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Dielectric Properties of Contaminated Soils at X-band Microwave Frequencies

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ABSTRACT: In this study we collected contaminated soil samples from five soil contaminated sites of North Maharashtra region. Microwave remote sensing of contaminated soils requires the study of electrical parameters of such soils. In this paper dielectric constant and dielectric loss of five contaminated soil samples have been measured with different moisture content at three microwave frequencies of X-band by using waveguide cell method. The dielectric constant and dielectric loss of five contaminated soil samples have been calculated. The results shows that the dielectric constant and dielectric loss of contaminated soil samples rapidly increases up to 20% moisture content, after 20% to 30% dielectric constant and dielectric loss increases slowly.

KEYWORDS: Soil samples, Dielectric constant, Dielectric loss, Moisture content, Microwave frequency.

I. INTRODUCTION

Soil is a thin layer that covers earth's rocky surface. Soil is an intimate mixture of organic and inorganic materials, water and air. Productive soils are necessary for agriculture to supply the world with sufficient food. Now a day's soil contamination has become a severe environmental problem. Soil contamination is occurrence of pollutants in soil above certain level. There are different ways which pollute soil such as seepage of landfill, discharge of industrial waste into the soil, percolation of contaminated water into soil, rupture of ground storage tanks, excess application of pesticides, herbicides or fertilizers and solid waste seepage.

Over the past decades remote sensing using microwave techniques is the emerging field for the study of natural planet earth. Remote sensing can play a role in the identification, inventory and mapping of soils that are on the surface of the earth. Microwave remote sensing of natural planet earth materials such as soil and water has a very close dependence on their electrical parameters. The most important parameters are the dielectric constant and dielectric loss. The knowledge of dielectric constant and dielectric loss helps in the study of dry and wet contaminated soils using microwave sensors.

In present research paper dielectric constant and dielectric loss of five contaminated soil samples were measured at three microwave frequencies of X-band from 8 GHz to 12 GHz. The contaminated soil samples were collected from different contaminated sites from North Maharashtra Region.

Many researchers are working on study of dielectric characteristics of soils, rocks and contaminated soils at microwave frequencies and also at low frequencies.

Abidin Kaya and Hsai-Yang Fang studied the dielectric properties of contaminated soils and the objective of this study is to investigate the possibility of using dielectric constant and electrical conductivity to characterize and identify contaminated fine-grained soils [1]. D.H.Gadani and A.D.Vyas measured the complex dielectric constant of soils of Gujrat at X-band and C-band microwave frequencies. This study shows that the dielectric constant of soils increases slowly with increase in the moisture content in the soil up to transition moisture, after which it increases rapidly with moisture content [2]. Yadav Vivek et. al. (2009) have studied the soil samples prepared by mixing different concentrations of some fertilizers using microwave source reflection Klystron of frequency range of X-band. This study investigates that different percentage of fertilizer content in soil gives large variation dielectric constant which is

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important for efficient use of soil [3]. Chaudhari H. C. and Shinde V. J. (2008, 2010, and 2012) have determined the dielectric constants for laden, red and black soils at X-band using Infinite Sample Method. Their study has proved that percentage of moisture significantly affect the dielectric properties of soil. AC electrical conductivity and relaxation time depends on dielectric properties [4,5]. Calla O. P. N. et. al. (2007) have carried out dielectric study, emissivity, scattering coefficient of dry and wet soils of Rajasthan with different moisture content using Waveguide Cell Method[6]. Shivastava S. K. and Mishra G. P. (2004) have carried out study of dielectric properties of Chhatisgarh soils at X-band frequency using Infinite Sample Method. The result of this study indicates that value of dielectric constant and purer loss first increases slowly and then rapidly with moisture content. The fertility of soil can be predicted with the help of dielectric constant and porosities [7]. Yakun Sun et.al. have studied the dielectric constant of chrome contaminated soil, and the result shows that the complex dielectric constant of chrome contaminated soil decreases with increasing frequency [8].
The work in this paper is divided in three stages. 1) Sample preparation, 2) measurement of Dielectric constant and 3) measurement of Dielectric loss. Section III presents experimental results and discussion showing results of dielectric constant and dielectric loss of all five contaminated soil samples at different moisture content at three microwave frequencies. Finally, Section IV presents conclusion.

II. RELATED WORK

1. Sample preparation: The soil samples were first sieved by gyrator sieve shaker to remove coarser particles from the samples. The sieved fine particles were dried to a temperature of about 110^0C for about half an hour to remove any trace of moisture completely. This dry sample was referred as dry base when compared with wet samples. The soil samples were also analysed for various chemical parameters by standard analytical methods.
The dielectric constants will be then measured Waveguide Cell Method.
2. Measurement of Dielectric constant: Each soil sample was dried to a temperature 110^0C, this soil sample was considered as dry or 0 % moisture content soil sample. Then on the basis of volumetric analysis 5%, 10%, 15%, 20%, 25% and 30% moisture content soil samples were prepared and the dielectric constant of five contaminated soil samples at microwave frequencies 9.655 GHz, 10 GHz and 10.582 GHz. The X-band microwave set-up consists of a Gunn oscillator in combination with Pin modulator as a microwave source. The waveguide cell method was used for measurement of dielectric constant and dielectric loss of contaminated soil samples. The equation of dielectric constant is,

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

where, a = inner width of rectangular waveguide,
λ_g = guide wavelength,
l_ε = sample length,
in this equation (1) x is found by following equation,

$$\frac{\tan x}{x} = \frac{\tan[\beta (l_\varepsilon + D_R - D]}{\beta\, l_\varepsilon} \qquad ------- \qquad (2)$$

where, $\beta = 2\pi / \lambda_g$, β is phase shift
$(D_R - D)$ is shift in minima
D_R is minima for without sample
D is minima for with sample

3. Loss tangent ($\tan\delta$)
The Loss tangent is calculated using the formula (Lance 1964)

$$\tan\delta = \{|\Delta x_s - \Delta x| / \varepsilon' l_\varepsilon\} \times (\lambda_o / \lambda_g)^2 \qquad ------ \qquad (3)$$

where, λ_o – free space wavelength
Δx = width at twice minima without sample

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Δx_s = width at twice minima with sample in the waveguide touching the short circuit end.

4. Measurement of Dielectric loss, Loss factor (ε'') is measured by equation (4).

$$\varepsilon'' = \varepsilon' \tan\delta \quad \text{------} \quad (4)$$

III. EXPERIMENTAL RESULTS

The soil samples were also analysed for various chemical parameters by standard analytical methods. The nutrient concentrations of soil samples are represented in Table1.

Parameter	Soil Sample No.1	Soil Sample No.2	Soil Sample No.3	Soil Sample No.4	Soil Sample No.5
pH	**6.33 Slightly Acidic**	**8.29 Moderately alkaline**	**8.62 Strongly Alkaline**	**8.31 Moderately Alkaline**	**8.21 Moderately Alkaline**
E.C. (dSm-1)	1.51 High	0.28 Normal	0.14 Normal	0.36 Normal	0.13 Normal
Organic Carbon (%)ss	0.93 High	0.44 Medium	0.23 Low	0.63 Moderately High	0.28 Low
Calcium Carbonate (%)	7.0 Calcareous	8.5 Calcareous	**27.25 Highly Calcareous**	**22.25 Highly Calcareous**	8.0 Calcareous
Available Nitrogen (kgha-1)	**639.74 High**	**125.44 Very Low**	**37.63 Very Low**	**75.26 Very Low**	**62.72 Very Low**
Available Phosphorus (kgha-1)	**75.12 Very High**	**2.49 Very Low**	**1.55 Very Low**	**13.89 Low**	**11.09 Low**
Available Potassium (kgha-1)	286.72 High	288.96 High	231.84 moderately High	499.52 Very High	**60.48 Very Low**
Available Iron (Fe)(ppm)	36.24 High	28.38 High	4.81 High	**4.44 Low**	**3.48 Low**
Available Manganese (Mn)(ppm)	88.14 High	11.37 High	8.85 High	15.93 High	11.14 High
Available Zinc (Zn)(ppm)	6.35 High	1.86 High	2.78 High	1.87 High	1.15 High
Available Copper (Cu)(ppm)	2.73 High	1.63 High	0.27 High	1.25 High	0.94 High

Table.1 Chemical parameters of soil samples

The pH value of soil sample 1 is 6.33, which shows that it is slightly acidic. The pH values (8.21-8.29) indicated that three soil samples are moderately alkaline and one (8.62) was strongly alkaline. The value of available Nitrogen in contaminated soil sample 1 (639.74) is high, while for remaining four contaminated soil samples available Nitrogen (37.63- 125.44) is very low. The phosphorous content (1.55-13.89) indicated that soil samples 2 and 3 contain very low

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amount of Phosphorous and soil samples 1 contain very high amount of Phosphorous. The phosphorus content (11.09-13.89) indicated that soil sample 4 and 5 contain low amount of Phosphorus.

The value of available Potassium in soil sample 5(60.48) is very low while for remaining four soil samples available Potassium (231.84-499.52) were high. The value of available Iron in soil sample 4 and 5 (3.48-4.44) is low while for remaining soil samples 1, 2 and 3 available Iron (4.81-36.24) is high. The Manganese content (8.85-88.14), Zinc content (1.86-6.35) and Copper content (0.27-2.73) are indicated that all five contaminated soil samples contain high amount of Manganese, Zinc and Copper. The content of Calcium Carbonate in soil sample1,2 and 3 (7.0,8.5 and 8.0) shows that these samples are calcareous while soil sample 3 and 4 (37.63 and 75.26) are highly calcareous.

A. Variation of Dielectric constant with Moisture content

In Fig.1 graphs are plotted for variation of dielectric constant with moisture content for all five contaminated soil samples at frequencies 9.655 GHz, 10 GHz and 10.582 GHz.

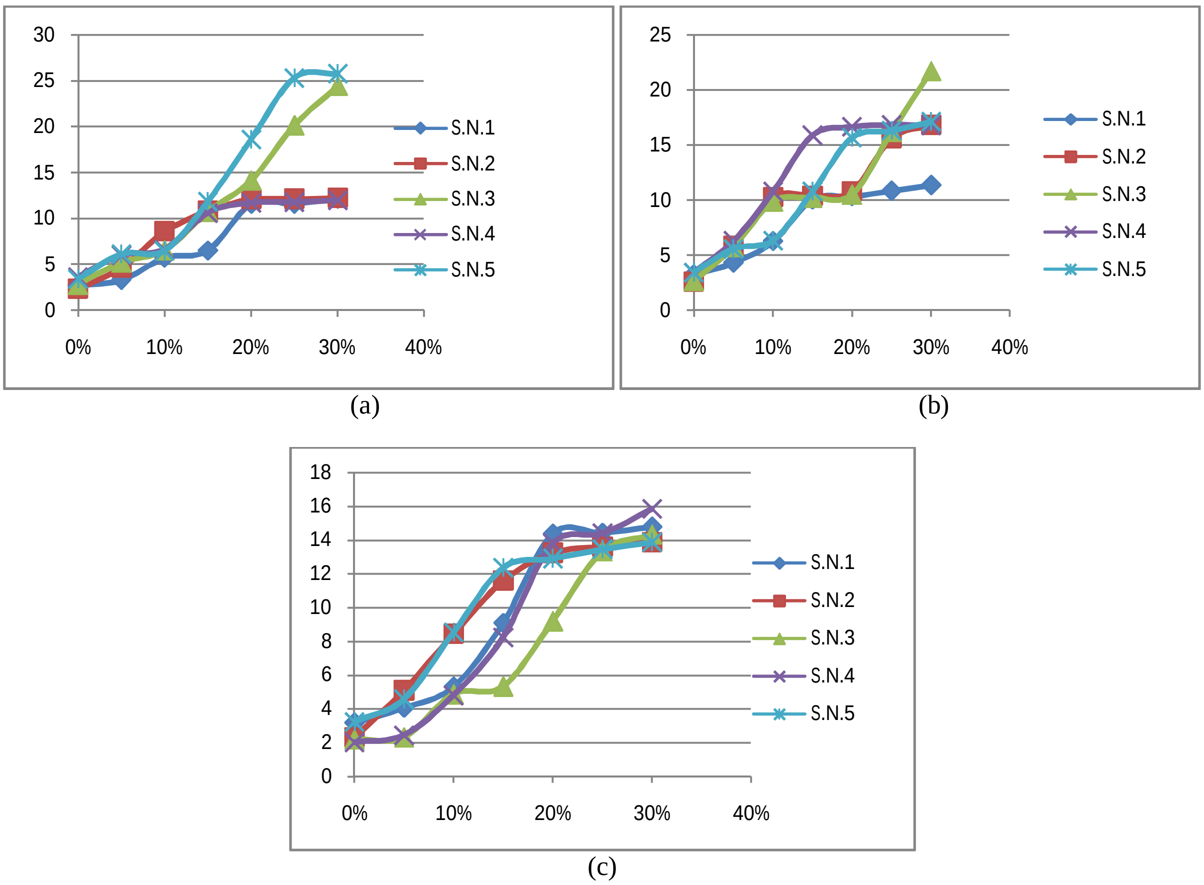
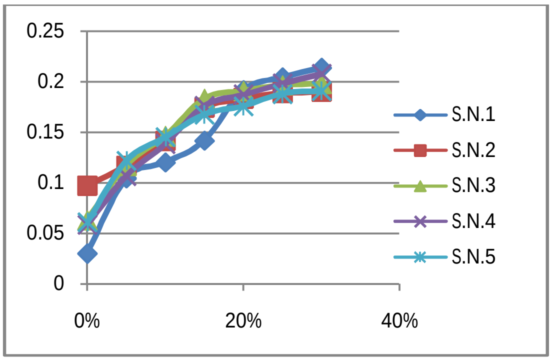


Fig.1 Graphs of Dielectric constant Vs moisture content for all contaminated soil samples (a) at frequency 9.655 GHz, (b) at frequency 10 GHz and (c) at frequency 10.582 GHz.

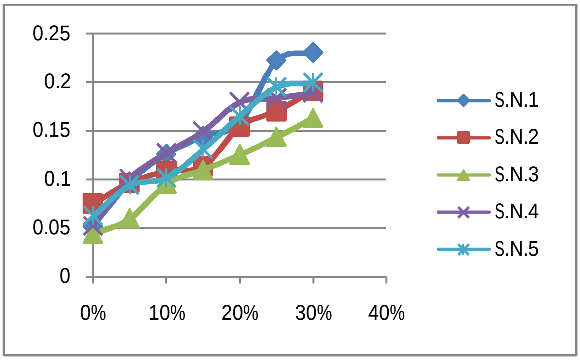
From fig.1 it is observed that the value of dielectric constant increases as moisture content increases at all frequencies. Sample no.2 is moderately alkaline and very low content of Nitrogen and Phosphorus. Its dielectric constant at 0% moisture content is very low 2.366 at 9.655 GHz, 2.636 at 10 GHz and 2.314 at 10.582 GHz. While for soil sample 1 which is slightly acidic the dielectric constant at 0% moisture content is 2.6812 at 9.655 GHz, 3.2215 at 10 GHz and 3.1821 at 10.582 GHz. The soil samples 3, 4 and 5 are alkaline. Also Nitrogen and Phosphorus contents of these soil samples are very low. The dielectric constant of these samples at 0% moisture content are 2.7952-3.6456 at 9.655 GHz, 2.6806-3.448 at 10 GHz and 2.0339-3.2328 at 10.582 GHz.

B. Variation of Dielectric loss with Moisture content

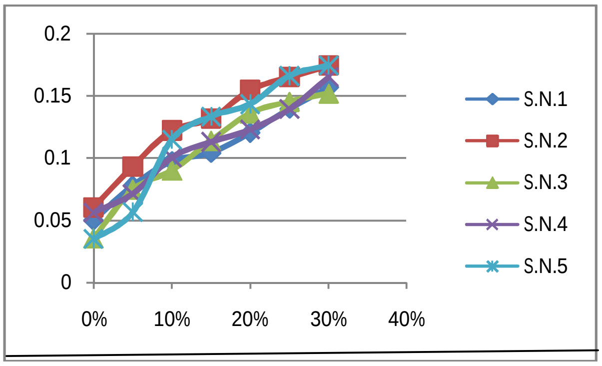
In Fig.2 graphs are plotted for variation of dielectric loss with moisture content for all five contaminated soil samples at frequencies 9.655 GHz, 10 GHz and 10.582 GHz.



(a)



(b)



(c)

Fig.2 Graphs of Dielectric loss Vs moisture content for all contaminated soil samples (a) at frequency 9.655 GHz, (b) at frequency10 GHz and (c) at frequency 10.582 GHz

From graphs it is observed that for all five samples the value of dielectric loss increases as moisture content increases at all frequencies. At 0% the value of dielectric loss of soil sample 2 were maximum compared to other soil samples. For soil sample 3 and 4 which are highly calcareous there is same change in dielectric loss with moisture content at frequencies 9.655 GHz and 10.582 GHz.

Our results get confirmed with the result reported for black and red soils by H. C. Chaudhari et.al.(5) and Study of characteristics of the soil of Chhattisgarh at X-band frequency by S. K. Srivastav et.al.(7).

IV. CONCLUSION

From the above results and discussion we have concluded the following points.

1. For contaminated soils the dielectric constant increases as moisture content increases at all three frequencies. The dielectric constant of soils increases rapidly up to 20% moisture content then slowly increases up to 30%.

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2. The variation of dielectric constant of slightly acidic soil is nonlinear with moisture content.
3. The dielectric loss is more for moderately alkaline soils.
4. For contaminated soils the dielectric loss increases as moisture content increases at all three frequencies. The dielectric loss of soils increases rapidly up to 20% moisture content then slowly increases up to 30%.
5. For highly calcareous soil change in dielectric loss is same with moisture content.

This study of Dielectric constant and Dielectric loss of contaminated soils at microwave frequencies in X band region plays an important role in the interpretation of various remote sensing data.

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