Variation of Dielectric Constant, Emissivity and Scattering Coefficient of Coastal Saline Soils of Maharashtra Region at Various Microwave Frequency Bands

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Abstract
This study presents experimental measurements of the complex dielectric constant of five coastal saline soil samples collected from representative locations along the Maharashtra coast — Pen, Alibag, Murud, Tarkarli, and Dapoli — at microwave frequency bands spanning 2 to 10 GHz, covering the L, S, C, J and X bands. A standard microwave bench setup operating in TE10 waveguide mode with VSWR detection was used. The measured complex dielectric constants were used to estimate emissivity via the Fresnel emissivity model and backscattering coefficients via the small perturbation model (SPM). The real part of the dielectric constant (ε′) was found to decrease with increasing frequency for all five samples. The decrease in ε′ from 2.35 GHz to 9.685 GHz for all five samples, consistent with the Debye dipolar relaxation model. At constant moisture condition, emissivity for vertical polarisation increases with incidence angle up to a pseudo-Brewster angle — ranging from approximately 54° (X-band) to 71° (L-band) — and then decreases sharply; for horizontal polarisation, emissivity decreases monotonically. Backscattering coefficient for vertical polarisation increases up to approximately 60°–70° and then decreases, while horizontal polarisation values remain stable up to 40°–50° before decreasing. These results are useful for designing passive and active microwave remote sensors for coastal saline soil monitoring in Maharashtra.

Keywords: dielectric constant; emissivity; scattering coefficient; coastal saline soil; microwave frequency.

I. Introduction

Remote sensors measure electromagnetic (EM) radiation that has interacted with the Earth's surface. The nature of these interactions depends on the dielectric and physicochemical properties of the soil exposed to the EM radiation [1–3]. In recent years, many research efforts have focused on the development of microwave remote sensing techniques to map soil moisture, salinity, and land surface properties at large spatial scales [1, 2]. Emission and scattering behaviour of soils depends upon the dielectric constant, moisture content, chemical composition, surface roughness, physical temperature, frequency, incidence angle, and polarisation. Saline soils along coastal regions present a particularly complex dielectric environment because dissolved salts introduce ionic polarisation losses in addition to the bound-water dipolar losses characteristic of moist soils [4–6]. A systematic study of the frequency-dependent dielectric, emissivity, and scattering behaviour of such soils is therefore essential for accurate interpretation of multi-frequency satellite remote sensing data.

Several investigators have studied the dielectric and emission-scattering behaviour of Indian soils at microwave frequencies. Hallikainen et al. [7] and Dobson et al. [4] established foundational dielectric models for moist soils across multiple frequency bands, while Calla and co-workers [8–11] reported the emission and scattering behaviour of dry and saline Indian soils. Alex & Behari [12] studied the microwave dielectric behaviour of soils at different moisture levels. Ahire et al. [13] systematically measured the variation of emissivity and scattering coefficient of four Indian soils with moisture content (0–25%) and incidence angle (0°–80°) at C-band (5.3 GHz), providing a reference dataset for passive and active sensor design. However, the frequency dependence of dielectric, emissivity, and scattering properties — critical for multi-band SAR and radiometer systems — has received comparatively less attention for the coastal saline soils of Maharashtra, and no dedicated multi-frequency study exists for this region.

The present study addresses this gap. Five coastal saline soil samples from Maharashtra were characterised for their complex dielectric constant across L, S, C, J and X microwave frequency bands (2–10 GHz) using the waveguide cell method. The measured dielectric constants were used to estimate emissivity via the Fresnel model and backscattering coefficients via the SPM. Emissivity and scattering properties are presented as functions of frequency, polarisation, and incidence angle (0°–80°). The present work extends the single-frequency approach of earlier investigators to a systematic multi-frequency framework spanning L through X bands, applicable to the coastal saline soils of Maharashtra. This study would provide a ground-truth reference for RISAT-1, Sentinel-1 C-band SAR [14], and SMAP/SMOS L-band radiometer [15] applications over saline coastal agricultural land in the region.

II. MATERIALS AND METHODS

A. Study Areas and Soil Sampling Techniques

Soil is a heterogeneous body; representative sampling is therefore essential to minimise spatial variability as a source of error [13]. Five topsoil samples (0–20 cm depth) were collected from coastal saline agricultural locations along the Maharashtra coast using composite sampling protocols, i.e., Pen, Alibag, Murud, Tarkarli, and Dapoli. These sites span a range of soil textures, salinity levels, and land-use types representative of the coastal agricultural zone of Maharashtra. Different sites were selected to cover the range of sand–silt–clay compositions and electrical conductivity values found in the region. For convenience, samples are numbered in order of increasing clay content. The physical and chemical properties of these five soil samples are given in Tables 1 and 2, respectively. All five samples are alkaline in nature (pH > 6.8).

Table 1: Physical properties of coastal saline soil samples from Maharashtra

Sample No.	Soil Sampling Site	1. Sand (%)	2. Silt (%)	3. Clay (%)	4. Soil Texture	5. Bulk density (g cc-1)	6. Hydraulic conductivity (cm day-1)
1	Pen (Maharashtra)	23.01	39.25	37.74	Clay Loam	1.36	0.75
2	Alibag (Maharashtra)	17.2	41.23	41.57	Clay Loam	2.4	0.23
3	Murud (Maharashtra)	20.2	37.35	42.45	Clay Loam	1.2	0.34
4	Tarkarli (Maharashtra)	19.1	38.23	42.67	Clay Loam	2.1	0.8
5	Dapoli (Maharashtra)	18.9	35.82	45.28	Clay Loam	1.59	0.92

Table 2: chemical properties of coastal saline soil samples from Maharashtra

	Sample 1	**Sample 2**	**Sample 3**	**Sample 4**	**Sample 5**
Location	Pen, Raigad,	Alibag, Raigad,	Murud, Raigad	Tarkarli, Sindhudurg	Dapoli, Ratnagiri
pH	6.80	6.98	7.35	7.03	7.65
EC (dS m-1)	25.04	24.44	25.99	25.44	29.23
N(Kg/ha)	186.91	187.6	187.7	187.4	186.2
P(Kg/ha)	12.82	18.1	126.1	123	007.2
K(Kg/ha)	217.78	216.99	221.13	220.23	216.34
$CaCO_3$(%)	3	3	4	2	3
Ca(mg/kg)	20.80	22.3	21.3	20.5	23.6
Mg(mg/kg)	18.21	18.50	17.2	2.7	18.23
Na(mg/kg)	14.50	14.31	14.76	14.81	14.43
WHC(%)	52.45	51.39	51.99	51.78	51.99
AD(gm/cc)	0.46	0.43	0.44	0.45	0.42
SD(gm/cc)	0.30	0.32	0.34	0.31	0.35
PS(%)	39	40	38	36	38
VEP(%)	22.99	22.34	22.68	21.99	22.89
OC(%)	0.23	0.22	0.25	0.24	0.04
B(mg/kg)	2.7	2.8	3.2	0.4	4.2
Fe(mg/kg)	0.1	1.5	55.7	0.1	0.5
Cu(mg/kg)	11.6	137	67.8	11.6	33.7
S(mg/kg)	3.1	3.7	2.9	7.3	9.1
Zn(mg/kg)	55.7	33.5	44	43.2	32.1

B. Preparation of Soil Samples

The collected topsoil samples were first sieved using a gyrator sieve shaker to remove coarser particles. The sieved fine particles were then dried in a hot-air oven at 110°C for approximately 24 hours to obtain the oven-dry base samples. These dry soil samples were then inserted into the solid dielectric cell for measurement of their dielectric properties.

C. Dielectric Constant Measurement

There are various methods of measurement of dielectric constant of soil at microwave frequency [4], [23]. A microwave bench setup in the TE_{10} mode using a Gunn oscillator or Reflex Klystron operated at the appropriate frequencies. The solid dielectric cell containing the soil sample is connected to the other end of the source. The signal generated by the microwave source is applied to the soil sample. The front surface of the soil sample reflects some of the incident wave. When the incident and waves reflect back, a standing wave pattern is produced. These standing wave patterns are then used to calculate the values of the shift in minima that occurs both before and after the sample is added. The dielectric constant is calculated by measuring the dielectric material's voltage standing wave ratio (VSWR). The setup for measuring dielectric constant of a solid using two-point method. The complex dielectric permittivity of the soil, ε_r, is the fundamental electrical property used to identify relationships.

Mathematically it is written as:

$$\varepsilon_r = \varepsilon' - j\varepsilon'' \quad \ldots. \text{(a)}$$

where: ε' is real part of complex dielectric constant, and ε" is dielectric loss factor.

For lossy dielectrics i.e. complex permittivity **ε**' and **ε**" dielectrics in such cases, we calculate the complex form of the reflection coefficient and the voltage standing wave ratio. Δx is the shift in minima for waves traveling in the guide with and without a dielectric. Now, VSWR can calculate the reflection coefficient. After determining the taken sample voltage standing wave ratio (S), the magnitude of the reflection coefficient (τ) is calculated using the following relation

$$\tau = \frac{s-1}{s+1} \ldots. \text{(i)}$$

In the two-point method, the complex dielectric constant is given by

$$Y\boldsymbol{\varepsilon} = \frac{X}{\beta l\varepsilon} \, angle 2(\theta - 90^0) = G_\varepsilon + jS_\varepsilon \ \ldots\text{(ii)}$$

and $\lambda_g = 2 \times$ (distance between successive minima with empty short circuited wave-guide cell).

The value of conductance G_ε and susceptance S_ε were obtained. The dielectric constant (ε') and dielectric loss (ε'') of the soil samples were then calculated as:

$$\varepsilon' = \frac{G\varepsilon + (\lambda_g/2a)^2}{1 + (\lambda_g/2a)^2}$$

And

$$\varepsilon'' = \frac{S\varepsilon + (\lambda_g/2a)^2}{1 + (\lambda_g/2a)^2}$$

Where, a is the rectangular waveguide's inner width Gε is a real part of an admittance. An imaginary part of the admittance is represented by $S\varepsilon$. We can connect admission to ε' and ε" by knowing it. The dielectric constant and dielectric loss of the soils are mostly determined by these characteristics.

***D.* Using the measured values of complex dielectric permittivity to calculate the emissivity of the soil**

The measured values of the soil's dielectric constant ε' and dielectric loss ε'' can be used to predict the emissivity of the soil as [22].

$$e(\theta, p) = [1 - R(\theta, p)] \qquad (1)$$

where, θ, is the look angle; p, polarization and R reflection coefficient.

The Fresnel equations relating the complex dielectric constant ε with R are given by the following equations [22].

$$R(\theta, H) = \left[\frac{\cos\theta - (\varepsilon' - \sin^2\theta)^{1/2}}{\cos\theta + (\varepsilon' - \sin^2\theta)^{1/2}}\right]^2$$

$$R(\theta, V) = \left[\frac{\varepsilon'\cos\theta - (\varepsilon' - \sin^2\theta)^{1/2}}{\varepsilon'\cos\theta + (\varepsilon' - \sin^2\theta)^{1/2}}\right]^2$$

For normal incidence $\theta = 0$, one gets the emissivity

$$e = 1 - \left|\frac{1 - (\varepsilon')^{\frac{1}{2}}}{1 + (\varepsilon')^{\frac{1}{2}}}\right|^2 \qquad (2)$$

ESTIMATION OF SCATTERING COEFFICIENT

The scattering coefficient and emissivity can be estimated using a variety of models. The standard deviation of surface height, or r.m.s. surface height (σ), surface correlation length (ℓ), value of wave number k= (2π/λ), and r.m.s. surface slope (m) are the values that determine the validity conditions and surface roughness, both of which must be met[8]. There are three types of surfaces: a two-scale composite rough surface, a smooth undulating surface, and a rough surface. A modest perturbation model is applied when the correlation length and surface standard deviation are both less than the wavelength, indicating a somewhat rough surface. We employed the small perturbation model because the surface of soil is smooth under the dielectric cell. The condition should be satisfied and are based on the values of the standard deviation of surface height or r.m.s surface height (σ), surface correlation length (ℓ), value of wave number $k = (2\pi/\lambda)$ and r.m.s. surface slope (m).

Any surface can be distinguished as a rough surface, a smooth undulating surface and a two-scale composite rough surface. When both the surface standard deviation and the correlation length are smaller than the wavelength, the surface is considered slightly rough, and the small perturbation model (SPM) is employed. In the present study, the soil surface under the dielectric cell was treated as slightly rough and the SPM was therefore applied. The validity conditions for the perturbation model to be satisfied are

$k\sigma < 0.3$

and

$\frac{\sqrt{2}\sigma}{\ell} < 0.3$ where, k = Wave length number $= 2\pi/\lambda, \sigma =$ Surface standard deviation, $\ell =$ Surface correlation length

In the present case

$k\sigma = 0.1$

$k\ell = 1.0$

The backscattering coefficient in this model is calculated using the equation:

$$\sigma^0_{ppn}(\theta) = 8k^4\sigma^2 \text{Cos}^4\theta x \left|\alpha_{pp}(\theta)\right|^2 W(2k\text{Sin}\theta), \quad (3)$$

Where pp = vv or hh i.e. like polarizations.

Also, $|\alpha_{hh}(\theta)|^2 = \Gamma_h(\theta)$ is the Fresnel reflectivity for horizontal polarization, which is given by

$$\alpha_{hh}(\theta) = \frac{\text{Cos}\theta - \sqrt{\varepsilon' - \text{Sin}^2\theta}}{\text{Cos}\theta + \sqrt{\varepsilon' - \text{Sin}^2\theta}} \quad (4)$$

and for vertical Polarization,

$$\alpha_{vv}(\theta) = (\varepsilon_r - 1)\frac{\sin^2\theta - \varepsilon'(1 + \sin^2\theta)}{\left[\varepsilon'\text{Cos}\theta + \sqrt{(\varepsilon' - \sin^2\theta)}\right]^2} \quad (5)$$

Where θ is the angle of incidence, ε_r is the dielectric constant of surface, $W(2k\sin\theta)$ is the normalized roughness spectrum, which is the Bessel transform of the correlation function $\rho(\xi)$, evaluated at the surface wave number of $2k\text{Sin}\theta$. For the Gaussian correlation function,

$$W(2k\text{Sin}\theta) = \frac{1}{2}\ell^2 \exp[(k\ell\text{Sin}\theta)^2] \quad (6)$$

We have considered the following assumption for estimations $k\sigma = 0.1$ and

III. Results And Discussion

The results on dielectric constant, emissivity, and scattering coefficient for the five coastal saline soil samples measured across frequency bands highly relevant to remote sensing applications: X-band (9.685 GHz), J-band (7.6 GHz), C-band (4.785 GHz), S-band (3.15 GHz) and L-band (2.35 GHz) are presented in graphical form. Fig. 1 shows the variation of dielectric constant (ε') for each sample at five representative frequencies. Fig 2 (a-e) show the corresponding emissivity and scattering coefficient as functions of incidence angle and frequency.

Fig. 1 shows the variation of dielectric constant (ε') of the five coastal saline soil samples at representative microwave frequencies X-band (9.685 GHz), J-band (7.6 GHz), C-band (4.785 GHz) S-band(3.15 GHz) and L band(2.35 GHz). It is observed that ε' decreases with increasing frequency for all five samples. This variation is non-linear, and its rate of decrease is relatively higher between L band(2.35 GHz) to C-band (4.785 GHz) compared to C-band (4.785 GHz) and X-band (9.685 GHz).. The higher ε' values at lower frequencies are also attributable to the greater contribution of ionic polarisation from dissolved salts, which diminishes at higher frequencies [8]. Our results are in close agreement with those reported by Hallikainen et al. [7] for soils of similar texture and with the frequency-dependent observations of Mätzler [6] and Dobson et al. [4]. The dielectric ordering of the five samples varies with frequency: at L and S bands, Sample 1 (Pen) shows the lowest ε′ while Sample 2 (Alibag) shows the highest; at C, J, and X bands, Sample 5 (Dapoli) consistently shows the highest ε′, consistent with its highest EC (29.23 dS m^{-1}) and clay content, while Sample 2 (Alibag) shows the lowest ε′ at C and X bands and Sample 4 (Tarkarli) at J-band. This frequency-dependent crossover in dielectric ordering indicates that no single physicochemical parameter governs ε′ uniformly across all bands, motivating the multivariate correlation analysis.

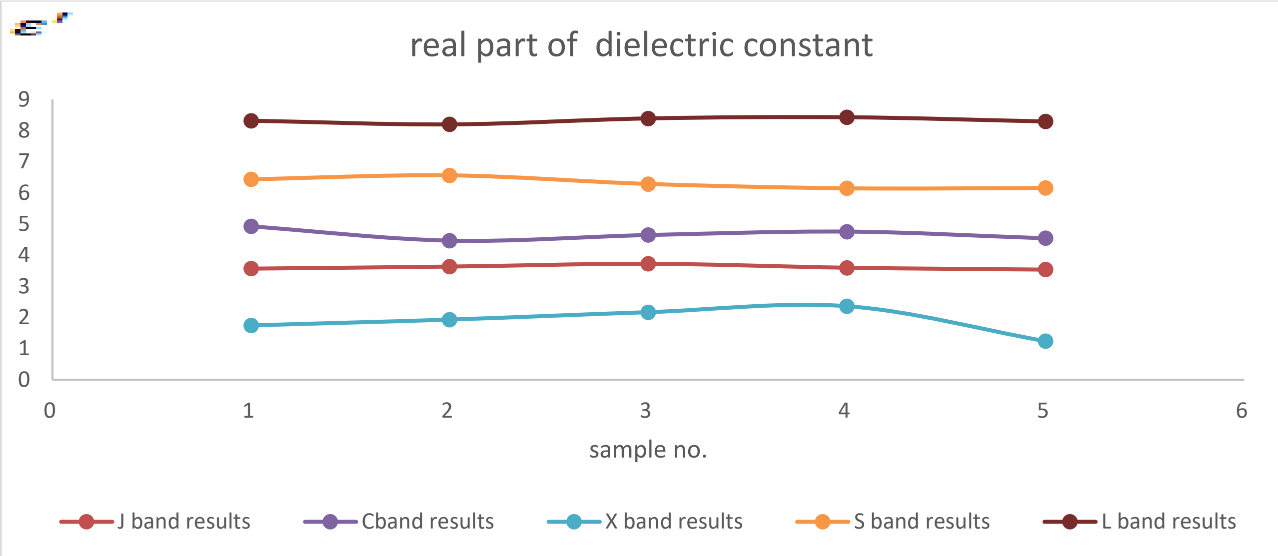

Fig. 1

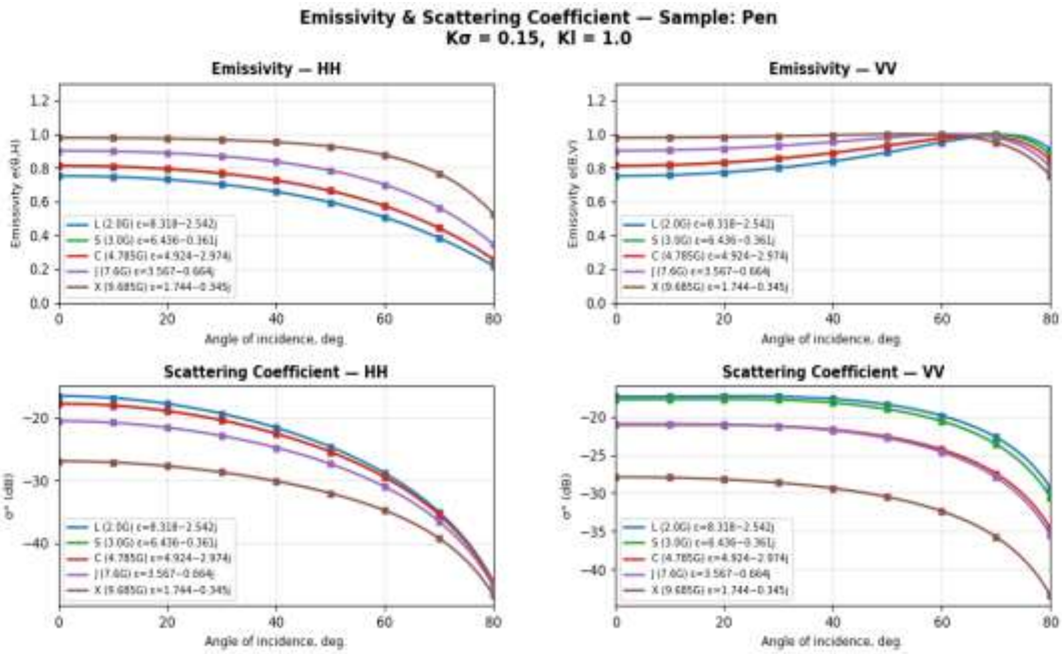

Fig. 2(a)

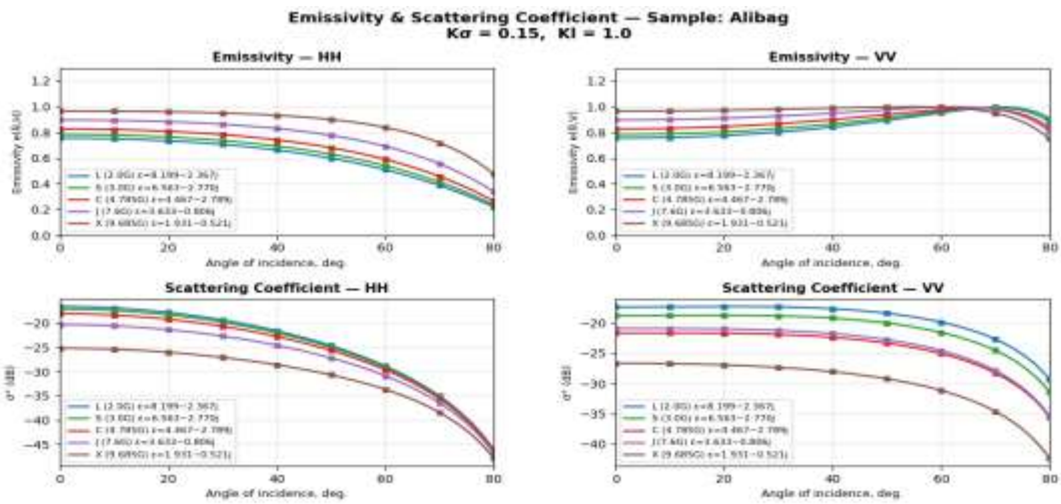

Fig. 2(b)

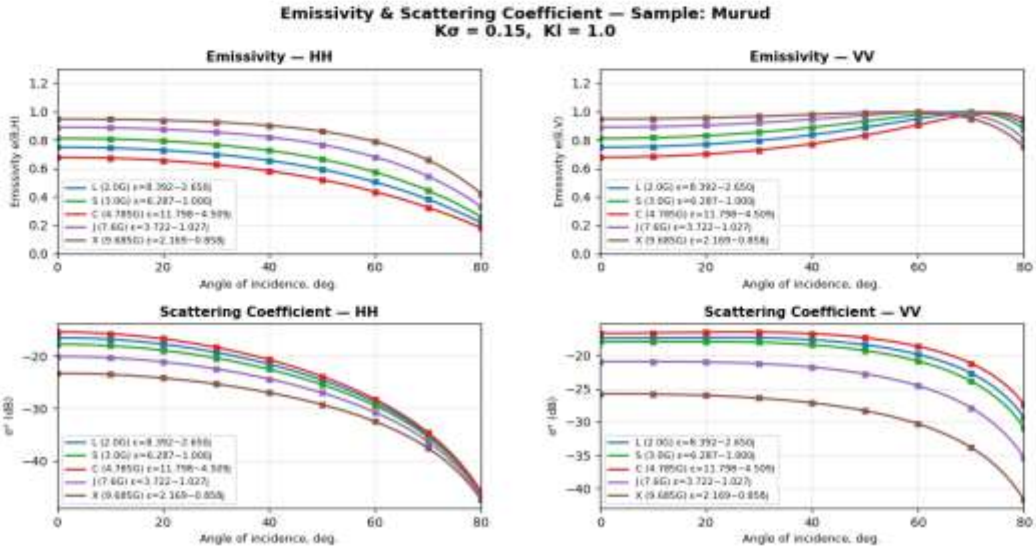

Fig. 2(c)

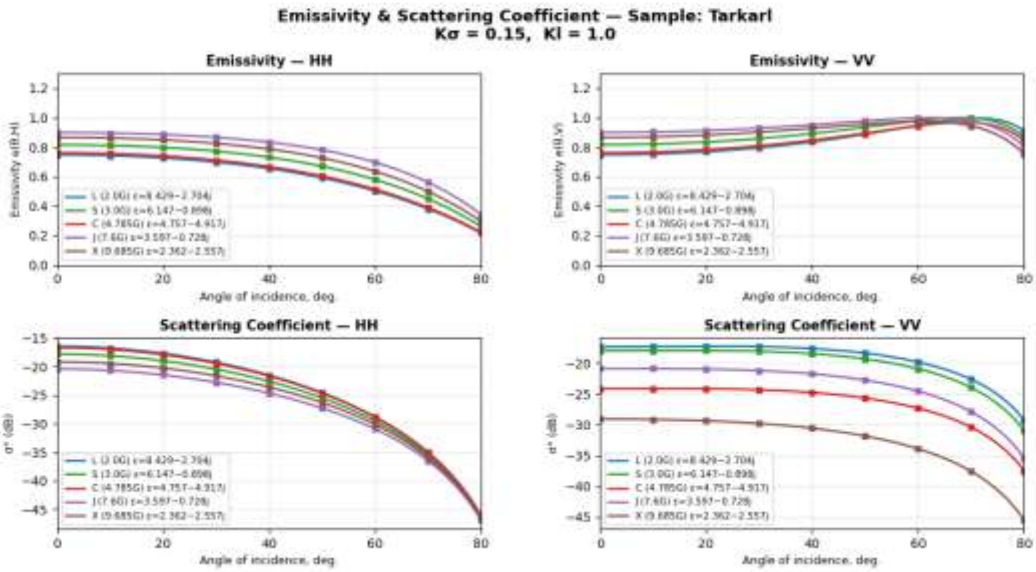

Fig. 2(d)

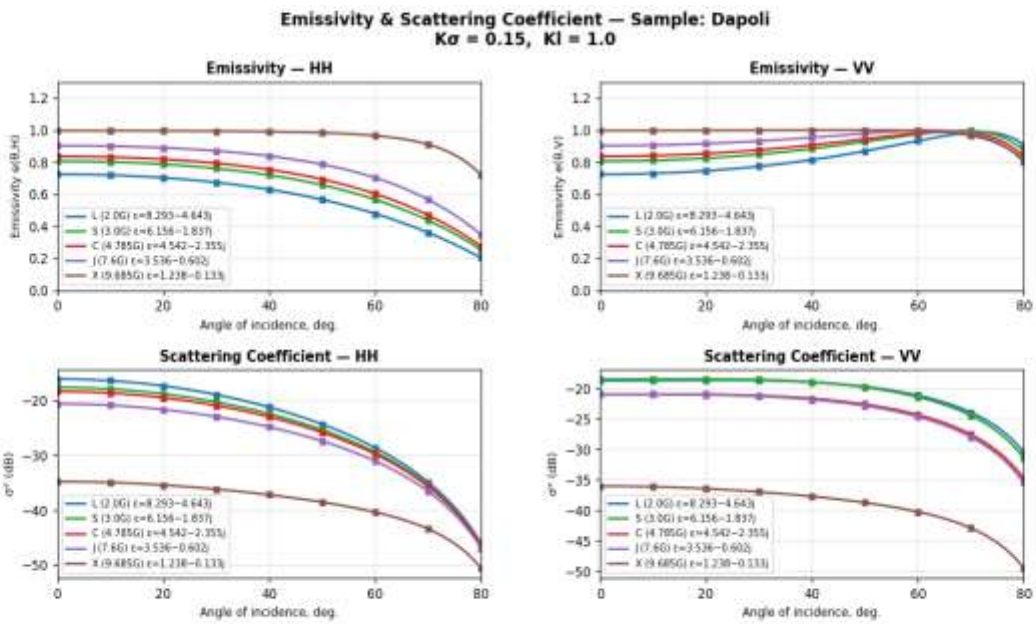

Fig. 2(e)

Figure 2(a-e): Variation of emissivity and scattering coefficient (vertical and horizontal polarisations) of coastal saline soils with incidence angle at X-band (9.685 GHz), J-band (7.6 GHz), C-band (4.785 GHz), S-band (3.15 GHz) and L-band (2.35 GHz) for five Maharashtra coastal saline soil samples: (a) Pen, (b) Alibag, (c) Murud, (d) Tarkarli, (e) Dapoli.
Fig. 2(a) to (e) shows the variation of emissivity $e_p(\theta)$ and scattering coefficient of the five coastal saline soil samples with incidence angle (0°–80°) for both horizontal (HH) and vertical (VV) polarisations at five representative frequencies: X-band (9.685 GHz), J-band (7.6 GHz), C-band (4.785 GHz) S-band(3.15 GHz) and L band(2.35 GHz).
It is observed that for vertical polarisation, emissivity of each soil sample increases with increasing incidence angle up to a certain angle — referred to as the pseudo-Brewster angle — at which it reaches a maximum and beyond which emissivity decreases sharply. For horizontal polarisation, the value of emissivity decreases with increasing incidence angle for all samples and all frequencies. These trends are in complete agreement with the Fresnel emissivity model expressed in Equations (1) and (2) [18] and with results reported by [9–11] for Indian soils, confirming that the coastal saline soils of Maharashtra behave as dielectric half-spaces at the measurement scale.
The Brewster angle crossover between the H-pol and V-pol emissivity curves occurs near 74° for all five samples, consistent with the theoretical expression $\theta_B = \arctan(\sqrt{\varepsilon'})$. The band-averaged pseudo-Brewster angles computed from the measured ε′ are: L-band 71.0°, S-band 68.5°, C-band 64.2°, J-band 61.9°, and X-band 53.8° [18]. The pseudo-Brewster angle (60°–70°) is where V-pol emissivity peaks. L-band V-pol reaches 0.997 at 70°, providing a near-blackbody calibration window. L-band passive moisture sensing is supported by a 19% dynamic range advantage due to L-band nadir emissivity (~0.777) compared to X-band (~0.924).[22]
Individual sample-level predictions range from 51.4° (Alibag, X-band) to 71.3° (Alibag, L-band), consistent with the emissivity peaks observed in Figs. 1(a–e) and confirming the self-consistency of the dielectric and emissivity datasets.
An important finding is the frequency dependence of emissivity: as frequency increases, ε' decreases, which shifts the nadir emissivity (higher frequency → lower reflectivity → higher nadir emissivity) and modestly shifts the pseudo-Brewster angle toward smaller values. At the same incident angle, emissivity for vertical polarisation is greater than for horizontal polarisation for all samples at all frequencies, consistent with published results [7, 13]. These results show fairly good agreement with the experimental results and theoretical predictions of earlier investigators [8, 10, and 13].
Fig. 2(a) to (e) shows the variation of scattering coefficient $\sigma°(\theta)$ (dB) of the five coastal saline soil samples with incidence angle (0°–80°) for HH and VV polarisations at X-band (9.685 GHz), J-band (7.6 GHz), C-band (4.785 GHz) S-band(3.15 GHz) and L band(2.35 GHz).It is observed that, for vertical polarisation, scattering coefficient increases with increasing incidence angle up to approximately 60°–70°, at which it reaches a maximum, and beyond this particular angle it decreases sharply. For horizontal polarisation, the value of scattering coefficient remains relatively stable up to incidence angles of 40°–50° and then starts decreasing. Beyond 50°, it decreases significantly with increasing incidence angle; at about 70°–80° the values from different frequencies become nearly equal. In general, for horizontal polarisation, scattering coefficient decreases with increasing incidence angle beyond 50°. The magnitudes of scattering coefficient at the same incidence angle are greater for vertical polarisation than for horizontal polarisation for all samples and all frequencies. These results show fairly good agreement with results reported by Ahire et al. [13], Calla & Hannan [8], and Calla & Sharma [9].
A key finding of the present study that extends the work of Ahire et al. [13] is the frequency dependence of the scattering coefficient. At a fixed incidence angle, the scattering coefficient increases with increasing frequency. This is a direct consequence of the k^4 dependence in Equation (3): as frequency increases, $k = 2\pi/\lambda$ increases, causing the scattering coefficient to scale strongly with frequency even for a fixed surface roughness. This observation is consistent with the theoretical predictions of Fung et al. [19] and the experimental observations of Gupta & Jangid [20] for Indian soils.
The results presented on dielectric constant, emissivity, and scattering coefficient Figs. 1 and 2 for the five coastal saline soil samples studied across L, S, C, J, and X bands show broadly consistent trends in their variations. The small deviations observed may be due to differences in texture and other physicochemical properties of the five samples, as documented in Tables 1 and 2. These trends confirm that Equations (1)–(6) provide a reasonable description of the microwave behaviour of these soils across the full 2–10 GHz frequency range. The results of this study on emissivity and scattering coefficient are directly useful for designing passive and active remote sensors for monitoring coastal saline soils in Maharashtra, and may find application in the RISAT-1 [11], Sentinel-1 [14], and SMAP/SMOS [15] application programmes.

A. Correlation between Physicochemical and Dielectric Parameters

Among chemical parameters, electrical conductivity (EC) is the strongest and most frequency-selective predictor of ε′, with the correlation coefficient increasing systematically. This frequency-selective strengthening is physically consistent with the ionic polarisation mechanism: at X-band (9.685 GHz), ionic polarisation from dissolved salts makes a dominant contribution to ε′, whereas at L-band, bound-water relaxation and mineralogical effects are more influential. Electrical conductivity (EC), a measure of soluble salt content, directly affects ε″ dielectric loss. More ionic conduction is made possible by higher EC soils, which raises dielectric losses related to energy dissipation. For instance, samples with higher EC values tended to exhibit greater ε″ values at the C-band and J-band frequencies. This is caused by increased microwave absorption by free ions, which increases energy loss and is particularly noticeable at oblique incidence and horizontal polarization [16],
The strong inter-parameter correlation between pH and EC ($r = +0.900$, $p < 0.05$, computed separately) confirms that alkalinity and ionic strength are co-determined by Na^+ and Ca^{2+} concentrations in these coastal saline soils. Calcium content (Ca) shows positive correlations with L-band ε′ ($r = +0.712$) and J-band ε′ ($r = +0.783$), reflecting the strong hydration shell of Ca^{2+} ions that enhances medium-frequency polarizability. $CaCO_3$ content shows a notable negative correlation with S-band ε′ ($r = -0.797$) and a positive correlation with J-band ε′ ($r = +0.760$), suggesting frequency-dependent structural effects of carbonate cementation on water retention and dielectric response. Collectively, these

results confirm that the dielectric response of coastal saline soils is governed by a frequency-dependent interplay of texture, ionic chemistry, and moisture retention, with the dominant mechanism shifting from mineralogical (L and S bands) to ionic (C, J, and X bands) across the 2–10 GHz range. The identified correlations — particularly EC–ε′ at X-band and Sand–ε′ at L-band — are directly applicable to the development of multi-frequency microwave retrieval algorithms for soil salinity mapping over the Maharashtra coastal region.

Dielectric constant (ε′) of all five coastal saline soil samples decreases with increasing microwave frequency from 2.35 to 9.685 GHz. This variation is non-linear, with the rate of decrease more pronounced between L-band (2.35 GHz) and C-band (4.785 GHz) than between C-band and X-band (9.685 GHz), consistent with the Debye relaxation mechanism. The dielectric ordering among samples is frequency-dependent: Sample 5 (Dapoli) consistently shows the highest ε′ at C, J, and X bands, consistent with its highest EC (29.23 dS m^{-1}) and clay content, while no single sample consistently shows the lowest ε′ across all bands. For vertical polarisation, emissivity increases with incidence angle up to the pseudo-Brewster angle — ranging from approximately 54° at X-band to 71° at L-band, computed as $\theta_B \approx \arctan(\sqrt{\varepsilon'})$ — at which it reaches a maximum, and beyond this angle it decreases sharply. For horizontal polarisation, emissivity decreases monotonically with increasing incidence angle for all five samples at all frequencies. At the same incidence angle, emissivity for vertical polarisation is greater than for horizontal polarisation. For vertical polarisation, backscattering coefficient increases with incidence angle up to approximately 60°–70° and then decreases sharply. For horizontal polarisation, backscattering coefficient remains relatively stable up to 40°–50° and then decreases significantly; at about 70°–80° values from different frequencies converge. At a fixed incidence angle, backscattering coefficient increases with increasing microwave frequency due to the k^4 dependence of the SPM, for both polarisations. This frequency sensitivity is greater for vertical polarisation than horizontal polarisation. The emissivity and scattering data reported here are directly useful for designing passive and active microwave remote sensors for coastal saline soil monitoring in Maharashtra, and provide a ground-truth reference for calibrating RISAT-1, Sentinel-1, and SMAP/SMOS systems over this region.

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