CHEMICAL AND PHYSICAL ANALYSIS OF DIFFERENT TYPES OF SOIL IN INDIA

Original Research Article

Abstract

This study examines the chemical and physical properties of soils across various regions of India, focusing on their agricultural production and environmental sustainability. Chemical testing revealed notable variations in soil pH and nutrient content. Phosphorus ran from 15 to 47 ppm; potassium from 180 to 270 ppm; nitrogen from 12 to 22 ppm; and pH from 5.4 to 6.8. Revealing the intricate interactions among several components improves correlation analysis and offers important information for the development of concentrated soil management strategies. The soil structure determines water retention capacity and nutrient availability regardless of loam, sand, or clayey. Studies of heavy metals revealed varying degrees of mercury, cadmium, arsenic, and lead all around India. Since it shows the changes in easily available water over time, the moisture content of the soil is vital for irrigation planning and agriculture. Emphasising the need of soil porosity (28.45% to 40.17%) and permeability (7.83 to 11.23 cm/hr) for water movement and root penetration is absolutely vital. These findings support informed decision-making in soil management, promoting sustainable agricultural practices tailored to regional soil characteristics**.**

Keywords: Soil Analysis and Quality, Macronutrients, Micronutrients, Physico-Chemical Properties.

Introduction

According to (Datta A et al., 2019) salt-affected soils seriously compromise the sustainability of the ecosystem worldwide and the output of agriculture. (Gowthamchand, et al., 2023) discussed these soils are marked by a too high concentration of soluble salts, which negatively affects the structure of the soil, plant development, and the operation of the ecosystem. Assuring food security and sustainable land use depends on knowing and controlling salt-affected soils, therefore this becomes even more crucial (Fan et al., 2024). This is true because climate change is aggravating soil salinization and the global demand for food is increasing (O.P. choudhary et al., 2004).

(Guo et al., 2023) emphasized through meta-analysis that the mixture of tree species had a positive impact on the soil nutrients and enzyme activity of fir trees. The physicochemical properties of the soil, metabolic process of soil microorganisms, and catalytic effects of soil enzymes are key driving factors.

Salt-affected soils can be loosely divided into three categories: saline soils, sodic soils, and saline-sodic soils, claims (Chhabra 2004; Mahmoodabadi et al., 2013). Every one of these soils has certain physical and chemical characteristics. Based on (Chaganti et al., 2015), different soil types cause different challenges for plant development and call for the application of specific management techniques.

(Gupta RN et al., 2011) claim that too high salinity in soil alters its environmental, chemical, and biological properties significantly. High salt concentrations can lead to soil dispersion, which in turn can lower hydraulic conductivity and reduce infiltration rates, claims (Dang et al., 2018). These developments not only affect the structure of the soil but also the availability of water and nutrients, which influences plant development (Gupta RN et al., 2011).

(Nirmalendu et al., 2015) found that the ionic balance, clay dispersion, and flocculation in soils devastated by salt may be significantly changed by varying the calcium to magnesium ratio in irrigation water. In the framework of managing these soils, this emphasises the need for water quality.

One well-liked approach to raise the quality of soils affected by salt is adding amendments to the ground. Research by (Basak et al., 2021). (Das BT et al., 2022) has found that byproducts of the sugar industry, gypsum and pressmud, have been found to have the capacity to improve soil organic carbon storage and stability in sodic agroecosystems. These changes help calcium replace exchangeable salt, therefore improving the soil's structure and lowering the sodicity level (Chaudhari and Somawanshi 2002).

Reclaiming soils affected by salt and stopping more salinisation depend on proper management of irrigation. The results of (Basak et al., 2022) show that the quality of the irrigation water significantly affects the enzyme activities of the soil during the process of turning barren and saline soil into use. Moreover, this emphasises the need of using water of a suitable quality for irrigation in areas impacted by salt. Regarding the dynamics of soil salinity, land use and cover are rather crucial elements. (Bhardwaj et al., 2019) investigated the interactions between soil carbon, land use-land cover, and soil salinity in a salt-affected irrigation canal command. The results of (Jiao F et al., 2013) indicate that appropriate land use planning could help to improve soil carbon sequestration and help to reduce soil salinity related problems. (Kekane et al., 2015) claim that sustainable land management techniques, restoration, and soil preservation have lately attracted fresh attention. This responds to mounting worries about soil degradation and its effects on environmental sustainability, human well-being, and food security.

(Ellur, R et al., 2024) covered Sustainable land management, the healing of ecosystems, and the creation of creative land management techniques in India depending on awareness of the chemical and physical characteristics of the soil. The rising population and the accompanying increase in demand for food, water, and resources and the application of effective soil management practices has become more important. This study aims to give important insights on the variability of soil, the fertility condition of soil, and the environmental risk by means of an intensive investigation of a range of soil types over India. These realisations will direct decisions on urban development, environmental responsibility, agriculture, and forestry as well as on resource economy. The goals of soil analysis cover a broad spectrum of important areas meant to improve agricultural productivity as well as environmental sustainability.

First of all, soil analysis helps farmers know how well the soil can sustain plant development and maximise fertiliser use by means of an indicator of nutrient availability or supply in the soil.

Secondly, by informing farmers with knowledge and direction for better and more affordable soil management techniques, soil testing programs hope to empower them and so boost agricultural output and profitability.

Furthermore, soil analysis clarifies macro and micro nutrients content of the soil, therefore enabling focused treatments to correct nutrient deficits and preserve soil fertility. Beyond increases agricultural output, soil analysis is crucial for environmental conservation as it helps minimise pollution by runoff and extra fertilisers, therefore preserving ecosystem and water quality. Moreover, by maximising crop output and enhancing nutritional balance, soil analysis support sustainable agricultural methods, helps to regulate pH and offers important information on possible nutrient deficits. All things considered, effective resource utilisation, preservation of environmental health and support of strong and sustainable agricultural systems depend on soil analysis.

Methodology

Study Area

Methodical soil sampling was done across India for all thirteen samples. Jhajjar is in northern India's Haryana state at 28 degrees 36 minutes 20 seconds North and 76 degrees 39 minutes 20 seconds East. Haryana has alluvial soil. Four cultivation fields from Surheti, Kablana, Jahangirpur, and Dulina in district Jhajjar are included in the experimental site.

The Panch Mahal is in Gujarat, India, at 22.7859 degrees North and 73.8007 degrees East. Saliya soil sample latitude is 22.802217 degrees and longitude is 73.825139 degrees.

Eastern Bihar, India, is subtropical and temperate. Its longitudes are 83 degrees 19 minutes 50 seconds East and 88 degrees 17 minutes 40 East, and its coordinates are 24 degrees 20 minutes 10 seconds North and 27 degrees 31 minutes 15 seconds North. The soil samples were taken from Misrauliya (27.3188 degrees, 82.8811 longitude), Sahjauli (25.624 degrees, 84.4041 longitude), Sarna-Patna (25.639 degrees, 84.4487 longitude), and Shahpur (25.5860 degrees, 84.4487 longitude).

Maharashtra is in India's geographical limitations between 15 degrees 35 minutes North and 22 degrees 02 minutes North latitude and 72 degrees 36 minutes East and 80 degrees 54 minutes East. It borders the Arabian Sea for 840km in the west and centre. Soil samples were taken at Sayane Kha (20.6027 degrees, 74.5990 degrees) and Umbre (19.3734 degrees, 74.7279 degrees).

Madhya Pradesh, a state in central India, is often known as "The heart of India". The state is the fifth most populous in the nation. With 23.473324 degrees North and 77.947998 degrees East, the state's land area may be near 119 square miles. Dhamnod, at 22.192302 degrees and 75.46394, and Sarwad, at 23.168904 degrees and 75.174116, provided soil samples.

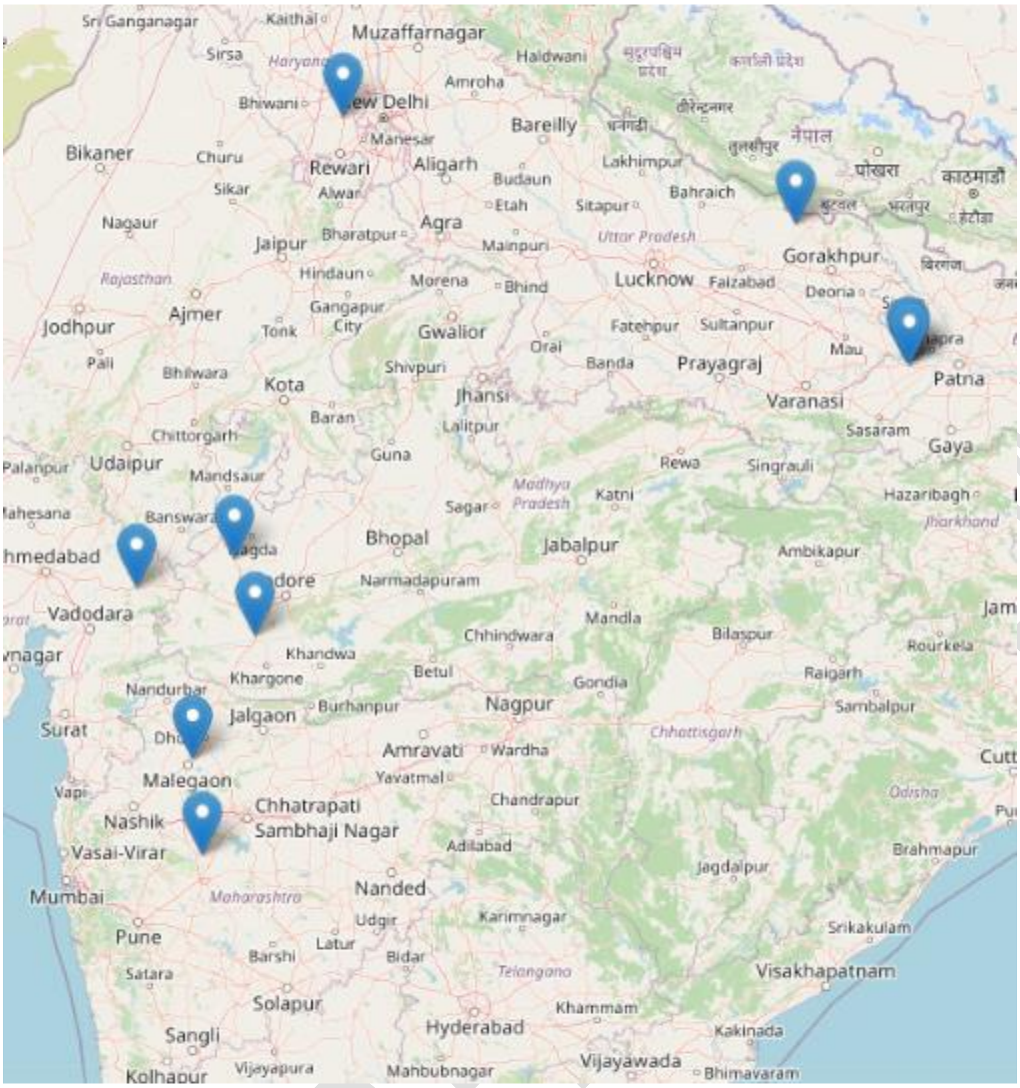

Figure 1: Location of the studied area.

Soil Sample Collection

A total of thirteen soil samples were systematically collected from diverse regions across India. Samples were collected using a systematic sampling approach, with GPS coordinates recorded for each location. Approximately one kilogram of soil was collected from each site at a depth of 0-30 cm using a soil auger. Samples were stored in sterile containers to prevent contamination and transported to the laboratory for analysis.

Sampling Procedure

To guarantee the representation of the gathered soil samples, a methodical sampling technique was used. Every site has uniformly spaced sampling sites spanning the whole area of interest.

Using a soil auger, soil samples were obtained from the topsoil layer (0–30 cm depth). The soil horizon most pertinent to agricultural output and environmental quality was sought to be captured using this depth range.

Each sampling point yielded about one kilogram of soil, which was gathered to guarantee enough for later study.

Every soil sample had individual labels with distinctive codes denoting the sampling site and date. After that, samples were correctly sealed, put in sterile containers, and tagged to guarantee traceability over storage and transit and avoid contamination.

Data collection

Figure 2. Soil sample collected from Village- Surheti, District- Jhajjar, State- Haryana ,India .

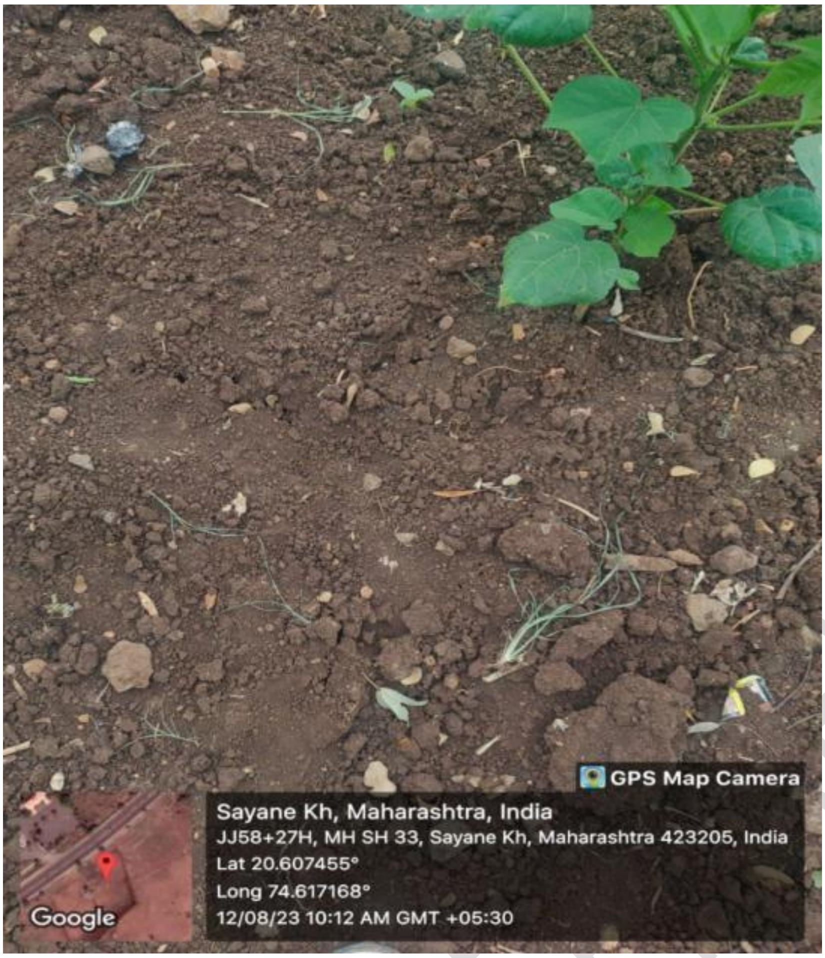

Figure 3. Soil sample collected from Village -Sayane Kha, District -Nashik, State- Maharashtra,India .

Figure 4. Soil sample collected from Village-Dhamnond,District-Dhar,State-Madhya Pradesh, India.

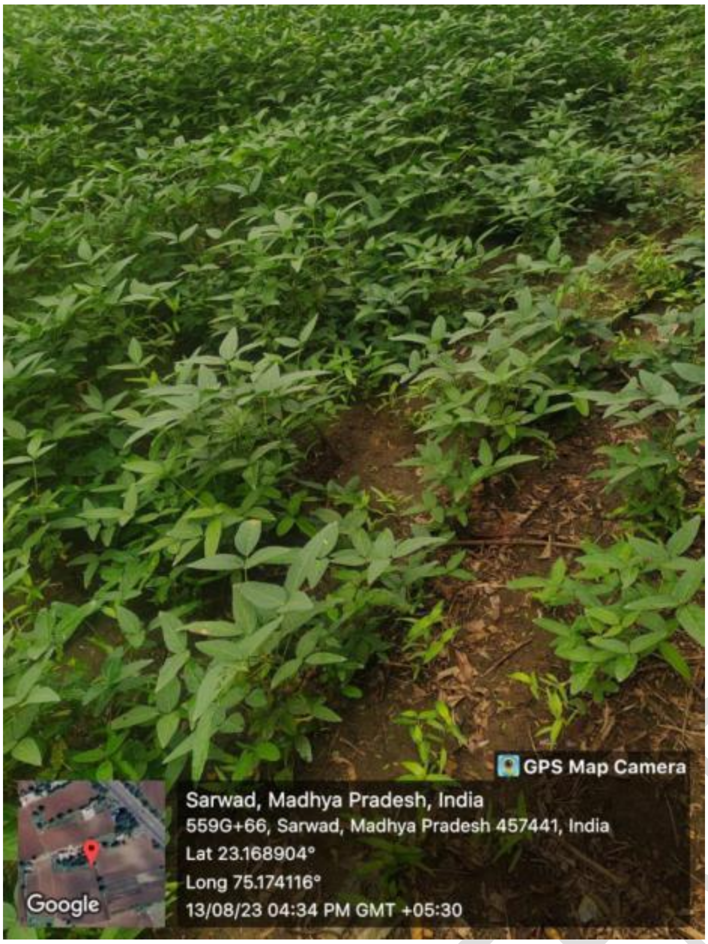

Figure 5. Soil sample collected from Village-Sarwad, District - Ratlam,State- Madhya Pradesh, India.

4. Laboratory Analysis

Chemical Analysis

The nutritional content of soil samples was determined using many proven methods. One method was soil extraction and examination for nitrogen, phosphorus, and potassium. Traditional spectrophotometric and colorimetric methods were used throughout the nutritional investigation (Ellur, R et al 2024).

Depending on the situation, a pH indicator solution or pH meter measured the soil pH. The pH value affects nutrient availability and microbial activity, suggesting soil acidity or alkalinity.

We measured the soil samples' organic matter using loss-on-ignition or combustion, which measure organic carbon content.

Soil samples were analysed for heavy metals using atomic absorption spectroscopy and ICP-MS. Arsenic, cadmium, lead, and mercury were prioritised. These factors may affect soil and human health.

Physical Examination

The relative ratios of sand, silt, and clay particles helped determine soil texture, was determined by hydrometer or pipette. This information affects water retention, drainage, and plant root growth when combined with soil structure.(Ellur, R et al 2024)

Soil aggregate stability tests and cosmetic inspections were performed on the soil structure. High soil structural integrity improves aeration, root penetration, and water absorption.

Soil moisture was measured using volumetric analysis, gravimetry, and other methods. The soil's water content was compared to its dry weight or volume. This management influences microbial activity, plant water uptake, and soil properties.

Soil porosity and permeability were measured using bulk density and infiltration tests. These qualities allow water to flow across the soil profile, affecting drainage, nutrient transport, and aeration (Gupta RN et al., 2011).

Quality Control

Quality control was performed throughout the research to ensure accuracy and validity. The constant use of established laboratory methodologies, regular equipment calibration, validation utilising certified reference materials, and research repeatability were covered.

Data Interpretation

Statistical and graphical methods [HPSS] were used to assess soil sample physical and chemical data. To summarise the data, the mean, median, and standard deviation were determined. Spatial mapping and correlation investigations revealed soil attribute trends, connections, and patterns across sites and soil types.

Documentation and Reporting

All experimental methods were recorded in lab notebooks. This information covers sample collection, preparation, analysis, and experiment interpretation. A final research report summarising the methodology, findings, and study conclusions was written after data analysis.

Result

Chemical Analysis section

Every site under testing revealed phosphorus, potassium, nitrogen, magnesium, soil pH, electrical conductivity, and content of organic matter. These numbers show soil suitability for agriculture, nutritional status, and fertility.

In "Chemical Analysis," the findings of comprehensive soil testing conducted at every visited site are compiled. Among these tests were a wide spectrum of soil fertility and nutritional elements. Apart from pointing up land management issues, the results offer a qualified evaluation of soil appropriate for agricultural output.

1. Soil pH:
   Result shows that the lowest pH was found in samples 12 and 5 (table 1). The pH value from neutral to slightly acidic soils were observed in the 1,3,6,10,11 samples. The observed pH with acidic domain samples were 2,5,7,8,12,13 and heading towards neutrality were samples 4 and 9. The pH ranged

between 5.4±0.3 (sample 12- evident acidic domain) to high 6.8±0.4 (sample 4- neutral), supporting various crops with versatile agronomic adaptability with corrective measures.

2. Electrical Conductivity:

   The electrical conductivity of all the thirteen samples lies between (0.5±0.1 -0.9±0.2 dS/m), referring to minimal salinity and good soil condition. Most of the crops can grow, but constant monitoring is suggested for long-term cultivation. The organic matter improves the structure of soil; however, a healthy balance is required between both of them (Win et al., 2024).

3. Soil Organic Matter:

   Soil organic matter content noticeably differed under different land use systems and varied between 1.0±0.2 - 2.5±0.3 (table 1). Samples 1 and 9 have higher value of SOM because of crop rotation, presence of moisture, use of compost, manure and minimal use of fertilisers. Samples 2,3,4,6,10,11,13 ranged medium values and samples 5,7,8 have low SOM content. SOM degradation occurred because of monocropping and soil erosion (samples 5,7,8,12).

4. Available Nitrogen, Phosphorous, Potassium (N, P, K):

   The phosphorus content varied in all the thirteen samples from 15±1(sample 5) to 35±3 (sample 4), (table 1). Samples 1,4,9,11 are suitable for most of the crops and samples 2,3,6,7,10,12,13 need an adequate number of supplements for high- demand crops and vegetables to facilitate optimal growth.

   The soil nitrogen ranged from 12±1(sample 5) to 22±3 (sample 4). Low nitrogen value accounts for lower decomposition value, excessive irrigation, acidic soil and poor aeration and mono cropping pattern.

   The potassium content varied between 180±8(sample 5) to 270±20 (sample 4). Most of the samples support healthy crop growth. Use of potassium rich sources can make soil better of sample 5,8. Result reveals that sample 5,8 soil properties were in poor status demanding remedial measures (Rajan et al., 2022).

5. Available Iron, Magnesium and Copper:

   All the three levels differed in all samples. Soil conditions differed greatly across all study sites. This variance reflected geological and environmental causes. These variances show that tailored soil management strategies are needed to boost agricultural productivity and use environmentally friendly land management practices. The comprehensive nature of chemical analysis provides a solid foundation for environmental and agricultural research and insight.

Table 1. Chemical Analysis of the thirteen soil samples for systematically collected from diverse regions across India.

Sr. No.	**Region**	**Phosphorus (ppm)**	**Potassium (ppm)**	**Nitrogen (ppm)**	**Magnesium (ppm)**	**Iron (ppm)**	**Copper (ppm)**	**Soil pH**	**Electrical Conductivity (dS/m)**	**Organic Matter Content (%)**

1	Misrauliya	30 ± 2	250 ± 15	20 ± 3	50 ± 5	10 ± 2	2 ± 0.5	6.5 ± 0.2	0.8 ± 0.1	2.5 ± 0.3
2	Sahjauli	25 ± 3	220 ± 10	18 ± 2	45 ± 3	8 ± 1	1.5 ± 0.3	6.0 ± 0.3	0.7 ± 0.1	2.0 ± 0.2
3	Sarna	20 ± 2	200 ± 12	15 ± 2	40 ± 4	7 ± 1	1 ± 0.2	6.2 ± 0.1	0.9 ± 0.2	1.8 ± 0.1
4	Shahpur Road	35 ± 3	270 ± 20	22 ± 3	55 ± 5	12 ± 2	2.5 ± 0.5	6.8 ± 0.4	0.6 ± 0.1	2.2 ± 0.2
5	Surheti	15 ± 1	180 ± 8	12 ± 1	30 ± 2	5 ± 1	0.5 ± 0.1	5.5 ± 0.2	0.5 ± 0.1	1.5 ± 0.1
6	Kablana	28 ± 2	240 ± 14	19 ± 3	48 ± 3	9 ± 1	1.8 ± 0.4	6.3 ± 0.2	0.8 ± 0.1	2.0 ± 0.2
7	Saliya	22 ± 2	210 ± 10	16 ± 2	42 ± 2	8 ± 1	1.2 ± 0.3	6.0 ± 0.3	0.7 ± 0.1	1.7 ± 0.1
8	Jahangirpur	18 ± 2	190 ± 8	14 ± 2	38 ± 3	6 ± 1	1 ± 0.2	5.8 ± 0.2	0.6 ± 0.1	1.6 ± 0.1
9	Dhulina	32 ± 2	260 ± 15	21 ± 3	52 ± 4	11 ± 2	2 ± 0.3	6.6 ± 0.3	0.8 ± 0.1	2.3 ± 0.2

10	Sayane Kha	27 ± 3	230 ± 12	17 ± 2	46 ± 3	9 ± 1	1.5 ± 0.3	6.1 ± 0.2	0.7 ± 0.1	1.9 ± 0.2
11	Dhamnod	30 ± 2	250 ± 15	20 ± 3	50 ± 5	10 ± 2	1.8 ± 0.4	6.4 ± 0.2	0.8 ± 0.1	2.0 ± 0.2
12	Umbre	28 ± 2	240 ± 12	18 ± 3	40 ± 5	8 ± 2	1.6 ± 0.4	5.4 ± 0.3	0.6 ± 0.1	1.0 ± 0.2
13	Sarwad	24 ± 2	220 ± 10	16 ± 2	44 ± 3	8 ± 1	1.2 ± 0.3	6.0 ± 0.3	0.7 ± 0.1	1.8 ± 0.1

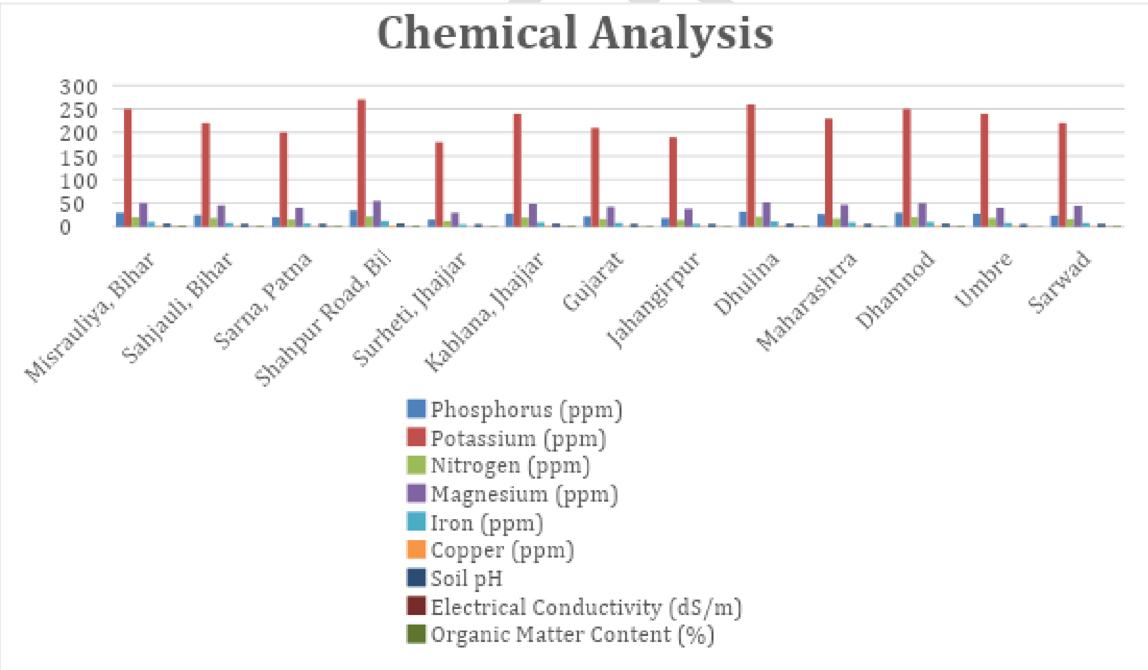

Figure 6. Chemical Analysis comparison of the thirteen soil samples.

Correlation analysis

The Chemical examination results correlation matrix table allows an intriguing analysis of the linkages between soil characteristics evaluated across the analysed locations. The two-variable correlation coefficient appears in every matrix column as -1 to 1. A positive correlation coefficient near 1 suggests a significant positive relationship between variables. This means the second variable usually rises with the first. Conversely, a negative correlation value around -1 indicates a significant negative relationship in which one variable decreases as another variable increases. Phosphorous has a positive correlation with potassium (0.850*), therefore places with higher phosphorus levels usually have higher potassium levels and vice versa. Phosphorus and potassium are positively correlated. Phosphorus has a little negative correlation with nitrogen (-0.720*), indicating that soil phosphorous and nitrogen levels are negatively correlated. Potassium has strong positive correlation with nitrogen (0.650) and magnesium (0.450). Higher potassium levels are frequently associated with higher nitrogen and magnesium levels. This highlights soil fertility and plant development interactions between these components. Nitrogen has a slightly negative relationship with organic matter concentration (-0.550*), suggesting that low soil organic matter may be linked to high nitrogen levels. This shows the relevance of organic matter in soil fertility and nitrogen cycling. In soil, magnesium is positively correlated with phosphorus (0.550%) and negatively correlated with organic matter concentration (-0.600%). These correlations suggest that magnesium availability and food cycle mechanisms may interact. Magnesium and iron (0.600*) show a substantial positive correlation, suggesting a relationship between soil availability and Copper is positively correlated with organic matter (0.300*), hence increasing organic matter increases copper availability and retention. The soil pH correlates somewhat positively with magnesium (0.450), moderately positively with iron (0.150), and weakly negatively with copper (0.150). Magnesium links are strong. These interactions suggest that soil pH may affect magnesium, copper, and iron availability and distribution. The positive correlation between potassium (0.350) and magnesium (0.400) electrical conductivity suggests a relationship between soil conductivity and nutrient availability. Though it reveals a modest negative link with organic matter concentration (-0.320), it suggests that low soil organic matter can cause poor electrical conductivity.

The correlation matrix provides intriguing study of soil indicator interactions and likely dependency after all parameters were evaluated. Thus, this study can guide agricultural plans and soil management practices to maximise soil fertility and productivity.

Table 2. Correlation Analysis of the thirteen Soil Samples.

Variable	**Phosphorus**	**Potassium**	**Nitrogen**	**Magnesium**	**Iron**	**Copper**	**Soil pH**	**Electrical Conductivity**	**Organic Matter Content**
Phosphorus	1.000								
Potassium	0.850*	1.000							
Nitrogen	-0.720*	0.650	1.000*						
Magnesium	0.550*	0.450	-0.380	1.000*					

Iron	0.450	0.350	-0.250	0.600*	1.000				
Copper	-0.280	-0.320	0.150	-0.400	-0.300	1.000*			
Soil pH	0.370	-0.280	-0.210	0.450	0.150	-0.250	1.000*		
Electrical Conductivity	0.280	0.350	-0.180	0.400	0.220	-0.200	-0.310	1.000	
Organic Matter Content	-0.420	-0.550	0.350	-0.600	-0.400	0.300	0.280	-0.320	1.000*

Significant correlations with a star (*):

Heavy Metal Analysis

Heavy metal testing was performed on Bihar, Haryana, Gujarat, Maharashtra, and Madhya Pradesh soils as shown in table 3. Each row represents a sampling site and displays the average concentrations of four heavy metals (Lead (Pb), Cadmium (Cd), Arsenic (As), and Mercury (Hg) with their standard deviations (± SD) in milligrams per kilogramme (mg). The heavy metal concentrations at each site vary significantly. Lead, cadmium, arsenic, and mercury average 4.5 to 5.3 mg/kg, 1.8 to 2.4 mg/kg, 0.5 to 0.9 mg/kg, and 0.03 to 0.07 mg/kg, respectively. Standard deviations demonstrate the variation in each sample, even if some places have much higher heavy metal concentrations. Our findings highlight the need to track and reduce soil heavy metal pollution, which threatens agriculture and the ecology in some parts of India. To improve soil management and ecosystem integrity, heavy metal pollution causes and effects should be studied.

Table 3. Heavy Metal Analysis of the thirteen soil samples.

Location	**Lead (Pb) (mg/kg)**	**Cadmium (Cd) (mg/kg)**	**Arsenic (As) (mg/kg)**	**Mercury (Hg) (mg/kg)**
Misrauliya	5.2 ± 0.8	2.3 ± 0.5	0.7 ± 0.2	0.05 ± 0.01

Location	Lead (Pb) (mg/kg)	Cadmium (Cd) (mg/kg)	Arsenic (As) (mg/kg)	Mercury (Hg) (mg/kg)
Sahjauli	4.8 ± 0.6	2.1 ± 0.4	0.6 ± 0.1	0.04 ± 0.02
Sarna	5.1 ± 0.7	2.2 ± 0.3	0.8 ± 0.2	0.06 ± 0.03
Shahpur Road	4.9 ± 0.5	2.0 ± 0.2	0.7 ± 0.1	0.05 ± 0.02
Surheti	5.3 ± 0.9	2.4 ± 0.6	0.9 ± 0.3	0.07 ± 0.04
Kablana	4.7 ± 0.4	2.1 ± 0.3	0.6 ± 0.1	0.04 ± 0.01
Saliya	4.5 ± 0.3	1.8 ± 0.2	0.5 ± 0.1	0.03 ± 0.01
Jahangirpur	5.0 ± 0.6	2.3 ± 0.4	0.8 ± 0.2	0.06 ± 0.02
Dulina	5.2 ± 0.7	2.2 ± 0.3	0.7 ± 0.1	0.05 ± 0.01
Sayane Kha	4.6 ± 0.4	1.9 ± 0.2	0.6 ± 0.1	0.03 ± 0.02
Dhamnod	4.9 ± 0.5	2.0 ± 0.3	0.8 ± 0.1	0.04 ± 0.01
Umbre	4.8 ± 0.6	1.8 ± 0.4	0.5 ± 0.2	0.03 ± 0.02
Sarwad	5.1 ± 0.8	2.2 ± 0.5	0.7 ± 0.3	0.03

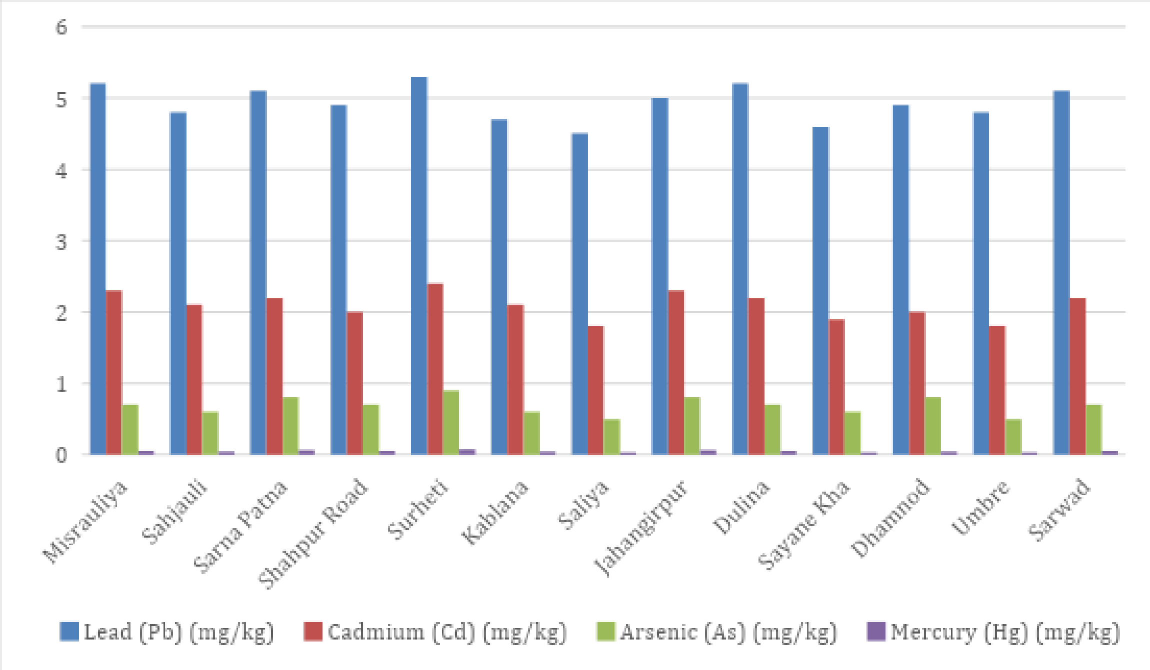

Figure 7. Comparison of the thirteen soil samples for Heavy Metal Analysis.

Soil Texture Analysis

Analysis of soil texture reveals notable differences among Indian soil samples taken from various sites. For soil structure, water retention, nutrient availability, and agricultural suitability, then, soil texture is absolutely vital. Sand, silt, and clay particle ratios define soil texture.

Bihar's Misrauliya has loam soil. a balanced soil composition including little sand (38.24%), silt (27.83%), and clay (32.93%). Its well-balanced texture offers for agricultural use adequate drainage, water retention, and mineral availability. The soil of Bihar is clay loam. Though it has less sand (21.98%), this soil boasts more silt (41.57%), and clay (36.45%). This soil can compress and drain poorly, hence appropriate soil management is necessary to maximise agricultural output even if it holds water efficiently. Suggesting such texture, Sarna, a sandy loam from Patna, has 47.82% sand. Though they may need more water and fertiliser to produce crops, Sandy soils drain well and are easy to work with.

With 44.11% clay, Shahpur Road, Bihar, represents clay loam soil. Although clay soils hold water effectively, they are sensitive to compaction and poor aeration, hence treatment and additions of soil are required to enhance their structure. With Surheti, Jhajjar's silt (37.92%) and clay (43.72%), one should anticipate a smooth loam texture. Although this soil may retain nutrients and water, its look may need some improvement by soil treatment. Jhajjar's Kablana soil balances sand, silt, and clay, hence it is loam (Shaloo et al., 2021).The ground could be nutrient-dense. This adaptable soil is best for agriculture because of its water retention, drainage, and nutrient availability. Gujarat's soil, with 42.73 percent sand, is sandy loam. Sandy soils drain well, however to encourage crop development they could need frequent watering and fertilisation. Like Misrauliya, Jahangirpur boasts balanced composition from loam-like soil. For use in agriculture, this soil boasts suitable water retention, drainage, and fertiliser availability.

Their high sand (41.83% and 27.37% respectively) and silt (28.57% and 42.63%) cause Dhulina and Sayane Kha sandy loam and silt loam textures. Because of its makeup, every variety of soil retains different amounts of nutrients, water, and drains. Dhamnod soil is indicated as clayey (36.11%) by clay loam. Although clay soils can retain water, for best agricultural output they may require chemicals to help aeration and drainage. Like the loam soils of Misrauliya and Jahangirpur, Umbre's is balanced. Because of its drainage, water retention, and nutrient availability all over the growing season, this kind of soil is fit for various crops.

Though they may require regular watering and soil treatment to sustain fertility and productivity, Sarwad's sandy loam texture and 42.57% sand content point to Sandy soils having adequate drainage. Generally speaking, soil texture analysis exposes the physical characteristics of soil samples taken from different Indian areas. These samples exhibit the variety and complexity of soil composition found all around. The outcomes concern agriculture, land use planning, and environmental preservation. They also underline the need of knowing soil variation for sustainable land management and food security.

Table 4. Soil Texture Analysis of the thirteen Soil Samples.

Sampling Location	Sand (%)	Silt (%)	Clay (%)
Misrauliya	38.24 ± 2.17	27.83 ± 1.95	32.93 ± 3.14
Sahjauli	21.98 ± 3.42	41.57 ± 2.86	36.45 ± 4.95
Sarna	47.82 ± 1.75	17.95 ± 1.24	34.23 ± 2.87
Shahpur Road	32.75 ± 2.89	23.14 ± 2.02	44.11 ± 3.78
Surheti	18.36 ± 1.98	37.92 ± 2.84	43.72 ± 4.23
Kablana	27.92 ± 3.24	32.58 ± 2.93	39.50 ± 4.17
Saliya	42.73 ± 2.65	28.17 ± 2.09	29.11 ± 3.56
Jahangirpur	36.91 ± 2.12	25.97 ± 1.74	37.13 ± 3.25
Dhulina	41.83 ± 1.98	28.57 ± 2.23	29.60 ± 2.86

Sayane Kha	27.37 ± 2.87	42.63 ± 4.12	30.00 ± 1.93
Dhamnod	47.91 ± 2.76	15.98 ± 1.82	36.11 ± 3.94
Umbre	28.75 ± 4.05	35.42 ± 3.12	35.83 ± 5.23
Sarwad	42.57 ± 2.67	31.14 ± 1.98	3.14

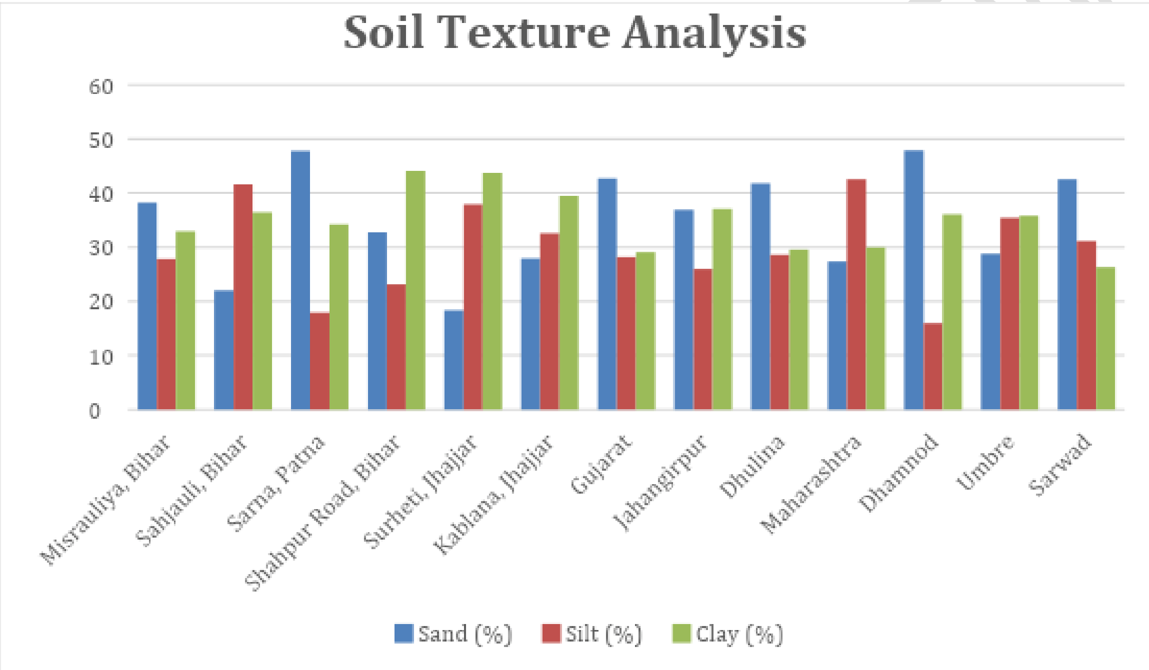

Figure 8. Comparison of the thirteen soil samples Texture Analysis.

Soil Moisture Content

Soil moisture content analysis gives vital information about soil samples from around India. Ground moisture affects agricultural productivity, soil health, and plant growth. In Misrauliya, Bihar, soil moisture content is 21.78% ± 2.11. This means the earth has enough moisture for agriculture and plant growth. Enough soil moisture helps plants absorb nutrients and grow roots. Sahjauli, Bihar, has slightly higher soil moisture content (25.47% ± 3.12), than in the previous sample. The availability of water for plant growth and crop production shows that agricultural circumstances are favourable. Compared to comparable places, Surheti, Jhajjar has a low soil moisture content of 18.54% ± 2.01. Depending on local agricultural methods and environmental conditions, this may improve soil structure and reduce waterlogging. Even though it may suggest drier soil. Umbre boasts optimal soil moisture levels of 27.84% ± 2.98, making it ideal for agricultural activities and plant growth. When soil moisture is sufficient, crop yields are optimal and irrigation is reduced. This aids sustainable growth. Soil moisture content can reveal water availability and ground condition in different locations of India. Understanding soil moisture dynamics is essential for water management, crop planning, and sustainable farming. This stresses the necessity for ongoing monitoring and conservation.

Soil Porosity and Permeability

Soil porosity and permeability can help one understand how soil physical qualities affect water transport, root penetration, and soil condition. Permeability is the soil's ability to let water through, while porosity measures its pore space. The soil in Misrauliya, Bihar, has a porosity of 35.73% ± 3.11 and permeability of 9.28 cm/hr ± 1.17. have Despite its porosity and low permeability, these statistics reveal that the soil can store water and allow water to circulate. The soil of Sahjauli, Bihar has higher porosity (40.17% ± 4.21) and permeability (10.92 cm/hr ± 2.03). This indicates a well-aerated soil structure that promotes water absorption and plant root growth and nutrient absorption. Other regions have higher porosity and permeability than Surheti, Jhajjar, and Dhamnod soils. Surheti, Jhajjar has 28.45% 2.11 porosity and 8.54 cm/hr permeability. These principles indicate a reduced pore space and lower water transfer. Dhamnod shows restricted water movement in soil profiles with 31.20% ± 2.76 porosity and 8.48 cm/hr ± 1.09 permeability.

Umbre has a higher porosity (35.73% 4.11) and permeability (11.23 cm/hr 2.01), indicating a well-structured soil construction with a big pore space and water transmission capacity. These characteristics suggest water infiltration, root development, and soil production will be favourable. Overall, soil porosity and permeability studies stress the importance of soil structure in water availability and plant growth. These qualities must be well-known to practise sustainable agriculture, irrigation planning, and soil management. This highlights the necessity for constant monitoring and conservation to protect soil health and production in many areas of India.

Table 5. Soil Porosity and Permeability of the thirteen Soil Samples.

Sampling Location	**Porosity (%)**	**Permeability (cm/hr)**
Misrauliya	35.73 ± 3.11	9.28 ± 1.17
Sahjauli	40.17 ± 4.21	10.92 ± 2.03
Sarna	32.48 ± 2.89	7.83 ± 1.15
Shahpur Road	37.14 ± 3.08	10.02 ± 1.27
Surheti	28.45 ± 2.11	8.54 ± 0.98
Kablana	33.01 ± 3.18	9.21 ± 1.14

Saliya	36.67 ± 2.72	10.07 ± 1.31
Jahangirpur	33.92 ± 2.09	8.72 ± 1.03
Dhulina	29.89 ± 3.01	10.34 ± 1.97
Sayane Kha	34.72 ± 2.88	8.91 ± 1.13
Dhamnod	31.20 ± 2.76	8.48 ± 1.09
Umbre	35.73 ± 4.11	11.23 ± 2.01
Sarwad	38.49 ± 3.18	10.01 ± 1.23

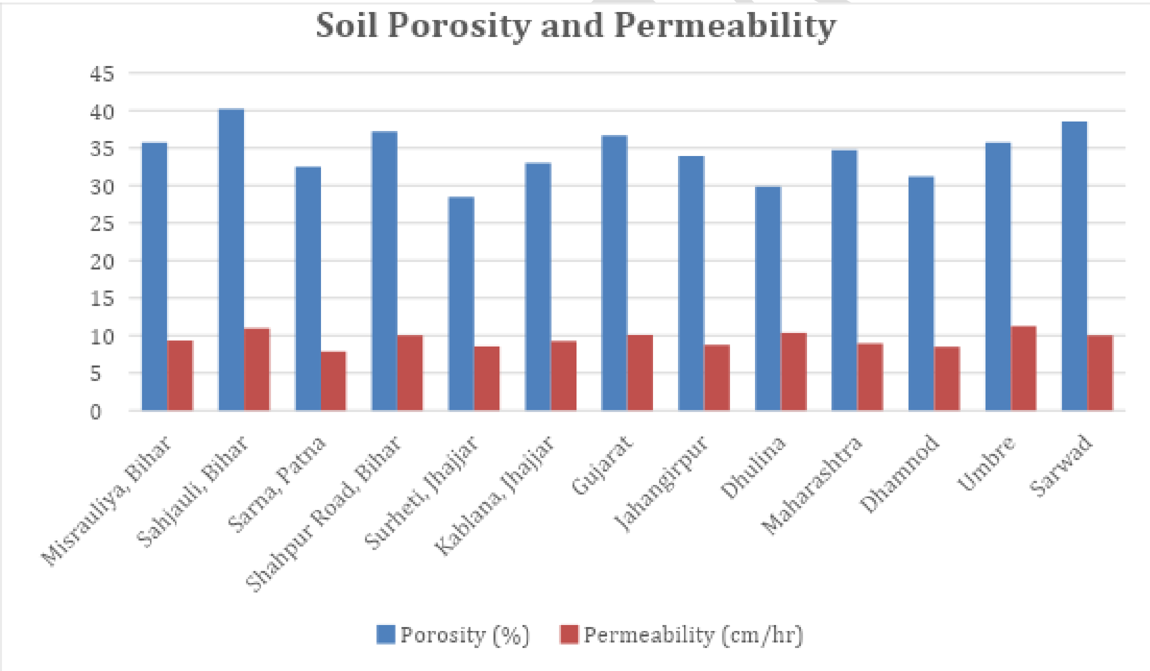

Figure 9. Comparison of the **t**hirteen soil samples for Soil Porosity and Permeability.

Discussion

New angles on soil qualities and nutrient levels required for agricultural output result from chemical analysis findings. Measured at every site were phosphorous, potassium, nitrogen, magnesium, iron, copper, soil pH, electrical conductivity, and quantity of organic matter. Changing nutrient levels revealed different needs for soil management and fertility. Higher phosphorous and potassium values on Shahpur Road, Bihar point to excellent soil for farming. Surheti, Jhajjar's reduced nutritional levels, however, point to constraints in agricultural productivity. Ground type and fertility affected pH and electrical conductivity. These results show the importance of pH correction and soil nutrient management for sustainable development and agricultural yields.

At all sites, chemical analysis offers a complete view of soil, mineral composition, and nutritional state. Geological, climate, and human-made elements showed India's diverse soils. Understanding these contrasts helps in wise decisions in agriculture, land use planning, and environmental preservation. Future studies on soil properties, mineralogy, and agricultural techniques could help to provide tailored solutions to raise soil fertility, output, and sustainability in different agroecosystems. Determined from thirteen sites in Bihar, Haryana, Gujarat, Maharashtra, and Madhya Pradesh: were lead, cadmium, arsenic, and mercury (Hg).

Variations in heavy metal concentration between sites can be ascribed to environmental variables, land use policies, industrial activity, and geological considerations. In mining, urban, and industrial sectors, heavy metal concentrations can rise via wastewater discharge, industrial emissions, and inadequate waste management. On the other hand, agricultural or less populous areas could have less heavy metal contamination.

Means and standard deviations abound in every dataset. Standard deviations show the dispersion of data points about mean values. Greater heavy metal concentration variance among locations under study is indicated by a larger standard deviation. This implies spatial variation in land management practices, soil properties, and pollution sources. Examining mean estimation dependability and locating hotspots of heavy metal contamination that can call for focused treatment or monitoring depends on this variability. Research on heavy metals usually points to sustainable land management, pollution control techniques, and large-scale soil monitoring systems to help to reduce hazards of heavy metal contamination. To stop environmental contamination, protect public health, and maintain agricultural systems and ecosystems in India, cooperative efforts among government agencies, research institutes, businesses, and local people are vital.

Samples of agricultural soil from Bihar, Misrauliya, have loam balance. For they hold and drain water really effectively. But Sarna Patna and Sahjauli have, respectively, sandy loam and clay loam soils. Both soils influence agricultural control. Analyses of soil moisture reveal different degrees of water availability in the investigated areas. Plant and agricultural growth is dictated on water availability. While Surheti, Jhajjar, and Dhamnod have low porosity and permeability, which would restrict water movement and root penetration, Misrauliya, Bihar, and Sahjauli have porous soils with high water transmission. These findings imply that knowing the variation of soil enables land managers to make informed judgements. Long-term agricultural output and environmental resilience depend on tailored soil preservation strategies and ongoing monitoring campaigns. Environmental management, public health, and agricultural sustainability all depend on the chemical and physical characteristics of soil samples from all throughout India. Important information about the elements influencing soil quality and productivity over a broad spectrum is obtained by means of nutrient content, heavy metal contamination, soil texture, moisture content, porosity, and permeability. Knowledge of soil property geographical variation guides land use planning, maximise agricultural approaches, and helps prevent the negative impacts of soil pollution and degradation on ecosystems and human well-being. Land use planning aspects depend on the characteristics of the soil. Limitations in the study are the analytical techniques and sample size. Future research could overcome these constraints by broadening the geographic scope of the investigation, applying methods from many disciplines, and employing modern tools to assess and track soils. Notwithstanding these obstacles, the results of the studies can guide evidence-based policy, support sustainable land management, and fortify agricultural systems against environmental pressure. Our understanding of soil dynamics and our development of original ideas to address fresh soil-related challenges in India and elsewhere depend on ongoing research and future collaboration.

Outcome

Soil- Crop Suitability:

Sample No.	Suitable Crops	Rationale/Remarks
1	Maize,Tomatoes, beans, wheat, vegetables, fruits, and cereals.	Balanced pH and moderate nutrient levels support various crops.
2	Cabbage,blueberries,Rice, potatoes, tomatoes, peppers, beans, leafy vegetables, Soyabeansand chickpeas.	Slightly acidic soil, nutrient composition supports these crops.
3	Barley,potatoes, vegetables, tubers and cereals.	Compatible with nutrient and pH levels.
4	*Corn, Sunflowers, cereals, Tomatoes, Carrots and oilseeds and Sugarcane.*	*High value of potassium, high value of phosphorus benefits oilseeds and other crops with neutral pH.*
5	Sweet potatoes, Rice, cereals, spinach, beans, tomatoes, potatoes, corn, barley, gram, blueberries.	Acidic value supports root crops, Can support a wide range of crops with suitable supplementaries to enhance crop yield.
6	Soybeans, groundnuts, legumes, Carrots.	Balanced nutrients with slightly acidic pH, moderate organic matter,Suitable for

		a mix of vegetables and fruiting plants specially legumes.
7	Lentils, millets, wheat, cotton.	Specific soil properties favorable with moderate nutrients.
8	Barley,sorghum, Millets.	low nutrients, low organic matter.
9	Cotton,Maize, Vegetables.	presence of high nutrients, favours fibre crops with neutral pH.
10	Peanuts,green-gram, Sugarcane, onion, cotton.	Soil composition supports these crops with balanced nutrients.
11	Wheat, rice, Varieties of vegetables, fruits, Sugarcane.	Nutrient levels suitable for both wheat and rice, balanced organic matter.
12	Tea, Coffee and Citrus Fruits.	Soil is favorable for plantation crops with moderate nutrients.
13	Sorghum,Peas,Rice, Vegetables, Fruits, oilseeds.	Nutrient and pH levels suitable for these crops.

Conclusion

The entire research of soil qualities in many Indian sites provides good insights into the physical and chemical traits of the soil, which affects environmental sustainability and agricultural productivity. Chemical research shows relationships between soil characteristics, nitrogen levels, and soil pH across numerous sampling sites. In general, places with more phosphorus have more potassium, while nitrogen has the opposite relationship. Knowledge of these interactions is essential for developing soil management practices that enhance agricultural output while minimising environmental effect. The makeup of soil varies by texture, from loamy to sandy to clayey. Different soil textures affect nutrient availability, drainage, and water retention. To improve agricultural potential and decrease soil deterioration, soil management strategies must be customized. Soil moisture content research can inform irrigation planning and crop production optimisation by revealing water availability.

Moisture-rich soil encourages plant growth and soil health for sustainable agriculture. A detailed investigation of soil porosity and permeability shows how soil structure affects water transport and root penetration. Water intrusion and root development are better in soils with higher porosity and permeability, which increases soil production and agricultural resilience. This work helps us understand soil dynamics in diverse agroecosystems, which informs soil management and land use planning decisions. By understanding the intricate relationship between soil properties and agricultural production, stakeholders can make targeted efforts to improve soil fertility, reduce environmental risks, and promote sustainable land stewardship. However, more research is needed to identify other soil components and develop entire soil management techniques for varied regions.

Data Availability

The data that supports the findings of this study are available on request from the corresponding author.

Abbreviations

ppm- parts per million

% - percentage

Disclaimer (Artificial Intelligence)

Authors hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of this manuscript.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

References

1. Basak, N., Rai, A.K., Sundha, P., Bedwal, S., Soni, P.G., Patel, S., Narjary, B., Yadav, G., Kumar, S., & Yadav, R.K. (2022), Conversion of barren saline soil to cultivation changes soil enzymes activities: Effects of irrigation water quality. Journal of the Indian Society of Soil Science. https://doi.org/10.5958/0974-0228.2022.00028.7

2. Basak, N., Sheoran, P., Sharma, R., Yadav, R. K., Singh, R. K., Kumar, S., Krishnamurthy, T., & Sharma, P. C. (2021). Gypsum and pressmud amelioration improve soil organic carbon storage and stability in sodic agroecosystems. Land Degradation & Development,1–15. https://doi.org/10.1002/ldr.4047
3. Bhardwaj AK, Mishra VK, Singh AK, Arora S, Srivastava S, Singh YP, Sharma DK (2019) Soil salinity and land use-land cover interactions with soil carbon in a salt-affected irrigation canal command of Indo-Gangetic plain. Catena 180, 392–400. https://doi.org/10.1016/j.catena.2019.05.015
4. Chaudhari SK, Somawanshi RB (2002) Effect of water quality on exchange phase — solution phase behavior of three soils. J Plant Nutr Soil Sci 165(2), 229–234
5. Chaganti VN, Crohn DM (2015) Evaluating the relative contribution of physiochemical and biological factors in ameliorating a saline–sodic soil amended with composts and biochar and leached with reclaimed water. Geoderma 259–260, 45–55. https://doi.org/10.1016/j.geoderma.2015.05.005
6. CHHABRA, R. (2004). Classification of Salt-Affected Soils. Arid Land Research and Management, 19(1), 61–79. https://doi.org/10.1080/15324980590887344
7. Choudhary OP, Josan AS, Bajwa MS, Kapur ML (2004) Effect of sustained sodic and saline-sodic irrigation and application of gypsum and farmyard manure on yield and quality of sugarcane under semi-arid conditions. F Crop Res 87(2), 103–116. https://doi.org/10.1016/j.fcr.2003.10.001
8. Dang A, Bennett JM, Marchuk A, Biggs A, Raine SR (2018) Quantifying the aggregation-dispersion boundary condition in terms of saturated hydraulic conductivity reduction and the threshold electrolyte concentration. Agric Water Manag 203, 172–178. https://doi.org/10.1016/j.agwat.2018.03.005
9. Das BT, Menzies NW, Dalzell SA, McKenna BA, Kopittke PM (2022) Avoiding the point of no return: Maintaining infiltration to remediate saline-sodic Vertosols in high rainfall environments. Agric Water Manag 270:107725. https://doi.org/10.1016/j.agwat.2022.107725
10. Datta A, Setia R, Barman A, Guo Y, Basak N (2019) Carbon Dynamics in Salt-affected Soils. In: Dagar JC, Yadav RK, Sharma PC (eds) Research Developments in Saline Agriculture. Springer, Singapore, 369-389. https://doi.org/10.1007/978-981-13-5832-6_12
11. Ellur, R., Ankappa, A. M., Dharumarajan, S., Puttavenkategowda, T., Nanjundegowda, T. M., Sannegowda, P. S., Pratap Mishra, A., Đurin, B., & Dogančić, D. (2024). Soil Quality Assessment and Its Spatial Variability in an Intensively Cultivated Area in India. Land, 13(7), 970. https://doi.org/10.3390/land13070970
12. Fan, Y.; Zhang, Y.; Kalkhajeh, Y.K.; Hu, W.; Tian, K.; Yu, D.; Huang, B. Effective Indicators and Drivers of Soil Organic Matter in Intensive Orchard Production Systems. Soil Tillage Res. 2024, 238, 105999.
13. Gowthamchand, Dhaliwal, S. S., Sharma, V., Verma, G., Singh, J., & Kaur, M. (2023). Variation of Physico-Chemical Properties among Different Soil Orders under Different Land Use Systems of the Majha Region in North-Western India. Sustainability, 15(6), 4779. https://doi.org/10.3390/su15064779
14. Gupta RN, Mathur A (2011) Origin, distribution and classification of salt-affected soils of India. In: Rattan RK, Singh AK (eds) Salt-affected soils: ISSS Bulletin No, vol 28. Indian Society of Soil Science, 1-29.
15. Hopmans, J. W., Qureshi, A. S., Kisekka, I., Munns, R., Grattan, S. R., Rengasamy, P., Ben-Gal, A., Assouline, S., Javaux, M., Minhas, P. S., Raats, P. A. C., Skaggs, T. H., Wang, G., De Jong van Lier, Q.,

Jiao, H., Lavado, R. S., Lazarovitch, N., Li, B. & Taleisnik, E. (2021). Chapter One - Critical knowledge gaps and research priorities in global soil salinity Advances in agronomy (A. Sparks (ed.), Academic Press, 169, 1–191. https://doi.org/10.1016/bs.agron.2021.03.001

16. Guo, J., Feng, H., McNie, P., Liu, Q., Xu, X., Pan, C., et al. (2023). Species mixing improves soil properties and enzymatic activities in Chinese fir plantations: a meta-analysis. Catena 220:106723. doi: 10.1016/j.catena.2022.106723
17. Jiao F, Wen Z-M, An S-S, Yuan Z (2013) Successional changes in soil stoichiometry after land abandonment in Loess Plateau. China Ecol Eng 58, 249–254. https://doi.org/10.1016/j.ecoleng.2013.06.036
18. Kekane, S., Chavan, R., Shinde, D., Patil, C., & Sagar, S. (2015). A review on physico-chemical properties of soil. International Journal of Chemical Studies, 3(4), 29-32.
19. Mahmoodabadi, M., Yazdanpanah, N., Sinobas, L.,R. andPazira, E. (2013) Reclamation of calcareous saline sodic soil with different amendments (1):Redistribution of soluble cations within the soil profile. Agricultural Water Management 120, 30-38.
20. Nirmalendu Basak, S. K. Chaudhari & D. K. Sharma (2015) Impact of Varying Ca/Mg Waters on Ionic Balance, Dispersion, and Clay Flocculation of Salt-Affected Soils, Communications in Soil Science and Plant Analysis, 46(7), 827-844. DOI: 10.1080/00103624.2014.1003937
21. Phyoe Phyoe Win, Swe Swe Mar, Yinn Mar Soe, Thu Zar and Kyaw Ngwe (2024), Assessment of Soil Chemical Properties under Different Land use System in Department of Agriculture Research, 8(4),1-7. https://doi.org/10.9734/asrj/2024/v8i4157
22. Pradeep Kumar, Parul Sundha, Nirmalendu Basak, Priyanka Chandra, Sandeep Bedwal and Arvind Kumar Rai (2024), Predominant Cropping Systems Affect Soil Organic Carbon Content in the Soil Profile of North–West India, *Journal of Soil Salinity and Water Quality, 16(2), 280-288. https://doi.org/10.56093/jsswq.v16i2.156658*
23. Rajan Pant, Dipendra Gurung, Bishal Bohara, Nishan Kafle, Janmajaya Gairhe, (2022), Spatial Analysis of Soil Characteristics Under Different Land Uses in Arun Rural Municipality and Shadananda Municipality of Bhojpur District, International Research Journal of Advanced Engineering and Science, 7(2), 249-254.
24. Shaloo, Rishi Pal Singh, Rajni Jain, Himani Bist, (2021), Assessment of Spatial Variability of Soil properties in Haryana using GIS Annals of Agri-Bio Research, 26(2), 169-172.
25. *Win PP, Mar SS, Soe YM, Zar T, Ngwe K. (2024) Assessment of soil chemical properties under cultivated soils in selected area of department of agricultural research. agpe the royal gondwana research. Journal of History, Science, Economic, Political and Social Science. 5(2),1-0.*