**Evaluation and Inversion of Oh, Dubois Models C – band (Sentinel 1) data for Soil Surface Parameter**

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**Abstract:** Soil moisture is a very use full parameter and has a wide application in agriculture, water resources and most important in climate prediction. Measurement of soil moisture is very complex from SAR data, the purpose of this study is to develop an inversion technique by which we can easily calculate not even soil moisture but also other important soil surface parameter ie. Surface roughness, dielectric constant of soil and water mixture. We have implemented and analyzed three popular empirical model (Oh, Dubois, and modified Dubois by Bagdadi (MDB) ) to simulate soil moisture, and also evaluate these models on the basis of their complexity and accuracy. These models, then used to retrieve the surface parameters. In this work we have inverted different models and find the values of surface parameters of soil using SAR processed data. We have also develop a GUI for calculating soil surface and SAR parameter. In this study we have used Sentinel – 1 data set which consists of C-band sensors in dual band (HV and VV). This work is mainly divided in three parts, in first; the models were evaluated by using field measurement data and backscattering models. In second part we have perform the inversion method to retrieve surface soil parameter, in this we have found all three models are not very complex to invert the surface parameter. Comparatively Oh model were very explanatory and give all surface parameter in simple expression as compare to other. We have also developed inversion equation for all three models. In third part, we have developed simple GUI for inversion method. Oh model and Dubois model were developed for full – pole polarization and MDB model were developed for dual – pole. We have not used a single model for inversion as one model are not independently able to find all surface parameter except Oh model but it can be apply only on Full – poll data. We have used the combination of three models and find important surface parameter which can be applicable for both full – pole and dual – Pole. We have collected soil sample (bare soil) from predefined location based on literature review, and calculate soil moisture in the lab using microwave bench and oven dry method.

SAR images of the same area have used for further processing and evaluation of three models and inversion also. First backscattering (σ0) value were calculated using SNAP simulation software for C- band at different incidence angle from 310 to 420 for Sentinel 1 data set. These values are used to retrieve the soil surface parameter and compare with lab data. In this study the inversion method results show that dual – pole data is sufficient for retrieving soil surface moisture and also other surface parameters.

**Keywords**: soil moisture, inversion, SAR, Oh model, modified Dubois model, bare soil

1. **INTRODUCTION**

Soil moisture is a important parameters for agriculture and also important in different crop production, water and energy balance, water requirement, and atmosphere change. Soil surface parameters retrieval is very difficult from microwave SAR data. SAR data is extensively investigated in the past four decades. Surface soil moisture are the key parameter for agricultural and hydrological applications [1], SAR data is widely used for finding surface soil parameters over the large area [2-7]. SAR data is very sensitivity to surface soil parameter which is usefull for water management, drought monitoring, flood forecasting, and sustainable agriculture [8]. The back scattering of SAR is based upon physical and electrical parameter of the target material [9-12] and also on SAR configuration (polarization, incidence angle, frequency, etc). As per the literature the most dependent parameter on which SAR scattering parameters depend is geophysical parameter of soil surface (surface soil moisture, surface roughness, dielectric constant, etc.) [13]. Many researcher have been explain the effect of surface roughness is more important as compared to the surface soil moisture on SAR back scattering coefficient [14-16]. Till date many researchers have studied the bare soil surface parameter and also have given many empirical, semi-empirical and physical models to estimate surface soil moisture using SAR data. All these methods can be divided in two groups such as physical and empirical model , empirical model depends on site condition, but physical model does not depends on the site and also does not required field calibration. The most popular physical model is the IEM (integral equation model) model developed in 1992 by Fung and Chen [17]. In this model SAR backscatter (σ0) considered as a function of SAR configuration and surface parameters. Empirical or semi- empirical model, are generally based on the field parameters and also required field calibration. In the different empirical and semi-empirical models Oh model gives significant results on bare soil surfaces which covers a large range of microwave signals (L-, C-, X- band) [18]. Theoretical scattering models [19-20], and radar measurement show that the σ0is more sensitive to surface roughness than soil moisture. As compare to other model Oh model can be preferred due to its simplicity and it gives the direct relation between the physical parameter (surface soil moisture, surface roughness and dielectric constant, etc.) and backscattering coefficient (σ0). In oh model one can easily estimate the surface soil moisture and other related parameter, and it is also preferable to invert the soil surface parameter.

In SAR (σ0) backscattering coefficient which is returning from the target to SAR antenna system that is most influence by the soil parameters soil moisture (dielectric constant) [21]. SAR images can be processed and used for retrieving the surface parameter using empirical, physical and theoretical models that gives relation between target parameter (soil moisture and surface roughness) and SAR configurations ( incidence angle, polarization and frequency) [22]. As we know that two parameters on which backscatter coefficient mostly depends are soil moisture and surface roughness, so multiple equations (two or more than two) are required which are multi- configuration SAR data solution [11].

Oh et al. in 1992 have calculated all parametric values and give simple inversion techniques for full pole data set, the work performed with extensive data set in in-situ measurements. Oh have given the first empirical model [18] in 1992 for inversion technique for radar scattering from bare soil surface. Experiment was performed on bare surface a field was selected of different soil moisture and surface roughness at different frequency bands (L-, C-, X- bands). This model was again modified and made it as simple as possible by himself in 2004 [23], in this model first time he was given a very improved three modified equations which gives simple inversion method from SAR data. In this study we are studying various physical and empirical models to understand the nature of backscattering parameter for surface soil parameter. Oh model have been studied in detail because it gives clear idea about the relation between SAR data and surface parameter. To retrieve the soil surface physical parameter, we have implemented first Oh model with full pole data. We have used two data set one is from the extensive study of Oh et al. in [18, 22], other dataset is composed of SAR images and in situ measurement (real data). We have simulated Oh model and compare with the real collected field dataset. We have also used other model (MDB,Dubois Models) for simulating the behaviour of SAR backscattering parameter with surface parameter.

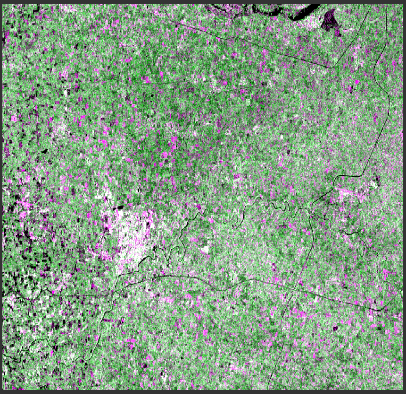
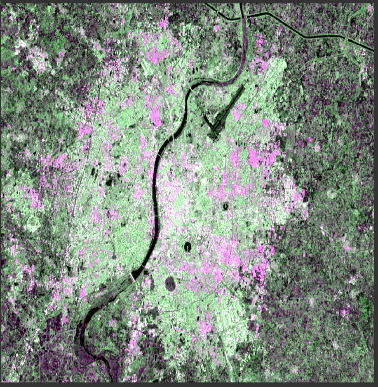
The aim of this study is to estimate the soil surface parameter using different models Oh model, MDB, Dubois Modelsand also evaluate the potential of these model. A real data set is collected to perform the evaluation. We have made two set of real dataset the first set is used to validate the simulation of σ0 by different models and other set is used to measure the accuracy of *Mv* (volumetric soil moisture) from the model for C- band. The calculated *Mv* based on the real SAR data processing obtained from C- band SAR images are compared with in-situ measurements.

The study start from the implementation of the different back scattering relations are given by Oh et al. [18, 23]. It may be noted that this model can be applied on different frequency bands. Simulations and development of Oh model, CIEM, MDM is explained in section 3. Results of experimental data accusation and comparisons with simulated model are given in section 4. Conclusions of this study are given in section 5.

1. **STUDY AREA AND DATA COLLECTION** 
   1. **Study site**

We have taken two study area, located in Bardoli which located at [*21.12°N 73.12°E*](https://tools.wmflabs.org/geohack/geohack.php?pagename=Bardoli&params=21.12_N_73.12_E_), in Gujarat and covers an area of 46 sq. km. images of these area is shown in (Figure 1) collected on 17-jun-2017. Collected data has four bands (HH, HV, VH, and VV) which is represented by red green and blue channel. The study area is lying between (**Lat*:*** *21.1475 – 21.2101,* **Long:** *73.14688 – 73.15707)*. About 56 samples were collected from study area which has various land cover by the team of ISRO. After that these samples were used for analysis of soil surface parameter (soil moisture).

In other study area we have selected Beed district, which is located at central west part of the Aurangabad (Maharashtra) between 18.280 and 19.280 longitudinally, and between 74.540 - 76.570 latitudinal. The area covered by the Beed district is 1061.53 Sq. Kms. Beed district comprises various types of soil with lots of variation in surface parameters.

(a) (b)

**Fig 1:** Sentinel 1 data dated 25/06/2018 (a) Bardoli district (b) Ahmedabad city

* 1. **SAR data**

We have used Sentinel 1, data for our study. Sentinel 1 is a state of art microwave remote sensing satellite which operates on C- band (5.35 GHz). Sentinel 1 is a European radar imaging satellite launched in 2014. Sentinel 1 SAR sensor collects data in dual pole VV, and VH. Sentinel 1 data images is freely available, we have downloaded and use the data,and used for our study. The images downloaded were very large so, we have taken a sub-set the image and collect the study area only. Another data is taken from the NISAR mission, this mission is a joint project between NASA (national aeronautics and space administration) and ISRO (Indian space research organization). NISAR mission will consist of dual frequency (L- , and S- band), fully polerimitric radar.

1. **METHODOLOGY FOR ESTIMATING OF SURFACE SOIL PARAMETER**

We have used two powerful simulation software, SNAP and ENVI. Using this we have calculated backscattering parameter fro SAR images. First the large images were converted into small one by selecting the study area using SNAP software. After performing sub-set operation geo-referencing has been done on the SAR row images. After geo-referencing backscattering coefficient has been calculated as per the different algorithm and formula provided by the different SAR image provider agencies i.e. (ISRO, ESA). Speckle noise has been removed by Lee-Sigma filter with the help of SNAP and ENVI software tools. The field measurement was collected on the same day as satellite data acquisition. The study was divided in three steps. We have evaluated the performance of the model first, then the measured sigma naught (*σ0*) sample field was compared with the simulated sigma naught (*σ0*), for each values of VV and VH polarization. Next soil moisture was calculated from sentinel 1 images field data, and checked the accuracy were compared with the ground measurement.

**3.1 Evaluation of Oh, CIEM, and MDB models**

We have performed The models simulation using Interactive data language (IDL) simulation tools, all models expression given in the literature were written in IDL software module, and simulate the parametric values (surface roughness (*s*), soil moisture *mv*, incidence angle *θ*). Geophysical parameter are obtained from image and the ground truth are used as known parameter to simulate (*σ0*) in VH and VV polarizations. After calculating RMSE and R2 for all models, it was observed that Oh model over estimated, and Calibrated Integral Equation Model (CIEM) and Modified Dubois model by Baghdadi et al.[27] MDS under estimate the parameters value. We have used Oh model equation (2, 3, 5, 6, 8). Where *q , p* is the cross , and co-polarization ratio, Fresnel reflectivity of the surface at nadir, dielectric constant, *θ* is incidence angle, *k* is wave number, *mv* soil moisture and *s* is the surface roughness. Simulating data set for C – band (frequency = 5.045 GHz). The surface roughness parameter *ks* , and dielectric constant real and imaginary part were calculated using (equation 5, 7) and (equation 4) respectively were calculated using inversion equation, dielectric constant is also calculated from and Hallikainen model [28] in (equation 17). The CIEM (equation 15, 16) and MDB (equation 13, 14) model are used to produce wide range of simulated data.

(2)

(3)

(4)

Equation (2, 6) describe the relation between the cross polarization of the image with incidence angle, and surface roughness parameter.

(5)

(6)

(7)

(8)

Bulk density (9)

Loss tangent

(10)

Imaginary part of dielectric constant

(11)

Skin depth (12)

The expression of modified Dubois model (MDB) by Baghdadi et al. [27].

(13)

(14)

CIEM for HV and VV polarization (15)

(16)

Hallikainen model:

(17)

Topp model

(18)

1. **Conclusion**

C- band SAR images of study area were studied and analyzed for the estimation of surface soil parameter (soil moisture, surface roughness and incidence angle). In addition radiative transfer model are used to simulate the C- band data. In this work we have simulated empirical models for estimating surface soil moisture using C- band (Sentinel 1 data) SAR data set. A semi- empirical model based on Oh et al. given in subsequent year of their research (1992, 1994, 2002, and 2004), ICEM and MDB models were used to estimate the surface parameter. Estimated values are in good agreement with the observed values. This study is to understand empirical model and to show the potential to estimate surface parameters. Oh model nearly estimate the parameters, using equations given by Oh in (2004) is more suitable for the estimation in both the band of data as compared with other model.

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