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Methodology Article **Open Access**

Passive Microwave Remote Sensing of Soil Moisture: A Step-By-Step Detailed Methodology using AMSR-E Data over Indian Sub-Continent

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Abstract This paper presents a detailed methodology to process AMSR-E soil moisture data to generate average soil moisture maps of desired durations be it weekly, monthly or yearly over a large geographical area like a continent or a sub-continent. The paper also explores utility of AMSR-E soil moisture product (AE_Land 3 product) to understand the soil moisture variations over Indian subcontinent by analysing daily soil moisture data for entire calendar year of 2009. In order to demonstrate the developed methodology the year 2009 was selected wherein a total of 730 AMSR-E daily scenes (365 each for ascending as well as descending passes) were processed and analysed. Although the absolute values of soil moisture derived from AMSR-E are not showing good agreement with soil moisture status on ground which is due to large variability in soil moisture within the coarse-resolution cell offered by passive sensors [1] but in general AMSR-E derived soil moisture values are well explained on the basis of rainfall data and agricultural practices adopted in different states of Indian sub-continent. The soundness of the detailed methodology proposed in this paper has been well supported by studying the variations in AMSR-E derived soil moisture with seasonal variations and rainfall data. It has been observed that the soil moisture variations are in line with the seasonal changes as well as the rainfall variations.
Keywords *AMSR-E; Passive Microwave Remote Sensing; Soil Moisture; Rainfall; Temporal Variations of Soil Moisture*

1. Introduction

Soil moisture is the water held in pores in the soil in liquid and vapour phases [2-3]. It can be defined as the temporary storage of water within a shallow layer of earth's upper surface. It plays a significant role in land surface-atmosphere interaction, as it directly influences the heat exchange between these two mediums through evaporation and transpiration [4-6]. The amount of water stored in the soil is fundamentally important to agriculture and is an influence on the rate of actual evaporation, groundwater recharge, and generation of runoff [7].

Soil moisture is of utmost importance in agricultural domain, for agriculture yield, crop growth forecasting, irrigation scheduling. Apart from this it is a very well-known fact that variation in soil moisture is directly associated with rainfall, and surface runoff is a phenomenon which is attributed to the fact that it occurs when rainfall rate is more than the infiltration rate. Furthermore the infiltration rate depends on factors like soil type, texture and soil moisture. Therefore soil moisture proves to be a contributing factor in case of surface runoff and hence, it is important for monitoring hazards like floods and droughts. It also plays an equally important role in meteorological applications in the sense that soil moisture is used in weather predication models and global circulation models to identify weather patterns.

Surface soil moisture information through remote sensing is very important in the field of agriculture, hydrology and meteorology [8-10]. Satellite remotely sensed data products particularly those that are derived from instruments operating in the microwave region of electromagnetic spectrum are being exploited and explored by researchers all over the world in the recent past [11-14]. The remotely sensed soil moisture microwave data products have immense potential to be used for above mentioned applications, for this each data product available should be understood to devise a methodology to generate maps and extract meaningful information. Passive microwave remote sensing data product like AMSR-E data has been studied in this paper and a detailed methodology to process it and generate average soil moisture maps for various time intervals at continent/ sub-continent level has been proposed in this paper.

2. Challenges of Soil Moisture Estimation over Large Areas

The conventional methods of measuring soil moisture are point specific and labour intensive, in the sense that soil moisture measurement probes are taken to the point of observation and the moisture content is sensed. In contrast to conventional methods, remote sensing techniques can play a major role in soil moisture estimation on routine basis. Different portions of electromagnetic spectrum like Optical, Thermal and Microwave can be used for soil moisture retrieval using remote sensing techniques [15-16]. Out of optical, thermal and microwave bands, microwave remote sensing is the best option for soil moisture retrieval due to its penetration capability and high dielectric constant of water i.e. 80 at microwave frequency [17]. Estimation of soil moisture using microwave remote sensing has been well established.

In a broader sense the advantage of remote sensing techniques over the in-situ methods is that the former allows the acquisition of global and synoptic view. The in-situ methods are very accurate in terms of point based estimating of soil moisture but the limitation is just that the information is localized [18]. Remote sensing methods offer rapid data collection of soil moisture over large areas with a high temporal resolution with a fact that the penetration depth changes with the wavelength [19-21]. To further add on, microwave sensors have advantages and unique capabilities over the optical sensors [22, 23]. These are:

a) All weather penetration capability through clouds.
b) Day and night capability (independent of intensity and angle of sun illumination).
c) Penetration through vegetation and soil to a certain extent.
d) Direct Sensing of moisture content of earth materials.

Both active as well as passive microwave remote sensing are being used very effectively to retrieve soil moisture. Active Microwave remote sensing techniques have an upper edge as far as the spatial resolution is concerned. Also the concept of soil moisture retrieval in active microwave remote sensing forms its basis on sensing the backscatter coefficient using radars. Many researchers have explored multi-incidence angle, multi-polarized, multi-frequency and temporal Synthetic Aperture Radar (SAR) data to retrieve soil moisture under variety of agricultural heterogeneity [24-27]. However, along with its strong sensitivity towards soil moisture, SAR signals are also sensitive towards other target properties like surface roughness, vegetation cover and soil texture [28-32]. Therefore, due to its sensitivity towards other target proper-ties soil moisture sensitivity decreases significantly due to presence of these noise parameters in a resolution cell.

On the other hand Passive Microwave remote sensing which forms its basis on sensing the brightness temperatures using radiometers is also being used extensively to retrieve soil moisture. A particular advantage of passive microwave sensors is that in the absence of significant vegetation cover soil moisture is the dominant effect on the received signal. However, soil moisture is highly variable both spatially and temporally [2] and passive microwave remote sensing is capable of estimating soil moisture with better temporal resolution at a larger scale as far as the area of observation is concerned.

Microwave observations, in particular, are sensitive to soil moisture since the presence of water strongly affects the dielectric constant and, consequently, the emissivity of land surfaces. Surface roughness and vegetation cover reduce the sensitivity of microwave emission to soil moisture, and their effects become more pronounced as the observation frequency increases.

The Advanced Microwave Scanning Radiometer for the Earth Observing System (AMSR-E) launched on board Aqua satellite observed several parameters related to water cycle and global energy. The most important parameter is surface soil moisture which can be retrieved from AMSR-E brightness temperature data [33]. Various algorithms have been developed for the retrieval of soil moisture from AMSR-E data. Several researchers have used these data products provided by AMSR-E and have validated these algorithms [34-37]. In the case of AMSR-E data, nonlinear iterative algorithm [38] has been used for the generation of soil moisture products and the final data product is being distributed worldwide by the National Snow and Ice Data Centre (NSIDC).

3. Scientific Rationale behind Soil Moisture Retrieval using Passive Microwave Sensors

The basic principle behind soil moisture estimation using passive microwave remote sensing is the measurement thermal energy emitted by the soil at low frequency microwave wavelengths. Microwave remote sensing dispenses a very distinctive capability for direct observation of soil moisture. Soil moisture is estimated by measuring either the reflected electromagnetic energy or the emitted electromagnetic energy. Active microwave measures the radar backscatter coefficient while the passive microwave measures emission or brightness temperature.

The dielectric properties and temperature of the soil, or combination of both are the governing factors for observed variations in intensity of microwave radiation. Theoretically there exist a large contrast between the dielectric properties of liquid water and dry soil and this forms the basis of soil moisture measurement using microwave remote sensing as it records the microwave emissivity [22]. The dielectric constant of water is as high as 80 in comparisons to that of dry soil which varies between 3 and 4. This drastic noticeable variation is because of the fact that water molecules are free to rotate at microwave frequencies [39]. Thus, as the soil moisture increases, the dielectric constant can increase to a value of 20 or more [40]. This variation directly reflects on emissivity changes from 0.95 for dry soils to 0.6 or less for wet soils. Thus it can be observed that there exists a direct relationship between soil moisture and brightness temperature.

The passive sensors, referred to as radiometers, detect the radiated energy in the microwave spectrum. Radiometers are used to measure the raw counts as the noise equivalent temperatures which are converted into the brightness temperature. The basic principle that works behind the process of detection by the radiometers is the Rayleigh Jeans approximation of Planck's law. The behaviour is guided by the electromagnetic emission from a blackbody at a given temperature T °K as governed by Planck's law.

The Planck's law when it is approximated for f/T <<< 2 $\times 10^{10}$, is known as Rayleigh Jeans approximation for blackbody, which is given by

$$B(\lambda, T) = \frac{2KT}{\lambda^2}$$

In natural situations, the ability to absorb or emit is related by Kirchoff's law which is given as

$$B(\lambda, T) = \varepsilon(\lambda)\left[\frac{2KT}{\lambda^2}\right]$$

Where, emissivity ε (λ) is the ratio of the emission between the object and the blackbody maintained at the same temperature. The emissivity depends upon a number of parameters such as temperature, polarization, frequency, angle of incidence, and the physical properties of the surface.

For radiometers working in shorter wavelength ranges, atmospheric attenuation and emission of the signal can be expressed as [41, 42]

$$T_B = t(H)\left[rT_{sky} + (1-r)T_{soil}\right] + \left(1 - t(H)\right)T_{atm}$$

Where, T_B is the microwave brightness temperature, $t(H)$ is the atmospheric transmission, r is the surface reflectivity and T_{sky}, T_{soil} and T_{atm} are the temperatures of the sky, soil and atmosphere, respectively. For typical soil moisture applications using longer microwave wavelengths, atmosphere is transparent in most atmospheric conditions ($t(H)$~1K) and $T_{sky}$is much less (~3.5K); hence these terms can be neglected. Therefore,

$$T_B = (1-r)T_{soil} = eT_{soil}$$

Where $e = (1-r)$ is the emissivity, which depends upon the dielectric constant of the medium [41].

4. Study Area

To demonstrate the potential of developed methodology during the course of this work, the study area has been selected as entire Indian sub-continent. The fundamental reason behind this selection is that it offers a complete range of soil moisture values due to availability of very dry as well as highly moist areas. The geographical extent of the area in concern is Upper left latitude- 40, Upper left longitude- 55, Lower right latitude- 5, and Lower left longitude- 100. Due to the presence of all types of meteorological conditions and variety in agricultural practices the selected study area is expected to provide a fantastic opportunity to test the developed methodology.

5. Dataset

The data set used is called AMSR-E/Aqua Daily L3 Surface Soil Moisture, Interpretive Parameters, & QC EASE-Grids, Version 2. Gridded Level-3 land surface product (AE_Land3). It measures the surface soil moisture and vegetation/roughness water content interpretive information, as well as brightness temperatures and quality control variables on daily basis. The product is available in hierarchical data format i.e. HDF-EOS. The spatial coverage is global but, here Indian sub-continent is taken as the area in concern. The temporal coverage is from 19 June 2002 to 3 October 2011. Data are provided in the Equal Area Scalable Earth (EASE)-Grid global cylindrical projection. The projection used for AMSR-E Level-3 land products is a generalized form of the EASE-Grid called Cylindrical Equal-Area (CEA), which is user-defined projection number 97 in the General Cartographic Transformation Package (GCTP).

Surface Soil Moisture in the top 1cm of soil is averaged over the retrieval footprint. Measurements of soil moisture are most accurate in areas of low vegetation. Attenuation from vegetation increases the retrieval error in soil moisture [43]. Surface type classifications are assigned to indicate low and moderate vegetation, and retrievals are not performed in dense vegetation. The retrieval algorithm does not explicitly model effects of topography, snow cover, clouds, and precipitation. Other potential error sources include anomalous inputs from bad radiometric data and low level processing errors. The processing algorithm includes checks to identify these and other anomalies and assign appropriate flags [42].

The 6.9 GHz channel in the AMSR-E sensor is shared with mobile communication services as a result of which retrieval of brightness temperatures and consequently soil moisture content using this frequency are subject to Radio Frequency Interference (RFI), especially at places near large urban land areas. To eliminate this problem, soil moisture algorithm uses the 10.7 GHz channel for data retrieval.

5.1. AMSR-E Sensor Description

AMSR-E is passive microwave radiometer, modified from the Advanced Earth Observing Satellite-II (ADEOS-II) AMSR, designed and provided by JAXA. It is multi-frequency, dual-polarized microwave radiometer that detects faint microwave emissions from the Earth's surface and atmosphere. This sensor provides the opportunity to retrieve geophysical parameters like, sea surface wind speed, precipitation, water vapour, cloud liquid water, snow water equivalent, sea surface temperature and soil moisture. The AMSR-E instrument operates in polar, sun-synchronous orbits, with equator crossings at 1:30 A.M. (descending) and 1:30 P.M. (ascending) local solar time. The AMSR-E is a modified technology to the Scanning Multichannel Microwave Radiometer (SMMR) and Special Sensor Microwave Imager (SSM/I) instruments, first launched in 1978 and 1987 respectively.

It provides observations of variables describing the Earth’s atmosphere, ocean, cryosphere, and land surface. The AMSR-E is a passive microwave instrument and is designed to measure brightness temperature at six frequencies, 6.925, 10.65, 18.7, 23.8, 36.5, and 89.0 GHz, with vertical and horizontal polarizations at each frequency for a total of twelve channels. For AMSR-E, global swath coverage is achieved every two days or less, separately for ascending and descending passes, except for a small region near the poles. Full daily coverage is obtained above approximately 550 latitudes. Spatial resolution of the individual measurements varies from 5.4 km at 89.0 GHz to 56 km at 6.9 GHz as given in Table 1.

The AMSR-E brightness temperatures are first resampled (for a given swath) to an Earth fixed grid. The gridded brightness temperature is then classified to determine feasible points for retrieval. In this paper, the L-3 products have been used. Table 1, describes the AMSR-E system characteristics.

AMSR-E sensor description has been referred to from the NSIDC official website http://nsidc.org

Table 1: *AMSR-E Performance Characteristics*

Polarization	Horizontal and Vertical					
Incidence angle	55°					
Cross polarization	Less than -20 dB					
Swath (km)	1445					
Precision	1 K					
Centre frequency (GHz)	6.93	10.65	18.7	23.8	36.5	89
Mean spatial resolution (km)	56	38	21	24	12	5.4
IFOV (km)	74×43	51×30	27×16	31×18	14×8	6x4

http://nsidc.org/data/docs/daac/amsre_instrument.gd.html

6. Methodology

6.1. Data Downloading

The satellite data product was freely downloaded from the following link http://reverb.echo.nasa.gov which is distributed by National Snow and Ice Data Center. The data sets were obtained for entire Indian sub-continent using AMSR-E passive microwave sensor. Gridded AMSR-E Level-3 soil moisture data product (AE_Land3) was freely downloaded from National Snow & Ice Data Center, NSIDC official website. The data product corresponds to a 56 km mean spatial resolution, which has been further resampled to a global cylindrical 25 km Equal-Area Scalable Earth Grid (EASE-Grid) cell spacing. It was required to input the latitudes and longitudes of the area in order to subset it, in this case the downloaded data extent were as follows, Upper left latitude- 40, Upper left longitude- 55, Lower right latitude- 5, Lower left longitude- 100. As a result all downloaded files were in .hdf format and size of the image being 173 pixels by 135 lines. This is a daily product and for each day there were 2 files, one for the ascending pass and the other for descending pass. So for 365 days of the year, a total of 730 hdf files were downloaded.

6.2. Soil Moisture Map Generation

For generating daily weekly and monthly average soil moisture maps batch file programming and coding in C was performed and two executable files were developed. There were certain logics and concepts followed to develop these files in the codes. There are 135 rows and 173 columns in each downloaded soil moisture dataset. Therefore each file has a total of 23355 pixels; in the soil moisture data product each pixel contains a 16 bit signed integer value which is a measure of soil moisture. In the downloaded datasets, for pixels that are void of any retrieval where no data is recorded due to inherent gaps between available swaths a fill value of 9999 is allotted and for no retrieval due to bad brightness temperature data or screening by land surface classification, or unsuccessful retrieval due to retrieval values outside the physical range, a fill value of -9999 is allotted. Both Ascending and descending soil moisture data sets give the soil moisture at 10.7 GHz resolution (g $/cm^3$) and the data in the pixels ranges between 0 and 500. Therefore to obtain soil moisture in g $/cm^3$ the data values were multiplied by 0.001. In the code, each row is processed and 173 column elements in each row are checked for the data range which should be between 0 and 500. And finally the data is multiplied by 0.001 and then by 100 to generate % soil moisture raster.

The first step was to extract the required channel data from the downloaded HDF file. To accomplish this task batch file programming scripts were written to extract ascending and descending soil moisture channel data. As a result for each day 2 files were extracted one for the ascending pass and the other for the descending pass. Consequently for a week a total of 14 files, for a month a total of 58 to 62 files and for a year a total of 730 files.

Figure 1 and 2 show extracted soil moisture data sets for the ascending passes from JULY 1, 2009 to JULY 7, 2009. The 7 ascending pass files and 7 descending pass files from 1st July 2009 to 7th July 2009 clearly show that entire Indian subcontinent is not covered in a single pass.

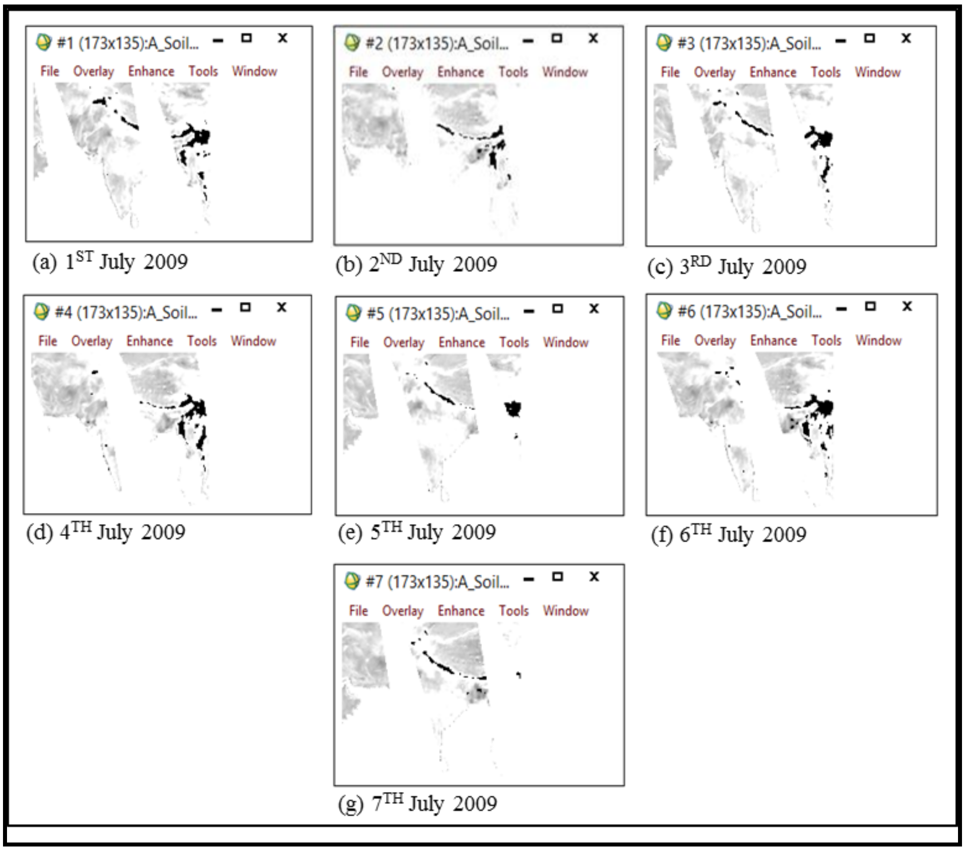

***Figure 1**: Ascending Pass Scenes Depicting Swaths on Which Soil Moisture Data was recorded from 1st July 2009 to 7th July 2009*

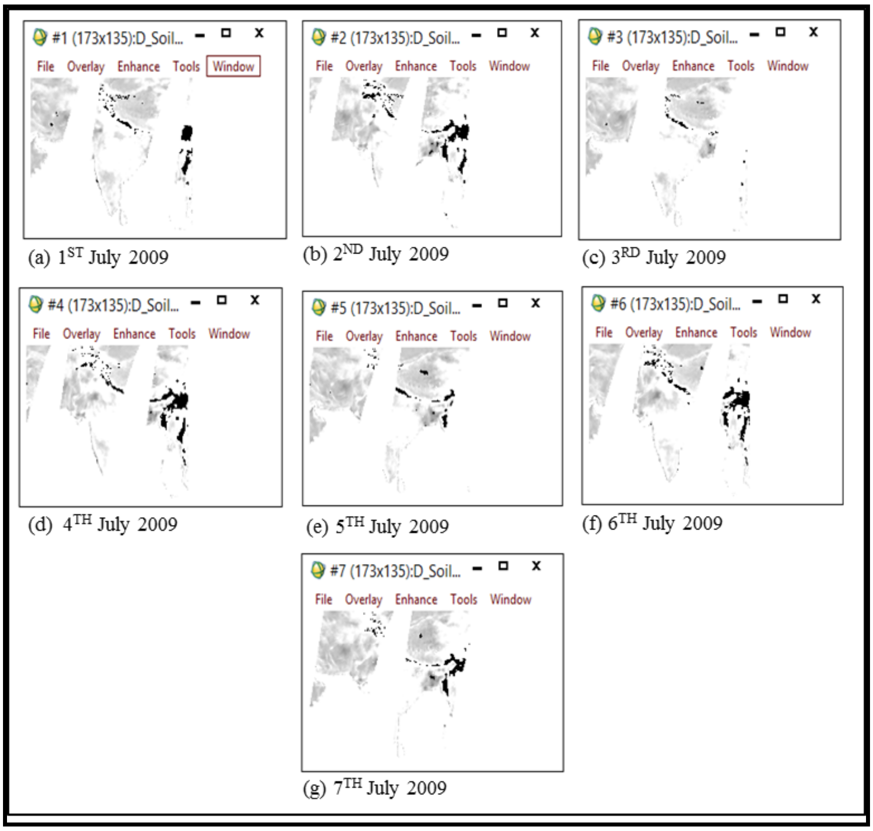

Figure 2: *Descending Pass Scenes Depicting Swaths on Which Soil Moisture Data was recorded from 1st July 2009 to 7th July 2009*

6.3. Deriving Average Soil Moisture Maps using Daily Soil Moisture Rasters

Once the ascending and descending files were extracted, the weekly and monthly average of these data sets was taken independently. For this, codes in C programming were developed and an executable file was created which, when given all extracted files of a week or a month as input, generated a weekly or monthly average soil moisture output file each for ascending and descending pass. As a result 2 output files were generated in .BIN format for each week or month.

After average binary soil moisture files for ascending and descending passes are generated they were averaged again to using another code written in C in which the two files, namely ascending and descending were supplied as input and the final average soil moisture file is obtained as an output.

6.3.1. Weekly Average Soil Moisture Map Generation

To generate weekly average soil moisture map for each week 7 ascending and 7 descending files were averaged using the developed C code which gives 2 output files, which are again averaged to give final weekly average soil moisture map. Figure 3 shows weekly average soil moisture maps of the 4 weeks generated for the July 2009.

6.3.2. Monthly Average Soil Moisture Map Generation

In case of monthly average soil moisture similar procedure as illustrated above was performed for 31 days July 2009 to generate a single map for July 2009 depicting average soil moisture. Figure 4 shows the average soil moisture map for July 2009.

6.3.3. Annual Average Soil Moisture Map Generation

To generate annual average soil moisture map for 2009, 12 monthly soil moisture files were averaged using the same codes. Figure 5 shows the 12 average monthly soil moisture maps for the year 2009 which were averaged to generate final annual average soil moisture map for year 2009.

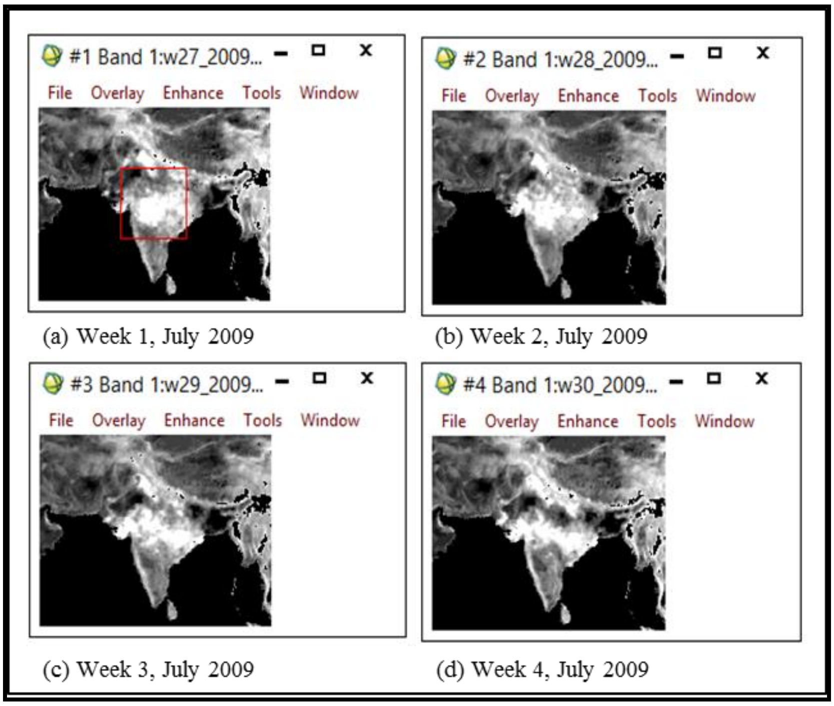

Figure 3: *Average Weekly Soil Moisture Maps July 2009*

WEEK 1: July, 1 to 7
WEEK 2: July, 8 to 14
WEEK 3: July, 15 to 21
WEEK 4: July, 22 to 28

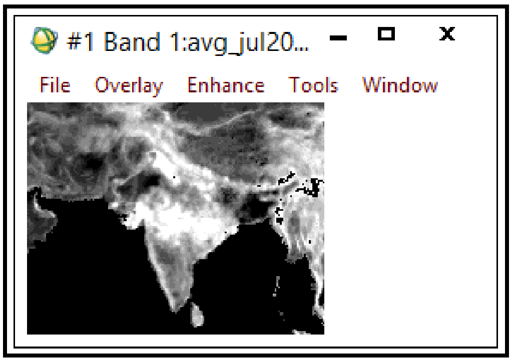

Figure 4: *Average Monthly Soil Moisture Map July 2009 (July 1 to 31)*

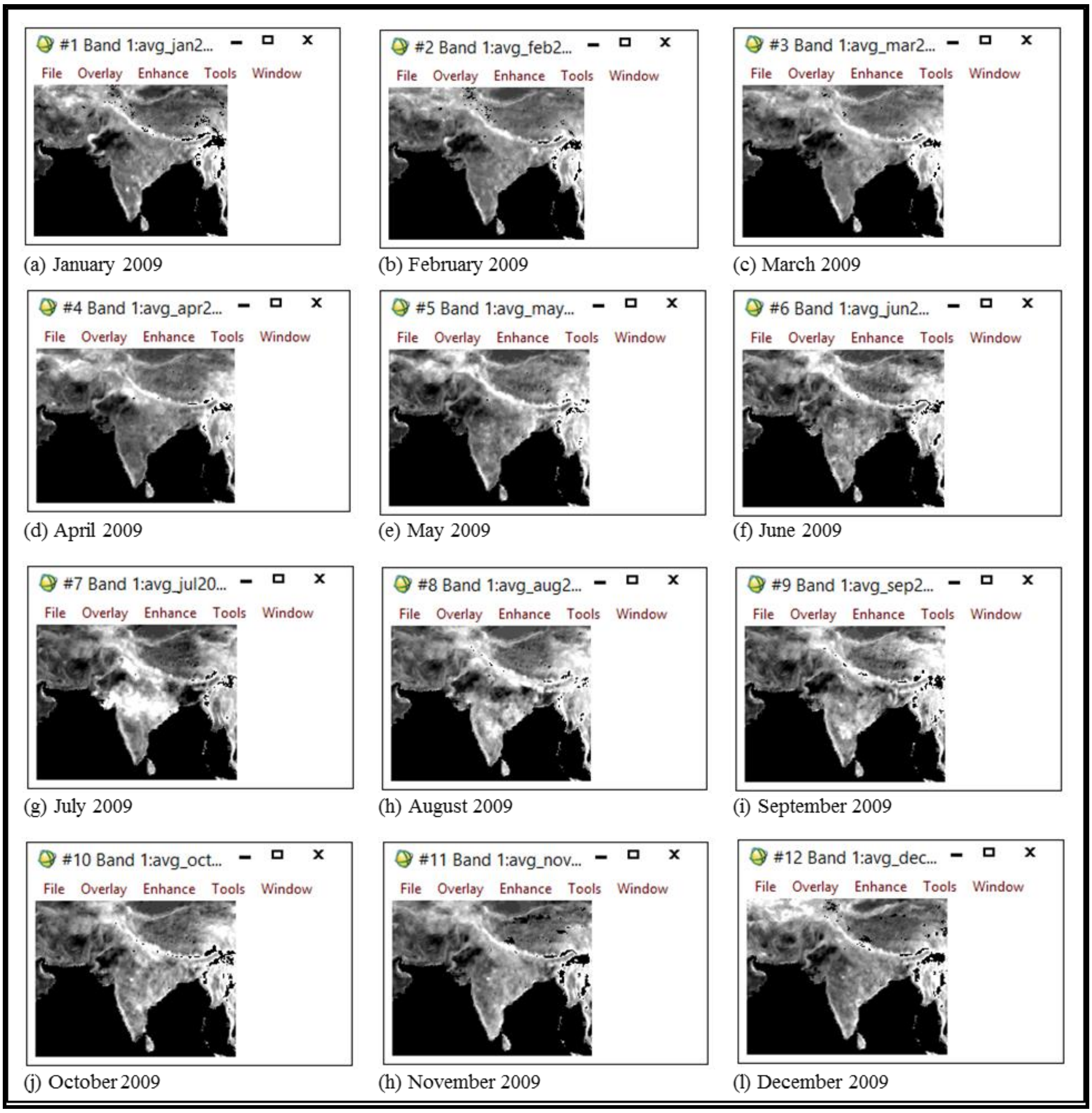

Figure 5: *Average Monthly Soil Moisture Maps January 2009 to December 2009*

6.4. Batch Geo-Referencing

It is to be noted that all the generated average soil moisture raster files were in binary file format and using ENVI software all these files were converted to TIFF format. The TIFF format can be easily used in ArcGIS software.

Once the average soil moisture raster maps were generated they were geo-referenced. And the geo-referenced files were overlayed with shape file of Indian sub-continent. For this purpose a model was developed in ArcGIS for batch geo-referencing shown in Figure 6.

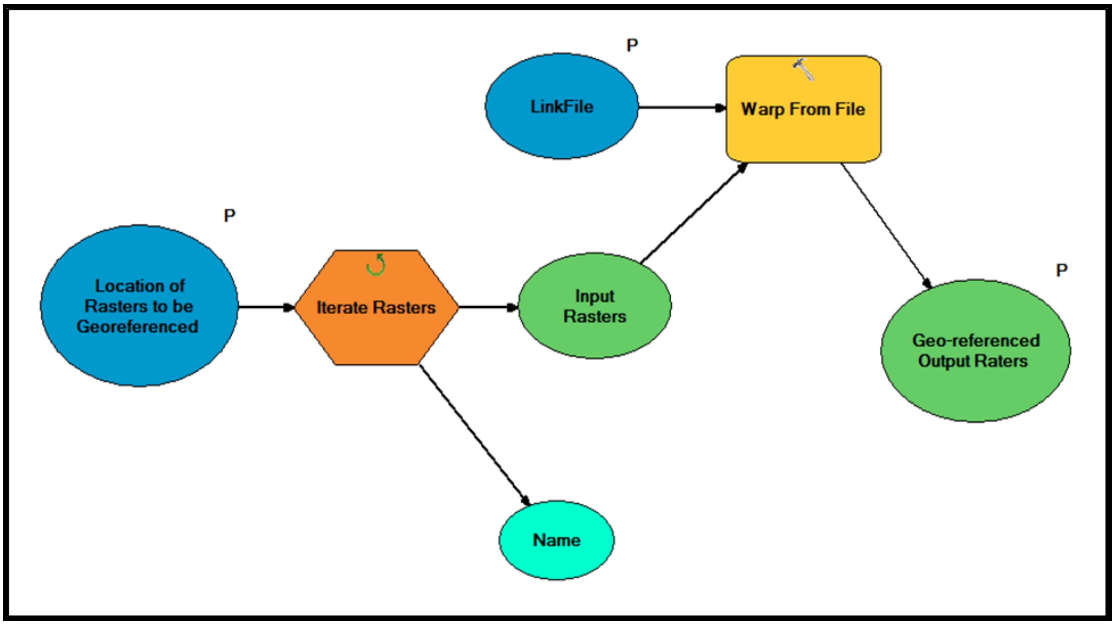

Figure 6: *Model for Batch Geo-Referencing*

6.5. Colour Coding

After geo-referencing the raster files, each file was opened in ArcGIS and displayed in pseudo colours and then the vector shape file (India Map) was overlaid. The final pseudo colour average soil moisture maps are shown in Figures 8, 9, 10 and 11. Since there are many maps and all maps should be coded with same colour and symbology, therefore for this purpose another model was developed in ArcGIS model maker for batch symbology shown in Figure 7.

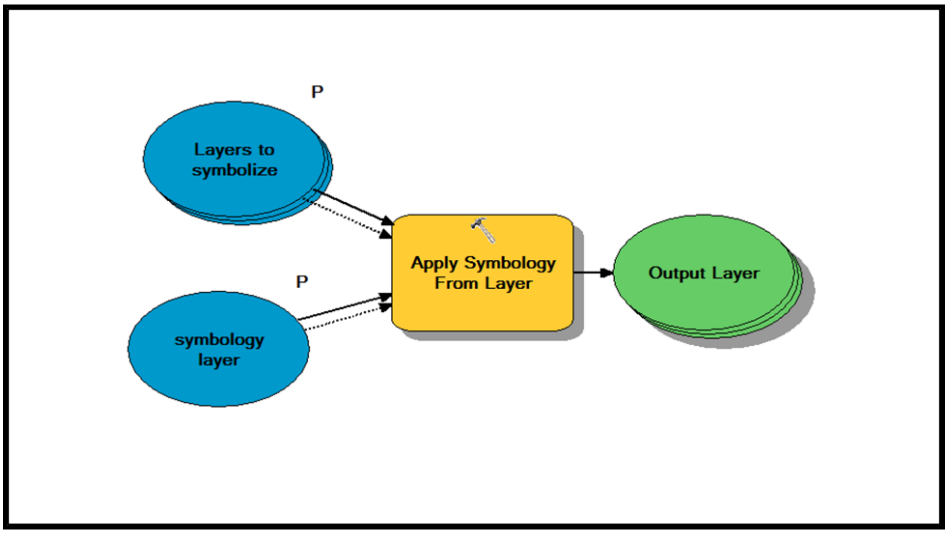

Figure 7: *Model for Batch Symbology*

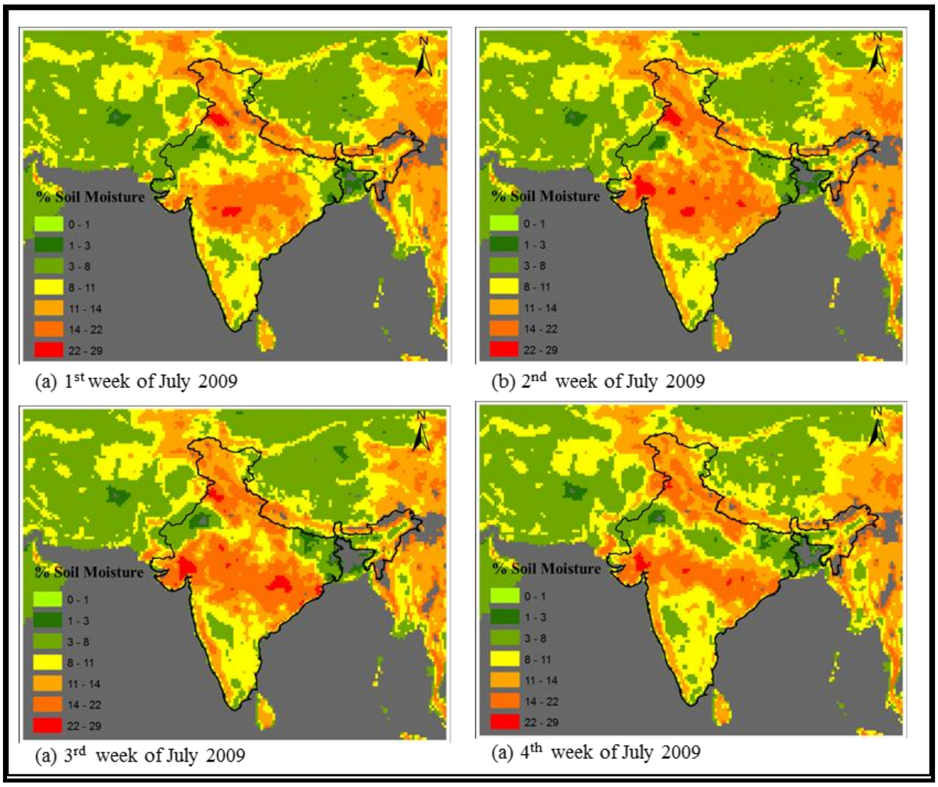

Figure 8: *Colour Coded Weekly Average % Soil Moisture Variations in July 2009 over Indian Sub-Continent Derived From AMSR-E*

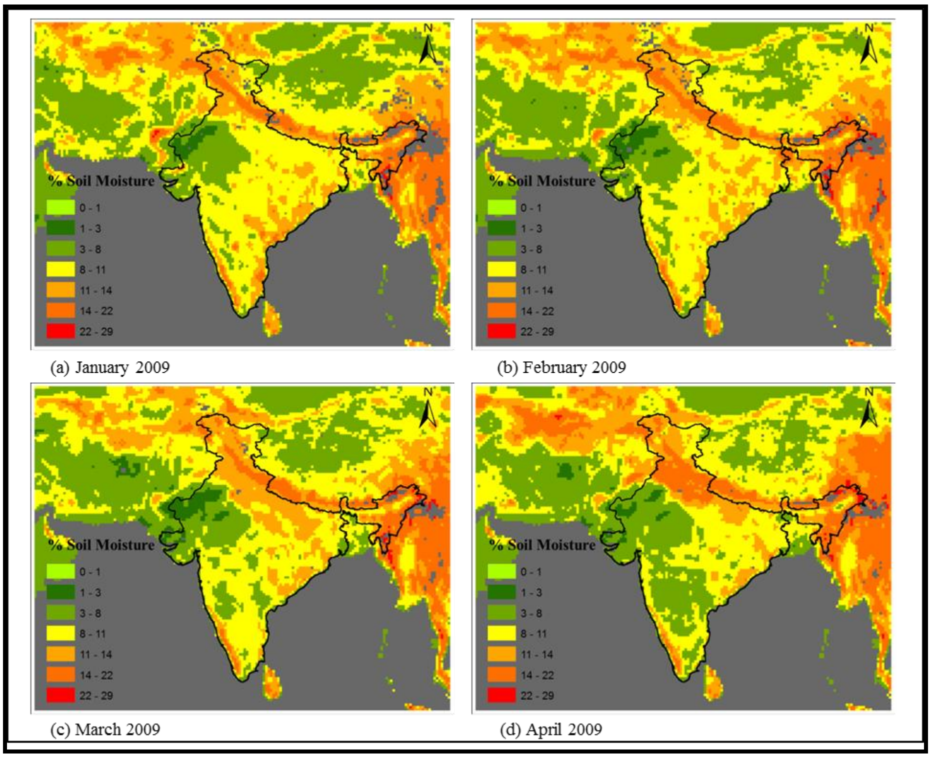

Figure 9: *Colour Coded Monthly Average % Soil Moisture Variations in 2009 over Indian Sub-Continent Derived from AMSR-E January 2009 to April 2009*

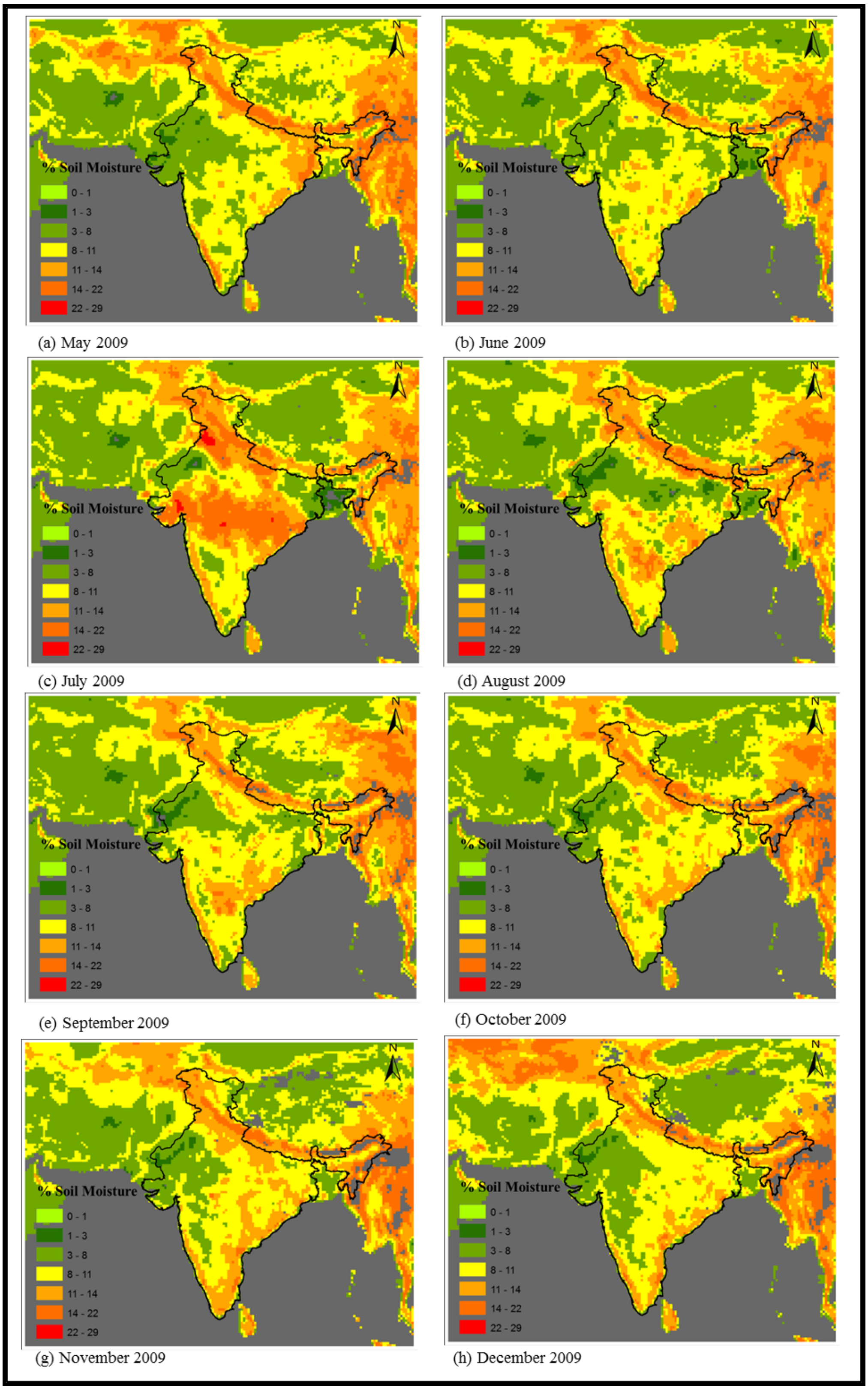

Figure 10: *Colour Coded Monthly Average % Soil Moisture Variations in 2009 over Indian Sub-Continent Derived from AMSR-E May 2009 to December 2009*

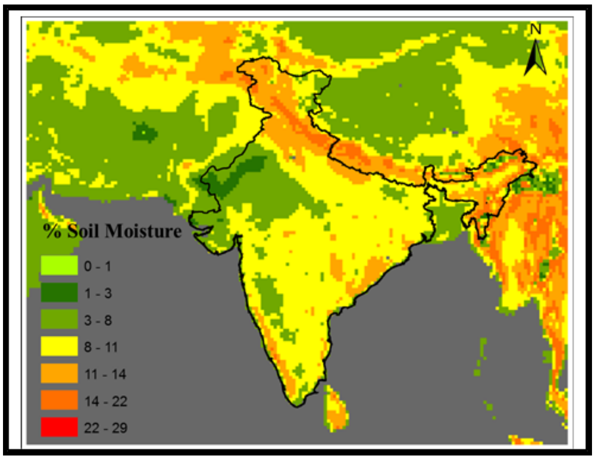

Figure 11: *Colour Coded Monthly Average % Soil Moisture Variations in 2009 over Indian Sub-Continent Derived from AMSR-E*

7. Results and Discussion

Figure 10 shows the monthly average soil moisture maps, for the period January 2009 to December 2009. The variation of soil moisture content over entire Indian subcontinent is mainly controlled by rainfall, seasons and agricultural practices adopted by farmers of different states. The maximum moisture content of the soil varies in the range 22% to 29% by volume. Although the values are significantly lower than the observed soil moisture values, which may be attributed due to the coarse resolution of AMSR-E sensor of the order of 56km which is resampled to a 25km resolution, due to this reason it is difficult to get pure pixels in agricultural areas. It has been observed that the soil moisture variation in the monthly temporal soil moisture maps of June, July and August are well explained on the basis of rainfall information. Soil moisture map of July indicates that 27% of total geographical area is under high soil moisture category of 14-22%. An interesting pattern can be observed in the maps that, northern part of the Indian sub-continent, i.e. Jammu and Kashmir, Himachal Pradesh & Uttarakhand, show soil moisture in 2 classes namely 11-14% and 14-22% throughout the year which can be attributed to, existence of more or less similar land cover conditions. Also the western part of the Indian sub-continent, Rajasthan region shows soil moisture towards the lower side, in 1-3% and 3-8% moisture classes majorly because large area is covered with sandy soil, which possesses low water holding capacity.

The variation in monthly rainfall can be explained with the help of temporal monthly soil moisture maps derived from AMSR-E. For example, it was observed from the rainfall data provided by Indian Meteorological Department, that an average rainfall of 345.80 mm occurred in the month of July, which was the highest rainfall in calendar year 2009. There is a considerable increase of 200.50% in rainfall in the month of July as compared to June from 115.06 mm to 345.80 mm; this is reflected in the soil moisture maps of June and July. The months June to September being the monsoon season show maximum rainfall and the similar variation is observed in the maps.

Table 2: *Average Monthly Rainfall Data for the Year 2009*

Months	Rainfall in mm
January	8.01
February	9.14
March	15.18
April	27.65
May	68.69
June	115.06

July	345.80
August	218.33
September	170.76
October	90.50
November	58.01
December	10.80

The average monthly rainfall data from Indian Meteorological Department (IMD) has been compiled in Table-II. An important aspect which must be considered here is that it is not possible to justify the monthly soil moisture variations highlighted in the soil moisture maps, blindly on the basis of seasons and rainfall. The reason being that even if the rainfall was less for example in the months of January to March, majority of irrigated area shows soil moisture in the range 8-11% and 11-14%, which are moderate soil moisture classes. This pattern can be attributed to the fact that irrespective of rainfall conditions, farmers of most of the irrigated areas used to irrigate their fields either through canal irrigation or by tube-wells. Another observation that AMSR-E derived soil moisture at places is not exactly matching with rainfall information, is supported by the fact that due to coarse-resolution cell of passive microwave sensor the large variation in the soil moisture on the ground is unable to be assessed [1]. In addition, mixed pixels due to large pixel size of AMSR-E also introduce error in soil moisture retrieval but research has verified the validity of AMSR-E data at 25 km resolution [1] which provides a platform for using AMSR-E data to understand spatial variability of soil moisture for large areas. However researchers have shown that accuracy of AMSR-E soil moisture data can be improved by incorporating vegetation/roughness parameter, g.

Data analysis revealed that for the entire year, approximately 2% of the total geographical area shows soil moisture less than 3%. Average soil moisture maps derived from AMSR-E indicate that for the months of January to June and September to December, geographical area ranging between 39% and 48% fall in the soil moisture category of 8% to 11%, which means majority portion of the Indian sub-continent shows moderate soil moisture except in the months of July and August which experienced highest rainfall in the year. Furthermore, 26.44% and 34.87% of geographical area in the months of July and August fall in the same soil moisture category as mentioned above. With the average rainfall of 8.01 mm, 9.14 mm and 15.18 mm in the months of January, February and March, 20.80%, 23.30% and 25.49% area respectively fall in soil moisture category of 11% to 14%. In the monsoon months of July to October, percentage of geographical area falling in the same soil moisture category increased considerably to 27.22%, 27.87%, 23.20%, & 23.66%, which can be justified by higher rainfall conditions. The category of 14% to 22% soil moisture, which is considered to be under high soil moisture category, is in close agreement with the occurred rainfall. Moreover since the rainfall in the months of January, February and March were very less, consequently only 7.80%, 8.07% and 6.9% of the total area during these months fall under 14% to 22% soil moisture category. A sudden increment in the percentage geographical area from approximately 6.90% to 11.76% in April can be attributed to the fact that there is a sudden jump in the rainfall from March to April. Similarly due to maximum rainfall in the month of July, 26.91% geographical area (i.e. highest area in this category of soil moisture) went to 14% to 22% soil moisture category. Likewise the gradual decrease in rainfall after July is well reflected as a decrease in percentage geographical area for the same soil moisture category.

8. Conclusion

During the course of this study efforts have been made to develop a detailed methodology for generation of average soil moisture maps of desired intervals (e.g. weekly/ monthly/ yearly etc.) over a very large geographical area like a continent or sub-continent. The proposed methodology is based upon the analysis of 730 AMSR-E scenes (365 scenes for the ascending pass and the same number of scenes for the descending pass) and has been well tested over Indian sub-continent for all the 365 days of the year 2009.

The main advantage of all the passive microwave sensors is their fine temporal resolution. This is in contrast with SAR sensors, which provide fine spatial resolution at the cost of temporal resolution. Therefore passive microwave sensors must be tested over a huge geographical area to fully exploit and demonstrate their capability of providing large coverage. Therefore in this study an attempt has been made to popularize the passive microwave data and its derived soil moisture products by selecting space-borne passive microwave radiometer (AMSR-E) over a large study area covering entire Indian sub-continent.

One of the major advantages of the proposed methodology is that a user can generate average soil moisture maps at desired intervals (e.g. weekly/ monthly /yearly etc.); this can significantly reduce the time and efforts of managers and decision makers. Monthly soil moisture maps generated by exploiting the developed methodology successfully explain the seasonal variation in soil moisture and confirm the soundness of the detailed methodology reported in this paper.

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