

## Evaluation of daily satellite rainfall product during high dense rainstorm for flood prediction over Iraq

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### Abstract

Precipitation in regions characterized by intricate terrain is frequently identified by significant variability and inadequate observation, which hampers efforts to effectively address water resource management concerns. In this study, we assess the accuracy of remote sensing and ground station-based gridded precipitation products in Iraq by comparing them to weather station precipitation observations on a daily basis. Moreover, the possibility of rainfall satellite-derived data to predict potential floods and damages in selected areas in eastern and central Iraq during previous rainstorms was studied. In the present study, the accuracy of GPM satellite precipitation data during a highly dense rainstorm for flood prediction over Iraq was evaluated. The findings revealed a strong agreement between satellite precipitation data and rain-gauge data, with a correlation coefficient of 0.88, indicating a high level of accuracy. Hence, it is ideal for utilization in meteorological and hydrological investigations as well as for the creation of rainfall contour maps. Based on the overly model that has been produced for the areas threatened by flooding then, the extraction function was used to polygons of these areas. Statistical calculations showed the areas vulnerable to flooding in the event of continued recurring rainstorms, as the total area reached 4,461,241 km<sup>2</sup>.

**Keywords:** Flood, digital elevation model, overlay, satellite precipitation

## 1 Introduction

Floods in eastern Iraq are one of the recurring problems facing this region. They usually occur as a result of heavy rainfall exceeding the natural amounts of water that rivers and valleys can absorb. Floods destroy public and private property, displace residents, and disrupt daily and economic life in the affected areas. Government statistics indicate that floods in eastern Iraq cause huge losses in human lives and property every year. Among the most prominent areas affected by floods are the regions of eastern Iraq (Fig. 1), where repeated floods occurred, submerging many homes, businesses, and infrastructure. These floods caused many prob-

lems, including power outages, disruptions to water supply and sanitation, water pollution, distortion of agricultural crops, and the spread of aquatic diseases. The government is working to confront this problem by developing rain drainage infrastructure, building dams and water canals, and providing aid and support to the affected population. However, there is still an urgent need for more efforts in flood preparedness and the development of sound coping strategies. It is also important to educate residents about flood safety and prevention methods and provide them with training and information. Local and international cooperation can help solve this problem and mitigate the effects of floods in eastern Iraq.

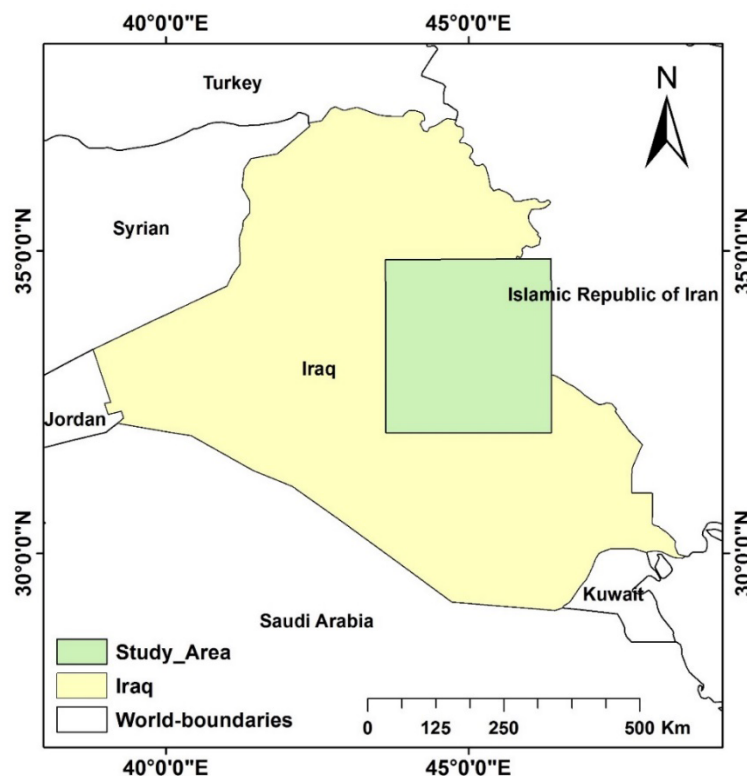


Figure 1. Location of Iraq relative to neighboring countries.

Precise quantification of precipitation and its spatial distribution plays a crucial role in evaluating water resources and forecasting floods. Nevertheless, in numerous areas, the quantity of ground measuring stations is severely restricted

and irregularly dispersed, posing challenges for flood prediction (Shrestha et al., 2011). In regions without a comprehensive rain gauge network, such as the eastern part of Iraq, satellite-based rainfall estimation can offer valuable insights

into the incidence, quantity, and spatial distribution of rainfall. Consequently, satellite rainfall estimations are used to anticipate floods in the eastern region of Iraq.

Precipitation is a crucial component of the hydrological cycle and has significant impacts on human life, particularly in agriculture and water supplies. From a climatic standpoint, rising temperatures, which are the main manifestation of global climate change, have undeniably altered the magnitude and spatial pattern of rainfall (Abdulrazzaq, 2020). Nevertheless, the specific direction and places that would be predominantly impacted remain uncertain. Accurate precipitation observations are crucial for enhancing our understanding of the mechanisms underlying climate change (Yang, 2005). To accomplish this, climate-related studies require a significant amount of data to encompass a wide range of events and get the most accurate results. Furthermore, the act of updating the rainfall contour map serves as a crucial foundation for strategic analyses.

Satellite measurements commenced throughout the 1970s, utilizing technology that operated within the infrared spectrum. Infrared images indirectly correlate the precipitation generated by clouds by measuring the temperature at their uppermost layer. Another frequency domain that is valuable for monitoring precipitation is the microwave domain. Microwave measurements directly assess the absorption, emission, or diffusion of radiation by water drops and ice crystals present in clouds (Laurent et al., 1998).

Several literature reviews have described the recent advances in measuring precipitation from satellite technologies, especially from meteorological radar data. The performance of satellite precipitation products was found to be correlated to the height above sea level of the study region, with the best performance

noted (Abdulrazzaq, 2020). Some of the reviewed studies investigated the independent applications of these satellite precipitation products in hydrological modeling and flood predictions. Hinge et al. (2022) used GPM IMERG and other products in flood prediction through descriptive data analysis. The performance of these products was found to be higher in temperate and tropical regions than in arid climates. The study recommended the need to benefit from satellite precipitation products for flood simulation and prediction due to their great potential for flood simulation and forecasting, with the need to enhance them with bias correction techniques, and model recalibration. Weng et al. (2023) evaluated the daily rainfall data of GPM IMERG and GSMaP to demonstrate their usefulness in monitoring drought and flood phenomena across the Xijiang River Basin. After quantitative evaluation of these products, the results indicate that GPM IMERG gives the highest correlation with gauge-based rainfall data while GSMaP gives the lowest relative error. It was also found that GSMaP tends to overestimate non-minor rainfall events. The study recommended the (Imerg-early) GPM IMERG product in hydrological studies as the most reliable in capturing extreme flow. Bhattarai et al. (2024) used IMERG half-hourly rainfall (GPM) data to rapidly predict urban flooding at the street scale using machine learning-based surrogate modeling. The study demonstrated the benefits of integrating geospatial data, hydrodynamic modeling, and machine learning to improve understanding of urban hydrodynamics, thereby increasing flood predictive capacity and quantifying predictive uncertainty.

The meteorological data collected from terrestrial stations is no longer enough for undertaking regional research, particularly in emerging nations, and is limited

to local studies in small regions. Consequently, numerous studies, such as those cited in references (Li et al., 2012; Huffman et al., 2015; Ringard et al., 2015; Akbari et al., 2017), have resorted to utilizing data acquired from airborne meteorological space radar via satellite. Over the last twenty years, there has been a substantial increase in the utilization of satellite rainfall estimates (SREs) for rainfall monitoring. Extensive work has been done in this field to ensure accurate performance and thorough error analysis (Huffman et al., 2015). The findings indicate that the satellite data from TRMM-3B42 and GPM\_3IMERGM can serve as viable input for distributed rainfall-runoff models across extensive regions (Huffman et al., 2015; Moazami et al., 2016; Akbari et al., 2017).

In the field of weather forecasting, rainfall is one of the most difficult subjects for both spatial and temporal prediction due to its sensitivity to topography and other weather factors like humidity, temperature, and wind. Before the birth of satellite images, forecasters only used weather maps, which were digitized from the observed data, including pressure, temperature, cloud types above the sky, and the amount of rain at limited synoptic stations.

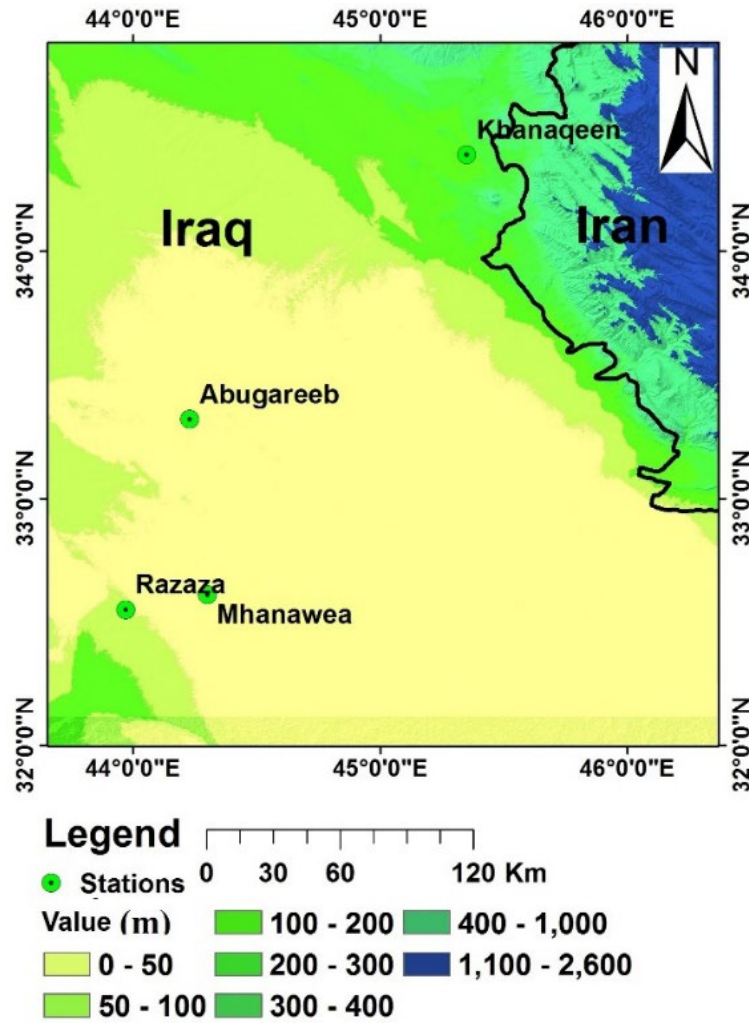
This study will analyze the performance of GPM data over eastern Iraq and surrounding areas from 20 November 2020 to 22 November 2020 in terms of space and rainfall amplitude. GPM\_3IMERGM products (the newest version up to now) with a spatial resolution of  $0.1^\circ$  are compared to the rain-gauge data of 4 stations in Iraq. These stations will evaluate the quality of GPM products for the areas, which would be a reference for weather forecasters in the future.

## 2 Data and methods

### 2-1 Data

In this study, digital elevation model (DEM) data was used to show the low-lying and flood-threatened areas in eastern Iraq (Fig. 2), where the topography is complex due to the presence of the Zagros Mountain range. The Shuttle Radar Topography Mission (SRTM) 1 Arc-Second Global is one of the best free digital elevation models available today. The SRTM data has been improved by filling in gaps to create digital elevation data with a resolution of 1 arc-second, covering the entire globe. The Shuttle Radar Topography Mission (SRTM) took place during the space shuttle Endeavor's flight from 11-22 February 2000. NASA and NGA collaborated on an international endeavor to obtain radar data, which were then used to generate the initial near-global compilation of land elevations (EROS, 2018).

Rain-gauge stations data for the gauge-based rainfall were collected from 4 stations across Iraq (Fig. 2) during a highly dense rain storm that happened in the period of 20 November 2020 to 22 November 2020 (Table 1). On the other hand, 4 stations data were derived from GPM satellite data as terrestrial stations equal to ground stations (Table 2). Daily rainfall was summed up from a three-day observation. This data set (Table 3) can be considered as a reliable reference and will be compared with the results of the GPM data set in this study (Figs. 3 and 4). Table 4 shows a summary of these data specifications. The average temperature in Iraq is about  $38^\circ\text{C}$  in July and August, and below zero in January and February. Most of the rain occurs in the period between December and April, and its average ranges between 340 and 512 mm annually. The study area falls into two climate categories: arid (mild winter and very warm summer) and semi-arid (cool winter and very warm summer) (Alwan et al., 2019).



**Figure 2.** The digital elevation model (DEM) shows the topography of the region and the distribution of the available rain-gauge stations in eastern Iraq.

**Table 1.** Rainfall data of 7 rain-gauge stations from a three-day observation (IAC, 2024).

Date/Time	Khabanaqeen	Abugareeb	Razaza	Mhanawea
20-Nov-2020	1.50	0	0.00	1.40
21-Nov-2020	20.80	0.1	0.10	12.00
22-Nov-2020	0.00	29	5.90	6.90
Accumulated total	22.3	29.1	6	20.3

**Table 2.** Rainfall data of 7 GPM stations from a three-day observation (Huffman et al., 2024).

Date/Time	Grid 1	Grid 2	Grid 3	Grid 4
	Long.: 45.35 Lat.: 34.35	Long.: 44.25 Lat.: 33.35	Long.: 43.95 Lat.: 32.55	Long.: 44.35 Lat.: 32.55
20-Nov-2020	4.852	2.878	0	4.906
21-Nov-2020	21.856	0.099	4.894	11.034
22-Nov-2020	0.123	22.927	5.827	6.757
Accumulated total	26.832	25.905	10.721	22.697

**Table 3.** Accumulation of daily rainfall data of rain-gauge and GPM stations from a three-day observation (IAC, 2024; Huffman et al., 2024).

Station	Long.	Lat.	Rain-gauge Accum.	GPM-Accum.
Khanaqeen	45.35	34.35	22.3	30.5137
Abugaree	44.25	33.35	29.1	26.0525
Razaza	43.95	32.55	6	8.71394
Mhanawea	44.35	32.55	20.3	11.034

**Table 4.** Summary of the specifications of GPM 3IMERGDE product (Huffman et al., 2024).

Long name: GPM IMERG Final Precipitation L3 1 day $0.1^\circ \times 0.1^\circ$ V06
Spatial Coverage: $-180.0, -90.0, 180.0, 90.0$
Data Resolution: Spatially ( $0.1^\circ \times 0.1^\circ$ ), Temporally (1 day )
Temporal Coverage: 2000-06-01 to 2024-01-01
Version: 06
Format: netCDF

The GPM mission was initiated jointly by NASA and JAXA in February 2014 with the objective of enhancing global precipitation measurements (Hou et al., 2014). GPM IMERG Final Precipitation Level 3 dataset labeled V06 (GPM\_3IMERGDF) with a spatial resolution of  $0.1^\circ \times 0.1^\circ$  and a temporal resolution of 1 day can be obtained from the Giovanni NASA website at <https://giovanni.gsfc.nasa.gov/giovanni/>.

The original IMERG algorithm calculates precipitation estimates by utilizing the 2017 version of the Goddard Profiling Algorithm (GPROF2017) on data collected from various satellite passive microwave (PMW) sensors within the GPM constellation. These estimates are then gridded, intercalibrated with the GPM Combined Ku Radar-Radiometer Algorithm (CORRA) product, and combined into half-hourly  $0.1^\circ \times 0.1^\circ$  (approximately  $10 \times 10$  km) fields. It should be noted that CORRA is calibrated to the monthly Global Precipitation Climatology Project (GPCP) Satellite-Gauge (SG) output to correct known biases in high-latitude ocean and tropical land areas (Hou et al., 2014).

The IMERG system operates in near-real time with two runs: an "Early" multi-satellite product approximately 4 hours after the observation time, utilizing only forward morphing, and a "Late" multi-satellite product approximately 14 hours

after the observation time, utilizing both forward and backward morphing. Additionally, there is a single run after the monthly gauge analysis is received, producing a "Final" satellite-gauge product approximately 3.5 months after the observation month. This final product incorporates both forward and backward morphing techniques and includes monthly gauge analyzes (Hou et al., 2014).

At now, the Early and Late half-hourly estimates do not undergo calibration. However, in the Final Run, which occurs after real-time, the multi-satellite half-hourly estimates are adjusted to ensure that they add up to the monthly satellite-gauge combination in the Final Run. The result consistently includes various fields that offer (Huffman et al., 2015).

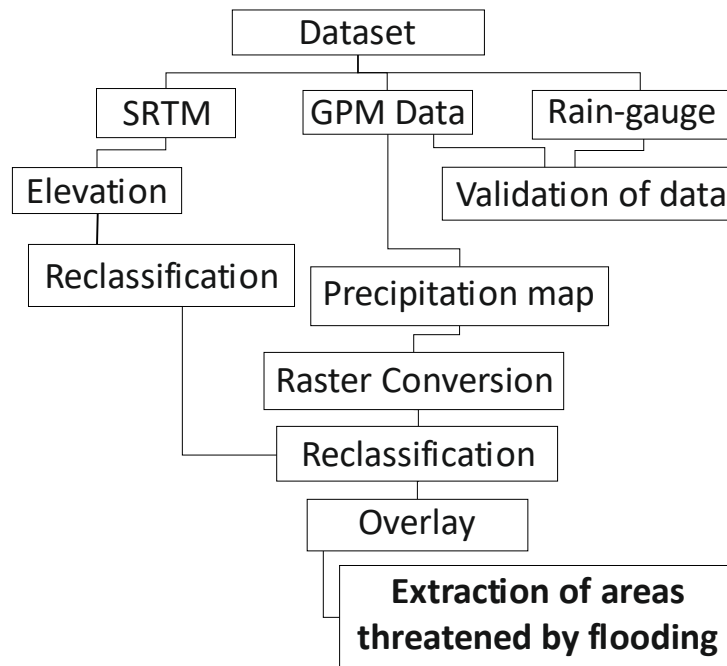
The idea of the GPM 3IMERG products is based on the integration of surface-based data and satellite-based data with a certain threshold indicating that the satellite-based data are cancelled. In the GPM 3IMERGM system, both microwave and infrared sensors are used to estimate daily rainfall. There are two major types of sensors used for this: passive and active sensors. Passive sensors provide day and night coverage in all weather conditions. They include the Scanning Multichannel Microwave Radiometer, Special Sensor Microwave/Imager, and the Advanced Microwave Sounding Unit. However, ac-

tive microwave sensors include the Precipitation Radar from the GPM, Special Sensor Microwave/Imager, and the Advanced Microwave Sounding Unit. This approach to estimating rainfall is part of the TRMM mission that is linked with the

advanced and precise estimation of precipitation.

## 2-2 Methods

Applying the study methodology (Fig. 3) begins with the step of downloading data from reliable sources.



**Figure 3.** Methodology flowchart.

A regression study was conducted to confirm the GPM data by comparing the accumulation of daily rainfall data from rain-gauge and GPM stations over a three-day period (Fig. 4). The analysis revealed a normal and linear relationship with a correlation coefficient of 0.88 ( $R^2$ ). The correlation coefficient provides proof of the suitability of the data when it approaches a value of 1 (Abdulrazzaq, 2020; Abdulrazzaq et al., 2022). The occurrence of GPM errors, whether they are excessively elevated or insufficiently low, is directly linked to the characteristics of the event being evaluated. The estimated correlation can be significantly

influenced by the areas near the measuring sites where no precipitation was observed (Santos et al., 2018).

After downloading DEM and rainfall data from available websites, it undergoes preliminary processing to transform it into nodal data called raster. Fig. 2 shows the SRTM data in raster format, which is converted to a contour map to present the elevation of the area, while Fig. 5 shows the GPM product data in raster format as well. The rainfall accumulation data was converted by interpolation using the spline algorithm, which interpolates a raster surface from points using a two-dimensional minimum curvature spline technique.

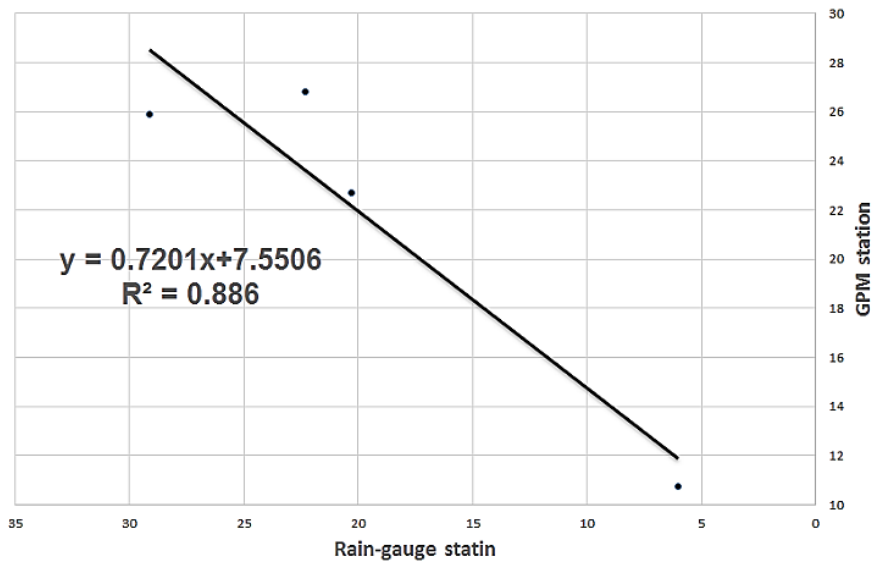


Figure 4. Regression analysis between rain-gauge and GPM data.

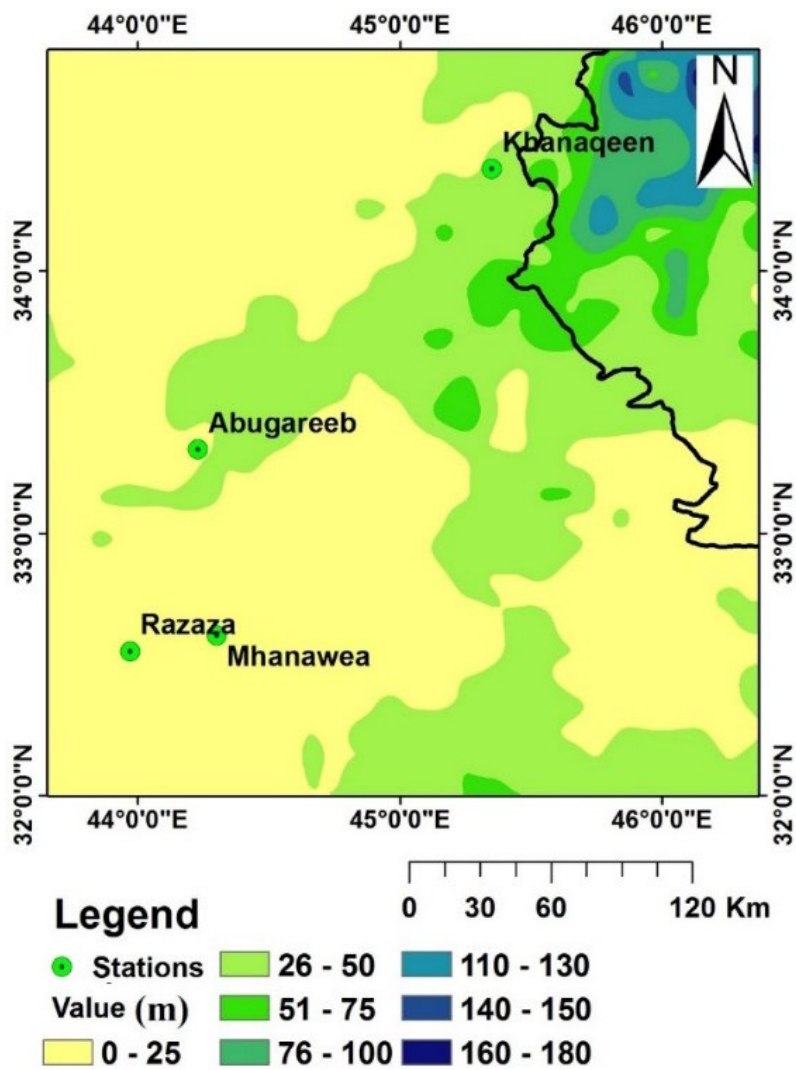


Figure 5. GPM product data in raster format for a three-day observation.

The next step of the methodology is called by reclassification which reclassifies (or changes) the values in a raster which can be described thus:

When reclassifying a range of values, it is important to ensure that the ranges do not overlap, except at the boundary where two input ranges meet. When there is overlap, the upper limit of the lower input range is included, but the lower limit of the higher input range is not included. For instance, when two ranges are defined, such as converting values from 1 to 5 to 100 and values from 5 to 10 to 200, any input value that is less than or equal to 5 will be allocated the value 100 in the output. Conversely, an input value greater than 5, such as 5.01, will be assigned the value 200 (ESRI, 2023). To achieve the most favourable outcomes, it is necessary to merge the reclassified datasets (Aretouyap et al., 2022). The datasets underwent reclassification to a uniform scale of measurement in order to facilitate integrated analysis, even when dealing with different and dissimilar inputs (Abdulrazzaq et al., 2022; Aziz et al., 2018). The final step is called Fuzzy Overlay, which combines fuzzy membership raster data based on the selected overlay type (Alwan and Aziz, 2022). Then, extract areas threatened by flooding.

### 3 Results and discussion

This study uses input layers to assess the results of integrating elevation and precipitation data through ArcGIS 10.8 software. Accordingly, the elevation layer and the accumulated precipitation layer were reclassified into 7 classes (Figs. 6a and 6b) by overlay combination method in GIS (i.e. value of elevation, precipitation). Reclassifying the elevation and precipitation maps have been done in order to use integer values instead of ranges and then use them as inputs in the

overlay model. The reclassify function was used to modify the classification of these maps. Each layer must encompass a consistent range of classes, ranging from 1 to 7. Overlay model was produced for the areas threatened by flooding then, and the extraction function was used to polygons of these areas (Fig. 7). Statistical calculations (Fig. 8) showed the areas vulnerable to flooding in the event of continued recurring rainstorms, as the total area reached 4,461,241 km<sup>2</sup>.

Abrupt flood calamities result in significant harm to agricultural productivity. Efficiently retrieving data on the extent of flooding in agricultural areas and assessing its impact on crops is crucial for estimating the affected area, facilitating the restoration of farmland after a disaster, and serving as a supplementary basis for decision-making in flood prevention and disaster relief agencies (Cui et al., 2023).

Flood forecasting is important for several reasons, most notably protection from human loss, as flood forecasting helps evacuate potential populations in threatened areas before floods occur, thereby reducing the risk of human loss from drowning or exposure. Also preventing material losses: flood forecasting can help to take preventive measures such as lifting property and closing water outlets, thereby reducing material losses that may occur as a result of floods, such as water damage to homes and buildings. In addition to improving urban planning, flood forecasting allows an understanding of the nature of floods and vulnerable areas, and this information can therefore be used in urban processes to guide buildings and infrastructure away from flood-prone areas. Flood forecasting also contributes to protection against water pollution, as floods can cause contamination of surface and groundwater, which residents use for various purposes.

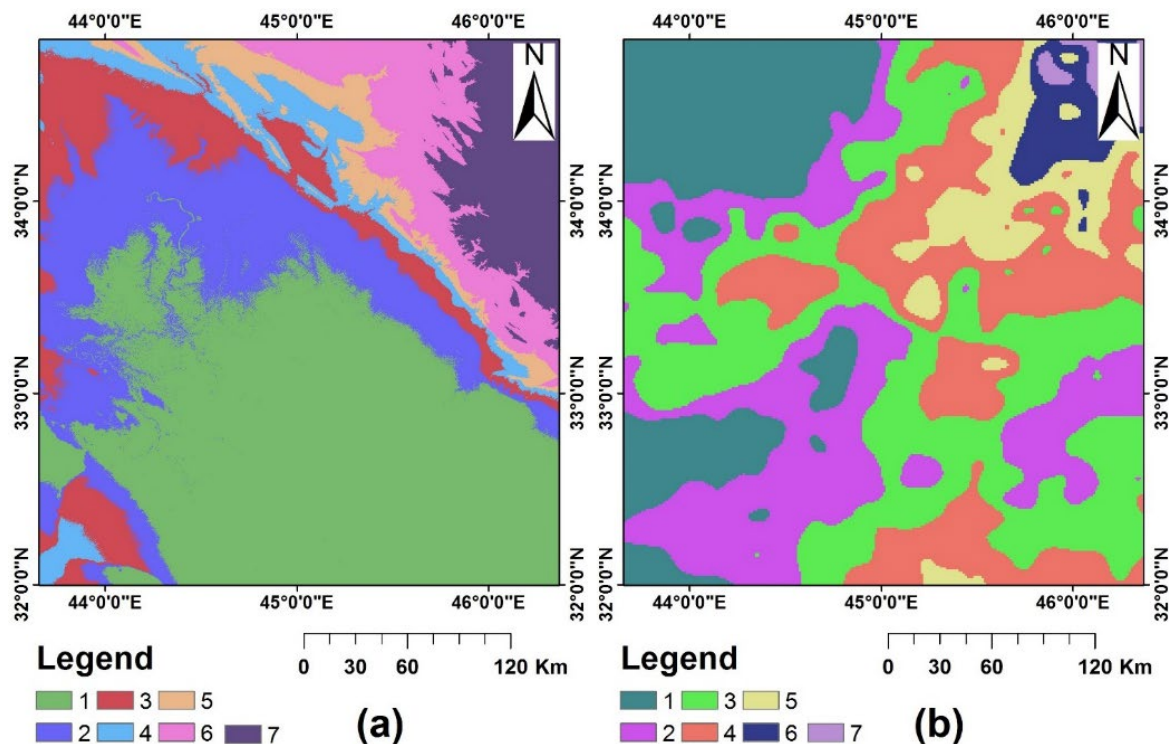


Figure 6. Reclassifying map. (a) elevation map (b) precipitation map.

such as drinking and irrigation. Flood forecasting can help take preventive action to protect against water pollution by placing dams or culling potential sources of pollution before flooding occurs

Rainfall data are a key factor in flood forecasting and are of great importance in this context. Here are some of the reasons why rainfall data is important in flood forecasting: Rainfall data helps assess how much rain can cause floods and determine the intensity and duration of rainfall. Based on this information, meteorologists and flood stakeholders can determine the impact of rainfall on water flow and the risk of floods in threatened areas. Weather models are also predicted, as rainfall data is used to develop weather models and forecasts. These models integrate rainfall data to provide detailed forecasts of rainfall quantities, time, and precipitation. Based on these predictions, officials and organizations can prepare for floods and take necessary

measures, such as evacuating threatened populations and securing the necessary resources. Climate records are also analyzed, as long-term rainfall data also helps to analyze climate records and assess the region's overall rainfall pattern over the past years and decades. This helps to understand climate change and raise awareness of changing rainfall patterns and potential trends to increase the frequency of floods. In addition to water resource planning, rainfall data not only contributes to forecasting but also helps to analyze the total amount of water available on Earth, thus helping to effectively plan water resources and their sustainable use. Generally speaking, rainfall data are a key element for flood forecasting and the preparation of associated risk response plans. These data provide information necessary for accurate risk assessment and appropriate action to reduce the impact of floods on the population and infrastructure.

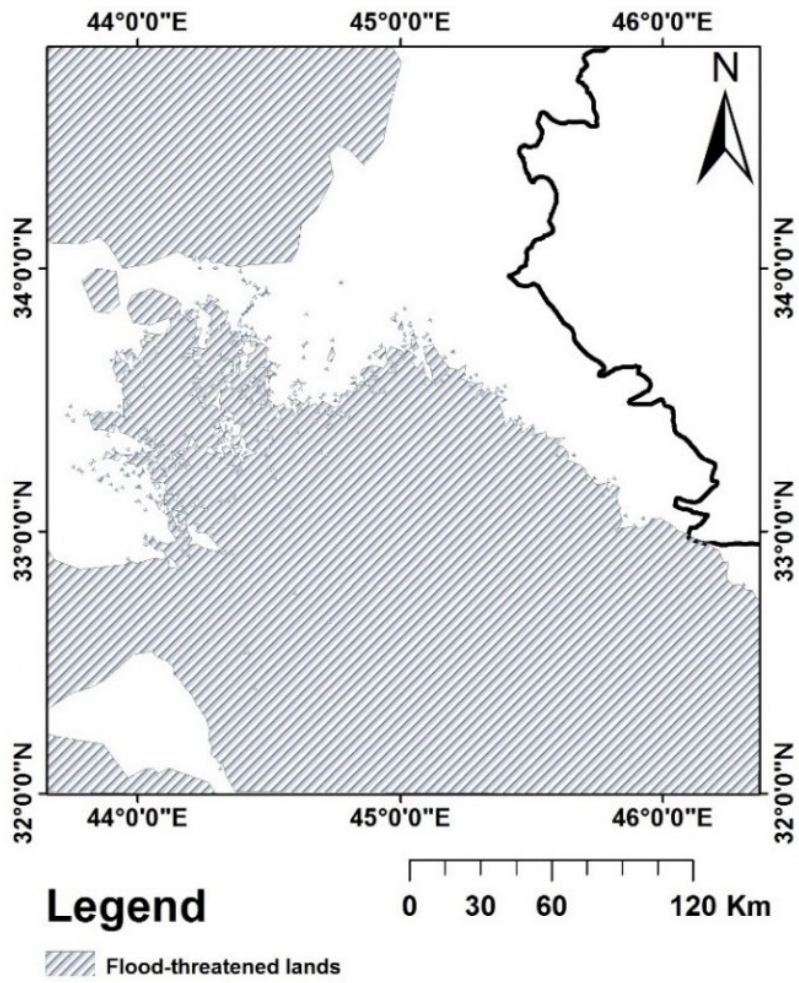


Figure 7. Flood-threatened lands.

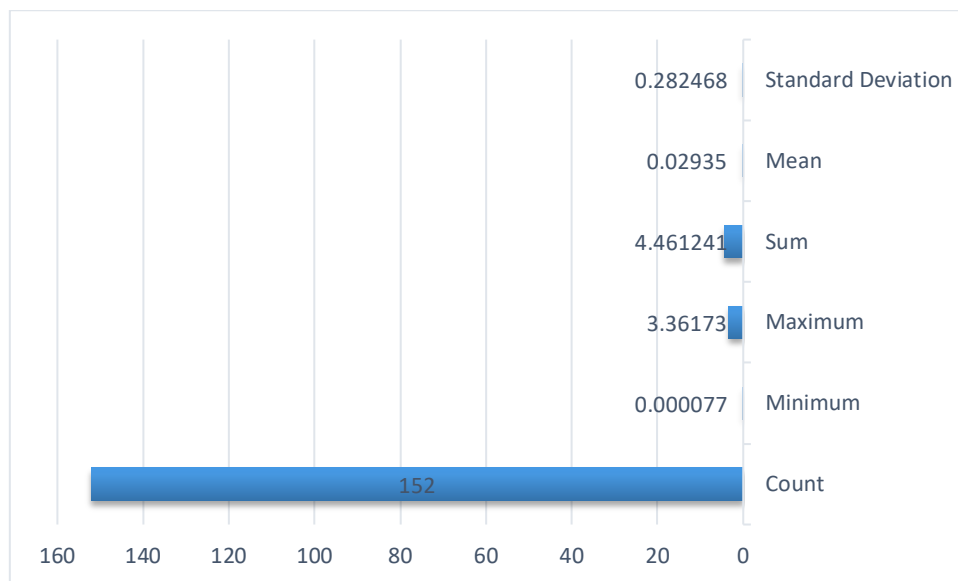


Figure 8. Statistical calculations showed the areas vulnerable to flooding.

The GPM\_3IMERGM product data is crucial in flood forecasting for several reasons:

1) **Precipitation Measurement:** The data provides accurate and timely information about precipitation patterns in a specific region. Precipitation is one of the primary factors in flooding, and having reliable precipitation measurements helps in understanding the potential risk of flooding.

2) **Spatial and Temporal Resolution:** The GPM\_3IMERGM product data has high spatial and temporal resolution, meaning it provides detailed information about precipitation at a localized level and is updated frequently. This allows for precise analysis of precipitation patterns, which is vital for flood forecasting.

3) **Multi-Sensor Data:** The product data integrates information from various satellite and ground-based sensors, resulting in a comprehensive dataset. This integration improves the accuracy and reliability of flood forecasts by reducing uncertainties and filling data gaps.

4) **Real-time Monitoring:** The GPM\_3IMERGM product data is available in real-time, allowing for continuous monitoring of precipitation. This real-time monitoring enables early detection of intense rainfall events that could lead to flooding, giving authorities and communities more time to prepare and take appropriate measures.

5) **Historical Analysis:** The GPM\_3IMERGM data is also valuable for conducting historical analysis of precipitation patterns and flood events. By studying past events, scientists and flood experts can identify trends, patterns, and potential risk areas, improving future flood forecasting and mitigation strategies.

#### 4 Conclusions

In conclusion, the GPM\_3IMERGM

product data plays a significant role in flood forecasting by providing accurate, high-resolution, multi-sensor precipitation information in real time. This data is crucial for assessing the potential risk of flooding, monitoring rainfall patterns, and developing effective strategies to mitigate floods and protect communities. The GPM satellite is a research tool specifically created to enhance our understanding of the distribution and fluctuations of precipitation within the climate system's water cycle. In the present study, the accuracy of GPM satellite precipitation data during a highly dense rainstorm for flood prediction over Iraq was evaluated. The findings demonstrate a strong agreement between satellite precipitation data and rain-gauge data, with a correlation coefficient of 0.88, indicating a high level of accuracy. Thus, it is appropriate for utilization in meteorological and hydrological investigations as well as for creating rainfall contour maps.

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