IJARSCT
International Journal of Advanced Research in Science, Communication and Technology
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
ISSN: 2581-9429
Volume 5, Issue 11, April 2025
Impact Factor: 7.67

Microwave Characterization of Soil Conductivity Post Contamination and Reclamation at 10.58 GHz

Nima P. Golhar
Associate Professor, Physics Departmen,
Nanasaheb Y. N. Chavan Arts, Science and Commerce College, Chalisgaon, Dist- Jalgaon. Maharashtra. 424101
nima.golhar@rediffmail.com

Abstract: *This study investigates the conductivity behaviour of contaminated and reclaimed soil samples over varying moisture contents at a frequency of 10.58 GHz. Measurements were taken across a range of moisture contents (0–30%) for five different sample sets. Results indicate that contamination significantly elevates soil conductivity compared to reclaimed soils, with differences becoming more pronounced at higher moisture contents. These findings contribute to the understanding of dielectric property restoration following soil reclamation processes.*

Keywords: soil conductivity, contamination, reclamation, moisture content,

I. INTRODUCTION

Soil contamination by hydrocarbons and industrial waste alters its electromagnetic properties, especially conductivity, impacting applications in geophysical sensing, environmental monitoring, and agriculture [1][2]. The dielectric behavior of soil at microwave frequencies, such as 10.58 GHz, is particularly important for remote sensing and ground-penetrating radar applications [3]. Restoration or reclamation processes aim to reduce contamination levels and restore soil properties to near-natural conditions. However, the extent to which conductivity is restored post-reclamation remains underexplored, particularly at high frequencies.

This study focuses on the comparative analysis of the conductivity of contaminated and reclaimed soil samples as a function of moisture content, utilizing precision measurements at 10.58 GHz. Understanding these variations is critical for validating soil remediation effectiveness and enhancing predictive electromagnetic models [4].

II. MATERIALS AND METHODS

Sample Preparation:

Five contaminated soil samples were collected from industrially polluted sites, while their corresponding reclaimed samples were obtained after undergoing bioremediation processes. The soils were oven-dried to eliminate existing moisture, then rehydrated systematically to achieve moisture contents of 0%, 5%, 10%, 15%, 20%, 25%, and 30% by weight.

Conductivity Measurement:

Conductivity measurements were carried out using a vector network analyzer operating at 10.58 GHz, calibrated with standard procedures [5]. The complex permittivity of each sample was determined, and conductivity was extracted following the Debye relaxation model [6].

The physical and chemical properties of soil samples were measured from soil testing laboratory of Government Agriculture College, Pune. The Soil samples were analyzed for soil pH, Electrical Conductivity, Organic Carbon, Calcium carbonate, Nitrogen, Phosphorus, Potassium, Iron, Manganese, Zinc, Copper, Calcium, Magnesium, Particle Density, Bulk Density, Sand, Slit, Clay and Textural Class. By using chemical analysis of contaminated soil samples, these contaminated soil samples were reclaimed with the help of Compost, Urea, Single Super Phosphate and Potash according to suggestions given by agricultural officer.

IJARSCT
International Journal of Advanced Research in Science, Communication and Technology
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
ISSN: 2581-9429 Volume 5, Issue 11, April 2025 Impact Factor: 7.67

The wave-guide cell method is used to determine the dielectric properties of contaminated and reclaimed soil samples. Dielectric constant (ε') of soils, contaminated soils and reclaimed soils with various moisture content will be determined at different microwave frequencies. Then the other dielectric parameters such as loss factor (ε''), loss tangent (tanδ), conductivity (σ) and emissivity (e) will be calculated by using the formulae given below (5),

Dielectric constant (ε')

$$\varepsilon' = \frac{\left(\frac{a}{\pi}\right)^2 \left(\frac{x}{l_\varepsilon}\right)^2 + 1}{\left(\frac{2a}{\lambda_g}\right)^2 + 1}$$

where, a = inner width of rectangular waveguide,
λg = guide wavelength
lε = sample length,
In this equation, x is calculated by following equation,

$$\tan x / x = \frac{\tan\left[\beta\left(l_\varepsilon + D_R - D\right]\right.}{\beta\, l_\varepsilon}$$

where β = 2π / λg, β is phase shift
(DR – D) is shift in minima
DR is minima without sample
D is minima with sample

If this value is close to the approximately known value, then the value obtained is true value. Otherwise repeat the experiment and so on. If approximate value of dielectric constant is not known, then identical experiments are to be performed with the samples of different lengths (multiple of λg / 4).

ii) Loss tangent (tan δ)

The Loss tangent is calculated using the formula,

$\tan\delta = \{|\Delta x_s - \Delta x| / \varepsilon' l_\varepsilon\} \times (\lambda_o / \lambda_g)^2$

where, λo - free space wavelength
Δx- width at twice minima without sample
Δxs - width at twice minima with sample in the waveguide touching the short circuit end.

iii) Loss factor (ε'')

$$\varepsilon'' = \varepsilon' \tan\delta$$

iv) Microwave conductivity (σ)

$$\sigma = f\,\varepsilon' \tan\delta / 1.8 \times 10^{12} \quad \text{or} \quad \sigma = \omega\varepsilon_o\varepsilon'' .$$

III. DATA SUMMARY, RESULTS AND DISCUSSION

The conductivity values of contaminated and reclaimed soil samples obtained are presented in Table 1 and Table 2 respectively. Each row corresponds to a moisture content level, and the columns differentiate between contaminated and reclaimed soils for each sample number (S.N.1 to S.N.5). Figure 2. Represents the graphs of conductivity of contaminated and reclaimed soil samples.

MC	S.N.1	S.N.2	S.N.3	S.N.4	S.N.5
0%	0.02947	0.05293	0.03558	0.01917	0.02105
5%	0.04576	0.06099	0.05499	0.0464	0.04393
10%	0.0574	0.06611	0.07193	0.05464	0.05305
15%	0.06128	0.07599	0.07752	0.06216	0.06716
20%	0.07081	0.08069	0.0911	0.07169	0.08004

IJARSCT

International Journal of Advanced Research in Science, Communication and Technology

International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal

ISSN: 2581-9429

Volume 5, Issue 11, April 2025

Impact Factor: 7.67

25%	0.08216	0.08669	0.0971	0.07928	0.08557
30%	0.09228	0.09345	0.10257	0.09069	0.08945

Table. 1. Conductivity of contaminated soil samples

MC	S.N.1	S.N.2	S.N.3	S.N.4	S.N.5
0%	0.009	0.01076	0.00676	0.00518	0.00229
5%	0.01412	0.01659	0.01594	0.02041	0.00876
10%	0.03958	0.02476	0.02799	0.03041	0.01123
15%	0.05375	0.03388	0.04223	0.0494	0.01406
20%	0.06563	0.03864	0.06134	0.05981	0.02999
25%	0.0751	0.05176	0.06699	0.07669	0.04511
30%	0.07851	0.05981	0.0714	0.08681	0.05928

Table. 2. Conductivity of reclaimed soil samples

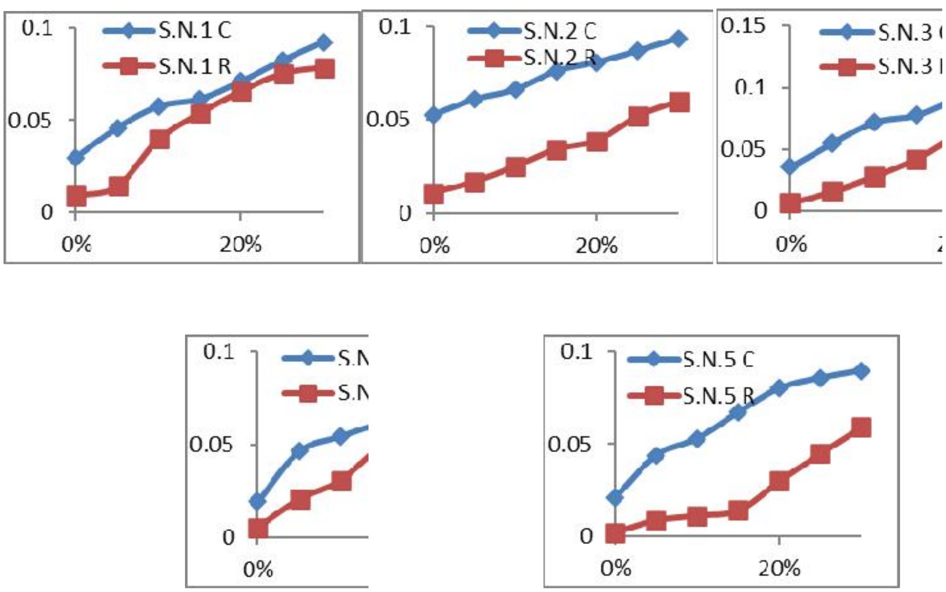

Fig. 1. Conductivity of all contaminated and reclaimed soil samples.

The conductivity of contaminated soils consistently exceeded that of reclaimed soils across all moisture levels (Table 1). At 0% moisture, contaminated soil samples exhibited baseline conductivities approximately 2 to 10 times higher than reclaimed soils. This difference can be attributed to the presence of residual conductive contaminants [7].

As moisture content increased, conductivity rose for both soil types, in line with previous findings that moisture enhances ion mobility in soils [8]. However, the rate of conductivity increase was more pronounced in contaminated soils. For instance, at 30% moisture content, S.N.3 contaminated soil showed a conductivity of 0.1026 S/m compared to 0.0714 S/m for its reclaimed counterpart, reflecting a 43.7% higher value.

Interestingly, while reclamation successfully reduced the overall conductivity, none of the reclaimed samples fully matched the low conductivity levels typically expected of uncontaminated soils at similar moisture contents [9]. This suggests that while remediation reduces mobile ion concentration, traces of conductive residues or altered mineralogy remain even after treatment.

DOI: 10.48175/IJARSCT-25807

Another observation is the reduction in variability among the five sample sets as moisture content increased. At higher moisture levels, the conductivity curves for all samples converged, indicating moisture as a dominant controlling factor over contamination history.

IV. CONCLUSION

This study highlights the persistent impact of contamination on soil conductivity, even after reclamation efforts. While moisture content significantly modulates conductivity in both contaminated and reclaimed soils, contaminated soils maintain consistently higher conductivity values at all moisture levels. These results underscore the importance of thorough remediation monitoring and suggest that electromagnetic surveys at microwave frequencies could be a useful tool for post-reclamation assessment.

Future work should investigate the long-term stability of reclaimed soils under varying environmental conditions and explore enhanced remediation techniques to further minimize residual conductivity anomalies.

V. ACKNOWLEDGMENT

The author is thankful to Prof. P.R.Chaudhari and Head of Physics Department and Principal, Z.B. Patil College, Dhule for providing research facilities. I am also very much thankful to the Principal, Nanasaheb Y. N. Chavan Arts, Science and Commerce College, Chalisgaon for his valuable guidance and kind co-operation.

REFERENCES

[1]. S. P. Friedman, “Soil properties influencing apparent electrical conductivity: a review,” Computers and Electronics in Agriculture, vol. 46, no. 1–3, pp. 45–70, 2005.

[2]. Revil and L. M. Cathles, “Fluid transport by capillarity and electroosmosis in unsaturated porous media: Electrical conductivity data,” Journal of Geophysical Research, vol. 104, 1999.

[3]. Mätzler, “Microwave dielectric properties of natural materials,” Remote Sensing of Environment, vol. 18, pp. 263–280, 1995.

[4]. N. N. Shilov, Dielectric and Electromagnetic Properties of Soil, CRC Press, 2001.

[5]. Keysight Technologies, ENA Series Network Analyzer: Measurement Guide, 2020.

[6]. R. Pethig, Dielectric and Electronic Properties of Biological Materials, Wiley, 1979.

[7]. M. L. Jackson, Soil Chemical Analysis: Advanced Course, 1958.

[8]. Or and J. M. Wraith, “Temperature effects on soil bulk dielectric permittivity measured by time domain reflectometry: A physical model,” Water Resources Research, vol. 35, no. 12, pp. 3711–3719, 1999.

[9]. J. A. Huisman et al., “Monitoring tracer movement in a forest soil using electrical resistivity tomography and time domain reflectometry,” Vadose Zone Journal, vol. 2, pp. 479–490, 2003.