



Evaluation of RISAT-1 data for soil moisture retrieval in semi-arid tropics of India

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Received: 28 July 2020; Accepted: 30 September 2021

ABSTRACT

The selection of better polarisation and incidence angle for soil moisture retrieval using RISAT-1 microwave data was experimented at Hayathnagar research farm of ICAR-CRIDA, Hyderabad. Fine Resolution Sensor (FRS-1) data (spatial resolution of 3 m) and Medium Resolution ScanSAR (MRS) data (spatial resolution of 25 m) acquired from circular and dual polarised microwave data were used for the retrieval of soil moisture and to identify the best polarisation suitable for the study area. The evaluation was carried out during 2016–17. FRS-1 data was more accurate than MRS data for the extraction of soil moisture in the study area. Circular and dual-Polarisation retrieved soil moisture values were compared with volumetric soil moisture values for assessing the better polarisation. Dual polarisation and the incident angle between 15-20 degrees with $R^2=0.952$ performed better as compared to circular polarisation with more or less than 20 degrees' incident angle. A correction factor of -0.723 was derived and applied to FRS-1 data with less than a 20-degree incident angle for getting real soil moisture values on the spatio-temporal basis to optimize the management of natural ecosystems under climate change threat.

Keywords: Microwave remote sensing, RISAT-1, Soil moisture

Soil moisture influences the earth system dynamics (Dunkl *et al.* 2021) critically. Soil moisture is a crucial parameter for deciding crop sowing date, irrigation management, and crop growth in a semi-arid environment. Spatial distribution of soil moisture and its mapping is thus playing a crucial role in various hydrological management at farm, catchment, or regional level. In recent decades, to get consistent data on soil moisture, in a spatial mode, remote sensing tools were used (Cheema *et al.* 2011). The high demand for data exhibited by the models and the high costs for ground measurements make remote sensing a highly viable option. High spatial and temporal variability of soil moisture within a time span is a challenge for its adequate monitoring and modelling (Pushpanjali *et al.* 2019). Thus, microwave remote sensing is one of the most promising tools for soil moisture estimation owing to its high sensitivity to dielectric properties of the target (Srivastava *et al.* 2006).

RISAT-1 (Radar Imaging SATellite) is India's first microwave remote sensing satellite carrying a SAR

payload operating in the C-band (5.35 GHz). PSLV-C19 successfully launched RISAT-1 on April 26, 2012. FRS-1 image (spatial resolution of 3 m) and MRS image (spatial resolution of 25 m) acquired at circular and dual polarisation has been used for the retrieval of soil moisture in and around Hayathnagar Research Farm of Central Research Institute for Dryland Agriculture (ICAR-CRIDA) situated in Hayathnagar village, Rangareddy district of Telangana. The overall aim of the study explains the RISAT-1 SAR retrieval of soil moisture both spatially and temporally to improve our understanding of the hydrological behaviour of soil and its wide application for model generation. The incident angle also plays a major role as influencing the radar backscatter and targets' appearance in the images. The objectives of this study are twofold. First, to analyse better polarisation and incidence angle for the soil moisture retrieval. Second, to derive a correction factor for the SAR data with best-suited polarisation and incidence angle, by which we can get the near ground truth (GT) soil moisture values for the study area.

MATERIALS AND METHODS

The study was carried out at Hayathnagar Research Farm (HRF) of the Central Research Institute of Dryland Agriculture, situated between 17.33–17.36 decimal degrees latitude and 78.58–78.61 decimal degrees, area comes under a semi-arid (dry) climate. Granites and gneiss dominate

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the study area with denuded rock outcrops in many parts. The soils are well to moderately well-drained with light textured. The mean annual rainfall is 764 mm, of which about 85% is received from June to September due to the southwest monsoon. During the time of field data collection, the humidity of that area was very low, with no rainfall and vegetation.

Soil sampling: The samples for ground-truthing were collected from the agriculture field with no crop stand. Minimum Sampling Unit Size (in m²) for RISAT-1 SAR (for an error of 5% on the signal amplitude at 90% confidence interval) for RISAT-1 (FRS-1 mode) as suggested by Patel and Srivastava (2013) a grid of 45 × 45 m² square was marked, same collection points was also used for MRS mode of RISAT-1. Soil samples were gathered at a depth of 0-5 cm from the points at the time of satellite pass, i.e. 6:30 pm. Thematic maps were prepared after characterising, 134 soil samples (exclusion of samples with extreme values).

Soil moisture content: Gravimetric soil moisture (SM^G) value was obtained from laboratory analysis, which was converted to volumetric soil moisture (SM^V) by multiplying bulk density (BD).

$$SM^V = SM^G * BD(1)$$

Data procured and processing: RISAT-1 designed to provide SAR images with a repetivity period of 24 days. Its orbit design takes the spacecraft crossing the equator in its descending path (north to south) at 6 am and crosses the equator in its ascending path (south to north) at 6 pm. It passes the study area by 6.30 pm. RISAT-1 microwave data has been procured from NRSC (National Remote Sensing Centre), Hyderabad (Table 1). For the study, software including SARC-View, ENVI 4.3, and ERDAS Imagine were used to process the acquired data. The evaluation was carried out in the year 2016-2017.

Surface roughness: In this study for dual polarisation data, cross polarisation ratio (HV/HH) was used for retrieving roughness as described by Thanabalan (2018). For circular polarisation, the difference in backscatter of RV and RH polarisation ($\sigma_{RV} - \sigma_{RH}$) (Rawat 2018) was used for surface roughness calculation.

Backscatter co-efficient: Backscatter (σ) for microwave data of the study area was calculated using the Eq. (2). Image is processed to retrieve σ (both RH and RV) by SARC-View. SARC-View is platform-based application

developed by NRSC particularly to process σ . To process the image required value of calibration constant (KdB), incidence angle for the pixel position p (ip) and incidence angle at the scene center were taken from the metadata file.

Dielectric constant and soil moisture retrieval: For Dual polarisation, dielectric constant (ϵ) was obtained from the modified Dubois model, which was used to derive the Soil moisture from Topp's equation (Srinivasa 2013 and Tahnabalan *et al.* 2018). For circular polarisation ϵ can be generated for a particular microwave frequency (in case of RISAT-1, 5.3 GHz) on the basis of SM and soil texture properties (Hallikainen *et al.* 1985). The ϵ was used for estimating SM using Topp model (Rawat *et al.* 2018). A methodology was developed for the study area for soil moisture determination using RISAT-1 microwave data given below (Fig.1).

RESULTS AND DISCUSSION

Soil's physico-chemical properties and its relationship to soil moisture can make better soil-management decisions. Soil composition greatly influence water infiltration, permeability, and water-holding capacity.

Description of soil conditions: Soil texture often exerts a more substantial influence than precipitation on soil moisture patterns at a larger scale (Dong *et al.* 2018). Soil texture is a crucial parameter, by which the soil properties depends (physical, chemical, and biological), and often used to estimate difficult-to-measure hydraulic soil properties including soil moisture (Bousbih *et al.* 2019). The subsurface soils are somewhat massive than the surface layers. Available water content (AWC) of these soils is comparatively low, and it ranges from 3.6–17.8%. Percentage of sand and clay varies from 70–85% and 10–15%, respectively. Observed bulk density was 1.3-1.45 g/cm³ in the study area.

Inverse distance weighting (IDW), the interpolation method was used to estimate the soil properties (Santoso *et al.* 2018). A neighborhood about the interpolated point is identified, and a weighted average of the observation values within proximity. Inverse distance weighting is a deterministic, nonlinear interpolation technique. Three soil texture groups, namely sandy loam and sandy clay loam soils (33% and 32 % area respectively) followed by loamy sand (28%), were identified for HRF. In order to find, if there is any significant variation in estimated soil moisture across the soil textures identified in study area, ground data

Table 1 Details of data procured from NRSC

RISAT-1 Data	Circular polarisation (< 20 degrees incidence angle)	Circular polarisation (> 20 degrees incidence angle)
FRS-1	23 March 2014	21 March 2014
MRS	12 May 2014	10 May 2014
	Dual polarisation (< 20 degrees incidence angle)	Dual polarisation (> 20 degrees incidence angle)
FRS-1	3 November 2014	21 December 2014
MRS	25 December 2014	12 September 2014

• Medium Resolution Scan SAR Mode (MRS): 25 m resolution, 115 km swath. Fine Resolution Stripmap Mode-1 (FRS-1): 3 m resolution, 25 km swath.

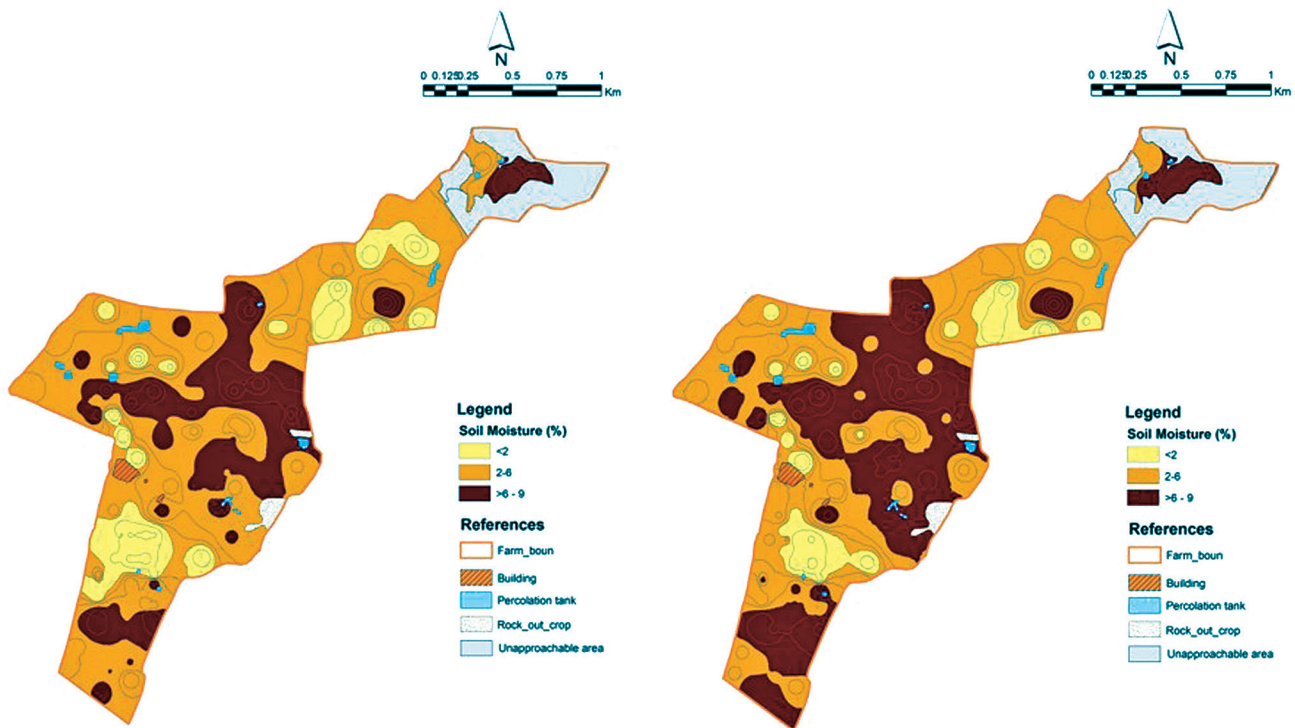


Fig 1 Soil moisture map using IDW interpolation method.

for soil moisture study from the grids being overlapped on soil texture map to capture the variations. Soil textures with coarser particle sizes have higher soil conductivity; as a result, water infiltrates more rapidly from the top to the bottom soil layers, which leads to reduced soil moisture in the top soil layer (Lin *et al.* 2016). So, there was no visible difference in satellite retrieved soil moisture across different soil textures in the study area.

Soil moisture retrieval from RISAT-1 data: Although within-pixel soil moisture distributions were not directly influenced by topography (Charpentier *et al.* 1992), homogeneous area pixels have better accuracy in soil moisture classification (Ahmed *et al.* 2011). The soil moisture can be secondarily derived from the dielectric constant using (Topp *et al.* 1980) model. Topp model is being used to derive soil moisture from all the SAR data used. This model has been used by many researchers effectively for retrieving soil moisture (Song *et al.* 2010) shows good correspondence.

The soil moisture retrieved through RISAT-1 data has a good correlation with the field measured soil moisture (Table 2). The observed soil moisture data and the retrieved data were analysed for the best fitting. It is essential to relate satellite-based backscattering measurements with *in-situ* soil moisture data for soil moisture studies (İmamoğlu *et al.* 2016). Regression is one of the widely used methods to create this relationship. The coefficient of determination was calculated as the square of the simple linear correlation coefficient between the retrieved and observed values; the closer to 1, the better. For validation, the sample size should be 17-25, as suggested by Patel *et al.* (2013), for

the models where R^2 is 0.85, with 95% of a user-defined upper limit. SAR data were compared with the observed using the coefficient of determination (R^2). Keeping all other parameters, the same FRS 21st March MW data with angle 23

Table 2 Results comparison of (synthetic aperture radar) SAR data

SAR data	Mean observed SM	Mean estimated SM	Equation	R^2
FCA2	4.303571	5.401429	$y = 0.780x + 1.695$	$R^2 = 0.893$
FCA1	1.346071	2.160714	$y = 0.821x + 1.423$	$R^2 = 0.939$
FDA2	5.121429	5.909286	$y = 0.931x + 1.140$	$R^2 = 0.915$
FDA1	2.642857	3.821429	$y = 0.944x + 0.914$	$R^2 = 0.952$
MCA1	3.144286	4.005714	$y = 1.095x + 0.688$	$R^2 = 0.839$
MCA2	4.207143	4.980714	$y = 0.420x + 1.594$	$R^2 = 0.796$
MDA2	3.205	4.076429	$y = 0.792x + 1.536$	$R^2 = 0.877$
MDA1	2.707857	3.536429	$y = 0.802x + 1.364$	$R^2 = 0.880$

SM, Soil moisture (%); F, Fine resolution; M, Medium resolution; C, Circular polarization; D, Dual polarization; A1, less than 20 incidence angle (17-19 degree); A2, More than 20 incidence angle (23-25 degree).

degree and MRS 10th May MW data with angle 23 degrees (same angle) is compared to choose the resolution which is best suited for soil moisture retrieval. FRS-1, as compared to MRS, proves to be better for the soil moisture retrieval. Better resolution of FRS-1 data may be the reason for more accuracy and functional relationship between observed and soil moisture retrieved from the FRS-1 data set (Rawat 2017). The MW data of FRS-1 of 23 March with circular and FRS 3 November MW data with dual polarisation with the same angle (17 degrees) were compared to choose the resolution which is best suited for soil moisture estimation. Dual polarisation as compared to circular polarisation (Table 2) showed better results ($R^2=0.0952$) for the retrieval of soil moisture in the study area. FRS-1 dual polarisation with less than 20 degree incidence angle showed better ($R^2=0.952$) result for soil moisture retrieval using RISAT-1 data.

Correction factor: When moisture contents are required near the surface, corrections have to be applied when the zone of measurement of the probe is not contained within the soil (Grant *et al.* 1975). Based on observation and retrieved value of soil moisture through microwave data, a correction factor was developed for the study area. The soil moisture extracted from satellite data was more than the observed value (Fig 1), as also observed by Palanisamy *et al.* (2018). A correction factor of -0.723 can be used to get more realistic estimate soil moisture value for this region through RISAT-1 microwave data.

Formula used for estimation of correction factor was :

$$c = \frac{1}{n} \sum_{i=1}^n x_i - y_i$$

$$Y = x_i + c$$

where, x_i = satellite retrieved soil moisture; y_i = estimated soil moisture from the equation 5; Y = corrected soil moisture; c = correction factor.

FDA1 (satellite retrieved soil moisture) and corrected soil moisture (estimated soil moisture after applying correction factor) were compared with the observed (ground truth soil moisture data) by the t-test ($P < 0.05$), and test statistics were significant (Table 3). The correlation between the soil moisture data obtained was highly correlated (0.97) and found to be significant at 1%. Moreover, Geostatistical approach was applied to create areal soil moisture maps from point based *in-situ* soil moisture measurements

Table 3 Correlation between observed, estimated and CF used estimated value of soil moisture

Correlation		SM observed	SM estimated	SM with CF
SM observed	Pearson	1	.976**	.976**
	Correlation			
SAR retrieved SM	Pearson	.976**	1	1.000**
	Correlation			
Corrected SM	Pearson	.976**	1.000**	1
	Correlation			

** Correlation is significant at the 0.01 level (2-tailed).

(İmamoğlu *et al.* 2016). For soil moisture mapping, IDW uses a weighted average of the soil moisture values from nearby sample points to estimate the soil moisture values of un-sampled locations.

Soil moisture is an essential variable in the climate system. Monitoring soil moisture provides the necessary information to adopt and implement strategies to reduce damage due to deficits in precipitation as well as determine approaches to optimise the management of natural ecosystems under the threat of climate change. Though, microwave data handling for soil moisture has its limitations yet promising. Dual polarised FRS-1 data with and incidence angle less than 20° proved to be for soil moisture retrieval. SAR derived SM data were slightly higher as compared to the ground truth data collected. A correction factor of -0.723 can be applied to assess SM over different agricultural regimes after calibration and testing following our approach.

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