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Araştırma Makalesi / *Research Article*

Evaluation of GPM-IMERG V07 Precipitation Data Against In-Situ Measurements in a Semi-Arid Region of Türkiye

Türkiye'nin Yarı Kurak Bölgesi için Tahmin Edilen GPM-IMERG V07 Yağış Verilerinin Gerçek Gözlemlerle Karşılaştırılması

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ABSTRACT

Accurate precipitation data are essential for hydrological modeling, water resource management, and climate impact assessments, particularly in semi-arid regions that are increasingly affected by water scarcity. Satellite-based products, such as the *Global Precipitation Measurement (GPM)* mission's *Integrated Multi-satellite Retrievals for GPM (IMERG) Final Run Version 07 (V07)*, may offer a valuable alternative to sparse and unevenly distributed ground-based observations. The primary objective of this study is to assess the performance of GPM IMERG V07 precipitation estimates for the semi-arid region of southern Türkiye by comparing them with gauge data from Adana Meteorological Station for the period 1998–2024. Statistical evaluation was conducted using the coefficient of determination (R^2), Pearson's correlation coefficient (r), and root mean square error (RMSE) at both monthly and yearly scales. Furthermore, F-tests and Student t-tests were applied to assess differences in precipitation variability and mean values between satellite and ground observations. Results indicate that IMERG V07 exhibits strong agreement with in-situ measurements, with high correlation values ($r \approx 0.95$) and RMSE of 23.02 mm/month and 158.63 mm/year, demonstrating its reliability in capturing precipitation dynamics. Nonetheless, despite the strong correlation, IMERG V07 systematically overestimates precipitation totals. This trend of overestimation, confirmed through Student t-tests, suggests that correction methods must be applied to enhance the accuracy of the data before it is used in hydrological and water resource applications. Overall, the findings support the utility of IMERG V07 as a robust precipitation dataset in data-scarce environments like semi-arid regions, provided that its systematic deviation is effectively addressed.

Keywords: Satellite precipitation products, GPM IMERG, semi-arid region, satellite validation, Türkiye

ÖZ

Yağış verileri, özellikle su kıtlığından giderek daha fazla etkilenen yarı kurak bölgelerde hidrolojik modelleme, su kaynakları yönetimi, iklim değişikliği ve etkilerinin değerlendirilmesine yönelik çalışmalarda büyük önem taşımaktadır. Küresel Yağış Ölçüm (GPM) misyonunun Entegre Çoklu Uydu Türevleri (IMERG) Nihai Ürün Sürüm 07 (V07) gibi uydu tabanlı ürünler, seyrek ve düzensiz dağılmış meteoroloji gözlem istasyonları gözlemlerine bir alternatif olmaktadır. Bu çalışmada, 1998–2024 döneminde Türkiye'nin güneyindeki yarı kurak bir bölgede IMERG V07 yağış tahminlerinin, aylık ve yıllık yağış gözlem verileriyle karşılaştırılarak kullanılabilirliğinin ortaya konulması amaçlanmıştır. Amaç doğrultusunda, Adana Meteoroloji İstasyonundan alınan veriler kullanılmıştır.

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İstatistiksel kıyaslamalar, aylık ve yıllık ölçeklerde belirleme katsayısı (R²), Pearson korelasyon katsayısı (r) ve ortalama karekök hata (RMSE) kullanılarak gerçekleştirilmiştir. Ayrıca, uydu ve yer gözlemleri arasındaki yağış değişkenliği ve ortalama değerlerin istatistiksel anlamda farklı olup olmadığının ortaya konulmasında, F-testi ve Student t-testi kullanılmıştır. Sonuçlar, IMERG V07'nin yer gözlemleriyle yüksek düzeyde uyum sağladığını, korelasyon değerlerinin yüksek olduğunu (r ≈ 0.95) ve RMSE değerlerinin aylık 23.02 mm ve yıllık 158.63 mm olduğunu göstermiştir. Bu durum, yağış dinamiklerini yakalama konusunda IMERG V07'nin güvenilirliğini ortaya koymuştur. Veri setleri arasındaki güçlü korelasyona rağmen, IMERG V07'nin yağış toplamlarını sistematik olarak fazla tahmin ettiği saptanmıştır. Student t-testleri ile doğrulanan bu aşırı tahmin eğilimi, GPM-IMERG V07 veri setlerinin hidrolojik modelleme, su kaynaklarının planlanması vb. uygulamalarda kullanılmadan önce, temsil niteliğini (doğruluğunu) artırmak amacıyla düzeltme yöntemlerinin uygulanmasının gerekliliğine işaret etmektedir. Araştırma bulguları bir bütün olarak değerlendirildiğinde, IMERG V07'nin yarı-kurak ve veri yetersizliği olan bölgelerde güçlü bir yağış verisi seti olarak kullanılabileceği; ancak, verilerdeki yanlılığın (sistematik sapmanın) uygun bir yöntem kullanılarak giderilmesi gerektiği sonucuna varılmıştır.

Anahtar Kelimeler: *Uydu yağış ürünleri, GPM IMERG, yarı kurak bölge, uydu doğrulama, Türkiye*

INTRODUCTION

Precipitation (P) is a fundamental component of the Earth's hydrological cycle, directly affecting planning of irrigation and drainage schemes, water resources management, and the occurrence of floods and droughts. Accurate and timely precipitation measurements are essential for addressing a range of scientific and practical challenges, including drought monitoring, flood forecasting, irrigation planning, and assessments of climate change (Aksu and Akgul, 2020). Precipitation is a fundamental component of the hydrological cycle, contributing to the sustainability of water resources and supporting both environmental systems and anthropogenic demands. For example, it plays a crucial role in replenishing groundwater, in human consumption, and in limiting the decline in freshwater abstraction from aquifers in the Eastern Mediterranean region of Türkiye, especially in the Cukurova region. Significant temporal and regional variability may be seen in P patterns, which are impacted by geographic factors, land cover dynamics, and climate change. To improve hydrological evaluations and support decision-making for sustainable resource management, high-quality data at various spatial and temporal scales is essential for a better understanding of these patterns.

Traditionally, precipitation data have been obtained using ground-based methods, including various types of rain gauges—such as the National Oceanic and Atmospheric Administration (NOAA) standard, simple, tipping-bucket, optical, and piezoelectric—and meteorological monitoring stations. Although these instruments provide high accuracy at specific locations, their limited number and spatial coverage, particularly in mountainous and rural areas, pose significant challenges for comprehensive hydrological monitoring (Reddy and Saravanan, 2023). Therefore, satellite-based precipitation estimation has emerged as a complementary approach, offering broad spatial coverage and frequent updates. Among these, the Global Precipitation Measurement (GPM) mission, launched in 2014 as a joint initiative by the National Aeronautics and Space Administration (NASA) and the Japan Aerospace Exploration Agency (JAXA), represents a milestone in global precipitation observation. GPM aims to provide advanced, high-resolution precipitation data globally, using a constellation of satellites equipped with passive microwave and radar sensors (Huffman et al., 2019a, 2019b).

The core instruments of the GPM mission include the Dual-frequency Precipitation Radar (DPR) and the GPM Microwave Imager (GMI), enhancing precipitation detection, particularly for light rainfall and snowfall. The mission's primary product, the Integrated Multi-satellite Retrievals for GPM (IMERG), combines data from multiple sensors to produce precipitation estimates at high spatial resolution of 0.1° (~10 km) and a temporal resolution of 30 minutes. IMERG has been widely adopted in hydrological, meteorological, and climate-related research due to improved accuracy compared to its predecessor, the Tropical Rainfall Measuring Mission (TRMM) (Huffman et al., 2019a; Islam et al., 2020; Moazami and Najafi, 2021; Aksu and Yaldiz, 2025). NASA's latest IMERG release (Version 07) introduces significant updates, and users have been advised not to mix it with earlier versions due to methodological differences (Aksu and Yaldiz, 2025). Given its high resolution and capacity to capture extreme precipitation events, IMERG V07 may be a suitable dataset for regional-scale hydro-meteorological studies. Nevertheless, the validation of these datasets with ground-based measurements is consistently necessary to ensure their reliability.

Several regional studies assessed the accuracy of GPM-IMERG products against in-situ precipitation observations. Moazami and Najafi (2021) assessed the accuracy of IMERG V06 against Canadian ground gauges at both hourly and daily scales (2014–2018), concluding that both IMERG V06 and Multi-Radar Multi-Sensor (MRMS) Precipitation Rate data can effectively complement ground observations. Islam et al. (2020) found that IMERG and the Multi-satellite Precipitation Analysis (TMPA) outperformed other satellite products. Their study compared these datasets with the Climate Prediction Centre Morphing Technique (CMORPH), Precipitation Estimation from Remotely Sensed Information using Artificial Neural Networks (PERSIANN), and the PERSIANN-Climate Data Record (PERSIANN-CDR) against ground gauge measurements across Australia over a five-year period from October 2014 to September 2019. Similarly, various studies have been conducted to evaluate their effectiveness in diverse geographical and climatic settings (Le et al., 2020; Reddy and Saravanan, 2023; Watters et al., 2024). In semi-arid regions, including parts of Türkiye, few validation studies have been conducted to assess the accuracy of GPM IMERG products against ground-based observations. For example, Aksu et al. (2023) evaluated the IMERG V06 Final Run using data from 99 meteorological stations across Türkiye between 2010 and 2020. Their results found Pearson's correlation coefficient of 0.64 between IMERG estimates and daily precipitation records. More recently, Aksu and Yaldiz (2025) validated IMERG V07 using observations from 214 ground stations and compared its performance with the previous V06 version from 2010 to 2022. Their findings demonstrated significant improvements in V07 across all seasons, particularly during winter. In this season, the correlation coefficient increased from 0.57 to 0.64, the mean absolute bias declined from 78.22% to 69.27%, and root mean square error (RMSE) was reduced from 11.10 mm/day to 9.70 mm/day.

The monthly precipitation estimates from IMERG V07 have potential as reliable inputs for calculating water balance, meteorological drought indices such as Standardized Precipitation Index (SPI) and Standardized

Precipitation Evapotranspiration Index (SPEI) (Yuan and Lia, 2025), and agricultural indicators, particularly in semi-arid areas where ground gauge data are scarce. Moreover, GMP IMERG V07 can be used to capture extreme precipitation indices. While GPM-IMERG V07 is extensively utilized for precipitation monitoring, validation with long-term precipitation data from the Adana meteorological station and its surrounding region is limited. Given the critical role of accurate precipitation data in agriculture and water management, this study evaluates the GPM IMERG V07 product by validating it against ground-based observations from the Adana Meteorological Station from 1998 to 2024 at monthly and yearly scales. The evaluation employs statistical metrics, including the correlation coefficient (r) and RMSE. Furthermore, F-tests and t-tests were conducted to compare the variability and mean rainfall values between satellite estimates and ground-based measurements, in order to assess the suitability of GPM IMERG data for hydrological modeling and climate impact assessments. We believe that the findings will provide valuable insights for stakeholders, researchers, and policymakers regarding the strengths and limitations of satellite precipitation data, supporting improved modeling, forecasting, and resource planning under evolving climate conditions.

MATERIALS AND METHODS

Study Area

This study focuses on Adana Province (14,030 km^2) in Türkiye's Eastern Mediterranean, a fertile and densely populated region with a typical Mediterranean climate. It lies at the center of the Cukurova (Cilician) Plain, between 36.5°–38.4°N and 35.0°–35.4°E, as shown in Figure 1. The region experiences hot, dry summers and mild, wet winters. According to long-term climate data (1960–2024) from Adana Meteorological Station (*Station No. 17351*, latitude 37.0041° and longitude 35.3441°), the region receives average annual precipitation of 662.4 mm, with nearly 50% falling during the winter months of December through February (Cetin, 2020). The average monthly temperature is about 19.2 °C, with peak temperatures in July and August averaging 28.4 °C and 28.7 °C, respectively. Relative humidity generally exceeds 80% in the summer months, whereas it can fall below 50% during the wet season (Cetin, 2020; Alsenjar et al., 2023a; 2023b).

Adana province, part of the Cukurova region, is vital to Türkiye's agriculture, which is supported by extensive irrigation and diverse crop cultivation. Winter crops include wheat, onions, potatoes, and lettuce, while summer crops predominantly comprise cotton, soybeans, corn, peanuts, and watermelon. In addition, citrus orchards cover a substantial part of the plain, making it one of the country's most fertile and productive agricultural regions (Ozcan et al., 2003; Cetin et al., 2023a; 2023b).

In-situ precipitation data

Observed precipitation data were obtained from the Turkish State Meteorological Service (TSMS, 2023) for Adana Meteorological Station (Station ID: 17351), located approximately 23 meters above sea level. This station has been in operation for decades, with recorded data going back as far as 1928, and is known for high-quality, continuous meteorological records. Daily precipitation data corresponding to the period 1998–2024, matching the timeframe of the IMERG data, were used in the analysis.

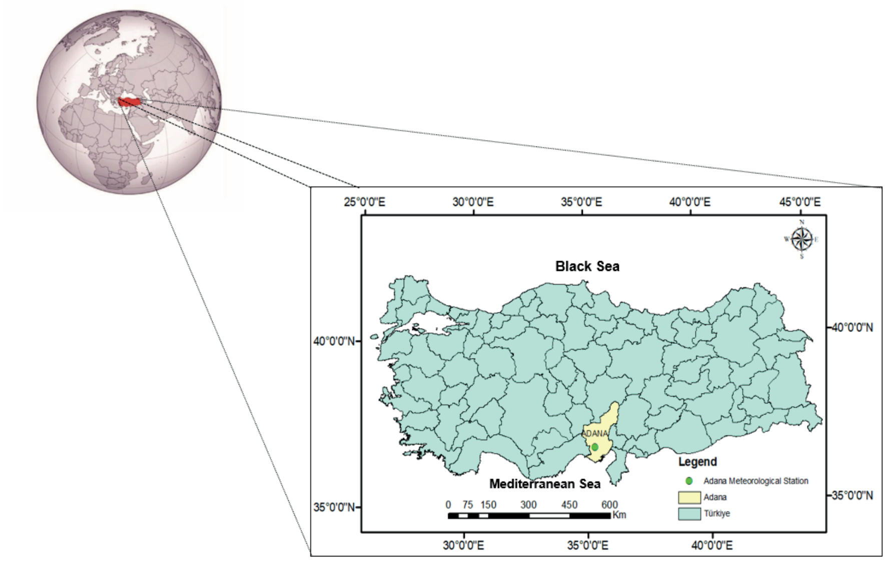


Figure 1. Location of Adana meteorological station (17351) in Türkiye.
Şekil 1. Adana meteoroloji istasyonunun (17351) Türkiye'deki konumu.

This period corresponds to the availability of complete records from IMERG Version 07. As a result, all precipitation data were full with no missing values, eliminating the need for data imputation. The gauge dataset was also visually examined through graphs to ensure consistency. The TSMS used a tipping-bucket rain gauge (200 cm², 0.2 mm/tip) to observe precipitation.

Satellite precipitation data

Satellite precipitation data were obtained from the Global Precipitation Measurement (GPM) Integrated Multi-satellite Retrievals for GPM (IMERG) Version 07 dataset. The IMERG V07 product offers high-resolution global precipitation estimates with a spatial resolution of 0.1° (10 km × 10 km) and a temporal resolution of 3 hours, making it suitable for analyzing precipitation variability and patterns in the study area. The Final Run includes gauge-based corrections (https://gpm.nasa.gov/resources/documents/imerg-v07-release-notes), making it ideal for research and hydrological applications. IMERG integrates data from multiple sensors, including microwave instruments, infrared sensors, and passive/active radar (e.g., DPR aboard GPM Core). These sensors collectively enhance the accuracy and spatial coverage of precipitation estimates. Monthly precipitation data spanning January 1998 to December 2024 were retrieved from the Google Earth Engine (GEE) using the "NASA/GPM_L3/IMERG_MONTHLY_V07" collection. Data extraction and processing were seamlessly integrated between GEE and Python within the Google Colab environment. Further information about the GPM mission and IMERG products is available on NASA's official website (https://gpm.nasa.gov/data/imerg, accessed April 22, 2025). Technical specifications and practical applications of these products were further detailed by Aksu and Yaldiz (2025).

Comparison of GPM IMERG V07 with in-situ precipitation measurements

To ensure consistency in the comparison, the IMERG grid cell corresponding to the coordinates of Adana Meteorological Station was extracted using the GEE platform. Monthly and yearly IMERG values were compared using a point-to-pixel approach to avoid uncertainties associated with interpolation methods applied to point-based precipitation data (Xu et al., 2015) from 1998 to 2024.

This study investigated the discrepancies between in-situ precipitation measurements and GPM IMERG V07 estimates across the study area using simple linear regression. In addition, a comprehensive statistical analysis was conducted to evaluate the accuracy and correlation of the dataset, utilizing the coefficient of determination (R^2), Pearson's correlation coefficient (r), and RMSE. Pearson's correlation coefficient is used to evaluate the goodness of fit of the linear relationship, in which a value of 1 is the perfect score (Kronthaler, 2023), as illustrated in Table 1. RMSE represents the average size of the errors between the datasets. Additionally, we conducted statistical tests on monthly and yearly rainfall datasets to evaluate the agreement between the GPM IMERG V07 satellite precipitation product and in-situ rainfall observations. First, an F-test was applied to compare the variances of the two datasets and assess whether the variability in the data differed significantly. Subsequently, parallel to the result of the F-test, a two-sample t-test (Çetin, 1997) was performed to determine if the mean rainfall amounts from the satellite data significantly differed from the ground measurements. These analyses enabled a robust comparison of the rainfall variability and magnitude in the datasets, providing insight into the accuracy and reliability of the GPM IMERG product for hydrological applications.

Table 1. Reference scale for assessing correlation coefficient strength (Kronthaler, 2023).

Çizelge 1. Korelasyon katsayısı gücünün değerlendirilmesine yönelik referans ölçek (Kronthaler, 2023).

Value of r	Correlation between two variables
r= 1	Perfect positive correlation
1 >r≥ 0.6	Strong positive correlation
0.6 >r≥ 0.3	Weak positive correlation
0.3 >r> -0.3	No correlation
-0.3 ≥ r>-0.6	Weak negative correlation
-0.6 ≥r≥ -1	Strong negative correlation
r= -1	Perfect negative correlation

RESULTS AND DISCUSSION

Validation of GPM IMERG V07 precipitation data

To assess the accuracy and applicability of the GPM-IMERG V07B Final Run precipitation estimates, a comprehensive performance evaluation was conducted using ground-based observations from Adana Meteorological Station, covering the period from January 1998 to December 2024. This long-term comparison aimed to validate the reliability of IMERG data for regional hydrological and climate studies. Statistical metrics, including the R^2, r, and RMSE, were employed to evaluate the consistency between satellite-derived and in-situ precipitation measurements at monthly and annual time scales.

Linear regression analysis was performed to quantify the strength of the relationship between the two datasets, with scatter plots generated to represent their alignment visually (Figure 2). The results demonstrated a consistently strong correlation across temporal scales. At the monthly level, IMERG V07 exhibited a high correlation with observed precipitation (r = 0.95), accompanied by relatively low RMSE of 23.02 mm/month. On a yearly basis, the agreement remained robust, with an identical correlation coefficient (r = 0.95) and RMSE of 158.63 mm/year. This annual RMSE represents approximately 25% of the mean annual precipitation (629 mm from 1998 to 2024), which is considered moderate and acceptable for satellite-based products. Additionally, monthly and yearly temporal variations shown on time series plots indicated that the GPM-IMERG product successfully captured the temporal pattern of precipitation events, as shown in Figure 3. Figure 3 illustrates that GPM IMERG V07 precipitation estimates are generally slightly higher (≈7%) than the corresponding in-situ measurements. This discrepancy likely stems from several contributing factors, including the spatial averaging inherent in satellite retrievals compared to the point-based nature of gauge observations, potential overestimation by IMERG algorithms under certain meteorological conditions, and the indirect detection methods influenced by microphysical cloud properties. Notably, the discrepancies were more pronounced in annual precipitation totals than in monthly values.

The statistical analysis comparing GPM IMERG V07 precipitation data with in-situ rainfall measurements revealed no significant difference in the variability of monthly (F-test, p = 0.1016) and yearly (F-test, p = 0.301) rainfall totals. The variance comparison results indicated that both datasets exhibit similar temporal variability, with no statistically significant difference between their variances. However, the two-sample t-tests showed a statistically significant difference in mean rainfall values at both monthly ($p < 0.0001$) and yearly (p = 0.0016) scales, with GPM IMERG consistently overestimating precipitation compared to ground observations. These results suggest that while the satellite product effectively captures rainfall variability and temporal distribution patterns, it consistently overestimates precipitation amounts, indicating a systematic positive bias in rainfall magnitude. This bias may be attributed to algorithmic limitations, sensor calibration issues, or the influence of local climatic and topographic factors (Huffman et al., 2019b; Aksu and Yaldiz, 2025). Although the flat terrain in the study area minimizes elevation-related errors, the overestimation observed in GPM V07 data may also be influenced by microphysical cloud properties—such as droplet size, vertical structure, and phase transitions—that were not fully addressed. These factors, combined with the inherent challenges of detecting light or convective rainfall in semi-arid climates, warrant further investigation to improve satellite precipitation reliability. Such discrepancies often arise from complex meteorological events, such as convective storms or prolonged light rainfall, which are difficult for satellites to capture accurately. Future research leveraging more detailed datasets will enable separate assessments of precipitation type, intensity, and phase, facilitating more precise and comprehensive analyses. Consequently, GPM IMERG V07 can be effectively used for trend and variability analyses. However, it should be bias-corrected or the equations proposed in this study should be used, as mentioned in Figure 2 (*monthly GPM IMERG V07 = 1.0712 × monthly in-situ precipitation; yearly GPM IMERG V07 = 1.2129 × yearly in-situ precipitation*), before direct application in hydrological modeling or water resource management to avoid overestimations. The correction factors were derived solely for Adana station, which may limit their applicability in other regions with different climatic or geographic characteristics. Additionally, these factors may vary over time, especially in long-term climate analyses. This limitation is acknowledged to ensure clarity regarding the broader use of the correction method.

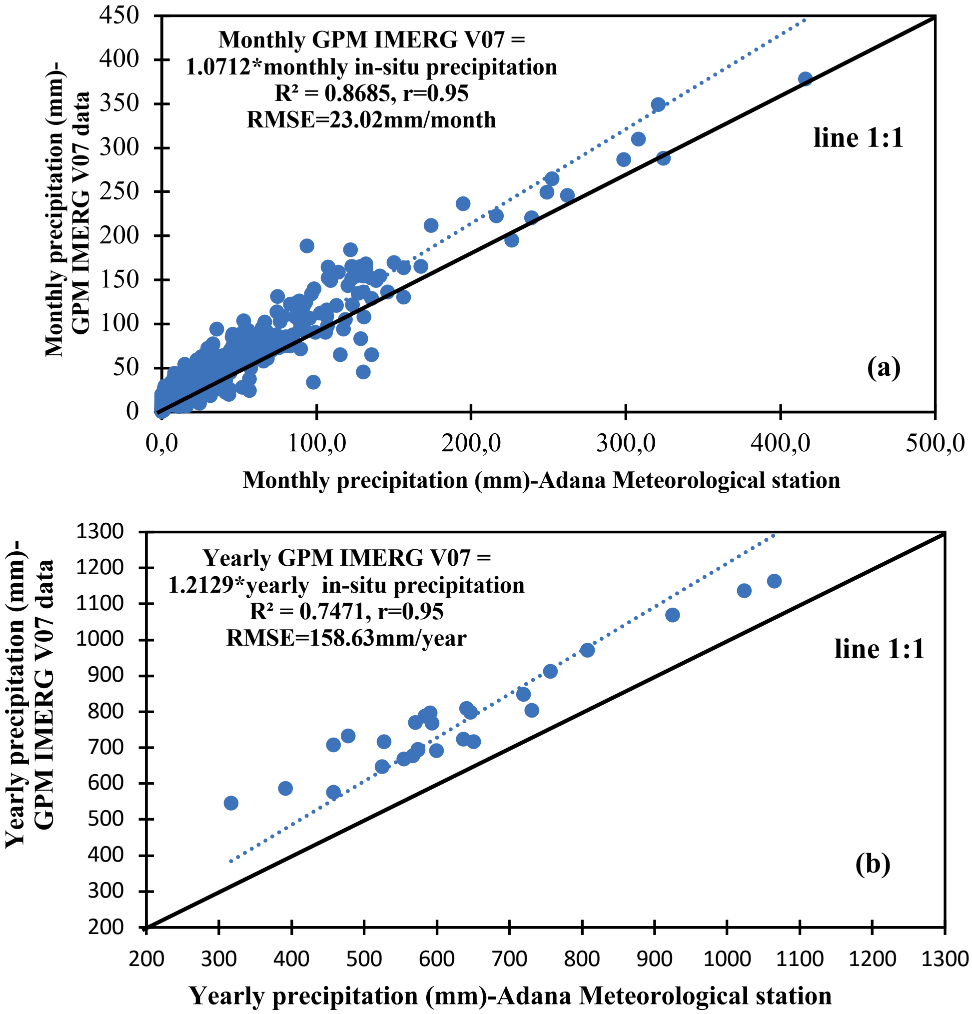
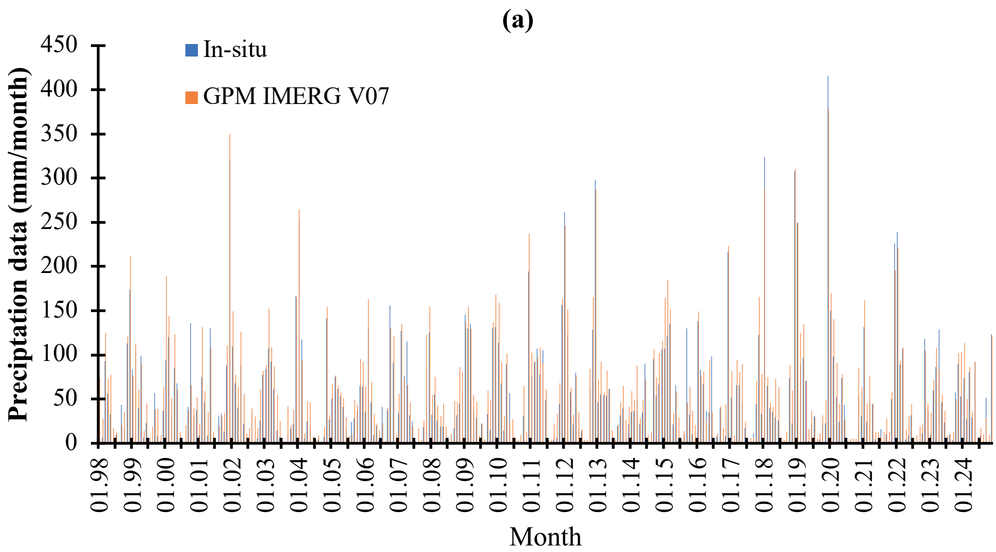


Figure 2. Linear relationship between IMERG V07 and in-situ precipitation observations in Adana at two temporal scales: (a) monthly and (b) annual, for the period 1998–2024.

Şekil 2. 1998–2024 Dönemi için Adana'daki IMERG V07 ve yerinde yağış gözlemleri arasındaki doğrusal ilişki: (a) aylık ve (b) yıllık zaman ölçeklerinde.

As GPM IMERG V07 is a relatively new product, validation efforts remain limited. Wang et al. (2023) demonstrated that V07 outperformed its predecessor (V06) both globally and in China, showing improved accuracy and lower RMSE values. However, issues such as overestimation in coastal areas and underestimation in mountainous regions (e.g., the Tibetan Plateau) were still evident. Similarly, Keikhosravi-Kiany and Balling Jr. (2024) reported modest improvements of V07 for Iran, while systematic underestimation persisted, particularly in high-altitude regions. In Türkiye, Aksu and Yaldiz (2025) conducted a comparative assessment of V07 and V06, concluding that V07 provided more accurate daily precipitation estimates across all regions and seasons.



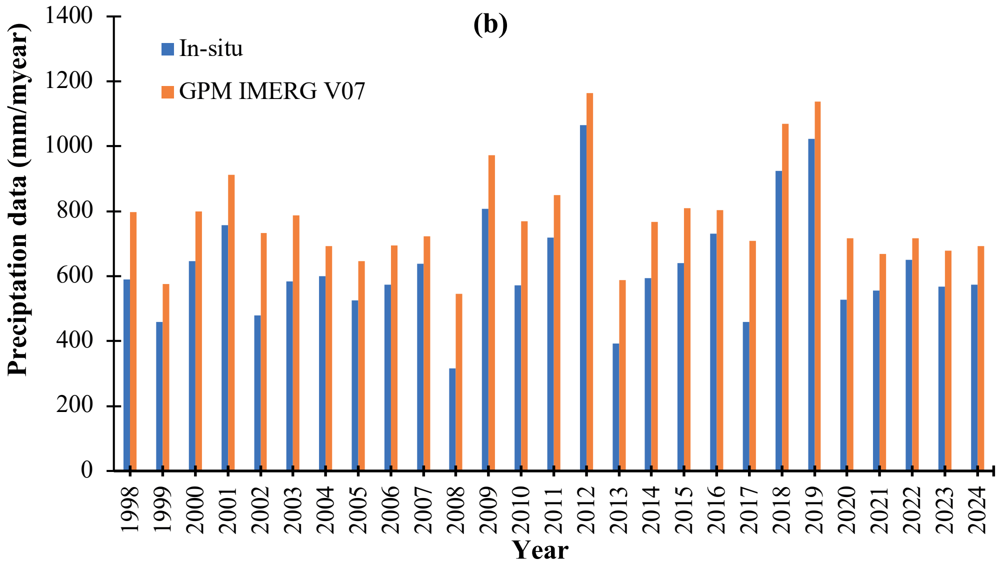


Figure 3. Temporal variation of precipitation in Adana from 1998 to 2024: (a) Monthly scale and (b) Annual scale.
Şekil 3.1998–2024 yılları arasında Adana'daki yağışların zamansal değişimi: (a) aylık ölçek ve (b) yıllık ölçek.

Nevertheless, their findings indicated that underestimation remained present in all four seasons, with the most pronounced discrepancy occurring during summer.

Notably, the GPM IMERG V07 product tends to overestimate monthly and annual precipitation totals in the eastern Mediterranean region of Türkiye. In this case study, GPM

IMERG's monthly precipitation estimates exceed ground-based observations by approximately 7% (Figure 2a). However, as seen in Figure 2b, this discrepancy increases to 21% at the annual scale, primarily due to the cumulative effect of persistent overestimation through many months.

Beyond its practical implications, this study highlights the potential to improve the accuracy of GPM IMERG V07 data through appropriate bias correction. Such enhancements would significantly strengthen its reliability for hydrological and climate-related applications, particularly in semi-arid and data-scarce regions. The findings reaffirm IMERG V07 as a valuable tool for precipitation monitoring where ground-based observations are limited. However, applying correction or calibration techniques is essential to ensure accurate quantitative analyses. While the current study focused on the Adana region, limiting generalizability, future research should extend the spatial coverage to evaluate performance across diverse climatic settings in Türkiye. This broader perspective will support more robust assessments and informed water resource management.

CONCLUSION

This study conducted a comprehensive evaluation of the GPM IMERG V07 precipitation product for the semi-arid region of southern Türkiye, using long-term ground-based observations from Adana Meteorological Station (1998–2024). The results indicate that IMERG V07 demonstrates strong performance at both monthly and annual scales, characterized by high correlation coefficients (up to 0.95) and acceptable RMSE) values, thereby confirming its effectiveness in capturing rainfall variability and seasonal precipitation patterns.

Despite this strong agreement, IMERG V07 consistently overestimates precipitation relative to ground measurements, with an average monthly overestimation of approximately 7%, which accumulates to 21% discrepancy at the annual scale. This systematic bias, confirmed through statistical testing, highlights the importance of recognizing and addressing the overestimation in applications such as hydrological modeling and climate impact assessments. Although a linear bias correction was applied using regression coefficients, we acknowledge that this method may be insufficient for capturing extreme precipitation and seasonal variations. Future studies should incorporate validation procedures and explore more advanced correction techniques—such as quantile mapping or machine learning methods—to improve reliability under varying climatic conditions.

Nonetheless, the findings underscore the potential of IMERG V07 as a valuable tool for precipitation monitoring in regions with limited ground-based data. To enhance its utility and reliability, especially for quantitative analyses, the application of bias correction or calibration techniques is recommended to increase general data accuracy. Overall, IMERG V07 represents a robust and practical resource for advancing regional precipitation assessment and informing sustainable water resource management in semi-arid environments.

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