ORIGINAL PAPER

Ground validation of diurnal TRMM 3B42 V7 and GPM precipitation products over the northeast of Iran

Zahra Shirmohammadi-Aliakbarkhani[1] (ORCID) · Abolghasem Akbari[2,3]

Abstract

Water resources planning and design always deal with precipitation estimation and measurements. In arid and semi-arid climates of developing countries with inadequate numbers of rainfall stations, satellite data become increasingly important. The main objective of this research is to assess the daily rainfall data from the Tropical Rainfall Measurement Mission (TRMM-3B42 V7) and Global Precipitation Measurement (GPM) products with rain-gauge data over a semiarid climate. The study was carried out in Khorasan Razavi Province located in northeast of Iran which is relatively very well equipped with synoptic rainfall stations. Daily rainfall data from 13 stations were collected for a period of 4 years, starting from Feb 2015 to Nov 2018 and compared with the available daily GPM and TRMM-3B42 V7 data. The comparison was performed on daily, monthly, and seasonal timescales. All satellite precipitation products (SPPs) correlated well with measurements from rain-gauge data on the monthly timescale, but moderately on the daily timescale. However, the TRMM data were found slightly better than GPM products. On the seasonal scale, it was found that all SPPs correlated well with measurements from gauges in spring, summer, and winter but in fall, TRMM products outperformed GPM. The GPM products slightly overestimated the data in all of the season except fall, but the TRMM products tended to underestimate the values in all of the seasons except spring. It was found that the TRMM data made a significant improvement in precipitation estimation and could potentially be one of the reliable sources of data for daily-based hydrological modeling in northeast of Iran.

1 Introduction

Determining spatial variations of rainfall over the watershed is an important step in semi-distributed hydrological modeling. It has also been well documented that rainfall characteristics including depth, intensity, and frequency have a direct impact on water resources management, floods, and drought forecasting.

✉ Zahra Shirmohammadi-Aliakbarkhani
mshirmohamady@yahoo.com

Abolghasem Akbari
akbariinbox@yahoo.com

1 Department of Water Science and Engineering, University of Torbat-e Jam, PO box 9571875335, Torbat-e Jam, Khorasan Razavi, Iran

2 Department of Civil Engineering, Binaloud Institute of Higher Education, Mashhad, Iran

3 University of Torbat-e Jam, Torbat-e Jam, Iran

Accurate estimation of rainfall in most developing countries is a crucial part of hydrological modeling due to the scarcity and inadequate number of rain gauges. Recent advances in weather and climate modeling coupled with earth observation technology have contributed to a significant progress in estimating temporal and spatial variations of precipitation over the space with relatively high-resolution SPPs.

The Tropical Rainfall Measuring Mission (TRMM) is an SPP for weather and climate research. It was a joint project between NASA and Japan, and launched in Nov 1997 from Japan. The products of TRMM have been used in order to evaluate rainfall at different timescales in many regions and therefore contributed to the climate and environmental studies. TRMM was turned off in Apr 2015, but a more advanced and comprehensive technology known as the Global Precipitation Measurement (GPM) was launched in Feb 2014, which is undertaking the same assignment (Hou et al. 2014; Yong et al. 2015). Remotely sensed precipitation data are very useful in many regions where the measurement is impossible or regions with sparse or nonexistent rain-gauge networks. Previous research has shown that the bias is the main problem with satellite-based precipitation measurements

and could cause significant uncertainty in hydrologic simulation. The bias results from the cloud conditions, precipitation algorithm, and land surface conditions are wrongly interpreted by a predetermined algorithm causing significant uncertainty in the hydrologic simulation (Katiraie-Boroujerdy et al. 2013; Kazmi et al. 2014; Wang and Lu 2015; He et al. 2017).

To determine the reliability of satellite data and a better understanding of rainfall variability in space and time, data quality assessment is essential across different regions (Wang et al. 2017). Some researchers have investigated the GPM rainfall product. For example, Tang et al. (2016) studied the performance of the TRMM-era 3B42V7 and 3B42RT products compared with IMERG product on the Ganjiang River basin in southeast China. Tan and Duan (2017) validated the capability of the latest IMERG and two TRMM products (TMPA 3B42RT and TMPA 3B42) for the period from Apr 2014 to Jan 2016 over Singapore. They identified that satellite precipitation products (SPPs) demonstrated a better estimation for gauge data on the monthly scale. On the other hand, they found a better characterization of precipitation than other periods when IMERG was compared with the TMPA products over tropical regions in the northeast monsoon season. Chen and Li (2016) analyzed GPM-IMERG data against gauge-data from Mar 2014 to Feb 2015 in Mainland China on several spatial and temporal scales. They found that IMERG slightly outperformed TRMM 3B43 on monthly and seasonal scales. Sharifi et al. (2016) evaluated the post-real-time of TRMM, TMPA-3B42, GPM-IMERG, and the Era-Interim product versus daily gauge data under various climatic conditions of Iran. According to the results in all four regions, IMERG demonstrated a better performance compared with the two other products and underestimated rainfall slightly on the daily scale. Comprehensive literature review shows that several other attempts have been made to evaluate the IMERG data over China (Wang and Lu 2015; Guo et al. 2016; Ning et al. 2016), the Netherlands (Rios Gaona et al. 2016), India (Prakash et al. 2016), Western United States (Wen et al. 2016), and the upper Blue Nile basin (Sahlu et al. 2016), as well as Korea and Japan (Kim et al. 2017). Most researchers concluded that the GPM rainfall product provides a more reasonable prediction for precipitation events. Nonetheless, the GPM rainfall products under various conditions, for example, spatial and temporal resolutions, have not been widely validated, especially investigating the topographical and seasonal effects on the accuracy and validity of GPM products.

In this research, both TRMM-3B42 V7 and IMERG rainfall products on daily timescale were investigated to compare with synoptic data over Khorasan Razavi, Iran. The main objective of this research was to assess the capability of the new product of satellite-based rainfall called IMERG in prediction of daily, monthly, and seasonal variations of rainfall over the semiarid climate of Iran. In addition, the GPM data and TRMM-3B42 V7 were compared with the gauge data using

daily rainfall data at 13 synoptic stations for the available period of Feb 2015 to Oct 2018. This is a highly demanding line of research due to scarcity of gauge data in arid and semi-arid climate of Iran and similar regions.

2 Materials and methods

2.1 Research area

Khorasan Razavi is located in northeast of Iran and extended within the 33°-38° N and 56°-62° E with a total area of 117,200 km^2 and mean annual rainfall 250 mm (see Fig. 1). According to Thornthwaite 1948 climate classification index, this area is classified as semi-arid climate.

2.2 Synoptic rain-gauge data

The ground-based data used in this study were synoptic gauge data of Khorasan Razavi Province of the Islamic Republic of Iran Meteorological Organization (IRIMO). The rainfall stations used for this study are listed in Table 1. All stations were standardized based on the WMO guidelines and instructions. The locations of the selected stations along with climate characteristics and observation periods are reported in Table 1. According to the IRIMO, all rainfall data were corrected for meteorological parameters such as wind speed, and due to the uniformity in topography and climate in Razavi Khorasan, the assumption of homogeneity of data may relatively be logical.

2.2.1 Quality control of rain-gauge data

According to Michaelides (2008), quality control of rain-gauge data has been an important step since the beginning of data collection. It involves several steps including gap filling, checking physically impossible values, checking for values above set thresholds, improbable zero values, unusually low daily values, unusually high daily values, and station data quality.

The synoptic rain-gauge data have passed IRIMO quality control procedures such as checking situation (latitude, longitude, and elevation), tests for data homogeneity, consistency with other meteorological parameters, and filling data gaps. There were no gap, no physically impossible values, no impossible zero values, and no values above the threshold (4SD). Consistency value testing was performed using double mass-curve analysis where no significant changes were found in the consistency of the data during the investigated period.

Rain-gauge catch correction is often given very little attention in hydrological modeling compared with model parameter calibration. Going through the literature, we have found very few examples where modelers have been specific about the precipitation correction applied in hydrological modeling.
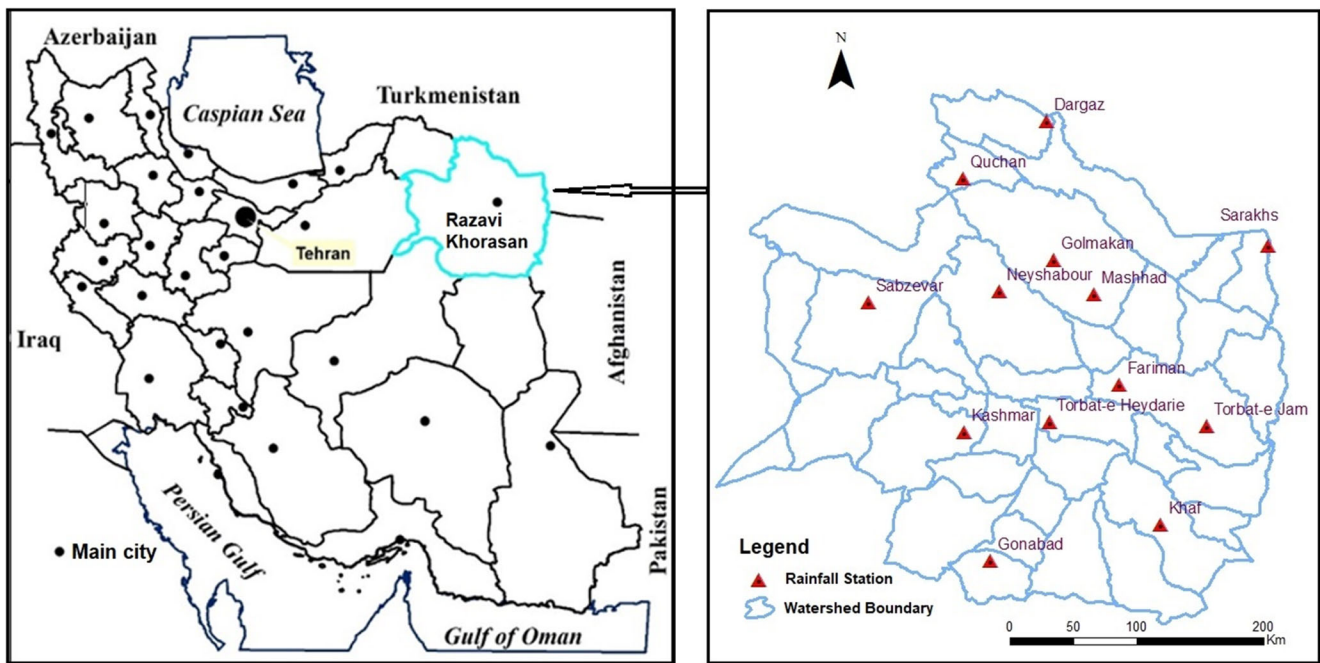
Fig. 1 Layout of the research area with the spatial distribution of synoptic rainfall stations

According to Stisen et al. (2011), even in the area with dense rain-gauge network, the estimated rainfall is associated with some uncertainty and possibly biased. The uncertainty is predominantly related to the precipitation catch deficiency as result of eddies that tend to reduce the catch of small rain-drops. Catch deficiency of 10% is typical for rain. It is also depending on the land use and seasons. According to Stisen et al. (2011), the catch deficiencies could range from 0 to 10% in the area with predominately bare soil land use in both winter and summer which is the case in this study area. Following this guideline, we have corrected the rain-gauge data for wind speed by increasing the ground data by 5%.

2.3 Satellite precipitation products

The TRMM is a multi-satellite precipitation product that provides TRMM-3B42 V7, daily (3B42) and monthly (3B43) precipitation from 1998 to the present. The TRMM satellite scanning the strip limited to 50° S and 50° N with 3-h time interval at 0.25° spatial resolution (Huffman et al. 2007). For this research, the 3-hourly TRMM-3B42 V7 data were downloaded for almost 4 years from 2015 to 2018 from the website http://trmm.gsfc.nasa.gov/3b42.html. The Level 3 IMERG final run product data with a spatial resolution of 0.25° × 0.0.25° were used as 0.5-h GPM data. The satellite

Table 1 General statistics of the synoptic stations used for validation in the study area

No.	Station name	Latitude	Longitude	Observation periods	Elevation (m)
ST1	Dargaz	37.47	59.25	4 years	514
ST2	Quchan	37.07	58.50	4 years	1287
ST3	Sarakhs	36.53	61.17	4 years	235
ST4	Golmakan	36.48	59.28	4 years	1176
ST5	Neyshabour	36.27	58.80	4 years	1213
ST6	Mashhad	36.23	59.63	4 years	999.2
ST7	Gonabad	34.35	58.68	4 years	1056
ST8	Sabzevar	36.20	57.65	4 years	962
ST9	Fariman	35.58	59.83	4 years	1460
ST10	Torbat-e Heydarieh	35.33	59.22	4 years	1451
ST11	Torbat-e Jam	35.27	60.58	4 years	950.4
ST12	Kashmar	35.27	58.47	4 years	1110
ST13	Khaf	34.58	60.15	4 years	998

products were downloaded for the duration of 4 years starting from Feb 2015 to Nov 2018, available at the https://pmm.nasa.gov/data-access/downloads/gpm.

2.4 Methodology

2.4.1 Model evaluation methodology

Our literature survey revealed that many researchers (Franchito et al. 2009; Buarque et al. 2011; Karaseva et al. 2012; Moazami et al. 2013; Mantas et al. 2015; Milewski et al. 2015; Akbari et al. 2017) have well used descriptive statistical indices for comparison and potential application of the TRMM and GPM products with the gauge data. Among those indices, relative bias (RBIAS), mean error (ME), correlation coefficient (CC), and root mean square error (RMSE) have been more frequently used in model assessments. Generally, the closer the values of CC to 1, and the value of ME, RBIAS, and RMSE to 0, the better the model performance. Also, due to the KGE-statistics advantages over the Nash–Sutcliffe efficiency, we used the Kling–Gupta efficiency (KGE′) statistic proposed by Gupta et al. (2009) and modified by Kling et al. (2012) (Nash and Sutcliffe 1970; Gupta et al. 2009). KGE′ ranges within (−∞, 1], with larger values indicating a better performance (Table 2). Furthermore, to evaluate precipitation occurrence the TRMM and GPM products, other statistical indices such as Critical Success Index (CSI) and Accuracy (fraction correct) which show the capability of products to detect precipitation occurrence. CSI is expressed as a function of the

false ratio (FR) and probability of detection (POD) were used (Tang et al. 2016; Xu et al. 2017). Table 2 shows the equations and perfect values of these investigated statistical indices.

2.4.2 Configuration

To compare the satellite products with the gauge data, we may define several types of grid configuration. According to Akbari et al. (2017), the rectangle grid would provide a better framework for comparison. In this scenario, 3PTRM vs. Synoptic data, the TRMM data from three points surrounding the synoptic rain gauges were averaged and compared with the corresponding rain-gauge data (see Fig. 2). To account for the variability of rainfall in space over the study area, three neighboring point data faced to the ground stations were used which would give more reasonable as we have seen in other similar studies.

3 Results and discussion

3.1 Diurnal variations

After carful data preparation, statistical analysis was performed and the results were presented in the form of tables and graphs. Scatter plot is used to identify various kinds of correlations between variables with a certain confidence interval. The scatter

Table 2 The statistical indices of daily precipitation estimates by GPM and TRMM-3B42 V7

Statistic indices	Equations[a]	Optimal value
Correlation coefficient (CC)	$CC = \dfrac{\frac{1}{N}\sum_{n=1}^{N}\left(f_n-\overline{f}\right)(r_n-\overline{r})}{\sqrt{\frac{1}{N}\sum_{n=1}^{N}\left(f_n-\overline{f}\right)^2}\sqrt{\frac{1}{N}\sum_{n=1}^{N}(r_n-\overline{r})^2}}$	1
Mean error (ME)	$ME = \frac{1}{N}\sum_{n=1}^{N}\left(f_n-r_n\right)$	0
Relative bias (RBIAS)	$RBIAS = \frac{\sum_{n=1}^{N}(f_n-r_n)}{\sum_{n=1}^{N}r_n}$	0
Root-mean-square error (RMSE)	$RMSE = \sqrt{\frac{1}{N}\sum_{n=1}^{N}\left(f_n-r_n\right)^2}$	0
Kling–Gupta efficiency (KGE′)	$KGE' = 1-\sqrt{(CC-1)^2+(\beta-1)^2+(\gamma-1)^2}$ $\beta = \frac{\overline{f}}{\overline{r}} \qquad \gamma = \frac{CV_f}{CV_r}$ $CSI = \frac{H}{H+F+M} = \frac{1}{\frac{1}{1-FR}+\frac{1}{POD}-1}$	1
Critical Success Index (CSI)	$FR = \frac{F}{H+F} \qquad POD = \frac{H}{H+M}$	1
Accuracy (fraction correct)	$Accuracy = \frac{H+Cn}{H+F+M+Cn}$	1

[a] Variables: n, number of data; f_n, representing satellite precipitation estimate; r_n, representing gauged observed precipitation; CV is the coefficient of variation. F means the number of the rainfall detected by respective satellite rainfall products; H means the number of observed rainfall correctly detected by respective satellite rainfall products; but not observed by rainfall gauge; M means the number of the rainfall observed by precipitation gauges, but not detected by respective satellite rainfall products; Cn is the number of the rainfall not detected by respective products and rainfall gauge

Fig. 2 Investigated satellite rainfall data and synoptic rain gauges with satellite-based gridding over the study area
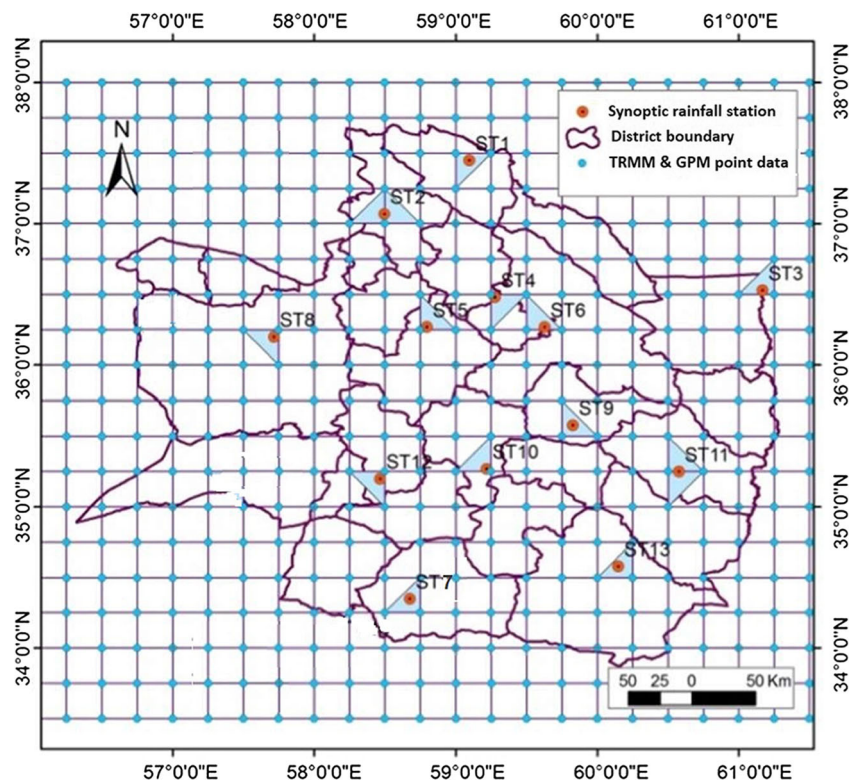
plots of average rainfall values on the daily timescale during the investigated period are shown in Fig. 3. According to Fig. 3 and Fig. 4, we compared the daily satellite precipitation products (GPM and TRMM) with the Synoptic rain-gauge data using some statistical indices as well as the categorical statistical metrics over this region, to evaluate the predictability performance of satellite precipitation products (Fig. 4 and Table 3).

The correlation coefficient values between the daily GPM and rain-gauge data ranged from 0.22 to 0.59 during the years of study with the 4-year mean value of 0.42. The correlation coefficient values between the daily TRMM and rain-gauge data ranged from 0.41 to 0.66 during the years of study with the 4-year mean value of 0.56. Among the two satellite precipitation

products, the TRMM showed the highest correlation with the rain gauge over the study areas (Fig. 4 and Table 3).

The mean error values between the daily GPM and rain-gauge data ranged from 0.006 mm/day to 0.11 mm/day during the years of study with the 4-year mean value of 0.03 mm/day. The mean error values between the daily TRMM and rain-gauge data ranged between − 0.08 mm/day and 0.04 mm/day during the years of study with the 4-year mean value of − 0.004 mm/day. Among the two satellite precipitation products, the TRMM revealed the lowest mean error with the rain gauge over the study areas (Fig. 4 and Table 3).

The relative bias was used to measure the average underestimation and overestimation by satellite precipitation products as compared with rain-gauge data (Fig. 4 and Table 3). In general, the bias values of GPM with rain-gauge data ranged from 1 to 23.8% during the years of study with the 4-year mean value 5.6% across this region. The bias results indicated that the GPM products overestimated the daily rainfall data. The bias values of TRMM with rain-gauge data ranged from − 14 to 8% during the years of study with the 4-year mean value of − 0.7% across this region. The bias results indicated that the TRMM products underestimated the daily rainfall data.

The values of RMSE for the daily GPM and rain-gauge data ranged from 1.57 mm/day to 2.13 mm/day during the years of study with the 4-year mean value of 1.87 mm/day (Fig. 4 and Table 3). The values of RMSE for the daily TRMM and rain-gauge data ranged from 1.57 mm/day to 1.89 mm/day during the

Table 3 Statistical metrics and the categorical statistical metrics of daily rainfall estimates by TRMM-3B42 V7 and GPM over the period of February 2015 to November 2018

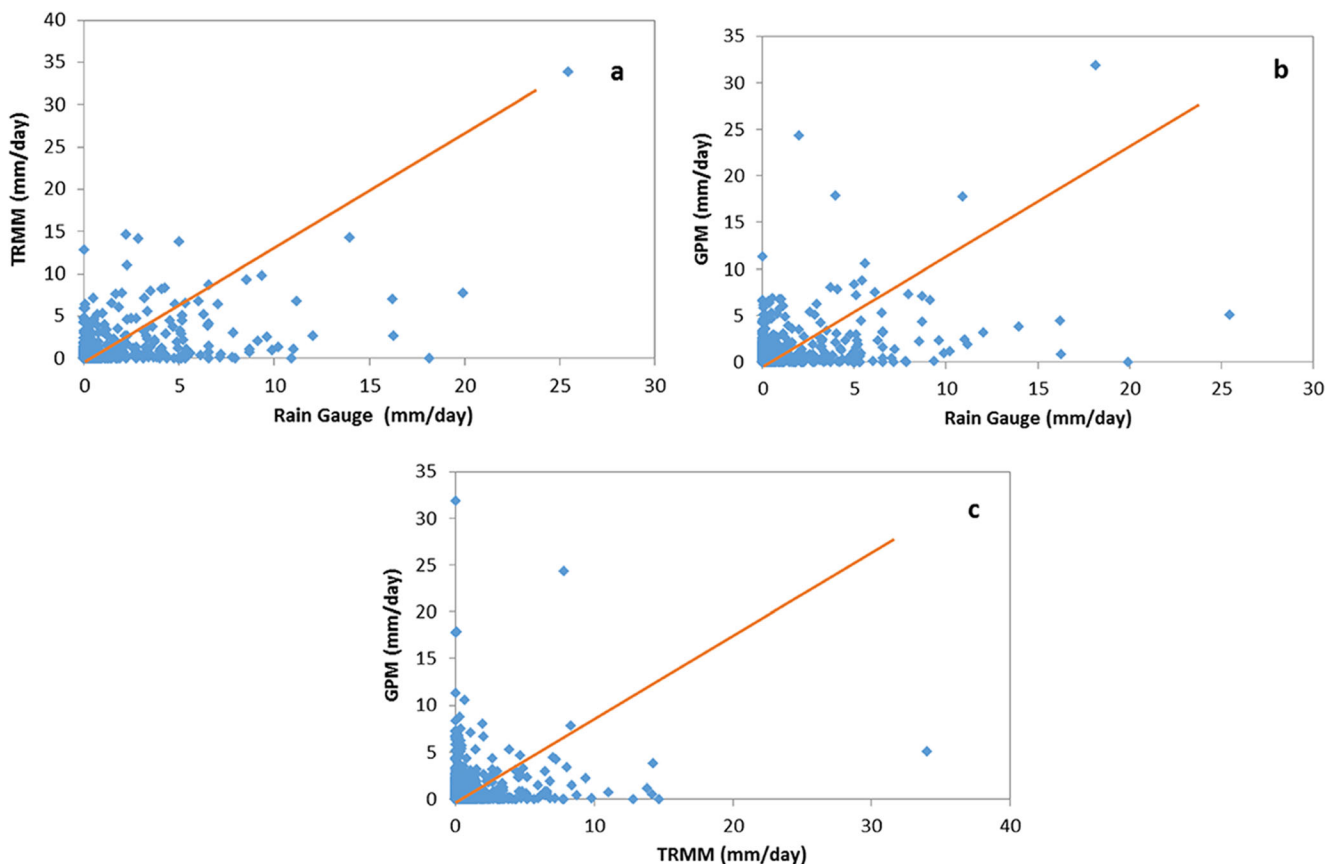| Metrics	GPM vis gauge	TRMM vis gauge	GPM vis TRMM
CC	0.42	0.56	0.17
ME (mm)	0.03	− 0.004	− 0.04
RMSE (mm)	1.87	1.64	2.21
RBIAS	5.92	− 0.72	− 6.3
KGE′	0.41	0.56	0.16
CSI	0.23	0.27	0.19
Accuracy	0.64	0.83	0.61

Fig. 3 (a) Daily precipitation event scatter plots of TRMM vs. rain gauge, (b) daily precipitation event scatter plots of GPM vs. rain gauge, (c) daily precipitation event scatter plots of GPM vs. TRMM (February 2015 to November 2018)

years of study with the 4-year mean value 1.64 mm/day. Across the study area, the mean lowest and highest values of RMSE were obtained from the TRMM (1.57 mm/day) and the GPM (2.13 mm/day). The TRMM products performed the best with the lowest RMSE value in this area.

The KGE′ coefficient revealed that the TRMM products performed the best in all years with the KGE′ values ranging from 0.4 to 0.64 with the 4-year mean value of 0.56. (Fig. 4 and Table 3). The KGE′ coefficient for the daily GPM and rain-gauge data ranged from 0.14 to 0.58 during the years of study with the 4-year mean value of 0.40.

Furthermore, we compared the daily satellite precipitation products (GPM and TRMM) with the Synoptic rain-gauge data using the categorical statistical metrics such as Critical Success Index (CSI) and Accuracy (fraction correct) representing the capability of products to detect precipitation occurrence (Fig. 4 and Table 3).

The Critical Success Index values among the daily GPM and rain-gauge data ranged from 0.21 to 0.25 during the years of study with the 4-year mean value of 0.23 (Fig. 4 and Table 3). The Critical Success Index values among the daily TRMM and rain-gauge data ranged from 0.25 to 0.29 during the years of

study with the 4-year mean value of 0.27. The TRMM products performed the best with the highest CSI value in this area.

The accuracy values among the daily GPM and rain-gauge data ranged from 0.61 to 0.71 during the years of study with the 4-year mean value of 0.64 (Fig. 4 and Table 3). The accuracy values among the daily TRMM and rain-gauge data ranged from 0.80 to 0.85 during the years of study with the 4-year mean value of 0.83. The TRMM products performed the best with the highest Accuracy value in this area.

Using the above statistical analysis, all satellite precipitation products correlated moderately with measurements from rain-gauge data on the daily scale. The TRMM products had a better performance in characterizing spatial precipitation variability and precipitation detection capability (with the highest CC, KGE′, CSI, and accuracy values and the lowest ME, RMSE, and RBIAS) compared with the GPM products in this area. Furthermore, note that TRMM and GPM on the daily scale still had a significant discrepancy with the ground data. Nevertheless, from the scatter plot Fig. 3 and Fig. 4, it is observed that there is a better agreement between the TRMM and rain-gauge data on the daily timescale. These results are not compatible with those reported by Tan et al. (2015) and Tan and Duan (2017).
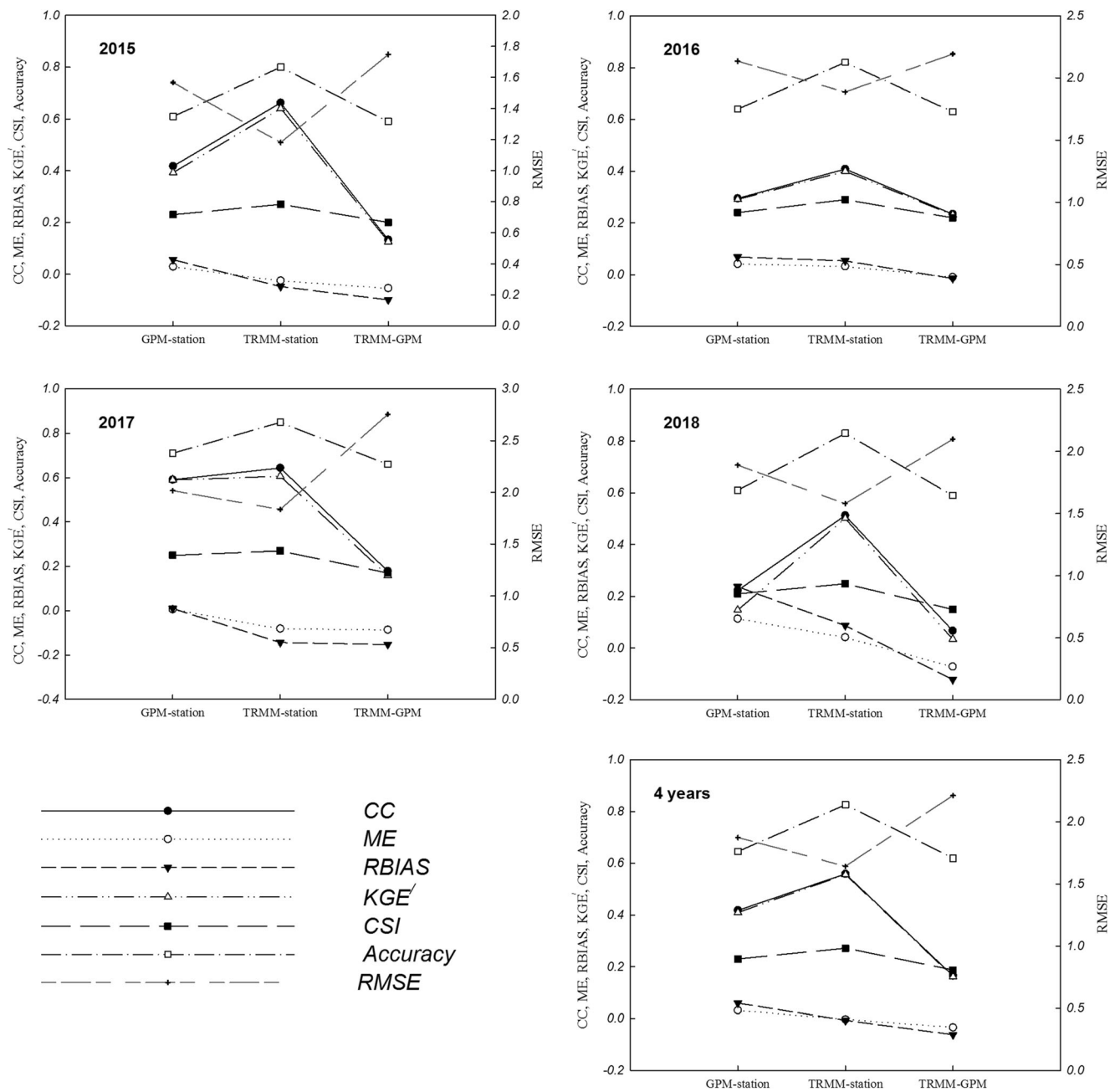
Fig. 4 The values of some statistical indices and the categorical statistical metrics for the comparison of the daily satellite precipitation products (GPM and TRMM-3B42 V7) with the Synoptic rain-gauge data across the study areas

Table 4 Statistical metrics of monthly rainfall estimated by GPM and TRMM-3B42 over the period of February 2015 to November 2018

Metrics	GPM vis gauge	TRMM vis gauge	GPM vis TRMM
CC	0.998	0.999	0.998
ME (mm)	0.92	− 0.09	− 1.018
RMSE (mm)	5.66	4.07	6.09
RBIAS	0.06	− 0.006	− 0.061
KGE′	0.93	0.96	0.89

3.2 Monthly variations

The comparisons of monthly rainfall from the satellite-based precipitation products (SPPs) and gauges from Feb 2015 to Dec 2018 are demonstrated in Fig. 5. All satellite precipitation products followed the temporal pattern of monthly rainfall significantly. For example, all products obtained a high rainfall for Apr 2016 and low rainfall for Aug 2016 on the monthly scale. TRMM provided a slightly better performance compared with the GPM with higher CC (0.999) and KGE′ (0.96) and lower
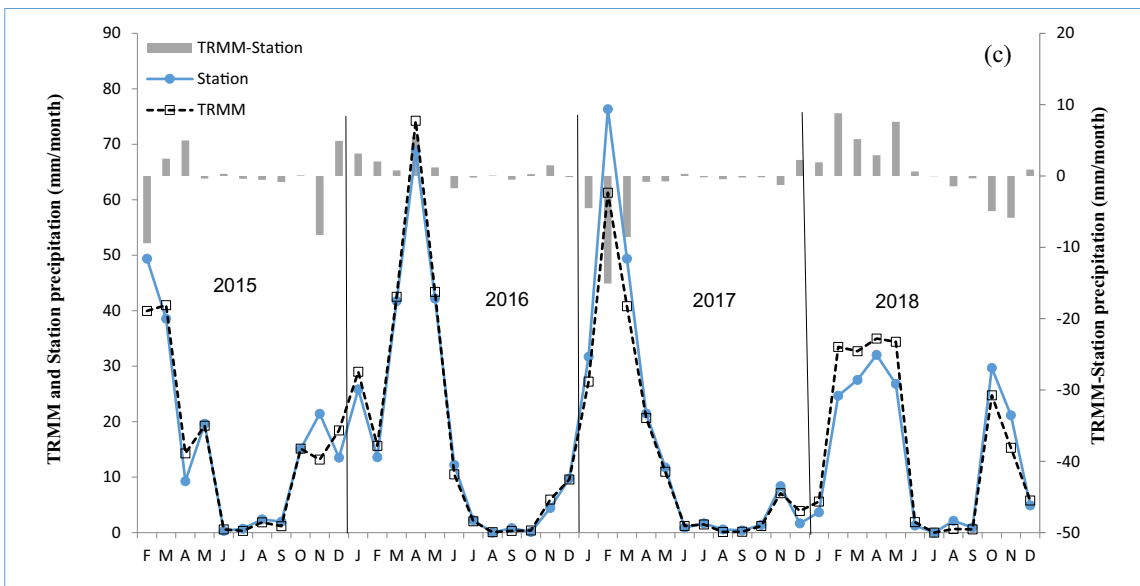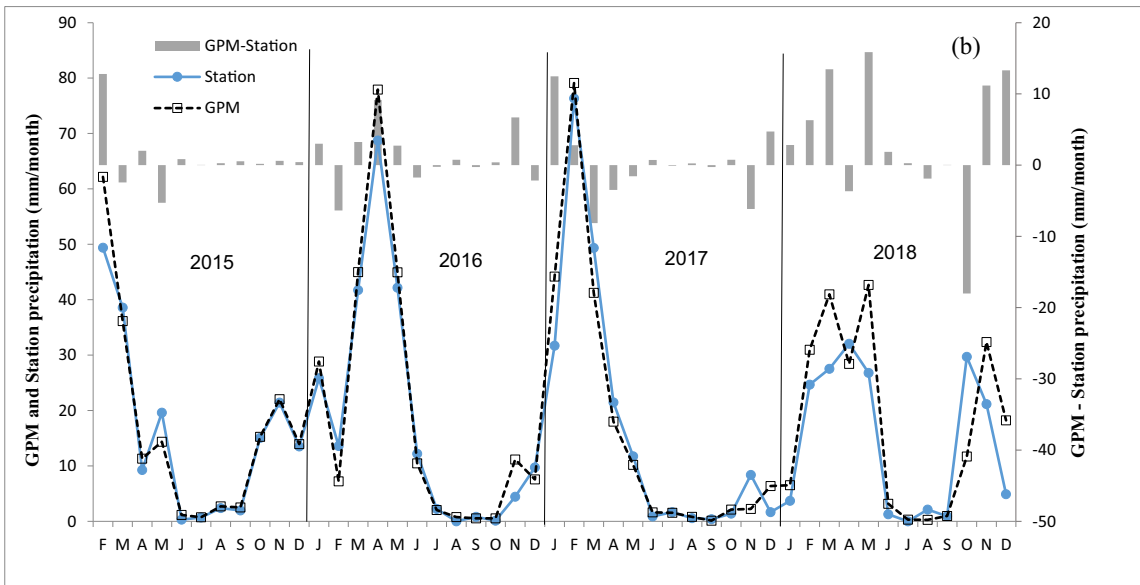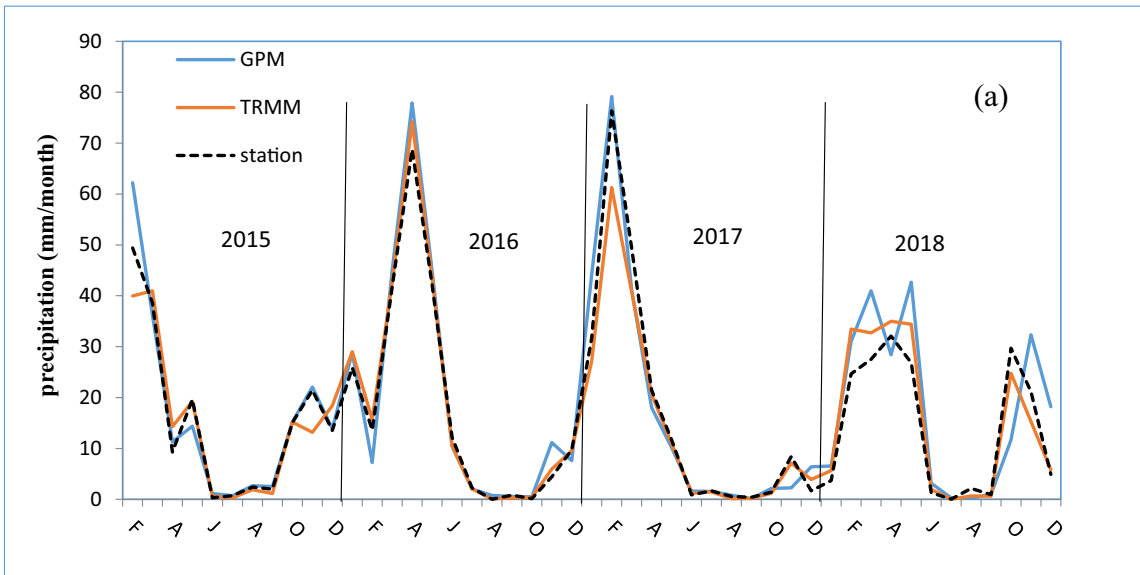
Fig. 5 (a) Monthly rainfall (mm) from gauges and two satellite rainfall products (Feb 2015 to Nov 2018), (b) temporal evolution of the monthly precipitation in each month during the 4-year period (Feb 2015 to Nov 2018); in (b), the dotted line represents the GPM data, the solid line represents the rain-gauge observations, and the bar represents the difference between GPM and the rain-gauge. (c) Temporal evolution of the monthly precipitation in each month during the 4-year period (Feb 2015 to Nov 2018); in (c), the dotted line represents the TRMM data, the solid line represents the rain-gauge observations, and the bar represents the difference between TRMM and the rain gauge

RMSE (4.07 mm/month) and ME (− 0.09 mm/month) as shown in Table 4. Also, there was a good correlation between the GPM products and the measured rainfall from gauges with the CC value of 0.99 and KGE′ value of 0.93. However, the GPM overestimated and TRMM underestimated the observed rainfall with relative bias (RBIAS) of 6% and − 0.6%, respectively. Overall, all satellite precipitation products correlated well with measurements from gauges on the monthly timescale. These results are compatible with those reported by Tan et al. (2015) and Tan and Duan (2017).

3.3 Seasonal variations

As shown in Fig. 6 and Table 5, in all seasons except fall, the GPM products tended to overestimate. The TRMM products showed underestimation in all seasons except in spring.
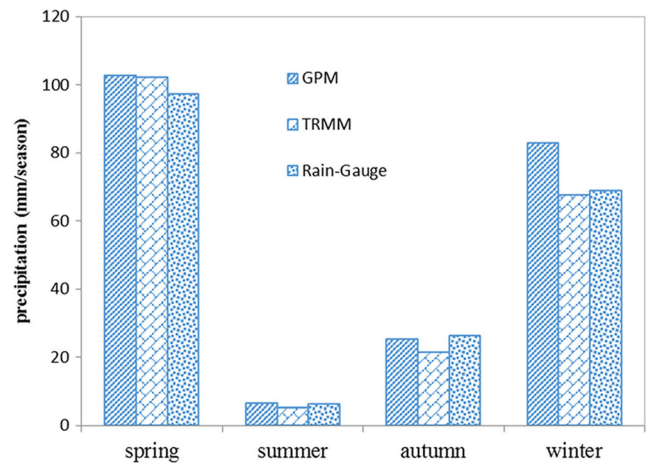

Fig. 6 Seasonal variations of rainfall data from GPM and TRMM rainfall products with rain-gauge data

In fall, TRMM products showed a better agreement as reflected in CC (0.97), RMSE (3.31), and KGE′ (0.8).

In spring, summer, and winter, all satellite precipitation products correlated well with measurements from gauges on the seasonal timescale. Nevertheless, TRMM provide a slightly better performance compared with the GPM with higher CC (0.96–0.98) and KGE′ (0.79–0.93), and lower RMSE (0.72–4.38 mm/month) and ME (− 0.46–1.67 mm/month), as shown in Table 5. Also, there was a good correlation between the GPM products and the measured rainfall from gauges with the CC value of 0.92–0.96 and KGE′ value of

Table 5 Statistical metrics and the categorical statistical metrics of seasonal rainfall measures by GPM and TRMM-3B42 V7 over the period of February 2015 to November 2018

Seasonal	Metrics	GPM vis gauge	TRMM vis gauge	GPM vis TRMM
Spring	CC	0.92	0.96	0.97
	ME (mm)	1.84	1.67	− 0.17
	RMSE (mm)	7.45	4.38	4.71
	RBIAS	0.06	0.05	− 0.005
	KGE′	0.87	0.93	0.88
Summer	CC	0.96	0.98	0.98
	ME (mm)	0.09	− 0.30	− 0.39
	RMSE (mm)	1.01	0.72	0.58
	RBIAS	0.04	− 0.15	− 0.18
	KGE′	0.79	0.85	0.68
Autumn	CC	0.77	0.97	0.72
	ME (mm)	− 0.35	− 1.7	− 1.35
	RMSE (mm)	6.67	3.31	7.04
	RBIAS	− 0.04	− 0.19	− 0.16
	KGE′	0.77	0.80	0.67
Winter	CC	0.96	0.97	0.93
	ME (mm)	4.56	− 0.46	− 5.03
	RMSE (mm)	7.56	6.48	11.14
	RBIAS	0.19	− 0.02	− 0.18
	KGE′	0.78	0.79	0.76

Table 6 Comparison of IMERG evaluation studies with the current research on daily timescale

Researcher	Research area	Statistical period	RMSE (mm)	CC
Our results	Iran	Feb 2015–Nov 2018	1.87−2.85	0.13−0.42
Tan and Duan	Singapore	Apr 2014−Jan 2016	11.83	0.53
Xu et al.	Southern Tibetan Plateau	May 2014−Oct 2014	7.16	0.46
Kim et al.	Korea, Japan	Mar 2014−Aug 2014	6.68−23.41	0.53−0.68
Tang et al.	China	May 2014−Sept 2014	4.44−13.09	0.62−0.9
Tang et al.	China	Apr 2014−Dec 2014	0.5	0.96
Sharifi et al.	Iran	Mar 2014−Feb 2015	6.38−19.41	0.4−0.52
Ning et al.	China	Apr 2014−Nov 2015	6.43	0.68
Guo et al.	China	Mar 2014−Mar 2015	0.56	0.93

0.78–0.87. Overall, it was found that the performance of the GPM and TRMM products was almost the same which is identical with the result obtained over Singapore (Tan and Duan 2017), China (Wang and Lu 2015), the Tibetan Plateau (Xu et al. 2017), Western United States (Wen et al. 2016), Iran (Sharifi et al. 2016), and India (Prakash et al. 2016), as well as Japan and Korea (Kim et al. 2017). For instance, the TRMM compared with the GPM product slightly improved the seasonal rainfall data in data in these seasons.

Although GPM provides data with a temporal resolution of half hourly at a spatial resolution of $0.1° × 0.1°$, the TRMM slightly improved the rainfall data in this region as compared with the GPM product. Following the Tan and Duan (2017), the result of this study was compared with that of similar studies as outlined in Table 6.

4 Conclusions

Satellite-based precipitation estimation technology is growing rapidly with the aim of delineating temporal and spatial variations of rainfall accurately. Validation of newly released GPM data as a result of recent advances in precipitation measurement via gauge data was conducted over the northeast of Iran. It was evaluated and compared with TRMM-3B42 V7 on daily, monthly, and seasonal scales over a semiarid region using 13 rain gauges at high standard synoptic stations for the period of Feb 2015 to Oct 2018. Different metrics and statistical indices were employed to quantify the efficiencies of the two satellite-based time series. TRMM demonstrated a slightly better performance than GPM products in estimating the daily rainfall over the research area. On the monthly scale, it was found that both satellite products performed well but GPM provided a slight overestimation specifically for higher rainfall. In contrast, TRMM demonstrated underestimation compared with the gauge data on the monthly scale. However, TRMM performed slightly better than GPM products. Eventually, on the seasonal scale, it was found that all satellite precipitation products correlated well with measurements from gauges in spring, summer, and winter but in fall, TRMM products outperformed GPM. The GPM products slightly overestimated the values in all seasons except fall, but the TRMM products tended to underestimate the data in all seasons except spring. Although SPPs facilitate rainfall estimation for the ungauged areas, as is evident from the result of this study and other investigations, there is still significant discrepancy between the observed data and those estimated by the satellite. This research may be extended using TRMM data for runoff simulation and see how well TRMM and GPM could potentially feed distributed hydrological model.

References

Akbari A, Daryabor F, Samah AA, Fanodi M (2017) Validation of TRMM 3B42 V6 for estimation of mean annual rainfall over ungauged area in semiarid climate. Environ Earth Sci 76:537. https://doi.org/10.1007/s12665-017-6867-3

Buarque DC, De Paiva RCD, Clarke RT, Mendes CAB (2011) A comparison of Amazon rainfall characteristics derived from TRMM, CMORPH and the Brazilian national rain gauge network. J Geophys Res Atmos 116(D19). https://doi.org/10.1029/2011JD016060

Chen F, Li X (2016) Evaluation of IMERG and TRMM 3B43 monthly precipitation products over mainland China. Remote Sens 8(6):472. https://doi.org/10.3390/rs8060472

Franchito SH, Rao VB, Vasques AC, Santo CME, Conforte JC (2009) Validation of TRMM precipitation radar monthly rainfall estimates over Brazil. J Geophys Res Atmos 114(D2). https://doi.org/10.1029/2007JD009580

Guo H, Chen S, Bao A, Behrangi A, Hong Y, Ndayisaba F, Hu J, Stepanian PM (2016) Early assessment of Integrated Multi-satellite Retrievals for Global Precipitation Measurement over China. Atmos Res 176–177:121–133. https://doi.org/10.1016/j.atmosres.2016.02.020

Gupta HV, Kling H, Yilmaz KK, Martinez GF (2009) Decomposition of the mean squared error and NSE performance criteria: implications for improving hydrological modelling. J Hydrol 377(1-2):80–91. https://doi.org/10.1016/j.jhydrol.2009.08.003

He Z, Yang L, Tian F, Ni G, Hou A, Lu H (2017) Intercomparisons of rainfall estimates from TRMM and GPM multisatellite products over the Upper Mekong River Basin. J Hydrometeorol 18(2):413–430. https://doi.org/10.1175/jhm-d-16-0198.1

Hou AY, Kakar RK, Neeck S, Azarbarzin AA, Kummerow CD, Kojima M, Oki R, Nakamura K, Iguchi T (2014) The global precipitation measurement mission. Bull Am Meteorol Soc 95(5):701–722. https://doi.org/10.1175/BAMS-D-13-00164.1

Huffman GJ, Adler RF, Bolvin DT et al (2007) The TRMM multisatellite precipitation analysis (TMPA): quasi-global, multiyear, combined-sensor precipitation estimates at fine scales. J Hydrometeorol 8(1):38–55. https://doi.org/10.1175/JHM560.1

Karaseva MO, Prakash S, Gairola RM (2012) Validation of high-resolution TRMM-3B43 precipitation product using rain gauge measurements over Kyrgyzstan. Theor Appl Climatol 108(1):147–157. https://doi.org/10.1007/s00704-011-0509-6

Katiraie-Boroujerdy PS, Nasrollahi N, Hsu K, Lin SS (2013) Evaluation of satellite-based precipitation estimation over Iran. J Arid Environ 97(Supplement C):205–219. https://doi.org/10.1016/j.jaridenv.2013.05.013

Kazmi DH, Rasul G, Li J, Cheema SB (2014) Comparative study for ECHAM5 and SDSM in downscaling temperature for a geo-climatically diversified region, Pakistan. Appl Math 5:137–143. https://doi.org/10.4236/am.2014.51016

Kim K, Park J, Baik J, Choi M (2017) Evaluation of topographical and seasonal feature using GPM IMERG and TRMM 3B42 over Far-East Asia. Atmos Res 187(Complete):95–105. https://doi.org/10.1016/j.atmosres.2016.12.007

Kling H, Fuchs M, Paulin M (2012) Runoff conditions in the upper Danube basin under an ensemble of climate change scenarios. J Hydrol 424-425:264–277. https://doi.org/10.1016/j.jhydrol.2012.01.011

Mantas VM, Liu Z, Caro C, Pereira AJSC (2015) Validation of TRMM multi-satellite precipitation analysis (TMPA) products in the Peruvian Andes. Atmos Res 163(Supplement C):132–145. https://doi.org/10.1016/j.atmosres.2014.11.012

Michaelides S (2008) Precipitation: advances in measurement, estimation and prediction. Springer Science & Business Media.

Milewski A, Elkadiri R, Durham M (2015) Assessment and comparison of TMPA satellite precipitation products in varying climatic and topographic regimes in Morocco. Remote Sens 7(5):5697–5717. https://doi.org/10.3390/rs70505697

Moazami S, Golian S, Kavianpour MR, Hong Y (2013) Comparison of PERSIANN and V7 TRMM multi-satellite precipitation analysis (TMPA) products with rain gauge data over Iran. Int J Remote Sens 34(22):8156–8171. https://doi.org/10.1080/01431161.2013.833360

Nash JE, Sutcliffe JV (1970) River flow forecasting through conceptual models part I - A discussion of principles. J Hydrol 10(3):282–290. https://doi.org/10.1016/0022-1694(70)90255-6

Ning S, Wang J, Jin J, Ishidaira H (2016) Assessment of the latest GPM-Era high-resolution satellite precipitation products by comparison with observation gauge data over the Chinese Mainland. Water 8:481. https://doi.org/10.3390/w8110481

Prakash S, Mitra AK, Rajagopal EN, Pai DS (2016) Assessment of TRMM-based TMPA-3B42 and GSMaP precipitation products over India for the peak southwest monsoon season. Int J Climatol 36(4):1614–1631. https://doi.org/10.1002/joc.4446

Rios Gaona MF, Overeem A, Leijnse H, Uijlenhoet R (2016) First-year evaluation of GPM rainfall over the Netherlands: IMERG day 1 final run (V03D). J Hydrometeorol 17(11):2799–2814. https://doi.org/10.1175/JHM-D-16-0087.1

Sahlu D, Nikolopoulos EI, Moges SA, Anagnostou EN, Hailu D (2016) First evaluation of the day-1 IMERG over the upper blue nile basin. J Hydrometeorol 17(11):2875–2882. https://doi.org/10.1175/JHM-D-15-0230.1

Sharifi E, Steinacker R, Saghafian B (2016) Assessment of GPM-IMERG and other precipitation products against gauge data under different topographic and climatic conditions in Iran: Preliminary results. Remote Sens 8(2):135. https://doi.org/10.3390/rs8020135

Stisen S, Sonnenborg TO, Højberg AL et al (2011) Evaluation of climate input biases and water balance issues using a coupled surface-subsurface model. Vadose Zo J 10(1):37–53. https://doi.org/10.2136/vzj2010.0001

Tan ML, Duan Z (2017) Assessment of GPM and TRMM precipitation products over Singapore. Remote Sens 9(7):720. https://doi.org/10.3390/rs9070720

Tan ML, Ibrahim AL, Duan Z, Cracknell A, Chaplot V (2015) Evaluation of six high-resolution satellite and ground-based precipitation products over Malaysia. Remote Sens 7:1504–1528. https://doi.org/10.3390/rs70201504

Tang G, Zeng Z, Long D, Guo X, Yong B, Zhang W, Hong Y (2016) Statistical and hydrological comparisons between TRMM and GPM Level-3 products over a midlatitude Basin: Is day-1 IMERG a good successor for TMPA 3B42V7? J Hydrometeorol 17(1):121–137. https://doi.org/10.1175/JHM-D-15-0059.1

Thornthwaite CW (1948) An Approach toward a rational classification of climate. Geogr Rev 38:55–94. https://doi.org/10.2307/210739

Wang W, Lu H (2015) Evaluation and hydrological applications of TRMM rainfall products over the Mekong River basin with a distributied model. In: International Geoscience and Remote Sensing Symposium (IGARSS) 26-31 :511-2514. doi:https://doi.org/10.1109/IGARSS.2015.7326321

Wang W, Lu H, Zhao T, Jiang L, Shi J (2017) Evaluation and comparison of daily rainfall from latest GPM and TRMM products over the Mekong River Basin. IEEE J Sel Top Appl Earth Obs Remote Sens 10(6):2540–2549. https://doi.org/10.1109/JSTARS.2017.2672786

Wen Y, Behrangi A, Lambrigtsen B, Kirstetter PE (2016) Evaluation and uncertainty estimation of the latest radar and satellite snowfall products using SNOTEL measurements over mountainous regions in western United States. Remote Sens 8. https://doi.org/10.3390/rs8110904

Xu R, Tian F, Yang L, Hu H, Lu H, Hou A (2017) Ground validation of GPM IMERG and trmm 3B42V7 rainfall products over Southern Tibetan plateau based on a high-density rain gauge network. J Geophys Res 122(2):910–924. https://doi.org/10.1002/2016JD025418

Yong B, Liu D, Gourley JJ, Tian Y, Huffman GJ, Ren L, Hong Y (2015) Global view of real-time TRMM multisatellite precipitation analysis: implications for its successor global precipitation measurement mission. Bull Am Meteorol Soc 96(2):283–296. https://doi.org/10.1175/BAMS-D-14-00017.1