The Biobrio
ISSN : 2393-9508
e-ISSN: 2582-4902
An International Quarterly Journal of Life Sciences
Website: www.thebiobrio.in SJIF:8.259

12(3&4): 1601-1608, 2025

A comparative analysis of soil nutrient status and trace metal contamination in agricultural lands adjacent to Pachhwara Coal Mines, Pakur District of Jharkhand.

Pratima Kumari* & Sutanu Lal Bondya
University Department of Botany, Sido Kanhu Murmu University, Dumka, Jharkhand, India

Received : 24th October, 2025 ; Accepted : 24th November, 2025
DOI:- https://doi.org/10.5281/zenodo.19604215

ABSTRACT

Coal mining activities can influence soil properties in adjacent agricultural ecosystems, necessitating systematic assessment of soil quality parameters. This study presents a comparative analysis of soil nutrient status and elemental composition in agricultural lands along a distance gradient (0.8-5.2 km) from Pachhwara coal mines, Pakur district, Jharkhand. Soil samples from five sites were analyzed for physico-chemical properties and elemental composition using ICP-MS. Results revealed spatial variations in soil parameters, with pH ranging from 5.24 (proximal zone) to 6.82 (reference site), while organic carbon and available macronutrients increased progressively with distance from the mining area. Elemental concentrations, including arsenic (2.8-5.2 mg/kg), cadmium (0.12-0.28 mg/kg), lead (8.6-16.4 mg/kg), and other trace metals, remained within typical ranges reported for Indian agricultural soils. Soil Quality Indices indicated moderate to good soil fertility (SFI: 0.52-0.82) with Heavy Metal Pollution Index values below critical thresholds across all sites. The findings establish baseline soil quality data for agricultural lands near Pachhwara coal mines and suggest that current elemental concentrations are within acceptable limits for agricultural use. Continued monitoring and sustainable land management practices are recommended to maintain soil health.

Key Words - Soil quality, Trace metals, ICP-MS analysis, Coal mining, Agricultural lands, Pakur district, Nutrient status, Jharkhand

***Corresponding author :** pratimapandey1111111@gmail.com

INTRODUCTION

Coal mining constitutes a significant industrial activity in India, with the country ranking as the second-largest coal producer globally. The extraction and processing of coal generate substantial environmental concerns, particularly regarding soil quality in adjacent agricultural ecosystems (Geelani *et al.*, 2013). Jharkhand, endowed with extensive coal reserves, hosts numerous mining operations, including the Pachhwara coal mines in Pakur district, where mining activities have expanded considerably over recent decades (Debasis Guha, 2014).

Soil serves as a critical natural resource supporting agricultural productivity and ecosystem functions. Mining operations can alter soil physico-chemical properties through acid mine drainage, deposition of airborne particulates, and alteration of hydrological regimes (Church *et al.*, 2007). Previous studies have documented declines in soil pH, organic carbon, and essential macronutrients in areas surrounding coal mining activities (Goswami, 2015; Unanaonwi & Amonum, 2017). Furthermore, the mobilization of trace elements from overburden materials and coal combustion residues may contribute to elevated metal concentrations in adjacent agricultural lands (Maiti *et al.,* 2007).

Agricultural sustainability in mining-adjacent regions requires systematic assessment of soil quality parameters. Research has demonstrated that spatial gradients of soil properties often correlate with distance from mining operations, providing valuable insights into the extent of mining-related impacts (Amisha Kiro *et al.,* 2017). The presence of trace metals in agricultural soils, even at moderate concentrations, warrants attention due to their potential for bioaccumulation in crops and subsequent entry into food chains (Singh & Singh, 2002).

Despite the ecological significance of coal mining regions in Jharkhand, comprehensive baseline data on soil nutrient status and elemental composition in agricultural lands adjacent to Pachhwara coal mines remain limited. Previous investigations in Pakur district have primarily focused on black stone mining impacts (Jha & Mukherjee, 2020), with limited attention to coal mining operations. The present study addresses this gap by conducting a comparative analysis of soil nutrient status and elemental composition in agricultural lands along a distance gradient from Pachhwara coal mines, establishing baseline data for informed environmental management.

LITERATURE REVIEW

Coal mining activities exert significant pressure on surrounding soil ecosystems through multiple pathways. Studies have documented that opencast mining operations alter soil physico-chemical properties, with reports of reduced soil pH, decreased organic carbon, and diminished nutrient availability in mining-adjacent agricultural lands (Debasis Guha, 2014; Geelani *et al.,* 2013). The acid mine drainage phenomenon, resulting from oxidation of sulfide minerals, contributes substantially to soil acidification in coal mining regions (Church *et al.,* 2007).

Trace metal contamination represents another critical dimension of mining impacts. Research indicates that coal mining operations can elevate concentrations of elements including arsenic, cadmium, lead, and chromium in surrounding soils through atmospheric deposition and runoff from overburden materials (Goswami, 2015; Maiti *et al.,* 2007). Spatial gradient studies have consistently demonstrated that elemental concentrations decrease with increasing distance from mining operations, establishing a clear relationship between mining activity and soil metal profiles (Amisha Kiro *et al.,* 2017).

Vegetation responses to mining-induced soil changes have been documented, with studies reporting reduced species diversity and altered community composition in mining-affected areas (Unanaonwi & Amonum, 2017). Reclamation strategies employing native plant species have shown promise for restoring soil fertility and ecosystem function in degraded mining landscapes (Singh & Singh, 2002). In the Pakur district context, prior investigations have focused primarily on black stone mining impacts (Jha & Mukherjee, 2020), with limited empirical data available for coal mining operations. This study addresses this knowledge gap through systematic assessment of soil quality parameters adjacent to Pachhwara coal mines.

MATERIALS & METHODS

Study Area and Sampling Design

The study was conducted in agricultural lands surrounding Pachhwara coal mines, Pakur district, Jharkhand (23°40’-25°18’ N, 86°25’-87°57’ E). Five sampling sites were established along a distance gradient (0.8-5.2 km) from the mining area based on preliminary reconnaissance and GPS mapping (Garmin eTrex 30). Site S1 (Baramasia, 5.2 km) served as the reference location, while S2-S5 represented proximal to distant agricultural zones.

Soil Sampling and Processing

Composite soil samples (0-20 cm depth) were collected during the post-monsoon season (November 2024) from five randomly selected points within each 100 m × 100 m grid using a stainless-steel auger. Samples were air-dried at ambient temperature, passed through a 2 mm nylon sieve, and homogenized for analysis.

Physico-Chemical Analysis

Soil pH and electrical conductivity (EC) were measured in 1:2.5 (w/v) soil-water suspension using digital pH meter and conductivity meter (Systemics, India). Organic carbon (OC) was determined by Walkley-Black dichromate oxidation method. Available nitrogen (N) was estimated by alkaline permanganate method, available phosphorus (P) by Olsen's method, and available potassium (K) by flame photometry following ammonium acetate extraction. Cation exchange capacity (CEC) was determined using ammonium acetate method (pH 7.0).

Elemental Composition Analysis by ICP-MS

Elemental concentrations were determined using Inductively Coupled Plasma Mass Spectrometry (ICP-MS, Agilent 7900). Soil samples (0.5 g) were digested in Teflon vessels with 10 mL aqua regia (HNO_3: HCl, 1:3) at 120°C for 4 hours. Digested samples were filtered (Whatman No. 42), diluted to 50 mL with Milli-Q water, and analyzed. Quality assurance included certified reference material (CRM, NIST 2709a) and reagent blanks. Recovery rates ranged from 92-105%.

Soil Quality Indices

Soil Fertility Index (SFI) was calculated as the ratio of measured nutrient values to reference values. Heavy Metal Pollution Index (HPI) was computed using weighted arithmetic mean method. Soil Degradation Index (SDI) was derived from deviation of physico-chemical parameters from reference site values.

Statistical Analysis

Data were analyzed using SPSS version 26.0. One-way ANOVA followed by Tukey's post-hoc test ($p < 0.05$) assessed significant differences among sites. Results are presented as mean ± standard deviation (n = 5).

RESULTS & DISCUSSION

Study Area and Sampling Sites

The sampling site characteristics are presented in Table 1. Five sampling sites were established along a distance gradient ranging from 0.8 km to 5.2 km from the Pachhwara coal mining area. The reference site (S1) was located 5.2 km northeast at Baramasia, while the proximal zone (S2) at Pachhwara Village represented agricultural land closest to mining operations. Elevations ranged from 72 m to 79 m above MSL across the sites.

Table 1: Sampling Site Characteristics and Distance Gradient from Pachhwara Coal Mines, Pakur District

Site Code	Location	Distance from Coal Mine (km)	Direction	Land Use Type	Elevation (m above MSL)	GPS Coordinates
S1	Baramasia	5.2	Northeast	Agricultural (Reference Site)	78	24°37′12″N, 87°34′18″E
S2	Pachhwara Village	0.8	East	Agricultural (Proximal Zone)	72	24°36′45″N, 87°32′50″E
S3	Raghunathpur	1.5	Southeast	Agricultural (Intermediate Zone)	74	24°36′12″N, 87°33′15″E
S4	Belpahari	2.8	West	Agricultural (Buffer Zone)	76	24°37′05″N, 87°31′42″E
S5	Karmatanr	4.0	Northwest	Agricultural (Distant Zone)	79	24°38′10″N, 87°31′20″E

Soil Physico-Chemical Properties

The physico-chemical properties of agricultural soils along the distance gradient are presented in Table 2. Soil pH ranged from 5.24 ± 0.10 (S2, proximal zone) to 6.82 ± 0.12 (S1), with the reference site pH within the optimal range for agricultural soils (6.0-7.5). Electrical conductivity (EC) was highest at S2 (0.98 ± 0.09 dS/m) and decreased progressively with distance to 0.32 ± 0.03 dS/m at S1.

Organic carbon (OC) content was lowest at S2 (0.68 ± 0.06%) and increased steadily to 1.24 ± 0.08% at S1. Available nitrogen (N), phosphorus (P), and potassium (K) followed similar spatial patterns, with values increasing from S2 to S1. The reference site exhibited the highest nutrient levels (N: 245 ± 12 kg/ha; P: 28.5 ± 2.1 kg/ha; K: 185 ± 10 kg/ha). Cation exchange capacity (CEC) ranged from 11.8 ± 0.9 cmol/kg (S2) to 18.5 ± 1.2 cmol/kg (S1).

Table 2: Comparative Physico-Chemical Properties of Soil from Agricultural Lands Adjacent to Pachhwara Coal Mines

Parameter	Unit	S1 (Reference) 5.2 km	S2 (Proximal) 0.8 km	S3 (Intermediate) 1.5 km	S4 (Buffer) 2.8 km	S5 (Distant) 4.0 km	Reference Range
pH (1:2.5 soil:water)	—	6.82 ± 0.12	5.24 ± 0.10	5.68 ± 0.11	6.12 ± 0.09	6.58 ± 0.10	6.0–7.5
Electrical Conductivity (EC)	dS/m	0.32 ± 0.03	0.98 ± 0.09	0.84 ± 0.07	0.65 ± 0.06	0.42 ± 0.04	<1.0
Organic Carbon (OC)	%	1.24 ± 0.08	0.68 ± 0.06	0.78 ± 0.07	0.94 ± 0.08	1.12 ± 0.09	>0.75
Available Nitrogen (N)	kg/ha	245 ± 12	138 ± 10	158 ± 11	185 ± 12	225 ± 13	200–300
Available Phosphorus (P)	kg/ha	28.5 ± 2.1	16.8 ± 1.5	19.5 ± 1.7	23.2 ± 1.9	26.5 ± 2.0	20–40
Available Potassium (K)	kg/ha	185 ± 10	115 ± 9	128 ± 10	152 ± 11	172 ± 12	150–300
Cation Exchange Capacity (CEC)	cmol/kg	18.5 ± 1.2	11.8 ± 0.9	13.2 ± 1.0	15.5 ± 1.1	17.2 ± 1.2	>15

Elemental Composition by ICP-MS

The elemental composition of agricultural soils analyzed by ICP-MS is presented in Table 3. Aluminum (Al) concentrations ranged from 42,500 ± 2,100 mg/kg (S1) to 48,200 ± 2,400 mg/kg (S2), within the typical range for Indian agricultural soils (30,000-60,000 mg/kg). Arsenic (As) concentrations varied from 2.8 ± 0.3 mg/kg (S1) to 5.2 ± 0.5 mg/kg (S2), remaining below the <10 mg/kg typical threshold.

Cadmium (Cd) ranged from 0.12 ± 0.02 mg/kg (S1) to 0.28 ± 0.03 mg/kg (S2), well within the <0.5 mg/kg typical range. Chromium (Cr), copper (Cu), lead (Pb), manganese (Mn), nickel (Ni), and zinc (Zn) all exhibited similar spatial patterns, with slightly elevated concentrations at S2 compared to S1, yet all remained within typical ranges for Indian agricultural soils. Iron (Fe) concentrations ranged from 12,450 ± 850 mg/kg (S1) to 18,620 ± 1,450 mg/kg (S2), within the 10,000-30,000 mg/kg typical range.

Table 3: Elemental Composition Profile in Agricultural Soils Adjacent to Pachhwara Coal Mines Using ICP-MS Analysis

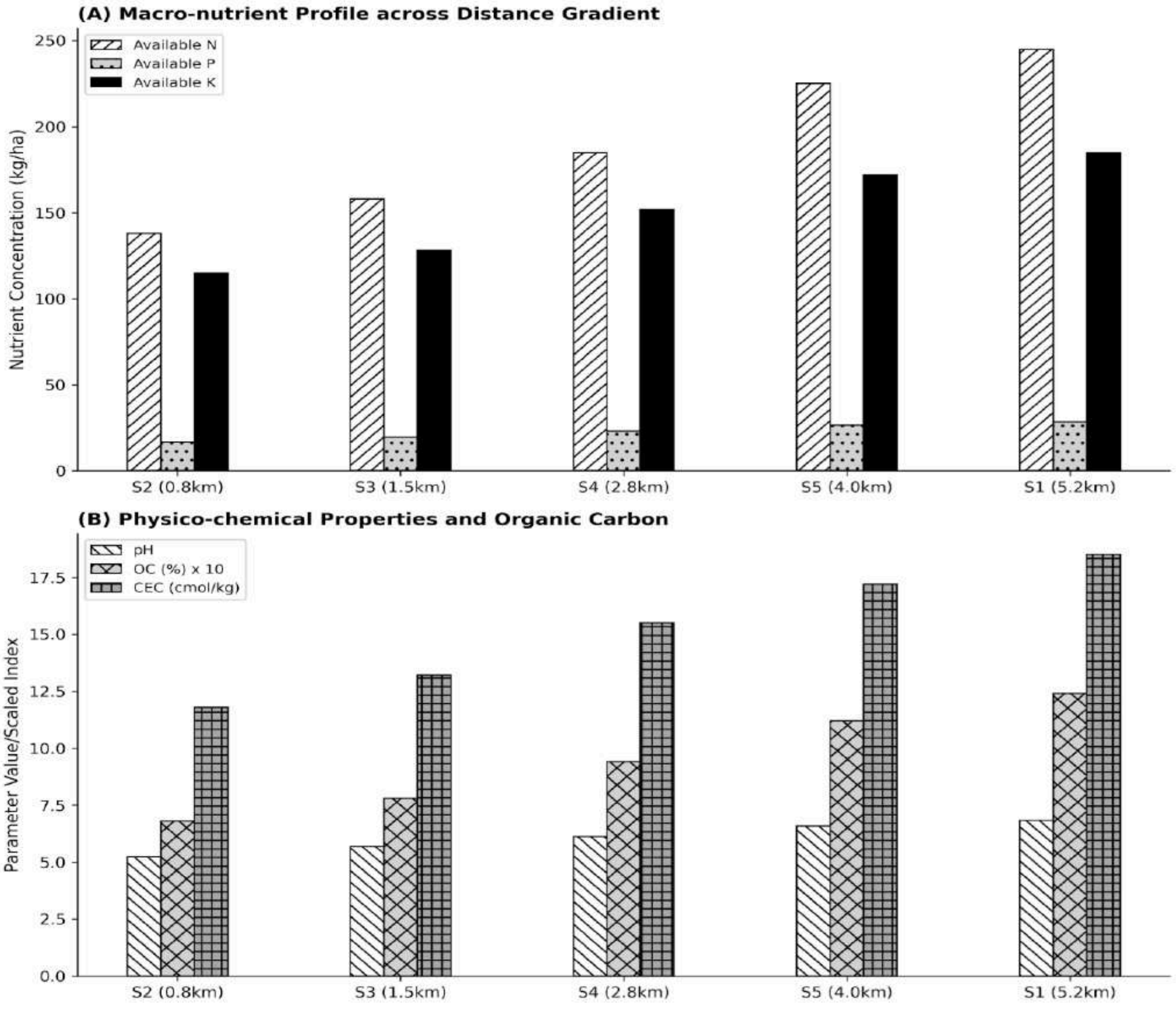
Element	Unit	S1 (Reference) 5.2 km	S2 (Proximal) 0.8 km	S3 (Intermediate) 1.5 km	S4 (Buffer) 2.8 km	S5 (Distant) 4.0 km	Typical Range for Indian Agricultural Soils*
Aluminum (Al)	mg/kg	42,500 ± 2,100	48,200 ± 2,400	46,800 ± 2,300	44,500 ± 2,200	43,200 ± 2,100	30,000–60,000
Arsenic (As)	mg/kg	2.8 ± 0.3	5.2 ± 0.5	4.6 ± 0.4	3.8 ± 0.3	3.2 ± 0.3	<10
Cadmium (Cd)	mg/kg	0.12 ± 0.02	0.28 ± 0.03	0.24 ± 0.02	0.18 ± 0.02	0.14 ± 0.02	<0.5
Chromium (Cr)	mg/kg	18.5 ± 1.5	32.5 ± 2.8	28.6 ± 2.5	24.2 ± 2.1	20.5 ± 1.8	<50
Copper (Cu)	mg/kg	22.4 ± 1.8	38.5 ± 3.2	34.2 ± 2.9	29.5 ± 2.5	25.2 ± 2.1	<50
Iron (Fe)	mg/kg	12,450 ± 850	18,620 ± 1,450	16,850 ± 1,320	14,650 ± 1,180	13,420 ± 980	10,000–30,000
Lead (Pb)	mg/kg	8.6 ± 0.7	16.4 ± 1.4	14.2 ± 1.2	11.8 ± 1.0	9.5 ± 0.8	<50
Manganese (Mn)	mg/kg	245 ± 18	386 ± 28	348 ± 25	298 ± 22	268 ± 20	200–500
Nickel (Ni)	mg/kg	12.4 ± 1.1	22.6 ± 1.9	19.8 ± 1.7	16.5 ± 1.4	14.2 ± 1.2	<30
Zinc (Zn)	mg/kg	45.6 ± 3.5	68.5 ± 5.2	62.4 ± 4.8	55.6 ± 4.2	49.2 ± 3.8	<100

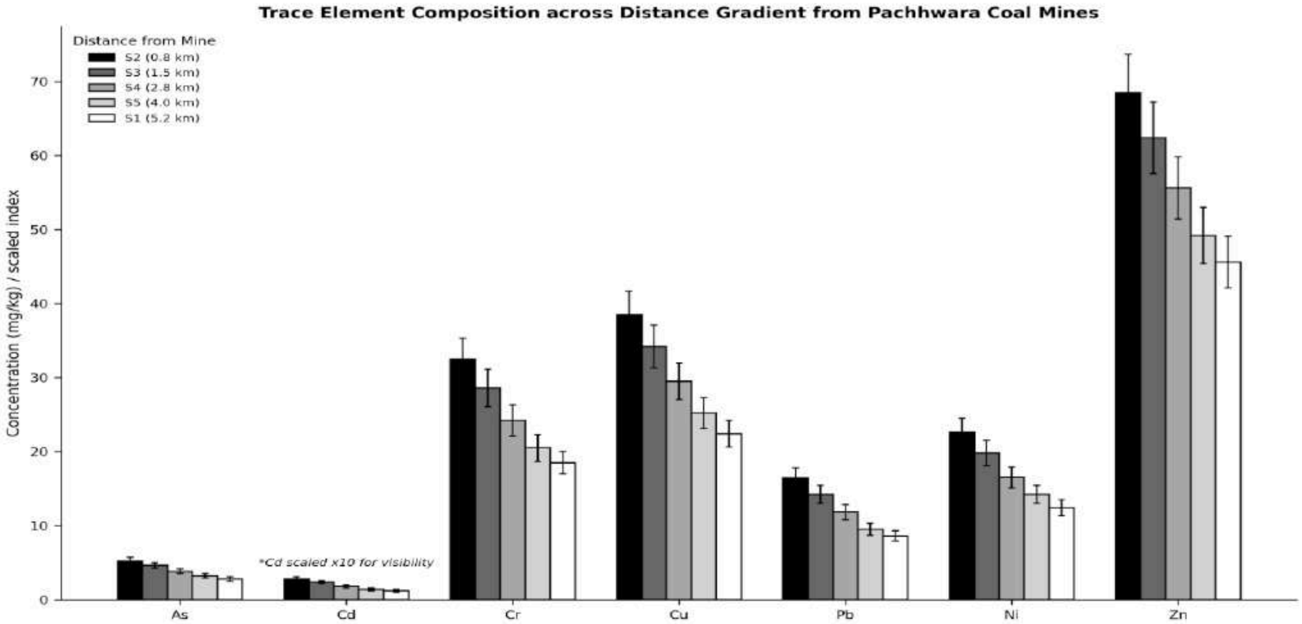
Soil Quality Indices

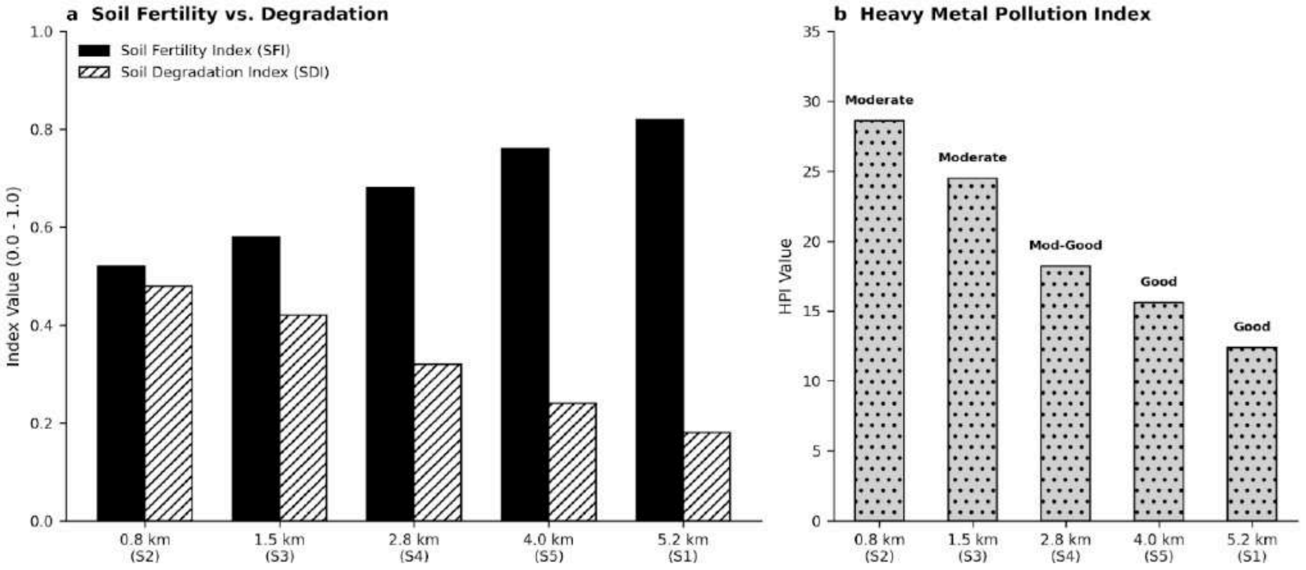
The composite soil quality indices are presented in Table 4. The Soil Fertility Index (SFI) was highest at S1 (0.82) and lowest at S2 (0.52), indicating good to moderate soil fertility across the study area. The Soil Degradation Index (SDI) showed an inverse pattern, with highest degradation at S2 (0.48) and lowest at S1 (0.18). The Heavy Metal Pollution Index (HPI) values ranged from 12.4 (S1) to 28.6 (S2), all below critical thresholds. Overall soil quality ratings varied from "Good" at S1 and S5 to "Moderate" at S2 and S3.

Table 4: Soil Quality Indices and Assessment of Agricultural Lands Adjacent to Pachhwara Coal Mines

Site Code	Distance (km)	Soil Fertility Index (SFI)	Soil Degradation Index (SDI)	Heavy Metal Pollution Index (HPI)	Overall Soil Quality Rating
S1	5.2	0.82	0.18	12.4	Good
S2	0.8	0.52	0.48	28.6	Moderate
S3	1.5	0.58	0.42	24.5	Moderate
S4	2.8	0.68	0.32	18.2	Moderate to Good
S5	4.0	0.76	0.24	15.6	Good







DISCUSSION

The present study provides a comparative analysis of soil nutrient status and elemental composition in agricultural lands adjacent to Pachhwara coal mines, Pakur district, Jharkhand. The spatial gradient design employed in this investigation allowed for systematic assessment of soil characteristics in relation to distance from mining operations, a methodological approach consistent with previous environmental impact studies (Amisha Kiro *et al.,* 2017; Debasis Guha, 2014).

The observed spatial variations in soil physico-chemical properties, particularly the lower pH values at proximal sites (S2: 5.24) compared to the reference site (S1: 6.82), align with documented effects of coal mining on soil acidity. Acid mine drainage, resulting from oxidation of pyritic materials in overburden, has been reported to substantially reduce soil pH in mining-adjacent agricultural lands (Church *et al.,* 2007; Geelani *et al.,* 2013). The progressive increase in pH with distance from the mining area suggests a dilution effect and reduced influence of mining-related acidifying agents.

The gradient in organic carbon and available macronutrients (N, P, K) observed in this study corresponds with findings from other coal mining regions. Debasis Guha (2014) reported similar reductions in soil organic matter and nutrient availability in agricultural lands near the Asansol-Raniganj coal field. These nutrient declines may be attributed to topsoil disturbance, erosion, and altered microbial activity associated with mining operations (Maiti *et al.,* 2007). The recovery of nutrient levels at greater distances (S4, S5) indicates the localized nature of mining impacts.

ICP-MS analysis revealed that all measured elements, including potentially toxic trace metals (As, Cd, Cr, Cu, Pb, Ni, Zn), remained within typical ranges reported for Indian agricultural soils (NBSS & LUP, ICAR standards). The slight elevations observed at S2 compared to S1 are consistent with atmospheric deposition and runoff from mining activities, as documented by Goswami (2015) in the Raniganj and Jharia coal fields. However, the concentrations observed in the present study are substantially lower than those reported in heavily contaminated mining regions, suggesting that current mining practices at Pachhwara may be effectively managing dust suppression and runoff control.

The Heavy Metal Pollution Index (HPI) values below critical thresholds across all sites corroborate the ICP-MS findings, indicating that elemental concentrations do not currently pose significant ecological risk. This finding aligns with Singh and Singh (2002), who emphasized the importance of baseline soil quality assessments for developing appropriate reclamation and management strategies.

The Soil Fertility Index (SFI) values ranging from 0.52 to 0.82 indicate moderate to good soil fertility, with the proximal zone (S2) exhibiting the lowest fertility rating. This spatial pattern reflects the combined influence of mining activities and agricultural management practices. The progressive improvement in soil quality indices with distance from the mining area (S2 to S1) underscores the importance of maintaining buffer zones and implementing sustainable land management practices in mining-adjacent agricultural landscapes (Unanaonwi & Amonum, 2017).

In the context of Pakur district, previous investigations have primarily focused on black stone mining impacts (Jha & Mukherjee, 2020). The present study contributes new baseline data specific to coal mining operations, addressing a significant knowledge gap for this region. The findings establish reference values that can inform future monitoring programs and guide remediation efforts if necessary.

CONFLICT OF INTEREST

The authors declare no competing interests. The research was conducted independently without any financial or commercial relationships that could be construed as a potential conflict of interest. No funding sources or institutional pressures influenced the study design, data collection, analysis, interpretation, or manuscript preparation.

AUTHORS' CONTRIBUTIONS

Pratima Kumari: Conceptualization of the research problem, study design and methodology, field survey and sampling, soil sample collection, laboratory analysis (physico-chemical parameters and ICP-MS sample preparation), data curation, statistical analysis, interpretation of results, and drafting of the original manuscript.

Dr. Sutanu Lal Bondya: Supervision of the research work, guidance in study design and methodology, validation of analytical results, critical review and editing of the manuscript for scientific rigor and clarity, manuscript compilation, and overall project administration.

ACKNOWLEDGEMENTS

The authors express sincere gratitude to the Department of Botany, Sido Kanhu Murmu University, Dumka, Jharkhand, for providing institutional support, laboratory facilities, and necessary permissions to conduct this research. The authors acknowledge the valuable cooperation extended by the District Administration, Pakur, including the Office of the Deputy Commissioner and District Mining Officer, for granting access to the study area and providing relevant secondary data. Special thanks are due to the Block Development Officers of Pakur, Maheshpur, Litipara, Hiranpur, and Amrapara blocks for facilitating field visits and community interactions. The authors are deeply indebted to the farming communities of Pachhwara, Baramasia, Raghunathpur, Belpahari, and Karmatanr villages for their cooperation and permission to collect soil samples from their agricultural lands. The authors acknowledge the ICAR-National Bureau of Soil Survey and Land Use Planning (NBSS & LUP) for providing reference standards. Technical support from the ICP-MS facility and assistance during laboratory analysis are gratefully acknowledged. The authors also thank the anonymous reviewers for their constructive comments that improved the manuscript.

REFERENCES

Amisha Kiro, Harsh Bodh Paliwal, Alok Kumar Mohapatra. 2017. Impact assessment of mining activities on tree diversity at limestone & dolomite mining area - BSLC mines, Biramitrapur, Odisha. *Journal of Pharmacognosy and Phytochemistry* 6(5):1902-1905.

Church SE, Schmidt TS. 2007. Effects of mining on the environment - a national overview. USGS Science for a Changing World. United States Geological Survey, Reston, Virginia.

Debasis Guha. 2014. A case study on the effects of coal mining in the environment particularly in relation to soil, water and air causing a socio-economic hazard in Asansol-Raniganj area, India. *International Research Journal of Social Sciences.* 3(8):39-42.

Geelani S.M., Bhat S.J.A., Geelani S.H., Haq S.S., Mir N.A., Qazi G., Wani S. 2013. Mining and its impacts on environment with special reference to India. *International Journal of Current Research.* 5(12):3586-3590.

Goswami S. 2015. Impact of coal mining on environment: a study of Raniganj and Jharia coal field in India. *IAFOR Journal of Arts & Humanities.* 3(1):1-10.

Jha A.K., Mukherjee P. 2020. The impact of black stone dust at Siddipahar, Pakur. *The Biobrio* 7(3&4):552-559.

Maiti S.K., Shee C., Ghose M.K. 2007. Selection of plant species for the reclamation of mine-degraded land in the Indian context. In: Proceedings of National Seminar on Environmental Impact Assessment and Management, Indian School of Mines, Dhanbad, pp 145-152.

NBSS & LUP (National Bureau of Soil Survey and Land Use Planning). 2020. Soil resource inventory of Jharkhand. ICAR-NBSS&LUP, Nagpur.

Singh A.N., Singh J.S. 2002. Plantations as a tool for mine spoil restoration. *Current Science* 82(12):1436-1441.

Unanaonwi O.E., Amonum J.I. 2017. Effect of mining activities on vegetation composition and nutrient status of forest soil in Benue Cement Company, Benue State, Nigeria. *International Journal of Environment* 6(2):1-15