

Comparison of FAO56-PM ET_0 estimates using meteorological parameters retrieved from MERRA-2 satellite and ground dataset for the humid Dehradun region of India

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Abstract: This study was conducted with specific objective to compare ET_0 estimates obtained at monthly and cropping (Autumn, Spring and Summer) season timescales with climatic parameters retrieved from MERRA-2 satellite and ground meteorological dataset with standardized FAO56-PM model for humid Dehradun region of Uttarakhand (India). It was found that during 29 years study period, about 84.45% months resulted in very good correlation between FAO56-PM ET_0 estimates obtained with meteorological parameters retrieved from MERRA-2 satellite and ground dataset, while about 37.93% and 27.59% Autumn seasons were observed under Very Strong Positive and Strong Positive levels, respectively. Similarly, about 93.10% and 6.90% Spring seasons were obtained with Very Strong Positive and Strong Positive correlation coefficient values. For Summer season, about 93.10% seasons showed Very Strong Positive correlation coefficient values. About 99.71% months during study period extended good agreement in terms of agreement index. On cropping season basis, 55.17% Autumn, 62.07%, Spring, and 7.31% Summer seasons, respectively showed agreement index values with medium agreement.

Keywords: MERRA-2 satellite, reference evapotranspiration, humid, Dehradun, India.

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1 Introduction

The knowledge of evapotranspiration (ET), which involves evaporation of water from land surfaces and transpiration by vegetation, is essential to determine requirements for best irrigation water practices (Allen et al., 1998). It also accounts for a significant percentage of precipitation over the land surface. Historically, the term “evaporation” which was recorded in the sixteenth century covered transpiration

and water loss from plants, and the converse was also valid and the broad and indefinite use of these both words has persevered even in the scientific literature for more than 400 years. The FAO Penman-Monteith (FAO56-PM) approach was advised as “standard” because it reliably estimates evapotranspiration of an imaginary reference vegetated field (Allen et al., 1998).

For calculating evapotranspiration estimates, a number of available energy balance, mass transfer

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based, water budget, radiation-based and temperature-based equations create very problematic situation to select any individual and, therefore, the Food and Agricultural Organization of the United Nations proposed the Penman-Monteith model in its Irrigation and Drainage Paper No. 56, referred to as FAO56-PM model, as “standard” or “index” for determining reference evapotranspiration (ET_0) estimates from complete meteorological data (Chávez et al., 2008). This approach is advantageous as it doesn't require any additional parameter for final ET_0 estimation and its results are tested using lysimeters but there are many disadvantages like requirement of large amount of ground meteorological parameters which are normally not recorded at many places on account of no installation of meteorological stations and sometimes, the condition of already installed stations are very poor with equipment not in good conditions, especially in developing countries and due to which researchers face lot many problems for obtaining accurate evapotranspiration estimates. Therefore, now-a-days, researchers are leaning towards retrieval of remotely sensed data as they are available depending upon the passing time and passing location of satellites. Remote sensing (RS) is identified as an important tool supporting the management of natural resources and agricultural practices for wider spatial coverage. Thus, RS-based daily ET models better suit the estimation of crop water use at a regional agriculture scale (Allen et al., 2007; Chowdary et al., 2009; Muthuwatta et al., 2010). Recently, various methodologies have been developed to estimate regional ET using RS derived land and atmospheric variables. During past three decades, many studies on RS -based evapotranspiration evaluation have appeared. Fortunately, RS can give estimates of meteorological parameters required to calculate ET at distinguished scales. Over the last decade, useful improvement in dynamic atmospheric retrieval techniques from RS has been made.

There are many satellites which provide imagery to extract required data or meteorological parameters for

estimating ET_0 values of different locations from where they pass for specific time period parameters from them. Some of the examples include Landsat, National Oceanic and Atmospheric Administration (NOAA)-Advanced Very High-Resolution Radiometer (AVHRR), and the MODerate-resolution Imaging Spectro-radiometer (MODIS) and Meteosat. But, in general, cloud-free imagery from these satellites for all days in a year is not available. For getting information on energy and water balances on the land surface, such as albedo, land surface temperature, leaf area index, and surface soil moisture, wind speed, air temperature, air pressure, RH etc., satellite RS is a desirable technique as one can get required data by accessing available datasets impregnated into it or through satellite imageries.

In this era, the importance of technological development is increasing day-by-day and the importance of programming languages is growing in every field. Hence, many data platforms which provide different meteorological parameters free of cost in encrypted form can be easily extracted by programming languages like Python, R, SQL etc. These datasets accompanied with ground meteorological dataset helps in easy and accurate calculation of ET estimates.

Granger (1995, 1997) showed that the two major parameters namely, net radiation and vapour pressure deficit required for ET estimation could be easily derived from remotely sensed data. The data from visible and infrared channels of remote sensors can be used to determine surface albedo and land surface temperature, respectively. The net radiation can be estimated from surface albedo, and vapour pressure deficit can be estimated from the land surface temperature.

Thus, RS data extend advantages in the field of evapotranspiration as not at every place, meteorological station is available and maintained properly but satellites pass from almost all places, and it is an economical technique as there is not much requirement of skilled persons or any kind of

infrastructure with costly equipment. During past decades, several methods have been developed to estimate ET at large scale by combining remotely sensed data with conventional meteorological ground data which vary in complexity. Remote sensors provide information on reflected solar radiation and surface temperatures, and remaining variables in energy balance equations can be measured at ground level, estimated, modelled or ignored.

Across the globe, a number of research workers (Granger, 1997; Jiang and Islam, 1999; Jiang and Islam, 2001; Rivas and Caselles, 2004; Batra et al., 2006; Venturini et al., 2006; Wang et al., 2006; Bois et al., 2008; Ryu et al., 2008; Bisht and Bras, 2010; Maeda et al., 2011; Farg et al., 2012; Carmona et al., 2015; Reyes-González et al., 2018) determined land surface temperature; instantaneous, daily and daytime average net radiation; evaporative fraction; components of land surface radiation; solar radiation; crop coefficients; RH; air temperature; wind speed; vegetation index; soil moisture; vapour pressure deficit and estimated surface evaporation, Normalized Difference Vegetation Index, while some of them created surface evaporation map with the help of AVHRR and MODIS sensors onboard NOAA14, NOAA16, Landsat 5 TM, Landsat 7 ETM+, Landsat 8, SMOS SPOT-4 and EOS-Terra satellites along with ASTER and MODIS datasets.

A lot many researchers (Price, 1990; Rivas and Caselles, 2004; Bisht et al., 2005; Nagler et al., 2005; Singh et al., 2005; Wang et al., 2005; Batra et al., 2006; Cleugh et al., 2007; Glenn et al., 2007; Tsouni et al., 2008; Wang et al., 2008; Liu et al., 2010; Tang et al., 2010; Anderson et al., 2011; Elhag et al., 2011; Papadavid et al., 2011; Zhan et al., 2011; Anderson et al., 2012; Du and Sun, 2012; Farg et al., 2012; Nagler et al., 2013; Papadavid et al., 2013; El-Shirbeny et al., 2014; Matinfar and Soorghali, 2014; Mo et al., 2015; Westerhoff, 2015; Jaber et al., 2016; Jana et al., 2016; Minacapilli et al., 2016; Goroshi et al., 2017; Knipper et al., 2017; Najmaddin et al., 2017; Wagle and Gowda, 2019; Ghaderi et al., 2020; Le et al., 2020; Park et al.,

2021) also calculated regional evaporation, daily, monthly & annual evapotranspiration, regional evapotranspiration, spatially distributed regional actual evapotranspiration, spatial reference evapotranspiration, riparian and agricultural evapotranspiration; surface longwave radiation of various natural objects viz., vegetation, soil, sand, etc., checked accuracy of actual daily evapotranspiration estimated by RS algorithms against Bowen ratio measurements, applied surface temperature-vegetation index triangle method to estimate regional evapotranspiration using MODIS-TERRA data, estimated daily forest evapotranspiration (ET_d), daily crop evapotranspiration (ET_c), actual crop evapotranspiration (ET_a), land surface ET and estimated ET_0 over wide areas including agricultural districts, rangelands, and natural ecosystems, while some of them analysed long-term ET trend, determined soil moisture products and evaluated drought characteristics. Gleason et al. (2002) studied the effect of orbital drift on land surface temperature, and brightness temperature obtained from NOAA-AVHRR.

By using remotely sensed satellite data, spatially distributed maps of evaporative fraction (ratio of evapotranspiration to available radiant energy), net radiation and daily evapotranspiration maps were also being developed by Batra et al. (2006), Venturini et al. (2006), Jiang et al. (2009) and Elhag et al. (2011), while Mu et al. (2007) improved MODIS global terrestrial evapotranspiration algorithm.

From the above, it is evident that throughout the globe, several researchers attempted to derive climatic parameters from remotely sensed data for calculating evapotranspiration values, but no information for Indian conditions, particularly for humid subtropical regions is available. Keeping this point into consideration, present work was undertaken by taking a distinct approach to estimate ET_0 values using standard FAO56-PM model with meteorological parameters retrieved from MERRA-2 satellite. An effort was, therefore, undertaken through this work to

compare MERRA-2 parameters-based FAO56-PM ET_0 estimates with that of ground meteorological dataset. The effectiveness of proposed technique will be evaluated in terms of how closely they correspond to ground-based point observations and in terms of their capacity to calculate FAO56-PM ET_0 estimates using them.

2 Materials and methods

2.1 Description of study area and meteorological dataset

The study was carried out for the humid subtropical Dehradun district (78.0154°E longitude, 30.3454°N latitude) of Uttarakhand State as study area which experiences an average annual rainfall of about 1600 mm. The months of May and early part of June are hottest with maximum temperature of about 42°C, while winter starts from November which lasts up to February.

2.1.1 Ground meteorological dataset

The standardized FAO56-PM model for estimating ET_0 values require different meteorological parameters like air temperature (maximum and minimum), sunshine hours, RH (maximum and minimum), wind speed etc. The daily meteorological dataset for Dehradun district for a period of 29 years (1991-2019) was obtained from India Meteorological Department, Pune. The study was conducted on monthly and cropping season basis and collected daily meteorological dataset was classified into 12 individual months (Jan-Dec) and cropping seasons (Autumn, Spring and Summer) in accordance with CWS-1 format suggested by India Meteorological Department, Pune. Before undertaking analysis, quality control of daily weather dataset was ensured by detecting missing data and outliers.

2.1.2 Satellite data

The satellite used for present study was Modern-Era Retrospective analysis for Research and Applications version 2 (MERRA-2), which is the latest version of global atmospheric reanalysis for the satellite era, produced by NASA Global Modeling and

Assimilation Office using the Goddard Earth Observing System Model (GEOS) v 5.12.4. The dataset covers period from 1980 to present with a latency of ~3 weeks after the end of a month. Moreover, datasets in file form are easy to extract in comparison to that from imagery. The major advantage to use this satellite is that the required data for computation purpose becomes available directly in the form of data files. The same standard CWS-1 format suggested by India Meteorological Department, Pune was adopted for all meteorological parameters derived from MERRA-2 satellite. Some of the advantages of using MERRA-2 satellite among different satellites includes, (i) no need to extract data from imagery, which is a time consuming and hectic process as it contains files in netCDF4 format which can be converted to Microsoft™ Excel® format by using programming language, (ii) satellite imagery provides data only from clear sky days but in case of MERRA-2 satellite, dataset for each and every individual day is available, and (iii) MERRA-2 satellite is not location-specific as meteorological parameters can be retrieved for any location by entering their coordinates (latitude and longitude). Some limitations in using MERRA-2 satellite includes, (i) values of meteorological parameters retrieved from MERRA-2 satellite cannot be used directly as it requires knowledge of programming language, like python as it is available in netCDF4 format, which cannot be opened in commonly used Microsoft™ Excel® directly, (ii) downloading of required files for each individual day of every year is hectic, and (iii) sometimes, values of meteorological parameters retrieved from MERRA-2 satellite can be on weaker side and, therefore, for obtaining at par FAO56-PM estimates, values of all retrieved parameters are firstly need to be cross-checked and validated with observed ground meteorological dataset.

To retrieve meteorological dataset from MERRA-2 Satellite, registration to its official website is required and later, required datasets are to be accessed. For this study, two datasets were used to fulfil the

requirement of different parameters to calculate reference evapotranspiration values. The first set included parameters like wind speed and air temperature, while second set included longwave radiation (upward and downward), shortwave radiation, surface Albedo, etc. The required dataset was downloaded in the following manner: (a) At first, required dataset was opened in GES DISC website. (b) Then by clicking options subset/get data, different options in series were adopted. The “Refine date range” option was selected to define study period and as data for 1991/01/01 to 2019/12/31 was required, the same was selected. Then, to refine study region (i.e., Dehradun), its coordinates were entered. Now, different variables were selected according to meteorological parameters required to calculate ET_0 values.

2.1.3 Software used

Microsoft® Excel™ was used for calculation and comparison purposes. Anaconda Navigator (Anaconda 3) is a Graphical User Interface which allows managing and launching various packages. A Command Line Interface was used in this study as one of the main components for extracting required meteorological parameters from MERRA-2 satellite. The netCDF4 files downloaded from MERRA-2 satellite dataset were extracted by using the code written in python language. The Spyder was used to run the code in simplest way where code was written and executed. It is a very popular combination of code, descriptive text, images, output, and interactive interface which can be edited, used, and viewed simultaneously.

2.1.4 Converting netCDF4 files to Microsoft® Excel™ files

The data files downloaded from MERRA-2 satellite were in netCDF4 format and, therefore, to access these files in Microsoft® Excel™, they were converted by using python programming language as the amount of dataset was very large and files with netCDF4 extension is not opened by general Microsoft applications (i.e., Excel). Further, required dataset was

accessed with Microsoft® Excel™ (.csv) extension by opening concerned files in the software and a new module was created by right-clicking on files by executing the code written in python language for different meteorological parameters as for albedo, shortwave radiation, upward longwave radiation, incoming longwave radiation, air pressure, air temperature and wind speed, ALBEDO, SWGDN, LWGEM, LWGAB, PS, TLML and SPEEDLML were used, respectively. The code written in python language used for extracting the files need some changes which depends upon location, meteorological parameters etc. e.g., for selected locations, its coordinates were entered in the code and for different parameters, their corresponding name codes were renamed e.g., to extract air pressure data, ‘PS’ was used.

2.3 FAO56-PM model for Reference evapotranspiration estimation

The models for water balance and irrigation scheduling include evapotranspiration as a key component. The FAO56-Penman-Monteith (FAO56-PM) model has been identified as standard for evaluating reference evapotranspiration (ET_0) on the recommendations of the Task Committee of the American Society of Civil Engineers and the Food and Agriculture Organization (FAO) of the United Nations as it provides ET_0 values closely to actual evapotranspiration measured in a wide range of locations and climatic conditions. The Irrigation and Drainage Paper No. 56 “Crop Evapotranspiration-Guidelines for Computing Crop Water Requirements” was introduced in 1998 by the Food and Agriculture Organization of the United Nations (generally called as FAO56) to revise guidelines for computing crop water requirements. The recommended form of FAO56-PM model consisting of aerodynamic and surface resistance terms (Allen et al., 1998) is presented as Equation 1:

$$ET_0 = \frac{0.408\Delta(R_n - G) + \gamma \left(\frac{900}{T_{mean} + 273} \right) U_2 (e_s - e_a)}{\Delta + \gamma (1 + 0.34 U_2)} \quad (1)$$

Where ET_0 is reference evapotranspiration, mm d

¹; Δ is slope of vapour pressure curve, kPa °C⁻¹; R_n is net radiation at crop surface, MJ m⁻² d⁻¹; G is soil heat influx density, MJ m⁻² d⁻¹; γ is psychrometric constant, kPa °C⁻¹; T_{mean} is mean daily air temperature, °C; U_2 is wind speed at 2 m height, m s⁻¹; e_s is saturation vapour pressure, kPa; e_a is actual vapour pressure, kPa; and $e_s - e_a$ is saturation vapour pressure deficit, kPa.

As values obtained from satellite data shall not contain direct measurement of meteorological parameters and, therefore, required values were calculated with the help of following direct or empirical relationships:

Net radiation (R_n): Net radiation is a key parameter in computing ET_0 values and is a driving force in many other physical and biological processes (Rosenberg et al., 1983). However, as it was very challenging to assess the value of net radiation directly from MERRA-2 satellite, the methodology used directly obtained values of shortwave radiation (R_s), net longwave radiation (R_{nl}), and albedo (α). The standard relationships prescribed in FAO56-PM handbook were used to calculate net radiation values. Details of parameters used to estimate net radiation are:

Net longwave radiation (R_{nl}): It is basically the difference between outgoing longwave radiation ($R_{l,up}$) and incoming longwave radiation ($R_{l,down}$). From MERRA-2 dataset, with direct availability of both $R_{l,up}$ and $R_{l,down}$, value of net longwave radiation (R_{nl}) was calculated by using relationship:

$$R_{nl} = R_{l,up} - R_{l,down} \quad (2)$$

Where R_{nl} is net longwave radiation (MJ m⁻² d⁻¹), $R_{l,up}$ is emitted or outgoing longwave radiation (MJ m⁻² d⁻¹), and $R_{l,down}$ is absorbed or incoming longwave radiation (MJ m⁻² d⁻¹).

Albedo (α) and Net Solar radiation (R_{ns}): Albedo is the portion of solar radiation which is reflected back by the Earth's surface and its value varies for different surfaces. For the present study, the value of albedo from MERRA-2 satellite was obtained directly on hourly basis.

Net solar radiation (R_{ns}): It is the component of radiation which is not reflected by the surface and its

value in MJ m⁻² d⁻¹ was estimated by using relationship between albedo and shortwave radiation, expressed as:

$$R_{ns} = (1 - \alpha) \times R_s \quad (3)$$

Similarly, computation of net radiation from data retrieved from MERRA-2 satellite was done as:

$$R_n = (R_{ns} - R_{nl}) \quad (4)$$

Where R_n is net radiation (MJ m⁻² d⁻¹), R_{ns} is net solar radiation (MJ m⁻² d⁻¹), and R_{nl} is net longwave radiation (MJ m⁻² d⁻¹).

Soil heat flux (G): As the magnitude of soil heat flux beneath grass reference surface for a day or ten-days is relatively small, it may be ignored (Allen et al., 1998) and, thereby, the value of "G" in present study was taken as zero.

Air temperature (T_a): The value of air temperature (Kelvin) directly obtained from MERRA-2 satellite was converted to degrees centigrade (°C) by using standard conversion formula.

Wind speed (U_2): The value of wind speed was obtained directly from MERRA-2 satellite at 10m height (Veste et al., 2020) and, therefore, for calculating FAO56-PM ET₀ estimates, wind speed was converted to 2m height using standard conversion formula.

Relative humidity (RH): It is one of the important factors for determining evapotranspiration. The sun's energy and surrounding air act as main factors responsible for vapour formation from water. As RH data obtained from MERRA-2 satellite was on very weaker side, corresponding ground meteorological dataset of RH for concerned period was used to compute evapotranspiration values.

Saturation vapour pressure (e_s), actual vapour pressure (e_a), saturation vapour pressure deficit ($e_s - e_a$), and slope of saturation vapour pressure curve (Δ): The values of saturation vapour pressure, actual vapour pressure, saturation vapour deficit and slope of saturation vapour pressure curve were estimated by using standard formulae prescribed in FAO56 handbook.

Psychrometric constant (γ): Its direct value (in kPa) obtained through MERRA-2 satellite was used for the

calculation purpose.

2.4 Statistical indices

Three statistical indices namely, correlation coefficient (r), agreement index (d), and confidence index (c) were used to compare FAO56-PM ET_0 estimates using ground meteorological dataset and the MERRA-2 satellite parameters by using MicrosoftTM Excel[®] as computing tool. The pertinent details of these considered statistical indices are:

Correlation coefficient (r): This statistical concept helps to understand a relationship between observed and predicted values through statistical analysis. Its value explains how well observed and predicted values match with each other. The value of “r” is always in between -1 and +1. The range of correlation coefficient values and their corresponding level of correlation adopted in the present work is on the basis of Meghanathan (2016), as mentioned in Table 1.

Agreement index (d): This index was introduced by Willmott (1981) and is a standardized estimate of the degree of predicted model error and varies between 0 and 1. Any estimated value which is “1” or “close to 1” indicate a perfect match, while its value closer to “0” or “equal to 0” indicate that predicted value has no agreement at all with the observed value.

Table 1 Levels of correlation coefficient corresponding to range of correlation coefficient values

Correlation coefficient range	Level of correlation
0.80 to 1.00	Very strong positive (VSP)
0.60 to 0.79	Strong positive (SP)
0.40 to 0.59	Moderate Positive (MP)
0.20 to 0.39	Weak positive (WP)
0.00 to 0.19	Very Weak Positive (VWP)

Table 2 Performance criterion for different ranges of Agreement index values

Agreement index range	Performance
0.75 to 1.00	Good Agreement (GA)
0.50 to 0.75	Medium Agreement (MA)
0.25 to 0.50	Moderate Agreement (MDA)
0.00 to 0.25	Poor Agreement (PA)

The range of agreement index (d), considered in this study are presented in Table 2.

Confidence index (c): This index is introduced by

de Camargo and Sentelhas (1997) as product of correlation coefficient (r) and agreement index (d), expressed mathematically as; $c = r \times d$. The criteria for interpreting confidence index values, used in this study are shown in Table 3. The computational form of considered statistical indices are presented in Table 4.

Table 3 Performance criterion for different ranges of Confidence index values

Confidence index range	Performance
> 0.85	Best (B)
0.76 to 0.85	Very Good (VG)
0.66 to 0.75	Good (G)
0.61 to 0.65	Fair (F)
0.51 to 0.60	Bad (BD)
0.41 to 0.50	Very Bad (VB)
≤ 0.40	Worst (W)

Table 4 Computational form of considered statistical indices

Statistical index	Notation	Computational form	Eq. No.
Correlation coefficient	r	$\sqrt{1 - \frac{\sum_{i=1}^n (O_i - P_i)^2}{\sum_{i=1}^n (O_i - \bar{O})^2}}$	(5)
Agreement index	d	$1 - \frac{\sum_{i=1}^n (O_i - P_i)^2}{\sum_{i=1}^n (P_i - \bar{O} + O_i - \bar{O})^2}$	(6)
Confidence index	c	$r \times d$	(7)

Note: O_i = FAO-56 PM ET_0 (mm d⁻¹), P_i = predicted value of ET_0 (mm d⁻¹) obtained with MERRA-2 satellite data, \bar{O} = mean of FAO-56 PM ET_0 (mm d⁻¹), \bar{P} = mean of ET_0 (mm d⁻¹) obtained with MERRA-2 satellite data, n = total number of observations.

3 Results and discussion

3.1 Comparison of monthly FAO56-PM ET_0 estimates obtained from MERRA-2 satellite parameters against ground meteorological dataset

The comparison of FAO56-PM ET_0 estimates obtained from MERRA-2 satellite parameters (considered as predicted values) against ground meteorological dataset (considered as observed values) evaluated on monthly (Jan-Dec) and cropping season (Autumn, Spring and Summer) basis in terms of three statistical indices namely, correlation coefficient (r), agreement index (d) and confidence limit (c) for a period of 29 years (1991-2019) for Dehradun district is presented in Tables 5&6, 7&8 and 9&10, respectively.

Table 5 Variation and summary of correlation coefficient observed between FAO56-PM ET₀ estimates obtained using MERRA-2 satellite parameters and ground meteorological dataset on monthly basis

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
1991	0.86 (VSP)	0.83 (VSP)	0.97 (VSP)	0.92 (VSP)	0.52 (MP)	0.69 (SP)	0.62 (SP)	0.93 (VSP)	0.89 (VSP)	1.00 (VSP)	0.88 (VSP)	0.63 (SP)
1992	0.74 (SP)	0.90 (VSP)	0.88 (VSP)	0.95 (VSP)	0.75 (SP)	0.86 (VSP)	0.88 (VSP)	0.85 (VSP)	0.40 (MP)	0.95 (VSP)	0.85 (VSP)	0.34 (WP)
1993	0.97 (VSP)	0.28 (WP)	0.71 (SP)	0.97 (VSP)	0.62 (SP)	0.96 (VSP)	0.92 (VSP)	0.99 (VSP)	0.99 (VSP)	0.97 (VSP)	0.87 (VSP)	0.89 (VSP)
1994	0.77 (SP)	0.97 (VSP)	0.99 (VSP)	0.97 (VSP)	0.71 (SP)	0.76 (SP)	0.17 (WP)	0.23 (WP)	0.40 (MP)	0.97 (VSP)	1.00 (VSP)	0.93 (VSP)
1995	0.79 (SP)	0.45 (MP)	0.94 (VSP)	0.97 (VSP)	0.96 (VSP)	0.99 (VSP)	0.60 (SP)	0.95 (VSP)	0.95 (VSP)	0.97 (VSP)	0.97 (VSP)	0.88 (VSP)
1996	0.92 (VSP)	0.93 (VSP)	0.96 (VSP)	0.93 (VSP)	0.71 (SP)	0.86 (VSP)	0.63 (SP)	0.88 (VSP)	0.98 (VSP)	0.94 (VSP)	0.97 (VSP)	0.36 (WP)
1997	0.85 (VSP)	1.00 (VSP)	0.59 (MP)	0.91 (VSP)	0.92 (VSP)	0.60 (MP)	0.87 (VSP)	0.43 (MP)	0.24 (WP)	0.86 (VSP)	0.94 (VSP)	0.50 (MP)
1998	0.31 (WP)	0.04 (VWP)	0.92 (VSP)	0.90 (VSP)	0.97 (VSP)	0.91 (VSP)	0.76 (SP)	0.91 (VSP)	0.95 (VSP)	0.92 (VSP)	0.23 (WP)	0.86 (VSP)
1999	0.97 (VSP)	0.58 (MP)	0.92 (VSP)	0.95 (VSP)	0.82 (VSP)	0.94 (VSP)	0.48 (MP)	0.65 (SP)	0.34 (WP)	0.71 (SP)	0.98 (VSP)	0.83 (VSP)
2000	0.81 (VSP)	0.83 (VSP)	0.85 (VSP)	0.93 (VSP)	0.43 (MP)	0.84 (VSP)	0.94 (VSP)	0.67 (SP)	0.57 (MP)	0.86 (VSP)	0.50 (MP)	0.84 (VSP)
2001	0.96 (VSP)	0.94 (VSP)	0.98 (VSP)	1.00 (VSP)	0.96 (VSP)	0.36 (WP)	0.20 (WP)	0.24 (WP)	0.13 (VWP)	0.91 (VSP)	0.92 (VSP)	0.92 (VSP)
2002	0.80 (VSP)	0.87 (VSP)	0.99 (VSP)	0.97 (VSP)	0.79 (SP)	0.90 (VSP)	0.54 (MP)	0.41 (MP)	0.85 (VSP)	0.65 (SP)	0.12 (VWP)	0.02 (VWP)
2003	0.52 (MP)	0.77 (SP)	0.94 (VSP)	0.92 (VSP)	0.94 (VSP)	0.94 (VSP)	0.66 (SP)	0.14 (VWP)	0.38 (WP)	0.98 (VSP)	0.90 (VSP)	0.66 (SP)
2004	0.76 (SP)	0.93 (VSP)	0.86 (VSP)	0.60 (SP)	0.98 (VSP)	0.46 (MP)	0.90 (VSP)	0.67 (SP)	0.96 (VSP)	0.96 (VSP)	0.96 (VSP)	0.65 (SP)
2005	0.18 (VWP)	0.95 (VSP)	0.98 (VSP)	0.02 (VWP)	0.94 (VSP)	0.99 (VSP)	0.19 (WP)	0.96 (VSP)	0.96 (VSP)	0.98 (VSP)	0.86 (VSP)	0.82 (VSP)
2006	0.72 (SP)	0.96 (VSP)	0.96 (VSP)	0.96 (VSP)	0.96 (VSP)	1.00 (VSP)	0.99 (VSP)	0.74 (SP)	0.12 (VWP)	0.99 (VSP)	0.87 (VSP)	0.34 (WP)
2007	0.85 (VSP)	0.98 (VSP)	0.94 (VSP)	0.93 (VSP)	0.92 (VSP)	0.83 (VSP)	0.91 (VSP)	0.78 (SP)	0.70 (SP)	0.89 (VSP)	0.69 (SP)	0.45 (MP)
2008	0.00 (VWP)	0.86 (VSP)	0.42 (MP)	0.85 (VSP)	0.43 (MP)	0.43 (MP)	0.54 (MP)	0.20 (WP)	0.72 (SP)	0.25 (WP)	0.90 (VSP)	0.53 (MP)
2009	0.97 (VSP)	0.95 (VSP)	0.22 (WP)	0.98 (VSP)	0.13 (VWP)	0.85 (VSP)	0.82 (VSP)	0.18 (WP)	0.94 (VSP)	0.37 (WP)	0.51 (MP)	0.87 (VSP)
2010	0.18 (VWP)	0.72 (SP)	0.99 (VSP)	0.71 (SP)	0.61 (SP)	0.87 (VSP)	0.28 (WP)	0.99 (VSP)	0.05 (VWP)	0.94 (VSP)	0.88 (VSP)	0.89 (VSP)
2011	0.22 (WP)	0.25 (WP)	0.93 (VSP)	0.93 (VSP)	0.53 (MP)	0.98 (VSP)	0.55 (MP)	0.45 (MP)	0.81 (VSP)	1.00 (VSP)	0.92 (VSP)	0.90 (VSP)
2012	0.96 (VSP)	0.98 (VSP)	0.79 (VSP)	0.86 (VSP)	0.99 (VSP)	0.84 (VSP)	0.79 (SP)	0.81 (VSP)	0.10 (VWP)	0.99 (VSP)	0.88 (VSP)	0.74 (SP)
2013	0.29 (WP)	0.94 (VSP)	0.95 (VSP)	0.84 (VSP)	0.25 (WP)	0.77 (SP)	0.15 (WP)	0.34 (WP)	0.67 (SP)	0.77 (SP)	0.48 (MP)	0.87 (VSP)
2014	0.32 (WP)	0.66 (SP)	0.83 (VSP)	0.94 (VSP)	0.73 (SP)	0.94 (VSP)	0.72 (SP)	0.34 (WP)	0.72 (SP)	0.88 (VSP)	0.80 (VSP)	0.48 (MP)
2015	0.00 (VWP)	0.00 (VWP)	0.92 (VSP)	0.91 (VSP)	0.93 (VSP)	0.92 (VSP)	0.02 (VWP)	0.99 (VSP)	0.85 (VSP)	0.99 (VSP)	0.05 (VWP)	0.69 (SP)
2016	0.94 (VSP)	0.98 (VSP)	0.99 (VSP)	0.97 (VSP)	0.93 (VSP)	0.00 (VWP)	0.27 (WP)	0.43 (MP)	0.91 (VSP)	0.92 (VSP)	0.45 (MP)	1.00 (VSP)
2017	0.99 (VSP)	0.92 (VSP)	1.00 (VSP)	0.77 (SP)	0.52 (MP)	0.65 (SP)	0.39 (WP)	0.04 (VWP)	0.95 (VSP)	0.93 (VSP)	0.66 (SP)	0.13 (VWP)
2018	0.91 (VSP)	0.76 (SP)	0.91 (VSP)	0.95 (VSP)	0.70 (SP)	0.05 (VWP)	0.24 (WP)	0.60 (SP)	0.33 (WP)	0.89 (VSP)	0.22 (VWP)	0.54 (MP)
2019	0.82 (VSP)	0.87 (VSP)	0.85 (VSP)	0.86 (VSP)	0.97 (VSP)	0.95 (VSP)	0.55 (MP)	0.91 (VSP)	0.76 (SP)	0.55 (MP)	0.65 (SP)	0.32 (WP)

Summary												
Index	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
VSP	15	19	25	25	14	19	8	11	13	23	18	13
SP	5	4	1	3	8	4	7	6	5	3	3	5
MP	1	2	2	0	5	3	5	4	3	1	4	5
WP	4	2	1	0	1	1	8	6	4	2	1	4
VWP	4	2	0	1	1	2	1	2	4	0	3	2

Note: VSP: Very Strong Positive, SP: Strong Positive, MP: Moderate Positive, WP: Weak Positive, VWP: Very Weak Positive.

Table 6 Variation and summary of correlation coefficient observed between FAO56-PM ET₀ estimates obtained using MERRA-2 satellite parameters and ground meteorological dataset on cropping season basis

Year	Autumn	Spring	Summer
1991	0.18 (VWP)	0.93 (VSP)	0.97 (VSP)
1992	0.69 (SP)	0.91 (VSP)	0.98 (VSP)
1993	0.93 (VSP)	0.83 (VSP)	0.98 (VSP)
1994	0.29 (WP)	0.96 (VSP)	0.96 (VSP)
1995	0.91 (VSP)	0.94 (VSP)	0.98 (VSP)
1996	0.83 (VSP)	0.96 (VSP)	0.97 (VSP)
1997	0.82 (VSP)	0.89 (VSP)	0.96 (VSP)
1998	0.87 (VSP)	0.86 (VSP)	0.96 (VSP)
1999	0.76 (SP)	0.94 (VSP)	0.93 (VSP)
2000	0.70 (SP)	0.94 (VSP)	0.89 (VSP)
2001	0.43 (MP)	0.94 (VSP)	0.91 (VSP)
2002	0.87 (VSP)	0.85 (VSP)	0.97 (VSP)
2003	0.39 (WP)	0.94 (VSP)	0.98 (VSP)
2004	0.85 (VSP)	0.91 (VSP)	0.90 (VSP)
2005	0.96 (VSP)	0.83 (VSP)	0.95 (VSP)
2006	0.42 (MP)	0.91 (VSP)	0.92 (VSP)
2007	0.50 (MP)	0.87 (VSP)	0.95 (VSP)
2008	0.42 (MP)	0.85 (VSP)	0.45 (MP)
2009	0.81 (VSP)	0.97 (VSP)	0.96 (VSP)
2010	0.63 (SP)	0.81 (VSP)	0.92 (VSP)
2011	0.71 (SP)	0.84 (VSP)	0.93 (VSP)
2012	0.89 (VSP)	0.92 (VSP)	0.95 (VSP)
2013	0.22 (WP)	0.83 (VSP)	0.89 (VSP)
2014	0.85 (VSP)	0.74 (SP)	0.92 (VSP)
2015	0.60 (SP)	0.79 (SP)	0.96 (VSP)
2016	0.52 (MP)	0.86 (VSP)	0.94 (VSP)
2017	0.55 (MP)	0.94 (VSP)	0.79 (SP)
2018	0.74 (SP)	0.87 (VSP)	0.84 (VSP)
2019	0.82 (SP)	0.84 (VSP)	0.94 (VSP)
Summary			
Index	Autumn	Spring	Summer
VSP	11	27	27
SP	8	2	1
MP	6	0	1
WP	3	0	0
VWP	1	0	0

Note: VSP: Very Strong Positive, SP: Strong Positive, MP: Moderate Positive, WP: Weak Positive, VWP: Very Weak Positive

Summary												
Index	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
GA	28	29	29	29	29	29	29	29	29	29	29	29
MA	1	0	0	0	0	0	0	0	0	0	0	0
MDA	0	0	0	0	0	0	0	0	0	0	0	0
PA	0	0	0	0	0	0	0	0	0	0	0	0

Note: GA: Good Agreement, MA: Medium Agreement, MDA: Moderate Agreement, PA: Poor Agreement.

Table 8 Variation and summary of agreement index observed between FAO56-PM ET₀ estimates obtained using MERRA-2 satellite parameters and ground meteorological dataset on cropping season basis

Year	Autumn	Spring	Summer
1991	0.59 (MA)	0.56 (MA)	0.61 (MA)
1992	0.52 (MA)	0.49 (MDA)	0.68 (MA)
1993	0.58 (MA)	0.48 (MDA)	0.59 (MA)
1994	0.41 (MDA)	0.51 (MA)	0.56 (MA)
1995	0.58 (MA)	0.52 (MA)	0.69 (MA)
1996	0.60 (MA)	0.51 (MA)	0.63 (MA)
1997	0.53 (MA)	0.57 (MA)	0.67 (MA)
1998	0.52 (MA)	0.50 (MDA)	0.61 (MA)
1999	0.51 (MA)	0.53 (MA)	0.47 (MDA)
2000	0.43 (MDA)	0.50 (MA)	0.48 (MDA)
2001	0.33 (MDA)	0.50 (MA)	0.55 (MA)
2002	0.56 (MA)	0.47 (MDA)	0.53 (MA)
2003	0.34 (MDA)	0.53 (MA)	0.58 (MA)
2004	0.55 (MA)	0.55 (MA)	0.49 (MDA)
2005	0.63 (MA)	0.51 (MA)	0.63 (MA)
2006	0.35 (MDA)	0.51 (MA)	0.54 (MA)
2007	0.37 (MDA)	0.53 (MA)	0.56 (MA)
2008	0.57 (MA)	0.54 (MA)	0.50 (MA)
2009	0.52 (MA)	0.56 (MA)	0.60 (MA)
2010	0.59 (MA)	0.56 (MA)	0.58 (MA)
2011	0.52 (MA)	0.48 (MDA)	0.55 (MA)
2012	0.64 (MA)	0.57 (MA)	0.63 (MA)
2013	0.45 (MDA)	0.49 (MA)	0.57 (MA)
2014	0.44 (MDA)	0.48 (MDA)	0.64 (MA)
2015	0.44 (MDA)	0.48 (MDA)	0.65 (MA)
2016	0.42 (MDA)	0.46 (MDA)	0.54 (MA)
2017	0.33 (MDA)	0.46 (MDA)	0.41 (MDA)
2018	0.48 (MDA)	0.47 (MDA)	0.44 (MDA)
2019	0.47 (MDA)	0.46 (MDA)	0.46 (MDA)
Summary			
Index	Autumn	Spring	Summer
GA	0	0	0
MA	16	18	23
MDA	13	11	6
PA	0	0	0

Note: GA: Good Agreement, MA: Medium Agreement, MDA: Moderate Agreement, PA: Poor Agreement

Table 9 Variation and summary of confidence index observed between FAO56-PM ET₀ estimates obtained using MERRA-2 satellite parameters and ground meteorological dataset on monthly basis

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
1991	0.71 (G)	0.78 (VG)	0.91 (B)	0.80 (VG)	0.49 (VB)	0.64 (F)	0.53 (BD)	0.90 (B)	0.86 (B)	0.87 (B)	0.82 (VG)	0.56 (BD)
1992	0.59 (BD)	0.85 (VG)	0.84 (VG)	0.86 (B)	0.69 (G)	0.81 (VG)	0.83 (G)	0.81 (VG)	0.39 (W)	0.80 (VG)	0.77 (VG)	0.31 (W)
1993	0.81 (VG)	0.28 (W)	0.70 (F)	0.90 (B)	0.61 (F)	0.95 (B)	0.87 (B)	0.97 (B)	0.96 (B)	0.90 (B)	0.82 (VG)	0.81 (VG)
1994	0.63 (F)	0.93 (B)	0.97 (B)	0.89 (B)	0.70 (G)	0.76 (G)	0.16 (W)	0.22 (W)	0.39 (W)	0.89 (B)	0.93 (B)	0.85 (VG)
1995	0.63 (F)	0.43 (VB)	0.91 (B)	0.92 (B)	0.95 (B)	0.98 (B)	0.58 (BD)	0.91 (B)	0.92 (B)	0.89 (B)	0.92 (B)	0.79 (VG)
1996	0.75 (G)	0.88 (B)	0.93 (B)	0.88 (B)	0.70 (G)	0.85 (B)	0.60 (BD)	0.85 (B)	0.94 (B)	0.85 (B)	0.90 (B)	0.33 (VG)
1997	0.67 (G)	0.96 (B)	0.56 (BD)	0.87 (B)	0.91 (B)	0.59 (BD)	0.83 (G)	0.42 (VB)	0.23 (W)	0.76 (VG)	0.85 (B)	0.43 (W)
1998	0.25 (W)	0.04 (W)	0.89 (B)	0.85 (B)	0.96 (B)	0.90 (B)	0.72 (G)	0.89 (B)	0.92 (B)	0.83 (VG)	0.21 (W)	0.79 (VG)
1999	0.77 (VG)	0.55 (BD)	0.90 (B)	0.89 (B)	0.81 (VG)	0.93 (B)	0.46 (VB)	0.63 (F)	0.33 (W)	0.65 (F)	0.92 (B)	0.76 (VG)
2000	0.66 (G)	0.79 (VG)	0.83 (VG)	0.92 (B)	0.42 (VB)	0.82 (VG)	0.87 (B)	0.65 (F)	0.56 (BD)	0.80 (VG)	0.46 (VB)	0.77 (VG)
2001	0.80 (VG)	0.84 (VG)	0.88 (B)	0.93 (B)	0.95 (B)	0.35 (W)	0.19 (W)	0.23 (W)	0.13 (W)	0.82 (VG)	0.86 (B)	0.84 (VG)
2002	0.64 (F)	0.82 (VG)	0.97 (B)	0.90 (B)	0.78 (VG)	0.89 (B)	0.52 (BD)	0.40 (W)	0.82 (VG)	0.60 (BD)	0.11 (W)	0.02 (W)
2003	0.43 (VB)	0.73 (G)	0.92 (B)	0.87 (B)	0.93 (B)	0.93 (B)	0.60 (F)	0.13 (W)	0.37 (W)	0.90 (B)	0.84 (VG)	0.60 (BD)
2004	0.57 (BD)	0.90 (B)	0.84 (VG)	0.57 (BD)	0.97 (B)	0.44 (VB)	0.86 (B)	0.63 (F)	0.94 (B)	0.86 (B)	0.89 (B)	0.59 (BD)
2005	0.14 (W)	0.88 (B)	0.95 (B)	0.02 (W)	0.93 (B)	0.99 (B)	0.18 (W)	0.94 (B)	0.92 (B)	0.90 (B)	0.82 (VG)	0.75 (G)
2006	0.57 (BD)	0.92 (B)	0.93 (B)	0.89 (B)	0.95 (B)	0.99 (B)	0.93 (B)	0.71 (G)	0.12 (W)	0.91 (B)	0.80 (VG)	0.30 (W)
2007	0.72 (G)	0.91 (B)	0.92 (B)	0.89 (B)	0.91 (B)	0.82 (VG)	0.85 (B)	0.75 (VG)	0.68 (F)	0.82 (VG)	0.64 (F)	0.41 (VB)
2008	0.00 (W)	0.83 (VG)	0.42 (VB)	0.80 (VG)	0.42 (VB)	0.42 (VB)	0.51 (BD)	0.19 (W)	0.70 (F)	0.22 (W)	0.84 (VG)	0.49 (VB)
2009	0.80 (VG)	0.92 (B)	0.21 (W)	0.94 (B)	0.13 (W)	0.85 (VG)	0.77 (G)	0.18 (W)	0.92 (B)	0.34 (W)	0.48 (VB)	0.77 (VG)
2010	0.14 (W)	0.65 (G)	0.97 (B)	0.68 (G)	0.61 (F)	0.85 (B)	0.26 (W)	0.95 (B)	0.05 (W)	0.85 (B)	0.82 (VG)	0.79 (VG)
2011	0.18 (W)	0.23 (W)	0.91 (B)	0.88 (B)	0.52 (BD)	0.97 (B)	0.50 (BD)	0.43 (BV)	0.78 (VG)	0.90 (B)	0.86 (B)	0.82 (VG)
2012	0.70 (G)	0.93 (B)	0.77 (VG)	0.82 (VG)	0.95 (B)	0.83 (VG)	0.74 (G)	0.77 (VG)	0.10 (W)	0.91 (B)	0.81 (VG)	0.67 (G)
2013	0.23 (W)	0.88 (B)	0.92 (B)	0.77 (VG)	0.24 (W)	0.76 (VG)	0.14 (W)	0.33 (W)	0.65 (BD)	0.67 (G)	0.44 (VB)	0.79 (VG)
2014	0.24 (W)	0.61 (F)	0.80 (VG)	0.89 (VG)	0.72 (G)	0.93 (B)	0.67 (G)	0.33 (W)	0.70 (F)	0.78 (VG)	0.75 (VG)	0.43 (VB)
2015	0.00 (W)	0.00 (W)	0.88 (B)	0.85 (VG)	0.92 (B)	0.91 (B)	0.02 (W)	0.96 (B)	0.83 (VG)	0.91 (B)	0.05 (W)	0.61 (F)
2016	0.74 (G)	0.94 (B)	0.96 (B)	0.90 (B)	0.92 (B)	0.00 (W)	0.25 (W)	0.41 (BV)	0.88 (B)	0.85 (VG)	0.43 (VB)	0.92 (B)
2017	0.81 (VG)	0.89 (B)	0.98 (B)	0.73 (G)	0.52 (BD)	0.64 (F)	0.37 (W)	0.04 (W)	0.93 (B)	0.87 (B)	0.62 (F)	0.12 (W)
2018	0.75 (VG)	0.74 (G)	0.90 (B)	0.89 (B)	0.70 (G)	0.05 (W)	0.22 (W)	0.58 (BD)	0.32 (W)	0.82 (VG)	0.20 (W)	0.49 (VB)
2019	0.64 (F)	0.81 (VG)	0.83 (VG)	0.80 (VG)	0.97 (B)	0.94 (B)	0.53 (BD)	0.88 (B)	0.73 (F)	0.49 (VB)	0.61 (F)	0.29 (W)

Summary												
Index	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
B	0	12	19	19	13	14	5	9	10	14	8	1
VG	6	7	6	6	2	6	0	3	3	9	10	11
G	7	3	0	2	5	1	6	1	0	1	0	2
F	4	1	1	0	2	2	1	3	4	1	3	1
BD	3	1	1	1	2	1	7	1	2	1	0	3
VB	1	1	1	0	3	2	1	3	0	1	4	5
W	8	4	1	1	2	3	9	9	10	2	4	6

Note: B: Best, VG: Very Good, G: Good, F: Fair, BD: Bad, VB: Very Bad, W: Worst.

Table 10 Variation and summary of confidence index observed between FAO56-PM ET₀ estimates obtained using MERRA-2 satellite parameters and ground meteorological dataset on cropping season basis

Years	Autumn	Spring	Summer
1991	0.11 (W)	0.51 (BD)	0.59 (BD)
1992	0.36 (W)	0.45 (VB)	0.66 (G)
1993	0.54 (BD)	0.40 (W)	0.58 (BD)
1994	0.12 (W)	0.50 (VB)	0.54 (BD)
1995	0.53 (W)	0.49 (VB)	0.68 (G)
1996	0.50 (VB)	0.49 (VB)	0.61 (F)
1997	0.44 (VB)	0.51 (BD)	0.64 (F)
1998	0.45 (VB)	0.43 (VB)	0.58 (BD)
1999	0.39 (W)	0.50 (BD)	0.44 (VB)
2000	0.30 (W)	0.47 (VB)	0.43 (VB)
2001	0.14 (W)	0.48 (VB)	0.50 (BD)
2002	0.49 (VB)	0.41 (VB)	0.52 (BD)
2003	0.13 (W)	0.50 (VB)	0.57 (BD)
2004	0.47 (VB)	0.50 (VB)	0.44 (VB)
2005	0.61 (F)	0.42 (VB)	0.60 (F)
2006	0.14 (W)	0.46 (VB)	0.50 (VB)
2007	0.19 (W)	0.46 (VB)	0.53 (BD)
2008	0.24 (W)	0.46 (VB)	0.23 (W)
2009	0.42 (VB)	0.54 (BD)	0.58 (BD)
2010	0.37 (W)	0.45 (VB)	0.54 (BD)
2011	0.37 (W)	0.40 (VB)	0.51 (BD)
2012	0.57 (BD)	0.52 (BD)	0.60 (F)
2013	0.10 (W)	0.41 (VB)	0.51 (BD)
2014	0.37 (W)	0.36 (W)	0.59 (BD)
2015	0.26 (W)	0.37 (W)	0.62 (F)
2016	0.22 (W)	0.39 (W)	0.51 (BD)
2017	0.18 (W)	0.43 (VB)	0.32 (W)
2018	0.35 (W)	0.40 (VB)	0.37 (W)
2019	0.38 (W)	0.39 (W)	0.43 (VB)
Summary			
Index	Autumn	Spring	Summer
B	0	0	0
VG	0	0	0
G	0	0	2
F	1	0	5
BD	3	5	14
VB	6	19	5
W	19	5	3

Note: B: Best, VG: Very Good, G: Good, F: Fair, BD: Bad, VB: Very Bad, W: Worst.

From Table 5, it is clear that at Dehradun, out of total 348 months during 29 years (1991-2019) period, about 58.33% months were found with Very Strong Positive (VSP) correlation coefficient (range: 0.80 to 1.00) between FAO56-PM ET₀ estimates obtained with MERRA-2 satellite parameters and ground meteorological dataset, followed by 15.52% months and 10.60% months with Strong Positive (SP) and Moderate Positive (MP) correlation coefficient values, respectively. From the above, it may be inferred that about 84.45% months (consisting of VSP, SP and MP) resulted in very good correlation between FAO56-PM ET₀ estimates obtained with MERRA-2 satellite parameters and the ground meteorological dataset.

Further, for cropping season (Table 6), it was found that during 29 years study period, about 37.93%, 27.59%, and 20.69% Autumn seasons were observed under VSP, SP, and MP levels. Similarly, it was found that about 93.10% and 6.90% Spring seasons were obtained with VSP and SP correlation coefficient values. About 93.10%, 3.45%, and 3.45% Summer seasons showed correlation coefficient values with VSP, SP and MP levels, respectively.

In terms of agreement Index (d) (Table 7), about 99.71% months showed Good Agreement (GA), while on cropping season basis, 55.17% and 44.83% Autumn seasons showed Medium Agreement (MA) and Moderate Agreement (MDA), respectively, while 62.07% and 37.93% Spring seasons produced MA and MDA agreement index values, respectively (Table 8), while about 79.31% and 20.69% Summer seasons showed agreement index values under MA and MDA categories, respectively. From the summary of Confidence index (c) observed between FAO56-PM ET₀ estimates obtained from MERRA-2 satellite parameters and ground meteorological dataset on monthly basis during 29 years study period (Table 9), it is clear that 35.63%, 19.83%, 8.05%, 6.61%, 6.61%, 6.32%, and 16.95% months were found with Best (B), Very Good (VG), Good (G), Fair (F), Bad (BD), Very Bad (VB), and Worst (W) confidence index values. On cropping season basis [Table 10], about 3.45%,

10.34%, 20.69%, and 65.52% Autumn seasons were observed with Fair, Bad, Very Bad and Worst confidence index values during study period, while about 17.24%, 65.62% and 17.24% Spring seasons were found with Bad, Very Bad, and Worst confidence index values, respectively whereas, about 6.90%, 17.24%, 48.48%, 17.24%, and 10.34% Summer seasons produced confidence index values in G, F, BD, VB and W categories, respectively.

4 Conclusions

The present study was undertaken with specific objective to compare ET₀ estimates at monthly and cropping season timescales with meteorological parameters retrieved from MERRA-2 satellite and ground meteorological dataset by using standardized FAO56-PM model using statistical indices. From obtained results, following conclusions could be drawn:

(1) About 58.33% months with Very Strong Positive, followed by 15.52% months and 10.60% months with Strong Positive and Moderate Positive correlation coefficient values totaling to about 84.45% months resulted in very good correlation coefficient values between FAO56-PM ET₀ estimates obtained with MERRA-2 satellite parameters and the ground meteorological dataset. For the cropping (Autumn, Spring and Summer) season, it was found that about 37.93%, 27.59%, and 20.69% Autumn seasons showed Very Strong Positive, Strong Positive, and Moderate Positive level correlation coefficient values. Similarly, for Spring season, it was found that about 93.10% and 6.90% seasons were obtained with Very Strong Positive and Strong Positive correlation coefficient values. For Summer season, about 93.10% seasons showed Very Strong Positive correlation values, followed by 3.45% and 3.45% seasons with Strong Positive and Moderate Positive levels, respectively.

(2) About 99.71% months showed Good Agreement (GA) in terms of agreement Index values, while on cropping season basis, 55.17% Autumn, 62.07% Spring, and 79.31% Summer seasons showed agreement index values under Moderate agreement category.

(3) In terms of confidence index, about 69.92% months consisting of 35.63%, 19.83%, 8.05%, and 6.61% months were found with Best, Very Good, Good, and Fair confidence index values, while on cropping season basis, about 3.45% Autumn and 17.24% Summer seasons were observed with Fair confidence index values, and about 17.24% Spring seasons were found with Bad confidence index values.

(4) It is recommended to derive standard equations between FAO56-PM ET_0 estimates obtained with MERRA-2 meteorological parameters and that of using ground meteorological dataset so that at par FAO56-PM ET_0 estimates for any location can be obtained even in the absence of meteorological observatory or if weather dataset of doubtful integrity is only available for that place.

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