EVALUATION AND CORRECTION OF DIFFERENT PRECIPITATION PRODUCTS OVER AKDENIZ BASIN, TURKEY

Anas Hesham¹, Ali Danandeh Mehr2 and Dursun Zafer Seker3
¹Istanbul Technical University, Graduate SchoolProgram of Geomatics Engineering, Maslak, 34469 Istanbul, Turkey
Email: khafagy20@itu.edu.tr
[2]Antalya Bilim University, Department of Civil Engineering, Döşemealtı, 07190 Antalya, Turkey
Email: Ali.danandeh@antalya.edu.tr
[3]Istanbul Technical University, Faculty of Civil Engineering, Department of Geomatics, Maslak, 34469 Istanbul, Turkey
Email: seker@itu.edu.tr

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ABSTRACT: Accurate rainfall estimation is an essential task for optimal water resources planning and management. However, it is a challenging issue in areas with complex topography. To cope with such problems, remote sensing technology is increasingly used instead of local measurement techniques. This study evaluates the accuracy of five remotely sensed precipitation products over the Akdeniz Basin, Turkey at a monthly scale. The products include Precipitation Estimation from Remotely Sensed Information using Artificial Neural Networks (PERSIANN) with 0.25˚ × 0.25˚ spatial resolution, PERSIANN-Cloud Classification System (PERSIANN CCS) with 0.04 ˚ × 0.04˚ spatial resolution, PERSIANN- Climate Data Record (PERSIANN CDR) with 0.25˚ × 0.25˚ spatial resolution, Group InfraRed Precipitation with Station data (CHIRPS) which combines satellite observation with 0.05˚ × 0.05˚ spatial resolution and rain gauge stations, and Tropical Rainfall Measuring Mission product Multi-satellite Precipitation Analysis 3B42V7 (TMPA 3B42V7) with 0.25˚ × 0.25˚ spatial resolution. To assess the remotely sensed precipitation accuracy, root mean square error (RMSE) and Pearson correlation coefficient (R) between each product and the observed data from four ground-based stations during the period of 2003 to 2018 were calculated used. In addition, the precipitation values of the best product were corrected using a linear regression method. The results showed that TMPA 3B42V7 and CHIRPS have higher accuracy than those of PERSIANN products. The R for TMPA 3B42V7 and CHIRPS were 0.9 and 0.86, respectively which are corresponding to a strong linear correlation between satellite product and observed data. The results also showed that PERSIANN CCS and PERSIANN provide a weak correlation with observed data. Also, RMSE confirms the superiority of CHIRPS and TMPA 3B42V7 over the study area with 23 mm and 19.7 mm respectively while PERSIANN, PERSIANN CCS, and PERSIANN CDR were 53.7 mm, 51.8 mm, and 34.9 mm, respectively. After the correction of TMPA 3B42V7 using linear regression, the RMSE dropped from 19.7 mm to 15.7 mm. The evaluation proposes that TMPA 3B42V7 and CHIRPS can be promising precipitation products (after a bias correction) to be used as complementary to the ground-based stations for potential applications in the Akdeniz basin in Turkey.

1. INTRODUCTION

Precipitation is a major element of the hydrological cycle and global climate (Prakash et al., 2015). It is the main input for hydrological and environmental models' studies (Daly et al., 1994). So, it is very important to estimate precipitation accurately and study its characteristics along space and time. Nowadays, there are three main precipitation observation methods including weather radar, rain gauge stations, and remote sensing products (Jiang et al., 2014). Weather radar is not widely used as it is expensive and not easy to use (Sadeghi et al., 2020). Rain gauge stations are the most effective, accurate, and widely used method. However, this method has limitations such as the number of stations and spatial distribution which are necessary to represent complex topography and large areas. Thus, the rain gauge-based method is not sufficient when there is a lack of the number of stations especially when the terrain is complex (Sun et al., 2018).

On the other hand, remote sensing products have a large spatial coverage comparing to rain gauge station, so remote sensing products is a good choice for obtaining precipitation in large areas. Despite this advantage, remote sensing products have a bias that varies according to location, elevation, weather condition, and amount of rainfall. Therefore, bias correction is not an easy task. There are several remote sensing precipitation products such as APHRODITE V1101, CHIRPS V2.0, CPC-Global, ERA5, GPCC V.2018 (V2), GPCP-1DD V1.2, PERSIANN, PERSIANN CCS, PERSIANN CDR, PDIR-Now, TMPA (3B42V7), TMPA (IMERG), and CMORPH. Although these data have been evaluated over a large scale, it is a must to evaluate them over a regional scale before using them in any hydrological or climate studies as the performance of different products changes over different regions. Qianxin Wu et al. (2021)

evaluated nine precipitation products with six rain gauge stations during 2001-2013 on annual, seasonal, and monthly scales in a region with cold climate as the Upper Reach of the Shule River basin in China and found that CMFD has the best performance and explained this as CMFD is based on merged ground observations and satellite data. Qian Ma et al. (2020) compared IMERG and TMPA for 20 years over 7 subregions in China with different climate conditions and found that IMERG overperformed TMPA, after that, they corrected the bias in IMERG which gave better results.

Girma Berhe Adane et al. (2021) reported evaluation and comparison of remote sensing products over different climate and terrain conditions in Ethiopia and found that the performance differs with the change in climate or elevation for example the PERSIANN-CDR products have low performance at elevations more than 2250m above sea level. Victoria M. Garibay et al. (2021) compared CFSR which is a reanalysis of precipitation data with ground-based data in the East African countries Kenya, Uganda, and Tanzania and made Bias correction which improved bias for different water resources studies in that region.

In this study, an evaluation and comparison will be done between many satellite precipitation products and ground-based stations over the Akdeniz basin in Turkey which is one of the most important basins and has a significant effect on the tourism and economy in Turkey. This study is important for future hydrological and environmental studies in this region.

2. STUDY AREA

In this study, the Akdeniz Basin is selected as a study area (Figure 1). This basin is one of the most important basins in Turkey (There are 25 basins in Turkey). Its area is about 120,000 km² and is located in the south of Turkey between longitudes 29º E to 37.7º E and latitudes 35.6º N to 38.45º N. Akdeniz Region is a mountainous region and has several rivers and lakes. The annual precipitation ranges from 580 to 1300 mm (Sensoy, 2004), most of the rain is in the winter while the summer is dry. Also, the mountains and the location corresponding to the coasts affect the amount of precipitation. For example, Antalya station which lies on the coast in the front of Taurus Mountain receives precipitation 3 times the amount received by the stations back of Taurus such as Karaman and Burdur stations (Sensoy, 2004). There are 7 provinces totally, 1 mostly, and 8 partially involved in the basin with a population of about 2,980,000.

Figure 1. Akdeniz Basin in Turkey (study area).

3. DATA USED

The precipitation data used in this study is coming from different remote sensing precipitation products such as PERSIANN, PERSIANN CCS, PERSIANN CDR, CHIRPS, and TMPA 3B42V7. The performance of each product was evaluated by verifying their data with ground-based stations data from 2003 to 2018.

3.1 Ground-based stations:

Four-gauge stations located in different regions in the Akdeniz basin (Mersin, Isparta, Kahramanmaras, and Ulukisla with 5m, 1043m, 549m, and 1451m elevation above sea level) were used to evaluate the satellite-based precipitation products. These data were collected from World Meteorological Organization (https://climexp.knmi.nl/start.cgi).

3.2 Satellite-based precipitation products

This section includes a brief description of each satellite product used in the study. Also, Table 1 gives a summary of them.

Table 1. Satellite-based precipitation products used in the study.

Product	Spatial resolution	Spatial resolution	Periods	Spatial coverage
CHIRPS V2.0	0.05°	Daily	1981-present	50°S-50°N
PERSIANN	0.25° x 0.25°	Hourly	2000-present	60°S to 60°N
PERSIANN CCS	0.04° x 0.04°	Hourly	2003-present	60°S to 60°N
PERSIANN CDR	0.25° x 0.25°	Daily	1983-present	60°S to 60°N
TMPA (3B42V7)	0.25 ° x 0.25 °	Daily	1998-2020	50°S-50°N

- PERSIANN: was developed by the Center for Hydrometeorology and Remote Sensing (CHRS) at the University of California Irvine with precipitation data coverage between 60º S to 60º N from March 2000 until present with an hourly temporal resolution with two days delay. It uses a neural network to estimate the rainfall at each 0.25º x 0.25º from infrared brightness temperature images. Later PERSIANN system was extended to use visible beside infrared images. The system uses a long-wave infrared channel (10.2-11.2 um) from GOES-8, GOES-10, GMS-5, Meteosat-6, and Meteosat-7 provided by CPC, NOAA. Also. It uses rainfall estimation from satellites such as TMPA, NOAA-15, -16, -17, DMSP F13, F14, F15 (Hsu et al., 1997, Hsu et al., 2000).

- PERSIANN CCS:A new version of PERSIANN which estimates precipitation based on classifying clouds from remote sensing infrared images based on their shape, geometry, texture, extent, etc. Estimation of rainfall is based on a specific curve that relates to the rain rate and brightness temperature. PERSIANN CCS provides real-time precipitation from January 2003 until the present covers from 60°S to 60°N with 0.04° x 0.04° spatial resolution and hourly temporal resolution (Hong et al., 2004).

- PERSIANN CDR: Which provides daily precipitation data covers from 60°S to 60°N with 0.25° x 0.25° spatial resolution since January 1983 and the last update is in September 2020. This long-term dataset enables studying the changes in daily precipitation which occurred due to climate change (Ashouri et al., 2015).

- CHIRPS: This uses data from both satellite images and gauge stations to build gridded precipitation time series to be used in trend analysis and seasonal drought monitoring. CHIRPS is used by the U.S. Agency for International Development (USAID) for drought monitoring. It provides daily precipitation data (the final product delays 3 weeks) spanning 50°S-50°N 1981 until present with 0.05° spatial resolution, also it provides 0.25° resolution for daily precipitation in Africa. The precipitation estimation is based on infrared Cold Cloud Duration (CCD) observations and using TMPA 3B42 v7 to calibrate it (Funk et al., 2015).

- TMPA 3B42 v7: The Tropical Rainfall Measuring Mission (TRMM) for monitoring global precipitation based on remote sensing data, which is a joint space mission between the National Aeronautics and Space Administration (NASA) and the Japanese Aerospace Exploration Agency (JAXA). TMPA uses different instruments to estimate and detect rainfall such as radar, microwave imager, visible infrared scanner, clouds, and earth's radiant energy system and lightning imaging sensor. In 2015 TRMM stopped working and a new product TMPA which uses data from different satellites was used to continue the TRMM mission. TMPA merges microwave data from different satellites such as SSMI, SSMIS, MHS, AMSU-B, and AMSR-E, these data are calibrated using the TRMM Combined Instrument (TCI). TMPA 3B42 provides 3-hours and daily precipitation data while TMPA 3B43 provides the data monthly. The data ranging from 1998 to 2019 with 0.25° spatial resolution spanning 50°S to 50°N (Huffman et al. 2021).

4. METHODOLOGY

The study aims to evaluate five satellite-based precipitation products at a monthly scale. Figure 2 shows the procedures of the study step by step.

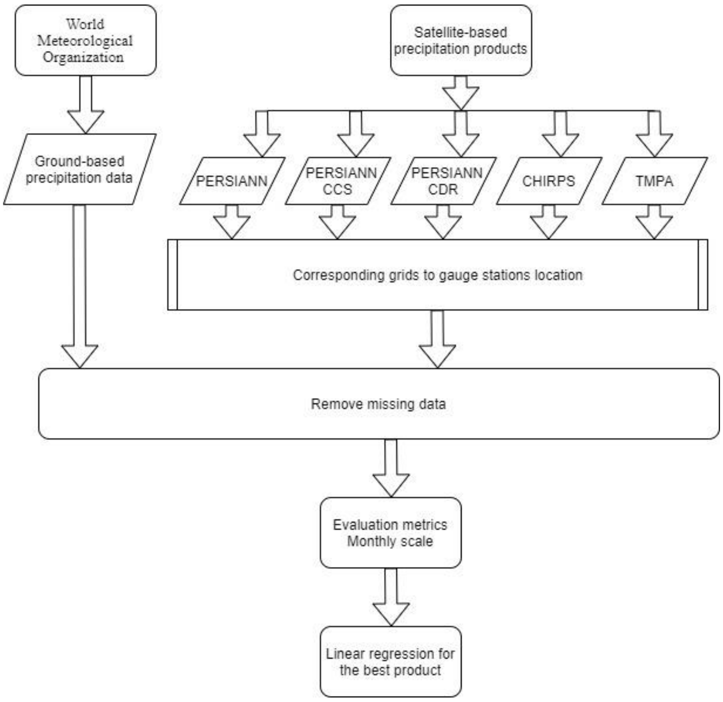

Figure 2. Flow chart of the research.

4.1 Missing data

For each precipitation product, there are missing data, and the dates of these data are different. Also, the same problem exists with the ground-based station data. To avoid this problem, if there is a missing estimation day in a certain product, all the data of that day is deleted for all other products to avoid any miscalculation.

4.2 Grids of satellite data vs gauge station's location

The precipitation data of satellite products is given according to grids which depend on the spatial resolution of that product as shown in Figure2. The grids used in the study are only the grids that contain or intersect gauge stations. For each precipitation product, the data of the grid is compared to the corresponding gauge station lies at that grid. If a gauge station is located at the intersection of two or four grids (as shown in Figure 2) the data of these grids were averaged, then compared to the data of the corresponding gauge station.

4.3 Evaluation of the satellite-based precipitation products

Root mean square error (RMSE) and Pearson correlation coefficient (R) was used to evaluate the accuracy of the precipitation products. These indicators were calculated between each satellite-based precipitation product and the data of each of the four-gauge stations.

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(S_i - G_i)^2}{n}} \qquad (1)$$

$$R = \frac{\sum(G_i - \bar{G})(S_i - \bar{S})}{\sqrt{\sum(G_i - \bar{G})^2 (S_i - \bar{S})^2}} \qquad (2)$$

where n represents the number of stations; S_i and G_i represent satellite and ground-based precipitation (mm) data, respectively while $\bar{G}\ and\ \bar{S}$ represent the average of $G$and S, respectively.

RMSE represents the precision of the product, the lower RMSE the more precision of the product. On the other hand, the values of R are classified into categories [(MRP and Arkin 2009], $0.8 < R \leq 1.0$ extremely strong correlation, $0.6 < R \leq 0.8$ strong correlation, $0.4 < R \leq 0.6$ moderate correlation, $0.2<R\leq 0.4$ weak correlation, and $0.0 \leq R\leq 0.2$ extremely weak or uncorrelated.

4.4 Bias correction of satellite-based precipitation products

After comparing the products with the gauge station, the product with the most appropriate results in the study area was founded and the data of it was enhanced using a linear regression algorithm between these data and the gauge stations data. The modified data was then compared to the ground-based precipitation data and the new error was obtained. Linear regression was applied to fit the parameters a and b which of the following equation between ground-based and satellite-based precipitation as follow:

$$Pr_{gauge} = a\, Pr_{satellite} + b \qquad (3)$$

where $Pr_{gauge} and Pr_{satellite}$ are the data of ground-based and satellite-based precipitation, respectively.

5. RESULTS AND DISCUSSION

Each satellite-based precipitation product was evaluated by comparing its data to the ground-based precipitation data. The results of all stations together as well as the results of each station individually were compared and discussed.

Table 2 and Figure 3 show that TMPA 3B42 v7 overperformed other products in both RMSE and R. Also, CHIRPS shows good results and is close to the accuracy of TMPA 3B42 v7. TMPA 3B42V7 and CHIRPS have a strong linear correlation between satellite product and observed data corresponding to the values of R which are more 0.8 for both products. In addition, PERSIANN CDR shows good and acceptable results while PERSIANN and PERSIANN CCS do not. Especially PERSIANN which has a weak correlation according to R-value.

Figure 3 shows that there is an overestimation when the amount of precipitation is low while it is an underestimation when the amount of precipitation is high.

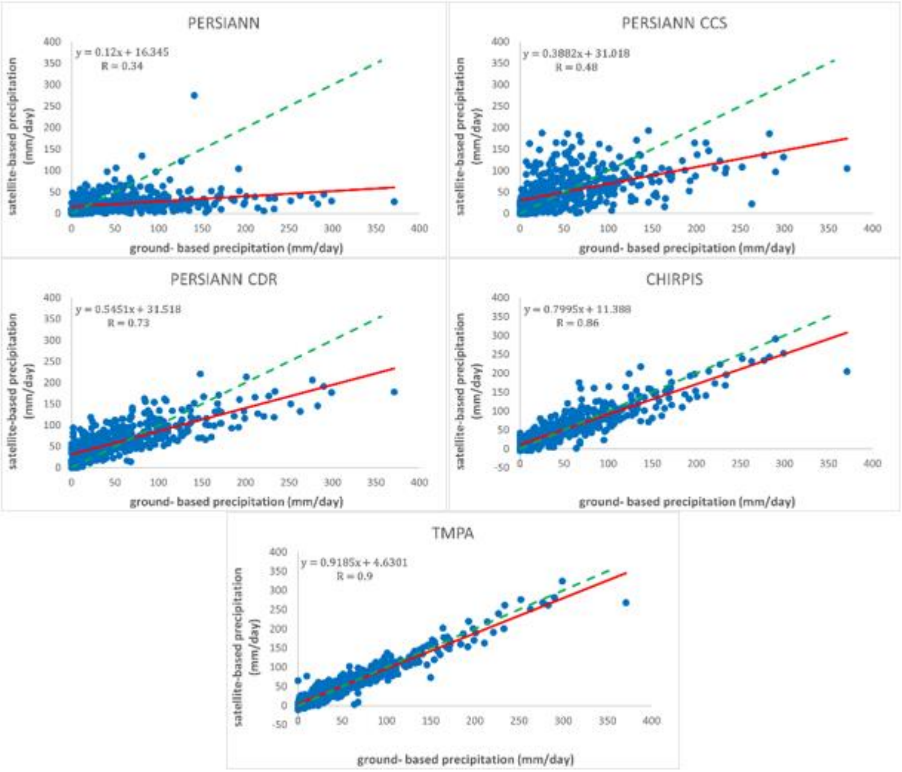

Figure 3. Scatter plots of ground-based precipitation data vs satellite-based precipitation data at monthly scale, red line refers to the relationship between the data from the precipitation product and the data from gauge stations while green line used as the reference.

Table 2. RMSE (mm) and R for each satellite-based precipitation products.

Product	PERSIANN	PERSIANN CCS	PERSIANN CDR	CHIRPS	TMPA 3B42 v7
RMSE (mm)	53.7	51.8	34.9	23	**19.7**
R	0.34	0.48	0.73	0.86	**0.9**

Furthermore, Table 3 R for each station shows the superiority of TMPA 3B42V7 for all stations except Ulukisla where CHIRPS is slightly better. Also, all products except PERSIANN got the best results at Kahramanmaras comparing to other stations.

Table 3. R for each satellite-based precipitation product for each gauge station individually.

Station/product	PERSIANN	PERSIANN CCS	PERSIANN CDR	CHIRPS	TMPA 3B42 v7
Mersin	0.33	0.48	0.82	0.89	**0.96**
Isparta	0.42	0.50	0.81	0.84	**0.91**
Kahramanmaras	0.21	0.52	0.83	0.91	**0.97**
Ulukisla	0.42	0.42	0.46	**0.79**	0.77

After that the data of TMPA 3B42V7 and CHIRPS were corrected using linear regression, the RMSE of TMPA 3B42V7dropped from 19.7 mm to 15.8 mm which shows better bias correction than CHIRPS which dropped from 23 mm to 22.5 mm as shown in Table4.

Table 4. RMSE (mm) before and after linear regression for CHIRPS and TMPA 3B42 v7.

Product	Before correction	After correction
CHIRPS	23	22.5
TMPA 3B42 v7	19.7	15.8

6. CONCLUSION

In this research five satellite-based precipitation products, PERSIANN, PERSIANN CCS, PERSIANN CDR, CHIRPS, and TMPA 3B42 v7 were evaluated by ground-based stations over the Akdeniz basin in Turkey in the period between 2003 and 2018. TMPA 3B42 v7 gave the best results compared to the other products. Also, the results showed that CHIRPS is still good and can be used for rainfall estimation in the study area beside TMPA 3B42 v7 after bias correction for both. In addition, in all products, there is an overestimation in low precipitation events while it is an underestimation for high precipitation events. In future work, there will be more analysis according to the principle of each product, the terrain of the study area, and seasonality to interpret the results in more detail. Also, more ground-based stations shall be used, and a longer period shall be added to get more precise results and efficient bias correction.

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