

Utilization of Himawari-9 and Radiosonde Weather Satellite Data in Heavy Rainfall Analysis (Case Study: Semarang, 14 March 2024)

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ABSTRACT

The heavy rainfall event that hit Semarang City on 14 March 2024 caused flooding at several points. To understand the cause of this event, a comprehensive meteorological analysis is required. This research utilises Himawari-9 weather satellite data with RGB, day convective storm and 24-hour microphysics methods, as well as upper air observations using radiosonde at 12 UTC in the Semarang area. The use of this method is effective in knowing the atmospheric conditions in the Semarang area. The results of observations with the RGB method show cloud conditions that cause heavy rain with high intensity. Observations with the day convective storm method detect convective clouds that have the potential to cause heavy rain. The 24-hour microphysics method identifies High Cumulonimbus, Dense Cirrus, and Thick Cirrus cloud types that can cause heavy rain. Upper air observations with radiosonde at 12 UTC showed the early phase of severe weather in the Semarang area. The results of this study confirm the importance of satellite and radiosonde data integration in predicting and analysing heavy rain events for hydrometeorological disaster risk mitigation.

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1. INTRODUCTION

Climate change and extreme weather variability have become increasingly prevalent in many parts of the world, including Indonesia, where these phenomena are intensifying in frequency and severity. This trend is further exacerbated by human activities such as deforestation, industrial emissions, and urbanization, which significantly magnify the adverse effects of climate change. Climate change is not merely a gradual shift in temperature but a catastrophic force that accelerates extreme weather events, both in terms of frequency and intensity. These disruptions contribute directly to global temperature rises, the warming of oceans, rising sea levels, and the intensification of severe weather events such as droughts and floods [1]. The consequences of these changes are far-reaching, disrupting ecosystems, agriculture, and water resources, all of which pose significant threats to sustainable development and the well-being of communities.

Among the most pressing challenges posed by climate change is the phenomenon of heavy rainfall, which has become one of the key concerns for natural disaster mitigation and regional development planning, particularly in densely populated urban areas like Semarang. As cities continue to grow and expand, urban planning often fails to keep pace with the demands of the increasing population, leading to inadequate drainage systems and poor infrastructure. These deficiencies in urban planning exacerbate the impacts of heavy rainfall, resulting in frequent flooding that affects daily life, damages property, and displaces communities. Furthermore, the consequences extend beyond physical damage, as the flooding increases the risk of public health issues, including the spread of waterborne diseases, creating significant challenges for public health authorities and urban planners alike.

The uncertainty surrounding rainfall intensity and duration adds an additional layer of complexity to the situation, with implications for transportation safety. Rainfall events that are difficult to predict lead to a higher frequency of accidents, particularly during peak traffic hours. Reduced visibility, slippery roads, and disruptions to public transportation schedules all contribute to making urban mobility more difficult and dangerous during rainy periods [2]. For example, sudden rain showers can create hazardous conditions, making it harder for commuters to navigate the city safely. This underscores the importance of accurate and timely weather predictions, as they are essential to mitigating the risks associated with such unpredictable weather patterns. Meteorologists often rely on various parameters to describe weather and climate, with rainfall intensity or volume being among the most critical of these [3]. Effective measurements and forecasts are crucial for minimizing the adverse effects of extreme weather events, particularly in urban environments.

In regions located at higher latitudes, the effects of climate change on snowfall extremes and freezing rain differ significantly from its impact on rainfall extremes, underscoring the need for more in-depth studies and region-specific research [4]. This distinction highlights the complexities of how climate change affects different geographic regions, stressing the importance of localized research to fully understand these phenomena and to tailor appropriate mitigation strategies.

Weather satellites such as Himawari-9 have become invaluable tools in providing critical meteorological data, including atmospheric conditions, which are vital for monitoring and predicting precipitation, especially in remote or hard-to-reach areas [5]. These satellites play a crucial role in improving our understanding of atmospheric dynamics and enhancing the accuracy of weather forecasts. The Himawari-8, a next-generation Japanese geostationary meteorological satellite, was launched on October 7, 2014, and became fully operational on July 7, 2015. On December 13, 2022, the operational control was transferred to the Himawari-9 satellite [6]. With their advanced imaging and monitoring capabilities, these satellites have revolutionized meteorological observations, providing high-resolution data that are indispensable for climate research, disaster management, and efforts to mitigate the impacts of extreme weather events. The ability to track and predict weather patterns with such precision has made significant contributions to improving disaster preparedness and response, especially in regions prone to heavy rainfall and flooding.

2. RESEARCH METHOD

Key objectives included analyzing the capability of satellite and radiosonde data in detecting convective cloud formations, assessing the accuracy of RGB methods in identifying severe weather conditions, and evaluating the effectiveness of upper-air observations in predicting heavy rainfall events.

a. Location and Time of Research

The research was conducted in Semarang City, Central Java. Semarang City is located between 6°50'7"10" South latitude and 109°35' - 110°50' East longitude. To the west, Semarang City is bordered by Kendal Regency, to the east by Demak Regency, to the south by Semarang Regency.

b. Band Determination

The data obtained came from the archives of the Meteorological Climatology and Geophysics Agency (BMKG) through the Japan Meteorological Agency (JMA). In this study, Band 10 (7.3 m) - Band 8 (6.2 m), Band 13 (10.4m) - Band 7 (3.9 m) and Band 3 (0.64 m) - Band 5 (1.6 m) were used. Band 13 (10.4m) - Band 15 (12.4 m), Band 11(8.6m) - Band 13 (10.4 m) / Band 11 (8.6 m) - Band 14 (11.2 m).

c. RGB Methods

In this research, the RGB (Red Green Blue) method is used which is implemented in the SATAID application. The RGB method is Day Convective Storm and 24 Hours Microphysics. The SATAID (Satellite Animation and Interactive Diagnosis) application is an application for processing binary type data from satellite imagery in real time and can be accessed easily [7]. In this study, the SATAID application was used to determine the type of clouds in rain events in Semarang City on 14 March 2024 at 7 to 12 UTC.

d. Day Convective Storm Method

The RGB method is used to identify convective clouds during the day. Day Convective Storm uses Band 10 (7.3 m) - Band 8 (6.2 m), Band 13 (10.4 m) - Band 7 (3.9 m) and Band 3(0.64 m) - Band 5 (1.6 m).

Color	Interpretation
Red	Deep precipitating cloud (precipitation is not necessarily reaching the ground) - high-level cloud, large ice particles
Bright yellow	Deep precipitating cloud (Cb cloud with strong updrafts and severe weather)* - high-level cloud, small ice particles *or thick, high-level lee cloudiness with small ice particles
Purple	Thin cirrus cloud (large ice particles)
Light purple	Thin cirrus cloud (small ice particles)
Dark blue	Ocean
Light blue	Land

Fig. 1. Classification of Day Convective Storm.

Source: Meteorological Satellite Centre (MSC) of JMA. Himawari Day Convective Storms RGB Quick Guide.

The bright yellow colour is identified as Cumulonimbus clouds carrying small ice particles, while the red colour contains high ice particles. Both clouds are clouds that bring severe weather.

e. 24H Microphysics Method

The 24H Microphysics method is used to analyse convective clouds at night (Abay and Haryanto, 2021). 24H Microphysics uses Band 13 (10.4m) - Band 15 (12.4 m), Band 11(8.6 m) - Band 13 (10.4 m) / Band 11 (8.6 m) - Band14 (11.2 m).

Color	Interpretation
Brick red	Thick, high and cold ice clouds
Dark blue	Thick water clouds
Light blue	Clouds with small particles
Black	Thin cirrus clouds
Pink	Dust (yellow sand)
Light blue	Sands with quartz mineral

Fig. 2. Classification of 24H Microphysics.

Source: Meteorological Satellite Center (MSC) of JMA. Himawari 24H Microphysics RGB Quick Guide.

The brick red colour in Fig. 2 shows that the cloud is a cumulonimbus cloud which brings bad weather.

f. Data Retrieval

To obtain comprehensive and accurate data on air weather conditions over the city of Semarang, satellite imagery from the Himawari-9 satellite was employed, in addition to upper air observation results obtained from the Wyoming Sounding on 14 March 2024. The Himawari-9 equipped with advanced imaging sensors, provides high-resolution images that are vital for tracking cloud formations, weather patterns, and atmospheric phenomena. The upper air observation data were captured through the use of a radiosonde, which is a sophisticated device mounted on a weather balloon to collect detailed meteorological data as it ascends through various layers of the atmosphere.

This device measures key atmospheric parameters such as pressure, temperature, and relative humidity, providing valuable insights into the vertical structure of the atmosphere [8,9]. Radiosondes have become an essential tool in atmospheric research, allowing researchers to acquire real-time, high-quality data that is critical for weather forecasting and climate studies. Numerous studies have effectively utilized radiosonde data in conjunction with other meteorological data to assess the accuracy of forecasting models, contributing significantly to the advancement of weather prediction technologies and climate modeling [10-13].

3. RESULT AND DISCUSSION

3.1 Day Convective Storm

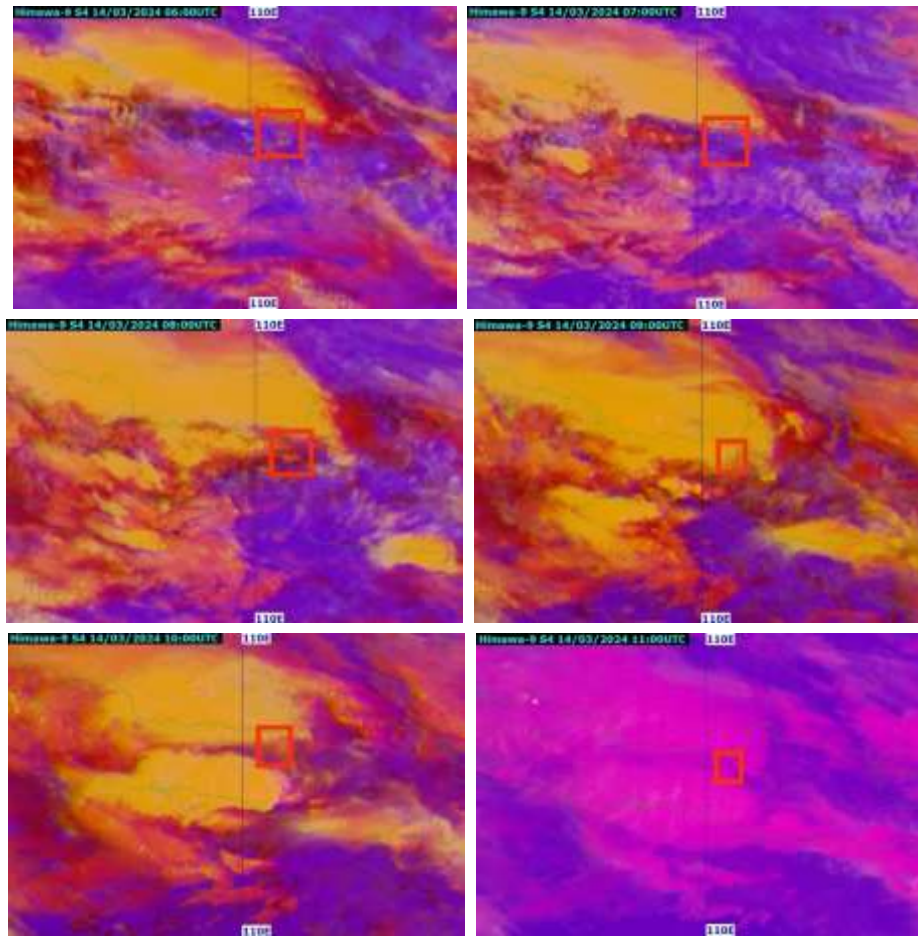


Fig. 3. Himawari-9 Day Convective Storm RGB Satellite Image on 14 March 2024 at 06.00- 11.00 UTC

3.2 24- Hour Microphysics

The system consists of transmitter and receiver parts. The components in the transmitter system consist of sensors, GPS, microcontroller and telemetry module. Figure 3 shows the block diagram of the transmitter system.

The red colour in the image above indicates thick clouds with high peaks (cumulonimbus clouds), while the black colour indicates thin high clouds (cirrus clouds). At 12.00 UTC, cumulonimbus clouds were seen covering the Semarang City area (white coloured box). This continued until at 17:00 UTC the cumulonimbus clouds covering the Semarang City area began to decay and were replaced by cirrus clouds.

3.3 Wyoming Sounding (Radiosonde)

Based on the data obtained from the Wyoming Sounding website on 14 March 2024 at 12:00 UTC, specifically from the Juanda Meteorological Station, several meteorological parameters were analyzed to assess the potential for severe weather in the Semarang City area. The Showalter Index (SI) resulted in a value of 0.38, indicating the presence of conditions favorable for thunderstorms. A value above 0 suggests the atmosphere's instability, which can lead to the formation of convective storms. The Lifted Index (LI), another important indicator of atmospheric instability, recorded a value of -1.21, signifying an unstable condition that enhances the potential for lightning activity. A negative LI value indicates that the air mass is relatively warmer and more buoyant than its surrounding environment, increasing the likelihood of upward motion and thunderstorms. Additionally, the K Index (KI), which takes into account temperature and humidity profiles to predict thunderstorm development, yielded a value of 38.10, pointing to a fairly high potential for thunderstorms. The SWEAT index, which assesses the likelihood of severe weather by evaluating wind patterns and moisture availability, reached 301.20, further suggesting a heightened risk of thunderstorms. The Convective Inhibition (CIN) parameter, which measures the resistance precipitation. These methods revealed the presence of such clouds over Semarang, indicating the likelihood of severe weather conditions.

Additionally, data from upper-air observations, specifically from the Radiosonde, provided critical insights into the atmospheric conditions above the city. The Radiosonde data, which measures key variables such as temperature, pressure, and humidity as the balloon ascends through the atmosphere, also pointed to the potential for heavy rainfall in Semarang. The combination of these observational techniques, which included both cloud-based monitoring and upper-air data, highlighted the severe nature of the weather event. The data suggested a high probability of intense rainfall, and ultimately, the heavy rain that followed caused significant flooding in multiple parts of Semarang City, overwhelming drainage systems and affecting daily life. These methods, together with real-time weather observations, allowed meteorologists to predict the heavy rain with greater accuracy, although the intensity of the rainfall still resulted in considerable local impacts.

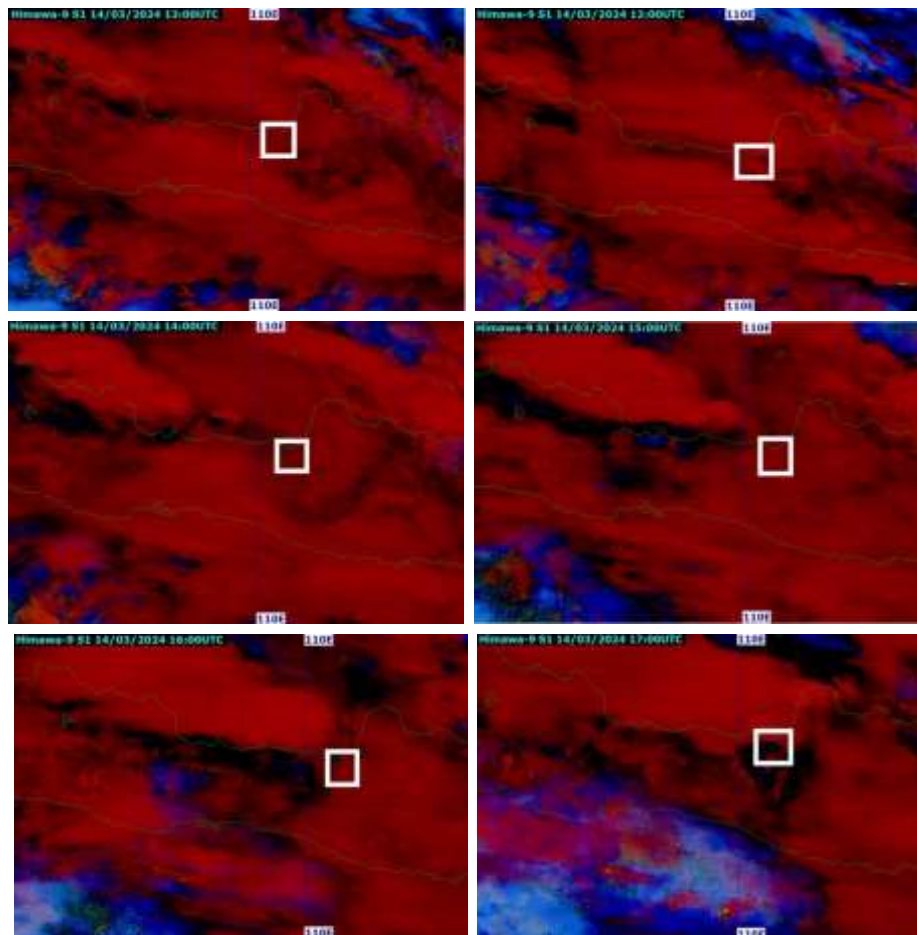


Fig. 4. Himawari-9 24-Hours Microphysics RGB Satellite Image on 14 March 2024 at 12.00-17.00 UTC.

4. CONCLUSION

On 14 March 2024, Semarang City experienced a significant weather event, as heavy rainfall led to widespread flooding in several areas across the city. This extreme weather phenomenon was identified and monitored through various meteorological methods, including the use of RGB (Red, Green, Blue) composite images, which are commonly employed to analyze weather conditions in satellite imagery. Specifically, the day convective storm and 24-hour microphysics methods were utilized to examine the formation and movement of convective clouds, which are often associated with intense to the upward movement of air, was -15.69, indicating an environment conducive to severe weather, as CIN values close to or below zero suggest limited inhibition of convection. Finally, the Convective Available Potential Energy (CAPE), a measure of the potential energy available to fuel storm development, recorded a value of 662.89, indicating a moderate to high potential for storm formation. With these parameters showing significant instability and favorable conditions for thunderstorm development, the Semarang City area on 14 March 2024 at 12 UTC was at risk for heavy rainfall and severe weather conditions, aligning with the observed heavy rain later that day.

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