Original Article

Development of a Rainfall-Landslide Early Warning System (RLEWS) Using GPM Satellite Data for Malaysia's Monsoon-Prone Areas

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Abstract - This study presents the development and evaluation of a Rainfall–Landslide Early Warning System (RLEWS) mobile application that uniquely integrates near–real-time rainfall data from NASA's Global Precipitation Measurement (GPM) satellite for landslide risk prediction in Malaysia. Unlike conventional landslide warning approaches that rely primarily on ground-based rain gauge data, the proposed system utilizes satellite-derived rainfall information combined with multi-timescale rainfall thresholds to capture spatial and temporal rainfall variability during monsoon seasons. Rainfall data collected for Kemensah Heights and Taman Melawati (Kuala Lumpur, Malaysia) between November 2023 and March 2024 are analyzed to establish 1-day, 3-day, and 30-day cumulative rainfall thresholds associated with landslide occurrence. The developed RLEWS mobile application provides real-time visualization of rainfall conditions and automated warning levels, delivering timely alerts to users in landslide-prone areas. Results indicate that higher cumulative rainfall significantly increases landslide risk, with multi-duration rainfall indicators improving predictive performance. This study demonstrates the novel integration of satellite-based rainfall monitoring and mobile application technology as an effective approach for enhancing landslide early warning and disaster preparedness in monsoon-influenced urban environments.

Keywords - Global Precipitation Measurement, Landslide, Mobile Application, Monsoon, Rainfall.

1. Introduction

Natural disasters, such as landslides, pose significant risks to both life and infrastructure, particularly in regions with steep terrain and heavy rainfall. In Malaysia, the occurrence of landslides is closely linked to rainfall patterns, soil conditions, and the seasonal monsoon cycles, which collectively influence the stability of slopes. The frequency and intensity of rainfall events, especially during the monsoon seasons, can push soil beyond its capacity to remain stable, triggering catastrophic landslides. Given the recurrent nature of these events, it is crucial to understand the dynamics of rainfall and its thresholds, as well as the impact of the monsoon seasons on landslide risks.

This reveals a critical research gap, which is the lack of an integrated real-time rainfall-landslide early warning system for Malaysia that combines satellite-based rainfall data, monsoon-season variability, and locally derived rainfall thresholds while delivering warnings through a user-centered mobile application. Addressing this gap is essential for improving landslide preparedness and reducing disaster risk in high-risk urban hillside areas.

This paper proposes the development of a Rainfall-Landslide Early Warning System (RLEWS), designed to predict and mitigate the risk of landslides triggered by extreme rainfall events. By integrating real-time data from Global Precipitation Measurement (GPM) satellites, this system aims to enhance disaster preparedness and response, particularly for communities in high-risk areas. The following sections will provide an overview of the key factors contributing to landslide hazards in Malaysia, beginning with the role of rainfall in shaping these risks.

1.1. Rainfall in Malaysia

Rainfall in Malaysia is characterized by high annual totals, strong seasonality, and significant regional and inter-annual variability, primarily driven by the monsoon systems and influenced by climate phenomena like El Niño and La Niña [1]. In La Niña, the volume of rainfall increases, especially in the north and east, raising flood risks [2].

Extreme rainfall events and floods are becoming more frequent, with some regions showing increasing trends in rainfall intensity and extreme indices [3]. Malaysia experiences high annual rainfall, typically ranging from 2000 to 4000 mm, with some regions (e.g., Johor) averaging around 2600 mm per year [4]. Rainfall is distributed year-round but is strongly influenced by two main monsoon seasons: the Northeast Monsoon (NEM, November-March), which brings intense rainfall, especially to the east coast of Peninsular Malaysia and parts of East Malaysia, often causing floods [5], and the Southwest Monsoon (SWM, May-September), which is generally drier, with less rainfall and more irregular distribution [6]. There are also the short inter-monsoon periods, which occur in March-April and September-October, that contribute to the rainfall variability [7].

In the context of regional and temporal variability, the East Coast of Malaysia, consisting of Kelantan, Terengganu, and Pahang, receives the highest rainfall during NEM, with frequent floods [8]. In the West Coast of Malaysia, consisting of states from north to south, such as Perlis, Kedah, Pulau Pinang, Perak, Selangor, Negeri Sembilan, Melaka, and Johor,

rainfall is spread out and less intense, with some areas experiencing rain shadow effects [9]. The states in East Malaysia, such as Sabah and Sarawak, show spatial heterogeneity, with central and eastern regions prone to droughts and high rainfall erosivity, especially during NEM [10]. Urban areas such as Kuala Lumpur increase local rainfall extremes due to urbanization, particularly in the late afternoon and evening [11]. Figure 1 shows the states available in Malaysia divided by their regions, and Table 1 shows the key rainfall characteristics by region.
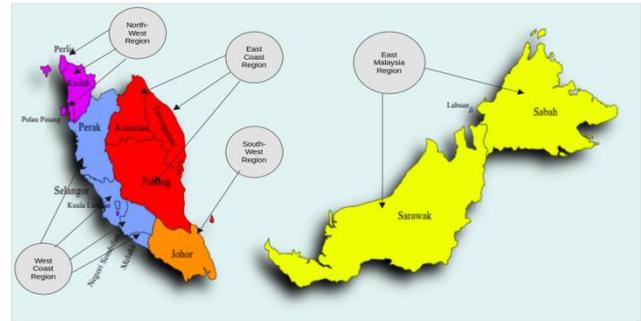

Fig. 1 Regions available in malaysia

Table 1. Key rainfall characteristics by region

Region	Annual rainfall (mm)	Monsoon Impact	Notable Features
East Coast (Peninsular)	2500-3500+	NEM (heavy rain/floods)	Frequent floods, high intensity [2]
West Coast (Peninsular)	2000-2600	SWM (drier)	More spread rainfall, rain shadow [4]
East Malaysia (Sabah/Sarawak)	2000-4000	NEM (variable)	Droughts, High erosivity, Landslides [10]
Urban (Kuala Lumpur)	~2500	SWM & NEM	Urbanization increases extremes [11]

1.2. Rainfall Threshold

Rainfall thresholds are typically defined as the rainfall value above which there is a high probability of a specific event occurring, such as a landslide or significant runoff. These thresholds can be based on various rainfall parameters, including:

Table 2. Summary of rainfall thresholds

- Intensity-Duration (ID)	:	Considers both how hard and how long it rains. [12]
- Accumulated Rainfall (AR)	:	Total rainfall over a specific period [13]
- Event-Duration (ED) and Event-Intensity (IE)	:	Focus on the characteristics of individual rain events. [14].

One of the applications of the rainfall threshold is in predicting landslides and debris flow. Rainfall thresholds are essential for predicting rainfall-induced landslides and debris

flows. They are used in early warning systems to mitigate risks by correlating past events with rainfall records and establishing critical values for hazard activation [14]. Another usage of rainfall thresholds is in the runoff generation. In hydrology, thresholds help identify when rainfall will lead to significant runoff, considering factors like soil moisture, catchment storage, and rainfall characteristics. The abruptness and variability of these thresholds can depend on local conditions such as slope, land cover, and waterhead features [15]. Table 2 shows the summary of rainfall thresholds consisting of the application area, threshold parameter, and purpose.

1.3. Landslide in Malaysia

There are several causes of landslides in Malaysia, and one of them is due to natural factors. Malaysia's tropical climate brings frequent, intense rainfall, especially during the monsoon season. Prolonged or high-intensity rainfall increases soil saturation, reduces soil strength, and triggers slope failures [16]. Malaysia's topography and slope angle are also factors in landslides. Steep slopes are highly susceptible

to landslides. Areas with higher slope angles experience greater gravitational pull on soil and rock, increasing landslide risk [17]. Soil and geological conditions are also factors that produce landslides in Malaysia. Certain soil types (e.g., silty sand, clay-rich soils) and underlying geology (e.g., granite, acid intrusive rocks) are more prone to landslides due to their permeability and structural weaknesses [18].

Besides natural factors, there are also human-induced factors such as urbanization and land use change. Rapid urban development, especially on hillsides, often involves slope cutting, removal of vegetation, and construction, all of which destabilize slopes and increase landslide risk [19]. Deforestation and agriculture are also among the human-induced factors contributing to landslides in Malaysia. Clearing forests for agriculture or development reduces root strength that stabilizes soil, making slopes more vulnerable to failure during heavy rains [20]. The development of infrastructure also induces landslides. Road and building construction on or near steep slopes can disturb natural land stability, further increasing susceptibility [21]. Other contributing factors include proximity to rivers and faults. Areas close to rivers and geological faults are more likely to experience landslides due to erosion and ground movement [17]. Population density is also a factor, as densely populated regions often overlap with landslide-prone zones, compounding risks due to increased exposure [22].

1.4. Monsoon in Malaysia

The monsoon system in Malaysia is characterized by two main reasons: the NEM in November-March and the SWM in May-September. These are driven by the differential heating of land and sea, causing seasonal wind reversals that bring moist air and heavy rainfall during the NEM and drier conditions during the SWM [23]. The NEM brings strong winds and heavy rainfall from the South China Sea, especially affecting the east coast of Peninsular Malaysia [24]. Large-scale atmospheric circulation and climatic phenomena such as the El Niño-Southern Oscillation (ENSO) events (e.g., El Niño and La Niña) significantly influence the intensity and distribution of monsoon rainfall.

El Niño typically brings drier conditions, while La Niña increases rainfall, especially during the Northeast Monsoon [2]. The Madden-Julian Oscillation (MJO) modulates rainfall patterns by enhancing or suppressing convection, affecting the timing and intensity of monsoon rains [25]. Besides ENSO and MJO events, cold surges from East Asia (e.g., China, Japan, Mongolia, North Korea, South Korea, and Taiwan) and typhoons in the region can also intensify monsoonal rainfall and trigger extreme weather events [26]. Malaysia's topography and regional geography are also key drivers of the monsoon. Malaysia's mountainous terrain and proximity to the South China Sea enhance rainfall during the NEM, while rain shadow effects and distance from moisture sources reduce rainfall in some regions [6].

1.5. Relationship between Rainfall, Landslide, and Monsoon

The monsoon brings sustained, heavy rainfall over days to weeks, especially in tropical and subtropical regions like Malaysia. This period is marked by both high total rainfall and frequent extreme rainfall events [27]. Landslides are most commonly triggered by intense or prolonged rainfall, which infiltrates the soil, raises pore water pressure, reduces soil strength, and destabilizes slopes. Both single-day heavy rain and cumulative rainfall over several days can initiate landslides [28]. The majority of landslides in monsoon-affected regions occur during or immediately after the monsoon rains, with landslide frequency and severity closely tracking rainfall intensity and duration during this season [29].

The relationship between rainfall, landslides, and monsoons is particularly critical in areas where steep terrain and heavy rainfall converge. The timing and intensity of rainfall during the monsoon season significantly influence the occurrence of landslides. For instance, a prolonged period of heavy rainfall during the NEM can lead to soil saturation over several days or weeks, which increases the risk of multiple landslides across large areas.

In contrast, intense short bursts of rain, common during the SWM, may result in localized but rapid landslides, especially in regions with already weakened soil from previous rain events. Additionally, the cumulative effect of rainfall over successive monsoon seasons can cause the soil to weaken, making it more prone to failure gradually. Understanding this dynamic is crucial for predicting when and where landslides are most likely to occur, as it highlights the importance of continuous monitoring of rainfall patterns throughout both monsoon seasons. For effective landslide prediction and early warning systems, it is essential to model these factors collectively, taking into account the seasonal variability of rainfall and its direct impact on slope stability.

1.6. Early Warning System

An Early Warning System (EWS) is designed to detect and predict hazards (such as natural disasters, disease outbreaks, or other threats), assess risks, and provide timely alerts to individuals, communities, and authorities so they can take action to minimize harm or loss [30].

The goal of EWS is to protect lives, livelihoods, and infrastructure by empowering people to prepare and respond before a disaster occurs [31]. EWS works by utilizing technology such as sensors, remote sensing, and data networks to collect real-time information about hazards [32]. Data is analyzed to assess risk and generate forecasts or alerts. Warnings are communicated through various channels (e.g., mobile alerts, sirens, media) to ensure people receive and understand the message. Effective EWSs also include public education and preparedness activities to ensure appropriate action is taken. Table 3 shows the key components of an Early Warning System (EWS).

Table 3. Key components of the early warning system

Component	Description
Hazard Monitoring [30]	Continuous observation and detection of potential threats (e.g., sensors, satellites)
Risk Assessment [32]	Analyzing data to evaluate the likelihood and potential impact of hazards
Forecast & Prediction [30]	Using models and data to anticipate when and where hazards may occur
Communication [30]	Disseminating clear, actionable warnings to at-risk populations
Preparedness & Response [30]	Ensuring communities know how to act on warnings and have response plans

1.7. Early Warning System Mobile Application

An early warning system mobile application is a smartphone app designed to deliver real-time alerts, risk information, and emergency instructions to users before and during disasters, helping them take timely protective actions. There are several key features and functions of the EWS mobile application, such as real-time alerts. These apps send push notifications about imminent hazards (e.g., floods, earthquakes, and storms) based on users' locations, allowing for rapid dissemination of warnings to at-risk individuals [33]. Official and local warnings are also part of the features. Many apps integrate both official government alerts and localized, impact-based warnings, providing users with actionable information tailored to their specific area [34].

EWS mobile app features often include checklists for self-protection, emergency contact directories, safety tips, and interactive maps to help users prepare for and respond to disasters [34]. Some of the apps provide user reporting and feedback, which allow users to report incidents, upload photos, and provide feedback, which can enhance situational awareness and support emergency response efforts [34]. There is also the EWS mobile application that introduces community engagement through features such as crowdsourcing and two-way communication that foster community involvement and improve the accuracy and reach of warnings [35]. One of the examples of EWS mobile applications is the A4alerts app, utilized in Catalonia, Spain, which provides site-specific flood warnings, official alerts, self-protection checklists, and allows users to report events and give feedback. Users found it useful for supporting emergency actions and reducing disaster impacts [34].This paper proposes the development of a mobile application for a Rainfall-Landslide Early Warning System (RLEWS) with the objective of predicting landslide events in Kemensah Heights and Taman Melawati, Wilayah Persekutuan, based on data provided by the GPM satellite, and analyzing the landslide EWS based on the connection between landslide events and rainfall threshold. The following section, Section 2, discusses the methodology for the research; Section 3 discusses the results and discussion; and Section 4 discusses the conclusion.

2. Methodology
2.1. Data Collection

The primary area of study is in Kuala Lumpur, Wilayah Persekutuan, Malaysia, consisting of two places, Kemensah Heights and Taman Melawati, as shown in Figure 2. Two of these places were selected due to the higher occurrence of landslide events in recent years.

In 2021, the Selangor Disaster Management Authority declared the Kemensah Heights landslide area as a disaster site [36], while in 2024, Taman Melawati residents were struck by a landslide [37]. Due to this, both areas were considered in the study. The dataset was retrieved from 2023 to 2024. The GPM satellite precipitation data were provided by the NASA Earth Data website [38] with a precision of 0.1º x 0.1º.
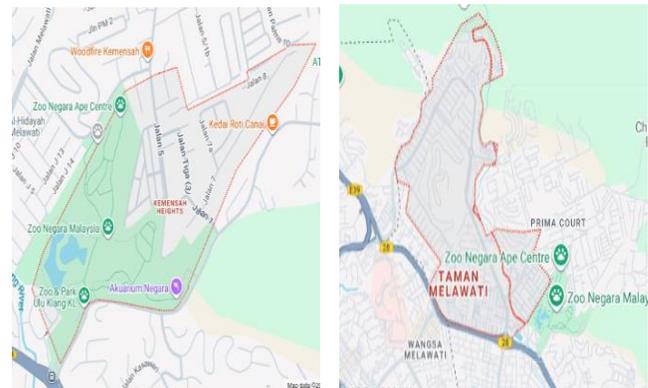

Fig. 2 Location of Study, (a) Kemensah Heights, and (b) Taman Melawati.

The rainfall data was captured daily by the GPM satellite, specifically in the area prone to landslides based on gridded point coordinates. The dataset utilized for this rainfall product was retrieved from NASA's Integrated Multi-Satellite E Retrievals for GPM (IMERG), called the GPM Level 3 IMERG Late Daily 10 x 10 km version 6 (GPM_3IMERGDL v06) [39] daily. The dataset was analyzed in real-time in order to ensure the warning level for rainfall.

The integration of this input with the Landslide Susceptibility Map (LSM) creates a hazard map for rainfall-landslides. Figure 3 shows the flowchart of RLEWS starting from the input gathered by the GPM satellite and the daily rainfall dataset of GPM_3IMERGDL v06, moving on to the analysis of rainfall, rainfall threshold, and rainfall-landslide mapping, and ending with the output of landslide-hazard level, which can be seen on the RLEWS User Interface (UI) accessed through smartphones.
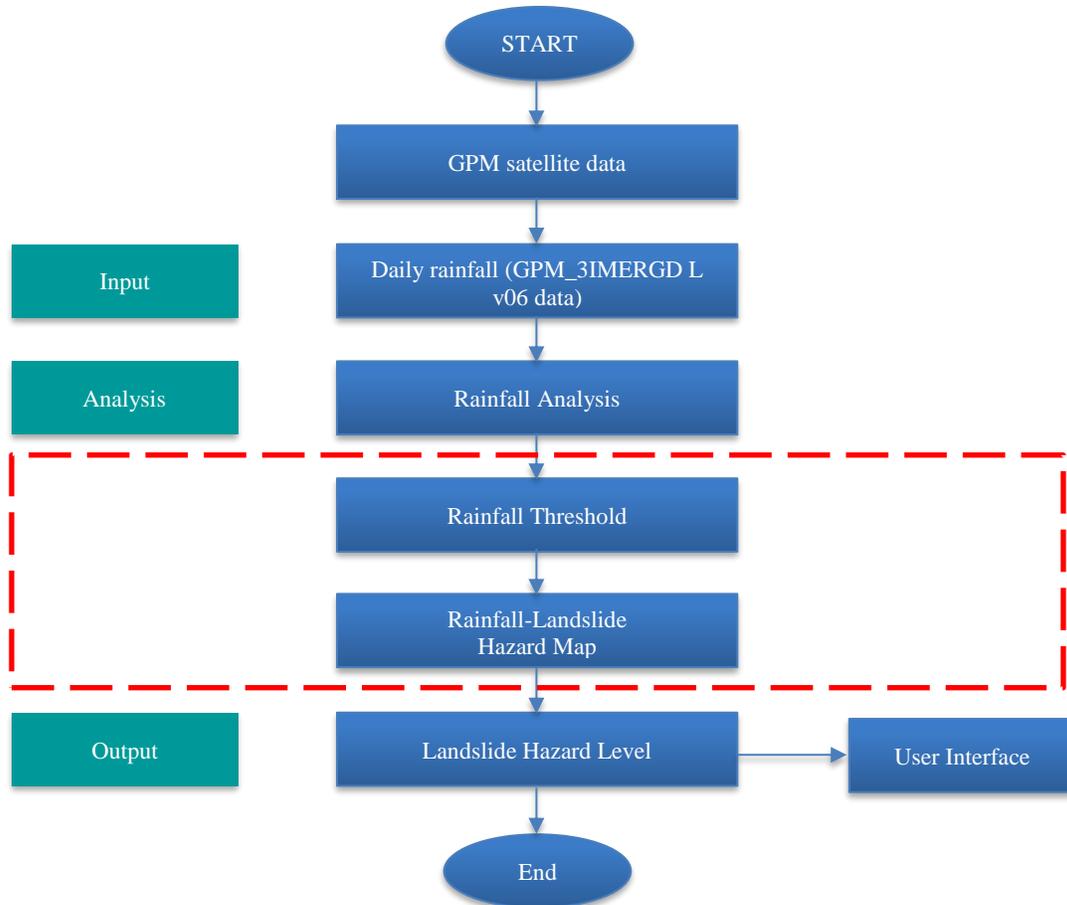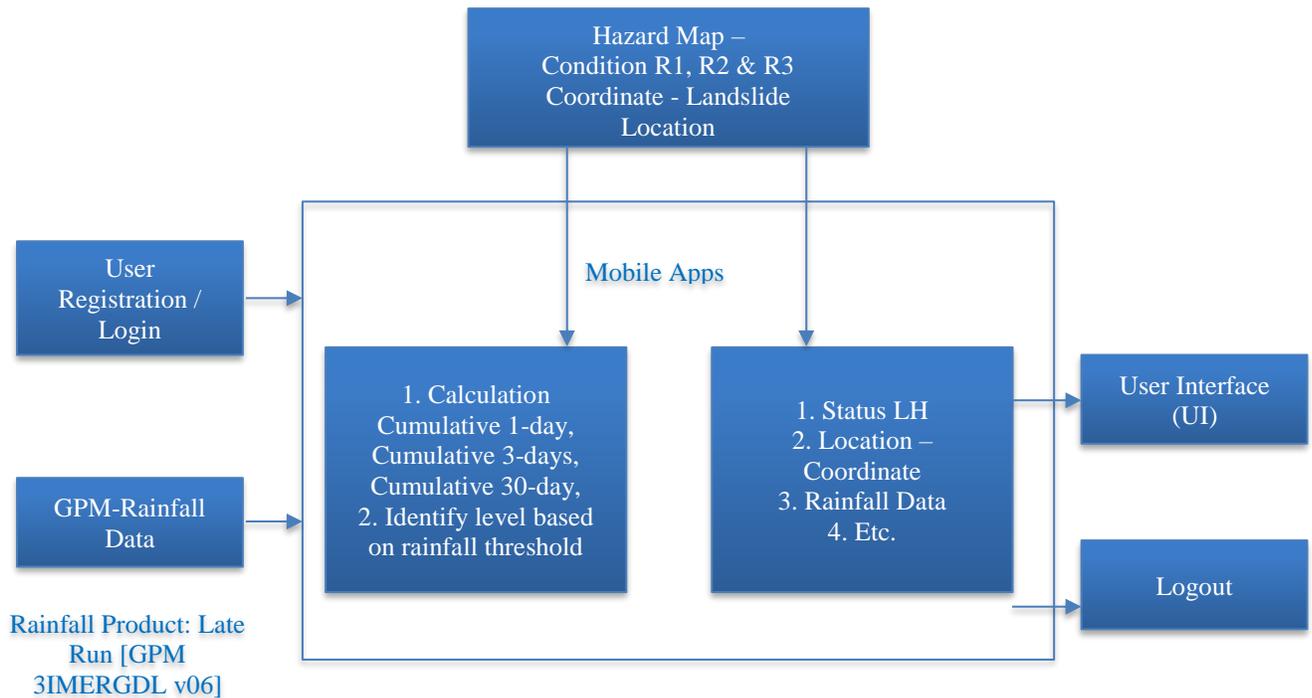
Fig. 3 RLEWS flowchart

Fig. 4 RLEWS mobile application block diagram

2.2. RLEWS Operation

The RLEWS operation starts with collecting GPM precipitation data as its input. A single grid point of the nearest location is needed to determine the amount of rainfall for the area prone to landslides in Kemensah Heights and Taman Melawati, Wilayah Persekutuan, Malaysia. Figure 4 shows the RLEWS mobile application block diagram, which takes the user registration/login and GPM rainfall data from NASA EarthData as its input. In the mobile apps, the calculation of cumulative 1-day, 3-day, and 30-day periods alongside the identification of rainfall thresholds resides in the back end. Besides cumulative calculation and rainfall threshold, the status of landslide hazard, location coordinates, and rainfall data also reside in the back end. The output of the mobile application shows the User Interface (UI) and the logout button.

2.3. Rainfall Threshold Model

For this study, the rainfall threshold follows previous research [40], where the plotting of the rainfall threshold follows the 3-day and 30-day cumulative rainfall (E3-E30).

Table 4 shows the summary of rainfall threshold level, rainfall threshold levels, rainfall threshold equation, warning levels, and landslide protection.

There are 3 rainfall threshold levels, namely "R1", which indicates lower warning levels and no occurrence of landslide; "R2", which indicates moderate warning levels and minor landslide occurrence; and "R3", which indicates high warning levels and major landslide occurrence.

Table 4. Rainfall threshold level

Rainfall Threshold Levels	Rainfall Threshold Equation	Warning Levels	Landslide Protection
R1	$Rainfall < E_{3(Major)} = 192.8 - 0.56E_{30}$	Low	No Landslide
R2	$E_{3(Major)} = 192.8 - 0.563E_{30} > Rainfall > E_{3(Minor)} = 140.6 - 0.973E_{30}$	Moderate	Minor Landslide
R3	$E_{3(Minor)} = 140.6 - 0.97E_{30} > Rainfall > E_{3(Extreme)} = 182.4 - 0.27E_{30}$	High	Major Landslide

2.4. Mobile App Development

The RLEWS mobile app development follows the steps available in Figure 5. The RLEWS application takes the input from NASA EarthData GPM_3IMERGDL to produce the rainfall data for rainfall-landslide analysis. The development of mobile apps consists of the Android Studio IDE, the programming languages of Kotlin and React Native for the backend and frontend of the mobile apps, and the Leaflet API to produce the mapping of landslides. Besides the programming language and the API utilized in the development, the logic, such as the hazard map consisting of the rainfall threshold (R1, R2, R3), the cumulative rainfall calculation, and the landslide status, was also included.

Fig. 5 RLEWS mobile app development

3. Results and Discussion

In this section, the results and discussion for RLEWS, alongside an analysis of cumulative rainfall, are discussed thoroughly.

3.1. User Interface (UI)

The User Interface (UI) of RLEWS is shown in this section, which discusses several features of the mobile application. Figure 6 shows the RLEWS application icon in mobile view, consisting of rain, landslide, and hazard icons as its thumbnail. Figure 7 (a) – (g) shows the main UI view of the RLEWS application. Figure 7(a) shows the startup page of RLEWS containing the icon, title, and the button for exploring. Figure 7(b) shows the main page consisting of location selection, date selection, a submit button, a clear form button, a button for providing a complaint and RLEWS copyright, and a button for information on location incidents. Figure 7(c) shows the available location to make the rainfall analysis, consisting of Kemensah Heights and Taman Melawati. Figure 7(d) shows the selection of dates for making the rainfall analysis. Figure 7(e) shows the complaint information that can be made to the Ministry of Natural Resources and Environmental Sustainability (NRES) alongside the RLEWS copyright text. Figure 7(f) shows the location information for both of the areas affected by the landslides. Figure 7(g) shows the forms reset and cleared through clicking the "Clear Form" button.
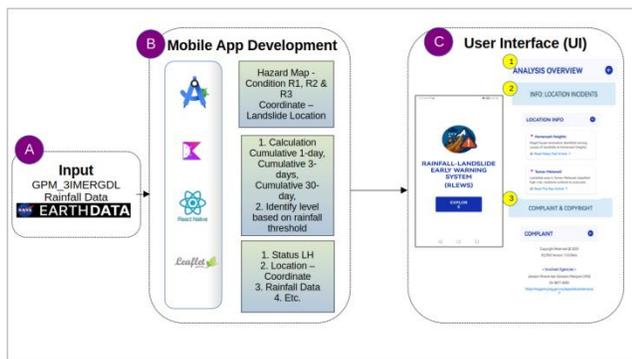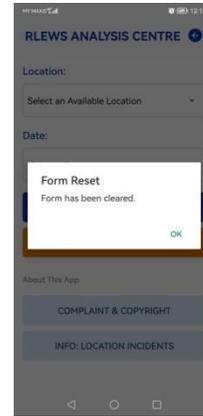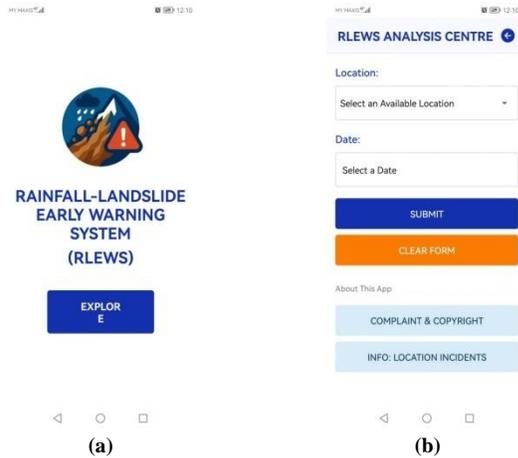
Fig. 6 RLEWS mobile app development (mobile view)

(a)

(b)

(c)

(d)

(e)

(f)

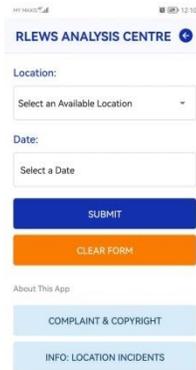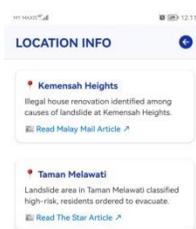**(g)**

Fig. 7 User Interface (UI) of RLEWS

3.2. Landslide Warning Level

The landslide warning level of RLEWS consists of "Low" and "High". Figure 8 shows the available landslide warning level in RLEWS. The rainfall status shows both the warning level and the landslide prediction. Figure 8(a) shows the rainfall status in green color, indicating a low warning level with no landslide prediction. Figure 8(b) shows the rainfall status in yellow-orange color, indicating a moderate warning level with a minor landslide prediction. Figure 8(c) shows the rainfall status in red color, indicating a high warning level with a major landslide prediction. Besides the rainfall status, the location map utilizing the Leaflet API also shows green and red color indicators based on its warning level.

(a)

(b)

(c)
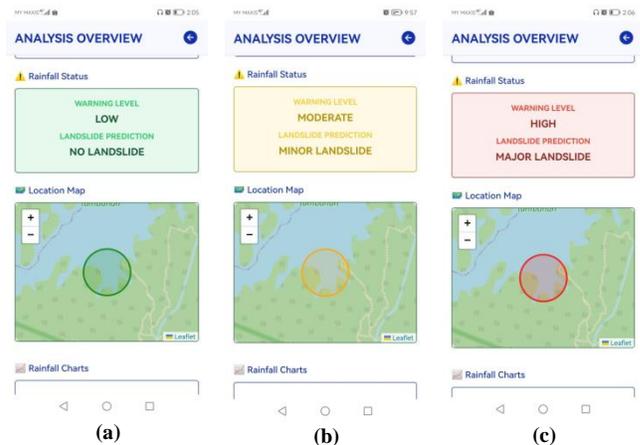
Fig. 8 Landslide Warning Level, (a) Low, (b) Moderate, and (c) High.

3.3. Average Rainfall and Monsoon Season

In this section, the rainfall cumulative pattern for Kemensah Heights, Kuala Lumpur, Malaysia, is discussed based on the average rainfall status for 1-day, 3-day, and 30-days periods for the years 2023 to 2024, as shown in Figure 9 and Table 5. Figure 9 shows the graph of the average rainfall status, with dashed lines indicating the year 2023 and normal lines indicating the year 2024. The months were also divided

into seasonal monsoons, namely the NEM, Inter-Monsoon, and SWM. From Table 5, the rainfall increases from January to March with NEM as its season, and continues to increase in April due to the Inter-Monsoon season. The rainfall decreases as it enters the month of May and continues through September for the SWM monsoon season.
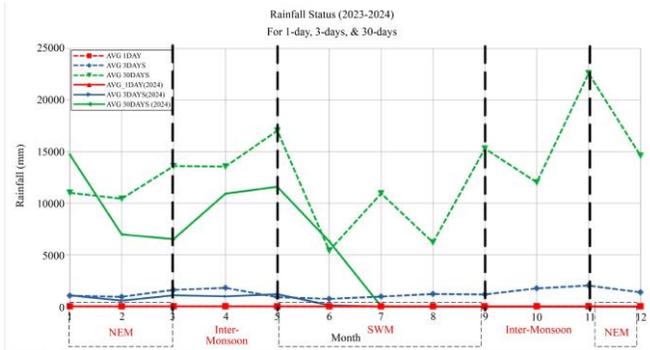

Fig. 9 Average rainfall status for 1-day, 3-day, and 30-days periods for the year 2023 to 2024

Table 5. Average rainfall for 1-day, 3-days, and 30-days and monsoon seasons

Date/Seasons		Rainfall (mm)		
Month	Seasonal	1-day	3-days	30-days
Jan (2023)	NEM	7.3	1043.3	11016.3
Feb (2023)	NEM	7.91	934.48	10445.73
Mar (2023)	NEM	9.9	1603.01	13610.8
Apr (2023)	Inter-Monsoon	13.86	1796.39	13563.55
May (2023)	SWM	4.83	894.02	17042.04
Jun (2023)	SWM	5.65	731.92	5410.55
Jul (2023)	SWM	6.08	956.41	10954.05
Aug (2023)	SWM	8.42	1204.86	6203.18
Sept (2023)	SWM	8.36	1160.63	15305.25
Oct (2023)	Inter-Monsoon	12.62	1752.77	12029.8
Nov (2023)	NEM	13.6	2022.75	22587.4
Dec (2023)	NEM	9.36	1366.7	14614.95

Jan (2024)	NEM	7.26	1079.03	14708.44
Feb (2024)	NEM	3.87	558.75	6980.12
Mar (2024)	NEM	8.28	1081.1	6525.4
Apr (2024)	Inter-Monsoon	6.05	976.44	10936.16
May (2024)	SWM	8.25	1186.47	11599.19
Jun (2024)	SWM	0.8	113.18	6305.61
Jul (2024)	SWM	0	0	15.76
Aug (2024)	SWM	0	0	0
Sept (2024)	SWM	0	0	0
Oct (2024)	Inter-Monsoon	0	0	0
Nov (2024)	NEM	0	0	0
Dec (2024)	NEM	0	0	0

3.4. Rainfall Cumulative Pattern

For the analysis of the rainfall cumulative pattern, the months between November and March and the last two years, 2023 and 2024, were chosen due to their relation to the Northeast Monsoon (NEM). Both Kemensah Heights and Taman Melawati, Kuala Lumpur, lie in the path of the monsoon winds. The Northeast Monsoon (NEM) would likely bring more significant rain and potential flooding risks. These regions are more affected by the heavy, sustained rainfall and potential floods in the Northeast Monsoon season, especially in areas near rivers or with steep terrain. Due to Taman Melawati being only 2.9 km from Kemensah Heights, the analysis assumes similar cumulative rainfall for both areas, thus focusing on a single area for the analysis.

3.4.1. Cumulative Pattern – 1-Day

In this section, the results for the cumulative pattern of 1-day are discussed. Figure 10 shows the cumulative pattern of 1 day in Kemensah Heights for November 2023. It can be seen that the highest cumulative rainfall is on the 4th of November 2023, with 60 mm, followed by the 14th of November 2023, at 35 mm, and the 22nd of November 2023, with 30 mm. The cumulative rainfall pattern for December 2023 is shown in Figure 11. The highest cumulative rainfalls occurred on 23rd

December 2023 with 36 mm, 29th December 2023 with 33 mm, and 12th December 2023 with 27 mm. The 1-day cumulative rainfall pattern for January 2024 is shown in Figure 12. In January 2024, the cumulative rainfall shows a minimum in value for the first five days and increases on 7th January 2024, with cumulative rainfall nearing 100 mm, then decreases throughout the month with smaller spikes seen. Figure 13 shows the 1-day cumulative rainfall for February 2024. The first day, 1st February 2024, shows the highest cumulative rainfall at 26 mm, and plummeted down to lower than 5 mm on 3rd February 2024, then increased in smaller spikes, followed by lower cumulative rainfall towards the middle of the month and the end of the month. Figure 14 shows the 1-day cumulative rainfall for March 2024. The highest rainfall produced is on 8th March 2024 with 44 mm, followed by 30 mm on 25th March 2024 and 30th March 2024. Starting from 9th March to 23rd March, the cumulative rainfall is at a minimum level.
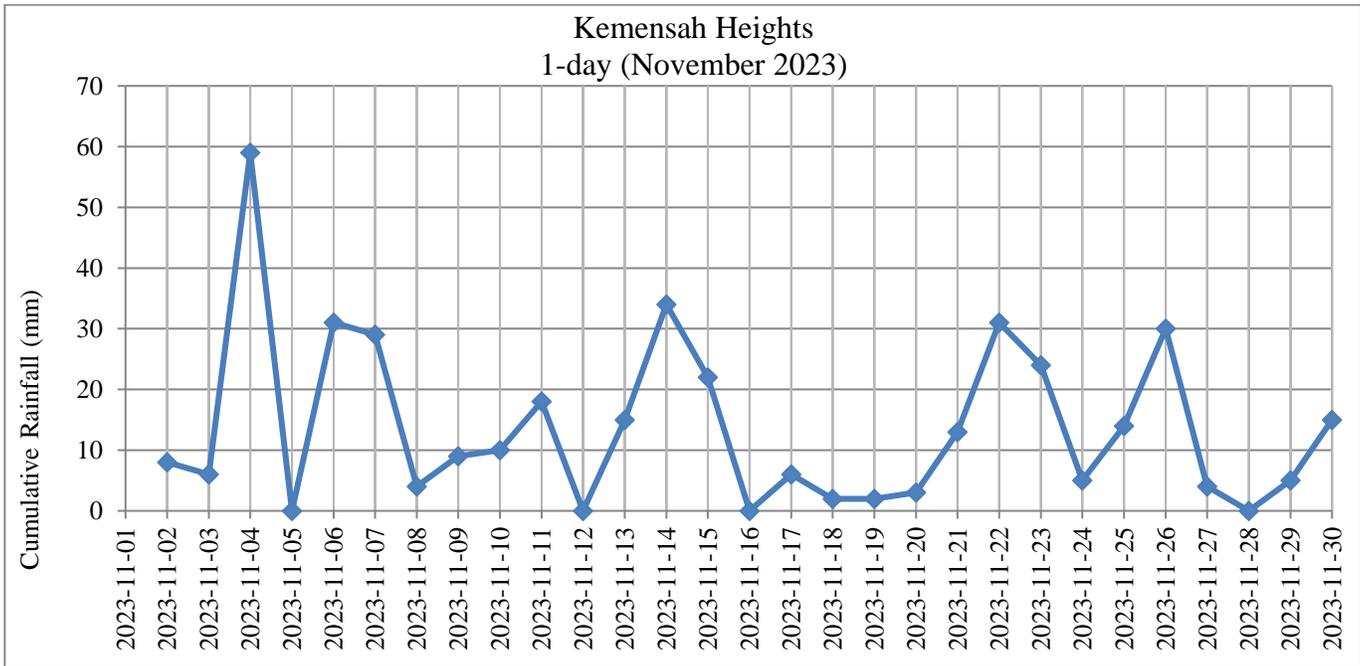
Fig. 10 1-day, November 2023
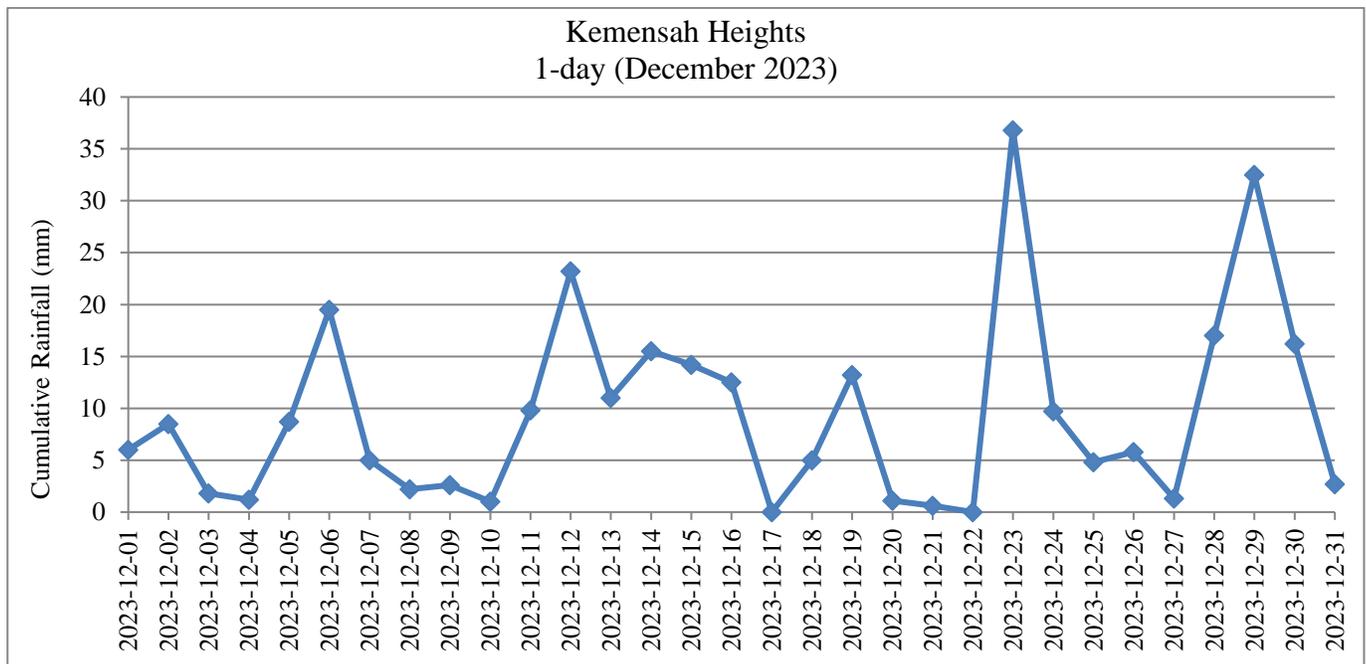
Fig. 11 1-day, December 2023
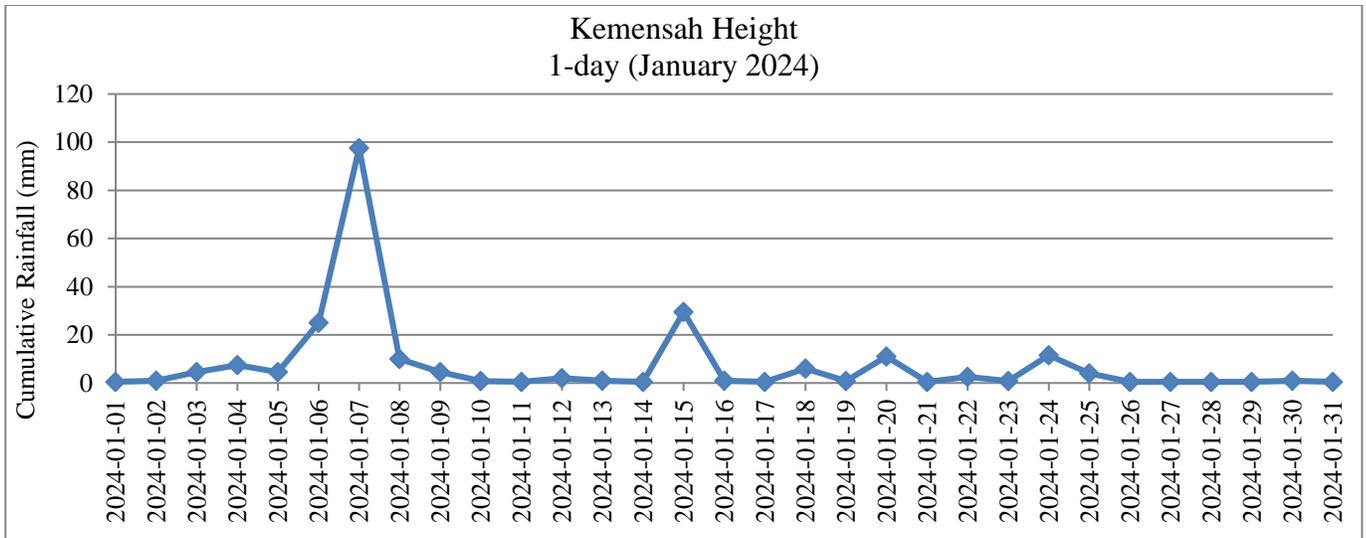
Fig. 12 1-day, January 2024
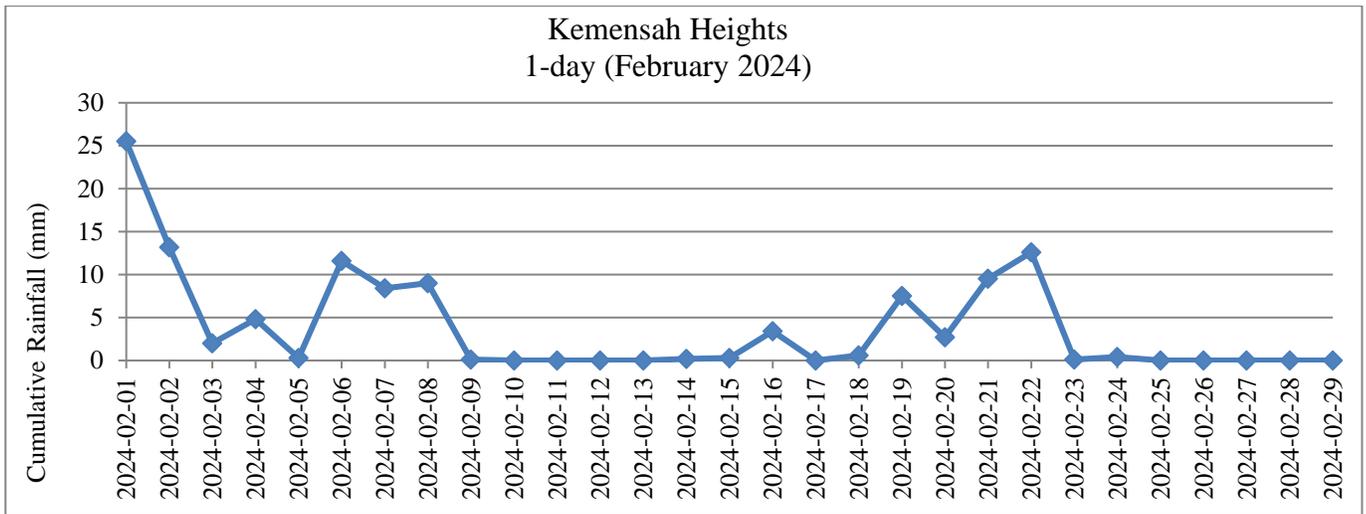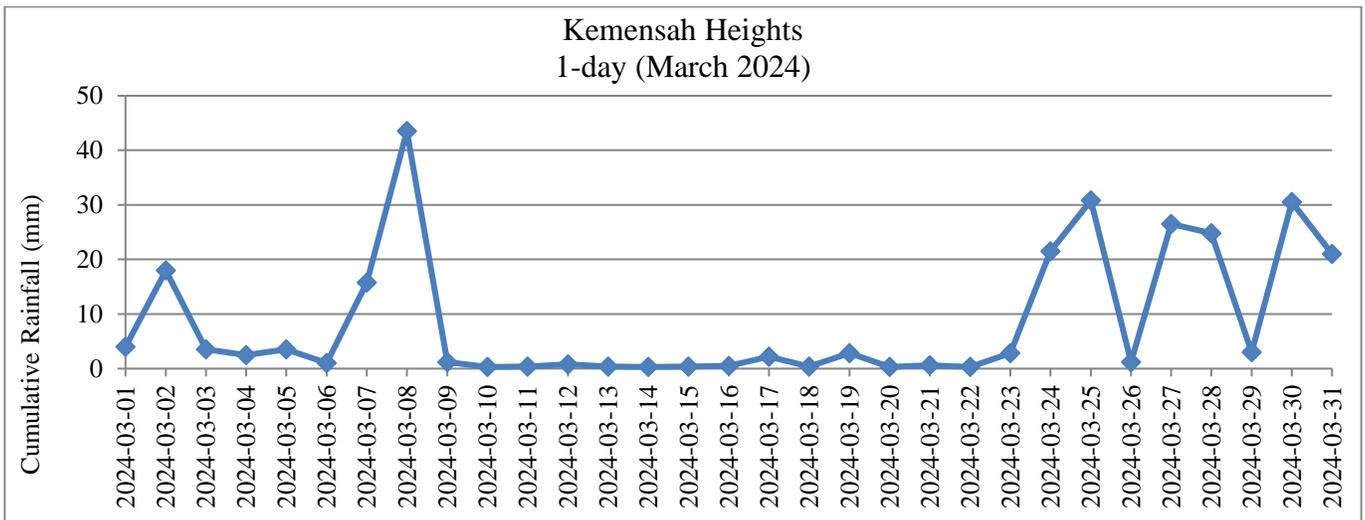

Fig. 13 1-day, February 2024

Fig. 14 1-day, March 2024

3.4.2. Cumulative Pattern – 3 Days

In this section, the cumulative rainfall pattern for 3 days in Kemensah Heights is discussed. Figure 15 shows the rainfall pattern in November 2023. The highest rainfall produced was on the 6th of November 2023, with cumulative rainfall >4000 mm. The following days show a reduction in rainfall, showing patterns that go through ups and downs, with the lowest on 20th November 2023, with < 500 mm. Figure 16 shows the 3-day rainfall cumulative pattern for December 2023. The pattern shows inconsistent rainfall for the area, with the highest rainfall occurring on 30th December with > 3000 mm and the lowest on 22nd December with < 500 mm. The 3-day cumulative pattern for January 2024 is shown in Figure 17. The cumulative rainfall starts below 2000 mm for the first 6 days and increases on 7th January with 6000 mm and goes on to increase on 8th January with 6300 mm. The pattern then plummeted throughout the month. Figure 18 shows the 3-day cumulative pattern for February 2024. The highest rainfall was recorded on 3rd February with 1967 mm, and then it decreased rapidly on 5th February to less than 500 mm. The month continues with smaller spikes of increasing rainfall and produces a lower amount of rainfall until the end of the month. Figure 19 shows the 3-day cumulative rainfall for March 2024. During this part of the year, there are several high levels of cumulative rainfall, such as 8th March, 9th March, 25th March, 27th March, and 30th March, all producing >2500 mm of cumulative rainfall. Lower cumulative rainfalls can be seen from 11th March to 23rd March.
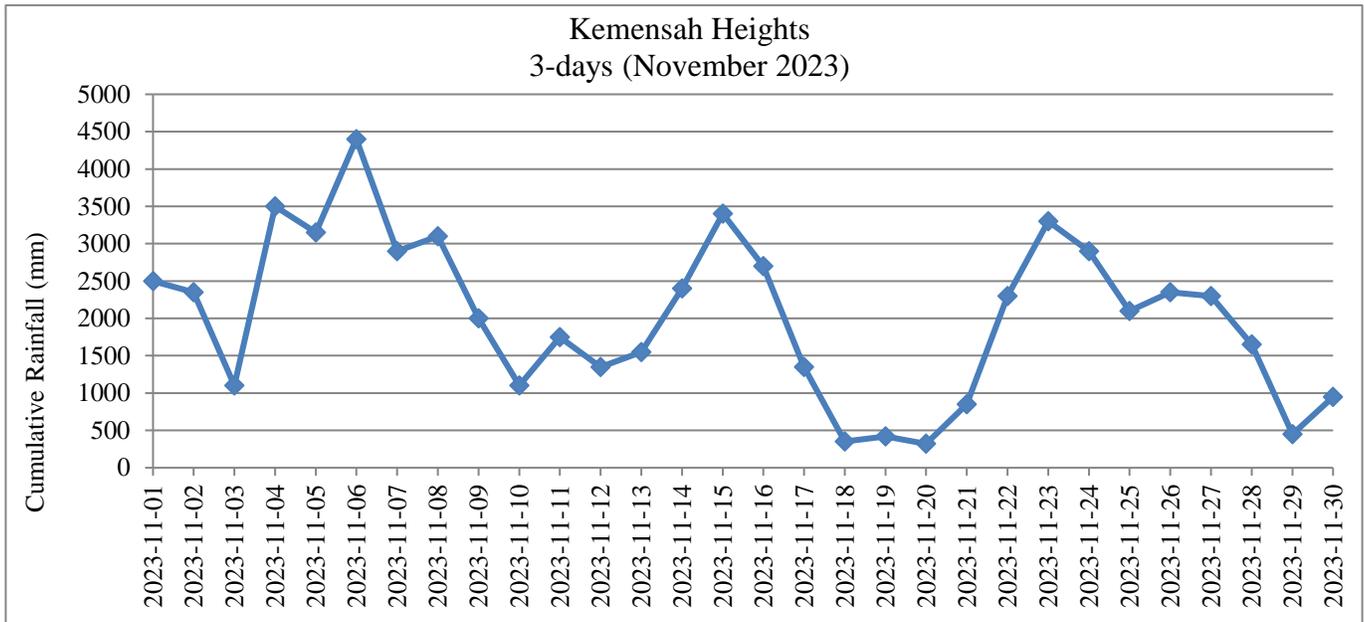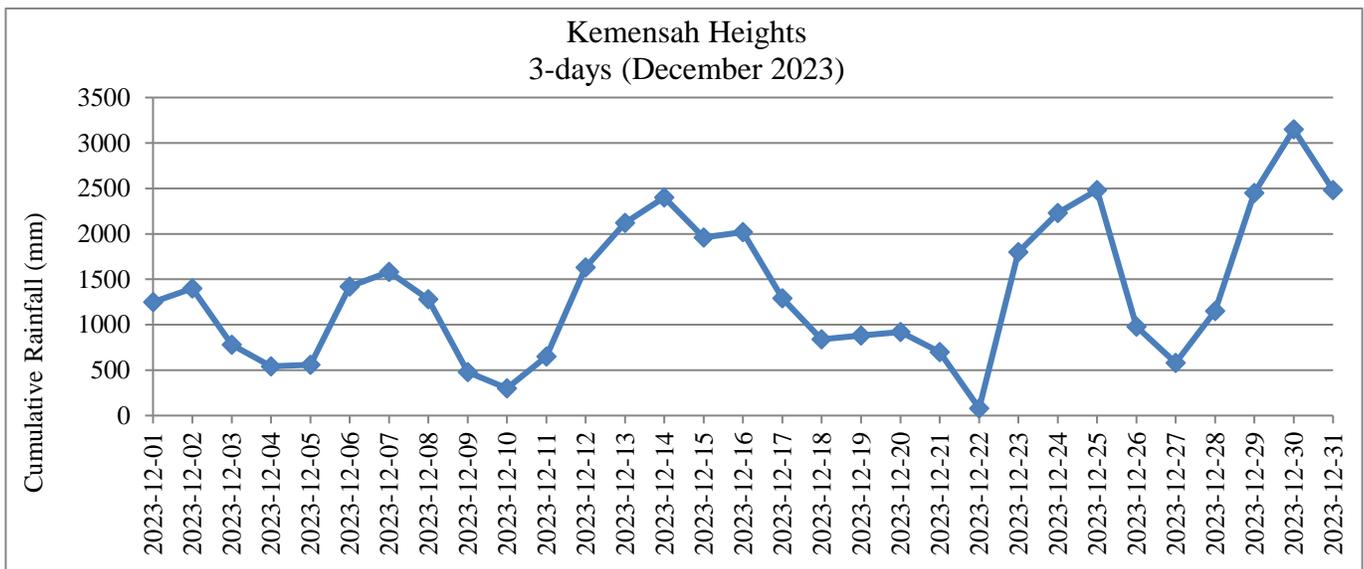

Fig. 15 3 days, November 2023
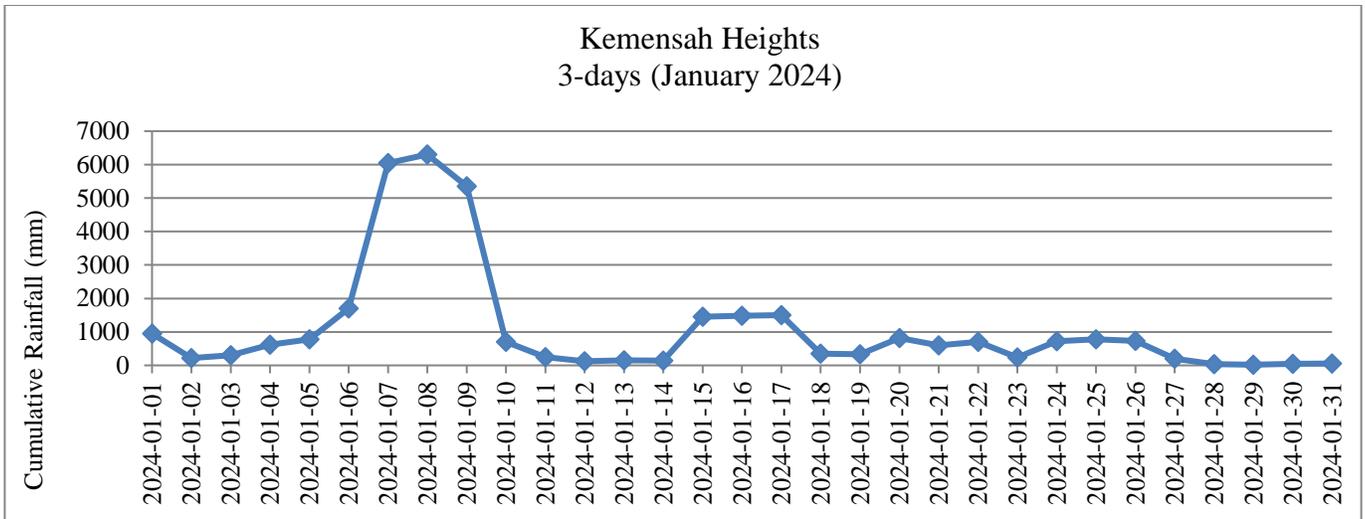

Fig. 16 3 days, December 2023

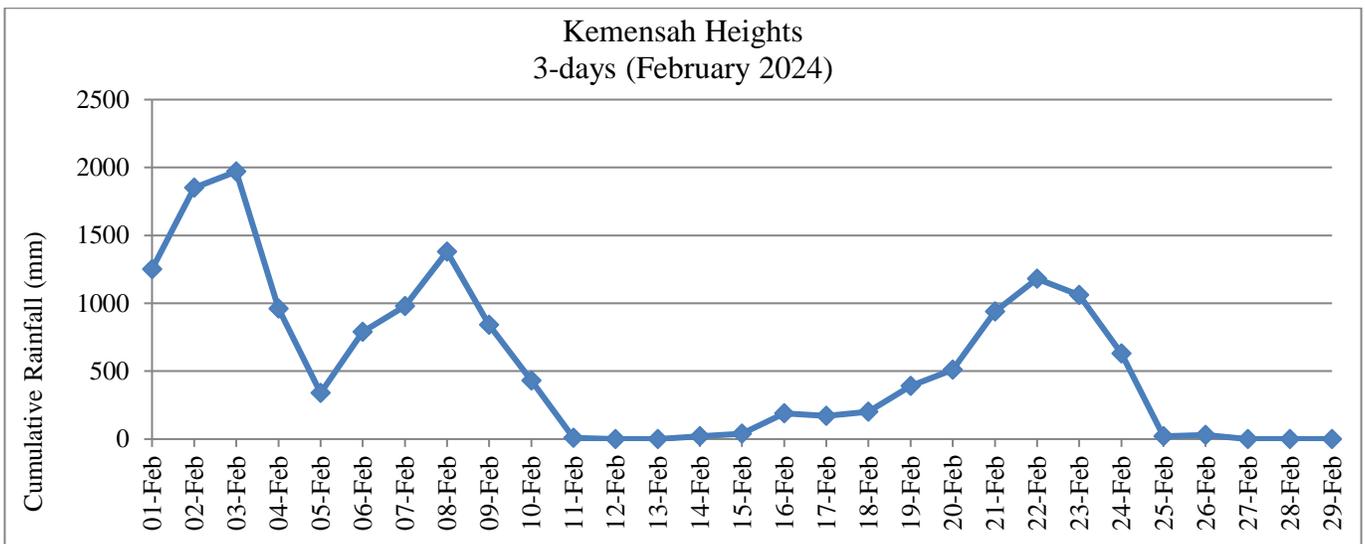**Fig. 17 3 days, January 2024**

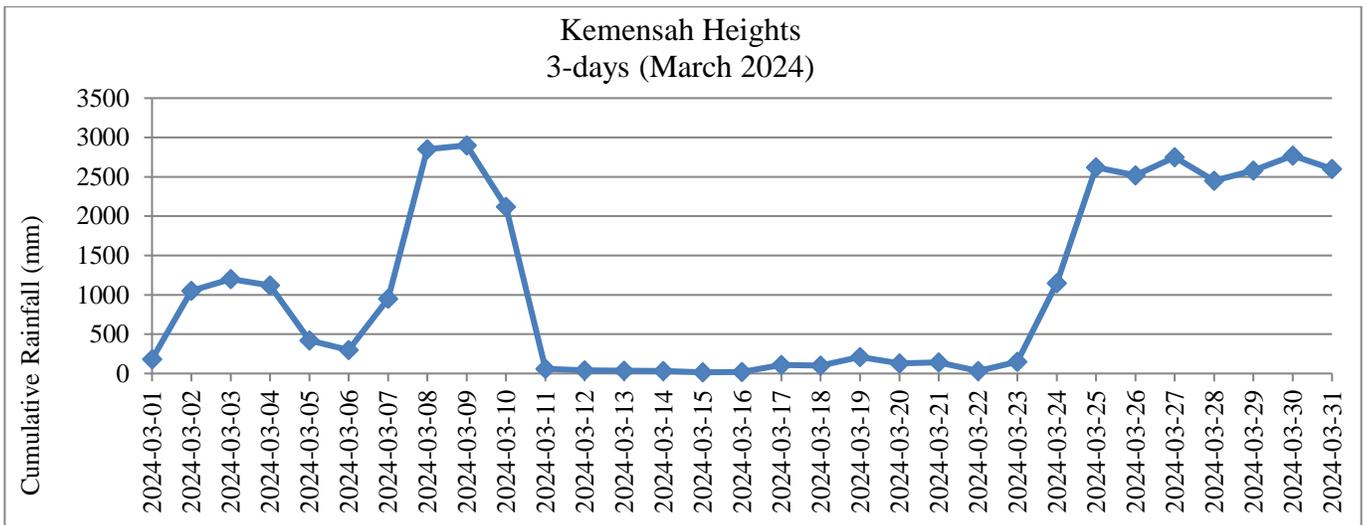**Fig. 18 3 days, February 2024**

Fig. 19 3 days, March 2024

3.4.3. Cumulative Pattern – 30 Days

The cumulative pattern for 30 days is discussed in this section. Figure 20 shows the 30-day cumulative rainfall for November 2023. It can be seen that throughout the months, the cumulative rainfall shows a steady pattern with rainfall greater than 15000 mm. The highest can be seen on 15th November at 26365 mm. Figure 21 shows the results for December 2023. The results also show steady patterns; however, the graph shows a decreasing trend. The highest cumulative rainfall starts on the first day of the month, 1st December, with 19450 mm and decreases until the end of the month. Cumulative rainfall for 30 days in January 2024 is shown in Figure 22. The first five days show a steady pattern with rainfall less than 14000 mm, then it increases to the second highest on 7th January at 18000 mm, and then the highest on 9th January at 18582 mm. The pattern decreases until the end of the month. The 30-day cumulative rainfall for February 2024 can be seen in Figure 23. The first five days show rainfall greater than 10000 mm, decreasing for 8 days (6th February - 13th February) to below 8000 mm, and steadily keeping below 6000 mm until the end of the month. Figure 24 shows the results for March 2024. The first seven days show cumulative rainfall below 6000 mm, increasing to 6547 mm on 8th March, and consistently staying above 6000 mm for 11 days to decrease to a few thousand millimeters, and skyrocketing from 23rd March until the 31st March, showing the highest at 12000 mm.

3.5. Comparison with Existing Researchers

The RLEWS mobile application is compared to another researcher's mobile-based warning system for overcoming flood events globally [41]. In [41], a mobile application called the "Smart Flood Warning System" was developed that provides users with flood information in real-time alongside predictive analytics. Despite its utilization of hardware such as ESP32 and sensors for sensing water flow rate, intensity of rainfall, and level of water, this dataset might be insufficient and capable of covering only a small-scale coverage of rainfall. RLEWS utilizes NASA's Global Precipitation Measurement (GPM) dataset, which is known globally for its precision and accuracy in detecting rainfall and precipitation. Due to this, RLEWS has better accuracy and precision in determining the rainfall level than researchers in [41].
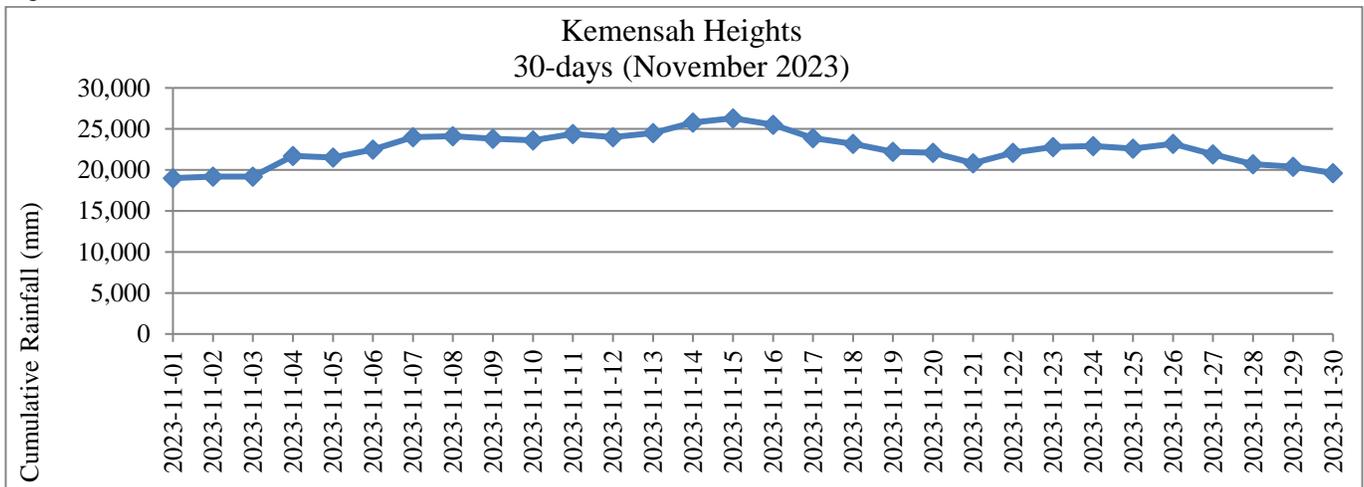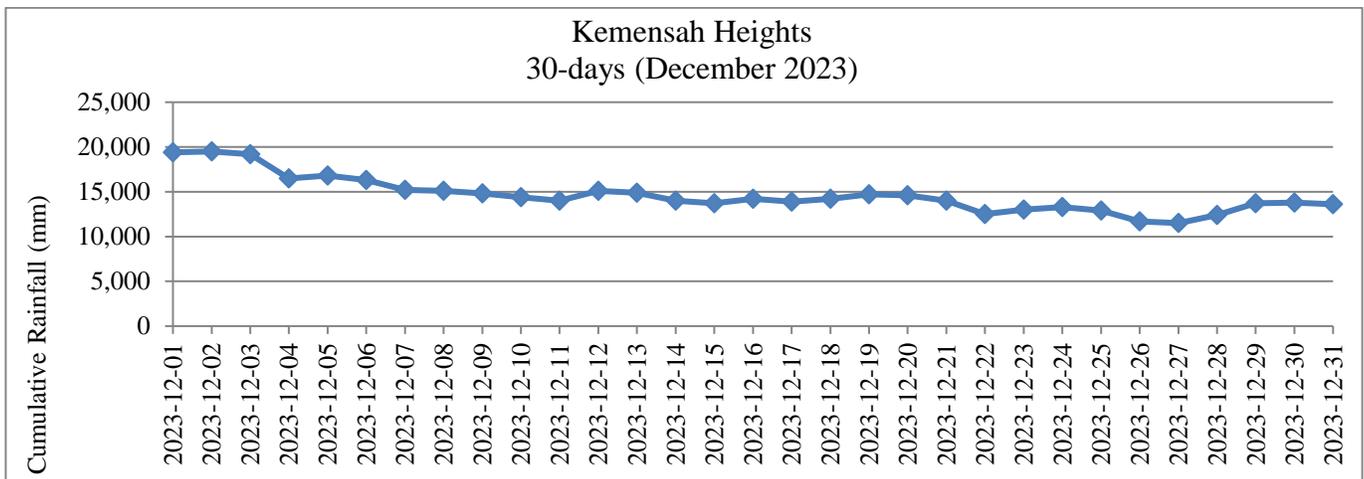

Fig. 20 30-days, November 2023
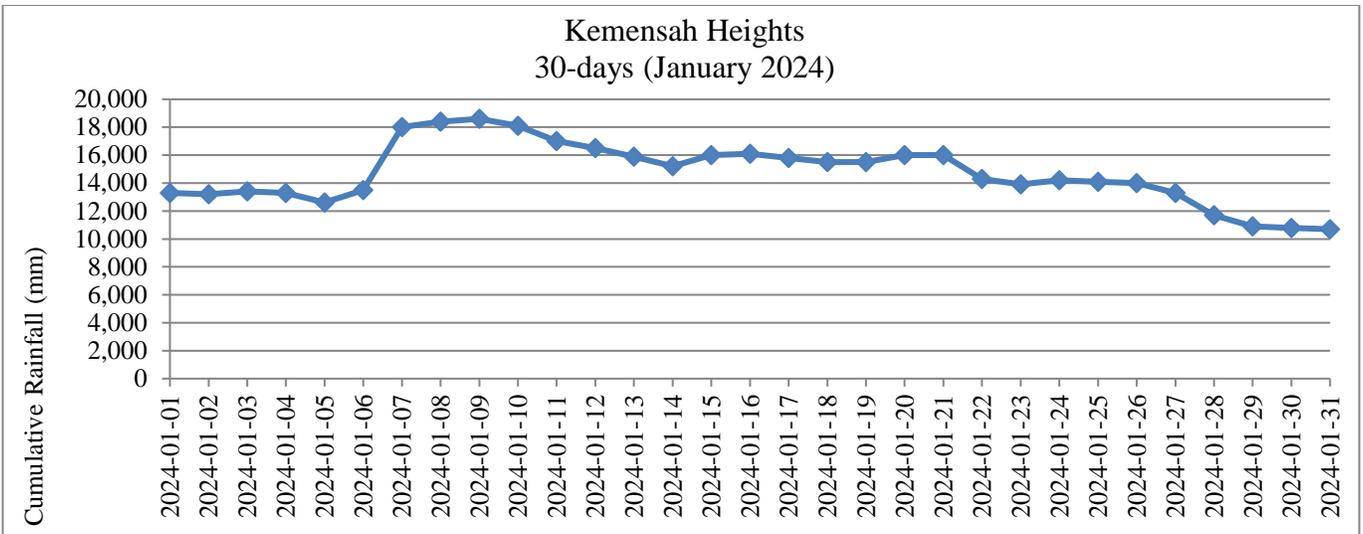

Fig. 21 30 days, December 2023
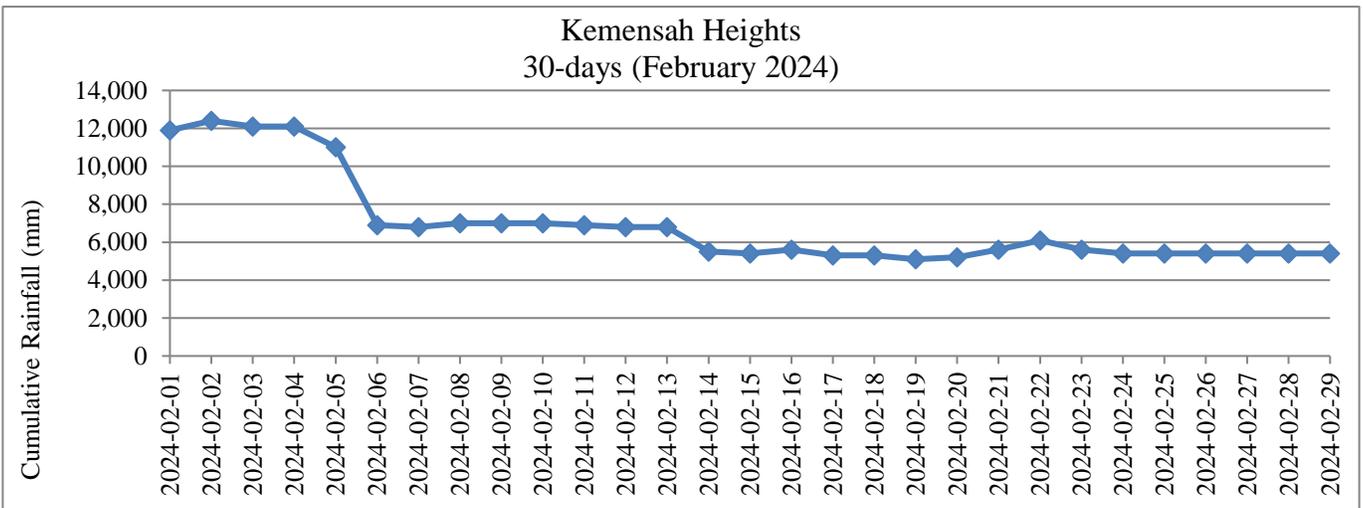
Fig. 22 30-days, January 2024

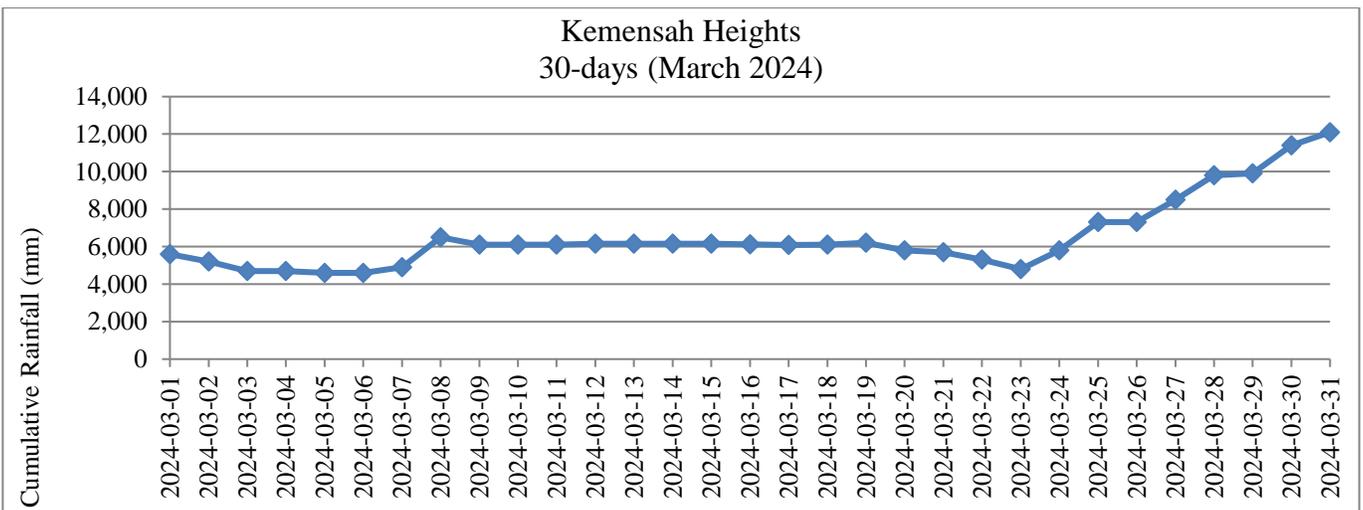**Fig. 23 30 days, February 2024**

Fig. 24 30 days, March 2024

4. Conclusion

The RLEWS mobile application successfully integrates real-time rainfall data from GPM with local landslide risk assessments, providing an effective tool for early warning and risk mitigation in Malaysia.

The analysis of cumulative rainfall patterns over the monsoon seasons of 2023 and 2024 demonstrates a clear correlation between rainfall thresholds and landslide risk, validating the application's predictive capabilities.

The user-friendly interface of RLEWS enhances accessibility, allowing users to receive critical warnings and engage with the system for reporting and monitoring purposes. This research contributes to the growing need for mobile-based disaster preparedness tools, particularly in countries like Malaysia that face recurring risks from natural hazards like landslides. Future work could explore the incorporation of additional environmental data, the expansion of RLEWS to other regions, and improvements in the system's predictive algorithms for more accurate and timely warnings.

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