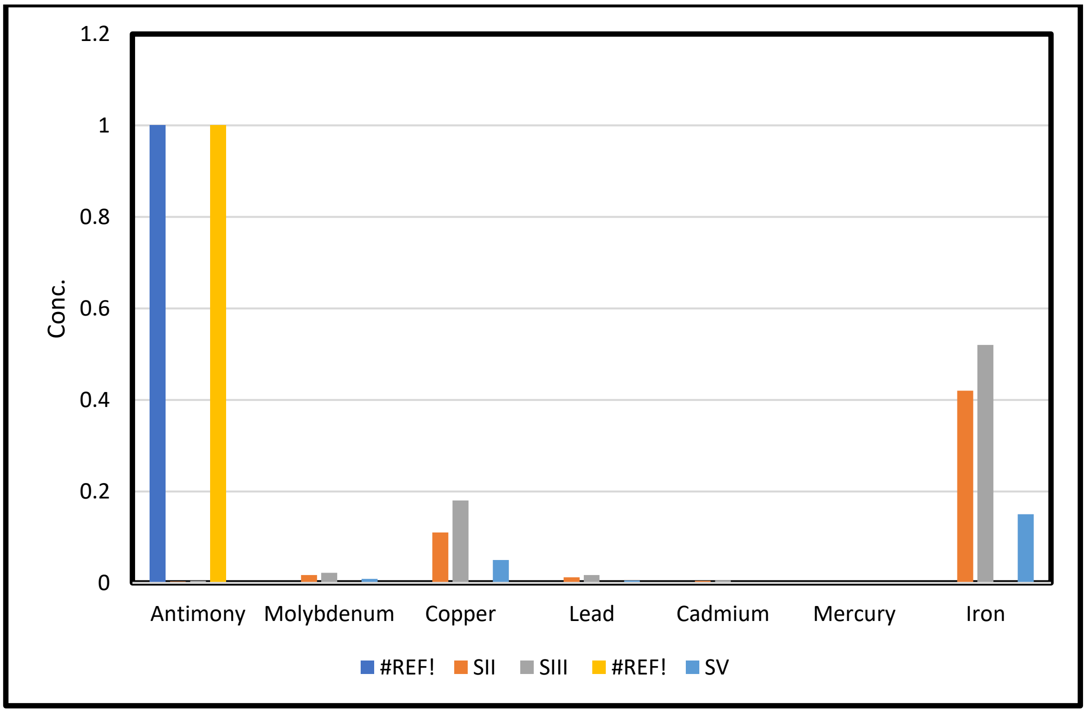
Heavy Metal (ppm)	WHO Standard limits (ppm)	SI	SII	SIII	SIV	SV
Antimony	0.005	0.0016	0.0034	0.0048	0.0042	0.0018
Molybdenum	0.07	0.006	0.019	0.023	0.021	0.011
Copper	2	0.024	0.13	0.19	0.17	0.048
Lead	0.01	0.003	0.014	0.018	0.015	0.006
Cadmium	0.003	0.0009	0.0042	0.0058	0.0047	0.0014
Mercury	0.001	0.0003	0.0007	0.00092	0.00081	0.00036
Iron	0.3	0.11	0.39	0.55	0.48	0.13

Pearson correlation analysis of heavy metals of premonsoon water sample

Metal	Antimony	Molybdenum	Copper	Lead	Cadmium	Mercury	Iron
Antimony	1						
Molybdenum	0.997	1					
Copper	0.924	0.935	1				
Lead	0.985	0.983	0.96	1			
Cadmium	0.978	0.981	0.943	0.995	1		
Mercury	0.917	0.923	0.95	0.927	0.915	1	
Iron	0.968	0.971	0.869	0.963	0.954	0.891	1

Heavy Metal analysis of Monsoon water sample

Heavy Metal (ppm)	WHO Standard limits (ppm)	SI	SII	SIII	SIV	SV
Antimony	0.005	0.0014	0.0032	0.0045	0.004	0.0017
Molybdenum	0.07	0.007	0.017	0.022	0.019	0.009
Copper	2	0.03	0.11	0.18	0.16	0.05
Lead	0.01	0.002	0.012	0.017	0.014	0.005
Cadmium	0.003	0.0008	0.0047	0.0056	0.0049	0.0016
Mercury	0.001	0.0003	0.0008	0.0009	0.0008	0.0004
Iron	0.3	0.12	0.42	0.52	0.44	0.15



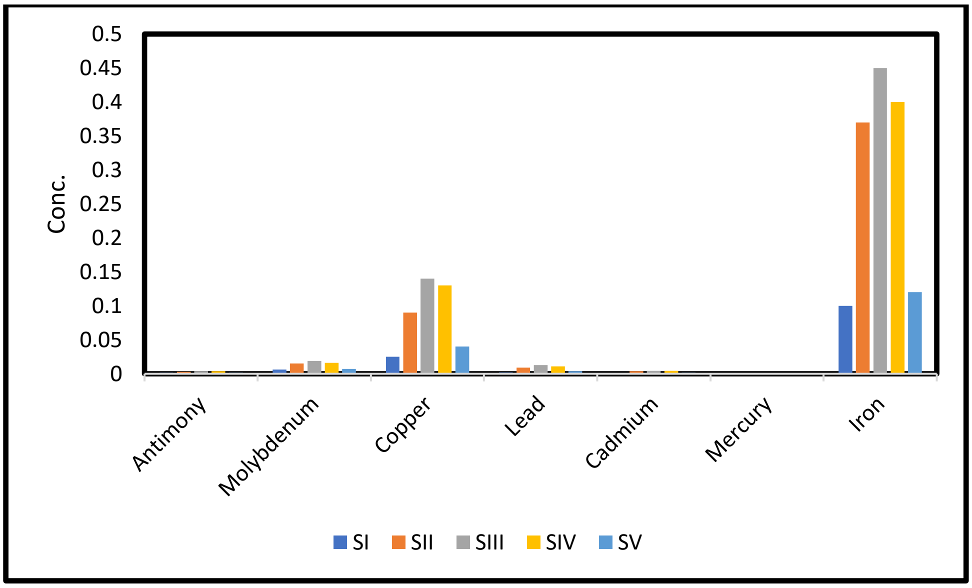
Heavy Metal analysis of Monsoon water sample

Pearson correlation analysis of heavy metals of monsoon water sample

Metal	Antimony	Molybdenum	Copper	Lead	Cadmium	Mercury	Iron
Antimony	1						
Molybdenum	0.994	1					
Copper	0.921	0.936	1				
Lead	0.987	0.986	0.955	1			
Cadmium	0.986	0.988	0.943	0.993	1		
Mercury	0.941	0.957	0.972	0.949	0.936	1	
Iron	0.975	0.981	0.903	0.978	0.969	0.915	1

Heavy Metal analysis of Postmonsoon water sample

Heavy Metal (ppm)	WHO Standard limits (ppm)	SI	SII	SIII	SIV	SV
Antimony	0.005	0.0013	0.0028	0.0038	0.0036	0.0015
Molybdenum	0.07	0.006	0.015	0.019	0.016	0.007
Copper	2	0.025	0.09	0.14	0.13	0.04
Lead	0.01	0.0018	0.009	0.013	0.011	0.004
Cadmium	0.003	0.0007	0.0039	0.0045	0.0041	0.0013
Mercury	0.001	0.00025	0.0006	0.0007	0.0006	0.0003
Iron	0.3	0.1	0.37	0.45	0.4	0.12



Heavy Metal analysis of Postmonsoon water sample

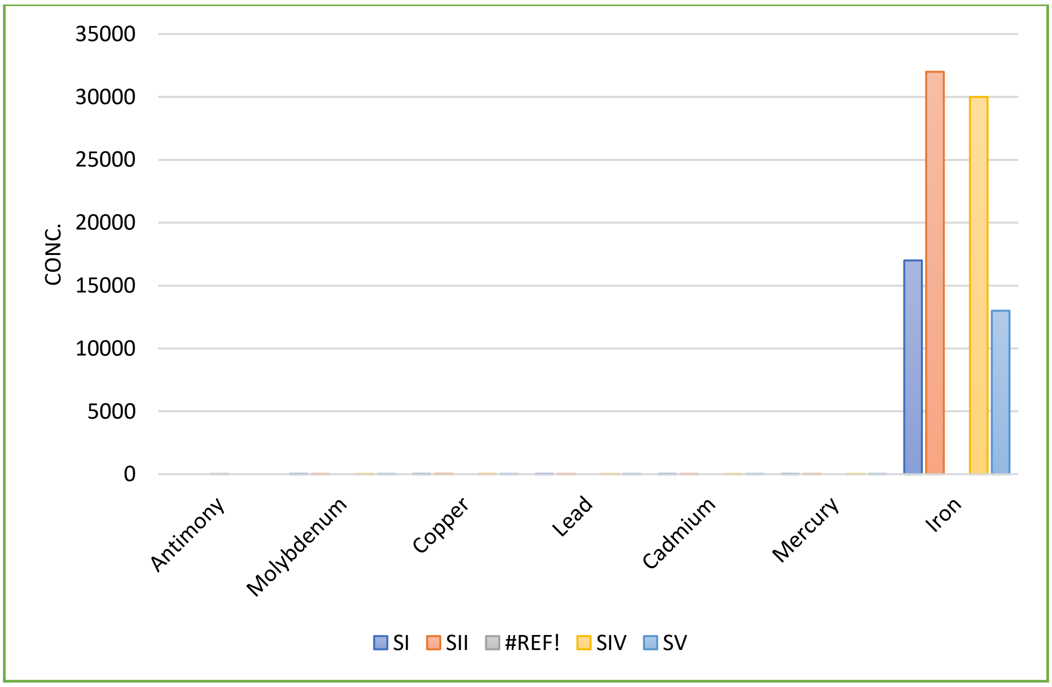
Pearson correlation analysis of heavy metals of post monsoon water sample

Metal	Antimony	Molybdenum	Copper	Lead	Cadmium	Mercury	Iron
Antimony	1						
Molybdenum	0.996	1					
Copper	0.947	0.949	1				
Lead	0.981	0.978	0.955	1			
Cadmium	0.976	0.98	0.938	0.991	1		
Mercury	0.925	0.945	0.967	0.944	0.935	1	
Iron	0.967	0.975	0.9	0.973	0.965	0.904	1

Heavy metal analysis of soil sample

Heavy metal analysis of Premonsoon soil sample

Heavy Metal (ppm)	WHO Standard Limits (ppm)	SI	SII	SIII	SIV	SV
Antimony	0.005	0.003	0.005	0.006	0.005	0.003
Molybdenum	0.07	0.02	0.03	0.04	0.03	0.02
Copper	50	18	32	36	31	16
Lead	10	3.1	7.3	8.2	6.9	2.8
Cadmium	0.3	0.08	0.16	0.18	0.15	0.06
Mercury	0.05	0.012	0.025	0.032	0.028	0.009
Iron	50,000	17000	32000	38000	30000	13000



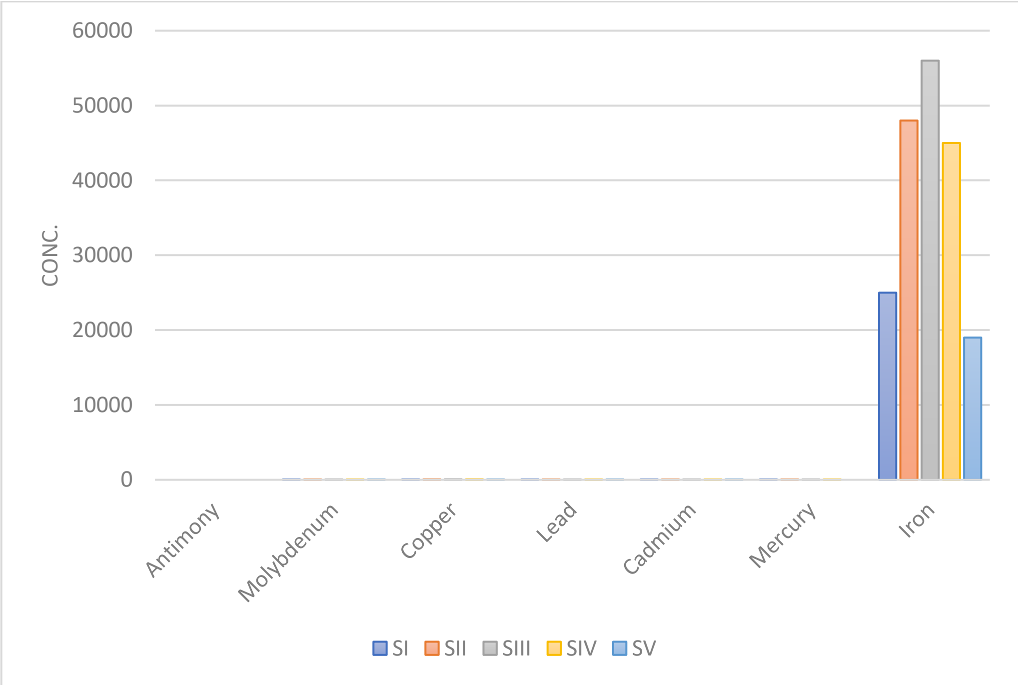
Heavy metal analysis of Premonsoon soil sample

Pearson correlation analysis of heavy metals of premonsoon soil sample

Metal	Antimony	Molybdenum	Copper	Lead	Cadmium	Mercury	Iron
Antimony	1						
Molybdenum	1	1					
Copper	0.928	0.928	1				
Lead	0.976	0.976	0.997	1			
Cadmium	0.968	0.968	0.994	0.998	1		
Mercury	0.987	0.987	0.994	0.996	0.991	1	
Iron	0.993	0.993	0.979	0.995	0.987	0.996	1

Heavy metal analysis of Monsoon soil sample

Heavy Metal (ppm)	WHO Standard Limits (ppm)	SI	SII	SIII	SIV	SV
Antimony	0.005	0.006	0.009	0.011	0.01	0.005
Molybdenum	0.07	0.04	0.06	0.08	0.07	0.04
Copper	50	29	50	58	54	25
Lead	10	2.7	6.4	7.8	6.3	2.3
Cadmium	0.3	0.1	0.22	0.26	0.2	0.08
Mercury	0.05	0.017	0.036	0.046	0.041	0.014
Iron	50,000	25000	48000	56000	45000	19000



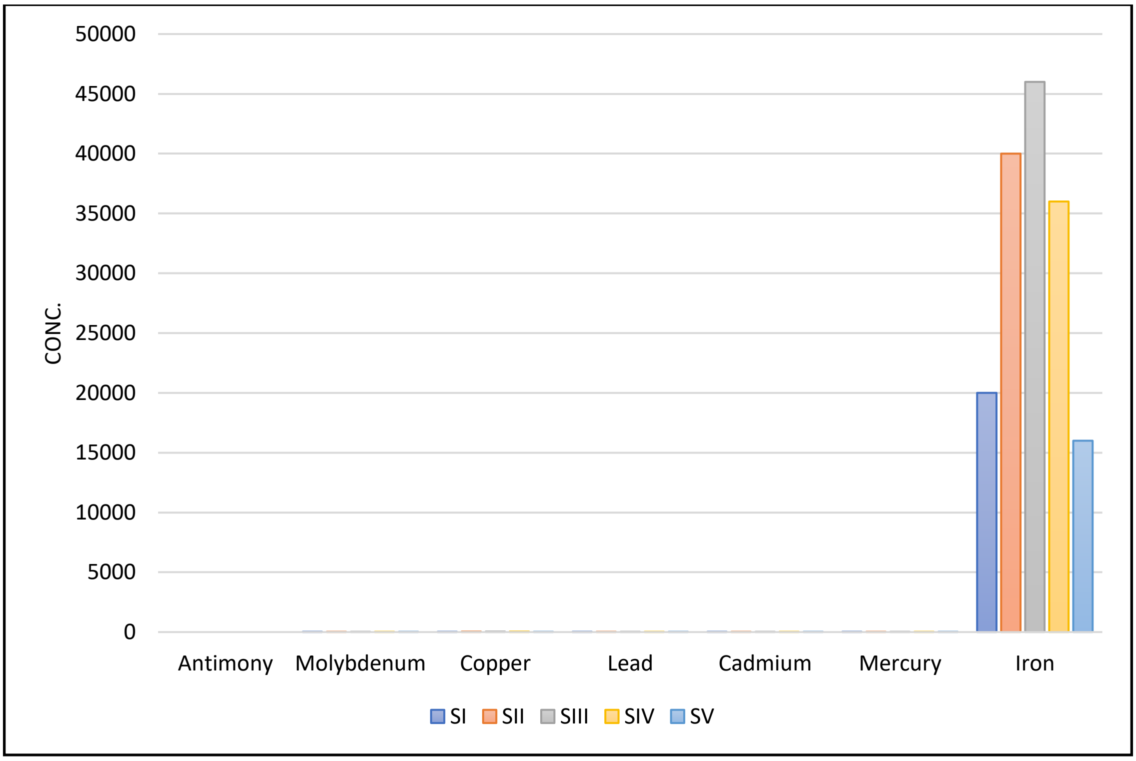
Heavy metal analysis of Monsoon soil sample

Pearson correlation analysis of heavy metals of monsoon soil sample

Metal	Antimony	Molybdenum	Copper	Lead	Cadmium	Mercury	Iron
Antimony	1						
Molybdenum	0.998	1					
Copper	0.962	0.965	1				
Lead	0.988	0.991	0.995	1			
Cadmium	0.974	0.98	0.991	0.997	1		
Mercury	0.991	0.994	0.993	0.995	0.989	1	
Iron	0.996	0.998	0.978	0.995	0.986	0.993	1

Heavy metal analysis of Post monsoon soil sample

Heavy Metal (ppm)	WHO Standard Limits (ppm)	SI	SII	SIII	SIV	SV
Antimony	0.005	0.004	0.007	0.008	0.007	0.004
Molybdenum	0.07	0.03	0.05	0.06	0.05	0.03
Copper	50	22	39	43	41	19
Lead	10	2.9	7.0	8.0	6.7	2.6
Cadmium	0.3	0.09	0.18	0.21	0.17	0.07
Mercury	0.05	0.014	0.028	0.036	0.032	0.011
Iron	50,000	20000	40000	46000	36000	16000



Heavy metal analysis of Post monsoon soil sample

Pearson correlation analysis of heavy metals of post monsoon soil sample

Metal	Antimony	Molybdenum	Copper	Lead	Cadmium	Mercury	Iron
Antimony	1						
Molybdenum	0.998	1					
Copper	0.918	0.927	1				
Lead	0.987	0.986	0.952	1			
Cadmium	0.981	0.978	0.94	0.993	1		
Mercury	0.911	0.922	0.954	0.931	0.922	1	
Iron	0.97	0.974	0.876	0.966	0.954	0.894	1

Conclusion

Mining activities in the Korba district profoundly degrade water and soil quality across multiple seasons. The SECL Gevra mine effluent outlet (SIII) is the most contaminated site, with physico-chemical and heavy-metal parameters consistently exceeding WHO standards. Monsoon dilution provides only temporary relief, as contaminant loads rebound post-monsoon. Soils near mine dumps suffer acidification, high salinity, reduced moisture and organic matter, and depleted nutrients, undermining agricultural productivity. Strong inter-parameter correlations suggest common pollution sources and enable streamlined monitoring using a subset of key indicators. Rice husk biosorption demonstrates promising heavy-metal remediation potential. Effective environmental management requires, rigorous effluent treatment and discharge controls at mining outlets Watershed-scale monitoring and pollution source tracing Application of low-cost biosorbents (rice husk) for heavy-metal removal Soil restoration via organic amendments and erosion control Continuous, multi-parameter assessment to guide adaptive remediation and protect ecosystem and public health in coal mining–impacted regions.

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