

Evolution of Dielectric Properties of Soil in Korba District, Chhattisgarh, India

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Abstract

Soil dielectric properties yield crucial insights on soil moisture, texture, density, mineral makeup, salinity, temperature, and several physicochemical attributes. The dielectric response of soil is crucial for microwave remote sensing, soil moisture assessment, electromagnetic sensing, precision agriculture, hydrological studies, and environmental surveillance. Korba is a district marked by environmental and geological diversity, with agricultural terrain, vast forested areas, coal deposits, mining operations, thermal energy production, industrial growth, and diverse soil compositions. Official hydrogeological data reveals that over 83% of the district is comprised of yellowish-to-reddish Alfisols, around 14% consists of lateritic Ultisols, and lesser regions are occupied by Inceptisols.

The research examines the intricate relative permittivity, denoted by the real part (ϵ') and the imaginary part (ϵ''), throughout certain microwave frequency ranges. Soil specimens ought to be gathered from agricultural, forested, mining-impacted, industrial, riparian, and comparatively pristine reference sites under varying moisture circumstances. Measurements can be conducted utilizing a vector network analyzer in conjunction with a suitable coaxial probe or waveguide apparatus. Soil moisture, texture, bulk density, electrical conductivity, pH, organic matter, and specific elemental concentrations ought to be assessed concurrently. The correlation between dielectric response and environmental factors can thereafter be examined by statistical analysis and recognized dielectric mixing models.

The projected shift involves a pronounced enhancement in dielectric permittivity correlated with heightened soil water content, coupled with frequency-dependent dielectric dispersion and variations related to texture, bulk density, salinity, temperature, and anthropogenic impacts. This investigation can develop a district-specific dielectric database for Korba and aid in advancing soil moisture monitoring, environmental evaluation, microwave remote sensing, and precision agricultural practices.

Keywords: Soil dielectric properties, dielectric constant, dielectric attenuation, relative permittivity, soil hydration, microwave remote sensing, coal extraction, soil analysis, and environmental assessment.

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Introduction

Soil is a multifaceted multiphase system predominantly composed of mineral particles, organic material, water, and air. The comparative ratios and spatial configuration of these elements significantly affect its electrical and electromagnetic properties. The key electromagnetic properties of soil are its complicated dielectric permittivity, electrical conductivity, dielectric loss, and electromagnetic penetration attributes.

The complex relative dielectric permittivity can be expressed as

$$\epsilon^* = \epsilon' - j \epsilon''$$

Where: ϵ' = real part of relative permittivity or dielectric constant, ϵ'' = imaginary part or dielectric loss factor, and j = Square root of -1 .

The real part predominantly signifies the soil's ability to retain electromagnetic energy, while the imaginary part pertains to dielectric dissipation and conductive processes. Contemporary soil-sensing

studies validate that both elements are influenced by moisture levels, frequency, temperature, salinity, texture, clay minerals, density, and various other soil characteristics.

The remarkably elevated dielectric constant of water, in contrast to dry mineral soil and air, renders dielectric tests especially valuable for assessing soil-water content. The relative dielectric constant of water is roughly 80 in typical circumstances, but dry mineral soil typically exhibits a significantly lower value. Consequently, as water permeates soil pores, the effective dielectric constant typically rises. The correlation was quantitatively determined by **Topp, Davis, and Annan**, who examined soils within the frequency range of roughly 1 MHz to 1 GHz and formulated an empirical connection linking apparent dielectric constant to volumetric water content.

Nevertheless, a universal correlation may not consistently yield optimal precision due to the variability in mineral composition, texture, density, salinity, organic content, and bound-water properties of actual soils. Recent evaluations highlight the significance of localized calibration and the assessment of environmental and soil-specific variables.

This matter is especially pertinent to Korba District, where agricultural soils exist alongside forests, coal mines, thermal power facilities, urban expansion, and industrial environments.

Materials and Methods

Study Area: Korba District, Chhattisgarh

Korba District is situated in the northern region of Chhattisgarh. The district administration reports that the district encompasses roughly 7, 14, 544 hectares, which includes a significant forested region. The district headquarters is situated roughly 200 kilometers away from Raipur.

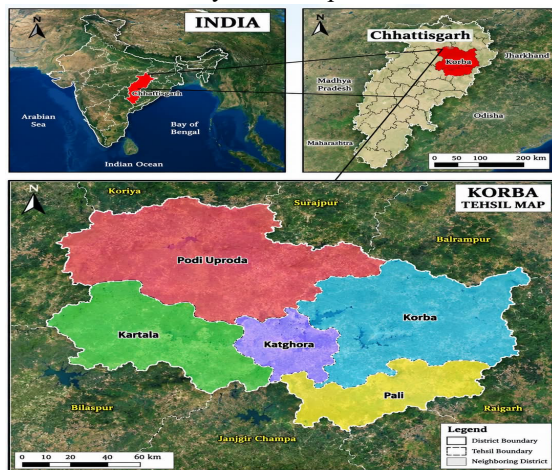


Fig. 1: Korba District Location Map

The Korba District is divided into five blocks: Korba, Kathgora, Pali, Kartala, and Pondi-Uproda. The Korba district is situated inside a hot climate zone, resulting in extremely high temperatures and arid conditions. The correlation between relative humidity and precipitation is significant.

The Central Ground Water Board indicates a geographical expanse of roughly 7,145.44 km², encompassing northern highland regions and the Chhattisgarh plain physiographic units. Prominent drainage systems encompass the Hasdeo, Teti, Son, and Mand rivers. The Hasdeo River holds significant importance as it affects drainage, groundwater replenishment, agricultural progress, and soil moisture allocation.

Korba endures a warm climate characterized by a significant monsoon period. District data indicates that the wet season typically spans from mid-June to September. The district administration indicates an average precipitation of roughly 1506.7 mm and a normative rainfall of around 1287.6 mm; however the Central Ground Water Board cites an annual average rainfall of approximately 1329 mm for its hydrogeological evaluation.

This seasonal precipitation pattern renders Korba especially apt for examining the temporal changes in soil dielectric characteristics.

A conventional seasonal cycle may be envisioned as:

Pre-monsoon dry soil → Monsoon wet soil → Post-monsoon drainage → Winter drying.

Given that soil dielectric permittivity is closely linked to moisture levels, these seasonal variations ought to provide quantifiable dielectric changes.

Soil Samples Collection

According to AILSC, Korba has three different types of soil: sandy clay soil, laterite soil, and red yellow soil. One of the most valuable natural resources supporting agricultural output is soil, which is primarily acidic in Korba. In addition to fly ash and loamy sand soil, the region has the following proportions of soil types: dorsa (33.92%), Kanhar (28.10%), and Mataci (26.65%). Five blocks in the Korba district—Korba, Kathgora, Pali, Kartala, and Pondi-Uproda—were used to gather soil samples. Identify the exact locations for soil samples in the five blocks of the Korba district's northern, southern, eastern, and western regions. At each site, collect soil samples at different depths (e.g., 0–15 cm, 15–30 cm) using systematic sampling techniques. The subsurface layer (15–30 cm) and the top layer (0–15 cm) were the two depths at which soil samples were collected.

Instruments required

Fourier-transform infrared (FTIR), ultraviolet (UV) spectrophotometer, sonicator (Ultrasonic Sonicator), conductivity meter, flame photometer, pH meter (Thermo Scientific), microbalance (Sartorius) and microwave test bench set up were used.

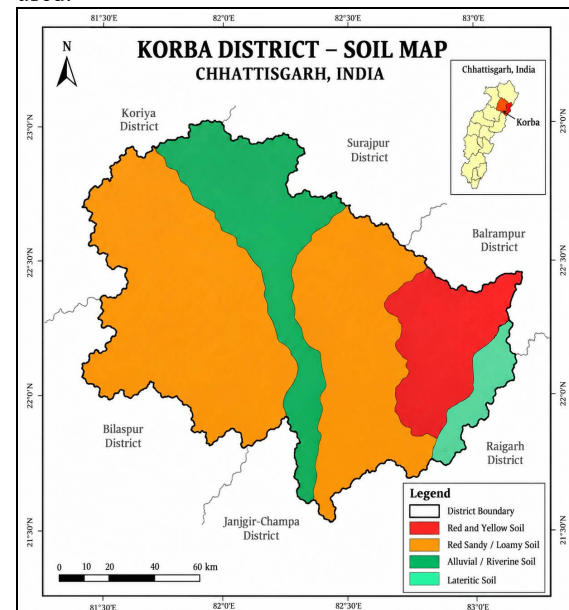


Fig.2: Korba District Soil Index
Fig.3: Map of the Chhattisgarh State

Table 1: Procedure used for Physico-Chemical Analysis of Soil of Korba District

Particulars	Methods	Scientist (years)
Texture	Bouyoucos Hydrometer	Bouyoucos (1927)
Soil Colour	Munsell Colour Chart	Munsell, (1911)
Particle Density (Mg m ⁻³)	Graduated measuring cylinder	Muthuval <i>et al.</i> , (1992)
Bulk Density (Mg m ⁻³)	Graduated measuring cylinder	Muthuval <i>et al.</i> , (1992)
Pore Space (%)	Graduated measuring cylinder	Muthuval <i>et al.</i> , (1992)
Water retaining capacity (%)	Graduated measuring cylinder	Muthuval <i>et al.</i> , (1992)
Soil pH	Digital pH meter	Jackson, (1958)
Electrical Conductivity	Digital EC meter	Wilcox, (1950)
Organic Carbon (%)	Rapid titration method	Walkley and Black, (1947)
Available Nitrogen (kg ha ⁻¹)	Kjeldahl method	Subbiah, (1956)
Available Phosphorous (kg ha ⁻¹)	Calorimetric method	Olsen <i>et al.</i> , (1954)
Available Potassium (kg ha ⁻¹)	Flame photometer method	Muthuval <i>et al.</i> , (1992)
Calcium and Magnesium (meq/100g)	EDTA method	Muthuval <i>et al.</i> , (1992)
Zinc (meq/100g)	DTPA method	Jackson, (1958)

Table 2: Physical Properties of Soil in Korba District

SAMPL E NO.	SA ND %	SI LT %	CL AY %	POROS ITY	BULK DENS ITY GM/C M ³
S1(Korb a)	75.05	2.03	22.03	0.1802	1.83
S2(Korb a)	75.05	2.06	22.89	0.203	1.61
S3(Pali)	76.08	2.12	21.88	0.2087	1.59
S4(Katg hora)	76.82	2.18	21	0.1574	1.57
S5(Katg hora)	77.89	2.3	19.81	0.2368	1.52
S6(Karta la)	77.95	2.35	19.7	0.1798	1.47
S7(Pond i-Uproda)	77.84	2.31	19.82	0.1989	1.49

Table 3: Chemical Properties of Soil in Korba District

Sa m ple	S1(Kor ba)	S2(Kor ba)	S3(P ali)	S4(Katg hora)	S5(Katg hora)	S6(Kar tala)	S7(Po ndi - Up rod a)
P H (1: 2.5)	6.5	6.48	6.72	6.47	6.36	6.31	6.34
E C (D sm ⁻¹)	0.11	0.06	0.08	0.1	0.09	0.13	0.14

O C (%)	0.57	0.51	0.525	0.561	0.559	0.59	0.61
Ca C O ₃ (%)	1.653	1.5	1.935	1.046	1.083	1.491	1.510
N (K g/ Ha)	138	140	143	155	160	148	151
P (K g/ Ha)	9.1	14.33	12.54	15.23	16.12	17.02	17.06
K (K g/ Ha)	214.1	303.06	350.51	322.1	357.62	365.97	367.21
Fe (p p m)	14.2	15.3	15.9	13.8	15.7	15.8	15.9
Zn (p p m)	0.7	0.65	0.83	0.58	0.92	0.86	0.88
Cu (p p m)	0.6	0.41	0.52	0.54	0.7	0.65	0.69
M n (p p m)	25.3	21.4	23.5	20.2	24.3	24.6	24.8

Dielectric Measurements

Dielectric investigations were conducted throughout a certain frequency range, extending from low radio frequencies to microwave frequencies, contingent upon the availability of equipment. The fluctuation of dielectric characteristics with frequency was noted as a result of the diminishing polarization mechanisms at elevated frequencies. Microwave dielectric assessments were performed at X-band frequency (9.967 GHz).

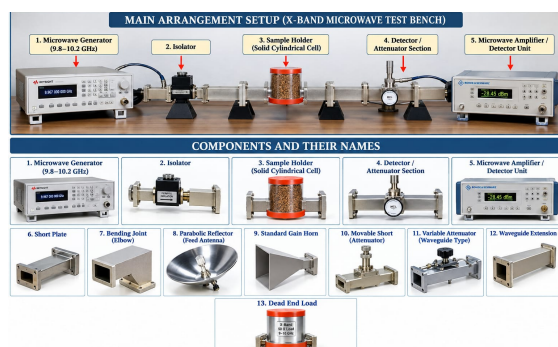


Fig. 4: X- Band Microwave Test Bench Setup

The samples were assessed for chemical characteristics such as pH, electrical conductivity, organic carbon, macronutrients, and micronutrients by established analytical techniques.

Furthermore, physical characteristics including soil texture, bulk density, porosity and moisture content were evaluated. The dielectric constants were assessed in the Department of Physics at Uma Vindhyavasini Sanskar College, Latori, District Surajpur, Chhattisgarh, employing an X-band microwave apparatus.

The two-point technique is the most acknowledged and extensively utilized approach for measuring complicated permittivity. It operates most well with "lossless" or somewhat lossy dielectrics. The dielectric constant and dielectric loss of the soil specimens were evaluated at 9.967 GHz (X-band) microwave frequencies using a microwave bench and the two-point technique. The reflex Klystron generates X-band microwave emissions. The sample holder for X-band assessments was fabricated using a conventional waveguide. To link the sample holder to the primary conduit, one extremity was affixed with a metallic flange, and the opposite extremity was meticulously shorted.

At first, without a dielectric present in the short-circuited line, the position of the first minimal dielectric resonance in the slotted line was determined. A soil specimen of specified dimensions and moisture level was positioned in the sample container, establishing contact with the short-circuited end. The initial minimal D position on the slotted line was later quantified, together with the associated VSWR. The Voltage Standing Wave Ratio was evaluated utilizing a VSWR meter. The incorporation of the VSWR meter enabled the amplitude modification of the microwave signal via pin diodes. The operation was performed on an extra soil specimen demonstrating the same moisture level and dimensions. The dielectric constant was evaluated at various moisture contents (0%, 10%, 20%, 30%, and 40%).

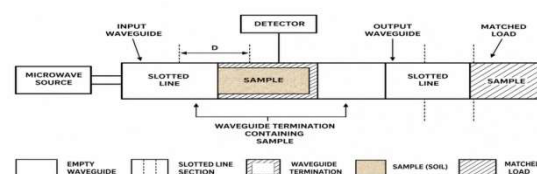


Fig.5: Measurement of Dielectric Constant of a High-Loss Material

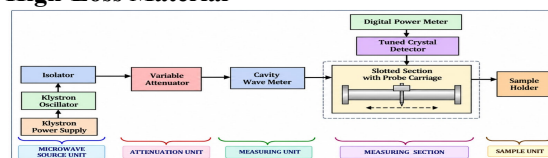


Fig. 6: Block diagram of experimental setup for measurement of dielectric properties

Table 4: Measured value real and imaginary part of dielectric constant of different moisture contents (10%, 20%, 30%, and 40%) for Korba District

S. No.	Sample	Real Part of Dielectric Constant					Imaginary Part of Dielectric Constant				
		Dry soil	10%	20%	30%	40%	Dry soil	10%	20%	30%	40%
1	S1	3.13	7.31	10.61	15.79	19.33	0.13	0.19	0.25	0.38	0.49
2	S2	3.16	7.34	10.63	15.82	19.35	0.14	0.19	0.26	0.39	0.49
3	S3	3.18	7.36	10.65	15.86	19.37	0.14	0.19	0.27	0.39	0.5
4	S4	3.2	7.39	10.66	15.89	19.38	0.15	0.21	0.27	0.4	0.51
5	S5	3.23	7.41	10.69	15.92	19.41	0.16	0.22	0.28	0.41	0.52
6	S6	3.27	7.44	10.72	15.96	19.44	0.16	0.23	0.28	0.41	0.52
7	S7	3.28	7.46	10.74	15.97	19.46	0.17	0.24	0.29	0.42	0.53

Graphical Analysis Required

Graphical analysis serves as a crucial instrument for depicting soil dielectric characteristics and comprehending the influence of factors including moisture content, particle density, bulk density, porosity, water retention capacity, and soil texture. It assists in identifying patterns, associations, fluctuations, and forecasting connections.

Dielectric Constant Vs Moisture Content Graph

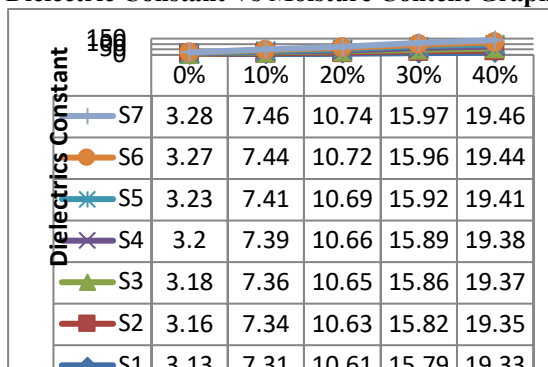


Fig.7: Variation of Real Part of Dielectric Constant with % of Moisture Content in Soil of Korba district at 0-15cm depth

Dielectric Constant Vs Soil Texture Graph

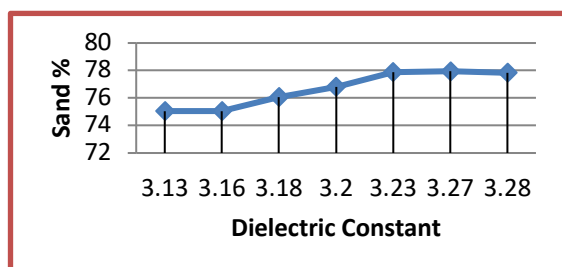


Fig.8: Variation of dielectric constant with % of Sand % in Soil of Korba district

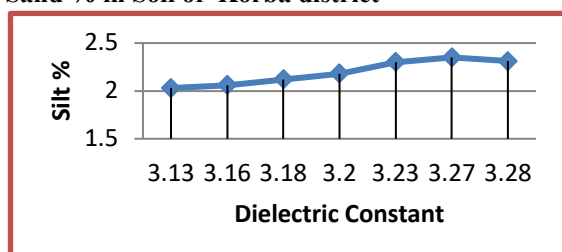


Fig.9: Variation of dielectric constant with % of Silt % in Soil of Korba district

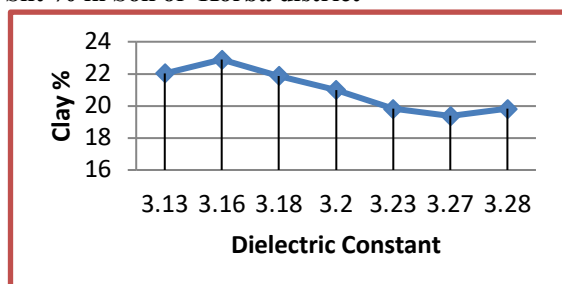


Fig.10: Variation of dielectric constant with % of Clay % in Soil of Korba district

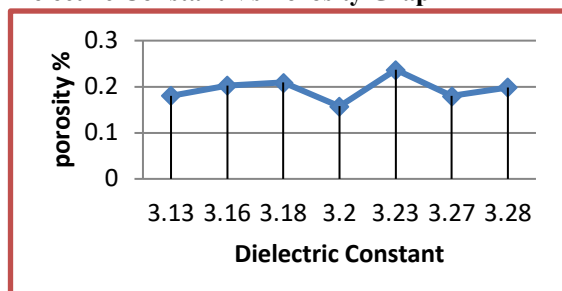


Fig.11: Variation of dielectric constant with % of porosity % in Soil of Korba district

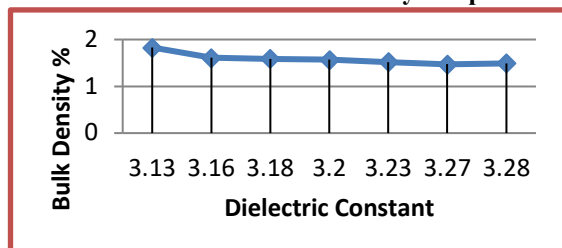


Fig.12: Variation of dielectric constant with % of Bulk Density % in Soil of Korba district

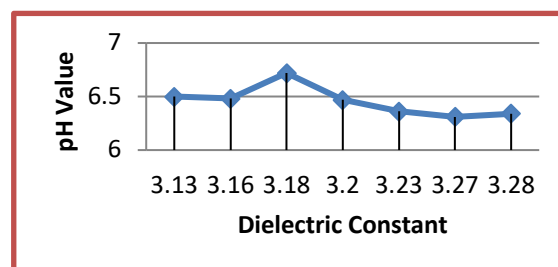


Fig.13: Variation of dielectric constant with % of pH value in Soil of Korba district

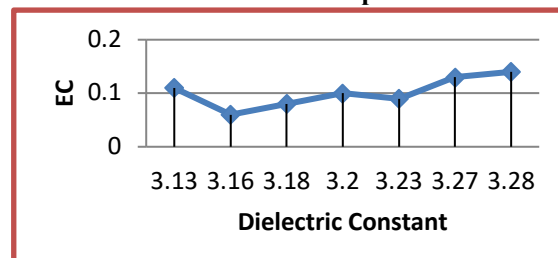


Fig.14: Variation of dielectric constant with % of EC in Soil of Korba district

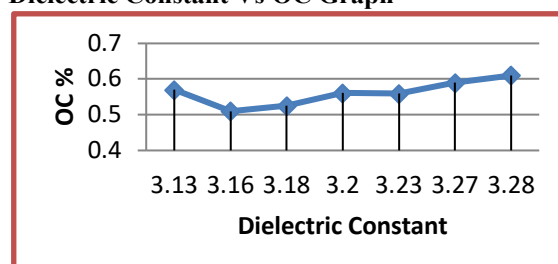


Fig.15: Variation of dielectric constant with % of OC% in Soil of Korba district

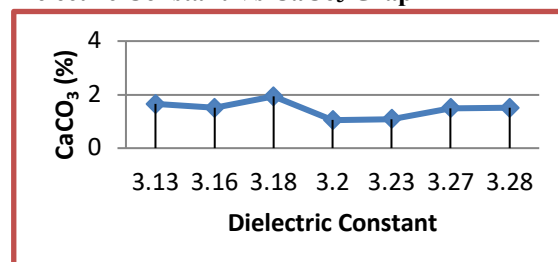


Fig.16: Variation of dielectric constant with % of CaCO₃ (%) in Soil of Korba district

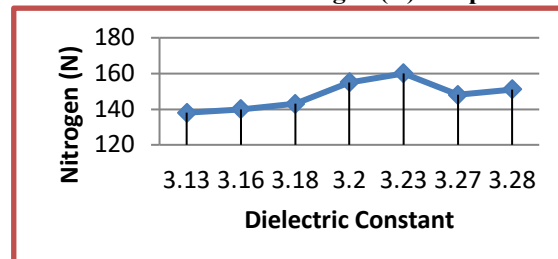


Fig.17: Variation of dielectric constant with % of Nitrogen (N) kg / ha in Soil of Korba district

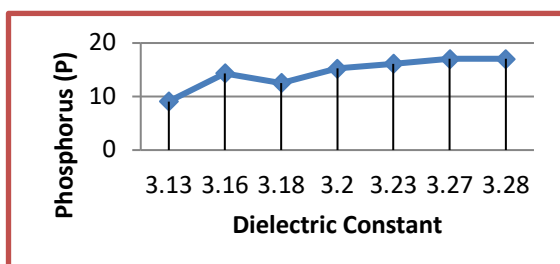


Fig.18: Variation of dielectric constant with % of Phosphorus (P) kg / ha in Soil of Korba district

Dielectric Constant Vs Potassium (K) Graph

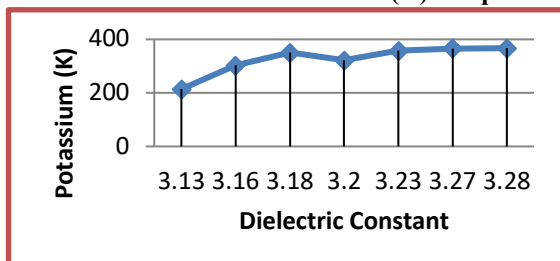


Fig.19: Variation of dielectric constant with % of Potassium (K) kg / ha in Soil of Korba district

Dielectric Constant Vs Iron (Fe) Graph

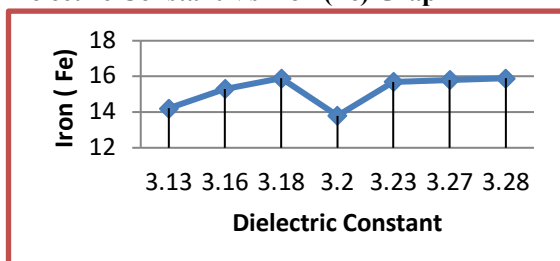


Fig.20: Variation of dielectric constant with % of Iron (Fe) ppm in Soil of Korba district

Dielectric Constant Vs Zinc (Zn) Graph

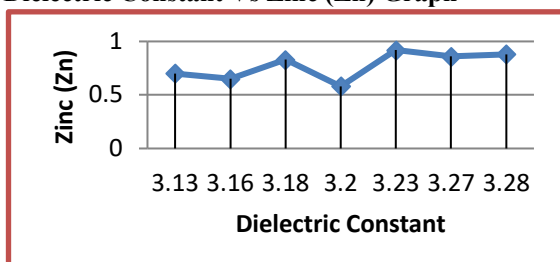


Fig.21: Variation of dielectric constant with % of Zinc (Zn) ppm in Soil of Korba district

Dielectric Constant Vs Copper (Cu) Graph

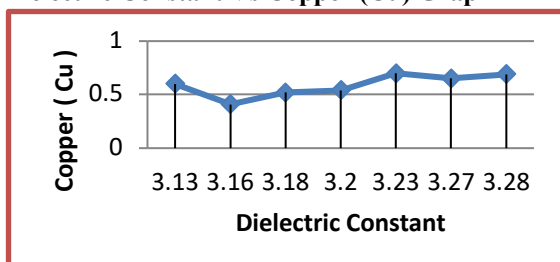


Fig.22: Variation of dielectric constant with % of Copper (Cu) ppm in Soil of Korba district

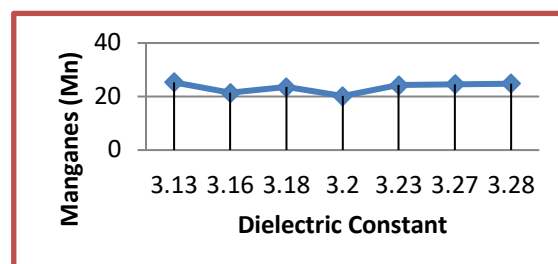


Fig.23: Variation of dielectric constant with % of Manganese (Mn) ppm in Soil of Korba district

Results and Discussion

The dielectric properties of soil in Korba District, Chhattisgarh, India were evaluated at 0–15 cm depths across various moisture levels (dry, 10%, 20%, 30%, and 40%). Soil texture, bulk density, porosity, and complex dielectric permittivity (including both real and imaginary parts) were examined to understand the influence of moisture and soil physical characteristics on electromagnetic properties. The findings correspond with established soil dielectric theory, suggesting that a rise in soil moisture content enhances both the dielectric constant and dielectric loss, given that water has far more dielectric permittivity than mineral soil constituents.

The correlation between the real component of the dielectric constant (ϵ') in arid soil conditions and various physical, chemical, and nutritional attributes was examined for seven soil samples obtained from diverse sites in the Korba area of Chhattisgarh. The dielectric constant of dry soil ranged from 3.13 to 3.28, signifying minor yet quantifiable variations among the soil specimens.

Sand (%) Vs Dielectric Constant

The sand composition fluctuated between 75.05 and 77.95%, but the dielectric constant of the dry soil spanned from 3.13 to 3.28. S1, containing 75.05% sand, demonstrated a dielectric constant of 3.13, whereas S6, with the maximum sand composition of 77.95%, revealed a dielectric constant of 3.27. The statistics indicate a favorable correlation between sand content and ϵ' under arid environments. Nonetheless, the correlation is not entirely linear as many soil components, such as clay, organic matter, mineral makeup, porosity, and bulk density, can influence the effective dielectric response. Given that the soil is primarily sandy, fluctuations in the mineral composition might account for some of the detected dielectric variance.

Silt% Vs Dielectric Constant

The silt concentration varied between 2.03 and 2.35%. The minimum silt concentration was seen in S1 (2.03%), which had a dielectric constant of 3.13, whilst the maximum silt concentration was found in S6 (2.35%), with $\epsilon' = 3.27$. A predominantly favorable correlation was discovered between silt concentration and the dielectric constant of dry soil. Nonetheless, the

limited variation in silt concentration implies that its specific impact cannot be distinctly isolated from the influences of other soil characteristics.

Clay% Vs Dielectric Constant

The clay composition varied between 19.70% and 22.89%. S2 exhibited the most clay composition at 22.89% and a dielectric constant of 3.16, while S6 displayed the least clay concentration at 19.70% with $\epsilon' = 3.27$.

The data indicate a general inverse relationship between clay concentration and dry-soil ϵ' , unlike that observed with sand and silt. This outcome must be regarded with caution due to the inverse relationship between clay and sand content in these samples. Thus, the observable clay-dielectric correlation may, in part, represent the cumulative influence of soil texture instead of a standalone effect of clay.

Porosity Vs Dielectric Constant

Porosity measurements varied between 0.1574 to 0.2368. S4 demonstrated the minimal porosity of 0.1574 and an ϵ' value of 3.20, while S5 displayed the maximal porosity of 0.2368 and an ϵ' of 3.23. The correlation between porosity and the dielectric constant of dry soil is tenuous and irregular. This is logical as, in arid conditions, the pores are primarily filled with air, which possesses a minimal dielectric constant. Consequently, alterations in pore volume by themselves may not lead to a significant rise in ϵ' unless they are coupled with modifications in mineral composition or residual moisture.

Bulk Density Vs Dielectric Constant

Bulk density ranged from 1.47 to 1.83 g cm⁻³. S1 exhibited the most bulk density (1.83 g cm⁻³) and the minimum dielectric constant (3.13), whilst S6 displayed the minimum bulk density (1.47 g cm⁻³) and a dielectric constant of 3.27.

The findings suggest a general negative correlation between bulk density and the dielectric constant of dry soil. Nonetheless, the association is affected by the concurrent changes in texture and porosity. Bulk density ascertains the comparative ratios of solid particles to pore space; hence, its effect on ϵ' is heavily reliant on the dielectric characteristics of the soil minerals and the substances filling the pores.

pH value Vs Dielectric Constant

The pH of the soil varied between 6.31 and 6.72. S3 exhibited the highest pH level of 6.72 and a dielectric constant (ϵ') of 3.18, while S6 displayed the lowest pH of 6.31 and a dielectric constant (ϵ') of 3.27.

The findings do not reveal a robust systematic correlation between pH and the dielectric constant of dry soil. This is anticipated as pH mainly characterizes soil chemical interactions and does not directly indicate the volumetric proportion of dielectric-active components. Any correlation identified in the current dataset is probably indirect

and may stem from variations in mineralogy or organic matter.

Electrical Conductivity Vs Dielectric Constant

Electrical conductivity measurements fluctuated between 0.06 and 0.14 dS m⁻¹. The minimum electrical conductivity (EC) was recorded in S2 at 0.06 dS m⁻¹, accompanied with $\epsilon' = 3.16$, whilst S7 exhibited the maximum EC at 0.14 dS m⁻¹, with $\epsilon' = 3.28$.

A discernible correlation exists between EC and dry-soil ϵ' . Nonetheless, all specimens exhibit comparatively modest electrical conductivity, and the variation is limited. Consequently, EC is improbable to be the principal element influencing the actual dielectric constant in arid environments. The influence of conductivity often increases when soluble ions are linked to enough water content.

Organic Carbon % Vs Dielectric Constant

Organic carbon fluctuated between 0.51 and 0.61%. S2 exhibited the minimal OC at 0.51% and ϵ' of 3.16, while S7 demonstrated the maximal OC at 0.61% and ϵ' of 3.28.

The findings suggest a broad favorable correlation between organic carbon and ϵ' . Organic matter can influence soil aggregation, pore configuration, moisture retention, and the dielectric characteristics of the soil matrix. Nonetheless, due to the limited scope of the OC range, its autonomous impact cannot be determined from the current dataset of seven samples.

CaCO₃ % Vs Dielectric Constant

The CaCO₃ concentration varied between 1.046 and 1.935%. S3 exhibited the peak CaCO₃ level at 1.935%, although possessed a comparatively low dielectric constant of 3.18. S4 exhibited the minimal concentration of CaCO₃ at 1.046% and $\epsilon' = 3.20$. The findings indicate an absence of a definitive monotonic correlation between CaCO₃ and the dielectric constant of dry soil. This suggests that the influence of carbonate concentration on ϵ' is probably less significant than the cumulative impacts of texture, mineral composition, density, and pore structure in the analyzed samples.

Accessible Nitrogen Vs Dielectric Constant

Nitrogen availability varied between 138 and 160 kg ha⁻¹. S1 exhibited the minimum nitrogen concentration at 138 kg ha⁻¹ with $\epsilon' = 3.13$, whereas S5 displayed the maximum nitrogen concentration at 160 kg ha⁻¹ with $\epsilon' = 3.23$. A slight positive correlation is noted between available nitrogen and ϵ' . The correlation between nitrogen availability and organic matter, as well as biological processes, suggests that the relationship with dielectric permittivity is likely indirect.

Accessible Phosphorus Vs Dielectric Constant

The quantity of available phosphorus varied between 9.10 and 17.06 kg ha⁻¹. S1 exhibited the minimal phosphorus concentration (9.10 kg ha⁻¹) with $\epsilon' = 3.13$, whereas S7 demonstrated the maximal phosphorus concentration (17.06 kg ha⁻¹)

with $\epsilon' = 3.28$. The data indicate a general favorable correlation between available phosphorus and ϵ' . This could indicate the impact of related soil attributes including organic content, mineral makeup, and moisture-holding capabilities instead of a direct dielectric action of phosphorus.

Accessible Potassium Vs Dielectric Constant

The measured potassium levels exhibited a considerable spectrum of 214.10–367.21 kg ha⁻¹. S1 recorded the minimum K concentration at 214.10 kg ha⁻¹ with $\epsilon' = 3.13$, whilst S7 displayed the maximum K concentration at 367.21 kg ha⁻¹ with $\epsilon' = 3.28$. A more pronounced positive correlation is evident between potassium and the dry-soil dielectric constant in comparison to various other nutritional metrics. Samples S5, S6, and S7 exhibited comparatively elevated K values alongside substantial dielectric constants. Nonetheless, this correlation should not be construed as a direct causal link, as potassium concentration may fluctuate alongside mineralogical composition and other soil characteristics.

Iron (Fe) Vs Dielectric Constant

Iron content varied between 13.8 and 15.9 ppm. S4 had the minimal Fe content at 13.8 ppm, with $\epsilon' = 3.20$, whereas S3 and S7 displayed concentrations of 15.9 ppm and dielectric constants of 3.18 and 3.28, respectively. The correlation between Fe and ϵ' seems tenuous and inconsistent. The limited variation in Fe concentration and the impact of other soil components complicate the establishment of a clear link.

Zinc (Zn) Vs Dielectric Constant

Zinc content varied between 0.58 and 0.92 ppm. S4 exhibited the minimal Zn concentration at 0.58 ppm and $\epsilon' = 3.20$, while S5 displayed the maximal Zn concentration at 0.92 ppm and $\epsilon' = 3.23$. The data indicate a little positive correlation between Zn and the real component of the dielectric constant. Nevertheless, the correlation is not adequately stable to directly link variations in ϵ' to Zn concentration.

Copper (Cu) Vs Dielectric Constant

The value of Cu ranged from 0.41 to 0.70 ppm. The lowest Cu content was observed in S2 (0.41 ppm), with $\epsilon' = 3.16$, whereas S5 exhibited the highest Cu concentration (0.70 ppm), with $\epsilon' = 3.23$. A general favorable trend is noted, however the correlation is quite tenuous. Similar to Zn and Fe, Cu exists in minimal amounts and is improbable to serve as a principal factor influencing the overall dielectric constant in arid environments.

Manganese (Mn) Vs Dielectric Constant

The content of Mn varied between 20.2 and 25.3 ppm. S4 exhibited the minimal Mn concentration at 20.2 ppm and $\epsilon' = 3.20$, while S1 displayed the maximal Mn concentration at 25.3 ppm and $\epsilon' = 3.13$. The Mn data exhibit a negative and somewhat

feeble correlation with ϵ' . The correlation is not consistent among all samples, suggesting that Mn content by itself does not account for the variations seen in dry-soil dielectric response.

The analysis of specific soil characteristics against the real component of the dielectric constant at 0% moisture indicates that the dielectric response is predominantly affected by the physical structure and density of the soil matrix rather than by distinct chemical or nutrient factors.

- Favorable trend: Sand, silt, electrical conductivity, organic carbon, nitrogen, phosphorus, potassium, zinc, and copper.
- Adverse trend: Clay, mass density, and manganese.
- Inconsistent/non-systematic inclination: Porosity, pH, CaCO₃, and Fe.

These tendencies ought to be considered as initial correlations, given the research relies on merely seven samples. To enhance the scientific rigor of a research paper's conclusion, it is essential to compute the Pearson correlation coefficient (r), p -value, R^2 , and regression equation for each parameter in relation to ϵ' at 0% moisture. This will enable the correlations to be conveyed quantitatively instead of merely descriptively.

References

1. Bouyoucos, G. J. (1927). The hydrometer as a new method for the mechanical analysis of soils. *Soil Science*, 23(5), 343–354.
2. Jackson, M. L. (1958). *Soil chemical analysis*. Prentice-Hall.
3. Munsell Color. (1975). *Munsell soil color charts*. Munsell Color.
4. Muthuval, P., Udayasoorian, C., Nateson, R., & Ramaswami, P. P. (1992). *Laboratory manual for physical and chemical analysis of soil: Introduction to soil analysis*. Coimbatore, India.
5. Olsen, S. R., Cole, C. V., Watanabe, F. S., & Dean, L. A. (1954). Estimation of available phosphorus in soils by extraction with sodium bicarbonate (USDA Circular No. 939). U.S. Department of Agriculture.
6. Subbiah, B. V., & Asija, G. L. (1956). A rapid procedure for the estimation of available nitrogen in soils. *Current Science*, 25, 259–260.
7. Survey of India. (2025). *Chhattisgarh: State map [Map]* (4th ed., Scale 1:1,000,000). Government of India.
8. Walkley, A., & Black, I. A. (1934). An examination of the Degtjareff method for determining soil organic matter, and a proposed modification of the chromic acid titration method. *Soil Science*, 37(1), 29–38. <https://doi.org/10.1097/00010694-193401000-00003>

9. Wilcox, L. V. (1950). Electrical conductivity. Journal of the American Water Works Association.