Validation of soil moisture derived from water balance method and satellite observation

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सार – इस अध्ययन में सामान्य जल संतुलन पद्धति तथा उपग्रह आँकड़ों का उपयोग करके पैन इंडिया मोड के अंतर्गत उच्च विभेदन मृदा नमी (एस एम) का आकलन किया गया है। इसका उद्देश्य मृदा नमी की गणना करना है और तदनंतर उसका सत्यापन जलवायविक सूचना के रूप में स्थानिक और कालिक पैमाने (डब्ल्यू सी) पर एस एम के वास्तविक आँकड़ों के साथ करना है। वर्ष 2013 के लिए इस मॉडल का सत्यापन शीत (जनवरी-फरवरी), मॉनसून पूर्व (मार्च-मई), मॉनसून (जून-सितम्बर) तथा मॉनसूनोत्तर (अक्तूबर-दिसम्बर) ऋतुओं के लिए किया गया है। विभिन्न ऋतुओं में 17 ग्राउंड स्टेशनों (396 युग्मित डाटासेट के लिए) से स्वस्थाने आँकड़ों के साथ मॉडल आकलनों की तुलना से 0.46 से 0.60 तक के बेहतर सहसंबंध गुणांक सामने आए। मॉनसून ऋतु के लिए मॉडल से आकलित एस एम तक उपग्रह एस एम की स्थानिक तुलना से भारत के अधिकांश भागों में बड़े सहसंबंध का पता चला है। भौगोलिक सूचना प्रणाली (जी आई एस) के साथ संयोजन में साप्ताहिक ग्रिडिड एस एम उच्च विभेदन उपग्रह एस एम के साथ सामान्य फॉर्म्यूलेशन और न्यूनतम सूचनाओं का उपयोग कर सकता है। एम एम का साप्ताहिक आधार पर आकलन किया जाता है तथा प्रस्तावित ब्लॉक स्तर की कृषि मौसम परामर्शी सेवाओं की बेहतर सटीकता के लिए ग्रिडिड वर्षा, स्थितिज वाष्पोत्सर्जन (पी ई टी) और फील्ड क्षमता (एफ सी) और मुरझाने (विल्टिंग) के बिंदु का उपयोग किया जा सकता है।

ABSTRACT. Under the present study estimation of high resolution soil moisture (SM) under Pan India mode using simple water balance method and from satellite data has been explored. It aims at the simple calculation of soil moisture followed by verification with ground truth data of SM on spatial and temporal scale (WC) as climatic input. The model has been verified for winter (January-February), pre-monsoon (March-May), monsoon (June-September) and post-monsoon (October-December) seasons of year 2013. The comparison of model estimates with the *in-situ* data from 17 ground stations (for 396 paired datasets) over different seasons produced a better correlation coefficient varying from 0.46 to 0.60. The spatial comparison of SM estimated from model and satellite SM for the monsoon season shows a greater degree of coherence over most parts of India. Model derived weekly gridded SM combined with higher resolution satellite SM could use simple formulation and minimum inputs in conjunction with geographic information system (GIS). The SM is calculated on weekly basis and using gridded rainfall, potential evapotranspiration (PET) and field capacity (FC) and wilting point be used for better accuracy of the proposed block level agrometadvisory services.

Key words – Soil water balance, Agromet advisories, Microwave soil moisture, GIS.

1. Introduction

Soil moisture is an important hydrological variable for climatic and agricultural modeling. It plays a critical role in governing water and energy balance between the land and atmosphere (Elfatih, 1998; Brubaker and Entekhabi, 1996; Brocca *et al.*, 2011). It is an important factor in crop water stress monitoring, water management studies and also as input data in various crop simulation and yield prediction models. The extreme events of floods and droughts are also strongly modulated by the soil moisture state of the landscape (Mohanty and Skaggs, 2001).The regular and national scale agro-meteorological monitoring requires retrieval or estimation land surface variables such as soil moisture to derive crop condition indicators to advise farming community on agricultural

TABLE 1

Selected ground observation stations for SWB model validation

Station	Soil texture	Climatic zones
Agra (27.10° E 78.05° N)	Sandy loam	Semi-arid
Basti (26.48° E 82.46° N)	Loam	Dry sub-humid
Bikaner (28.10° E 72.55° N)	Sand	Arid
Jammu (32.88° E 74.84° N)	Sandy loam	Dry sub-humid
Kalyani (22.57° E 88.20° N)	Silty clay	Moist sub-humid
Nagpur (21.06° E 79.06° N)	Clay loam	Dry sub-humid
Niphad (20.06° E 74.07° N)	Clay loam	Semi-arid
Sabour (25.14° E 87.04° N)	Clay loam	Dry sub-humid
Sagar (23.51° E 78.45° N)	Clay loam	Dry sub-humid
Udaipur (24.35° E 73.42° N)	Sandy loam	Semi-arid
Ludhiana (30.56° E 75.52° N)	Sandy loam	Semi-arid
Solapur (17.67° E 75.90° N)	Clay loam	Semi-arid
Pune (18.53° E 73.85° N)	Clay loam	Dry sub-humid
Bellary (15.15° E 76.85° N)	Clay loam	Semi-arid
Thrissur (10.31° E 76.13° N)	Sandy loam	Humid
Hissar (29.17° E 75.77° N)	Loam	Semi-arid
Karnal (29.72° E 76.97° N)	Loam	Dry sub-humid

operations and management. The SWB and water balance indices at a given location provides useful information on soil moisture storage, the period of water deficit and water surplus (Shweta and Krishna, 2014). The estimates of SWB are used for estimating probable length of growing season, irrigation needs (Droogers *et al.*, 2010), leaching of soils for salts (Maas and Hoffman, 1977), fluctuations in water table, drought hazards and soil water availability in different regions and for judging the agricultural potential of the region. The quantitative results obtained also can be utilized for agro meteorological applications.

A large part of India lies in the arid and semi-arid tract, where irrigation sources are limited; agricultural in these areas depends mainly on the distribution of rainfall. Erratic distribution of rainfall in these regions draws special attention to plan different strategies of crop production using stored water in the soil profile. Research studies to calculate soil moisture using soil water balance method, and its application to agriculture as well as hydrology have been carried previously by Adhikari *et al.*, 2004; Allen *et al.*, 1998; Ghadekar, 2003; Mehta *et al.*, 2006; Pascua, 2000; Sontakke *et al.*, 2008. In these studies, soil water balance parameters have been computed mostly on monthly basis for limited number of

stations. From the agricultural point of view, information of soil moisture on weekly basis, on a spatial scale would be highly useful to the scientific community, planners and other users. The weekly soil moisture data can also be utilized to plan suitable time of sowing of both *kharif* and *rabi* crops. The accurate spatial and temporal distribution of soil water content is essential in hydrology, climate and soil-vegetation interaction processes. The available SM is the upper layers of the soil are of much importance for crop sowing and crop health during the crop growing period. Site specific water content cannot be applicable over a regional scale (Westenbroek *et al.*, 2010). The soil water content calculated in gridded format using simple GIS data layers and climatological data layers are useful for regional studies. The development of such simple gridded soil water content information is extremely helpful to the proposed project Gramin Krishi Mausam Sewa (GKMS) launched by India Meteorological Department (IMD), Ministry of Earth Sciences (MoES) in the country under the 12th Five Year Plan to provide additional input for framing for the block level agromet advisory. The use of the modelled SM is to be verified for the use of agromet Advisories. In future the model and satellite SM product would be combined together for the proposed block level agromet advisory services. The
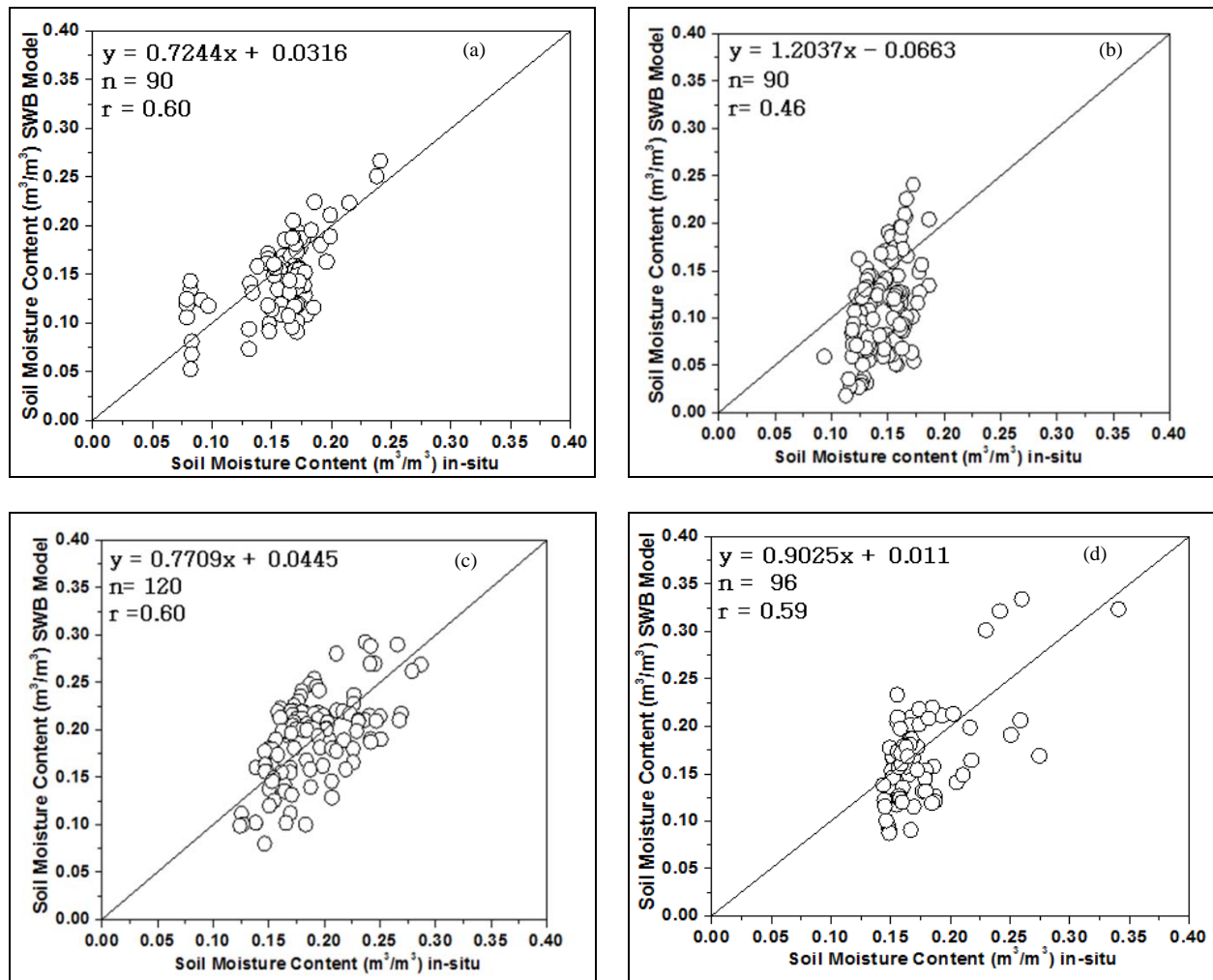
Figs. 1(a-d). Comparison of modeled SM with observed SM (a) Winter season (b) Pre-monsoon season (c) Monsoon season and (d) Post-monsoon season

objectives of this study are (*i*) To generate the weekly gridded maps of SM using water balance model over India (*ii*) its validation using the *in-situ* observations from soil moisture network stations and (*iii*) Spatial comparison of model and satellite SM

2.   Study area and data used

2.1.   *Study area*

Different agricultural regions spread over India were selected for *in-situ* soil moisture measurements to validate SWB moisture content estimates. The lists of these regions and their coordinates, as well as climatic characteristics are given in Table 1. The regions represent a wide variety of soil types. Observations in *rabi, kharif* and dry (bare soil) season were taken at these ground stations. At some of these stations, Cotton is generally is

grown as a rainfed crop in India. The other crops taken in the monsoon season (*kharif*) are rice, maze and gram. *Rabi* groundnut is grown in residual soil moisture conditions. The other *rabi* crops like wheat, mustard and gram are taken in post monsoon and winter seasons.

2.2.   *In - situ data*

2.2.1.   *Soil moisture content (SM)*

The list of stations from which *in-situ* soil moisture data observations used in this study are presented in Table 1. In India, there is a network of 42 soil moisture observatories which are collecting the soil moisture data. A quality check of the data was performed for each available station. Out of the 42 stations 17 available stations with different climatic conditions, cropping patterns and soil types were selected for this study.
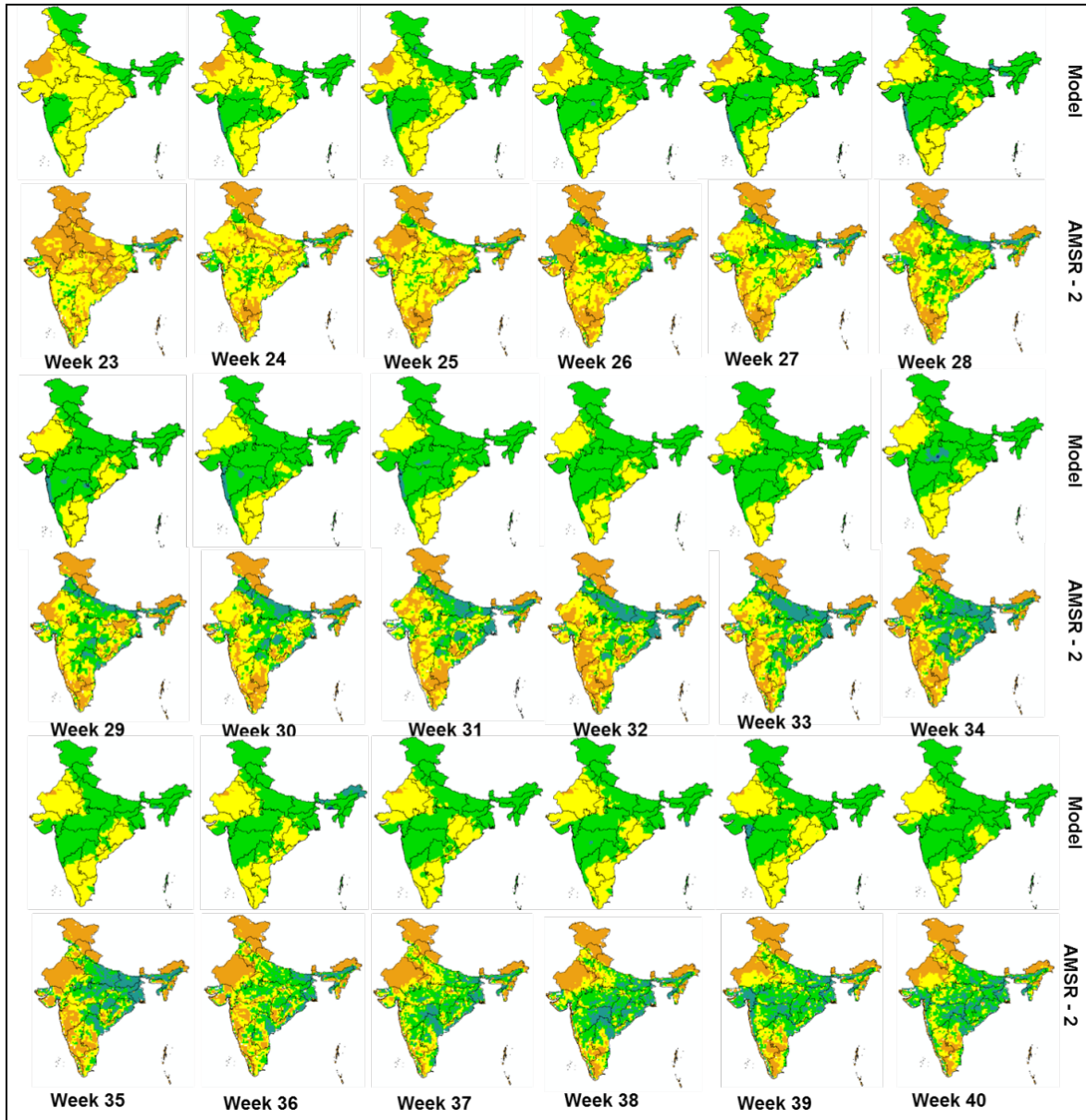
Fig. 2. Weekly comparison of modeled and AMSR -2 SM for monsoon season

The gravimetric method, also called the thermostat-weight technique (Robock *et al*., 2000), is used to measure soil moisture at these stations. Gravimetric methods of soil moisture estimation are the most widely used techniques and also considers standard for calibration of all other soil moisture determination techniques.

2.2.2. *Gridded rainfall*

The gridded rainfall data are being produced daily over India at a grid resolution of 0.25° × 0.25° through Shepard interpolation of measured rainfall from 6955 rain-gauge stations distributed over India(Rajeevan *et al*., 2006; Pai *et al*., 2013). The daily gridded rainfall data for 2013 areavailable from National Climate Centre (NCC), IMD Pune. The average weekly gridded data from daily files is computed for further analysis.

2.2.3. *Potential evapotranspiration (PET)*

Meteorological data on maximum and minimum temperature, morning and afternoon relative humidity, wind speed and bright sunshine hours for the

period (1971-2005) have been utilized from well distributed 144 locations in India for estimation of Potential Evapotranspiration (PET) by Penman-Monteith equation (Allen, 1998). Data of weekly PET have been utilized as input for computing weekly climatic SWB. The station wise climatological PET data for 144 stations were used from published work of IMD (2008).

2.3. *Satellite data*

2.3.1. *AMSR- 2 soil moisture*

The Advanced Microwave Scanning Radiometer 2 (AMSR-2) is a passive microwave sensor on-board the Japan Aerospace Exploration Agency (JAXA's) Global Change Observation Mission 1-Water (GCOM-W1) satellite launched in May 2012. It is the successor of the first passive microwave sensor, Advanced Microwave Scanning Radiometer for the Earth Observing System (AMSR-E) used widely for soil moisture retrieval (Koike *et al.*, 2004; Njoku *et al.*, 2003; Paloscia *et al.*, 2006). The surface soil moisture for the year 2013 from AMSR-2 is acquired from GCOM-W1 site (https://gcom-w1.jaxa.jp). The surface soil moisture content from AMSR-2 at 25 km ~ 0.25° is used for further spatial validation of the model SM.

3. Methodology

3.1. *Spatial interpolation of PET and FC*

PET and FC data from 144 stations were stored as point data in the GIS software. These point information were interpolated to prepare spatial raster layers of PET and FC. The interpolation technique provides values for any location in the region of interest. The kriging technique is adopted for creating the raster layers from point data in ArcGIS software. The grid size for both the layers was given to be $0.25° \times 0.25°$ corresponding to the gridded rainfall grid size. The spatial layer was projected to Geographic Lat./Long., WGS 84 projection. These weekly generated spatial layers of PET and FC were further used as inputs in the SWB model.

3.2. *Soil water balance model (SWB)*

The Soil water balance equation is used to determine the water stress or excess water content in the soil. A simple soil water balance has been computed weekly by water budgeting procedure based on the method of Thornthwaite and Mather (1955).The model is mentioned as simple as it requires knowledge of just three variables, field capacity (FC), rainfall (RF) and potential evapotranspiration (PET). The water budget components are calculated by comparing values for RF and PET. The

actual soil moisture (SM) was calculated using following two equations:

(*i*)   When RF exceeds PET

$$SM = RF - PET \tag{1}$$

(*ii*)   When PET exceeds RF

$$SM = (FC) \times e^{\frac{ACC(RF-PET)}{FC}} \tag{2}$$

Acc. (P- PET) is the accumulated potential water loss. FC is the field capacity per meter depth of soil.

The station wise PET was converted to a raster layer in GIS using simple interpolation method. The raster layer was prepared with same sample size of the gridded rainfall. The FC varies according to the soil type and soil texture at the given place. The soil texture at each PET station and ground observation station of SM was studied. Accordingly the raster layer of FC was generated. These raster layers along with the gridded rainfall were incorporated in equation 1 and 2 and SM content was calculated using GIS environment. The weekly spatial maps of average SM were generated for all the standard 52 weeks of 2013. The gravimetric data from the ground observations was converted to volumetric measurements using equation 3 to compare with the model SM.

$$SM_v = SM_g \times \frac{\rho_b}{\rho_w} \tag{3}$$

where, SM_v is volumetric SM and SM_g is ground observation data. ρ_b is the soil bulk density (*g* dry soil per cm^3 soil) and ρ_w is density of water (1 g water per cm^3 water).

In this study, the AMSR-2 soil moisture content, representative of a layer depth of ~ 5-10 cm is spatially compared spatial outputs of model SM. Pearson correlation coefficient, bias and root mean square deviation (RMSD) were used to compare the molded and *in-situ* SM. RMSD was used to underline that ground measurements may also contain errors (instrumental and representativeness) and, hence, they cannot be considered as the "true" SM.

4. Results and discussion

The modelled SM for all the seasons is compared with observed SM_v. A total of 396 paired datasets of observed and modelled SM over all the four seasons at available ground stations are compared. The modelled and

TABLE 2

Error analysis of modeled and observed soil water content

Season	n	RMSD	% MAD
Winter	90	21.31	-12.93
Pre-Monsoon	90	30.09	-22.69
Monsoon	120	20.83	-3.15
Post-Monsoon	96	23.89	-9.57

observed SM_v were categorized in winter, pre-monsoon, monsoon and post-monsoon season. The Figs. 1(a-d) represents the seasonal scatters of SM. In the winter season better correlation ($r = 0.60$) is observed between the modelled and *in-situ* data. In the pre-monsoon season the model estimated marginally larger SM as compared to the ground observation. The model did not perform well in the pre-monsoon (dry) season presenting a low correlation coefficient of 0.46. The scatter plot of monsoon and post monsoon seasons show a correlation coefficient $r = 0.60$ and $r = 0.59$ respectively. RMSD and MAD were calculated to compare the modeled and *in-situ* SM. The least RMSD of 20.83% with MAD of -3.15% was observed for monsoon season and maximum RMSD of 30.09% with MAD of -22.69% was in pre-monsoon season (Table 2).

The difference in the model and observed SM_v can be attributed to the difference in the spatial coverage. The gridded rainfall data also fails to show spatial variability as compared to the observed data. Moreover the static PET values used in the model along with generalized raster layer of FC can also lead to the error gap between modelled and observed SM_v. The irregularity of the ground observation data is also a general problem of the validation study.

In the present study spatial comparison of modeled SM with AMSR-2 satellite SM is performed for the monsoon season starting from first week of June (Standard week no. 23) to last week of September (Standard Week no. 40).The spatial variation in the both the SM content for the monsoon season is given in Fig. 2. The maps are categorized in to 4 classes depending on the available SM, very low (< 0.1), low (0.1-0.2), moderate (0.2-0.3) and high (> 0.3). The increasing SM area with the advancement of the monsoon season is clearly seen for the modeled and satellite outputs. The model shows higher values in the northern region as compared to the satellite SM. The western, central and gangetic plains of India show a moderate SM throughout the monsoon season in the model output. Whereas the satellite output show a

higher range of SM in the standard weeks from 32 to 39. The North western part and Southern part of India shows a very low and low SM in both the outputs. The model SM shows a limited variation as compared to satellite SM. The model is not able to detect the higher (>0.3) and lower (<0.1) range of SM. The use of common FC and saturation of PET and gridded rainfall values may have limited the SM variation in the model. However the model SM matches with the satellite SM over most part of India except area with higher satellite SM in the gangetic plains. The overall spatial pattern of low and moderate SM matches in both the outputs over the western, eastern and central region of India. The limited station PET and FC data over the northern hilly and eastern coastal region could be one of the reasons for the model to fail in these regions. Further analysis is required to improve the model SM. The AMSR-2 SM shows better spatial variation than the modeled SM.AMSR-2 SM needs to be further validated with the *in-situ* data from more stations, over different seasons for confirmation on the usability for agromet advisory services. Also the approach of integration of the modeled and satellite data can be established for the further improvement in estimated SM.

5.   Conclusions

The simple SWB model described above can prove to be a useful tool to calculate the available water content on a regional scale for agro-climatological analysis. The attempt made to use a simple agro meteorological model may not be a very accurate tool to calculate the different components of the crop water balance. However, the model can be used to give an idea on a regional scale to monitor the soil water budget and to provide agromet advisories for irrigation scheduling on a broad range. This simple model approach can be operationally implementable to generate weekly SM at regional-scale. However, some uncertainties in this model approach have been identified. The model is unable to distinguish between bare (uncovered) soil surface and vegetation. It distinguishes five soil texture classes, but does not differentiate between salt-affected soils and others. The

model gives no information on the runoff of the water surplus. In spite of these weaknesses, the present model makes possible the overall spatial estimation of SM. The use of static PET instead of near-real time PET and the limited number of PET stations in the northern hilly and eastern coastal region for preparation of raster layer could also be the possible reasons of the uncertainties. With the increased number of ground station network and ground truth data the results can be improved. At present agromet advisories are provided on district level. The integration of the high resolution satellite SM with the modelled SM can improve the outputs for block level agromet advisories. This integrated gridded information generated on country-wide SM status on a weekly basis will be helpful for planning and policy making related to agriculture and water resource development. Further scope of the study is the use of satellite data inputs in the SWB model to improve the results. The AMSR-2 and SMOS SM will be further integrated with the model SM to improve the results to provide high resolution outputs for block level advisories.

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