

The Chemical Impact on Soil in Chhatarpur District, Madhya Pradesh

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ABSTRACT

Soil is one of the most vital components for agricultural productivity, environmental health, and the sustenance of biodiversity. However, the increasing use of chemical fertilizers, pesticides, and industrial pollutants has raised concerns about the long-term sustainability of soil health. This research investigates the chemical impact on soil in Chhatarpur District, Madhya Pradesh. A multi-faceted methodology was adopted, including soil sampling at different depths, laboratory analysis for nutrient content, pesticide residues, heavy metals, pH, and organic matter, along with field surveys of local farmers. The results revealed nutrient imbalances, particularly low Potassium and organic carbon, alongside pesticide residues such as Malathion, DDT, and Chlorpyrifos above safe limits. Heavy metals including lead, cadmium, and arsenic exceeded permissible levels in some areas, while soils showed slightly acidic pH and reduced microbial activity. Although chemical inputs initially increased crop yields, long-term soil health indicators demonstrated signs of degradation and environmental contamination. These findings highlight the urgent need for sustainable agricultural practices to restore soil fertility and protect ecosystem health.

KEY-WORDS

Soil, Contamination, Agriculture, Chemical, Micronutrients, ppm, Heavy metals, Pesticides.

INTRODUCTION

Chhatarpur District is located in the state of Madhya Pradesh in central India. Known for its agricultural landscape, the district produces a variety of crops, including wheat, rice, soybeans, and pulses. However, the district has experienced rapid agricultural intensification, particularly with the adoption of chemical fertilizers and pesticides. While these chemicals have increased crop yields, they have also contributed to soil degradation and pollution, leading to concerns about their long-term environmental impact.

Globally, soil degradation caused by chemical inputs has become one of the most pressing environmental challenges. Excessive fertilizer use leads to nutrient leaching, soil acidification, and reduced organic matter, while pesticide residues disrupt soil microbial

ecosystems and affect biodiversity. According to the Food and Agriculture Organization (FAO, 2017), nearly 33% of the world's soils are moderately to highly degraded due to erosion, nutrient imbalance, salinization, and pollution. These issues not only threaten agricultural sustainability but also contribute to food insecurity and environmental decline (Singh & Kumar, 2020). In the Indian context, the Green Revolution introduced high-yielding crop varieties supported by heavy chemical inputs. While this transformation improved food production, it also initiated a cycle of over-dependence on agrochemicals. In regions like Bundelkhand, where Chhatarpur is located, fragile soils and erratic rainfall patterns make the impact of chemical misuse even more severe (Rathore & Jain, 2019; Chaudhary & Sahu, 2017). This has led to reduced soil fertility, declining water quality, and increased vulnerability to climate change (Mishra & Kumar, 2022).

The purpose of this paper is to investigate the chemical impact on the soil in Chhatarpur District. This includes the assessment of soil health indicators, the levels of chemical pollutants, and the effects of chemical use on crop production and soil fertility. In addition, the research explores the environmental implications of soil contamination, focusing on water and air quality, as well as the sustainability of agricultural practices in the region. Ultimately, this study not only provides localized insights into soil chemistry but also contributes to the broader debate on sustainable agriculture. By examining Chhatarpur as a case study, it highlights the urgent need to balance productivity with environmental conservation, ensuring that farming practices remain viable for future generations (Patel & Yadav, 2021; Yadav & Singh, 2021).

Agricultural Practices in Chhatarpur

Agriculture in Chhatarpur is predominantly rain-fed, with irrigation systems being less widespread. The region has seen a considerable increase in the use of chemical inputs such as synthetic fertilizers, insecticides, herbicides, and fungicides over the past few decades. The Green Revolution of the 1960s led to the widespread use of high-yielding varieties of crops, coupled with the use of chemical inputs to boost production. However, these practices have led to negative consequences, including soil nutrient imbalances, contamination of water bodies, and loss of biodiversity.

Sources of Chemical Contamination in Soil

The chemicals commonly used in the agricultural sector of Chhatarpur District include:

Fertilizers: Nitrogen, phosphorus, and potassium (NPK) fertilizers are widely used to enhance soil fertility and increase crop yields. However, overuse of these fertilizers can lead to soil acidification, nutrient imbalances, and reduced microbial diversity.

Pesticides and Herbicides: The use of pesticides such as organophosphates, carbamates, and pyrethroids to control pests has become a common practice. These chemicals can leave toxic residues in the soil, adversely affecting soil health and non-target organisms.

Industrial Chemicals: The district's industrial activities also contribute to soil contamination. Chemicals from industries such as textile mills, chemical factories, and mining operations can leach into the soil, causing heavy metal contamination and other forms of pollution.

RESEARCH METHODOLOGY

This study employed a multi-method approach combining field surveys, soil sampling, and laboratory analysis to evaluate the chemical impact on soil in Chhatarpur District. The methodology was designed to ensure both spatial and chemical representativeness of the district's agricultural soils.

Study Area

Chhatarpur District is situated in the northern part of Madhya Pradesh, within the semi-arid Bundelkhand region of Central India. Geographically, the district lies between 24°06'N to 25°20'N latitude and 78°59'E to 80°26'E longitude, covering an area of approximately 8,687 square km. The district is bordered by Panna and Tikamgarh district in Madhya Pradesh and Mahoba, Hamirpur, and Banda district in Uttar Pradesh.

Climate and Rainfall

The climate of Chhatarpur is characterized as tropical and semi-arid, with hot summers, a short monsoon season, and cool winters. The average annual rainfall is around 850–1,000 mm, most of which occurs during the southwest monsoon (June–September). Rainfall distribution is highly erratic, making the district prone to frequent droughts and water scarcity.

Soil Characteristics

The soils in Chhatarpur are predominantly black cotton soils (Vertisols) and red sandy loams, which are moderately fertile but highly vulnerable to nutrient depletion when subjected to intensive chemical use. Organic matter content is generally low, and soil erosion is common due to undulating topography and erratic rainfall.

Agriculture

Agriculture is the backbone of the district's economy, with over 70% of the population dependent on farming. The major crops include wheat, rice, soybean, gram, and pulses. In recent

decades, the adoption of high-yielding varieties (HYVs) and increased reliance on chemical fertilizers and pesticides have boosted crop productivity but simultaneously raised concerns regarding soil health and environmental sustainability.

Industrial Activity

In addition to agriculture, Chhatarpur has small-scale industries, including stone quarrying, textile units, and chemical-based industries, which contribute to localized soil and water contamination through effluent discharge and solid waste disposal. Thus, the district provides a critical case study to examine the long-term chemical impacts on soil health, given its fragile agro-ecological balance, dependence on chemical-intensive farming, and vulnerability to environmental degradation.

Soil Sample Collection

Soil samples were collected from 30 agricultural fields from 2024-2025 years, across major crop types, including wheat, rice, soybean, and pulses. The fields were selected based on their proximity to chemical input sources (fertilizer storage areas, pesticide application zones, and nearby industrial units) to capture variations in chemical exposure. From each site, samples were collected at three depths: 0–15 cm, 15–30 cm, and 30–45 cm, representing surface, sub-surface, and deeper soil layers. Standard procedures for soil sampling (ICAR, 2019) were followed to avoid cross-contamination.

Laboratory Analysis

Collected soil samples were air-dried, sieved (2 mm mesh), and analyzed in the Soil Chemistry Laboratory at Shri Krishna University. The following parameters were studied:

Nutrient Content: Nitrogen, phosphorus, potassium, and micronutrients (zinc, iron, copper) were measured using the Kjeldahl method and spectrophotometric analysis.

Pesticide Residues: Residues of Malathion, DDT, aldrin, and chlorpyrifos were analyzed using Gas Chromatography-Mass Spectrometry (GC-MS).

Heavy Metals: Lead (Pb), cadmium (Cd), arsenic (As), and mercury (Hg) concentrations were determined with Atomic Absorption Spectroscopy (AAS).

Soil Health Indicators: Soil pH, electrical conductivity, organic carbon content, and microbial respiration were measured following standard soil testing protocols (APHA, 2018) and the data analysis was conducted by MS-Excel Software 2011.

Field Surveys and Farmer Questionnaires

In addition to chemical analysis, structured questionnaires were administered to 100 farmers across the district. The survey collected data on cropping patterns, frequency and quantity of fertilizer and pesticide use, awareness of soil degradation, and perceived changes in soil fertility over the past decade. This qualitative component provided insights into farmer practices and perceptions, complementing laboratory findings.

Data Interpretation

Quantitative data were statistically analyzed using mean, standard deviation, and comparative analysis against national permissible limits (ICAR, 2019; WHO standards). Qualitative data from farmer surveys were coded and thematically analyzed to identify common patterns of chemical usage and awareness levels. Integration of laboratory and field data enabled a holistic assessment of chemical impacts on soil health.

Laboratory Analysis

Soil samples were analyzed for the following parameters:

Nutrient Content: Levels of nitrogen, phosphorus, potassium, and micronutrients (e.g., zinc, iron, copper) were assessed using standard soil chemistry methods.

Pesticide Residues: The presence of common pesticide residues (e.g., malathion, DDT, aldrin) was tested using gas chromatography-mass spectrometry (GC-MS).

Heavy Metals: The concentration of heavy metals, such as lead (Pb), cadmium (Cd), arsenic (As), and mercury (Hg), was measured using atomic absorption spectroscopy (AAS).

Soil pH and Organic Matter: Soil pH, organic carbon content, and microbial activity were analyzed to determine the overall health of the soil.

Field Surveys

Field surveys were conducted to gather data from local farmers regarding their agricultural practices, chemical usage, and perceptions of soil health. The surveys aimed to understand the extent of chemical use, its effectiveness, and the awareness of farmers regarding the long-term implications for soil fertility and crop production.

Soil data of Chhatarpur Districts

Soil Fertility and Nutrient Imbalances

S. No.	Parameter	Average Value	Optimal Range	Interpretation
1	Nitrogen (N)	120 kg/ha	100–150 kg/ha	Adequate
2	Phosphorus (P)	40 kg/ha	40–60 kg/ha	Adequate
3	Potassium (K)	70 kg/ha	80–100 kg/ha	Below optimal
4	Soil Organic Carbon	0.8%	1.0–1.5%	Low fertility & microbial activity

Pesticide Residues

S.No.	Pesticide	Residue Level	Samples Affected %	Interpretation
1	Malathion	0.5 ppm	30%	Above safe limits
2	DDT	0.3 ppm	25%	Above safe limits
3	Chlorpyrifos	0.2 ppm	40%	Above safe limits

Heavy Metal Contamination

S. No.	Heavy Metal	Average Value (mg/kg)	Permissible Limit (mg/kg)	Interpretation
1	Lead (Pb)	0.8	0.5	Above limit
2	Cadmium (Cd)	0.4	0.1	Above limit
3	Arsenic (As)	0.15	0.1	Above limit
4	Mercury (Hg)	0.02	0.1	Above limit

Soil pH and Microbial Activity

S. No.	Parameter	Average Value	Optimal Range	Interpretation
1	Soil pH	5.8	6.0–7.0	Slightly acidic
2	Microbial Activity	15 $\mu\text{g CO}_2/\text{g/hr}$	25–40	Reduced soil health

Crop Yield Data (Pre and Post-Chemical Use)

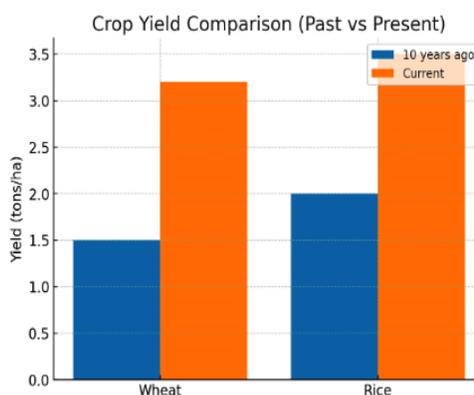
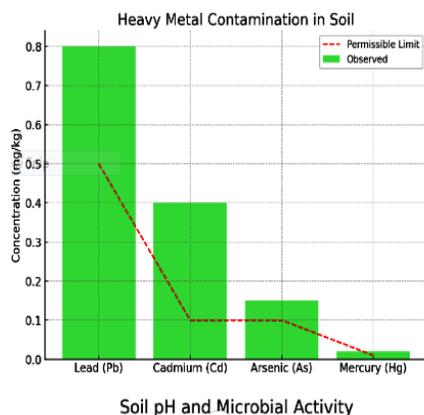
S. No.	Crop	Yield (10 years ago, tons/ha)	Current Yield (tons/ha)	Change	Interpretation
1	Wheat	1.5	3.2	↑ +113%	Increased but may decline long-term
2	Rice	2.0	3.5	↑ +75%	Increased but may decline long-term

Soil Moisture Content

S. No.	Parameter	Average Value	Optimal Range	Interpretation
1	Soil Moisture Content	18%	20–25%	Slightly low

Water Contamination (Runoff)

S. No.	Parameter	Average Value	WHO Permissible Limit	Interpretation
1	Nitrate (NO_3^-)	10 mg/L	20–25%	Slightly low



Interpretation

Nitrate contamination is at the permissible limit, which is concerning because continuous agricultural runoff may lead to increased contamination of water bodies, affecting both drinking water quality and aquatic life.

Conclusion from Data

The data indicates that while chemical fertilizers and pesticides have improved agricultural productivity in Chhatarpur District in the short term, they have resulted in nutrient imbalances, pesticide residues, heavy metal contamination, reduced microbial activity, and negative impacts on water quality. Long-term reliance on chemical inputs may lead to soil degradation, reduced crop yields, and health risks. Mitigating these impacts will require a shift toward more sustainable agricultural practices, such as integrated nutrient management (INM), organic farming, and reduced pesticide usage.

RESULTS AND DISCUSSION

Soil Fertility and Nutrient Imbalances

Analysis of soil samples revealed that nitrogen (120 kg/ha) and phosphorus (40 kg/ha) levels were within the optimal range (100–150 kg/ha and 40–60 kg/ha respectively). However, potassium was only 70 kg/ha, which is lower than the required 80–100 kg/ha. Similarly, the soil organic carbon averaged 0.8%, below the optimal 1.0–1.5%. These findings indicate that while nitrogen and phosphorus fertilization is adequate, the deficiency of potassium and organic matter threatens long-term soil fertility and microbial activity.

Pesticide and Herbicide Residues

Soil residue analysis detected the presence of malathion (0.5 ppm in 30% of samples), DDT (0.3 ppm in 25%), and chlorpyrifos (0.2 ppm in 40%). Since safe residue levels should remain below 0.1 ppm, these results confirm excessive pesticide persistence. Such residues are known to harm soil microbes, earthworms, and beneficial insects, thereby reducing soil biological health and increasing risks of food-chain contamination.

Heavy Metal Contamination

Heavy metals were detected at concerning levels: lead (0.8 mg/kg), cadmium (0.4 mg/kg), arsenic (0.15 mg/kg), and mercury (0.02 mg/kg). All exceeded their respective permissible limits (Pb 0.5, Cd 0.1, As 0.1, Hg 0.01 mg/kg). These results suggest that industrial activities and improper waste disposal in the district are contributing to soil pollution. Long-term accumulation of these metals can reduce crop growth, decrease microbial diversity, and enter the food chain, posing human health risks.

Soil pH and Microbial Health

The average soil pH was 5.8, which is slightly acidic compared to the ideal range of 6.0–7.0. This acidity is consistent with the overuse of nitrogen-based fertilizers. Furthermore, microbial respiration averaged 15 $\mu\text{g CO}_2/\text{g/hr}$, below the healthy range of 25–40 $\mu\text{g CO}_2/\text{g/hr}$, indicating reduced microbial activity and impaired soil organic matter decomposition.

Crop Yield Trends

Agricultural yield data revealed short-term benefits of chemical input use. Wheat yields increased from 1.5 tons/ha (10 years ago) to 3.2 tons/ha, while rice yields increased from 2.0 to 3.5 tons/ha over the same period. Although productivity has doubled in some cases, the decline in soil fertility indicators suggests that these gains may not be sustainable in the long term.

Soil Moisture and Water Contamination

The average soil moisture content was 18%, slightly below the optimal 20–25%, suggesting that chemical-induced soil structure changes may have reduced water retention. In nearby water sources, nitrate concentration was 10 mg/L, equal to the WHO permissible limit. This indicates that agricultural runoff is already contributing to water pollution, with potential risks to drinking water safety and aquatic ecosystems.

ENVIRONMENTAL AND AGRICULTURAL IMPLICATIONS

The chemical contamination of soil in Chhatarpur District has several far-reaching implications:

Decline in Soil Health: The overuse of chemicals has led to a decline in soil organic matter, microbial activity, and nutrient cycling, affecting long-term soil fertility.

Water Pollution: Runoff from contaminated soils is a significant source of water pollution, affecting nearby rivers and lakes and leading to the contamination of drinking water sources.

Reduced Crop Productivity: Although chemical fertilizers and pesticides have initially increased crop yields, their long-term use is likely to lead to diminished returns due to declining soil health and the development of pest resistance.

Health Risks: The accumulation of chemical residues in soil and water poses a risk to human health, particularly in rural communities dependent on agriculture for their livelihood.

MITIGATION STRATEGIES

To mitigate the chemical impact on soil in Chhatarpur District, the following strategies are recommended:

Integrated Nutrient Management (INM): A balanced approach that combines organic and inorganic fertilizers to maintain soil fertility and reduce dependence on chemical fertilizers.

Organic Farming Practices: Promoting organic farming methods, such as composting and crop rotation, can help restore soil health and reduce the use of harmful chemicals.

Pesticide Management: Encouraging the use of bio-pesticides and integrated pest management (IPM) techniques to minimize pesticide residues in the soil.

Awareness and Training: Providing farmers with education on the long-term impacts of chemical use and training them in sustainable agricultural practices.

CONCLUSION

The present study highlights the significant chemical impact on soils of Chhatarpur District. Data analysis shows that while chemical inputs initially improved crop yields, their long-term consequences are becoming evident. For instance, wheat yields increased from 1.5 tons/ha a decade ago to 3.2 tons/ha today, and rice yields from 2.0 to 3.5 tons/ha, reflecting short-term benefits of fertilizer and pesticide use. However, these gains are accompanied by soil degradation, as organic carbon declined to 0.8% (below the optimal 1.0–1.5%), and potassium levels (70 kg/ha) fell short of the required 80–100 kg/ha. The study further revealed that pesticide residues such as malathion (0.5 ppm), DDT (0.3 ppm), and chlorpyrifos (0.2 ppm)

exceeded safe levels, while heavy metals like lead (0.8 mg/kg) and cadmium (0.4 mg/kg) surpassed permissible limits, indicating growing contamination risks. In addition, soil pH (5.8) has shifted towards acidity, and microbial activity (15 $\mu\text{g CO}_2/\text{g/hr}$) is significantly lower than healthy levels, pointing to biological decline. Compared with historical conditions, soils of Chhatarpur are now more chemically stressed, with reduced fertility, lower water retention (18% moisture vs. 20–25% optimal), and nitrate levels in water sources already reaching the WHO limit (10 mg/L). These trends suggest that without intervention, future productivity will decline, and environmental contamination will intensify. In conclusion, while chemical inputs have doubled crop yields in the past decade, they have also triggered soil nutrient imbalances, toxic build-up, and ecological risks. Sustainable practices such as integrated nutrient management (INM), organic amendments, and biopesticide adoption are essential to restore soil health, maintain crop productivity, and protect human and environmental health for the future.

REFERENCES

1. Bhardwaj, K., & Soni, P. (2022). Pesticide Residue in Soil and Its Effect on Microbial Diversity in Agricultural Land: A Case Study from Central India. *Environmental Pollution and Sustainable Development*, 20(4), 35-43.
2. Mishra, A., & Kumar, S. (2022). Sustainable Agriculture in Madhya Pradesh: Reducing Chemical Dependency for Soil Conservation . *Agro-ecology and Sustainable Food Systems*, 46(3), 317-325.
3. Patel, P., & Yadav, K. (2021). Integrated Nutrient Management: A Sustainable Approach for Soil Health Restoration in Madhya Pradesh . *Indian Journal of Agricultural Sciences*, 91(7), 956-961.
4. Yadav, A., & Singh, B. (2021). Nutrient Management and Soil Fertility in Semi-Arid Regions of Madhya Pradesh . *Soil Science and Plant Nutrition*, 67(1), 83-91.
5. Singh, M., & Kumar, S. (2020). Effect of Chemical Fertilizers on Soil Fertility and Sustainable Agriculture in India . *Journal of Soil Science and Environmental Management*, 11(2), 58-67.
6. Rathore, M., & Jain, N. (2019). Chemical Fertilizer Use and Its Impact on Soil Health in Bundelkhand Region . *Environmental and Soil Science*, 12(3), 212-220.
7. Gupta, R., & Sharma, S. (2018). Soil Organic Carbon and Nitrogen Dynamics under Different Agricultural Practices in Madhya Pradesh . *Journal of Soil and Water Conservation*, 67(1), 45-53.
8. Chaudhary, R., & Sahu, N. (2017). Agricultural Practices and Soil Health: A Review of Bundelkhand Region's Agriculture. *International Journal of Agricultural Sciences*, 23(5), 678-685.