GEOSCIENCE AND REMOTE SENSING TECHNOLOGY
ISSN: 2963-7767 (Online) Journal homepage: https://www.geo-rest.org

Date of publication December 31, 2024, date of current version December 31, 2024.

Digital Object Identifier doi.org/10.57265/georest.v2i2.32.

Analysis of Extreme Rainfall in Padang Using GSMaP Satellite Imagery: Case Study of the July 2023 Flood

Hanifsyah Rozi[1,2], Pakhrur Razi[1,2*], Harman Amir[1], Nofi Yendri Sudiar[1], Aulia Rinadi[3]
[1]Departmen of Physics, Faculty of Mathematics an Natural Sciences, Universitas Negeri Padang, 25131, Indonesia
[2]Center of Disaster Monitoring and Earth Observation (DMEO), Universitas Negeri Padang, 25131, Indonesia
[3]Minangkabau Meteorological Station Class II Padang Pariaman, Meteorology Climatology and Geophysics Agency, 25586, Indonesia

Corresponding author: fhrrazi@fmipa.unp.ac.id Orcid ID: 0000-0003-0598-2560

ABSTRACT
Extreme rainfall is a major cause of major flooding in coastal areas, such as Padang, Indonesia. This study analyzes the extreme rainfall event that caused the Padang flood on July 14, 2023 using rainfall data from the Global Satellite Rainfall Mapping system (GSMaP). The aim is to evaluate the spatial and temporal distribution of rainfall during the event and assess the accuracy of GSMaP satellite imagery in capturing the heavy rainfall that caused the flooding. GSMaP satellite data were processed to examine the intensity and distribution of rainfall from July 13, 2023 to July 14, 2023. The analysis showed that rainfall occurred evenly over the entire Padang area, with a peak rainfall intensity of 20-99 mm/day on July 13 and a much higher intensity of 145-434 mm/day on July 14, as recorded by ground-based rain stations. The peak rainfall on the first day occurred at 14:00 UTC, and on the second day at 00:00 UTC. Although GSMaP effectively captured the large-scale rainfall pattern, differences were seen in the local intensity. This continuous rainfall causes severe waterlogging, which then escalates into flooding, which is classified as extreme rainfall. These findings demonstrate the utility of GSMaP in monitoring extreme rainfall, especially in areas with limited ground-based observation infrastructure, and emphasize the role of satellite data in improving early warning systems and flood management strategies in flood-prone areas such as Padang.

INDEX TERMS ***Extreme Rainfall, GSMaP Satellite Imagery, Padang Flood, Region Rain Post, satellite data validation.***

I. INTRODUCTION
Extreme weather events, particularly heavy rainfall, have been increasingly linked to climate change and urbanization [1], [2], posing significant risks to human settlements in vulnerable areas. In tropical regions such as Indonesia, extreme rainfall events are a major trigger for flood [3], which can lead to severe infrastructural damage and loss of life. Padang, a coastal city in West Sumatra, Indonesia, is particularly susceptible to flooding due to its geographical location and seasonal rainfall patterns [4]. On July 14, 2023, an extreme rainfall event caused widespread flooding throughout the city, affecting thousands of residents and disrupting critical infrastructure [5].

Understanding the spatial and temporal distribution of rainfall during such events is crucial for improving flood prediction and management efforts [6]. Traditional ground-based rain gauges and weather stations provide valuable data but often lack the spatial coverage needed for comprehensive analysis, especially in regions with complex terrain or limited observational networks [7]. To address this gap, satellite-based precipitation products, such as the Global Satellite Mapping of Precipitation (GSMaP), offer a powerful tool for monitoring and analyzing rainfall events on a large scale [8].

GSMaP provides near real-time precipitation estimates with high spatial and temporal resolution, making it a suitable instrument for studying extreme rainfall events [9]. In this study, we utilize GSMaP satellite imagery to analyze the extreme rainfall event that occurred [10], in Padang on July 14, 2023. By comparing satellite-derived data with ground-based observations, we aim to assess the accuracy of GSMaP in capturing the rainfall intensity and distribution during this event [11].

The findings of this research will contribute to a better understanding of satellite precipitation data's role in flood risk management and early warning systems, particularly in regions with limited ground-based observational capacity [12]. Furthermore, the results will provide insights into the strengths and limitations of using satellite data to monitor and predict extreme rainfall events in urban coastal areas like Padang [13].

II. STUDY AREA AND RADAR DATASET

A. TOPOGRAPHY AND CLIMATE OF PADANG CITY

Padang is the capital city of West Sumatra, Indonesia, located on the west coast of the island of Sumatra. The city is situated at the confluence of several rivers and is surrounded by hills, making it particularly vulnerable to flooding during periods of heavy rainfall [14], [15]. The geographical features of Padang, combined with its tropical climate, contribute to a seasonal rainfall pattern characterized by intense rainfall during the monsoon season, which typically spans from November to March [15], [16]. However, extreme rainfall events can occur outside this period, as evidenced by the flood on July 14, 2023.

The flooding event on this date was significant, affecting various neighborhoods, displacing thousands of residents, and causing damage to infrastructure, including roads, bridges, and homes. Understanding the rainfall patterns during this event is essential for assessing flood risks and developing effective mitigation strategies [17].

B. RAINFALL

Rainfall occurs through three main mechanisms: convection, orographic lifting, and frontal systems [18]. In tropical regions like Padang, convective rainfall is common, where intense surface heating causes moist air to rise, cool, and condense, leading to localized heavy rain. Additionally, Padang's proximity to the Bukit Barisan mountain range results in orographic rainfall, where moist air is forced upwards by the mountains, producing heavy rain on the windward side [19]. Frontal rainfall, caused by the meeting of warm and cool air masses, is less frequent in tropical regions [20]. Accurate rainfall measurement using satellite data such as GSMaP is essential for understanding extreme rainfall patterns, such as the event that triggered the July 14, 2023, flood in Padang.

This classification, based on the Indonesian Meteorology Climatology Geophysics Agency (BMKG), assists in providing information on the level of rain intensity that can impact the weather and potential disasters such as floods or landslides to the public and related parties.

TABLE I
CLASSIFICATION OF RAINFALL INTENSITY

Rainfall Category	Description
Light Rain	0.1 - 2.0 mm/h or 5 - 20 mm/day
Moderate Rain	2.1 - 15.0 mm/hour or 20 - 50 mm/day
Heavy Rain	15.1 - 30.0 mm/hour or 50 - 100 mm/day
Very Heavy Rain	30.1 - 60 mm/h or 100 - 150 mm/day
Extreme Rain	>60.1 mm/hour or >150.1 mm/day

C. SATELLITE DATASET

This study uses the Global Satellite Mapping of Precipitation (GSMaP) dataset, a satellite-based system designed to provide high-resolution rainfall estimates. GSMaP offers near real-time rainfall data with a spatial resolution of about 0.1 degrees (about 10 km) and a temporal resolution of 30 minutes. The dataset is generated from multiple satellite sensors that capture microwave signals emitted from the Earth's atmosphere, which are then processed to estimate the intensity and distribution of rainfall. This data was downloaded from the JAXA (Japan Aerospace Exploration Agency) website.

For the case study of the July 14, 2023 floods in Padang, GSMaP data were used to analyze the spatial and temporal dynamics of extreme rainfall events. These satellite-derived data provide extensive coverage, especially useful in regions where ground-based observations are sparse or unavailable. The GSMaP dataset makes it possible to examine in detail the intensity and patterns of rainfall that contribute to flood events.

III. METHODS

This study uses a combination of satellite data and ground-based observations to analyze extreme rainfall events in Padang on 14 July 2023. The Global Satellite Mapping of Precipitation (GSMaP) dataset was used to obtain high-resolution rainfall estimates, providing spatial and temporal analysis of rainfall patterns. In addition, data from local rainfall stations were used to validate the satellite measurements, ensuring accuracy in the assessment of rainfall intensity and distribution. The analysis involved timing peak rainfall events, mapping rainfall data across Padang to identify areas most affected by the events, and examining the influence of topography on rainfall distribution. This comprehensive approach helped to understand the dynamics of the extreme rainfall event that caused the flooding in July 2023.

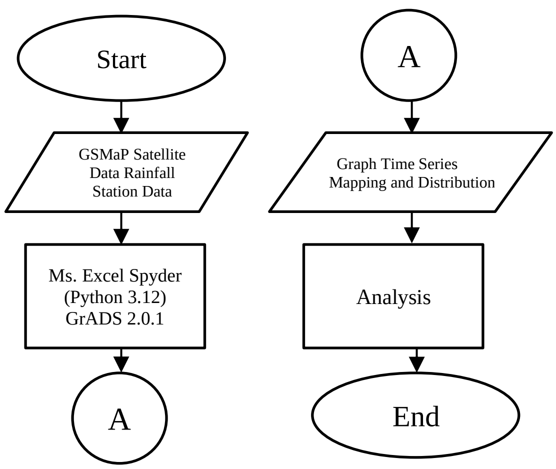

Figure 1. Research Diagram

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3.1 Data Analysis

The analysis used includes spatial and temporal analysis of rainfall events that cause flooding in the Padang City area using GSMaP satellite image data, and evaluating the ability and accuracy of the GSMaP satellite in identifying weather events during heavy to extreme rainfall.

3.1.1 GSMaP Satellite Imagery

GSMaP (Global Satellite Mapping of Precipitation) is a satellite imagery product developed to map the global distribution of rainfall with high spatial and temporal resolution. The data is obtained through a combination of remote sensing instruments from satellites, such as microwave and infrared, which are operated internationally. GSMaP is widely used in hydrometeorological analysis, as it can provide real-time estimates of rainfall in areas that are difficult to access by direct measuring devices, such as rainfall stations. In this study, GSMaP imagery was used to analyze the distribution and intensity of extreme rainfall that caused flooding in Padang on 14 July 2023, with the help of Microsoft Excel, Spyder (Phyton 3.12), and GrADS software.

3.1.2 Rainfall Station

A regional rainfall station is a measurement site that records the amount of rainfall in a specific region. To calculate the total amount of rainfall that occurs in a given time period, meteorological tools such as manual or automatic rain gauges are often used. The regional rainfall stations used in this study are shown in Table 2, which is sourced from the Minangkabau Meteorological Station class II.

TABLE II
NAME AND DESCRIPTION OF REGIONAL RAINFALL STATION

Name of Rain Post	No Post	Lattitude	Longitude
Teluk Bayur Maritime Station	13710101a	-0,983857	100,382796
Water Plan-Semen Padang	13710704a	-0,953901	100,469659
Lubuk Minturun Post	13711102a	-0,844918	100,384511
Limau Manih-Unand Post	13710803a	-0,916888	100,459552
Nanggalo Post	13711001a	-0,893545	100,369761

Table 2 describes the specifications of some of the regional rainfall stations in Padang city that will be used in the study.

IV. RESULT AND DISCUSSION

Analysis of GSMaP satellite rainfall data that has been downloaded from the JAXA website, processed using Microsoft Excel software, and plotted using Spyder software (Phyton 3.12) starting at the rain event on Thursday 13 July 2023 until Friday 14 July 2023. Figures 2 and 3 show the temporal rainfall pattern in real time in mm/hour on July 13, 2023 to July 14, 2023 to see the peak of rain at each observation point or rain post.

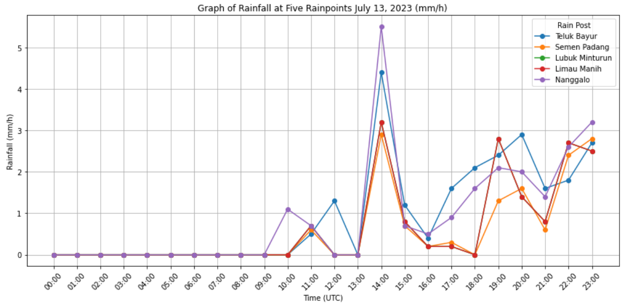

Figure 2. Graph of Rainfall at Five Rainpoints July 13, 2023

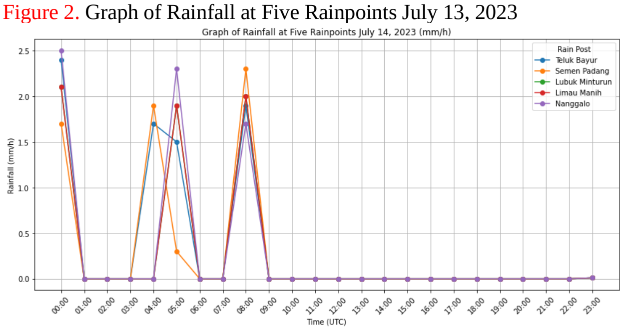

Figure 3. Graph of Rainfall at Five Rainpoints July 14, 2023

Figures 2 and 3 visualize the different levels of rainfall in mm/h in real time at each hour at five rainfall stations in the Padang city area. Through tables 3 and 4 to see the peak rainfall at each rain station.

TABLE III
RAINFALL EVENT TIME JULY 13, 2023

Rain Post	Time (UTC)	Peak Rainfall (UTC)
Teluk Bayur Maritime Station	00.00 - 23.59	14.00
Water Plan-Semen Padang	00.00 - 23.59	14.00
Lubuk Minturun Post	00.00 - 23.59	14.00
Limau Manih-Unand Post	00.00 - 23.59	14.00
Nanggalo Post	00.00 - 23.59	14.00

TABLE IV
RAINFALL EVENT TIME JULY 14, 2023

Rain Post	Time (UTC)	Peak Rainfall (UTC)
Teluk Bayur Maritime Station	00.00 - 23.59	00.00
Water Plan-Semen Padang	00.00 - 23.59	08.00
Lubuk Minturun Post	00.00 - 23.59	00.00
Limau Manih-Unand Post	00.00 - 23.59	00.00
Nanggalo Post	00.00 - 23.59	00.00

For spatial data analysis, mapping of daily rainfall estimates in millimeters using GrADS software is visualized in Figure 3 and Figure 4.

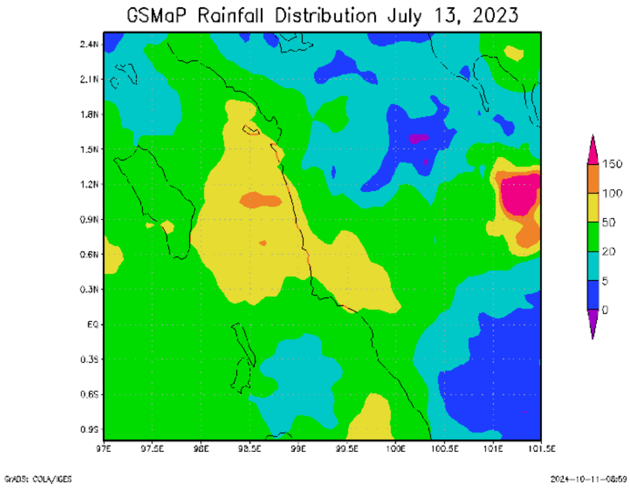

Figure 3. GSMaP Rainfall Distribution July 13, 2023

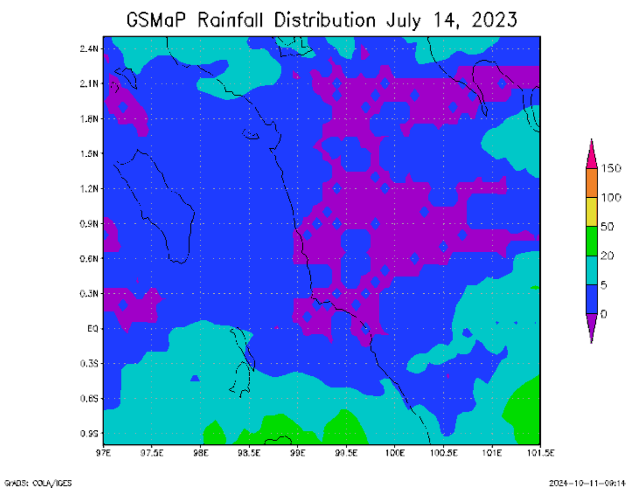

Figure 4. GSMaP Rainfall Distribution July 14, 2023

Based on spatial analysis on July 13, 2023, light to moderate intensity rain occurred in almost all areas of Padang City, with intensities ranging from 20 to 99 mm/day. Data from rainfall posts recorded accumulated rainfall at five observation points with intensities of 8 to 96 mm/day. This analysis shows that the rain was generally evenly distributed throughout Padang City on that date. From this analysis, it was concluded that rain occurred in the Padang City area on July 13, 2023.

On July 14, 2023, spatial analysis showed that rainfall accumulation ranged from 0.1 to 5.1 mm/day, while rainfall station data recorded values between 145 to 434 mm/day. This analysis indicates that the rain continued from July 13 to July 14, 2023, causing the inundation to increase drastically on July 14, resulting in flooding in the Padang City area. This condition can be categorized as extreme rainfall that caused flooding in the area.

For validation, Figure 5 shows a graph of rainfall accumulation for 24 hours at the time of flooding at the five observation points of the rain post.

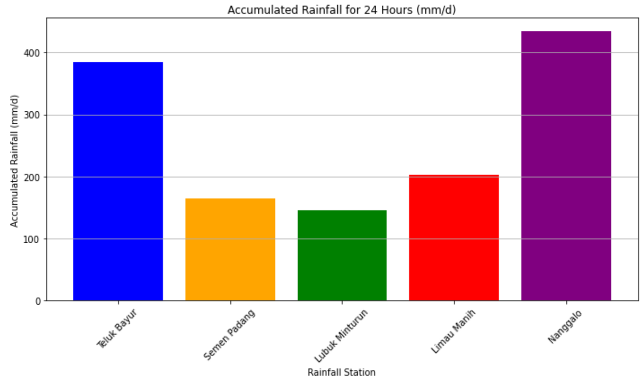

Figure 5. Rainfall Accumulation Chart of Rainfall Post on July 14, 2023

According to Figure 5, which depicts a 24-hour rainfall accumulation graph at five rainpoints in Padang city, it can be seen that the nanggalo rainpoint has the highest accumulation rate of 434 mm/day, followed by bayur bay with 385 mm/day, limau manih-unand rainpoint with 203 mm/day, air rencana-semen padang rainpoint with 165 mm/day, and lubuk minturun rainpoint with 145 mm/day.

V. CONCLUSION

Based on GSMaP satellite data, rain has occurred evenly in the Padang city area since July 13, 2023 at 12.00 UTC until July 14, 2023 at 12.00 UTC. The peak of rain occurred at 14:00 UTC on the first day, followed by the second day the peak of rain occurred at 00:00 UTC. On July 13, 2023, rain with light to moderate intensity is evenly distributed throughout the Padang City area, with an intensity of 20-99 mm/day and rain post data shows 8-96 mm/day. On July 14, 2023, the rain continued with higher intensity, reaching 145-434 mm/day at the rain post. This condition caused waterlogging to increase dramatically, triggering flooding in Padang City, which was categorized as extreme rainfall.

ACKNOWLEDGMENT

The DMEO Laboratory Team has provided assistance and support to the authors during this research, for which the authors are quite grateful. The Meteorology Climatology and Geophysics Agency, Padang State University, and Minangkabau Meteorological Station Class II Padang Pariaman are also acknowledged by the author.

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