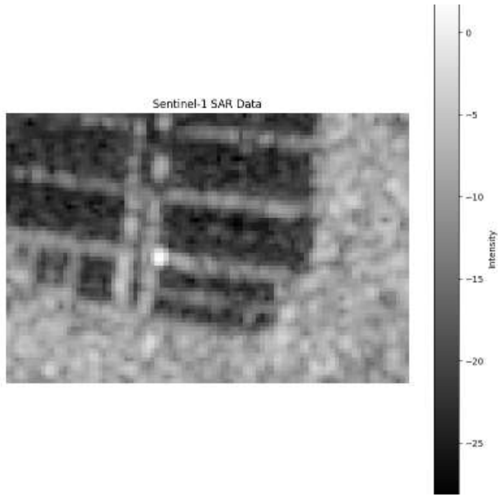
Title: Soil Roughness and Moisture Estimation from SAR Data Using Power spectral Density algorithm and Fractal Analysis

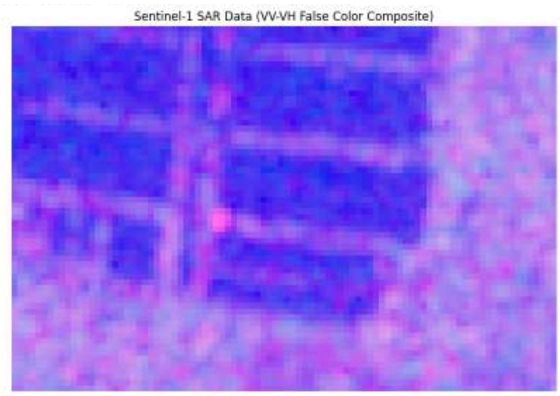
Abstract:

Soil roughness and moisture are essential parameters influencing various agricultural and environmental processes. This report presents a study on soil roughness and moisture estimation using Synthetic Aperture Radar (SAR) data. Two methods are explored: Power Spectral Density (PSD)-based analysis for roughness estimation and Fractal Analysis for both roughness and moisture estimation. SAR data acquired from [Copernicus Open Access Hub] covering the period from [2014] to [2023] is utilized for the analysis. Results indicate significant variations in roughness and moisture estimates between the two methods.

I. Introduction:

Soil roughness and moisture play crucial roles in agricultural productivity, soil erosion control, and water management. Synthetic Aperture Radar (SAR) data provides valuable information for estimating these parameters due to its sensitivity to surface characteristics. This report investigates two methods for soil roughness and moisture estimation using SAR data: PSD-based analysis for roughness and Fractal Analysis for both roughness and moisture.



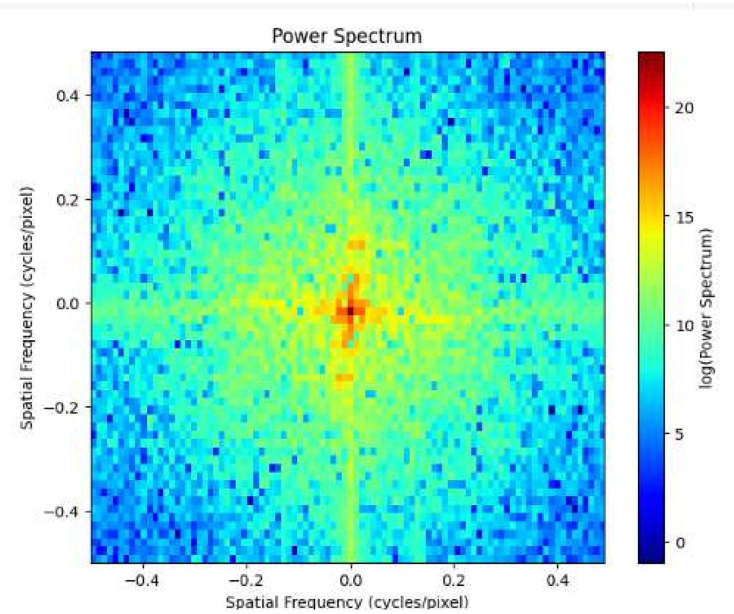


II. Methodology:

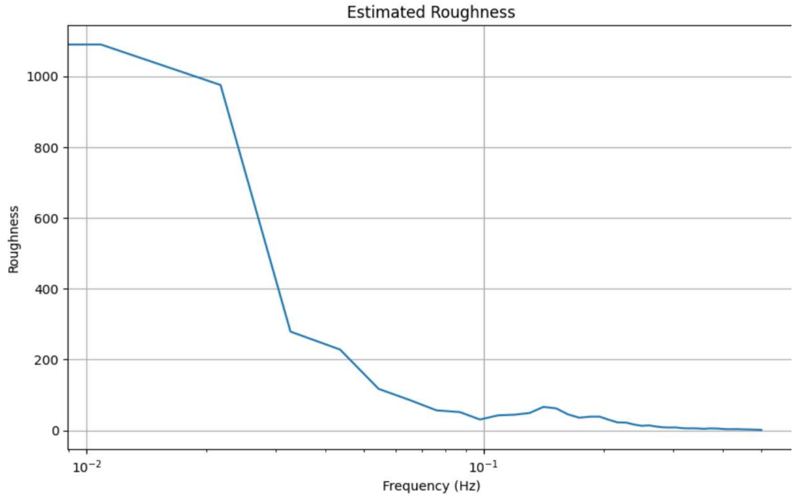
A. Data Acquisition: Sentinel-1 SAR data operating at C band (5.4 Hz) interferometric Wide (IW) swath mode (VV + VH Polarization, descending orbit) at Ground Range Detected (GRD) ,for the study area was obtained from Copernicus Open Access Hub, processed by ESA. The dataset spans from 2014 to 2023.

B. PSD-Based Roughness Estimation:

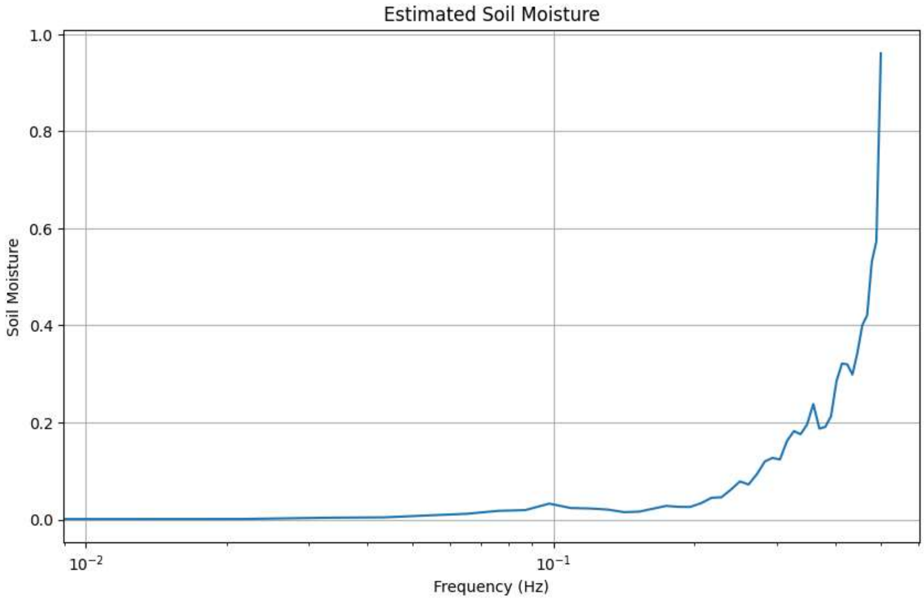
1. **Compute PSD:** The PSD of SAR data was computed using the Welch method, dividing the signal into overlapping segments and computing a Fourier transform on each segment.



2. **Roughness Estimation:** Soil roughness was estimated directly proportional to PSD



3. **Soil Moisture Estimation:** Soil moisture was estimated inversely proportional to the PSD.



The generated graphs perfectly align with the fact that as soil moisture exponentially increases in our region of interest (Kolkata and surrounding regions), soil roughness exponentially decreases.

C. Fractal Analysis:

3. **Compute Fractal Roughness:** Fractal roughness was computed using the formula:

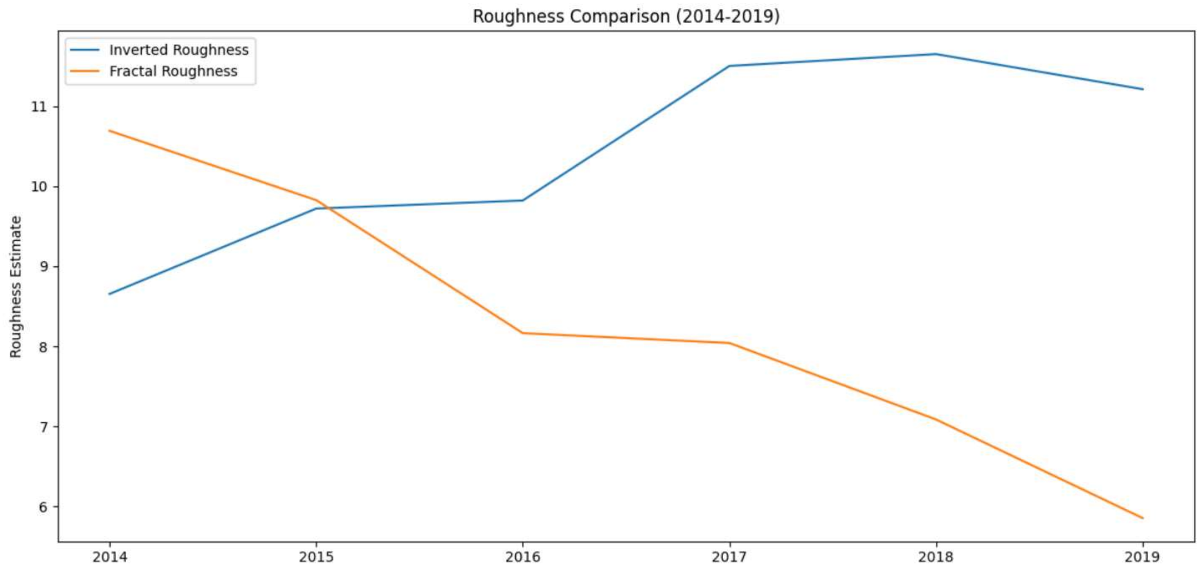
fractal_roughness = rms_height * np.exp(-LAI / correlation_length)

where rms_height is the Root Mean Square (RMS) height of the surface, correlation_length is the correlation length of the surface, and LAI is the Leaf Area Index indicating vegetation growth.

D.Inverted Roughness Analysis:

Inverted_roughness=RMS_height×correlation_length

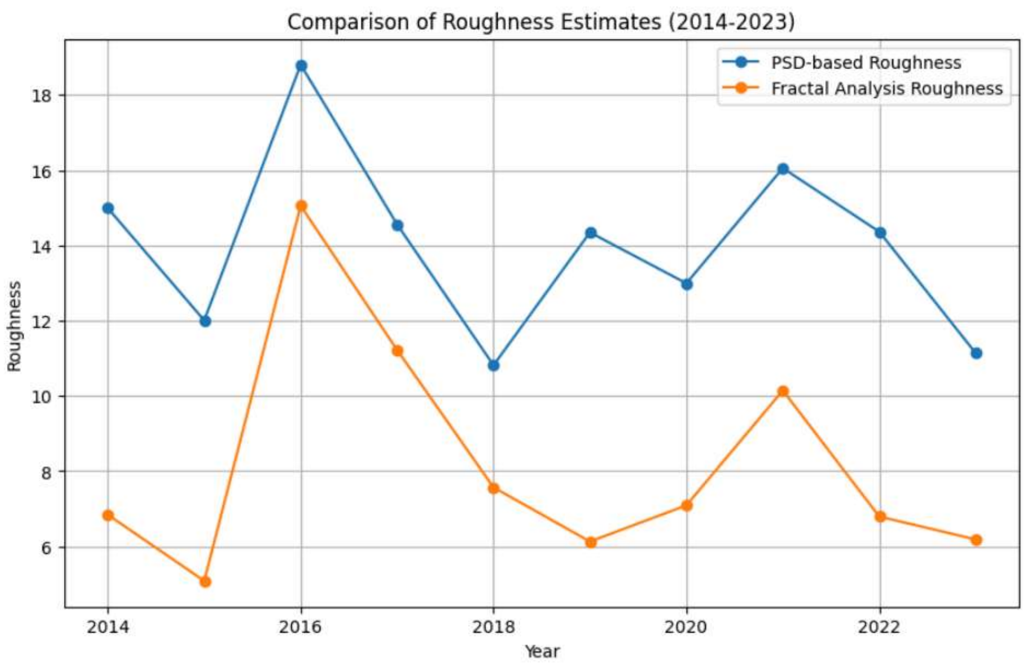
Time Series data for 10 years-
Graphs showing the relation between Inverted Roughness and Fractal Roughness



IV. Discussion:

A. Comparative Analysis:

- Comparison between PSD-based and Fractal Analysis methods revealed differences in roughness and moisture estimates.



Fractal analysis often involves complex computational tasks, including calculating parameters like Leaf Area Index (LAI) and correlation length, which can be computationally intensive. In contrast, the rescaled Power Spectral Density method is generally easier to implement and does not require as much computation, making it more accessible for practical applications.

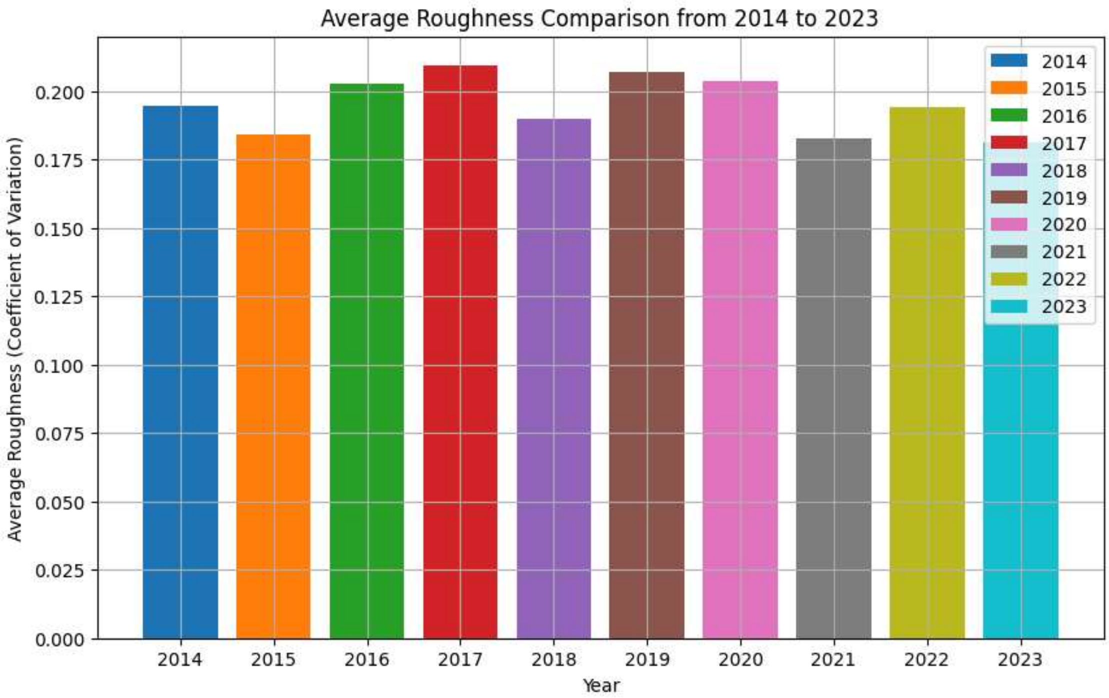
B. Comparison between Roughness and Moisture Estimates:

The comparison between roughness and moisture estimates revealed interesting patterns and correlations. While roughness estimates tended to fluctuate within a certain range, moisture content exhibited more pronounced variations, reflecting changes in soil moisture availability and land surface conditions

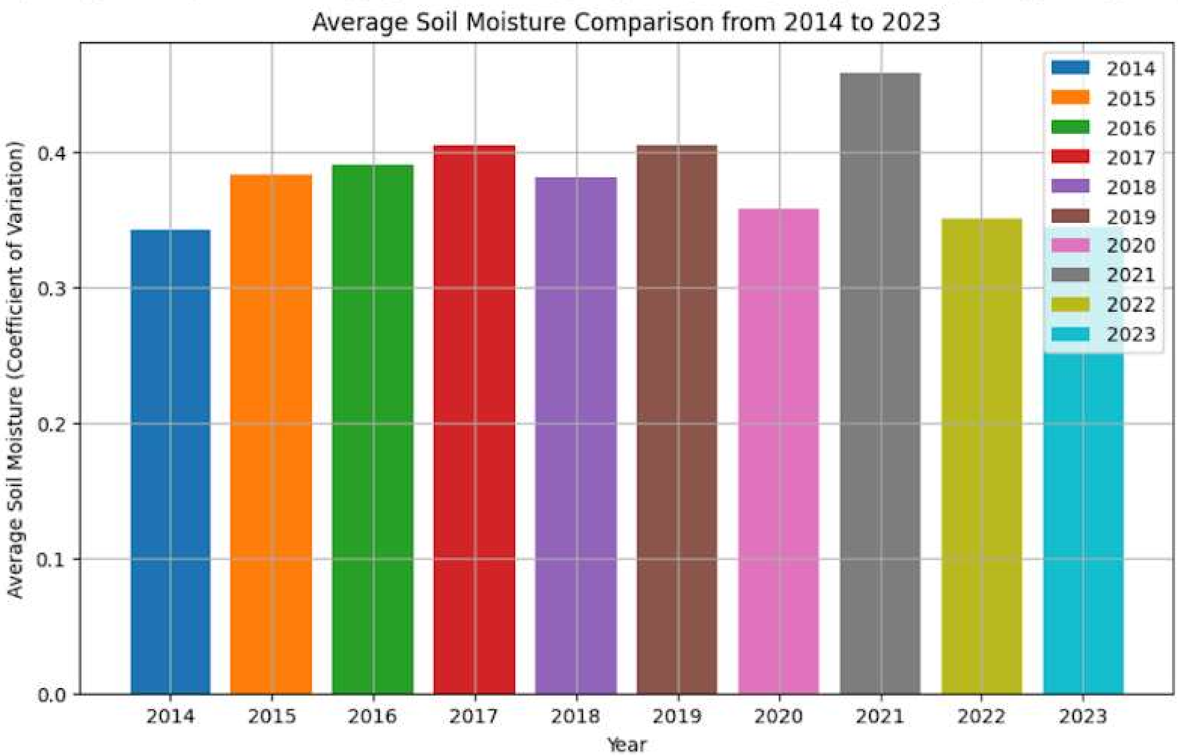
Tabular Format Comparison of data year-wise from 2014-2023

YEAR	RMS HEIGHT	CORRELATION LENGTH	LAI	AVG SOIL MOISTURE	AVG SOIL ROUGHNESS
2014	15.183243	0.57	0.2	0.19865831	42.235836
2015	16.199472	0.60	0.3	0.18207654	46.060894
2016	15.108516	0.65	0.4	0.20543410	64.47997
2017	16.427942	0.70	0.5	0.18545351	63.36352
2018	17.128516	0.68	0.6	0.19819714	59.85295
2019	17.792843	0.63	0.7	0.12254261	77.62473
2020	17.27252	0.59	0.5	0.15116546	82.323074
2021	16.353012	0.65	0.4	0.24486622	74.340096
2022	17.510206	0.57	0.7	0.28730983	66.06848
2023	17.072598	0.62	0.69	0.24486622	74.340096

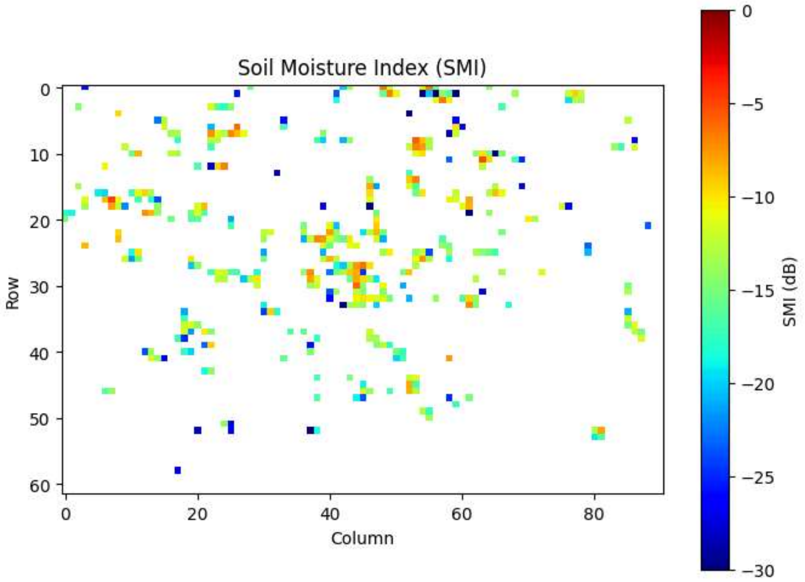
Average Roughness Comparison from 2014-2023 (10 years data)



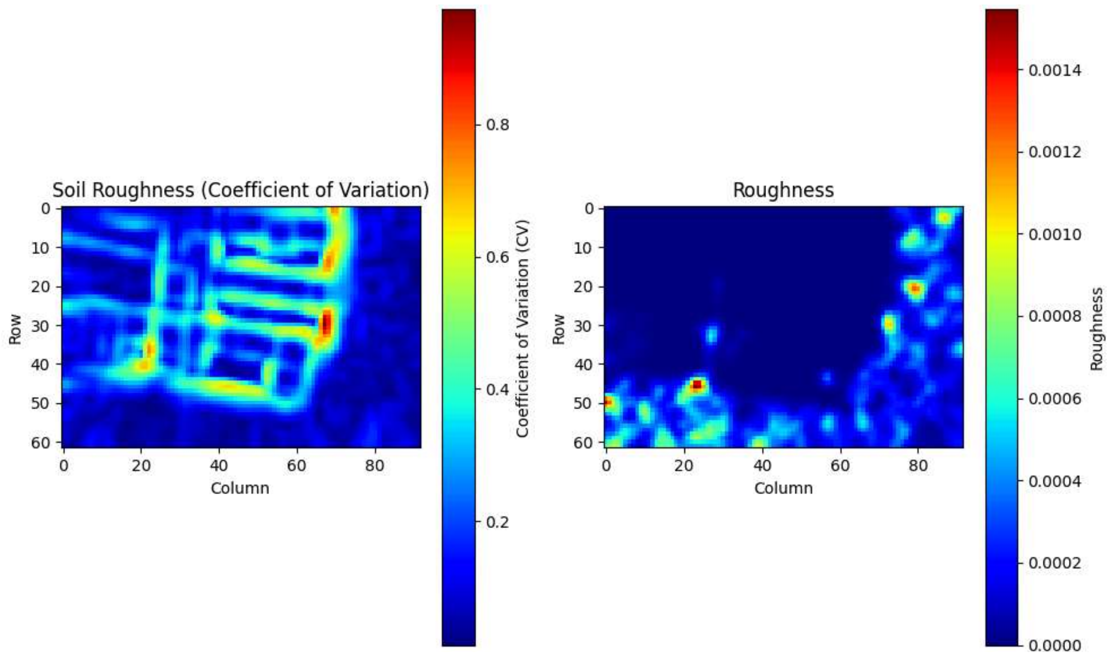
Average Soil Moisture from 2014-2023 (10 years data)



Scatter plot representing Soil moisture index of the region of interest kolkata and its surrounding:



Soil Roughness (Coefficient of Variation) and Roughness Comparison on the 2018 Data



Future Scope of Rescaled Power Spectrum Density to estimate Soil Roughness and Soil Moisture

Enhancing Multi-Scale Analysis: Further research could focus on refining the multi-scale analysis of soil roughness using rescaled Power Spectral Density (PSD) with Synthetic Aperture Radar (SAR)-inverted root-mean-square (RMS) height. This could involve investigating additional scales and incorporating more complex fractal models to better represent the variability of soil surfaces.

Improved Soil Moisture Retrieval: The study demonstrates the potential of using non-stationary fractal roughness for soil moisture retrieval. Future work could explore advanced inversion algorithms and machine learning techniques to further improve the accuracy of soil moisture estimation from SAR data, especially under varying surface roughness conditions.

Validation and Calibration: Further validation of the proposed method could be conducted using more extensive field measurements and ground truth data. Additionally, calibration of the model parameters could be performed using data from different locations and environmental conditions to enhance the robustness and generalizability of the approach.

Integration with Other Remote Sensing Data: Integration of SAR data with other remote sensing datasets, such as optical and thermal imagery, could provide a more comprehensive understanding of soil properties and improve the accuracy of soil moisture estimation. This integration could also help in monitoring other environmental parameters, such as vegetation dynamics and land use changes.

Conclusion:

In conclusion, the analysis of soil moisture using rescaled power spectral density (PSD) provides valuable insights into the spatial variability and fractal nature of soil moisture patterns. By rescaling the PSD, we can effectively characterize the non-stationary fractal roughness of soil moisture across different spatial scales. This approach allows for a deeper understanding of soil moisture dynamics, including its spatial distribution, heterogeneity, and scaling behavior. Through rescaled PSD analysis, researchers can gain valuable information for various applications, including agriculture, hydrology, and environmental monitoring, ultimately enhancing our ability to manage and sustainably utilize soil resources.

References

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