www.ijarp.com ISSN 2456-9992 Page: 01-06

International Journal Advanced Research Publications

Research Article

Volume: 02
Issue: 06

INVESTIGATION OF PHYSICO-CHEMICAL PROPERTIES OF SOIL AS A MULTIPHASE PHYSICAL SYSTEM IN SANJAY PARK, AMBIKAPUR, CHHATTISGARH

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Article Received: 6 May 2026, Article Revised: 26 May 2026, Published on: 16 June 2026

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Doi: https://doi-doi.org/101555/ijarp.1683

ABSTRACT

This research presents a systematic physical and chemical analysis of soil as a multiphase system collected from various sectors (sub-divided as locations R_1 to R_5) in Sanjay Park, Ambikapur (Surguja, Chhattisgarh). Soil dynamics are evaluated through fundamental principles of thermodynamics, fluid mechanics, and electrical charge transport. Key parameters including pH, Electrical Conductivity (EC), Organic Carbon (OC), and primary macronutrients (N, P, K) were quantified. Soil pH ranges from 5.1 to 6.7, showing slight acidity to near neutrality. Electrical conductivity values (0.14– 0.90 dS/m) demonstrate non-saline conditions suitable for sustainable flora maintenance. Natively generated TikZ/PGFPlots graphs describe spatial variations across the sampling profiles. The paper integrates classical transport equations to construct a quantifiable modeling matrix for soil ecosystem management.

INDEX TERMS: Multiphase Physical System, Porous Media, Darcy's Law, Fourier's Law, Ohm's Law, Electrical Conductivity, Soil Mechanics.

1 INTRODUCTION

Soil is a fundamental natural resource that plays a crucial role in sustaining terrestrial ecosystems and agricultural productivity. It is not merely a static layer of the Earth's crust but a dynamic and evolving system influenced by physical, chemical, and biological processes. In scientific research, particularly in interdisciplinary fields, soil is considered a complex physico-chemical system where multiple processes occur simultaneously.

From a physics perspective, soil can be understood as a heterogeneous porous medium that exhibits distinct macroscopic transport properties such as permeability, porosity, and electrical conductivity. The application of foundational physical principles allows for the mathematical modeling and quantitative analysis of fluid flow, thermal distribution, and ionic movement across the solid, liquid, and gaseous phases of the soil environment.

In recent years, extensive localized testing of natural systems—ranging from the surface and subsurface configurations of agricultural soils in Lakhanpur [6], the geological profiles of the high-altitude Mainpat area [7], to nearby hydrological matrices such as the Banki Dam [4] and Marine Drive Talab [10]—has underscored the strong dependence of resource quality on geographic and human-induced variations within the Surguja district.

2 Governing Physical Laws in Soil Media

To accurately map transport phenomena and baseline properties in the soil matrix, three critical physical principles are implemented.

2.1Fluid Dynamics: Darcy's Law

The physical transport of the fluid phase (water containing dissolved electrolytes) through the interconnected porous network of solid mineral aggregates is governed by Darcy's law. In a clean one-dimensional formulation, the fluid flux velocity vector v is written as:

$$v = -K \cdot \frac{dh}{dx} \qquad (1)$$

Where K represents the hydraulic conductivity or permeability of the soil layout, and $\frac{dh}{dx}$ indicates the hydraulic gradient. Soil structural shifts alter pore diameters, defining the system's hydraulic conductivity parameters. Environmental factors such as surface runoff from agricultural or semi-urban boundaries often introduce suspended sediment particles, which heavily clog or modify these open pore diameters, as evidenced by recurring turbidity anomalies observed in localized urban water systems [10].

2.2Thermodynamic Transport: Fourier's Law

Soil heat transfer modulates chemical solubility profiles and seed kinetics. The internal conductive heat flux q through the solid-liquid-gas boundary matrices follows Fourier's Law of Heat Conduction:

$$q = -\lambda \cdot \nabla T \quad (2)$$

Where λ represents the bulk thermal conductivity of the soil matrix (strongly modified by localized moisture content and bulk density parameters) and ∇T represents the spatial temperature gradient.

2.3Electrolytic Transport: Ohm's Law

The electrical profiling of the porous medium relies on the movement of dissolved ions within the fluid phase. The current density J within the pore channel network obeys the differential version of Ohm's Law:

$$J = \sigma \cdot E \quad (3)$$

Where σ represents the Electrical Conductivity (EC) of the soil matrix, and E is the localized applied electric field vector. The bulk parameters of σ provide an accurate indirect look at total soluble ion concentration levels. On a microscopic scale, this macroscopic ionic transport mirrors the behavior of weak or low-ionic-strength natural electrolyte systems [9], where current transmission remains fundamentally tied to the charge, volume fraction, and operational mobility of dissolved species under localized field potentials. Furthermore, a system's molecular capacity to sustain this polarization and govern overall ion dynamics remains strongly influenced by the bulk dielectric constant of the liquid media [8].

3 Methodology and Study Area

Systematic core soil samples were extracted from five locations (R_1 to R_5) within Sanjay Park, Ambikapur, situated in the Surguja district of Chhattisgarh. Samples were extracted at standardized core depths, dried, sieved through a 2 mm mesh to eliminate mechanical artifacts, and analyzed using standard scientific methods. The protocol follows standard physical-analytical methodologies used across similar local topsoil layer evaluations [6], [7] (glass electrode potentiometry for pH, conductivity cells for EC, and standard spectrophotometric/flame photometric protocols for macronutrients).

4 RESULTS AND DISCUSSION

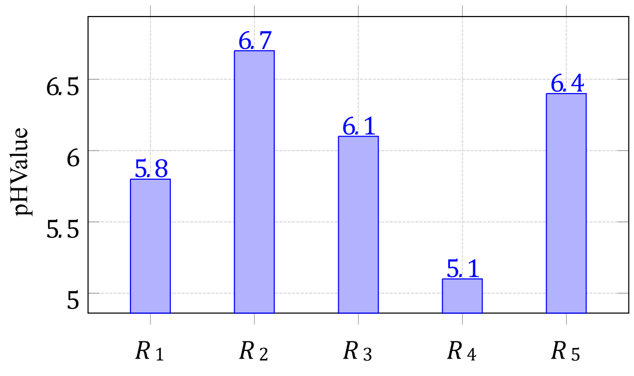
The empirical parameters derived from the five independent sampling sites are listed comprehensively in Table 1.

TABLE 1: Physico-Chemical Properties of Sampled Soil Sites.

Site ID	pH	EC (dS/m)	OC (%)	N (kg/ha)	K (kg/ha)
R_1	5.8	0.14	0.42	250.80	217.28
R_2	6.7	0.34	0.67	312.15	245.25
R_3	6.1	0.90	0.62	376.30	658.50
R_4	5.1	0.24	0.34	213.24	220.10
R_5	6.4	0.43	0.42	289.40	310.60

4.1Spatial Acidity and pH Fluctuations

The soil pH landscape falls between 5.1 and 6.7 across the study area. Site R_4 registers the most acidic profile ($pH = 5.1$), indicating higher localized acidity. This shift toward acidity modifies the structural integrity of localized mineral frameworks, frequently triggering phosphorus fixation via altered chemical interaction states. This moderately acidic distribution aligns closely with broader regional observations in the Surguja plains, such as the Lakhanpur block where soil profiles typically maintain a moderately acidic reaction range between 5.54 and 6.00 [6]. Sites R_2 and R_5 approach nearneutral baselines, matching trends seen in stable, unpolluted natural catchments like the Banki Dam reservoir network [4].

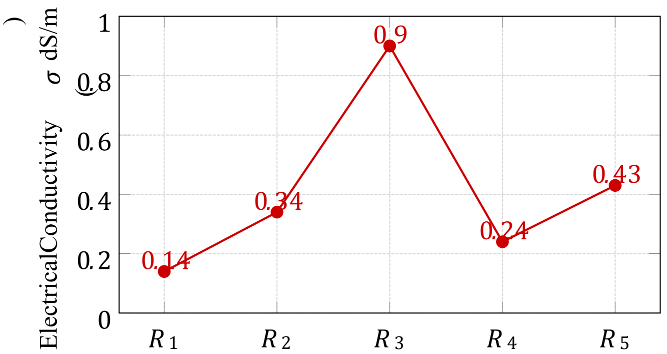


Sampling Sites

Fig. 1: Soil pH spatial profile across sampling sites showing a minimum at location R_4.

4.2Electrical Conductivity Gaps and Ionic Charge Flux

The baseline ion conduction profiles vary between 0.14 dS/m and 0.90 dS/m. In general, values below 2 dS/m fall into standard non-saline classifications. Interestingly, site R_3 (Sankar Ghat sector) spikes significantly to 0.90 dS/m. According to Ohm's Law (Eq. 3), this shift points to an elevated local concentration of mobile electrolytic salts in the liquid phase, increasing electrical current density parameters under an applied field gradient. This non-saline status is consistent with baseline observations recorded at nearby natural sources, such as the Ultapani water resource line (0.34 dS/m) [7] and Butapani flow points [5], which uniformly demonstrate safe mineral salt parameters well below critical salinity bounds.



Sampling Sites

Fig. 2: Electrical conductivity curve showing localized ionic accumulation at site R_3.

4.3Organic Carbon and Macronutrient Distribution

Organic Carbon ranges from 0.34% to 0.67%, confirming low to moderate organic accumulation compared to nearby agricultural profiles where surface organic carbon frequently extends past 0.75% due to crop residues [6]. Primary macronutrients display distinct spatial distributions. Nitrogen levels range from 213.24 kg/ha (R_4) to 376.30 kg/ha (R_3). Potassium concentrations vary widely, peaking at 658.50 kg/ha within site R_3, which indicates a mineral-rich parent structural material in that sector. This high concentration matches the elevated electrical conductivity documented at that specific site, illustrating how geological parental matrices define localized electro-physical transport pathways.

5 CONCLUSION

This study validates that the soil matrix in Sanjay Park, Ambikapur, functions as a highly variable, multiphase physical system. Incorporating transport mechanisms like Darcy's, Fourier's, and Ohm's laws allows for a precise structural assessment of porous soil frameworks. While the non-saline characteristics across all locations support proper biological growth, the distinct acidity pockets found at site R_4 demonstrate a clear need for targeted soil remediation measures, such as lime applications, to optimize nutrient availability.

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