International Journal of Agriculture and Environmental Sciences
ISSN: 3108-088X | Volume 2 Issue 3, 17-21, July-September 2026
DOI: https://doi.org/10.64137/3108088X/IJAES-V2I3P103

Received: 06/07/2026 Revised: 25/07/2026 Accepted: 30/07/2026 Published: 03/08/2026

*Original Article*

# Seasonal Assessment of Physicochemical Characteristics and Nutrient Status of Chromium-Contaminated Industrial Soil

**[1]A. A. KAMBLE, [2]N. M. GHANGAONKAR, [3]R. K. AHER, [4]H. S. KARPE**
[1,2,4]PG & Research Centre, Department of Botany, C. T. Bora College, Shirur, Pune, Maharashtra, India.
[3]Department of Botany, New Arts, Commerce and Science College, Parner, Ahilyanagar, Pune, Maharashtra, India.

**ABSTRACT:** *The rapid expansion of industrial activities has led to the deterioration of soil quality through the accumulation of heavy metals and alterations in soil physicochemical properties, posing distinct environmental and agricultural challenges. This study investigated the seasonal variation in the physicochemical characteristics and nutrient status of chromium contaminated soil collected from the Ranjangaon MIDC industrial area, Pune, Maharashtra, India. Soil samples were collected seasonally in the summer, monsoon and winter based on meteorological data and analysed following standard protocols. The parameters studied were soil temperature, pH, electrical conductivity (EC), moisture content, water-holding capacity (WHC) and texture of the soil, tillage before planting, and available nitrogen (N), phosphorus (P) and potassium (K). Results: The results identified seasonal differences in soil physicochemical characteristics and nutrient availability. While soil temperature and EC were the highest in summer (32°C, 1.20 ± 0.71 dS $m^{-1}$), maximum values of moisture (25 ± 0·4%) and WHC (45%) took place during the monsoon season. A soil pH of 7.5 in summer reduced to a low value through rainfall that leached and diluted the water's calcium carbonate content (6). Soil textural class was determined to be clay loam for all three seasons, suggesting no obvious seasonal change to soil type. Available nitrogen, phosphorus and potassium concentrations were highest during the rainy season, indicating that nutrient availability varied significantly between seasons as a result of increased mineralisation and microbial activity. These findings suggest that seasonal fluctuations may have different effects on physicochemical properties and nutrient dynamics of polluted industrial soils, which can also further influence heavy metal mobility, decrease soil fertility and phytoremediation efficiency. This study offers baseline knowledge for environmental monitoring and assists in the planning of sustainable management and remediation protocols on industrially polluted soils.*

**KEYWORDS:** *Chromium Contamination, Industrial Soil, Seasonal Variability, Soil Fertility, Nutrient Availability, Ranjangaon MIDC.*

## 1. INTRODUCTION

Soil is the basic medium of the terrestrial ecosystem, and it serves as a sub-structure for environmental quality, agricultural productivity and ecological balance. (Panda, S. 2025). Soil is a medium for plant growth, influences nutrient cycling, stores water and supports many microbial communities (Sharma et al.,2025). On the other hand, growing industrialisation and urban development have led to near-continuous release of toxic-associated hazardous pollutants into soil, hence leading to a rapid decrement in its quality (Swain, C. K., 2024). Heavy metals are a significant issue among these pollutants due to their long-lasting presence, toxicity and bioaccumulation in soil (Ozarde et al.,2025). Chromium (Cr) is a widely spread heavy metal contaminant from various sources such as effluent released directly into the soil, developed by human activities including electroplating, leather tanning and other chemical industries, in addition to the engineering industry, among others (Kamruzzaman et al., 2026). The continuous discharge of CRC containing effluents and solid wastes is responsible for the gradual accumulation of Cr in soil, which affects the health as well as the functioning of its ecosystem (Dotaniya et al 2023). Soil microbiome plays a pivotal role in maintaining soil quality and ensuring plant growth, while high concentrations of Cr can change the physicochemical properties of soils and may limit microbial activity as well as nutrient availability for plants. In addition, chromium can be absorbed by plants that grow around the contaminated area and enter the food chain (2), posing a potential ecological risk to human health.

Soil physicochemical properties are widely considered as reliable indicators of soil quality and environmental condition (Ogwu et al.,2024). Soil properties, including soil pH and electrical conductivity (EC), temperature, moisture content, water-holding capacity (WHC) and texture, impact nutrient availability, microbial activity and other environmental factors affecting the mobility of heavy metals [6]. These properties are not seasonally invariant but change significantly with yearly climatic factors (Huggi et al., 2024). These factors interact with soil moisture, salt concentration, nutrient transformation and metal solubility, affecting the overall behaviour of contaminated soil (Ghosh et al., 2026). Seasonal quantification of soil nutrient status is vital since N, P and K are the three main macronutrients responsible for controlling soil fertility and plant productivity (Zaman et al., 2022). Shifts in climatic conditions change nutrient cycling through processes like leaching, mineralisation and the microbial decomposition of organic matter, as well as soil chemical reactions (Chatterjee et al., 2024). Seasonal changes in physicochemical properties and nutrient availability are essential for developing strategies for soil quality assessment as well as for designing better management practices of soils under industrial regions (Umair et al., 2025).

The Ranjangaon MIDC, located in Pune district, Maharashtra, is a fast-developing industrial estate containing automobile, engineering and allied manufacturing industries; pharmaceutical product manufacturing forms part of this view. Heavy metal pollution, particularly in soil, from continuous industrial activities across this region has raised concerns (Wu K et al., 2025). While a number of heavy metal contamination studies have been conducted in industrial areas, minimal information is available on seasonal variations of soil physicochemical characteristics and nutrient dynamics of the Ranjangaon MIDC region. This type of information is critical to understanding the contamination pathways and for designing recovery as well as environmental management approaches.

AIM: Knowledge of seasonal variation in physicochemical characteristics and nutrient status of chromium-contaminated soils collected from the Ranjangaon MIDC industrial area, Pune, Maharashtra is lacking to address these gaps. This study uses a systematic approach by combining seasonal analysis of soil characteristics such as temperature, pH, electrical conductivity (EC), moisture content and water-holding capacity, texture, nitrogen uptake pattern and phosphorus availability index to assess potassium supply in order to offer an overall evaluation of soil quality. The generated baseline data will contribute to environmental monitoring, sustainable soil management, and the planning of remediation strategies for industrially contaminated ecosystems.

## 2. MATERIALS AND METHODS

### *2.1. STUDY AREA*

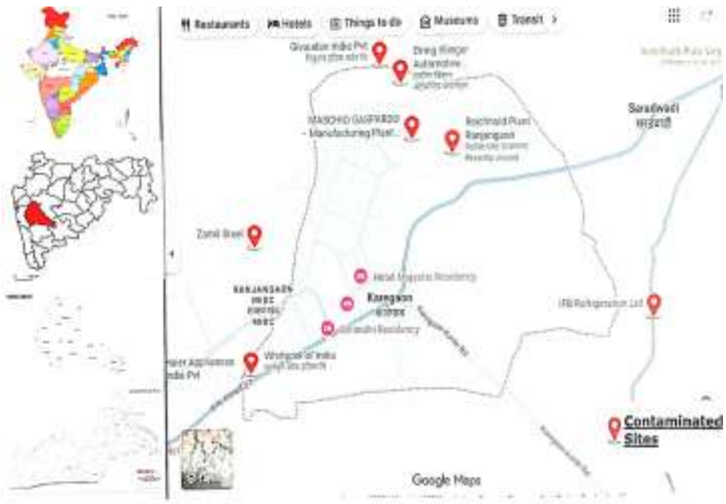


**FIGURE 1 Location Map of the Study Area Showing the Soil Sampling Site in Ranjangaon MIDC, Shirur Taluka, Pune District, Maharashtra, India**

Ranjangaon MIDC was established in 1979 along State Highway 27 (Pune-Ahmednagar corridor) and has an area of approximately ≈ km². The park is rated five stars by the Maharashtra Industrial Development Corporation[2] for quality of infrastructure. Geospatial coordinates position it ≈50 km north-east of Pune (19.02°N, 74.72°E) with optimal access to the Mumbai-Pune industrial corridor: (Tadvi S., & Patil K.A. 2025). The experiment was conducted in May 2022, September 2022 and February 2023.

### *2.2. SOIL ANALYSIS*

#### *2.2.1. SAMPLE COLLECTION*

Three seasons were used to collect soil samples: winter (October–February), summer (March–May), and rainy/monsoon (June–September). In May 2022, September 2022 and February 2023, samples covering three seasons- summer (May), wet season (September) and winter (February) were collected. Soil sampling was performed in a chromium-polluted Ranjangaon MIDC industrial area located near Pune, Maharashtra, India. A natural vegetation habitat that supports a representative sampling plot was selected. A quadrat of 1 m x 1 m was established at the chosen position. Soil subsamples were extracted to a depth of 0–22 cm with clean sampling instruments from four corners and the centre of each quadrat. The subsamples were then combined to form a representative composite soil sample for each season. The sampled composites were placed in sanitised, labelled bags and taken to the laboratory for further analysis.

### 2.2.2. PREPARING A SOIL SAMPLE

The gathered soil samples were allowed to air-dry at room temperature in the lab. To get rid of stones, plant waste, and other coarse elements, the dry soil was gently crushed and run through a 2-mm screen. Prior to conducting additional physicochemical and nutrient analyses, the sieved soil was carefully homogenised and kept in hygienic, labelled containers.

## 3. RESULTS AND DISCUSSION

**TABLE 1 Physicochemical Characteristics of Soil Samples across Seasons**

| Soil Parameter | Summer (Mar-May | Rainy (June-Sep) | Winter (Oct- Feb.) |
|---|---|---|---|
| Soil Temperature ( $^{0}$ c) | 32 ºC | 26 º C | 18 ºC |
| pH | 7.5 | 6.8 | 7.2 |
| EC ( (dS m⁻¹) | 1.2 ±0.71 | 0.3 ± 0.11 | 0.5±0.78 |
| Texture | Clay loam | Clay loam | Clay loam |
| Soil moisture (%) | 15 ± 0.3 | 25 ± 0.4 | 12 ± 0.2 |
| Water-holding capacity (%) | 35 | 45 | 40 |
| Available Nitrogen (kg/ha) | 237.05 ± 0.3 | 411.88 ± 0.3 | 309.5 ± 0.7 |
| Available Phosphorus (kg/ha) | 15.55 ± 0.4 | 35.79 ± 0.3 | 20.17 ± 0.8 |
| Available Potassium (kg/ha) | 301.11 ± 0.3 | 489 ± 0.6 | 288.04 ± 0.3 |

Footnote: Values are expressed as mean ± standard error (SE) of three independent observations (n = 3). Soil temperature is expressed in °C, electrical conductivity (EC) in dS $m^{-1}$, soil moisture and water-holding capacity (WHC) in % and available N, P and K in kg $ha^{-1}$. Seasonal observations were recorded during summer (March–May), rainy (June–September), and winter (October–February). The physicochemical properties and nutrient status of the soil showed clear seasonal variation (Table 1). Here, soil temperature was highest in summer (32 °C), followed by the rainy season (26 °C) and winter (18 °C). The higher summer temperature could have resulted from more solar heating and less soil moisture, while the lower winter temperature reflects seasonal decreases in ambient temperature (Lai et al., 2026).

pH: The pH of soil was observed to be 7.5 in summer, reduced to 6.8 in the rainy season and rose again to around 7 (ranges from 0–14) during winter months [Table 2]. The decreased pH recorded during the rainy season is likely related to soil moisture and rainfall, which are capable of promoting dissolution processes as well as vertical transport of soluble ions in soils. The high pH during summer might also be due to lower moisture conditions and greater concentration of soluble constituents due to evaporation (Maitry et al., 2025).

Electrical conductivity (EC): Electrical conductivity (EC) was lower during the monsoon season (0.30 ± 0.11 dS $m^{-1}$), with soluble salts becoming diluted and leached under severe rainfall events (Manikandan et al.,2020). However, the highest was recorded during the summer (1.20 ± 0.71 dS $m^{-1}$), which may be due to higher evaporation in summers and consequent build-up of soluble salts in soil [21]. The soil textural class remained clay loam for three seasons, consequently, and no seasonal change in depth was noted.

Condition of soil moisture: Soil moisture and water holding capacity (WHC), seasonally, are displayed in Table 1 (Stratev et al., 2017). Soil moisture showed significantly different seasonal patterns, with the highest (25±0.54%) in the rainy season and lowest values both in summer (15±0.23 %) and winter (12 ± 0.12%). The influence of more frequent precipitation on water availability and the substantial reduction in evaporative losses might explain the increased soil moisture over 15 years under natural vegetation (Jiao et al). In contrast, reduced rainfall and the relatively slow depletion of unsaturated soil water stores tend to lead to decreased soil moisture over winter.

### 3.1. WATER HOLDING CAPACITY

Similarly, water retention capacity also varied seasonally and was 35% in summer, whereas it reached a maximum level of 45% during the rainy seasons, as well as held up to levels of only about 40% around winter. A higher WHC observed in the rainy season indicates increased water storage capacity (Menzies et al.). WHC was lower during the summer time, which could be due to higher temperatures and greater evaporation leading to reduced water holding capacity.

### 3.2. AVAILABILITY OF NITROGEN (N, P, K)

The available nitrogen had a marked periodic fluctuation, being greater in the rainy season (411.88 ± 0.3 kg $ha^{-1}$) as compared with winter(309.50±0.7kg/ha), which was followed by summer(237.05 ± 0.3 kg ha $^{1}$). Possibly, the decreasing nitrogen availability with rainfall dates back to soil dryness and nutrient cycling conditions that favour nutrient loss (Mao et al.,2025) on these sites. Seasonal fluctuation of available phosphorus was also observed, from 15.55 ± 0.4 kg $ha^{-1}$ in summer to the peak value (35.79 ± 0.3) during the rainy season, before a declining trend as exhibited by winter average values (20.17±0·8). Out of 3 recorded seasons, available potassium was also maximum in the rainy season (489 ± 0.6 kg $ha^{-1}$), followed by summer

(301.11 ± 0.3 kg $ha^{-1}$) and winter (288.04±0.3kg/ha). The variation of these nutrients indicates that soil moisture changes and environmental conditions affect nutrient status in this industrial field seasonally (Nissanka et al.,2024).

**TABLE 2 Chromium Accumulation in Portulaca Oleracea Collected from Ranjangaon MIDC**

| Sample | Cr concentration (mg $kg^{-1}$) |
|---|---|
| Reference Soil | 0.02 |
| Ranjangaon MIDC industrial soil | 2.42 |
| Portulaca oleracea | 1.53 |

The concentration of chromium in the reference soil was 0.02 mg kg-1, and that present in the chromium-contaminated Ranjangaon MIDC industrial area dominating body contained 2.42 mg/kg−1514,15 As such, the very high concentration of chromium in industrial soil compared with the corresponding control study area confirms that this site represents an enrichment of chromium. [11] The potential of Portulaca oleracea from the industrial area for phytostabilisation to accumulate chromium in contaminated soil, based on the analysis, resulted in 1.53 mg $kg^{-1}$ chromium. Soil moisture seasonal trends, along with pH as well as electrical conductivity levels, in addition to the rainfall timing of contaminated soils might explain the observed variations in chromium biodegradation potential between dry and rainy seasons. However, season-specific chromium concentrations were not determined in the present study. Therefore, seasonal differences in chromium concentration cannot be established from the present data. (Banerjee *et al*., 2025). Soil and *Portulaca oleracea* L. samples from the Ranjangaon MIDC industrial area were evaluated for chromium levels and compared to reference soil (Mulik, A., & Jagtap, K., 2025).

## 4. CONCLUSION

The results of the study show specific seasonal differences in soil physicochemical characteristics and availability of plant nutrients in chromium-contaminated soil from Ranjangaon MIDC industrial zones. Higher soil temperature and electrical conductivity values were observed in summer, while the rainy season showed greater moisture, water-holding capacity, as well as available N, P and K, which could potentially affect both soil quality and mobility of chromium. Hence, seasonal monitoring is crucial for realistic evaluation and efficient management of contaminated soils. These findings provide baseline information for sustainable soil management and season-independent phytoremediation strategies.

### ACKNOWLEDGMENTS

The authors sincerely acknowledge the valuable guidance and support of Dr N. M. Ghangaonkar and Prin. Dr R. K. Aher throughout the course of this research work. The authors express their sincere gratitude to Prof. K. C. Mohite, Principal, C. T. Bora College, Shirur, Pune, Maharashtra, India, for his valuable institutional support and encouragement. The authors are also grateful to the Department of Botany, C. T. Bora College, Shirur, for providing the necessary laboratory facilities and institutional support. The author gratefully acknowledges the financial support received from the Dr Babasaheb Ambedkar Research and Training Institute (BARTI), Pune, under the BANRF-2022 Fellowship, vide Outward No BARTI-Pune/BANRF Fellowship-202212024-251.

## REFERENCES

[1] S. Banerjee et al., "Mycorrhiza-assisted phytoremediation of spiked chromium-contaminated soil: Assessing AMF-vetiver symbiosis for Cr accumulation and soil quality enhancement," Environmental Research, vol. 283, p. 122143, Oct. 2025, doi: 10.1016/j.envres.2025.122143.

[2] D. Chatterjee, S. R. Das, S. Saha, A. Sarkar, and H. Pathak, "Impacts of Climate Change on Soil Processes," Advances in Global Change Research, pp. 3–36, 2024, doi: 10.1007/978-981-99-7935-6_1.

[3] M. L. Dotaniya et al., "Chromium Dynamics in the Soil-Plant Continuum," Environmental Science and Engineering, pp. 167–189, 2023, doi: 10.1007/978-3-031-44029-8_8.

[4] Ghosh, D. Sarkar, A. K. Gupta, and A. Mondal, "The Interplay Between Climatic Variables and Heavy Metal Concentration in the Agricultural Soil: A Review," Sustainability Sciences in Asia and Africa, pp. 1–26, 2026, doi: 10.1007/978-981-95-7746-0_1.

[5] Lingaraj Huggi, M. N. Thimmegowda, Shankarappa Sridhara, M. H. Manjunatha, and B. Das, "Climate Change-Induced Spatiotemporal Monsoon Variability: Assessment of Its Implications on Global and Regional Production Systems," Advances in Global Change Research, pp. 713–758, Jan. 2024, doi: 10.1007/978-981-99-7935-6_26.

[6] Y. Jiao et al., "Estimating non-productive water loss in irrigated farmland in arid oasis regions: Based on stable isotope data," Agricultural Water Management, vol. 289, p. 108515, Nov. 2023, doi: 10.1016/j.agwat.2023.108515.

[7] Md. Kamruzzaman et al., "Chromium Toxicity: Source, Distribution, Challenges, and Remediation," Chromium Toxicity, pp. 1–48, 2026, doi: 10.1007/978-3-032-14323-5_1.

[8] B. Lai, Z. Lin, H. Cui, C. Zhang, and D. Zhou, "Rainfall-Driven Electron Acceptors Loss Constrain Natural Attenuation of Petroleum Hydrocarbons and Development of a Rainfall-Responsive Biostimulation Strategy," Journal of Hazardous Materials, p. 143091, July 2026, doi: 10.1016/j.jhazmat.2026.143091.

[9] Maitry, G. Patil, P. Dubey, and R., "Seasonal analysis of Physico-chemical parameters of mine soil under various forest tree species in Nandini limestone mines, Chhattisgarh," International Journal of Advanced Chemistry Research, vol. 7, no. 2, pp. 06–14, Jan. 2025, doi: 10.33545/26646781.2025.v7.i2a.260.

[10] E. Manikandan, N. Rajmohan, and S. Anbazhagan, "Monsoon impact on groundwater chemistry and geochemical processes in the shallow hard rock aquifer," CATENA, vol. 195, p. 104766, Dec. 2020, doi: 10.1016/j.catena.2020.104766.

[11] C. Mao, Y. Wang, J. Ran, C. Wang, Z. Yang, and Y. Yang, "A meta-analysis of warming and precipitation change effects on soil nitrogen cycles," Journal of Plant Ecology, May 2025, doi: 10.1093/jpe/rtaf051.

[12] E. G. Menzies Pluer et al., "Returning Degraded Soils to Productivity: an Examination of the Potential of Coarse Woody Amendments for Improved Water Retention and Nutrient Holding Capacity," Water, Air, & Soil Pollution, vol. 231, no. 1, Jan. 2020, doi: 10.1007/s11270-019-4380-x.

[13] Mulik and K. Jagtap, "Assessing Heavy Metal Contamination and Health Risks in Crop/Vegetables/Medicinal Plants Irrigated with Industrial Wastewater: A Multi-Analytical Approach," International Journal of Environmental Research, vol. 19, no. 5, July 2025, doi: 10.1007/s41742-025-00840-5.

[14] S. P. Nissanka, R. S. Dharmakeerthi, W. S. Dandeniya, and D. N. Vidanagamage, "Nutrient and Soil Moisture Dynamics Under Changing Climate," pp. 355–395, Jan. 2024, doi: 10.1007/978-981-97-6635-2_12.

[15] M. C. Ogwu, E. F. Ahuekwe, D. Balogun, Z. Kwarpo, K. A. Shittu, and S. C. Izah, "Methods for Assessing Soil Physicochemical and Biological Properties," Sustainable Soil Systems in Global South, pp. 49–82, 2024, doi: 10.1007/978-981-97-5276-8_2.

[16] Y. Ozarde, D. Purandare, S. Deshmukh, and R. Gadhave, "Heavy metals and cardiovascular health: Uncovering links and health challenges," Journal of Trace Elements in Medicine and Biology, vol. 89, p. 127648, June 2025, doi: 10.1016/j.jtemb.2025.127648.

[17] S. Panda, "Soil and Water Conservation for Sustainable Resources and Ecosystem Resilience," The Palgrave Encyclopedia of Sustainable Resources and Ecosystem Resilience, pp. 1–81, 2025, doi: 10.1007/978-3-030-67776-3_30-1.

[18] S. Saikia, S. K. Dansena, and A. S. Kalamdhad, "Application of unsegregated municipal solid waste char produced at low temperature and vermicompost for remediation of coal mine tailings soil," Environmental Geochemistry and Health, vol. 47, no. 5, Mar. 2025, doi: 10.1007/s10653-025-02436-6.

[19] D. Sharma, Ashim Das Astapati, S. Dey, D. Bhattacharjee, Deepti Mala Singha, and S. Nath, "Microbial Interactions in Soil Ecosystems: Facilitating Plant Growth, Nutrient Cycling, and Environmental Dynamics," pp. 21–48, Jan. 2025, doi: 10.1007/978-3-031-90530-8_2

[20] D. Stratev, T. Popova, G. Zhelyazkov, I. Vashin, L. Dospatliev, and E. Valkova, "Seasonal Changes in Quality and Fatty Acid Composition of Black Mussel (Mytilus galloprovincialis)," Journal of Aquatic Food Product Technology, vol. 26, no. 7, pp. 871–879, Aug. 2017, doi: 10.1080/10498850.2017.1346742.

[21] Chinmaya Kumar Swain, "Environmental pollution indices: a review on concentration of heavy metals in air, water, and soil near industrialisation and urbanisation," Discover Environment, vol. 2, no. 1, Jan. 2024, doi: 10.1007/s44274-024-00030-8.

[22] S. Tadvi and K. A. Patil, "Alignment Option Study of Industrial Corridor in Maharashtra State," Lecture Notes in Civil Engineering, pp. 243–257, 2025, doi: 10.1007/978-981-96-8448-9_17.

[23] L. Thomte, A. K. Bhagabati, and S. K. Shah, "Soil moisture-based winter–spring drought variability over West Karbi Anglong region, Assam, Northeast India using tree rings of Pinus kesiya," Environmental Challenges, vol. 7, p. 100512, Apr. 2022, doi: 10.1016/j.envc.2022.100512.

[24] M. Umair et al., "Soil Physical Properties and Their Influence on Plant Growth," Frontier Studies in Soil Science, pp. 79–131, 2025, doi: 10.1007/978-3-031-91114-9_5.

[25] K. Wu et al., "Elevated chromium levels and potential health risks among six heavy metals in agricultural soils of China," Environmental Research, vol. 287, p. 123106, Dec. 2025, doi: 10.1016/j.envres.2025.123106.

[26] F. Zaman et al., "Natural variations and dynamics of macronutrients for 87 tea plant (Camellia sinensis) varieties throughout the growing seasons in Wuhan," Scientia Horticulturae, vol. 306, p. 111425, Dec. 2022, doi: 10.1016/j.scienta.2022.111425.