SOIL MOISTURE RETRIEVAL USING MICROWAVE REMOTE SENSING

A dissertation submitted in partial fulfilment of the requirement of the award of degree of

MASTER OF TECHNOLOGY

IN

GEOTECHNICAL ENGINEERING

BY

VIKAS

(ROLL NO. 2K14/GTE/20)

Under the Guidance of

Dr. K.C.TIWARI

Professor

Department of Civil Engineering

Delhi

DELHI TECHNOLOGICAL UNIVERSITY

(FORMERLY DELHI COLLEGE OF ENGINEERING)

DELHI – 110042

June – 2016

CANDIDATE'S DECLARATION

I do hereby certify that the work presented in the report titled "**Soil moisture retrieval using microwave remote sensing**" in partial fulfilment of the requirements for the award of the degree of "Master of Technology" in geotechnical engineering submitted in the Department of Civil Engineering, Delhi Technological University, is an authentic record of my work carried out from December 2015 to June 2016 under the supervision of Dr. K.C. Tiwari Professor, Department of Civil Engineering.

I have not submitted the matter embodied in this report for the award of any other degree or diploma.

Vikas

Date: 30 June 2016 (2K14/GTE/20)

CERTIFICATE

This is to certify that the above statement made by Vikas (2K14/GTE/20) is correct to best of my knowledge.

Dr. K.C.Tiwari
Professor
Department of Civil Engineering
Delhi Technological University, Delhi
Date: June 2016

DELHI TECHNOLOGICAL UNIVERSITY

ACKNOWLEDGEMENTS

I would like to express my deepest sense of gratitude and indebtedness to my guide and motivator **Dr. K.C.Tiwari**, Civil Engineering Department, Delhi Technological University for their valuable guidance and support in all the phases from conceptualization to completion of the project.

I wish to convey my sincere gratitude to **Dr. N.D. Dev,** H.O.D, and all the **faculties** of Civil Engineering Department, Delhi Technological University who have enlightened me during my project work.

I am deeply thankful towards all the lab assistants and other staff of my college who have helped me in conducting the experiments.

I would also like to thank my parents for their encouragement and persistent support which has helped me to do better in all of my endeavours.

Last but not the least; I would like to thank all the people directly and indirectly involved in successful completion of this project.

VIKAS
Roll No. 2K14/GTE/20

ABSTRACT

The moisture content which a soil can hold is termed as soil moisture. It is an important parameter that plays a vital role in various hydrological and geotechnical applications. It can be categorized into various types namely gravitational, hygroscopic and capillary water. There are various ways in which soil moisture can be estimated. Soil moisture retrieval with the help of remote sensing is one such emerging technique of soil moisture estimation. Scope of remote sensing in soil moisture retrieval is growing day by day. This study presents measurement of soil moisture with the help of active microwave remote sensing using RISAT-1 (5.35GHz) data. With the help of active microwave remote sensing, soil moisture can be measured up to the depth of 5-10cm. The behaviour of RISAT-1 signals are analysed for two polarisation i.e. RH and RV with the incidence angle of 42.130^0. A theoretical study of all the models is done for soil moisture retrieval using active microwave remote sensing and the Dubois model has been preferred in this work. The relationship between radar backscattering coefficient (σ^0) and various soil parameters like dielectric constant (ε) and soil moisture are studied with the help of linear regression equations and coefficient of determination. For analysing satellite images ERDAS IMAGINE and ENVI software have been used. The results thus obtained with remote sensing data are cross examined using 'truth data' obtained from the relevant sites. For accuracy assessment between the soil moisture estimated model obtained and field calculated soil moisture, various parameters like mean absolute error, root mean square error and index of agreement are calculated. Finally, the conclusions are derived based on the results obtained from two methods of soil moisture retrieval.

Key words: Soil moisture, Active microwave remote sensing, Dubois model, Accuracy assessment

CONTENTS

LIST OF FIGURES

LIST OF TABLES

Chapter 1
Introduction

1.1 General

Soil, a layer of unconsolidated material that is found on earth's surface, is influenced by various soil forming factors such as physical and chemical weathering of rocks etc. Soil moisture is one of the key parameters to carry out any study related to soil. Soil moisture can be defined as the water content in the soil above the water Table whereas, the water content below the water Table is known as ground water. Water associated with soil is found in three forms viz. gravitational water, capillary water and hygroscopic water. Free water that moves across the soil by the force of gravity is known as gravitational water. Capillary water exists in micro-pores and hygroscopic water is present in very thin film around the soil particles. Soil water content or soil moisture content is referred in two ways i.e. based on mass (mass of water in soil/mass of dry soil) and volumetric soil moisture (volume of water/volume of sample). Soil moisture is measured in three ways are in-situ measurement, measurements using hydrological or land surface models and measurements using remote sensing. The most accurate way for soil moisture measurement is in-situ measurement but it has its area limitations. To obtain soil moisture in large spatial scale remote sensing is the most easy and appropriate method.

1.2 Field methods of soil moisture estimation:

1. **Gravimetric method of soil moisture**

   In this method soil samples are collected from the field with the best available tools like shovels, spiral hand augers. Soil samples are taken to the laboratory and weighed, then the soil samples are oven dried and weighed again. Soil moisture can be given as ratio of weight of water to the weight of dry soil.

2. **Lysimetry** – It is non-destructive variant of gravimetric measurement. In this methos a container filled with soil is weighed either occasionally or continuously to indicate changes in total mass in the container, which may in part or totally be due to changes in soil moisture.

3. **Radiological methods**

   a. **Neutron scattering method**

In this method of soil moisture measurement, a probe containing a radioactive source emitting high-energy fast neutrons and a counter of slow neutrons is lowered in the ground. The hydrogen present in the water molecules is at least ten times effective for slowing down neutrons upon collision. The density of slow thermalised neutrons in the vicinity of the neutron probe is nearly proportional to volumetric soil water content.

b. **Gamma ray attenuation**

In gamma ray attenuation method, basic procedure is same as that of neutron scattering method. Difference between both the methods is that in neutron scattering method volumetric soil moisture of large sphere is measured whereas, in gamma ray attenuation a thin layer is considered for moisture measurement.

4. **Methods based on soil water dielectrics**

a. **Time domain reflectometry**

It is method which determines dielectric constant of the soil by monitoring the travel of electromagnetic pulse which is generated by pair of parallel rods embedded in the soil.

b. **Frequency domain measurement**

In frequency domain reflectometry, sensors measure values of dielectric constant at single microwave megahertz frequency. It requires utilisation of an open-ended coaxial cable and a single reflectometer at probe tip to measure amplitude and phase at a particular frequency. Soil moisture is then calibrated with liquids of known dielectric properties.

1.3 Remote sensing and soil moisture:

Remote sensing is the process of collecting information about an object, area or phenomenon from a distance with the help of a device that is not in direct contact with the object. Generally, the term remote sensing is referred to images and image information obtained using satellites and air borne platforms. Remote sensing is a very economical tool in reducing the time for studying spatial and temporal variations of various land surface parameters. It has vast areas of applications from land surface parameters to climatic changes. Soil moisture is one of the parameters of land surface that can be estimated from remote sensing. Sensors which are used to get information on soil moisture are mainly of 2 types i.e. optical sensors which uses electromagnetic spectrum in visible, infrared and thermal range and the other one is microwave sensors which uses electromagnetic spectrum in microwave range. Every surface has its unique thermal and dielectric properties which help in detecting the amount of soil moisture. Recent studies have shown that remote sensing has the ability to estimate soil moisture under various vegetation and topographical conditions. Estimation of soil moisture through microwave data is much more effective and advantageous over other methods that include penetration through clouds particularly at frequencies <10 GHz. This makes it an all weather working tool. In addition, active microwave remote sensing is independent of solar light i.e. it can work in both day and nighttime. The theoretical basis of soil moisture estimation through microwave remote sensing is mostly based on di-electrical properties of dry soil and water. The high dielectric constant (=80) of pure water compared to that of dry soil (=4) is attributed to the fact that water molecules rotates freely at microwaves frequencies (Jackson *et al.* 1989). Thus with change in soil moisture the dielectric constant also changes (Schmugge,1980). This variation in dielectric constant varies the reflectivity and backscatter coefficient. To determine backscattering and reflectivity both active and passive microwave sensors can be used. Both active and passive microwave sensors have their own limitations and advantages. Some of passive microwave sensors are AMSR (Advanced Microwave Scanning Radiometer), SSM/I (special satellite microwave/imager) and TMI(Tropical Rainfall Measurement Mission Microwave Imager) and they have coarse resolution in comparison to active microwave sensors. Among all the available active microwave sensors, SAR (Synthetic Aperture Radar) gives comparatively high resolution but they are available at very high costs. Frequency beams of low frequency (<6GHz) gives the best results on soil moisture. Therefore, for most researches the L-band (1-2GHz) and C-band (3.95-5.85 GHz) data is preferred. Many satellites carry active and passive microwave sensors like ERS, RADARSAT1, RADARSAT2, RISAT-1 and RISAT2. Amongst all RISAT has been recently launched and is first Indian satellite which carries SAR sensors. It also captures data in circular polarisation. The work in this thesis has been carried out using RISAT data.

1.4 Objectives of the study

1. To study and explore various methods of soil moisture estimation/retrieval.
2. Estimate the soil moisture using active microwave remote sensing.
3. Analysing backscattering coefficient behaviour with variation in soil moisture and dielectric constant.

4. Accuracy assessment by comparing the estimated moisture using microwave data and that obtained in lab using field data.

1.5 Outline of thesis

The first chapter gives an introduction of the study. Chapter 2 presents literature review of the whole soil moisture estimation processes. In Chapter 3 study area and data used are discussed. Chapter 4 is theoretical study related to work that has to be done. Chapter 5 is all about methodology and implementation. Chapter 6 presents results, discussions and chapter 7 draws conclusions.

Chapter 2
Literature Review

Soil moisture retrieval using remote sensing is not a very traditional method but it has came into existence in 1975 when the Landsat was launched by NASA. The data type provided by Landsat was passive. The advancement in active microwave remote sensing for soil moisture retrieval came with the launch of ESRI-1 in 1991 by European space agency. Thereafter JERS-1, SIR C/X-SAR, ERS-2, RADARSAT-1 were launched for active microwave in the year 1992, 1994, 1995 and 1995 respectively (Ahmad *et al.* ,2011).

Estimation of soil moisture with help of remote sensing is not a direct measurement. It involves various empirical, semi-empirical and theoretical models through which soil moisture can be derived. These models are as follows (Said *et al.*,2008):

1. Empirical models: Dubois model, Oh model
2. Theoretical models: Geometrics optics, Physics optical model or Kirchhoff's model and Small perturbation model.
3. Semi-empirical models: Radiative transfer model and wave approach model.

A combination of Small Perturbation Model and Kirchhoff's Model is done in the model named as Integral Equation Model (IEM). Though the soil moisture estimation using none of the model is 100 percent, correct and each model has its own advantage and disadvantages. Various experiments and research work that had been carried out in this regard are summarised in this section.

Wang *et al.*(1987) have also studied the effect of surface roughness on radar backscatter using SIR data in L-band where the incidence angle was 21^{o} and the study was done on various agricultural sites. Role of surface roughness was found to be more significant. When the bare soil is compared with the land having vegetation there is an appreciable change in radar signals.

Dobson *et al.*., 1985 developed an algorithm to obtain soil moisture with respect to soil texture, bulk density and roughness. The results showed that soil moisture is found to be more sensitive for roughness than the soil texture. There is a great change in soil moisture estimation when there is change in surface roughness as when the root mean square height changes from 0.5-2.0 the change in moisture content was up to 90%.

Edwin and Wang (1987) conducted an experiment, in that three backscatter models were taken and effect of surface roughness on radar backscatter were observed. It was stated that Small Perturbation Model showed greater effect on backscatter due to surface roughness than the Physics optics model

Bindlish and Barros (2000) applied inverse algorithm of IEM to estimate the moisture content of soil using data of SIR-C and X-SAR of multi-polarisation state. It was concluded in respect of sensitivity of backscatter with respect to surface roughness that sensitivity decreases as root mean square height increases above 1 cm. In Gaussian function sensitivity was found to be more than that in exponential function.

Ksneman and Gleich(2000) studied soil Moisture estimation with TerraSAR-X with the Dubois model. Two SAR images study in the time delay of 11 months were used for the study with the incidence angle of 33.944^{o} and 46.246^{o}. Dubois model was applied to the data sets and it was concluded that because of high capturing frequency at X band problem of forest penetration arises. This problem was due to the fact that electromagnetic radiation gets bounced by the hurdles which are greater than the wavelength.

Baghdadi *et al.*(2006) used IEM model with semi empirical calibrations. Baghdadi have also provided the equations to estimate soil moisture in the Indian field site conditions. These equation are valid when incidence angle ranges from 34^{0}-37^{0} and 20^{0}-24^{0} at frequencies of L,C,X bands.

Various studies have been done to determine the moisture content of soil with the help of backscattering coefficient of radar. An algorithm was presented by Paloscia *et al.*(2001) to estimate the soil moisture on the basis of Bayes theorem. ENVISAT SAR data of C band was used from two agricultural fields. In his experiment the backscattering coefficient obtained from SAR was compared with the theoretical backscatter coefficient from IEM for HH and VV polarisation. The values obtained from the model have been reported to considerably match with the values obtained from ground with the mean error less than 10%. Main problem experienced was that this algorithm overestimates the low values and underestimates the higher values of soil moisture.

In an experiment, Cai *et al.* (2008) used four ENVISAT ASAR data images of VV polarisation. Their first step was to do data processing which includes removing speckle noise then converting DN values into radar backscattering coefficients using ENVI software and then estimation soil moisture. It was concluded that VV polarisation in C band with low incidence angles values is not sensitive to surface roughness and radar calculated surface roughness is little greater than field calculated roughness.

Ponnurangam and Rao(2011) used sets of ALOS PALSAR fully polarimetry and ENVISAT ASAR dual polarimetry data were used for soil moisture mapping over the various regions of India. SAR data was processed with help of PolSAR pro and NEST software respectively. It was concluded that Dubois et. al model overestimates soil moisture when it was compared with Oh model. Estimation of soil moisture with Oh model and X-Bragg model was also done and the difference of soil moisture with these two model was also observed. It was also concluded that X-Bragg model is lesser sensitive to images of lower incidence angle.

Rishi Prakash *et al.* (2012) also performed an experiment with fusion approach of soil moisture retrieval with SAR and Optical data. ALOS PALSAR L-band data which is SAR data and MODIS which is optical data were used to develop an algorithm and validation between SAR and Optical data. Pre-processing of both the data sets were done which includes Polari metric calibration, multiple looking, geo-coding, speckle filter and polarisation synthesis of SAR data and MODIS data was geometrically rectified to UTM coordinates. It was observed that PALSAR data was used efficiently with the polarimetry abilities to classify vegetation, land cover and bare soils. The problem of soil moisture estimation arises in vegetated land which was efficiently dealt with the MODIS data. Roughness effect was minimised with Dubois model with in the estimation of soil moisture.

Many other studies too have been done in order to check the sensitivity of backscatter with the soil moisture at different frequencies and different incidence angles. Holah *et al.* (2005) have also studied the effect of sensitivity of ASAR signals with the soil surface parameters at different polarisations like HH,VV,HV,VH and different incidence angles. It was concluded that backscatter coefficient with VV polarisation is very less dependent on the surface roughness. For the high values of soil moisture *i.e.* greater than 35% the backscatter coefficient become independent of the polarisation state. Backscatter coefficient decreases rapidly with the surface roughness in case of low and high incidence angles and as a result soil moisture gets minimised.

A lot of work has been done in the field of soil moisture estimation with help of remote sensing but there are only few works that have been done with the RISAT data and Dubois model for soil moisture estimation.

Chapter 3

Study Area and Data

3.1 Site Description

The area of the study is Delhi Technological University located in north-west region of capital city of Delhi India bounded by the coordinates upper left (28.7565^{0}N, 77.1045^{0}E), upper right (28.7568^{0}N, 77.1258^{0}E), lower left (28.7437^{0}N, 77.10479^{0}E) and lower right (28.7428^{0}N, 77.1272^{0}E)(Google maps,2016). Delhi is bounded by the states of Haryana from western side and Uttar Pradesh from eastern side. Delhi being in the northern region of India is situated at 200-250m above mean sea level. The total area of Delhi is around 1484 km^{2}and the area of water bodies is approximately 18 km^{2} approximately. The two main geographical features of Delhi are Yamuna flood plains and Delhi ridge. Delhi Technological University spreads over an area of 0.708 km^{2} approximately and is representative of Delhi's climate and soil properties. Location of the study area has been shown in Figure 3.1.

Figure 3.1 A map showing the location of study area (Source: Bing maps)

3.2 Sites of field data collection

A total of 8 sites are chosen within the premises of Delhi Technological University for the collection of bare soil. The soil samples are collected from these 8 sites and soil moisture and other parameters such as bulk density of the soil is measured in order to have the volumetric soil moisture. The coordinates of each sampling sites are noted with the help of GPS in order to allow the identification of the sampling site in the image. Sampling sites and coordinates of sampling sites are shown in Figure 3.2 and Table 3.1 respectively.

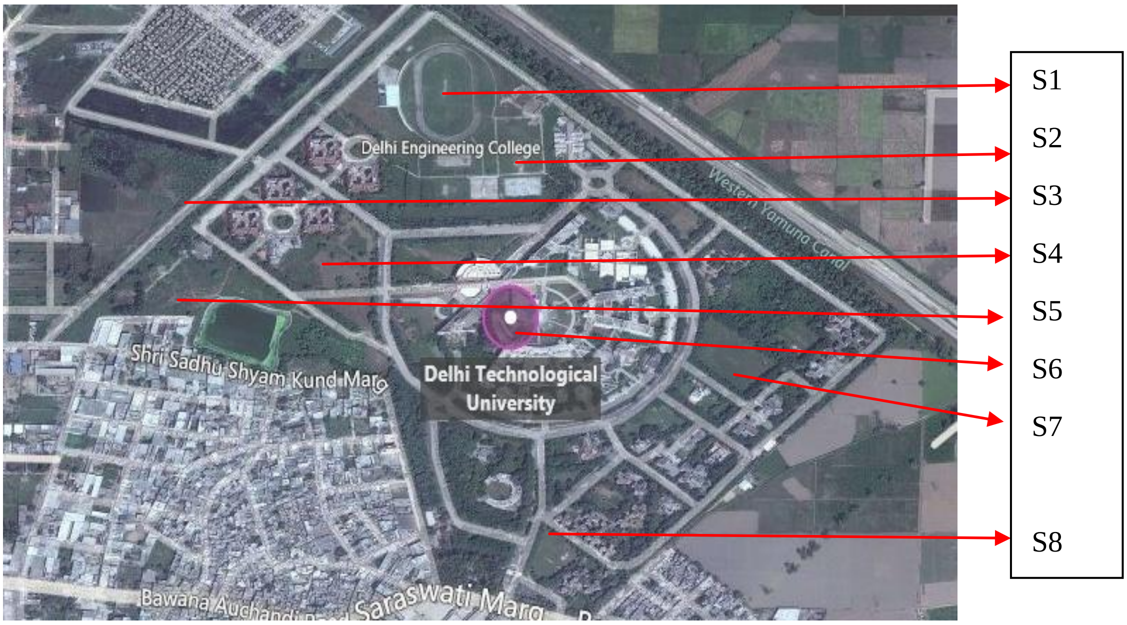

Figure 3. 2 Soil sampling sites for truth data (Source: Bing maps)

Table 3. 1 Coordinates of sampling sites

S.No.	**Name of the site**	**Coordinates**
S1	Cricket ground	28.75302213^{0}N, 77.11574976^{0}E
S2	Football ground	28.75235866^{0}N, 77.11695251^{0}E
S3	Soil near sports complex	28.75196466^{0}N, 77.11084563^{0}E
S4	Near JCB hostel	28.75023968^{0}N, 77.11403295^{0}E
S5	Beyond pond	28.74972050^{0}N, 77.11192152^{0}E
S6	Soil of open area theatre	28.74896403^{0}N, 77.11920586^{0}E
S7	Soil near VMH	28.74853972^{0}N, 77.12026825^{0}E
S8	Soil of Aryabhatta ground	28.74533332^{0}N, 77.11748834^{0}E

3.3 Properties of Satellite and Data

Data used in this study is of RISAT-1 SAR data. RISAT-1 is a acronym for Radar Imaging Satellite 1 which is a microwave remote sensing satellite carrying a SAR (Synthetic Aperture Radar) payload which operates in C-band and at frequency of 5.35GHz (www.isro.gov.in). Being in active microwave range, it has ability to work both in day as well as in night and also under all weather conditions. RISAT-1 started working with effect from 01 May 2012. RISAT has the capability of imaging in different polarisations like HH,HV,VH,VV and circular polarisation in C band. This is the reason for its wide variety of application in various fields like flood mapping, agriculture, soil moisture and forestry etc. As RISAT-1 is a side looking active sensor, approximately 107km of either side of sub-satellite track comes under non-image able area of the orbit under consideration. The antenna which is deployed in the RISAT-1 has dimensions of 6.29m*2.09m*0.220m. RISAT-1 is the only C-band SAR working in the world which has capability of giving 1m resolution over 10km*100km spot region. It is the first SAR in the world having capability of circular polarisation data that overcomes the disadvantage of not capturing data in low incidence angle i.e<35 and it has capability of capturing data in low incidence angle of up to 12^0. Data used in this study was purchased from www.nrsc.gov.in.

Since in this study, we are targeting towards soil moisture estimation and the proposed model for soil moisture retrieval is Dubois model. Therefore, data to be used is co-polarised microwave data as the equation given in Dubois model requires co-polarised backscattering coefficient (Equation 4.8 and 4.9). The RISAT hybrid polarised data is assumed to applicable for empirical based Dubois model for soil moisture inversion algorithm with an assumption that there is small backscattering coefficient variation between HH-RH and VV-RV channels within 2dB(Ponnurangam *et al.*,2014). Data used in this study is RISAT-1 data, date of passing over the Delhi Technological University is 01 September 2015. Data is enhanced geo-referenced image of Delhi region in which our area of interest (i.e. Delhi Technological University) is located. Enhanced geo-referenced image is that image which is geo-referenced as well as which is set for its optimum contrast and brightness level. Format of the images available is GEOTIFF and datum is WGS_84. Images are of FRS1 type (Fine Resolution Strip map mode-1which is based on conventional mode of SAR stripmap imaging providing a 25km swath with 3m resolution) and number of polarisation are two i.e. hybrid polarisation of RH and RV format(earth observation resources,2016). Mean incidence angle is 42.1300^0 and calibration constant for RH and RV is 70.681 and 67.681 respectively and these can be obtained from image metadata itself. Properties of the data are enlisted in the Table 3.1.

Table 3. 2 Properties of the data used in the study
(Source: Obtained from image metadata)

Parameters	Properties
Product ID	163249261
Product code	STPC00ETV
Band	C band
Wavelength	5.6cm
Data format	Unsigned 16bit
Resolution	3.33*2.34
Polarisation	Circular (RH and RV)
Product type	Level 2 Enhanced Geo-ref
No. Of records and samples in a grid	528,458
Nominal Pixel Spacing(m) along*across	2.25*2.25

Soil moisture can be estimated using both i.e. active and passive microwave remote sensing but in this study only active microwave remote sensing is used. A theoretical study of active microwave and different models to retrieve soil moisture is presented in this section.

4.1 Active microwave remote sensing

The part of electromagnetic spectrum used microwave remote sensing comes under the wavelengths of 100μm to 1m or the frequency range of 0.3GHz to 300GHz. The microwave region of electromagnetic spectrum is further divided in eight bands as shown in Table 4.1.

Table 4. 1 Frequency bands of microwave region, (Sabins,1987)

BAND	FREQUENCY(GHz)	WAVELENGHTS (cm)
Ka	40-26.5	0.8-1.1
K	26.5-18	1.1-1.7
Ku	18-12.5	1.7-2.4
X	12.5-8	2.4-3.8
C	8-4	3.8-7.5
S	4-2	7.5-15.0
L	2-1	15-30
P	1-0.3	30-100

There are two types of microwave remote sensing i.e. active and passive. In active remote sensing microwaves are transmitted towards earth surface and received back at the sensor in contrast to the passive remote sensing in which only radiation from the ground object in microwave region are studied. Active microwave system measures the electromagnetic waves which returns from targets after they get reflected and undergoes atmospheric attenuation (reduction of radiation due to atmospheric particles like ice, ozone, water vapour etc.). Active microwave systems are of two types i.e. ground based (weather radars) and satellite based (Tropical Rainfall Measuring Mission,TRMM). The most common active microwave sensor is RADAR which stands for radio detection and ranging.

RADAR equation (Raju,2008) can be given as:

$$p_r = 10^{-20}\,\frac{p_t G^2 \theta^2 \Pi^2 h|k|^2 z}{1024 \ln 2\lambda^2{}_r{}^2} \qquad ....(4.1)$$

Where.

p_r and p_t = received and transmitted power,

G = antenna gain which is a dimensionless quantity denoting ratio of power on beam axis to power from an isotropic antenna at same point,

θ = half power beam width(in radians),

h = pulse width(m),

λ = wavelength of radar(cm),

z = radar reflectivity factor,

r = range or distance to target(km)

and k = complex dielectric factor of the targets.

Radar backscattering coefficient is given by:

$$\sigma^0=\sigma/A \qquad ....(4.2)$$

where

σ^0 = backscattering coefficient,

σ = radar cross section

and A = the area on the ground associated with that object.

Backscatter coefficient σ^0 depends mainly on system parameters (roughness, dielectric constant) as well as on the radar parameters (depression angle, frequency, polarization etc). Frequency used also plays a important role in penetration through the vegetation cover. Surface parameters and radar parameters are explained below.

Radar parameters

1. **Azimuth direction**: It is the direction of the aircraft.
2. **Range direction**: It is the direction of radar beams and it is generally perpendicular to the azimuth direction. Ground range and slant range are shown in Figure 4.1.

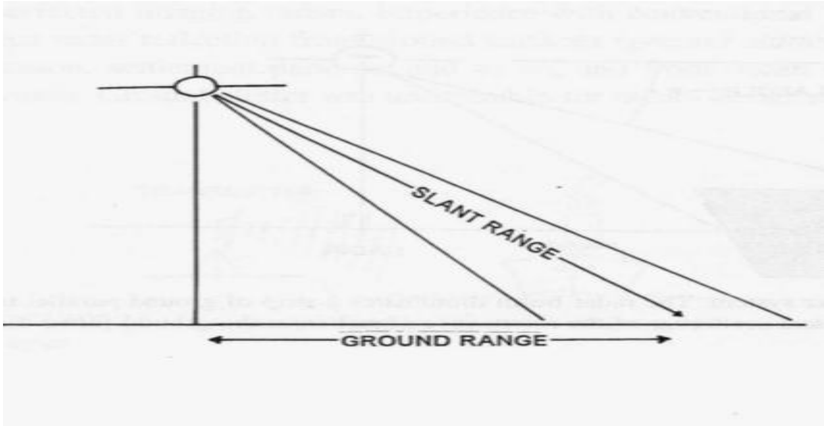

Figure 4. 1 Ground range and slant range (Source: www.geog.ucsb.edu)

3. **Incident angle**: It is the angle between microwave pulse and line perpendicular to the ground as shown in Figure 4.2.
4. **Depression angle**: It is the angle between microwave radiation and line parallel to the ground as shown in Figure 4.2.

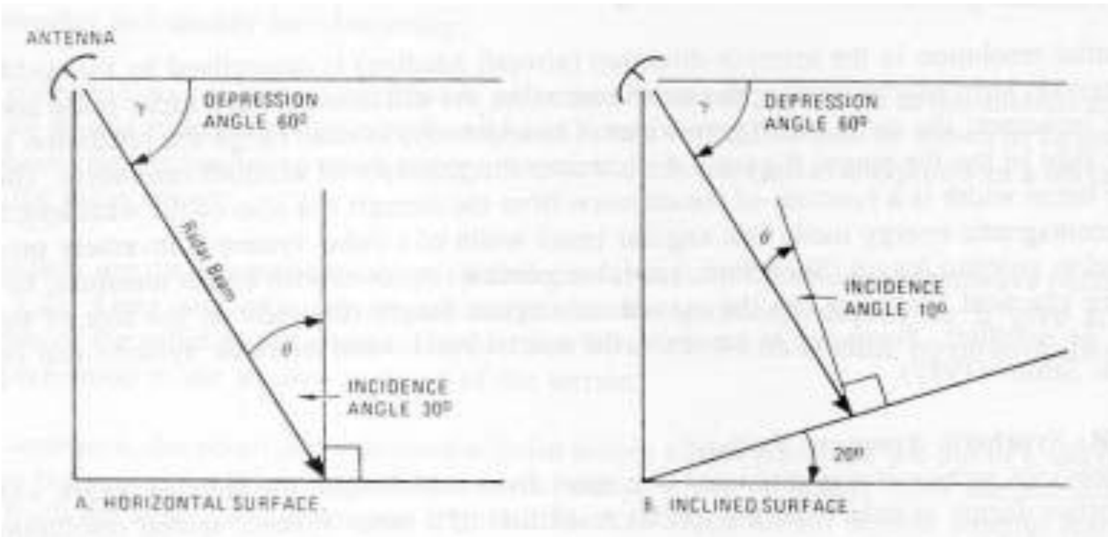

Figure 4.2 Depression and incident angle (Sabins,1987)

5. **Polarisation**: It is defined as the direction of electric field vector with respect to the propagation of the beam direction. Polarisation is generally of 2 types H and V where H denotes the horizontal and V denotes the vertical. Recent advancement is circular polarisation which is denoted by R. Transmitting and receiving polarisation can also be different or same depending upon our needs. HH, HV, VH, VV, RH and RV are different types of polarisation combination for transmitting and receiving beams. Different types of cross or co-polarisation shows different characteristics like HH

polarisation is more sensitive to roughness than VV signals. Various types of polarisation are shown on Figure 4.3.

Figure 4.1 (i) shows a elliptically polarised wave. The red ellipse is direction of electric field vector with respect to direction of wave propagation.

Figure 4.1 (ii) shows types of polarisation *i.e.* horizontal, vertical, linear 45^0 and circular polarisation.

Figure 4.1 (iii) shows the scattering with respect to polarisation.

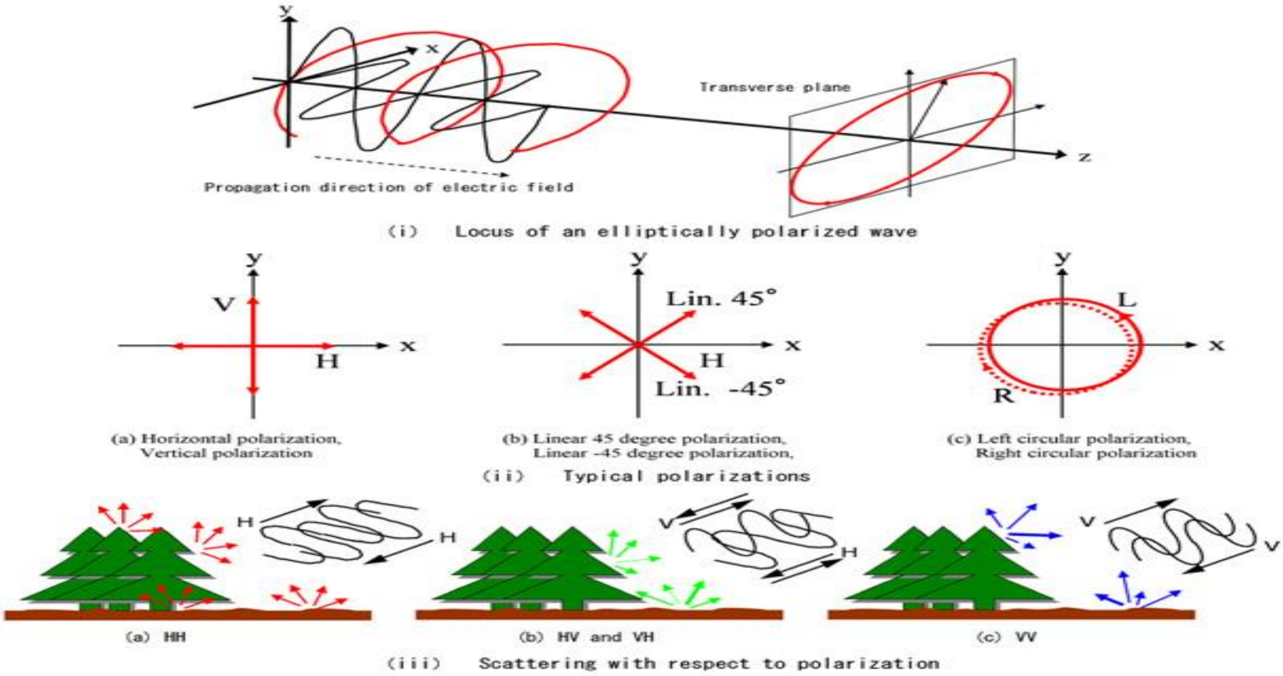

Figure 4. 3 Different types of polarisation (Source: www.geog.ucsb.edu)

SURFACE PARAMETERS

1. **Dielectric properties**: Dielectric constant is the measure of electric properties of the surface. It consists of two parts i.e. conductivity and permittivity. Figure 4.4 shows the variation of dielectric constant with soil moisture.

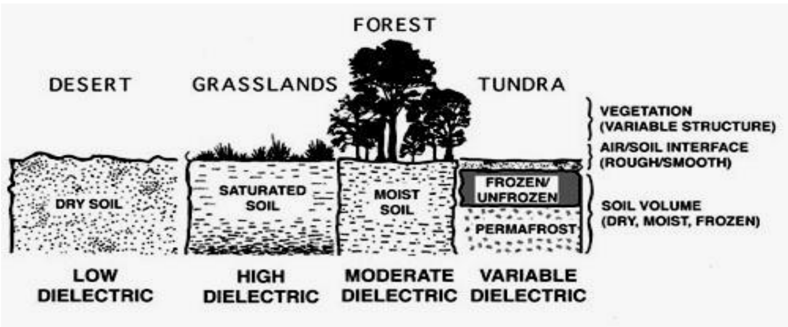

Figure 4. 4 Variation of dielectric constant with soil moisture (Source:www.geog.ucsb.edu)

2. **Surface roughness**: It is the terrain property that influences the strength of radar returns. It is measured in cm and is determined by textural features of the surface comparable in the size to radar wavelengths such as leaves and branches of vegetation and sands. Rayleigh has given the criteria for a surface to be called rough or smooth. According to Rayleigh criteria a surface is called smooth if $h<\lambda/(8 \sin\theta)$,

   Where

   h is vertical relief (cm),

   λ is radar wavelength (cm),

   and θ is depression angle of the radar system.

3. **Feature orientation**: It is orientation of the thing which we are going to identify with respect to look direction. For example features oriented parallel to the look direction are comparatively difficult to identify.

Estimation of soil moisture through remote sensing depends upon varying values dielectric constant from 80 to 4 of pure water and dry soil respectively and the reason behind this that the alignment of electric dipole of water molecule is greatly affected by the electric fields of microwave frequencies. Penetration capabilities of microwave emission is up-to few centimetres of soil usually 5-10 cm. Another parameter that is used to study variations of substances is emissivity. Emissivity is defined as ratio between radiant flux of the object and radiant flu8x of a blackbody with same temperature (Jong *et al.* 2004).Variations of soil moisture tend to vary the emissivity of the soil from 0.92 for dry soil and 0.95 for wet soils and 0.993 for pure water (Jong *et al. 2004).* These variations can be observed by microwave sensors. Therefore, the main work to determine soil moisture using remote sensing we actually need to determine the dielectric constant of the soil from the radar backscattering coefficient.

4.2 Surface scattering models

There are many models to estimate soil moisture using radar backscattering one such model is radar surface diffusion model. These models are classified as empirical and theoretical models. Empirical models are based on specific sites and are applied to the specific conditions. Empirical models depend on surface properties and the site on which they are developed whereas on the other hand theoretical models are derived from the theory of electromagnetic radiation and are applied everywhere. Theoretical models give us site independent relationships based on surface parameters(surface roughness and soil moisture content) and radar configuration such as incidence angle, polarisation and frequency. Such models are classified as under:

1. Theoretical models: Small perturbation model
2. Empirical models: Oh *et al.* 1992, Shi *et al.* 1995, Dubois 1995

4.2.1 Theoretical model: Small Perturbation model

A smooth surface has zero backscatter at oblique incidence angle. The presence of roughness can be seen as a perturbation of smooth surface scattering problem in the Bragg scattering region(i.e. for normalised roughness values ks<<0.3). in this case the backscattering coefficients are obtained by the small perturbation or Bragg scattering model which is derived from Maxwell's equations(Oh *et al.*,1992). According to this model the random surface is decomposed into its Fourier spectral components, each one corresponding to an idealised sinusoidal surface. The scattering is mainly due to spectral component of the surface which matches with incidence wavelength and angle of incidence. The scattering matrix for a Bragg surface is in the form (ESA manuals, 2005):

$$[S] = \begin{bmatrix} S_{HH} & S_{HV} \\ S_{VH} & S_{VV} \end{bmatrix} = m_s \begin{bmatrix} Rs(\theta,\varepsilon) & 0 \\ 0 & Rp(\theta,\varepsilon) \end{bmatrix} \quad \text{....(4.3)}$$

Where m_s is the backscatter amplitude containing the information about the roughness condition of the surface and R_s and R_p are Bragg scattering coefficients perpendicular and parallel to incidence plane. Both are the functions of complex permittivity ε and angle of incidence.

$$R_s = \frac{\cos\theta - \sqrt{\varepsilon - sin^2\theta}}{\cos\theta + \sqrt{\varepsilon - sin^2\theta}}, \qquad R_p = \frac{(\varepsilon-1)(sin^2\theta - \varepsilon(1+sin^2\theta))}{(\varepsilon cos\theta + \sqrt{\varepsilon - sin^2\theta})^2} \quad \text{....(4.4)}$$

It can be seen from above equations that co-polarised ratio R_s/R_p depends only on the complex permittivity and local incidence angle and is independent of surface roughness. This model is valid for incidence angle range from 25-60 degrees. Small perturbation model is insensitive to very wet surface and therefore its inversion yields too large uncertainties for moisture content estimates above saturation level.

4.2.2 Empirical model: The Oh model and Dubois model

4.2.2.1 The Oh model

This model was developed by Y. Oh, K. Sarabandi and F.T. Ulaby in 1992 (ESA manuals, 2005) at university of Michigan. The radar measurements used in this model were obtained by a truck mounted scatterometer (LCX POLARSCAT) operating at three frequencies (1.5,4.5 and 9.5 GHz) with an incidence angle range 10-70^0.

The equation for co-polarised and cross polarised ratio of backscatter given by Oh *et al.*, 1992 are:

$$p=\frac{\sigma^0 HH}{\sigma^0 VV}=\left(\left(1-\left(\left(\frac{2\theta}{\Pi}\right)\right)^{\frac{1}{3\Gamma^0}}.e^{-ks}\right)^2\right) \quad \text{....(4.5)}$$

$$q==\frac{\sigma^0 HV}{\sigma^0 VV}=0.23\sqrt{\Gamma^0}(1-e^{-ks}) \quad \text{....(4.6)}$$

where p and q indicate co-polarised and cross polarised ratio of backscattering coefficients, and θ is angle of incidence, ks is RMS height normalised to wavelength and Γ^0 is Fresnel reflectivity coefficient at nadir(i.e. θ=0) and value of Fresnel reflectivity coefficient can be given as:

$$\Gamma^0=\left|\frac{1-\sqrt{\varepsilon'}}{1-\sqrt{\varepsilon'}}\right|^2 \quad \text{....(4.7)}$$

ε' is the relative dielectric constant.

P and q comprises of two non linear equations with two unknowns ks and ε'.

This model shows good agreement with ground measurements in the range of $0.1\leq ks \leq 6, and\ 9\leq mv \leq 31$. This model is appropriate for applications at lower frequencies like S, L and P band.

4.2.2.2 Dubois model

Dubois model is an empirical model and also it is a simplification of the Oh model. The algorithm of this model were developed using data from RASAM Systems and scatterometer data from LCX POLARSCAT. The RASAM is a truck mounted scatterometer which uses data of quad polarisation i.e. HH,HV,VH,VV with incidence angle range from 30^0 to 60^0. It operates in the frequency range of 2.5 to 11GHz. The POLARSCAT is a truck mounted network analyser based scatterometer and includes the measurements of HH,VH.HV backscatters and the angle of incidence varies between 10 to 70^0. These two datasets then describes co-polarised backscattering ratio in relation with surface roughness, incidence angle, dielectric constant and frequency. In Dubois model co-polarised channels are used which makes it less sensitive on system noise. The equation given by this model are as follows (ESA manuals, 2005):

$$\sigma 0_{HH}=10^{-2.75}\frac{\cos^{1.5}\theta}{\sin^{5}\theta}\,10^{0.028\varepsilon\tan\theta}(khsin\theta)^{1.4}\lambda^{0.7} \quad ....(4.8)$$

$$\sigma 0_{VV}=10^{-2.35}\frac{\cos^{3}\theta}{\sin^{3}\theta}\,10^{0.046\varepsilon\tan\theta}(khsin\theta)^{1.1}\lambda^{0.7} \quad ....(4.9)$$

where,

$\sigma 0_{HH}$= backscattering coefficient in HH polarisation, dB (decibels);

$\sigma 0_{VV}$= backscattering coefficient in VV polarisation, dB;

θ= angle of incidence

k= wave number ($2\Pi/\lambda$)

h= surface roughness

λ= wavelength, cm

The advantage of this model over Oh model is that Oh model does not uses two polarised channels. Range of Dubois model is that it is applicable only value of incidence angle is above 30^0, and value of moisture content m_v<35% and value of normalised value of surface roughness is <2.5. For low value of NDVI (<0.4) the accuracy of moisture content is about 4.2% and accuracy for normalised surface roughness is 0.4. Various other properties of Dubois are listed below:

1. Backscattering coefficient decreases with increase in incidence angle or with decreasing value of surface roughness.
2. Backscattering coefficient increases with increase in soil moisture which is clearly visible on vertical polarisation sensitivity toward moisture content.

Chapter 5
Methodology and Implementation

In this section the process of soil moisture retrieval is discussed. Results with the help of remote sensing data and other with the help of field data are obtained and both are compared with the help of various parameters like mean value error, root mean square error and index of agreement.

5.1 Soil Sampling and Laboratory Measurement of Soil moisture

The soil samples taken from the respective 8 sites, were sealed and taken back to the laboratory. After weighing the wet soil sample along with the container the soil sample is allowed to dry in an oven for a minimum of 24 hrs at 110^0C. After the period of 24 hrs the soil samples were taken out and again the weight is measured. Then the soil is removed from the containers and weight of the empty container is taken. The gravimetric soil moisture is measured with the help of weight of dry soil and the weight of wet soil. The formula for gravimetric soil moisture is given below:

$$m_g=W_w/W_d \qquad ....(5.1)$$

where W_w= weight of water

W_d= weight of dry soil or solids

5.1.1 Conversion of gravimetric soil moisture into volumetric soil moisture

Weight of water is obtained by subtraction of weight of dry soil from the weight of wet soil and weight of solids is obtained by subtraction of the weight of empty container from weight of dry soil with container.

Volumetric soil moisture is obtained with help of bulk density. The volumetric soil moisture is determined assuming the fact that soil does not shrink or expand in relation to soil moisture. Volumetric soil moisture is obtained simply by multiplication of soil bulk density with the gravimetric soil moisture. The formula for volumetric soil moisture is given below:

$$M_v= \frac{W_w*Y_d}{W_d*Y_d} 100\% \qquad ....(5.2)$$

Where,

M_v= volumetric soil moisture of the field,%

W_w= weight of wet soil, g;

W_d= weight of dry soil, g;

Y_d= oven dry bulk density. g/cm^3;

Y_w= density of water, g/cm^3.

Or in other words we can say, M_v= m_g* soil bulk density

5.1.2 Measurement of Bulk Density

Bulk density is ratio of the weight of the soil to volume of the soil. It is used to measure the extent of compaction of the soil. It means greater the bulk density of the soil lesser will be the pore space available for water movement and root growth. In field it can be measured using different techniques like core cutter method, sand replacement and water balloon method. In our study we used core cutter method in which core cutter with diameter 10 cm and height of 13 cm is used to obtain the soil samples as shown in Figure 5.1. The core cutter is inserted with the help of rammer of 9 kg and a length of 900 mm.

Figure 5.1 Core cutter and rammer for bulk density measurement

The soil samples collected were carefully lifted after digging around the core cutter and excess soil is removed with help of blade. The top and bottom of the sample is made even with the edges of the samples with the help of knife. Collected samples were kept in the oven for drying for a minimum of 24 hrs to obtain dry bulk density. After the period of 24 hrs the samples were taken and weighed. Then the empty core cutter is also measured. The bulk density of the soil can be given with the help of equation as follows:

SBD(dry soil bulk density)(g/cm^3)= oven dry weight of the soil/volume of the sample

Soil sampling sites and bulk density measurement are shown in Figure 5.2 to Figure5.9. These photographs give a rough idea of site condition at the time of soil sampling.

Figure 5.2 a) Soil sampling at site S1

Figure 5.2 b) Bulk density measurement at site S1

Figure 5.3 a) Soil sampling at site S2

Figure 5.3 b) Bulk density measurement at site S2

Figure 5.4 a) Soil sampling at site S3

Figure 5.4 b) Bulk density measurement at site S3

Figure 5.5 a) Soil sampling at site S4

Figure 5.5 b) Bulk density measurement at site S4

Figure 5.6 a) Soil sampling at site S5

Figure 5.6 b) Bulk density measurement at site S5

Figure 5.7 a) Soil sampling at site S6

Figure 5.7 b) Bulk density measurement at site S6

Figure 5.8 a) Soil sampling at site S7

Figure 5.8 b) Bulk density measurement at site S7

Figure 5.9 a) Soil sampling at site S8

Figure 5.9 b)Bulk density measurement at site S8

5.2 Soil moisture retrieval using remote sensing (Active microwave)

5.2.1 Pre-processing of the image

Prior to application of surface scattering model pre-processing has been done on the data that is available to us. In pre-processing various things are done in order to enhance the data to make it workable and easier to understand. In this study RISAT-1 C band enhanced geo-ref. data is used to estimate soil moisture. Pre-processing is done with the help of ERDAS IMAGINE and ENVI software. Various steps involved in pre-processing are :

1. Geo-referencing of the image
2. Creating the subset of the image
3. Speckle filtering

1. Geo-referencing of the image:

It is process in which image pixels are given values of latitudes and longitudes in accordance with the physical space (Hackeloee *et al.*,2014). Geo-referencing of an image can be done in 2 ways i.e. with the help of another image that is geo-referenced and other with the help of keyboard by selecting the ground control points(GCP) if one knows the exact coordinated of the place in the image. In this study the data used is Level2 Geo-ref data which is already geo-referenced. Hence this step is excluded in this study.

2. Creating the subset of the image

As the data available to us was whole of the Delhi region but we are interested only in the study of Delhi Technological University's region. Therefore, we need to create a subset of the image available to us. Creating subset of the image is the process of cropping the interested region from the whole image and work with that region only. It makes the whole process easier and less time consuming. Subset is created with help of ERDAS IMAGINE software with its simpler and easier user interface.

3. Speckle filtering

Speckle filtering is the process in which noise of the picture is reduced in order to enhance its workability or in order to increase the ease with which we can work with the picture. Speckle noise in SAR causes difficulties in image interpretation. The scattering of the incident beam causes speckle noise by the particles present in atmosphere like water vapour and dust particles. When a beam is incident, on the target it is reflected back by the surface and the sensor is supposed to measure only that reflected back radiance but in addition to outgoing radiance sensor also measures path radiance which creates the noise in the imagery. Path radiance is the scattering of incident beam by water vapour or dust particles.

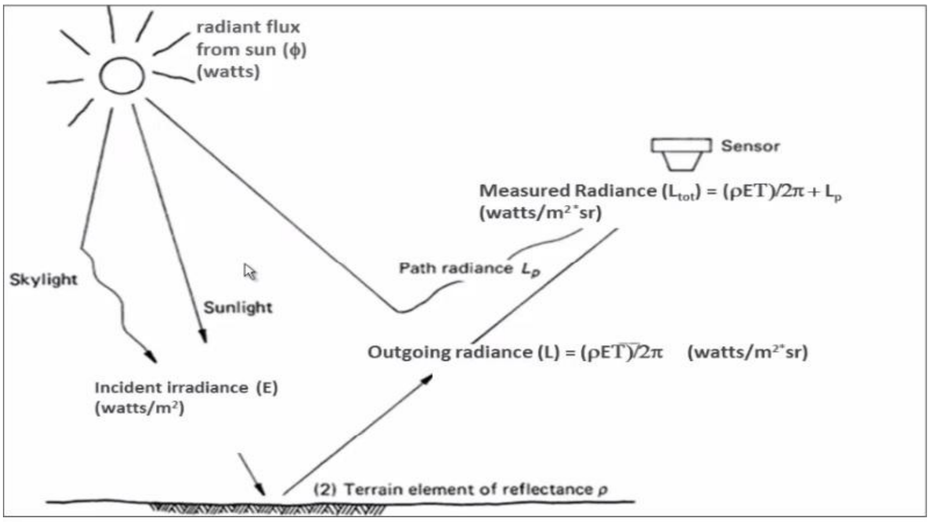

Figure 5.9 Path radiance causing speckle noise (Source: www.geog.ucsb.edu)

Firstly a function in ENVI software called dark subtraction is applied on the images. In the process of dark subtraction the value of darkest pixel is subtracted from the values of every pixel which causes the reduction in the path radiance. Effect of dark subtraction is not visible to naked eyes but it makes a difference in the image pixel value or the digital number (DN).

Next process to reduce the speckle noise of the image is applying convolution filtering. Convolution is a neighbourhood operation in which each output pixel is weighted sum of neighbouring input pixels. Depending on the requirement, various mathematical models are available for which filtering. Various needs can be edge detection, low pass, haze reduction and many more. In our study a convolution filter of 3*3 for haze reduction is applied in order to reduce the speckle noise in the image with the help of ERDAS IMAGINE software. The process of speckle filtering should be such that it increases the workability of the image interpretation and consecutively it does not adversely affect the details in the image.

5.2.2 Calculation of backscattering coefficient from digital number (DN) values

Digital number or the image pixel values are the values which a sensor gives us. A sensor cannot directly give the values of soil moisture i.e. rather than giving the values of required parameter, a image has digital number values. Every pixel has its own digital number and from that DN value backscattering coefficient has to be calculated. These values of backscattering coefficient are then applied to surface scattering model in order to have the value of desired parameter. Backscattering coefficient is the parameter to calculate the amount of energy scattered back by the target. In other words we can say backscattering coefficient is the ratio of amount of energy backscattered to amount of energy transmitted. Backscattering coefficient is a function of moisture content of the surface, surface roughness, wavelength, angle of incidence and the polarisation used. Derivation of backscattering coefficient is made with the help of equation 5.3 (ISRO, 2015):

$$\sigma^0{}_{dB}=20*\log_{10}(DN)-k+\log_{10}\left(\frac{\sin\theta i}{\sin\theta ref}\right) \quad ....(5.3)$$

where,

σ^0= backscattering coefficient, dB;

DN= Digital number value;

θ_i= angle of incidence for the pixel considered or the local incidence value;

θ_{ref}= mean angle of incidence for whole of image

values of digital number can be obtained from the image and value of mean incidence angle can be obtained from image metadata provided along with the images by NRSC. Value of mean incidence angle is 42.13045^0(image metadata) and values of θ_i can be calculated with the grid text files or with the help of generating the local incidence angle image. Values of backscattering coefficient for different polarisation (RH and RV) are calculated.

5.2.3 Application of soil moisture algorithm

There are various algorithm available from which soil moisture can be estimated using the backscattering coefficient values. For active microwave remote sensing the models are Dubois model, Small perturbation model and Integral Equation Model. Every model has its own limitation and advantages. The model which we have used in this study is Dubois model.

5.2.3.1 Inversion of Dubois Model

In order to simplify the calculation process the inverse Dubois is also available from which the value of dielectric constant and surface roughness can easily be calculated. The inverted Dubois model is a simplified version of Dubois model in which equation of Dubois model are solved with the backscattering coefficient, incidence angle and wavelength value the values of dielectric constant and surface roughness can be directly obtained. The inversion equation for estimating dielectric constant and surface roughness is given by:

$$\varepsilon' = \log_{10}(\sigma^0_{HH}{}^{0.7875}/\sigma^0_{VV})*10^{-0.19}\cos^{1.82}\theta\sin^{0.93}\theta\lambda^{0.15} \quad ....(5.4)$$

$$kh=\sigma^0_{HH}{}^{1/1.44}10^{2.75/1.}4(\sin2^{.57}\theta/\cos^{1.07}\theta)10^{-0.02\varepsilon'\tan\theta}\lambda^{-0.5} \quad ....(5.5)$$

where

ε'= dielectric constant (0-80), 4 for dry soil and 80 for pure water;

k= wave number;

h= surface roughness;

σ^0_{HH} and σ^0_{VV}= backscattering coefficient for HH and VV polarisation;

and λ is wavelength used.

5.2.3.2 Topp's Equation

After the value of dielectric constant is obtained from inverting Dubois model the values of volumetric soil moisture can easily be obtained with the Topp's equation (Prakash *et al*,2011). It is the most simplified method of conversion of dielectric constant into soil moisture. Topp's equation can be given as follows:

$$m_v= -5.3*10^{-2}+2.92*10^{-2}\varepsilon-5.5*10^{-4}\varepsilon^2+4.3*10^{-6}\varepsilon^3 \quad ....(5.6)$$

where

m_v= volumetric soil moisture content from remote sensing;

ε= dielectric constant.

5.3 Accuracy assessment

It is the last step of this study and it is done to check the reliability of remote sensing data which is obtained or to check the performance of the scattering model we have applied. There are certain indexes given by Willmott (1992) which can be used in order to compare the values:

1. **Mean Absolute error(MAE):** It is the quantity used to measure the mean difference between the model predicted values and the true values.

$$MAE=\frac{1}{N}\sum_{i=1}^{N}|Pi-Oi| \quad ....(5.7)$$

2. Root Mean Square Error(RMSE): RMSE is the parameter used to measure the difference between the value obtained by a model and the values actually observed. It represents the sample standard deviation between both the values.

$$RMSE=\sqrt{\frac{1}{N}\sum_{i=1}^{N}(Pi-Oi)^2} \quad ....(5.8)$$

3. Index of agreement (d): Index of agreement is the standard parameter to measure the degree of model prediction error. Value of this parameter varies between 0 and 1. Value 1 stands for the perfect match and the value 0 stands for no agreement at all.

$$d=1-\left[\frac{\sum_{i=1}^{N}(Pi-Oi)^2}{\sum_{i=1}^{N}(|Pi-\frac{1}{N}\sum_{i=1}^{N}Oi|+|Oi-\frac{1}{N}\sum_{i=1}^{N}Pi|)^2}\right],\ 0\leq d\leq 1 \quad ....(5.9)$$

where

P_i is the value obtained from the backscattering model;

O_i is the value from the field data or truth data

N is the number of values taken into account

A detailed flowchart of the methodology followed is presented below:

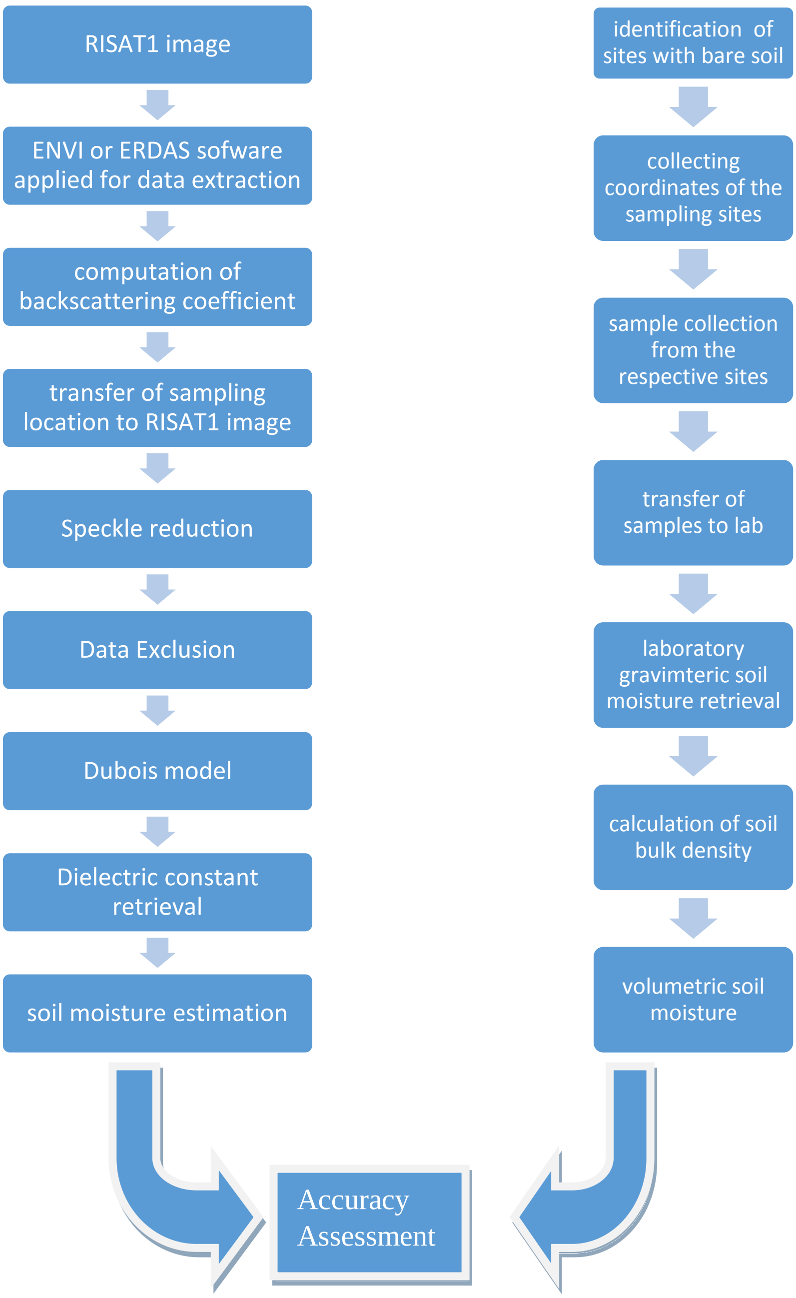

Figure 5.10 Flow chart of methodology

6.1 Soil moisture from the Field or Truth data

Eight different sites with the bare soil are selected and samples were collected from these sites and soil moisture is calculated based on laboratory experiments.

6.1.1 Calculation of gravimetric soil moisture

Gravimetric soil moisture was calculated by oven drying method. Both types of samples were weighed i.e. wet and dry soil samples and soil moisture was calculated by simple calculations. Different values of weight of sample and obtained values of gravimetric soil moisture are shown in Table 6.1.

Table 6. 1 Calculation of gravimetric soil moisture

Name of the site	Weight of the wet sample with container	Weight of dry sample with container	Weight of the empty container	Gravimetric soil moisture
1. Cricket ground	22.49	21.73	9.33	0.0620
2. Football ground	23.52	22.53	9.33	0.0754
3. Near sports complex	25.28	24.05	9.33	0.0836
4. Near JCB hostel	21.31	20.56	9.33	0.0670
5. Beyond pond	26.93	25.55	9.33	0.0856
6. Soil of open area theatre	29.05	27.68	9.33	0.0749
7. Soil near VMH	31.44	30.68	9.33	0.0543
8. Soil of Aryabhatta ground	30.21	28.54	9.33	0.0874

6.1.2 Calculation of bulk density

To have the volumetric soil moisture from gravimetric soil moisture, the parameter needed is bulk density. Bulk density is directly multiplied with the gravimetric soil moisture to obtain volumetric soil moisture. Bulk density is calculated with the help of core cutter method. Bulk density of soil samples so obtained is given in Table 6.2.

Table 6. 2 Calculation of soil bulk density

Name of the site	Weight of the dry soil sample(g)	Volume of the soil sample(cm^3)	Bulk density (g/cm^3)
Cricket ground	1674.44	1021	1.64
Football ground	1654.02	1021	1.62
Near sports complex	1694.86	1021	1.66
Near JCB hostel	1623.39	1021	1.59
Beyond pond	1674.44	1021	1.64
Soil of open area theatre	1643.81	1021	1.61
Soil near VMH	1551.92	1021	1.52
Soil of Aryabhatta ground	1705.07	1021	1.67

6.1.3 Calculation of Volumetric soil moisture (Field data)

Gravimetric soil is converted into volumetric soil moisture directly by multiplying soil bulk density by gravimetric soil moisture and the obtained values are shown in Table 6.3.

Table 6. 3 Calculation of volumetric soil moisture from gravimetric soil moisture

Site name	Gravimetric soil moisture	Soil bulk density	Volumetric soil moisture, M_v
Cricket ground	0.0620	1.64	0.1016
Football ground	0.0754	1.62	0.1223
Near sports complex	0.0836	1.66	0.1371

Near JCB hostel	0.0670	1.59	0.1065
Beyond pond	0.0856	1.64	0.1404
Soil of open area theatre	0.0749	1.61	0.1207
Soil near VMH	0.0543	1.52	0.0543
Soil of Aryabhatta ground	0.0874	1.67	0.1434

6.2 Soil Moisture retrieval using remote sensing

Backscattering coefficient of the RISAT-1 data was determined in accordance with the documentation provided by ISRO using ERDAS IMAGINE and MATLAB software. Step 1 was to create a subset of the image in order to attain the working area from whole image of Delhi region. Image Speckle filter of 3*3 is applied in order to study the details of the image. Behaviour of radar with respect to various parameters like dielectric constant is studied and a linear regression plot is generated.

6.2.1 Creating subset of the image

Original and subset image of polarisation RH and RV are shown in Figure 6.1 and 6.2 respectively. Original image is the image which is the satellite image of the whole of the Delhi region and subset is the image of Delhi Technological University that has been cropped from the original image.

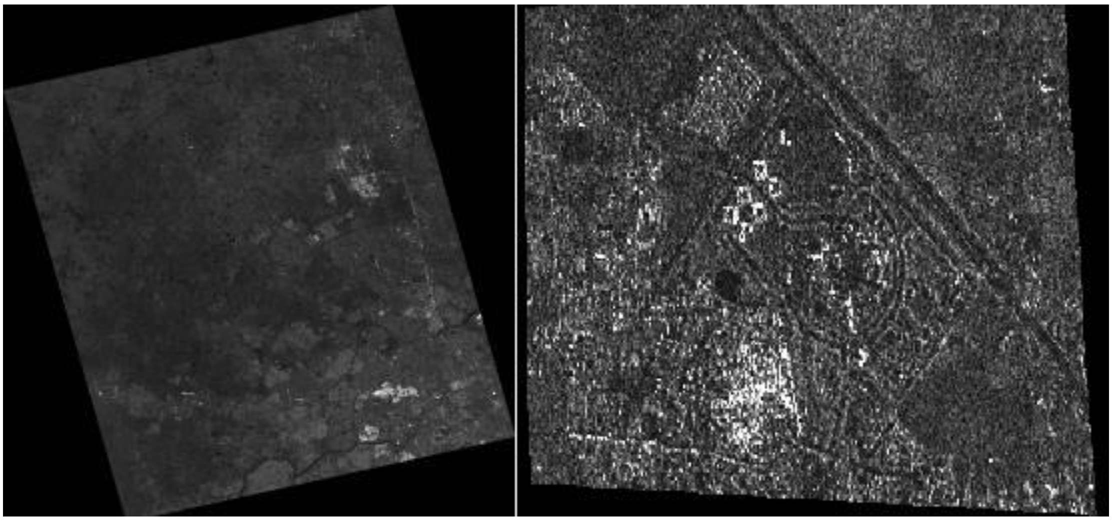

Figure 6.1a) Original image in RH polarisation   b) subset

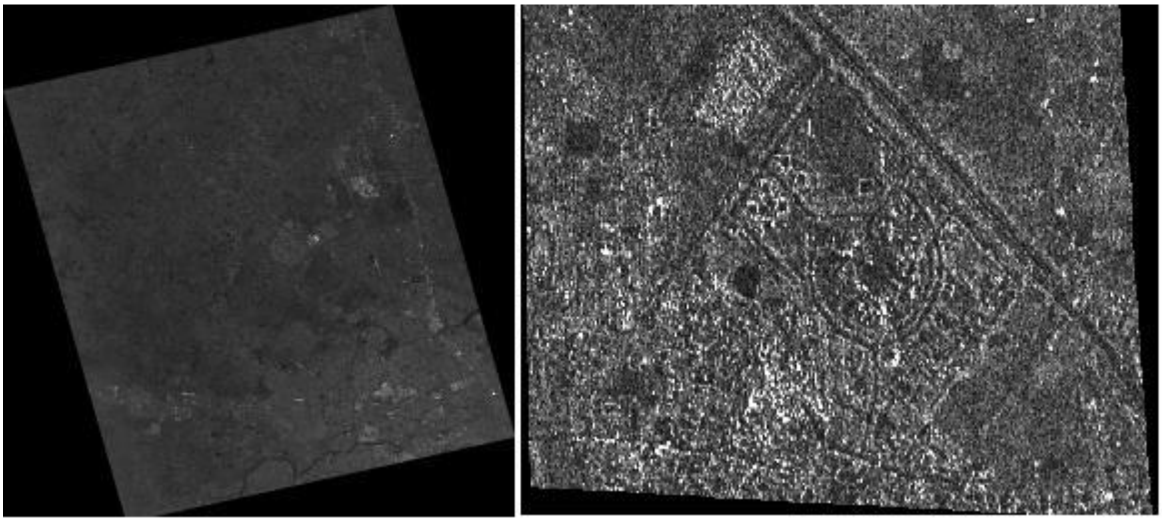

Figure 6.2 a) Original image in RV polarisation b) subset

6.2.2 Applying speckle filter

In order to subtract the effect of path radiance and to obtain clear details of the image speckle filtering is done. Figure and Figure show dark subtracted and speckle filter of 3*3 haze reduction applied image. Dark subtracted image and speckle filtered image are shown in Figure 6.3 and 6.4 respectively.

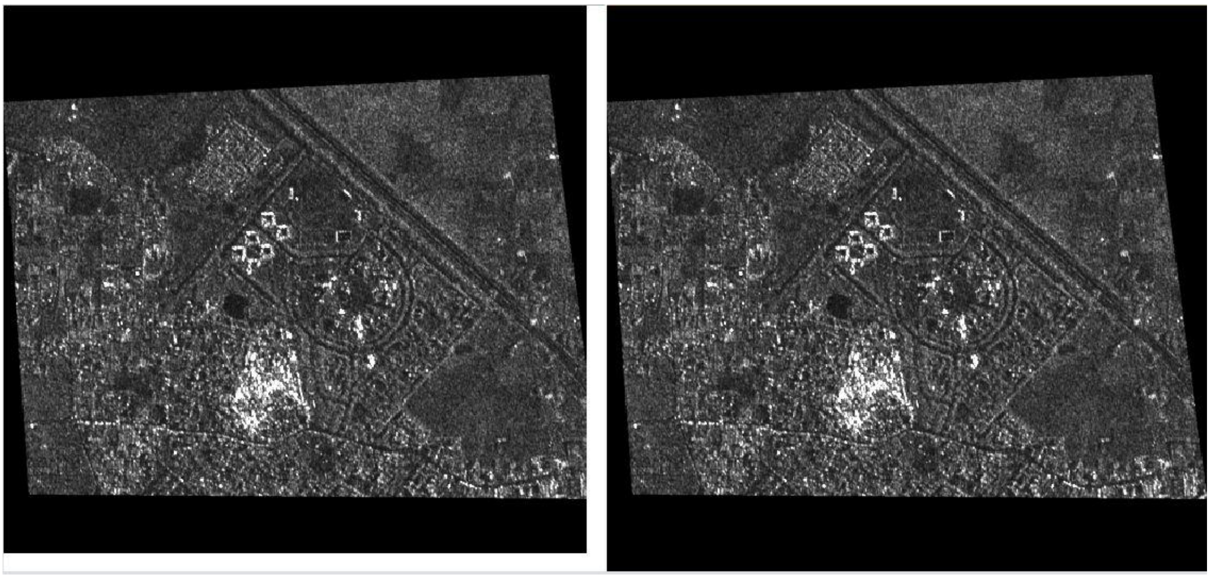

Figure 6.3 a) Original image b) Dark subtracted image

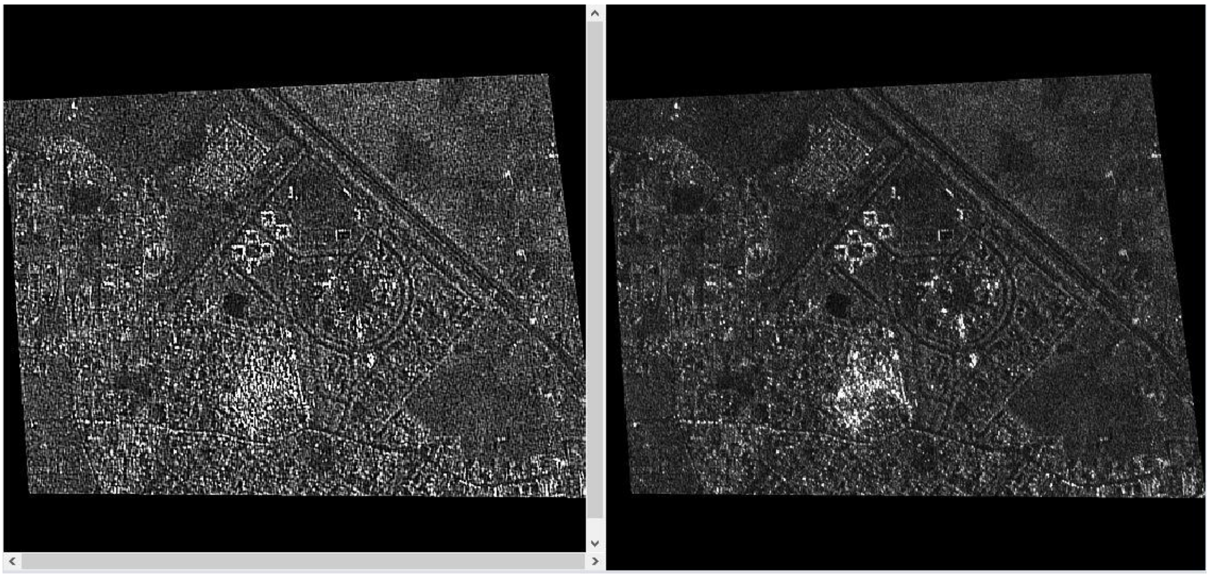

Figure 6.4 a) Dark subtracted image b) Speckle filtered image

6.2.3 Calculating Backscattering Coefficient σ^0 from DN values

DN values are obtained with the help of ERDAS IMAGINE software and DN values are then converted into backscattering coefficient as per formula as given in equation 5.3, provided by ISRO with the help of incidence angle values provided with the image data. Values of backscattering coefficient so obtained are given in Table 6.4.

Table 6. 4 Calculation of backscattering coefficient from DN values

Name of the site	DN value (RH)	DN value (RV)	Local incidence value	σ^0_{RH}(dB)	σ^0_{RV}(dB)
Cricket Ground	1402	590	41.868	-8.24796	-12.76588
Football ground	1325	462	41.634	-9.53397	-15.68545
Near sports complex	1119	393	41.675	-10.8334	-16.92217
Near JCB hostel	1301	544	41.658	-9.59257	-14.16614
Beyond Pond	1944	779	41.671	-6.05191	-10.99508

Soil of open area theatre	1164	364	41.626	-10.6937	-17.79073
Soil near VMH	1275	869	41.620	-9.92862	-10.25859
Soil of Aryabhatta Ground	1182	391	41.644	-10.4836	-17.09243

6.2.4 Obtaining dielectric constant with the help of Backscattering coefficient

To obtain dielectric constant from backscattering coefficient Dubois model is applied. Dubois model requires co-polarised data. Data used in this study is circular polarised with an assumption is made that over bare soil surfaces there is a small backscattering variation between HH-RH and VV-RV polarisation, and this variation is usually less than 2dB. It should be noted that value of dielectric constant varies between 4 and 80. 4 comes for the dry soil and value of 80 is for pure water, therefore value of soil-water mix varies between in this range. Inverse Dubois model that are applied are given as equation 5.4 and 5.5. Values of dielectric constant obtained are given in Table 6.5.

Table 6. 5 Calculation of Dielectric constant from backscattering coefficient

Name of the site	σ^0_{RH}(backscattering coefficient of RH polarisation)	σ^0_{RV}(backscattering coefficient of RV polarisation)	ε (Dielectric constant)
Cricket Ground	-8.24796	-12.76588	5.99909
Football ground	-9.53397	-15.68545	6.69216
Near sports complex	-10.8334	-16.92217	6.51068
Near JCB hostel	-9.59257	-14.16614	5.95484

Beyond Pond	-6.05191	-10.99508	6.69893
Soil of open area theatre	-10.6937	-17.79073	6.93813
Soil near VMH	-9.92862	-10.25859	4.26721
Soil of Aryabhatta Ground	-10.4836	-17.09243	6.76532

6.2.5 Obtaining volumetric soil moisture from Dielectric constant

After the dielectric constant is calculated volumetric soil moisture can directly be measured with the Topps equation as given in equation 5.6. Values of volumetric soil moisture are given in Table 6.6.

Table 6. 6 Calculation of soil moisture from dielectric constant

Name of the site	**ε (Dielectric constant)**	**m_v (volumetric soil moisture)m^3/m^3**
Cricket Ground	5.99909	0.112983
Football ground	6.69216	0.128763
Near sports complex	6.51068	0.124693
Near JCB hostel	5.95484	0.112159
Beyond Pond	6.69893	0.128881
Soil of open area theatre	6.93813	0.134189
Soil near VMH	4.26721	0.054910
Soil of Aryabhatta Ground	6.76532	0.130372

From above values of it can been seen that the volumetric soil moisture of 8 selected sites ranges between 0.05-0.1342 m^3/m^3.

6.3 Study of relationship between Radar parameters with Surface parameters

In order to study the relation and variation between different parameters(like ε, σ, m_v, M_v etc) various plots have been generated in form of the linear regression equation and coefficient of determination (r^2) is also calculated. All the parameters are listed in Table 6.7. Coefficient of determination is a value that shows the proportion of the variance in dependent variable that is predicted variable from independent variable.

Table 6.7 Values of different parameters such as σ^0, ε, m_v and M_v

Name of the site	σ^0 RH	σ^0 RV	ε	m_v	M_v
Cricket Ground	-8.24796	-12.76588	5.99909	0.112983	.1016
Football ground	-9.53397	-15.68545	6.69216	0.128763	.1223
Near sports complex	-10.8334	-16.92217	6.51068	0.124693	.1371
Near JCB hostel	-9.59257	-14.16614	5.95484	0.112159	.1065
Beyond Pond	-6.05191	-10.99508	6.69893	0.128881	.1404
Soil of open area theatre	-10.6937	-17.79073	6.93813	0.134189	.1207
Soil near VMH	-9.92862	-10.25859	4.26721	0.054910	.0543
Soil of Aryabhatta Ground	-10.4836	-17.09243	6.76532	0.130372	.1434

1. Simple linear regression between soil moisture m_v and backscattering coefficient σ^0

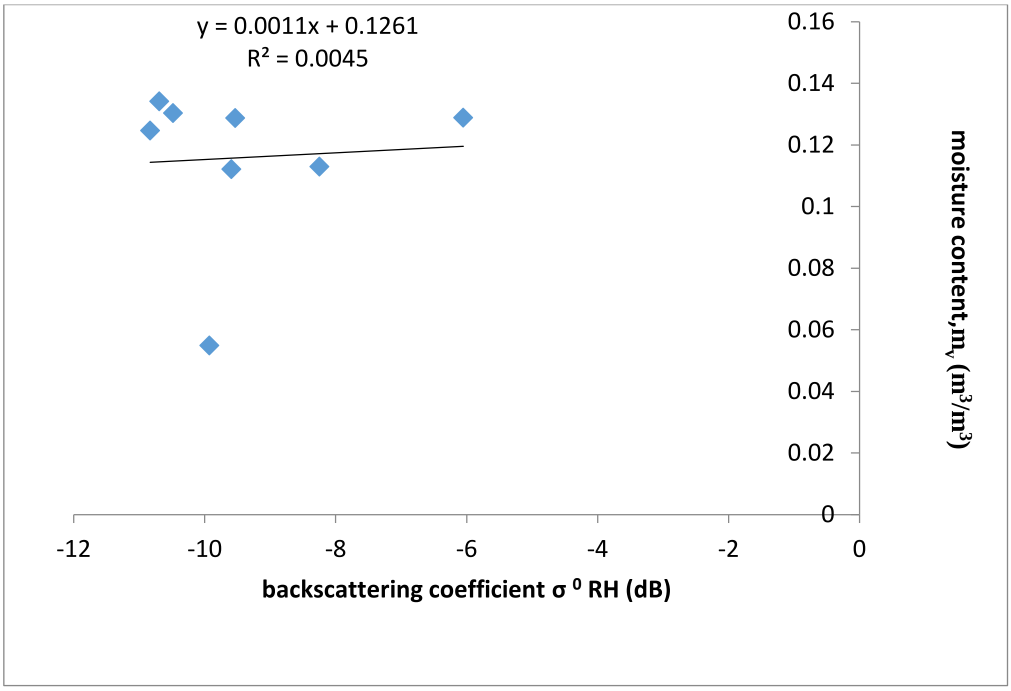

Figure 6. 5 Simple Linear regression between backscattering coefficient RH and moisture content, m_v

(Ref.: Table 6.7)

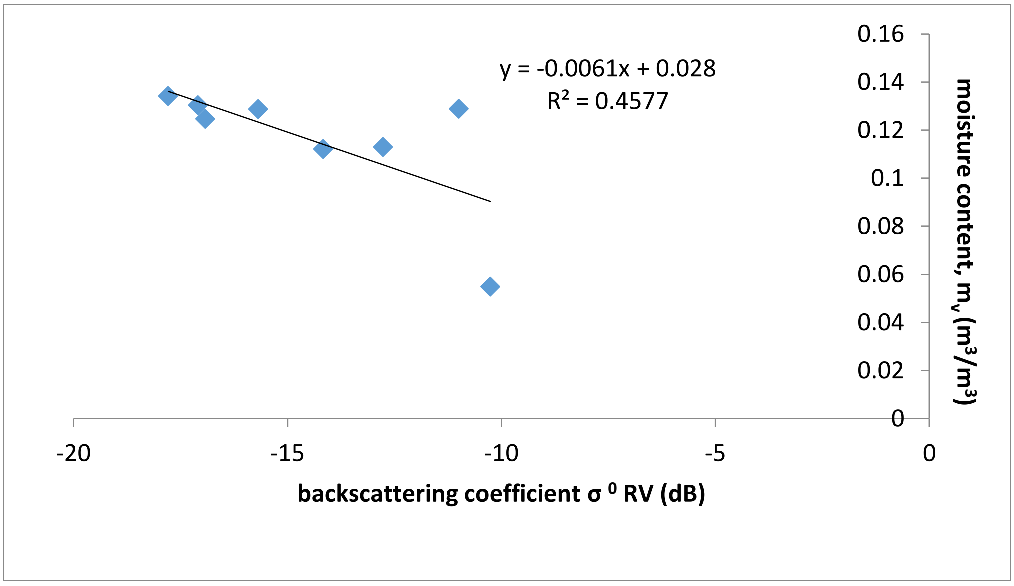

Figure 6. 6 Simple Linear regression between backscattering coefficient RV and moisture content, mv

(Ref.: Table 6.7)

2. Simple linear regression between dielectric constant ε and backscattering coefficient σ^0

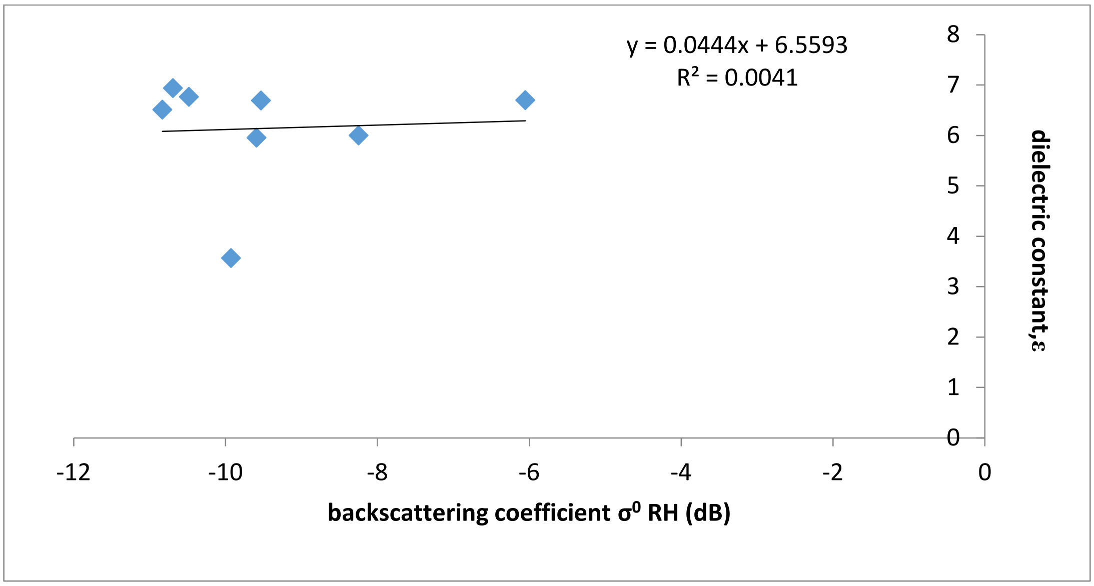

Figure6. 7 Simple Linear regression between backscattering coefficient RH and dielectric constant, ε

(Ref.: Table 6.7)

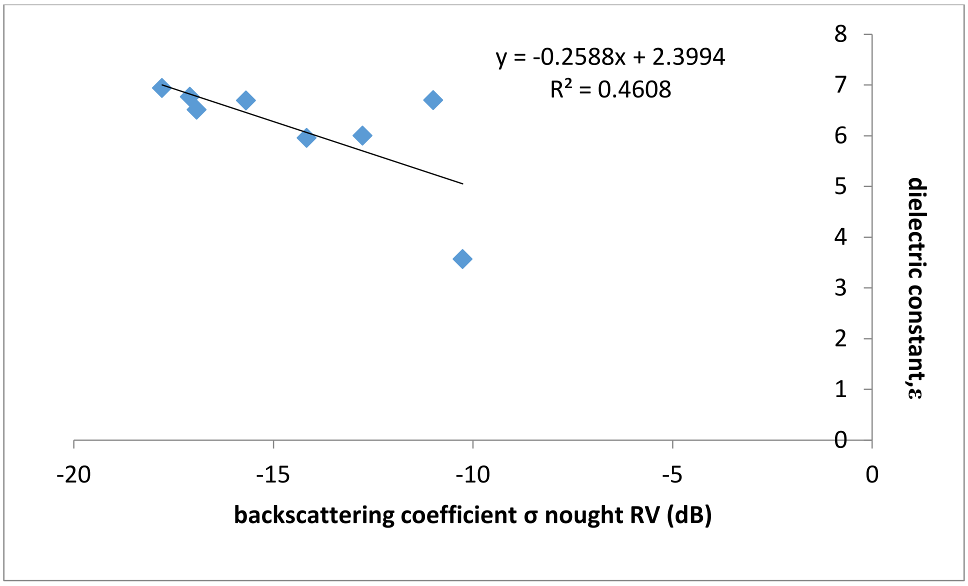

Figure6.8 Simple Linear regression between backscattering coefficient RV and dielectric constant, ε

(Ref.: Table 6.7)

6.4 Comparison of model obtained values with field data

Table 6. 8 Comparison of soil moisture estimated using microwave remote sensing and field data

Name of the site	Soil moisture from Dubois model, $m_v(m^3/m^3)$	Ground values of soil moisture, M_v (m^3/m^3)
Cricket Ground	.1129	.1016
Football ground	.1287	.1223
Near sports complex	.1246	.1371
Near JCB hostel	.1121	.1065
Beyond Pond	.1288	.1404
Soil of open area theatre	.1341	.1207
Soil near VMH	.0549	.0543
Soil of Aryabhatta ground	.1303	.1434

1. Simple linear regression relationship between modelled value m_v and true value M_v of soil moisture

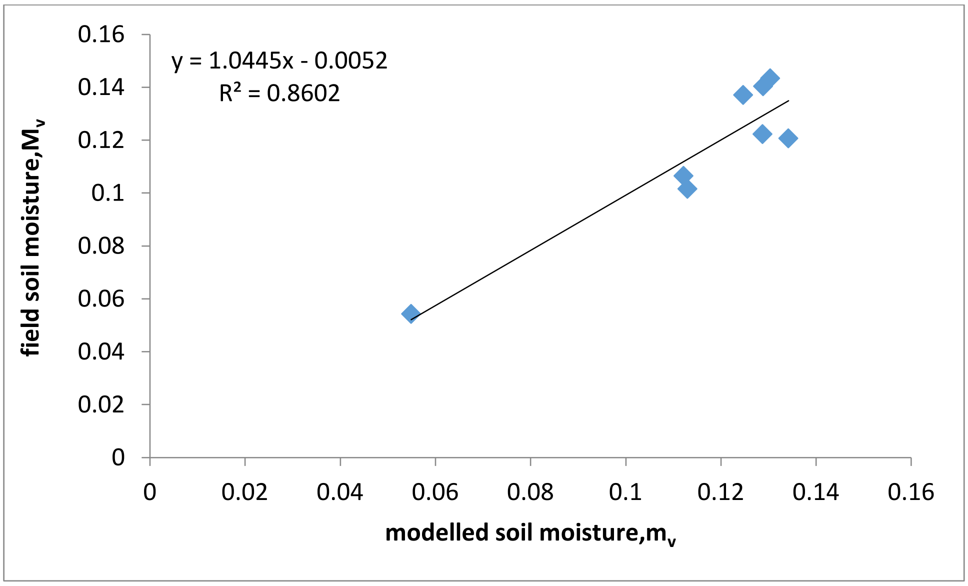

Figure 6. 9 Relationship between modelled soil moisture m_v and true soil moisture M_v (Ref.: Table 6.8)

6.5 Accuracy assessment

Various parameters like mean absolute error, root mean square error and index of agreement are available to evaluate the results obtained or to compare both the results.

1. **Mean Absolute Error**: With reference to equation 5.7 value of MAE in this study comes out to be **0.009319**
2. **Root Mean Square Error (RMSE)**: With reference to equation 5.8, RMSE value for our study comes out to be **0.0105**

3. **Index of Agreement, d**: With reference to equation to 5.9 value of d in this study comes out to be **0.90**

Chapter 7
Conclusions

- Among all the empirical, semi empirical and theoretical model, a detailed study of small perturbation model, Oh model and Dubois model has been done. Dubois model has been preferred for the study.
- Apart from field methods, there are various methods to retrieve soil moisture with the help of remote sensing especially active or passive microwave remote sensing. Synthetic Aperture Radar have a good potential to retrieve soil moisture. This study uses an empirical model to calculate soil moisture i.e. Dubois model. Backscattering coefficient of RH polarisation comes broadly in the range of -11 dB to -6dB and backscattering coefficient of RV polarisation comes broadly in the range of -18 dB to -9dB as shown on Table 6.5. Values of dielectric constant comes broadly in the range of 4.2-6.7 as shown in Table 6.5. Value of volumetric soil moisture of selected sites of Delhi Technological University with the help of remote sensing comes in the range of 0.0549-0.1342 m^3/m^3.
- Backscattering coefficient decreases with increase in soil moisture, which is clearly seen on vertical polarisation sensitivity towards moisture content as shown in Figure 6.6. Similarly backscattering coefficient for RV polarisation decreases with increase in dielectric constant as shown in Figure 6.8.
- The value of volumetric soil moisture from the field data comes in the range of 0.054-0.144m^3/m^3 and that from remote sensing comes in the range of 0.0549-0.1342 m^3/m^3. Value of correlation coefficient for both the values of soil moisture is 0.86 which shows that there is high similarity between the remote sensing methods and field methods. Other parameters which shows relation between soil moisture obtained from remote sensing and field data are MAE, RMSE and index of agreement, the value of which comes out to be0.009319, 0.0105 and 0.90 respectively which also shows the reliability on remote sensing is quite good and is on higher side. Hence we have obtained a confidence level of approximately 90%.

References

1. **Bindlish R., A.P. Barros**(2000), "Multi-frequency soil moisture inversion from SAR measurements with the use IEM."Remote sensing of Environment, 71, pp. 67-88
2. **Engman Edwin T. and James R. Wang** (1987), Evaluating roughness models of radar backscatter, IEEE Transaction on Geoscience and Remote sensing, GE-25
3. **N. Baghdadi, N. Holah and M. Zribi**(2006)."Soil moisture estimation using multi-incident and multi-polarisation ASAR data". International journal of remote sensing, vol. 27, pp. 1907-1920.
4. **Wang James R., Edwin T. Engman, James C. Shiue, M, Rusek and Charlotte Steinmeier**(1986)." The SIR-B observations of microwave backscatter dependence on soil moisture, surface roughness and vegetation covers". IEEE Transaction on Geoscience and Remote sensing, Vol. GE-24
5. **Paloscia S., P. Pampaloni, S. Pettinato, P. Poggi and E. Santi** (2005)."The retrieval of soil moisture from ENVISAT/ASAR data, EARSel eProcessing,4.
6. **Xuhua Cai, Huili Gong, Xiaojuan Li, Lin Zhu**(2010)."Remote sensing retrieval of soil moisture using ENVISAT ASAR images: A case study in suburban region of Peking, China". IEEE,pp 1-4
7. **G.G. Ponnurangam and Y.S. Rao**(2011).'Soil moisture mapping using ALOS PALSAR ENVISAT ASAR data over India". IEEE, pp. 1-4
8. **Rishi Prakash, Dharmendra Singh and Nagendra P.Pathak**(2012)."A fusion approach to retrieve soil moisture with SAR and Optical data" IEEE Journal of selected topics in applied earth observations and remote sensing,vol.5
9. **Matej Kseneman, Dusan Gleich**(2009)." Soil moisture estimation with TerraSAR-X with Dubois Empirical Model".IEEE
10. **Holah N., N. Baghdadi, M. Zribi, A. Bruand and C. King**(2005)." Potential of ASAR/ENVISAT for the characterisation of soil surface parameters over bare agricultural fields". Remote sensing of Environment, 96,pp 78-86
11. **Saif Said, Umesh C. Kothyari and Manoj K. Arora** (2008)."Journal of hydrologic engineering ©ASCE
12. **Steven M. De Jong, Raymond Sluiter, Maarten Zeijlmans, Elisabeth Addink**(2004)." Remote sensing- a tool for environment observation".

13. **K.R.Arora**(2005).”Soil Mechanics and Foundation Engineering”,Standard Publishers Distributors
14. **I. Hajnsek, K. Papathanassiou**(2005),”Rough surface scattering models” European space agency manuals, (www.esa.int) Vol.1
15. **Indian Space Research Organisation, ISRO**(2015).”RISAT data product formats” SAC/ISRO manuals,(www.isro.gov.in). Vol. 1
16. **Sonika Sharma**(2006).”Soil moisture estimation using active and passive microwave remote sensing techniques” Indian institute of remote sensing
17. **Amer Ahmad, Yun Zhang and Sue Nichlos**(2011). “Review and evaluation of remote sensing methods for soil moisture estimation”. Society of photo-optical instrumentation engineers.© SPIE
18. **Ponnurangam G.G., Thomas Jagdhuber, Irena, Hajnsek, Y.S. Rao** (2014). “Soil moisture inversion using hybrid polarimetric RISAT-1 data” EUSAR©VDE VERLAG GMBH.Berlin. pp. 256-259