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# ASSESSMENT OF SOIL QUALITY NEAR CHHAL COAL MINE IN RAIGARH CHHATTISGARH: A COMPARATIVE STUDY OF EASTERN AND WESTERN BANK OF MAND RIVER BASIN VILLAGE AREA

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**Abstract-** *This research investigated the physicochemical properties and nutrient dynamics of soils affected by coal mining activities in the Chhal mining region of India analysis revealed significant spatial variations in soil pH, electrical conductivity (EC), organic carbon, macronutrients (N, P, K), and trace metal concentrations across mine-affected (C1) and western control (S1–S5) sites. The C1 soil sample exhibited a markedly acidic pH of 4.89 and a low EC value of 0.29 dS/m, indicating leaching and reduced soluble salt content, which is typical of degraded mine soils. In contrast, the western samples displayed near-neutral pH and moderate EC, suggesting comparatively better soil health in the western region. The organic carbon content in C1 (0.28%) was substantially lower than that in the western samples, reflecting diminished microbial activity and organic matter accumulation due to mining-induced disturbances. However, the elevated concentrations of nitrogen and phosphorus in C1 were attributed to anthropogenic deposition and localized enrichment from mining emissions and mineralized rock weathering. Conversely, potassium levels were higher in western soils, likely resulting from enhanced mineral weathering and a stable soil structure. Trace metal analysis revealed elevated levels of Cr, Pb, Ni, and Zn in the C1 sample, confirming* contamination by coal extraction and associated activities. *Overall, the findings demonstrate that coal mining operations profoundly alter soil chemistry, reducing fertility, organic matter content, and microbial activity, while increasing heavy metal contamination. Such degradation underscores the need for targeted reclamation strategies and continuous soil monitoring to restore the ecological balance in mining-impacted landscapes.*

***Key Words*: Soil, physicochemical properties, macronutrients, trace metal**

## 1.INTRODUCTION

Chhal mines, which are situated in Chhattisgarh's Raigarh district, have a substantial impact on the adjacent villages' soil quality. The primary causes of the damage are coal mining operations and overburden dumping. The Barakar formation of the Gondwana basin contains the coal from the chhal mine with a moisture content of 4–10%, ash of 10–27% (mean ~18%), volatile matter of 22–35%, fixed carbon of 38–52%, and sulphur of less than 1%, it is categorised as sub-bituminous to high-volatile bituminous thermal (non-coking) coal (Singh et al., 2016; Ministry of Coal, 2020)[1,2]. Coal mining is one of the major industrial activities in Chhattisgarh, particularly in regions such as Raigarh, Korba, and Surguja, where open-cast mining has expanded rapidly in the past two decades. The ecology of the surroundings are drastically changed by coal mining. Open-cast and underground mining activities cause soil degradation, contaminate the air and water, and have a negative impact on human and animal health. Topsoil removal all lower soil fertility by increasing the accumulation of heavy metals and reducing organic carbon (Singh & Pandey, 2019)[3]. Residents in nearby areas suffer from respiratory illnesses (CPCB, 2019; Singh et al., 2020)[4,5]. Soil quality degradation is a major socio-environmental concern because communities surrounding coal mines are primarily dependent on agriculture and livestock. A comparative assessment of Eastern and Western villages around the Chhal and nearby coalfields provides insight into spatial variation in contamination levels influenced by mining intensity. Fig. 1 shows how coal mining in the Chhal region causes soil degradation, heavy metal contamination, and loss of fertility, and highlights modern mitigation technologies such as biochar, phytoremediation, and remote sensing to restore soil health. Land subsidence caused by mining activities can alter the water content, nutrient levels, and biological activity of the soil. A decrease in soil fertility, including lower concentrations of total nitrogen, dissolved organic carbon, and vital nutrients like phosphorus and potassium, is seen in regions impacted by land subsidence.

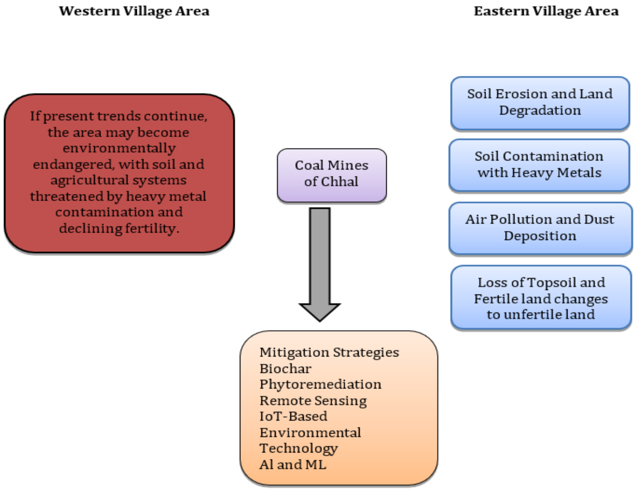


**Fig. 1:** Sustainable technologies reduce pollution and protect farmlands in coal mining regions

### 1.1 Study Area

The present study was conducted in western and eastern village area in bank of Mond river basin, located in the kharsia tehsil of Raigarh district, Chhattisgarh, India (Latitude 22°07' to 22°128' N, Longitude 83°055' to 83°140' E). The village area lies on the western bank of the Mand river, a tributary of the Mahanadi river basin, and is traversed by the Kurket river, which provides seasonal surface water flow and supports nearby agricultural lands. The region experiences a subtropical climate, characterized by hot summers (up to 45°C), moderate winters (as low as 10°C), and an average annual rainfall of about 1200–1400 mm, mainly from the southwest monsoon.

### 1.2 Sample Collection

Five soil samples were collected from near the western bank of the Mand river basin village area in the Kharsia tahsil, and one soil sample was taken from the eastern bank of the Mand river basin area, which represents the mining-affected agricultural zone of Raigarh district, Chhattisgarh(shown in Table 1). The samples were taken from a depth of 0 to 20 cm in the field. After collection, the soil was cleaned by removing herbs, plant residues, and stones by hand. The samples were kept in plastic sample bags. The soil was then air-dried and passed through a 2 mm brass sieve to remove larger particles. After sieving, the samples were stored in an oven at 30°C until further use. From each sample, 100 grams of soil was transferred into a labelled sample bag. Each bag was marked with the sample date, location, and sample number. Five samples were selected and a study was carried out based on a wide range of physio-chemical properties.

**Table -1:** List of collected soil samples

| Western bank side area | Eastern bank side area |
|---|---|
| S1 - Farkanara | C1 - Chhal |
| S2 - Kewali | |
| S3 - Jobi-Barra | |
| S4 - Khamhar | |
| S5 - Rampur | |

## 2. METHODOLOGY

The soil samples were brought to the laboratory for further analysis. Soil samples were air-dried, sieved (2 mm), and examined for fundamental physico-chemical characteristics. A digital pH and conductivity meter was used to measure the pH and electrical conductivity (EC) of the soil in a 1:2.5 soil–water suspension, respectively (Jackson, 1973)[6]. The Walkley and Black (1934)[7] wet-oxidation method, which involves oxidizing organic materials with potassium dichromate and titrating with ferrous ammonium sulphate, was used to analyse organic carbon (OC). The alkaline permanganate method (Subbiah & Asija, 1956)[8], which releases nitrogen as ammonia by oxidation with alkaline $KMnO_4$ and measures it by acid titration, was used to determine available nitrogen (N). Olsen's method with 0.5 M $NaHCO_3$ (pH 8.5) was used to extract available phosphorus (P), which was then colorimetrically quantified using the molybdate blue method (Olsen et al., 1954)[9]. A flame photometer was used to measure the amount of available potassium (K), which was extracted using 1 N neutral ammonium acetate (Jackson, 1973)[6]. The data were represented in kg/h of soil on an oven-dry basis, and all analyses were carried out in triplicate. Soil heavy metal concentrations were determined using Inductively Coupled Plasma–Mass Spectrometry (ICP-MS) following the USEPA Method 3052 (1996)[10] microwave-assisted acid digestion protocol (APHA, 2017; ISO 17294-2:2016)[11,12].

## 3. RESULTS

### 3.1 Total Nitrogen Availability

The highest mean value was observed in S3 (198.55 kg/ha), followed by S4 (196.88 kg/ha) and S1 (195.95 kg/ha), while S2 (189.67 kg/ha) and S5 (188.99 kg/ha) recorded the lowest values. The one-way analysis of variance (ANOVA) revealed a significant variation among the samples ($p<0.05$), indicating that the samples had a statistically significant influence on the measured parameter. Tukey's HSD post-hoc analysis further confirmed highly significant differences ($p<0.01$) among all samples (S1–S5), shown in Fig. 2. Each sample exhibited distinct statistical behaviour, with no overlapping significance groups.

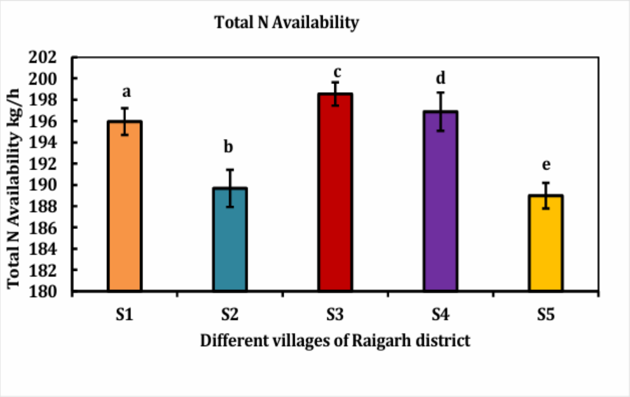


**Fig. 2:** Nitrogen (N) content (kg/ha) in different samples (S1–S5). Values with different letters differ significantly (Tukey HSD, $p<0.01$).

### 3.2 Total Phosphorus availability

Fig. 3 shows the mean values of the total phosphorus (P) under different samples were 10.22 (S1), 10.89 (S2), 10.56 (S3), 10.11 (S4), and 10.72 (S5). The highest mean value was observed in the S2 sample, and the lowest mean value of P was found in the S4 sample. The one-way ANOVA revealed a significant difference ($p<0.05$) among the samples, indicating that the sample had a statistically significant influence on the parameter. Subsequent post-hoc Tukey HSD analysis ($p<0.01$) confirmed that all samples differed significantly from each other, suggesting distinct treatment effects.

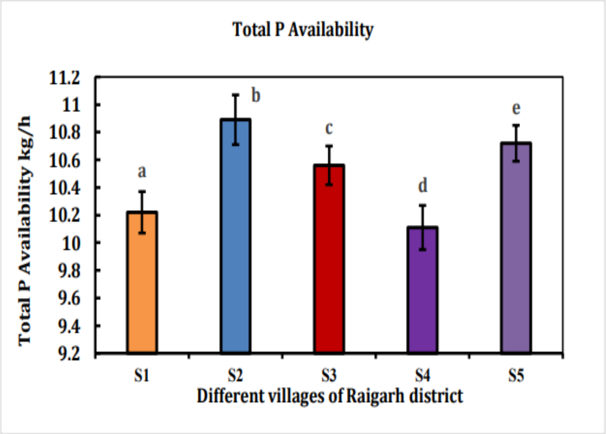


**Fig. 3:** Phosphorus (P) content (kg/ha) in different samples (S1–S5). Values with different letters differ significantly (Tukey HSD, $p< 0.01$).

### 3.3 Total Potassium Availability

The mean K content under different samples was recorded as 310.75 (S1), 282.98 (S2), 302.64 (S3), 285.36 (S4), and 305.43 (S5). The one-way ANOVA revealed a significant difference ($p < 0.05$) among the samples, indicating that the sample had a statistically significant effect on potassium content. Further, the post-hoc Tukey HSD test ($p<0.01$) confirmed that all pairwise sample comparisons (S1–S5) were highly significant, demonstrating distinct variations in potassium accumulation among the samples. Based on the mean comparison, S1 recorded the highest potassium content (310.75), followed by S5 (305.43) and S3 (302.64), whereas S2 (282.98) and S4 (285.36) exhibited comparatively lower values (Fig. 4)

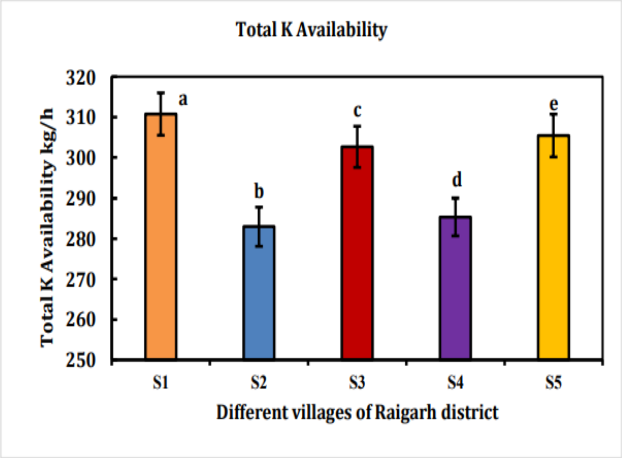


**Fig. 4:** Potassium (K) content (kg/ha) in different samples (S1–S5). Values with different letters differ significantly (Tukey HSD, $p < 0.01$).

### 3.4 Organic Carbon

The Organic carbon (OC) content ranged from 0.52% to 0.60% across samples (S1–S5). ANOVA ($p<0.05$) indicated significant differences among the samples (Table 2). Tukey HSD showed that S1 and S2 were statistically similar, while S3, S4, and S5 had significantly higher OC values ($p < 0.05$–$0.01$). The OC trend followed S5 > S4 > S3 > S1> S2.

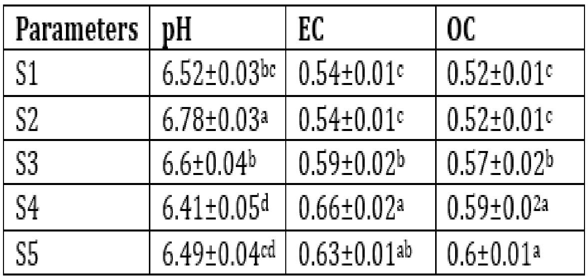
### 3.5 pH

The soil pH values of different samples ranged from 6.42 to 6.78, indicating that all samples were slightly acidic in nature. The highest pH (6.78) was recorded in S2, followed by S3 (6.60), S1 (6.52), S5 (6.49), and the lowest in S4 (6.42). The one-way ANOVA ($p<0.05$) confirmed a significant difference in soil pH among the samples, suggesting that the amendments influenced soil reaction. According to the Tukey HSD post-hoc test, S2 differed significantly ($p<0.01$) from most other samples (S1, S3, S4, and S5), while differences between S1, S3, and S5 were statistically insignificant. S4 showed a significantly lower pH compared to S2 and S3, indicating stronger acidifying effects under this treatment, as shown in Table 2.

### 3.6 Electrical Conductivity

The electrical conductivity (EC) of soil varied from 0.54 to 0.66 dS m$^{-1}$ among the samples. The lowest EC was recorded in S1 (0.54 dS m$^{-1}$) and S2 (0.54 dS m$^{-1}$), while the highest was found in S4 (0.66 dS m$^{-1}$), followed by S5 (0.63 dS m$^{-1}$) and S3 (0.59 dS m$^{-1}$). The one-way ANOVA ($p<0.05$) indicated a significant difference in EC among the samples, suggesting that soil salinity levels were affected by the applied sample. According to the Tukey HSD post-hoc test, S1 and S2 showed no significant difference, but both were significantly lower than S3, S4, and S5 ($p<0.05–0.01$). S4 exhibited the highest EC, differing significantly from S1, S2, and S3, while S4 and S5 were statistically similar, shown in Table 2.

**Table. 2:**. Variation in soil physico-chemical properties (pH, EC, and OC) under different samples (S1–S5). Values represent mean ± standard deviation (n = 3). Means followed by different letters within a column differ significantly according to Tukey's HSD test ($p < 0.05$).



| Parameters | pH | EC | OC |
|---|---|---|---|
| S1 | 6.52±0.03$^{bc}$ | 0.54±0.01$^{c}$ | 0.52±0.01$^{c}$ |
| S2 | 6.78±0.03$^{a}$ | 0.54±0.01$^{c}$ | 0.52±0.01$^{c}$ |
| S3 | 6.6±0.04$^{b}$ | 0.59±0.02$^{b}$ | 0.57±0.02$^{b}$ |
| S4 | 6.41±0.05$^{d}$ | 0.66±0.02$^{a}$ | 0.59±0.0$^{2a}$ |
| S5 | 6.49±0.04$^{cd}$ | 0.63±0.01$^{ab}$ | 0.6±0.01$^{a}$ |

### 3.7 Sample of Chhal (C1)

The concentrations of Cr (196.87 mg/kg), Ni (120.04 mg/kg), Cu (112.19 mg/kg), Pb (312.06 mg/kg), and Zn (318.55 mg/kg) in the C1 soil sample exceeded the WHO/FAO (1978) permissible limits, particularly for Cr and Ni, shown in Table 3. This indicates significant heavy metal contamination, likely arising from industrial and mining activities, which may negatively impact soil quality and pose environmental and health risks. The soil sample showed slightly acidic pH (4.89) with low electrical conductivity (0.29 dS/m), indicating minimal salinity. Organic carbon (0.28%) was low, suggesting poor organic matter. Nitrogen (201.34 mg/kg) and phosphorus (29.48 mg/kg) were moderate, while potassium (152.87 mg/kg) was relatively high, reflecting balanced but slightly nutrient-deficient soil fertility, shown in (Table 4).

**Table. 3:** The concentration of selected heavy metals (Cr, Ni, Cu, Pb, and Zn) in soil sample C1 was compared with the permissible limits prescribed by WHO/FAO (1978)

| Metal | C1 Mean ± SD (mg/kg) | Permissible limit of heavy metals in soil (mg/kg) WHO/FAO(1978) |
|---|---|---|
| Cr | 196.87 ± 3.48 | 100-150 |
| Ni | 120.04 ± 5.36 | 50-70 |
| Cu | 112.19 ± 2.04 | 30-100 |
| Pb | 312.06 ± 1.79 | 50-300 |
| Zn | 318.55 ± 8.92 | 100-300 |

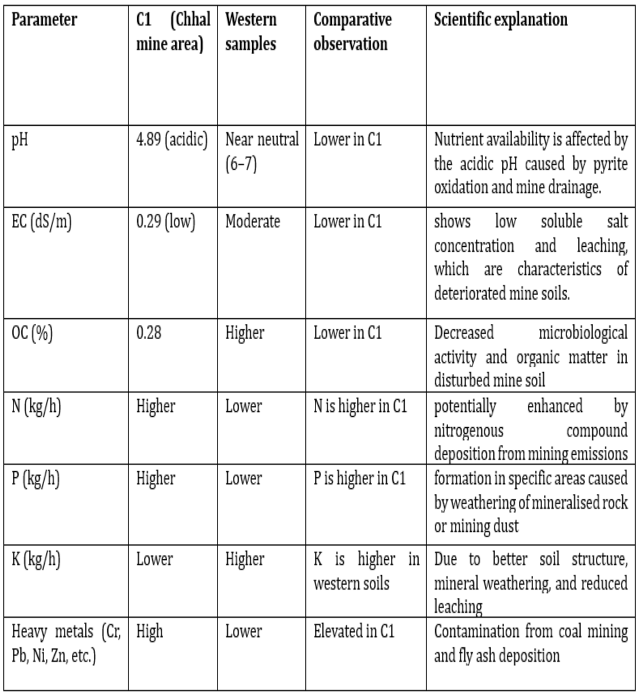
**Table 4:** Physico-chemical properties of the soil sample (C1) showing triplicate values (mean ± SD, n = 3). Parameters include nitrogen (N), phosphorus (P), potassium (K), electrical conductivity (EC), pH, and organic carbon (OC).

| Parameter | Mean ± SD |
|---|---|
| N | 201.34 ± 1.36 |
| P | 29.48 ± 0.49 |
| K | 152.87 ± 2.55 |
| EC | 0.29 ± 0.00 |
| pH | 4.89 ± 0.09 |
| OC | 0.28 ± 0.01 |

### 3.8 Discussion

The pH of soils in coal mining regions generally varies from acidic to slightly alkaline, reflecting alterations in soil chemistry caused by mining activities (Shown in Table 5). Studies have reported increased concentrations of trace elements such as Cr, Pb, Co, Cu, Cd, Fe, Ni, Mn, Zn, As, and Al in the surrounding soils of mining areas in India, largely attributed to mining operations (Chakraborty et al., 2023)[13]. The C1 soil sample, located near the Chhal mines, exhibited a pH value of 4.89, indicating a highly acidic nature. Such acidity can adversely influence nutrient availability and microbial activity. Coal mining can alter the pH and electrical conductivity (EC) of the soil. The alterations in soil structure lead to changes in physical and chemical properties, including pH and EC (Zhang et al., 2022; Ivanova et al., 2023)[14,15]. Soil EC, an indicator of soluble salts and overall soil salinity, is directly related to nutrient status and can be altered by coal mining activities. According to Othaman et al. (2020)[16], the correlation between EC and macronutrient (NPK) levels is critical in assessing soil fertility. The EC value of 0.29 dS/m observed in the C1 sample suggests leaching and a low soluble salt content, characteristic of reclaimed or degraded coal mine soils with reduced fertility. Comparative analysis of the five soil samples with the Chhal mine (C1) sample revealed distinct variations in nutrient distribution. The concentrations of nitrogen (N) and phosphorus (P) were higher in the C1 sample compared to the western site samples, indicating localized enrichment possibly due to anthropogenic inputs from mining activities. In contrast, potassium (K) concentration was higher in the western samples than in C1, which may be attributed to better soil structure and mineral weathering in less-disturbed areas. Moreover, organic carbon content was found to be higher in the western samples and comparatively lower in C1. Coal mining results in soil compaction and pollution, which further degrade soil quality. The presence of heavy metals and other pollutants from mining tailings can lead to a decrease in soil nutrients and microbial diversity, as toxic compounds impede the functioning of soil microorganisms (Rouhani et al., 2023; Li et al., 2011) [17,18].

**Table – 5:** Comparative assessment of soil nutrient and chemical properties between eastern Chhal mine area soil (C1) and western soil samples (S1, S2, S3, S4, S5) of the Mand river basin



| Parameter | C1 (Chhal mine area) | Western samples | Comparative observation | Scientific explanation |
|---|---|---|---|---|
| pH | 4.89 (acidic) | Near neutral (6–7) | Lower in C1 | Nutrient availability is affected by the acidic pH caused by pyrite oxidation and mine drainage. |
| EC (dS/m) | 0.29 (low) | Moderate | Lower in C1 | shows low soluble salt concentration and leaching, which are characteristics of deteriorated mine soils. |
| OC (%) | 0.28 | Higher | Lower in C1 | Decreased microbiological activity and organic matter in disturbed mine soil |
| N (kg/h) | Higher | Lower | N is higher in C1 | potentially enhanced by nitrogenous compound deposition from mining emissions |
| P (kg/h) | Higher | Lower | P is higher in C1 | formation in specific areas caused by weathering of mineralised rock or mining dust |
| K (kg/h) | Lower | Higher | K is higher in western soils | Due to better soil structure, mineral weathering, and reduced leaching |
| Heavy metals (Cr, Pb, Ni, Zn, etc.) | High | Lower | Elevated in C1 | Contamination from coal mining and fly ash deposition |

## 4. CONCLUSION

The comparative assessment of soil samples from the Chhal mining region and western sites revealed significant variations in soil chemical properties and nutrient dynamics influenced by mining activities. The C1 sample exhibited a highly acidic indicating leaching and reduced soil fertility typical of mine-affected soils. Elevated nitrogen and phosphorus concentrations in C1 suggest localized enrichment from mining-related anthropogenic inputs, whereas higher potassium and organic carbon levels in the western soils reflect better structural stability and biological activity. Overall, the findings indicate that coal mining operations have caused notable degradation of soil quality through acidification, nutrient imbalance, and organic matter depletion. Restoration strategies involving organic amendments and vegetation cover are essential to improve the fertility and ecological resilience of reclaimed mine soils.

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