6.1 INTRODUCTION:

The identification of effect of saline water on soils with their location is useful to both the planner's and farmer's point of view. The delineation of salt affected soils is possible using visible and NIR data, but the delineation of salt affected areas in coastal and desert areas as well as in the black clay regions is difficult. In the coastal and desert areas containing sandy soils, the reflectance of surface salt encrustation and that of the sand is almost the same. On the contrary in black clay soils, the formation of salt encrustation on the surface is not sufficient to give a good contrast so that the effect of salinity on the soil can not be distinguished. The problem becomes more complicated under wet soil conditions.

Sreenivas et al. measured the complex dielectric constant of sand, sandy clay loam and clay using an L-band dielectric probe (1.25 GHz). Various concentrations of sodium chloride (NaCl) and sodium acetate (CH₃COONa) solutions were prepared in distilled water and mixed with the soils. It has been observed that the dielectric constant \( \varepsilon' \) is dependent on the soil texture and volumetric moisture content in the soil, whereas salinity has no much influence on the dielectric constant at this frequency. Further it has been observed that the dielectric loss \( \varepsilon'' \) increase with increase in salinity and increase in moisture content in the soil. Under the dry soil condition, the soil has low conductivity and the lower value of dielectric loss. It has been explained due to the fact that under the dry conditions, more air is entrapped in the soil which have dielectric loss \( \varepsilon''_{air} = 0 \), thus reducing the bulk dielectric loss of the dryer soil. For wet soils, the conductivity of soil increases with increase in the salt content in turn increasing the dielectric loss \( \varepsilon'' \). It has been explained that with increase in soil moisture, a greater amount of salt gets dissolved into the soil system increasing the conductivity of the soil. Further it has been explained that the dielectric loss \( \varepsilon'' \) of sandy soils increase linearly with increase in salinity level where as for
clay soil the dielectric loss variation with increase in salt and moisture content is curvilinear.

Now a day, desertification is a serious consequence of global warming, and is a most crucial issue for the global change community. The salinization of soil is one of the major factors responsible for desertification. Soil degradation and salinization devastate vast farmlands, grasslands and forests particularly in the arid and semi arid regions.

Yun Shao et al. measured the dielectric properties of artificially moistened and salinized soils, and the saline soil samples taken from a salt lake. The measurements were carried out using a microwave network analyzer operating in the frequency range from 1-18 GHz. The dielectric measurements were also compared with the back scattering coefficients extracted from a RADARSAT image. It has been observed that \( e' \) gradually decreases with increase in frequency from 1 to 18 GHz. The dielectric constant \( e' \) increased rapidly with increase in moisture content in the soil. Salinity has little impact on the dielectric constant. Further it have been observed that the dielectric loss \( e'' \) decreased rapidly with increase in frequency in the lower frequency range \(< 2 \text{ GHz}\). In the higher frequency range, the soil salinity had little impact on the dielectric loss \( e'' \) which remained almost constant. In the 1-6 GHz range, at higher moisture content \( > 20\% \), the value of \( e' \) decreases slowly with increase in salinity, but the value of \( e'' \) increased rapidly with increase in salinity in the soil. It has also been concluded that the dielectric loss \( e'' \) is more sensitive to salinity at L-band than at C-band.

The soil salinity and surface soil moisture can be estimated by passive microwave remote sensing methods. Since both of these properties vary over an area, it is important to know how to distinguish salinity in the soil when the moisture content in the soil is varied, and vice versa. Water in the soil changes its microwave dielectric constant, which in turn is responsible for the change in its emissivity. Further, the concentration of salts in water also affects its microwave dielectric property. When saline water is added in the soil, the dielectric properties of this mixture are different from those of the pure water and soil mixture.
Jackson and O'Neill\textsuperscript{3} measured the brightness temperature of Elinsboro loamy sand at various moisture contents and various salinity levels of water such as 0, 5000, 15000, and 30000 ppm in water. They used radiometers operating at frequency of 1.4 GHz, and 5 GHz, as well as a hand-held thermal infrared radiometer for the measurements. The emissivity of the soil for various moisture contents and salinity levels were calculated from the measured brightness temperature. The dielectric mixing models proposed by Wang and Schmugge\textsuperscript{4}, and Dobson\textit{et al.} model\textsuperscript{5} were used in conjunction with the emissivity model to predict the emissivity from a bare smooth uniform profile. Nearly identical results were produced by the models near zero salinity which were well reproduced by the observed data at L-band (1.4 GHz) microwave frequency. Discrepancies occurred at C-band (5 GHz) due to depth of sampling problems.

The electrical parameters like emissivity and scattering coefficient can be derived from the dielectric constant of the material. Calla and Kalita\textsuperscript{6} estimated the scattering coefficient of saline soil for slightly rough surface and undulating surface from the measured values of dielectric constant at X-band (8.2-10 GHz) microwave frequencies. The salinity in the soil varied from 4000 ppm to 40,000 ppm for different moisture contents ranging from 0\% to 30.43\%. Using the perturbation model and geometric optical model, the scattering coefficient has been calculated for different look angles varying from 0\(^\circ\) to 60\(^\circ\) for both the vertical and horizontal polarizations. It has been observed that for the slightly rough surface (i) the scattering coefficient increases with increase in moisture content in the soil at given frequency (8.7 GHz), (ii) the scattering coefficient decreases with increase in frequency (8.3 GHz to 9.7 GHz) at 11\% moisture content at 28,000 ppm salinity in the soil, (iii) the scattering coefficient decreases with increase in salinity at 8.7 GHz for 11\% moisture content in the soil, (iv) the scattering coefficient decreases with increase in look angle for both the horizontal and vertical polarizations. The variation of the scattering coefficient for horizontal polarization is found to be more than that for vertical polarization at 11\% moisture content in the soil at 8.7 GHz microwave frequency. (v) For undulating surface the value of the scattering coefficient increases with increase in look angle for horizontal polarization, where as for vertical polarization the scattering coefficient decreases with increase in look angle at 11\% moisture content at 8.7 GHz microwave frequency.
Lasne et al. measured the effect of salinity on the dielectric properties of sand in the frequency range from 1 to 7 GHz using Vector Network Analyzer coupled to an open-ended coaxial probe (SMA type). The dielectric constant $e'$ and dielectric loss $e''$ of sand/saline water mixture were measured as a function of frequency and moisture content for two salinity values of $S = 40$ and 100/o/o. It has been observed that the dielectric constant $e'$ decreases with increase in salinity as well as frequency. The dielectric loss $e''$ increases rapidly with increase in salinity. Between 1-2 GHz dielectric loss $e''$ shows steep variation with change in frequency. The measured values were also compared with the values calculated using Wang and Schmugge model including the complex dielectric constant of water calculated using Stogryn equations. It has been observed that the values of dielectric constant $e'$ are in good agreement with the measured values in 1-3 GHz frequency range. The model underestimates the measured values of dielectric loss $e''$. They also computed the radar backscattering coefficients from the measured values of complex permittivity at L-band (1.5 GHz). It has been observed that the sensitivity of the backscattering coefficient to the salinity depends on the moisture content in the soil. The strong dependence of the backscattering coefficient on the salinity is observed at lower moisture contents.

Thus considerable work has been done to determine the effect of salinity on dielectric properties of moist soil at microwave frequencies; however, few attempts have been made to study the dielectric properties of moist soil at radio and microwave frequencies. Therefore, to gain more information in this area, controlled experiments were conducted to study dielectric properties of wet saline soil of Gujarat state at radio and microwave frequencies. The following sections describe sample preparation, measurement technique and results obtained by this study.

6.2 MATERIALS AND METHODS:

The sandy loam soil of Gandhinagar district was oven dried, and then wet soil samples were prepared by adding distilled water, saline water of 10,000 ppm and 30,000 ppm in the soil samples. Now time of 24 hours was allowed to saturate. As the days went on, the moisture content in the soil decreased and the measurement of complex dielectric constant of the soil samples for various moisture contents of wet
and artificially salinized wet soil were carried out using microwave bench set up operating at 5.65 GHz and in the frequency range from 100 MHz to 1.6 GHz using VNA employing the methods explained in chapter IV.

6.3 RESULT AND DISCUSSION:

The measured values of the dielectric constant $\varepsilon'$ and dielectric loss $\varepsilon''$ of the sandy loam soil using VNA for various moisture contents and for various salinity levels of 10000 ppm and 30000 ppm are shown in the figure (6.1), for the frequency range from 100 MHz to 1.6 GHz. It can be observed from the figure (6.1) that the dielectric constant and dielectric loss of the dryer soil does not change appreciably with the variation of frequency. The dielectric constant and dielectric loss of the soil increases with increase in moisture content in the soil, irrespective of the salinity of water or the frequency of measurement. Further at any given moisture content irrespective of salinity, the dielectric constant of the soil remains almost constant above 300 MHz. But in the frequency range from 100 MHz to 300 MHz the dielectric constant increases with decrease in the frequency. The value of dielectric loss increases rapidly with increase in salinity level in the soil particularly in this frequency band. The dielectric loss decreases with increase in frequency from 100 MHz to 1.6 GHz, irrespective of salinity level for all moisture contents. The rate of decrease in the dielectric loss with increase in frequency reduces as the salinity in the soil increases and moisture content in the soil decreases.

The dielectric constant is not showing distinguishable variation with salinity in the soil. This may be due to the fact that the real part is influenced mainly by the soil texture and soil moisture, and not correlated with the salinity in the water. Where as the increase in the salinity increases the conductivity of the soil-water mixture, increasing the dielectric loss. Further at higher moisture contents the effect of salt dominates the dielectric constant value rather than the moisture content in the soil. For very low moisture contents, the variation in the dielectric loss can not be distinguished with the salinity variation. This may be due to the lower conductivity of the soil-saline water mixture producing weak variation in the imaginary part.
To distinguish the effect of salinity from that of the distilled water in the soil, the dielectric constant and dielectric loss of wet salinized soil against moisture content at spot frequencies of 0.21 GHz, 0.5 GHz, 1.01 GHz, and at 1.4 GHz, is shown in figure (6.2) (the results for the soil-distilled water mixture are taken from VNA results of chapter V). It is clear from the figure (6.2) that there is no much visible variation in the dielectric constant at any moisture content with and without salinity in the soil. But at higher moisture contents above transition moisture, the dielectric loss $\varepsilon''$ increases with increase in the salinity. Further the increase in the dielectric loss with salinity is more at the lower end of the microwave frequency range. Hence at higher moisture contents,

$$
\varepsilon''_{\text{soil+distilled water}} < \varepsilon''_{\text{soil+10,000 ppm saline water}} < \varepsilon''_{\text{soil+30,000 ppm saline water}}
$$

The measured values of the dielectric constant and dielectric loss of the sandy loam soil of Gandhinagar district at C-band microwave frequency of 5.65 GHz are shown in figure (6.3) for various volumetric moisture contents (in cm³/cm³) of distilled water, as well as for the water solutions of 10,000 ppm and 30,000 ppm salinity. It is seen from the trend lines of figure (6.3) that the dielectric constant and dielectric loss of the soil increases with increase in moisture content in the soil. Further it is seen that the salinity has no much effect on the dielectric constant of the soil, but the dielectric loss increases with increase in salinity. The results agree well with the available data in the literature 1–3.

From the measured values of the dielectric constant $\varepsilon'$ and the dielectric loss $\varepsilon''$ of the Gandhinagar sandy loam soil, at 0.21 GHz, 0.5 GHz, 1.01 GHz, 1.4 GHz, and at 5.65 GHz microwave frequencies, the emissivity values of the soil for normal incidence were calculated using the relation

$$
\varepsilon = 1 - \frac{1 - (\varepsilon')^{1/2}}{1 + (\varepsilon')^{1/2}}
$$

where, $\varepsilon$ = the complex dielectric constant of the soil.
The plot of emissivity versus moisture content for normal incidence, in case of Gandhinagar district soil is shown in figure (6.4) at given fixed microwave frequencies, for various salinity levels in the water.

It can be seen that for all frequencies emissivity decreases with increase in moisture content in the soil. Further at given moisture content the emissivity of the soil decreases with increase in the salinity of the water. For dryer soil the effect of salinity can not be distinguished from the emissivity of the soil. The rate of decrease in emissivity with increase in moisture content in the soil is almost the same for all frequencies considered here for the moist soil with distilled water. For the salinity of 10,000 ppm in the water, the emissivity decreases rapidly with decrease in frequency at given moisture content in the soil. Further, it is observed that this decrease is more rapid at salinity of 30,000 ppm in the water. Also, the decrease in emissivity with increase in salinity of water at given higher moisture content is more profound at lower frequency. Thus, at given moisture content and given frequency of measurement, the emissivity varies as

\[ e_{\text{soil}+30,000 \text{ ppm saline water}} < e_{\text{soil}+10,000 \text{ ppm saline water}} < e_{\text{soil}+\text{distilled water}} \]

The comparison of variation of the emissivity of the soil at particular frequencies of 0.21 GHz, 0.5 GHz, 1.01 GHz, 1.4 GHz, and at 5.65 GHz for various moisture contents may be very much useful for the detection of salinity and moisture content in the soil, as well as in remote sensing applications.

Figure (6.5) shows the comparison of measured values of dielectric constant \( e' \) and the dielectric loss \( e'' \) of moist salinized soil with the values calculated using the Wang & Schmugge model, in which the values of dielectric constant \( e' \) and the dielectric loss \( e'' \) of water are calculated using Stogryn equations for various salinity levels and various frequencies. It is observed that for 10,000 ppm saline water/soil mixture, at spot frequencies of 0.5 GHz, 1.01 GHz, and 1.5 GHz, the measured values of dielectric constant \( e' \) and the dielectric loss \( e'' \) agree very well up to 15 % moisture content after which the calculated values using the model are lower than the measured values. Further, for 30,000 ppm saline water/soil mixture, at 0.5 GHz, 1.01 GHz, and
1.4 GHz microwave frequencies, the measured values agree very well up to 20 % moisture content in the soil after which the calculated values using the model are lower than the measured values. At 5.65 GHz microwave frequency and 10,000 ppm saline water/soil mixture the measured values of dielectric constant $\varepsilon'$ and the dielectric loss $\varepsilon''$ agree very well with the values calculated using the Wang & Schmugge - Stogryn equations up to 12 % moisture content in the soil after which the calculated values using the model are lower than the measured values. Further, at 5.65 GHz microwave frequency and 30,000 ppm saline water/soil mixture the measured values of dielectric constant $\varepsilon'$ and the dielectric loss $\varepsilon''$ agree very well with the values calculated using the Wang & Schmugge - Stogryn equations up to 10 % moisture content in the soil after which the calculated values using the model are lower than the measured values.

Figure (6.6) shows the comparison of measured values of dielectric constant $\varepsilon'$ and the dielectric loss $\varepsilon''$ of water with the values calculated using the Stogryn equations, for salinity levels of 10,000 ppm and 30,000 ppm in the frequency range from 100 MHz to 1.5 GHz. It can be observed that the measured values of dielectric constant $\varepsilon'$ and the dielectric loss $\varepsilon''$ of water agree very well with the values calculated using the Stogryn equations. At 10,000 ppm salinity in the water the values of $\varepsilon''$ calculated using the Stogryn equations are lower than the measured values after 1.1 GHz. At 30,000 ppm salinity in the water the values of $\varepsilon''$ calculated using the Stogryn equations are higher than the measured values below 500 MHz. Further it is observed that as the salinity in the water increases from 10,000 ppm to 30,000 ppm the dielectric constant $\varepsilon'$ does not vary appreciably but the value of the dielectric loss $\varepsilon''$ increases considerably. The increase in the value of the dielectric loss $\varepsilon''$ is more at lower end of the frequency.
Figure 6.1: The measured values of the dielectric constant $\varepsilon'$ and dielectric loss $\varepsilon''$ of the sandy loam soil using VNA for various moisture contents and salinity levels of 10000 ppm and 30000 ppm in water for the frequency range from 100 MHz to 1.6 GHz.

![Graph showing the measured values of the dielectric constant and loss for different conditions.]

Figure (6.1.1)

![Graph showing the dielectric loss for different frequencies.]

Figure (6.1.2)
Gandhinagar soil + 30000 PPM saline water

Figure (6.1.3)

Dielectric Loss $\varepsilon''$

Figure (6.1.4)
Figure 6.2: Measured values of the dielectric constant $\varepsilon'$ and dielectric loss $\varepsilon''$ of the sandy loam soil using VNA at spot frequencies of 0.21 GHz, 0.5 GHz, 1.01 GHz and at 1.4 GHz, for various moisture contents and salinity levels.

Figure (6.2.1)

Figure (6.2.2)
Complex Permittivity

Figure (6.2.3)

Figure (6.2.4)
Figure 6.3: Measured values of the dielectric constant $\varepsilon'$ and dielectric loss $\varepsilon''$ of the sandy loam soil using microwave bench set up at 5.65 GHz, for various moisture contents and salinity levels.
Figure 6.4: The emissivity values of the soil for normal incidence for the Gandhinagar district sandy loam soil, at 0.21 GHz, 0.5 GHz, 1.01 GHz, 1.4 GHz and at 5.65 GHz microwave frequencies

Figure (6.4.1)

Figure (6.4.2)
1.4 GHz

- Double Dist. Water in soil
- 10,000 ppm saline water in soil
+ 30,000 ppm saline water in soil

Volumetric Moisture Content (cm^3/cm^3)

Figure (6.4.4)
Figure (6.4.5)
Figure 6.5: The comparison of measured values of dielectric constant $\varepsilon'$ and the dielectric loss $\varepsilon''$ with the values calculated using the Wang & Schmugge-Stogryn equations for various salinity levels and various frequencies.

Figure (6.5.1)

Figure (6.5.2)
Gandhinagar, 10000 PPM, 1.5 GHz

- Measured $\varepsilon'$
- Measured $\varepsilon''$
- Wang-Stogryn equations $\varepsilon'$
- Wang-Stogryn equations $\varepsilon''$

Volumetric Moisture Content

Gandhinagar, 30000 PPM, 0.5 GHz

- Measured $\varepsilon'$
- Measured $\varepsilon''$
- Wang-Stogryn equations $\varepsilon'$
- Wang-Stogryn equations $\varepsilon''$

Volumetric Moisture Content
Figure (6.5.5)

Gandhinagar, 30000 PPM, 1.01 GHz

- Measured $\varepsilon'$
- Measured $\varepsilon''$
- Wang-Stogryn equations $\varepsilon'$
- Wang-Stogryn equations $\varepsilon''$

Figure (6.5.6)

Gandhinagar, 30000 PPM, 1.5 GHz

- Measured $\varepsilon'$
- Measured $\varepsilon''$
- Wang-Stogryn equations $\varepsilon'$
- Wang-Stogryn equations $\varepsilon''$
Figure (6.5.7)

Figure (6.5.8)
Figure 6.6: The comparison of measured values of dielectric constant $\varepsilon'$ and the dielectric loss $\varepsilon''$ of water with the values calculated using the Stogryn equations, for salinity levels of 10,000 ppm and 30,000 ppm in the frequency range from 100 MHz to 1.5 GHz.

Figure (6.6.1)

Figure (6.6.2)
REFERENCES:


