Application of Artificial Neural Network for Soil Moisture Prediction Incorporating the Effects of Surface Roughness and Vegetation

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ABSTRACT
During this critical period of pandemic, agriculture is the main source of income for any country, to be specific developing countries like India. During the 21st century agriculture is not the profession of illiterate villagers but the main occupation of literates too. Nowadays farmers are using modern equipment and technology in the field of agriculture to grow more crop with less effort and in uncongenial atmosphere. Farmers have to grow different crops in different areas and at different time period. To select the type of crop in a particular time period soil moisture of the given field plays a major role which directly depicts the water absorbing capacity of the soil in a given field. So, measurement of the soil moisture of a given field becomes utmost important. After a thorough literature survey it was found that soil moisture probes are inserted in a given field at a particular distance gap which gives the measure of soil moisture. This method is useful for a small field. In order to measure the soil moisture globally, satellite images are decoded using different algorithms to calculate soil moisture. In a step ahead soil moisture is predicted from the previous data using Artificial Neural Network. Since the satellite images are captured from an altitude, surface conditions to be specific – vegetation cover and surface roughness will have a serious effect on the captured image. In this paper an attempt is made to develop an algorithm incorporating the effects of surface conditions to decode the satellite images in calculating the soil moisture.

General Terms
Application of Artificial Neural Network, Soil Moisture Prediction

Keywords
Soil moisture, ANN, Regression analysis, Surface roughness, NDVI, Curve fitting, regression coefficient.

1. INTRODUCTION
Soil moisture is an important parameter of agriculture in this era where water is scares commodity. In the above context soil moisture prediction is utmost important.

1.1 Soil Moisture
When a field is irrigated either by rain or artificially, part of the water run away which is not the subject of the paper, some part seeps into the ground which mix with the soil particles and held by the particles itself for a certain duration that gives the information of soil moisture of the given field. When the target field is irradiated by a source of light (natural source like sun or an artificial source like radar), some part of the incident radiation is scattered, some part is absorbed and remaining part is emitted [1] which is the subject of this study.Amount of emitted light depends on the moisture content of the soil particles of the field under study. This study is very accurate because of the large dielectric contrast between dry soil <4 and liquid water ~ 80. In this study Multi frequency Scanning Microwave Radiometer (MSMR) on board of IRS-P4 oceansat is made use to obtain the image. Microwave part of the electromagnetic spectrum is made use in this study since this range of frequencies (1GHz to 1000GHz) are very less affected by the atmospheric dust, fog and air currents.[2] Three districts in the state of Andhra Pradesh, India were considered for the study.

Many researchers have studied the dielectric properties of mixture of soil and water [3], [4]. In a given mixture of soil and water, the dielectric constant of the mixture is strongly dependent on the amount of water content present. Keeping the amount of dry soil constant, if the water content is increased, dielectric constant of the mixture also raises and the deviation in the dielectric constant can be easily sensed and detected by many sensors. So researchers have developed many analytic and empirical models relating dielectric constant and volumetric soil moisture. From the literature survey it is evident that C band (4-8 GHz) is advantageous since measurement in this band is less affected by sky temperature, atmospheric temperature and apparent temperature.

As the moisture content in the soil increases, the dielectric constant of the mixture increases and the change in dielectric constant is detectable by many microwave sensors [5]. The effect of moisture on the dielectric properties of soil is a promising and interesting area of research and many analytic andempirical models based on this effect are developed. Literature survey demonstrates the strong dependence of dielectric permittivity on the volumetric moisture of a sample at a given frequency and proved that C band (4 – 8 GHz) is the most advantageous [6]. If the measurement is carried out at C band the effect of sky temperature, atmospheric temperature and apparent temperature can be neglected.[7] Much research work [8-12] have been carried out in the above topic and different soil moisture models, probes have been developed. However the existing models [13] have not incorporated any measures to reduce the error occurred due to vegetation and unevenness of the surface lying between the sensor and the target. Hence an attempt is made to develop an empirical model based on regression analysis that nullifies the error due to the above two factors (vegetation and surface roughness). Soil moisture values calculated using the developed model is validated against ground measured (In-Situ) values of SM.

1.2 Objectives of the study
The objective of our study is two fold

(1) To develop an empirical model relating soil moisture and

measured brightness temperature over Anantapur, Karimnagar and Nandyal test sites for four soil types incorporating the correction for vegetation cover and surface roughness.

(2) To develop an ANN architecture to predict the coefficients of the empirical model for different surface roughness, vegetation index and soil type, so that the model will have an application worldwide.

1.3 Area of study

Different soil type samples used in this study are collected from different parts of Andhra Pradesh, India and the corresponding data are tabulated in table 2 (Surface soil texture of four aggregated soils of Andhra Pradesh (original source: 1:1 M surface soil texture prepared by National Bureau of SS & LUP, Nagpur, India)). The satellite image of the area under study is shown in fig 1.

Fig-1 Satellite image of the area under study.Karimnagar, Anantapur and Nandyal districts of Andhra Pradesh, India

Fig 1 shows the satellite image of the study area, Anantapur, Nandyal and Karimnagar districts of Andhra Pradesh. On the bank of Bay of Bengal which is a huge water body, the red color patch shows the paddy field, the data collected and used in this study is pertaining to paddy field. The data was collected on every month on the same days from 30-8-2000 to 29-8-2001. On these days, the brightness temperature, the value of NDVI (pertaining to the growth of paddy plants) and roughness factor (using Polari meter) of the surface is collected and used for the study. The data related to the Bay of Bengal is not used since the study is related only for agricultural field. The blocks in the second image of fig1 shows the urban area of test site which will not come under the preview of the study.

Extent of each of the soil categories in 3 test sites in the study area along with the number of soil samples collected for ground truth are shown in table 3.

Table-1Major Specifications of MSMR

1	Frequency (GHz)	6.6	10.65	18	21
2	Polarization	V&H	V&H	V&H	V&H
3	Orbit inclination (Deg)	98.25			
4	Altitude (Km)	720			
5	Antenna Diameter (cm)	86			
6	Incidence angle (Deg)	49.9			
7	3 dB Beam width (Deg)	4.2	2.6	1.6	1.4
8	Beam Footprint (km)				
	Along track	77	47	30	25
	Across track	119	73	46	39
9	Cell dimensions (Km^2)	150X150	75X75	50X50	50X50
10	Spatial resolution (Km)	120	75	45	40
11	Swath (Km)	1360			
12	Temp. Resolution (k)	1			
13	Dynamic Temp. Range (K)	10-330			
14	Data rate (Kbps)	5			
15	DC Power (w)	76			
16	Weight (Kg)	65			

2. DATA AND METHODOLOGY:

2.1: Data Source

The data used in this paper was collected from NRSA Hyderabad, India. The data used was obtained by a Multi Frequency Scanning Microwave Radiometer (MSMR) which was boarded on an Indian remote sensing satellite IRS-P4. Detailed specifications of MSMR is given in the table-1 below. The table containsboth the target specifications and system specifications.

Table -2 Surface soil texture of four aggregated soils of Andhra Pradesh (original source: 1:1M surface soil texture map prepared by National Bureau of SS&LUP, Nagpur, India)

Group	Percentage			Soil Type
	Sand	Silt	Clay	
1	28	26	46	Clay
2	49	11	39	Sandy clay
3	60	17	24	Sandy clay loam
4	64	23	13	Sandy loam

Table –3Extent of each of the soil categories in 3 test sites in the study area along with the number of soil samples collected for ground truth

Test Site	Percentage area under each of the soil categories and number of soil samples collected in each soil category			
	Clay	Sandy clay	Sandy clay loam	Sandy loam
1- Karimnagar	25(6)	2(1)	23(5)	50(12)
2- Nandyal	15(4)	4(1)	28(7)	53(12)
3- Anantapur	16(4)	5(1)	16(4)	63(15)

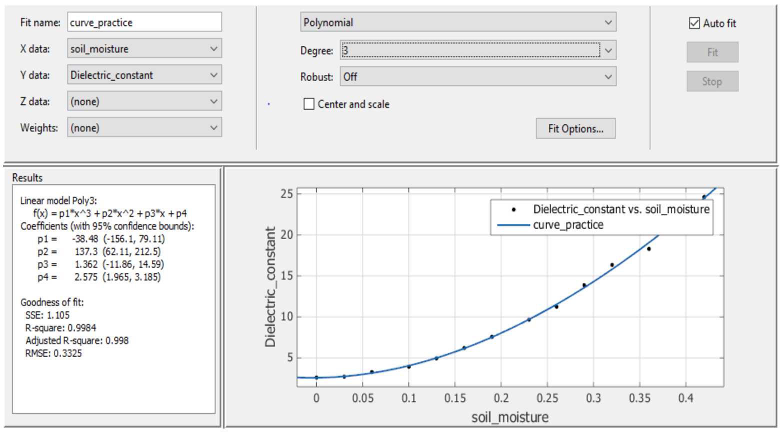

Fig – 2 polynomial of degree 3 relating soil moisture and dielectric constant €

The Indian remote sensing satellite, IRS -P4 (Oceansat-1) launched on 26 may 1999 is the first in the series of the Indian satellites with the primary objectives of collecting data for oceanographic, coastal and atmospheric applications. The data obtained includes brightness temperatures collected in two polarizations (VV and VH) for 4 frequencies (6.6, 10.6, 18 and 21 GHz). (VV-Vertical transmit/Vertical receive and VH-Vertical transmit and horizontal receive). For the proposed model only VH (Vertical transmit/Vertical receive) is considered since the sensitivity of VH is more to SM as compared to VV polarization.[14] Further the data used is surface roughness obtained by profilometer. (h=0 for smooth surface, h=0.2 for moderate surface and h=0.4 for very rough surface).The obtained data also contain the information about vegetation obtained in the form of NDVI [15] (Normalized Difference in Vegetation Index). NDVI=0 to 0.6. NDVI=0 leads to barren land and NDVI=0.6 means forest.

2.2 Stepwise Procedure

The step wise procedure followed in development of this model is furnished below and the corresponding flow chart is illustrated in Annexure II

STEP: 1 Data collection from the field under study (target)

STEP: 2 Corrected values of emissivity for a given NDVI (using equation given in the annexure) are computed.

STEP: 3 for the corrected emissivity obtained in step 2 the necessary correction for different surface roughness factors (using equation given in the annexure) are obtained.

STEP: 4 for the corrected emissivities obtained in step 3 corresponding corrected reflectivities are calculated.

STEP: 5 from the calculated corrected reflectivities Complex Dielectric constant '€' is obtained using equation given in the annexure.

STEP: 6 Regression analysis (to be specific Least square fit method) [27] is used to obtain the suitable order polynomial of € which relates %SM and € (In the present paper it is polynomial of order 3). This recursion process [28] is repeated till the model gives the soil-moisture value as close as possible to the measured value (least error).

3. DEVELOPMENT OF THE MODEL

A case study is conducted to assertion the effectiveness of the proposed model. The data collected from NRSA (National Remote Sensing Agency) for various frequencies, various Roughness surfaces at different NDVIs are used to compute the % soil moisture and the computed values are compared with the existing models and the actual field measured values. From the study and literature survey [16-18] it was found that 6.6 GHz (L band) is found to be the appropriate frequency for soil moisture prediction [19-20]. So, the results of 6.6 GHz is considered which is illustrated in the graph

Curve fitting tool box of MATLAB [21, 23] is used to formulate a third order polynomial relating the corrected emissivity and dielectric constant. For the curve fitting of the present data, [22] the square correlation coefficient (R^2) of the regression line between soil moisture and dielectric constant is found to be 0.9984 with RMSE of 0.3324. The coefficients and constant of the polynomial is shown in fig-2 below.

4. VALIDATION OF THE MODEL

Using the polynomial developed using above regression analysis, [22] MATLAB program was developed to calculate the soil moisture (SMST) from the dielectric constant (€). The regression line drawn between the calculated soil moisture and the In-Situ (measured at the site) is shown below (fig-3), where the square correlation coefficient (R^2) of 0.9992 with RMSE of 0.1444.

5. DESIGN OF ARTIFICIAL NEURAL NETWORK ARCHITECTURE FOR THE PREDICTION OF SOIL MOISTURE

Artificial Neural Network (ANN) is a highly level optimization method of mathematical data driven model used to relate input and output to solve complex problems. [23] It exploits the nonlinearity between input and output. It is made up of many building blocks called neurons which work together and parallel to solve a particular complex task. It is a model free estimator as it does not rely on an assumed form of the underlying data. Using some of the labelled data obtained by experience, the ANN will try to obtain an approximation to a given system that generates the observed data through a process called training.[24] This is a method which is based on very sound mathematical principles called optimization techniques and it has proved very successful in developing computationally efficient algorithms [25] for geophysical applications like satellite remote sensing, oceanography, numerical weather prediction and climate studies. [28]. A multilayer perceptron model having input, hidden and output layers trained by a back propagation algorithm [26] has been used successfully for the retrieval of soil moisture.

In the present case, look angle, emissivity measured at L band, surface roughness (h), NDVI and soil type were used as inputs of the ANN to obtain the soil moisture. One hiddenlayer with 20 neurons was considered. The result of the developed ANN architecture in predicting the soil moisture is shown below.

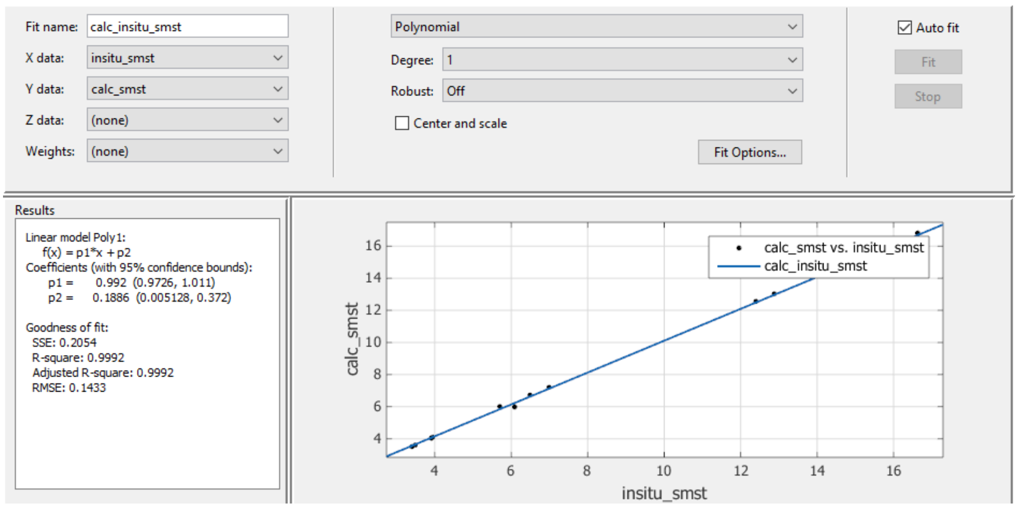

Fig – 3 Curve fitting showing the accuracy of the calculated soil moisture VS Insitu soil moisture

Table below gives the comparison of in-situ (ground truth), calculated (using the developed empirical model) and predicted values (using the developed ANN model) of soil moisture for same sample target. SMST indicates surface soil moisture.

Tabulation of the result

Table – 4 comparison of ground measured, calculated and predicted values of SMST

Sl.No	SMST (IN-SITU)	Emissivity (e)	Reflectivity 'R' (uncorrected)	Corrected R wrt NDVI	Corrected R wrt surf roughness	Dielectric Constant (€)	SMST (calculated)	SMST (Predicted)
1	16.17	0.81	0.19	0.1993	0.2021	4.21	16.11	16.09
2	16.63	0.8	0.2	0.2314	0.2214	5.562	16.72	16.78
3	6.49	0.8366	0.1634	0.1754	0.1814	6.1923	6.72	6.81
4	6.99	0.86	0.14	0.151	0.1651	5.0923	7.21	7.15
5	12.4	0.836	0.164	0.168	0.1712	4.8216	12.56	12.38
6	12.88	0.8533	0.1467	0.1523	0.1616	5.1261	13.03	13.01
7	5.7	0.876	0.124	0.130	0.132	3.5612	6.01	6.03
8	3.49	0.88	0.12	0.16	0.159	2.7531	3.62	3.59
9	3.91	0.886	0.134	0.152	0.161	2.9612	4.04	4.06
10	6.09	0.883	0.117	0.121	0.151	2.3418	5.98	6.12
11	3.4	0.89	0.11	0.141	0.149	2.2286	3.51	3.56

Fig below shows that the developed model is very accurate for NDVI=0 to 0.6 (error<3%) which is mostly agricultural area which is the objective of this study. Developed modelis also very accurate for h=0, 0.2 and 0.4 (error<4%). If h>0.4, it is mostly hilly area which is out of scope of this study

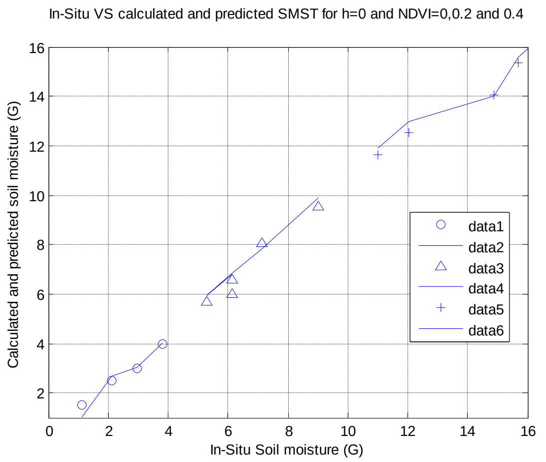

Fig – 4 Graph depicting the accuracy of calculated and predicted SMST VS In-Situ values for h=0

Data 1 and data 2- Calculated and predicted VS In-Situ soil moisture values for NDVI=0 and h=0.

Data 3 and data 4- Calculated and predicted VS In-Situ soil moisture values for NDVI=0.2 and h=0.

Data 5 and data 6- Calculated and predicted VS In-Situ soil moisture values for NDVI=0.4 and h=0.

From the above graphs, it can be concluded that the developed model is very accurate for NDVI=0.2 which refers to agricultural field. (Error of ± 1.02%). Since this paper mainly refers in helping the farmers, the developed model is found to be appropriate. The developed model is also accurate for bare field and forest area. (Error of ± 5.06%).

For a moderately rough surface with h=0.2, the developed model is very accurate especially for NDVI = 0.2 which is the vegetation index for staples at the growing period which is the main objective of this paper. Model is also quite accurate for NDVI=0 ie the field during ploughing before plantation.

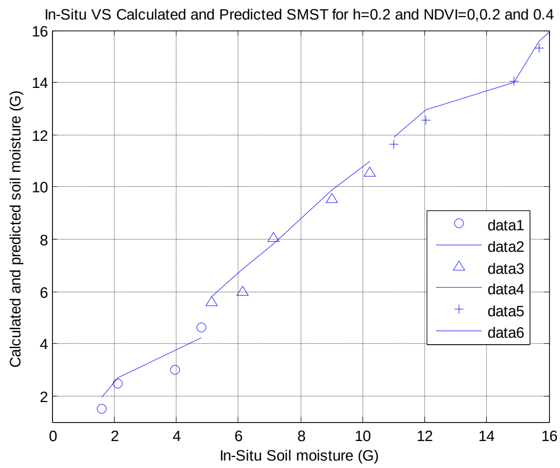

Figure 5 shows the accuracy of the developed model for NDVI=0, 0.2 and 0.4 and surface roughness h=0.2

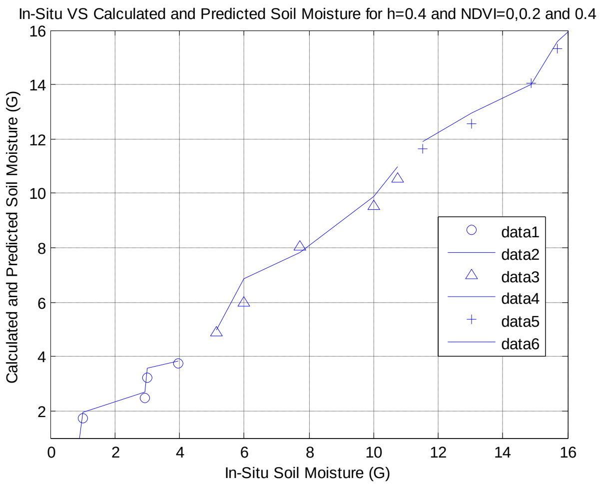

Fig 6 is the graph depicting the accuracy of the model for different NDVIs such as NDVI=0, 0.2 and 0.4 with very rough surface with h=0.4.

6.2 Discussion

Soil moisture is an utmost important parameter and its prediction is very much useful for modern agriculture and land slide prediction. So state wise and country wide measurement of this parameter is very difficult and time consuming. So remote measurement of soilmoisture from satellite data is an attractive alternative for the tedious in-situ measurement. In this paper an attempt is made to develop an empirical model relating the measured reflectivity and the required soil moisture incorporating the field effectssuch as Normalized Difference in Vegetation Index (NDVI) and surface roughness.

The developed empirical model is a third order polynomial obtained using curvefitting tool box available in MATLAB. The developed model shown in fig 2 is very accurate with correlation coefficient R^2= 0.9984 and Root Mean Square Error RMSE of 0.3324. Further the results obtained from the model is validated from the In-Situ measured value shown in fig 3. The calculated soil moisture is found to be very accurate against the In-Situ measured soil moisture which is again evident by the curve fitting shown in fig 3 with correlation coefficient R^2= 0.9992 and Root Mean Square Error (RMSE)= 0.1444

After thorough analysis, following conclusions were drawn

1) Vegetation decreases the efficiency of the computation. For every 0.1 increase in NDVI the error in the computed % volumetric soil moisture increases by 2-3%. (For NDVI>0.6 which occurs in forest area which is not our interest of study).

2) Roughness factor (h) also decreases the efficiency of computation. For every 0.2 increase in roughness factor, the error increases by 4-5%. (For h>0.4, error increases more than 15% which occurs rarely in valleys and mountains which is not our interest of study).

3) The existing models are accurate for smooth surfaces without vegetation but erroneous for rough surfaces with vegetation. Developed model is very accurate, since we are providing the field constants (h and NDVI) along with the measured parameters (R, frequency, soil type) as inputs to the ANN.

7. CONCLUSION

Empirical model for the calculation of soil moisture (SMST, 0-0.05m) from the measured brightness temperature and surface temperature is established. The data used was obtained from NRSA (National Remote Sensing Agency) Hyderabad, India. Multiple Linear Regression (MLR) is used to develop and validate the model shown in fig 2 and fig 3. The Soil moisture calculated is used to train the Neural Network using back propagation algorithm and trainlm training function in offline environment and testing of unseen data was carried out in online environment. Emissivity, soil type, NDVI and surface roughness was used as input variables for ANN and volumetric soil moisture was the output. The predicted soil moisture is quite accurate compared with the In – Situ (ground measured) soil moisture as shown in fig 4, 5 and 6. The same prediction procedure was carried out for NDVI = 0.2 and 0.4. Similar procedure was carried out for different surface roughness expressed in terms of RMS height factor ‘h’. The values of h used in this study is h=0, 0.2 and 0.4. Results are shown in the above graphs (fig- 4, 5 and 6).

8. ANNEXURE

Mathematical Relationship:-

Brightness temperature T_b, smooth surface reflectivity (R) and emissivity (e) are related as shown below

$T_b = (1\text{-}R)T_{sfc} = eT_{sfc}$ where T_{sfc} is the surface temperature

e = (1-R) is the emissivity and R= (1-e) where R the reflectivity is proportional to the dielectric constant of medium under measurement.

Fresnel equation describes the behavior of electromagnetic waves at a smooth boundary which also describes the reflectivity. According to the above Fresnel equation at non – nadir incidence angle (α) and for horizontally polarized wave [H], the Fresnel coefficient is given by

$$R(H,\alpha) = \left|\frac{\cos\alpha - \sqrt{€ - sin^2\alpha}}{\cos\alpha + \sqrt{€ - sin^2\alpha}}\right|^2$$

Where € is the complex dielectric constant of the emitter. Since for a smooth surface it is known that incidence angle is equal to reflection angle, by Fresnel equation’s inversion, we get an approximate value of the effective dielectric constant of the emitting layer as

$$€_{eff} = \pm sin^2\alpha + cos^2\alpha \left[\frac{\sqrt{R}+1}{\sqrt{R}-1}\right]^2$$

The value of R (reflectivity) used in the above equation is the uncorrected reflectivity with respect to surface roughness and vegetation cover. For the calculation of accurate soil moisture the correction procedure because of uneven surface (surface roughness) and greenery (vegetation cover) should be incorporated.

8.1 Correction for the Reflectivity for the Vegetation Cover

For every type ofvegetation, a vegetation parameter was assigned by name Vegetation Water Content (VWC). Vegetation Water Content was calculated using NDVI values obtained by Land Sat Thematic Mapper (LTM) images of the region.

$VWC = 1.9134(NDVI)^2 - 0.3215\ (NDVI)$ for NDVI < 0.5

$VWC = 4.2857(NDVI)^2 - 1.5439\ (NDVI)$ for NDVI >0.5

Optical depth (J) = S (VWC) where S is an empirically derived value for the slope of the regression line between VWC and J.

Transmissivity of the observing layer is

$$\wp^2 = \exp(-2J\ sec\alpha\ )$$

Where α is the incidence angle (in this study α= 49.9 degree)

Now the corrected emissivity with respect to NDVI is $e = 1 - R\wp^2$ where R is the uncorrected reflectivity and eis the corrected emissivity.

8.2 Correction for the effect of surface roughness

The author in [26] has developed a mathematical model for correcting the effects of uneven surfaces, in which the reflectivity of the smooth surface is given by $R_S(\alpha) = R_r(\alpha)\exp(h\cos^2\alpha)$

Where $R_r$is the reflectivity of the rough surface at look angle α and h is given by

$$h = 4\sigma^2[2\pi/\lambda]^2$$

Where σ^2 is the surface height distribution variance and λ is the wavelength of observation

FLOW CHART OF THE PREDICTION OF SOIL MOISTURE

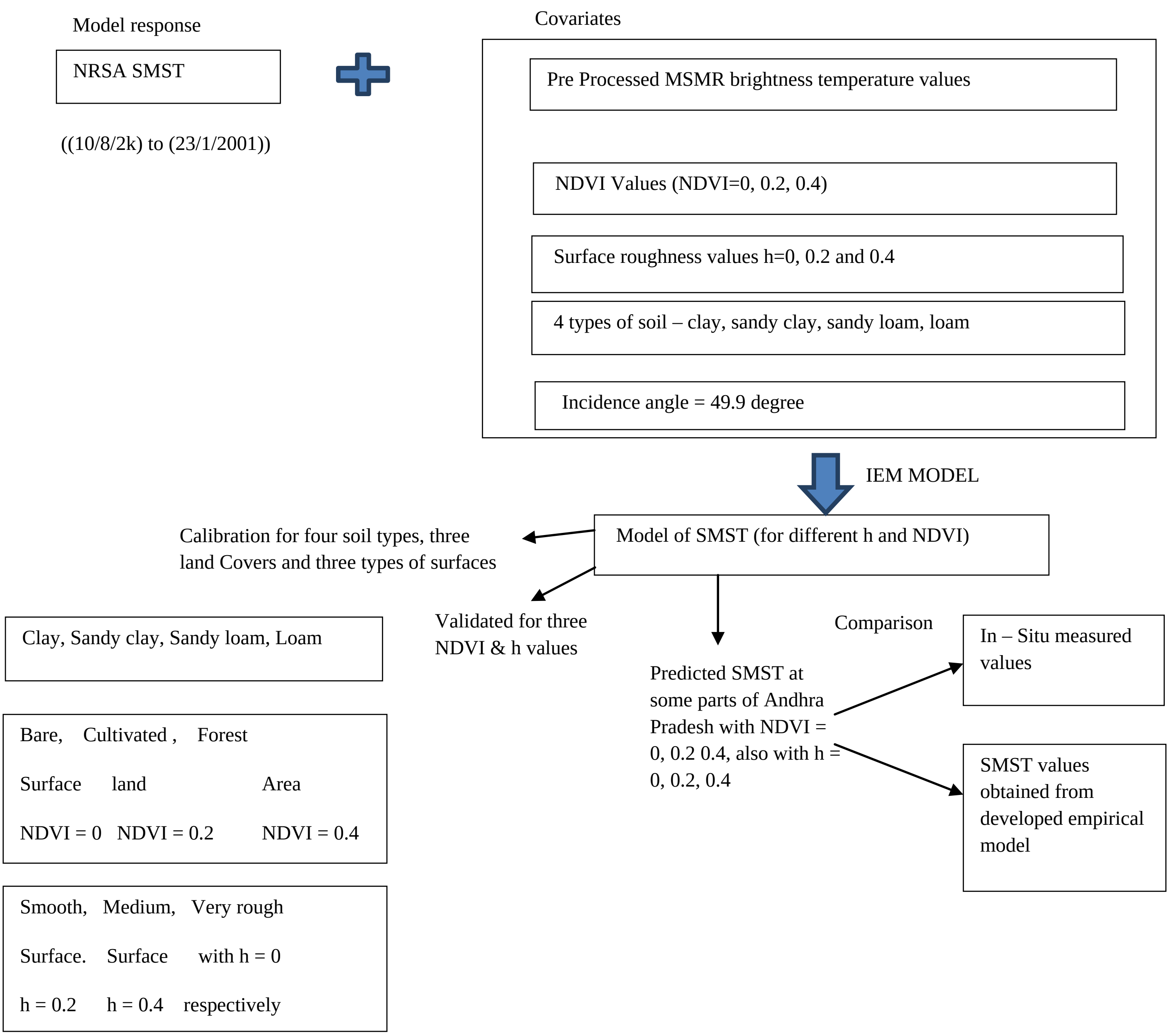

Fig-7 Flow chart depicting the methodology used for soil moisture prediction

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