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High-Frequency Electrical Conductivity of Soils: Effects of Contamination and Reclamation at 10 GHz

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Abstract: *This paper presents a comparative analysis of the electrical conductivity of contaminated and reclaimed soil samples at a high radio frequency of 10 GHz. The purpose of this study is to evaluate how soil contamination and subsequent reclamation affect the soil's ability to conduct electrical signals in the gigahertz frequency band. Conductivity measurements were obtained for five distinct soil samples across varying moisture content levels ranging from 0% to 30%. The results indicate a significant difference in conductivity values between contaminated and reclaimed soils, particularly at higher moisture content.*

Keywords: Soil conductivity, 10 GHz, contaminated soil, reclaimed soil, moisture content, electromagnetic properties

I. INTRODUCTION

Understanding the dielectric and conductive properties of soil at microwave frequencies is crucial for a range of applications including remote sensing, ground-penetrating radar, and telecommunications. Electrical conductivity (EC) is a crucial parameter for assessing soil salinity and overall soil health. It is expressed in deciSiemens per meter (1) (dS/m) and is widely used in agriculture, environmental science, and soil science to monitor soil salinity. It provides insights into the concentration of soluble salts and helps in understanding the soil's ability to support plant growth and nutrient uptake. Soil conductivity depends heavily on factors such as moisture content, chemical composition, and particle size. Contamination can alter the ionic concentration in the soil, thereby modifying its conductive characteristics. This study aims to investigate and compare the conductivity behavior of contaminated and reclaimed soils at 10 GHz, a frequency relevant to satellite and radar communication.

II. METHODOLOGY

Soil samples were collected from a contaminated site and a corresponding site that had undergone a reclamation process. The soil contaminated sites due to Oil factory, Chemical factory, Sugar factory and Textile mills are selected for this study. Each set comprised five samples labeled S.N.1 through S.N.5. The samples were subjected to varying levels of moisture content: 0%, 5%, 10%, 15%, 20%, 25%, and 30%.

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.

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 ($\tan\delta$), conductivity (σ) and emissivity (e) will be calculated by using the formulae given below (5),

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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).

Loss tangent (tan δ)

The Loss tangent is calculated using the formula (Lance, 1964)

tan δ = {|Δxs - Δx| / ε'lε} x (λo / λg)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.
Loss factor (ε")
ε" = ε' tan δ
Microwave conductivity (σ)
σ = f ε' tan δ / 1.8 x 1012 or σ = ωεoε"

III. RESULTS AND ANALYSIS

The measured conductivity values (in S/m) for contaminated and reclaimed soil samples are summarized as follows:

Moisture	S.N.1 (Cont./Recl.)	S.N.2 (Cont./Recl.)	S.N.3 (Cont./Recl.)	S.N.4 (Cont./Recl.)	S.N.5 (Cont./Recl.)
0%	0.028901 / 0.003501	0.038293 / 0.005224	0.041850 / 0.002890	0.043684 / 0.002557	0.024677 / 0.002001
5%	0.054411 / 0.007003	0.045907 / 0.006558	0.053744 / 0.005558	0.061303 / 0.004224	0.033347 / 0.009115
10%	0.070195 / 0.012505	0.056301 / 0.018952	0.060524 / 0.020453	0.067527 / 0.005335	0.053188 / 0.011171
15%	0.080366 / 0.018785	0.088036 / 0.024288	0.063192 / 0.027178	0.079254 / 0.010449	0.061358 / 0.017674
20%	0.088036 /	0.108266 /	0.085812 /	0.101930 /	0.069917 /

	0.022898	0.031957	0.040516	0.020008	0.023009
25%	0.123661 / 0.027289	0.134888 / 0.043295	0.094816 / 0.035681	0.122327 / 0.029345	0.079977 / 0.029790
30%	0.128163 / 0.029290	0.162288 / 0.054911	0.106432 / 0.050687	0.141502 / 0.045741	0.090981 / 0.037126

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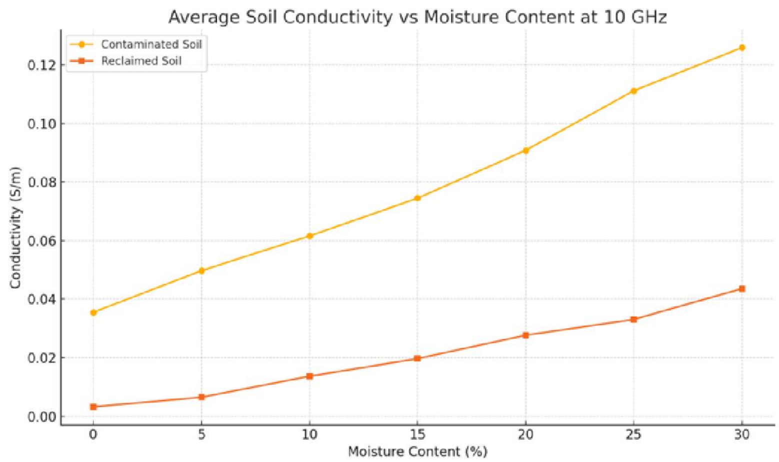
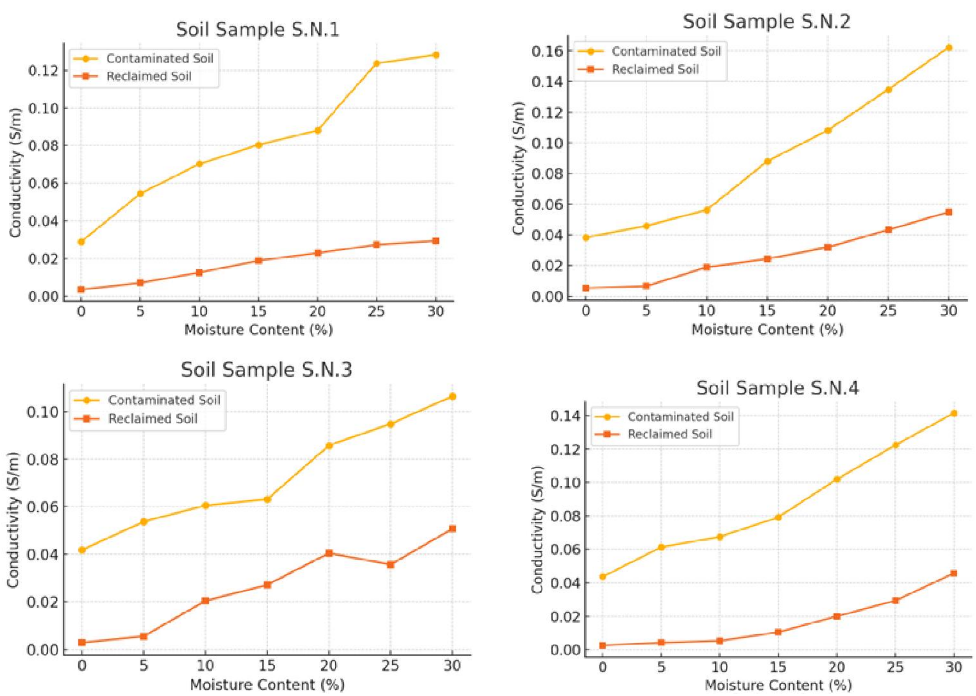


Figure 1: Average conductivity of contaminated and reclaimed soils vs moisture content.



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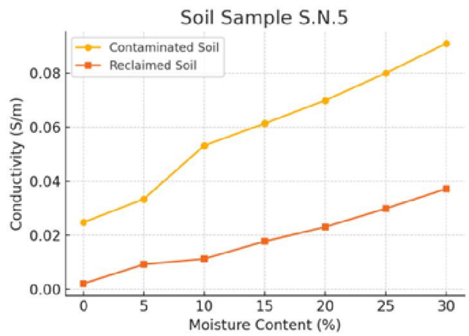

Figure 2: Conductivity vs moisture content for all Soil Samples

The conductivity of soil is highly sensitive to both moisture and chemical composition. Contaminated soils generally contain higher concentrations of salts, heavy metals, and other conductive materials, which enhance the free ionic mobility especially when moisture is present (2 and 7). In contrast, reclaimed soils having undergone treatments such as washing, neutralization, and aeration show reduced ionic concentrations, translating to lower conductivity values. The gap in conductivity increases with moisture content, highlighting that the contaminant effects are more pronounced under wet conditions.The conductivity of soil is highly sensitive to both moisture and chemical composition. Contaminated soils generally contain higher concentrations of salts, heavy metals, and other conductive materials, which enhance the free ionic mobility especially when moisture is present (2 and 7). In contrast, reclaimed soils having undergone treatments such as washing, neutralization, and aeration show reduced ionic concentrations, translating to lower conductivity values. The gap in conductivity increases with moisture content, highlighting that the contaminant effects are more pronounced under wet conditions.

IV. CONCLUSION

This study confirms that soil contamination significantly increases electrical conductivity at 10 GHz, especially as moisture content rises. Reclamation processes, though beneficial, do not fully restore soil conductivity to the level of uncontaminated natural soils but do produce a measurable reduction. These findings are important for applications in environmental monitoring and high-frequency communication technologies, where soil properties can influence signal propagation (6 and 3).

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