Mobile Application for Rainfall-Landslide Early Warning System (RLEWS) using Global Precipitation Measurement (GPM)

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Abstract— Malaysia has tropical climates near the equatorial zone that deliver widespread rainfall each year. Due to this, Malaysia is susceptible to landslide incidents as one of the main factors that can induce a landslide is rainfall. Landslides have a significant impact on many environmental and socioeconomic issues, including the loss of life, damage to property and infrastructure, and psychological stress among victims. According to a study, geological circumstances are primarily responsible for slope collapse in a number of these countries. A landslide-specific early warning system must be established despite the increased sensitivity to landslides to lower the danger of landslide hazards. The objectives of this project are to develop a mobile app for a landslide early warning system to be used as a monitoring tool of landslides using estimates from the Global Precipitation Measurement (GPM) precipitation data to alert if any warning signs from potential landslides occurrences were seen in Ulu Klang. The methodology of this project is using MySQL as a database server, and PHP as a programming language with the input/data from GPM rainfall data. The result is all users are notified of the condition of the landscape and the landslide occurrence in Ulu Klang.

Keywords- Global Precipitation Measurement (GPM); Landslide; PHP; MySQL; Mobile Application; Early Warning System

I. INTRODUCTION

These Landslides are a common natural disaster in Malaysia that occurs due to various factors such as heavy rainfall, erosion, deforestation, and inadequate construction practices. In addition, the occurrence of landslides depends on the geological environment in which the geological body is located and is dominated by a variety of factors [1]. These events can result in significant damage to infrastructure, homes, and human lives. Landslides are a significant hazard in Malaysia, due to the country's mountainous terrain, high rainfall, and as the country experiences frequent monsoon seasons. There were two slope failures that contributed to the deadly landslide incident at Batang Kali, Selangor. The landslide in Batang Kali was caused mainly by high soil saturation and pressure by the buildup of subterranean water beneath the campsite [2]. The landslide was classified as Malaysia's second-deadliest disaster [3].

In Malaysia, rainfall is a major factor in the occurrence of landslides. Landslides in Malaysia typically occur in areas with steep slopes, loose soils, and heavy rainfall. In regions of high vulnerability, these complex hazards can cause significant negative social and economic impacts [4]. The amount of rainfall varies from one rainy day to the next [5]. The rain and consistently high temperatures throughout the year lead to intensive and extensive weathering of features on the ground. These combinations of climate and geological conditions together with other causative factors such as slope angle, drainage conditions, geological boundaries, etc. [6] have led to landslides becoming one of Malaysia's most common natural disasters. The most affected areas are the states of Johor, Pahang, Perak, and Selangor. Residential areas, roads, and other infrastructure are often impacted, leading to disruption of transportation, communication, and other essential services.

The rainfall threshold refers to the level of rainfall intensity and duration above which landslides are more likely to occur. The threshold varies depending on various factors such as soil type, slope steepness, presence of vegetation, and the antecedent moisture conditions of the soil. Generally, the higher the rainfall intensity, the lower the rainfall threshold. When the rainfall intensity exceeds the threshold, it can cause saturation of the soil, leading to reduced shear strength and increasing the likelihood of a landslide. For example, in areas with a high proportion of clay soils, the threshold for landslides may be lower than in areas with sandy soils.

Rainfall thresholds have been estimated using satellite precipitation estimates. However, satellite precipitation thresholds vary from equivalent gauge thresholds in the same regions. They also emphasized that it has consequences for landslide early warning systems performance evaluations and operational landslide forecasting [7]. Gariano *et al.* [8] studied that the rainfall thresholds were widely used, considering different scales of analysis (global, regional, and local), a wide range of rainfall parameters, different physiographical settings, and different types of landslides. Furthermore, new technologies are urgently required for monitoring and lowering disaster risks due to climate change and processes of land loss. According to Patrick et al. [9], rain gauge stations are quite rare in Malaysia, particularly in rural regions. The ability to provide estimates of rainfall that are spatially distributed is a benefit of remote sensing technology.

Remote sensing technology is often used in Malaysia to monitor and predict landslides, by analyzing factors such as soil moisture, vegetation health, and land use. The frequency and severity of landslides have increased in recent years, due to a combination of factors such as population growth, urbanization, deforestation, and climate change. Satellite remote sensing can provide observations of global precipitation and clouds [10]. However, as the number of landslides and sensors increases, the amount of monitoring data generated is close to massive, and the traditional monitoring systems are gradually unable to manage and analyze the acquired data, hence an automated early warning system is needed [11].

A. *The Internet of Things (IoT)*

Network of devices that are connected to the Internet and can communicate with each other. IoT technology can be used to develop mobile applications for early warning systems of landslides. One way this can be done is by using GPM data from remote sensing technology to monitor the conditions that can lead to landslides. These sensors can measure factors such as rainfall intensity. The data collected by these sensors can then be analyzed in real-time to identify areas at risk of landslides.

B. *A Mobile Application*

Developed to provide users with real-time information about the risk of landslides in their area. The application can use the data collected to create a map that shows the areas at risk of landslides. The application can also send alerts to users when the risk of landslides is high so that they can take appropriate actions to protect themselves and their property.

C. *Early Warning Systems (EWS)*

Include alarm, warning, and forecasting systems. When a predefined level is achieved by slope movement, alarm systems issue a timely warning to persons in the immediate vicinity of the landslide (e.g., flashing lights and sirens).

Comparatively, alert methods are favoured where specialists in charge of analysing the situation and minimizing danger can be informed by putting in place effective measures and where progressive degradation phases can be identified [12]. For LEWS, two scales investigated by Segoni *et al.* [13] might be created and applied. Local systems are those that address specific landslide sites (Lo-LEWSs). Territorial Systems (Te-LEWS) are large-scale, regional systems that are employed in and around a lake, a region, or a state. However, Lo-LEWSs are frequently employed to address the threat associated with one or more confirmed landslides as reported by Piciullo *et al.* [14]. It may be possible to construct an early warning system with the aid of comparison and analysis of the rainfall threshold in relation to the factor safety for landslides, especially in areas where Naidu *et al.* [15] found that natural landslides are a concern.

Furthermore, [16] found the structure has explicitly divided the landslide model, alarm model, and warning system. The alarm system model is one of the landslide model elements and early warning system parts. Landslide models are based on the practical relationship between climate conditions and landslide occurrence which considers several characteristics of the area. A warning model includes a landslide model which outlines a variety of decision-making processes desired to set alert levels.

The objective of this research is to develop a mobile application for a landslide early warning system using PHP and MySQL as the scripting languages and Kodular software as an online suite for mobile app development. In addition, the objective of the research is to predict landslide occurrence in Ulu Klang, Selangor based on Near Real-Time (NRT), and Post Real-Time (PRT) data provided using the GPM satellite and to analyse the landslide early warning system based on the relationship between rainfall threshold analysis and landslide occurrence.

With more data and better spatiotemporal precision than TRMM satellite products, GPM is a new generation of satellites. Such products are crucial for landslide warnings in mountainous regions that are susceptible to severe rainfall but lack reliable rainfall data.

II. METHODOLOGY

A. *Material and Data Collection*

1) Study Area: The research area is in Ulu Klang, Selangor, which is 10 kilometers from Kuala Lumpur city as shown in Fig. 1. The data obtained is on 6th May 2023. The demand for land in Ulu Kelang for economic development, including housing and real estate projects, is rising because of the city's rapid urbanization. Ulu Kelang is regarded as one of Malaysia's most landslide-prone regions as a result. This has been regularly threatened by landslides since 1990. This study makes use of the closest point (Kemensah, Ulu Kelang), which has latitude and longitude of 3.184° N and 101.7675° E and is a gridded point of GPM data with 0.1o x 0.1o precision. The NASA Earth Data website offers the GPM satellite precipitation data estimates.

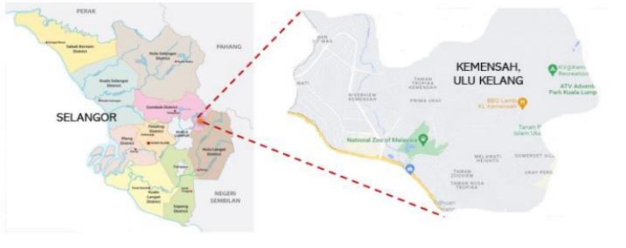


Fig. 1. Location of the study area, Ulu Klang, Selangor

2) *Data Collection* :The GPM satellite captured the daily rainfall data in the landslide-prone area based on the coordinates of a gridded point. The daily rainfall product GPM_3IMERGDL v06 is retrieved from USGS data every day or every 24 hours. The GPM_3IMERGDL v06data will be analyzed in real-time on the server (real-time information) to determine the rainfall warning level. This dynamic input is integrated with the landslide susceptibility map to produce a rainfall-landslide hazard map. This automation process is conducted by existing RLEWS as stated in the red dot box in Fig. 2. Fig. 2 shows the output of RLEWS will be obtained from mobile apps that can be accessed through mobile phones, and tablets.

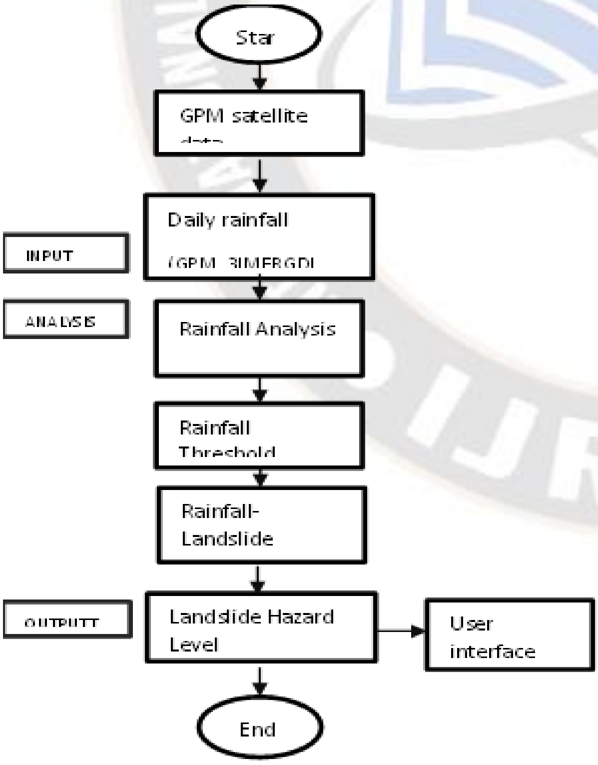


Fig. 2. Flowchart of RLEWS operation

B. *The operation of the Rainfall-Landslide Early Warning System (RLEWS)*

It may be possible to construct an early warning system with the aid of comparison and analysis of the rainfall threshold in relation to the factor safety for landslides, especially in areas where Naidu *et al.* [17] found that natural landslides are a concern. Just as importantly, the system permits threshold levels for different slope performance indices to be redefined and refined in the system as advanced warning criteria [18]. The RLEWS starts with a GPM precipitation data collection as input. One grid point of the nearest location is required to indicate the rainfall amount of the landslide-prone area in Kemensah, Ulu Kelang, Selangor.

GPM rainfall data is provided by NASA and can be accessed through the Earth Data Network website. The system analyses daily rainfall to determine the rainfall warning levels which are low, moderate, high, and very high. The rainfall warning level will integrate to generate rainfall-landslide hazard zonation scenarios. The rainfall-landslide hazard map (RLHM) provides landslide hazard levels for all locations on the map. The mobile apps based on RLEWS show the status of warning levels, landslide hazard maps, rainfall analysis, and graphs as an output in the user interface. The daily rainfall is analysed every day as it is a real-time monitoring and continues to update the daily rainfall every day on the mobile apps-based platform. Fig. 3 shows the flowchart of the mobile application of RLEWS.

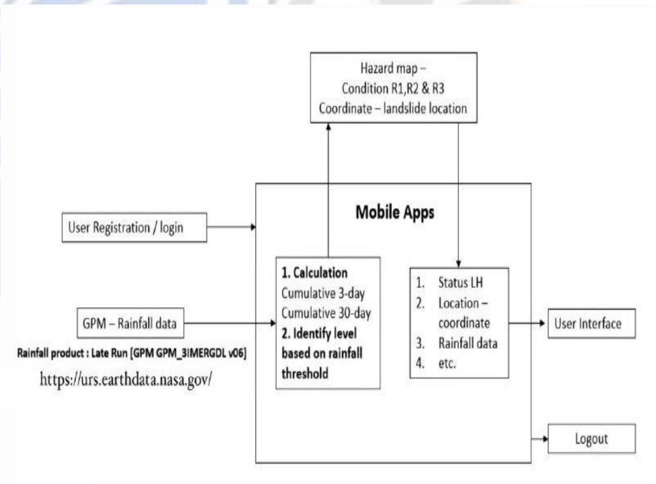


Fig. 3. Block diagram of mobile application of RLEWS

C. *Rainfall Threshold Model*

The rainfall threshold is analysed with GPM satellite precipitation data estimates for 3 days and 30 days of rainfall data. A threshold is a condition stated by a mathematical law in quantitative terms that, when overcome, causes a change in the state of a system, according to Segoni *et al.* [19]. Ivanov *et al.* [20] discovered that a threshold indicates the lowest level of hydrological circumstances (such as rainfall and soil moisture infiltration) known to cause landslides. However, Gariano *et al.* [21] found that the thresholds for rainfall were frequently employed, considering various study scales (global, regional, and local), a wide variety of rainfall factors, various physiographical settings, and various types of landslides. The rainfall threshold level that is used has been revised based on past research [22], where the rainfall threshold in Ulu Kelang, Selangor is plotted using 3 days and 30 days of cumulative rainfall (E3-E30). The determination of the warning level of potential landslides includes a minor landslide, a major landslide, and extreme rainfall. The landslide susceptibility map (LSM) is a component that offers spatial probability which is integrated with the rainfall threshold level. The LSM that is used in this RLEWS is based on existing LSM adopted from a previous study [23]. The spatial probability class is divided into three classes: low, moderate, and high. Table 1 shows the rainfall threshold level, the equation of limitation threshold line, warning levels, and landslide prediction. The rainfall threshold was established based on the cumulative rainfall that triggers the landslides, which were classified according to their magnitude.

TABLE 1. CENTRE WAVELENGTH OF LANDSAT BANDS

Rainfall Threshold Levels	Rainfall Threshold equation	Warning Levels	Landslide Prediction
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	$E_{3(Minor)} = 140.6 - 0.97E\ E_{30}$ $>$ **Rainfall** $>$ $E_{3(extreme)} = 182.4 - 0.27E_{30}$	High	Major landslide

Fig. 4 shows the three-limitation threshold line plotted in a graph based on the minor landslide, major landslide, and extreme non-landslide rainfall occurrences. The rainfall threshold is divided into three levels which are no landslide (R1), minor landslide occurrences (R2), and major landslide occurrences (R3). The threshold line of E30 (extreme) defines the situation as being very dangerous due to intense rainfall event that increases the high probability of landslide occurrence.

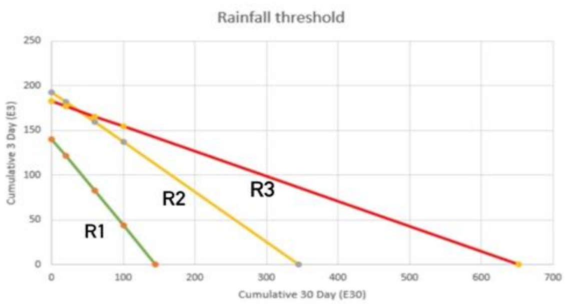
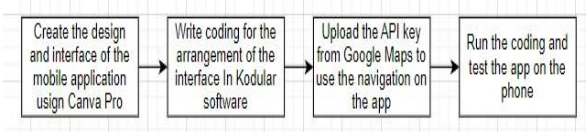


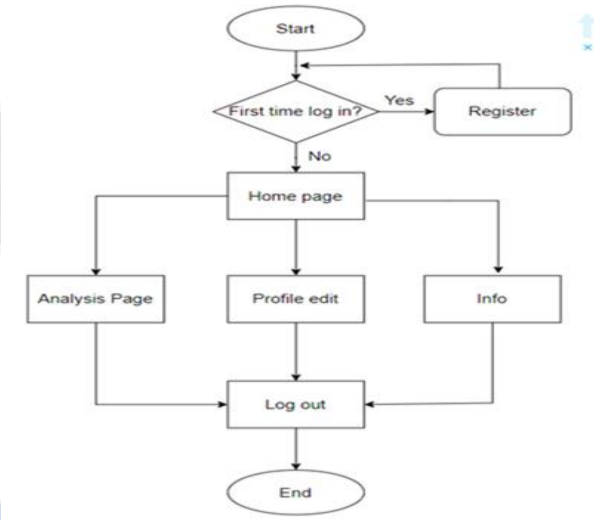
Fig. 4. Rainfall threshold model of Ulu Klang

D. *Mobile Apps-Based System Development*

After developing the mobile application, the data that are used is extracted from the GPM satellite database as shown in Fig. 5 (a) and Fig. 5 (b). The system and the scripting language that is used are PHP and MySQL. The Kodular software is used to develop this mobile application. For data analysis, 3-day cumulative and 30-day cumulative will be calculated to identify real-time information and to display rainfall threshold levels. Furthermore, there are 4 different locations in Ulu Klang that will be monitored closely in the app such as Taman Zooview, Ukay Perdana, and Taman Kelab Ukay, usually created by empirical correlations between rainfall intensity (I) and duration (D) [24].



(a)



(b)

Fig. 5. (a) Flow of mobile application development
(b) Flowchart of the mobile application

III. RESULTS

A. *Mobile APPS Result*

This mobile application has 5 pages including a sign-up/sign-in page, home page, analysis page, and profile page.

1) *Sign-up/sign-in Page:* Fig. 6 shows the first page which is the sign/up page, for this page, a new user needs to register their new account. The information that is required to register is a username, email, and password.

Fig.6. Sign up/Sign in page

2) *Home Page:* Fig. 7 shows the Home Page, in this page, a picture of the study area will be displayed which is Ulu Klang, and several locations are pinpointed to be analyzed such as Taman Zooview, Ukay Perdana, Taman Kelab Ukay, and Taman Bukit Jaya. Also, there is a date search box for the user to view the latest rainfall data.

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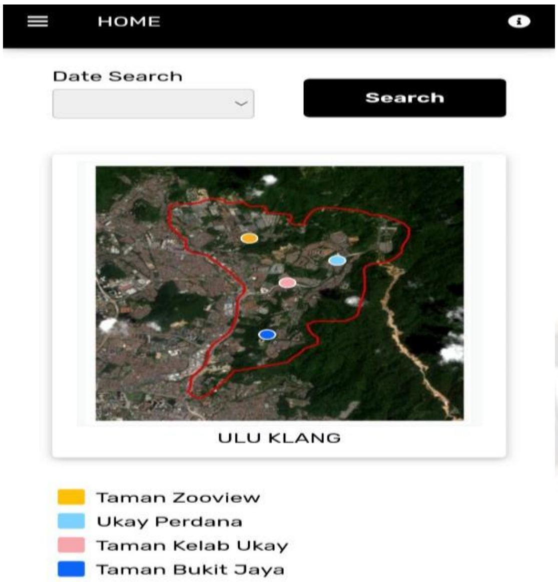

Fig.7. Home Page

3) Analysis Page: The analysis page is where real-time rainfall information will be displayed such as the latest amount of daily rainfall, 3-day cumulative rainfall, and 30-day cumulative rainfall (E3-E30). E3-E30 graph to determine the warning level of potential landslide occurrence. There would be 3 warning levels of potential occurrence which are low, moderate, or high. There will be four buttons on this page for each location, these 4 buttons will link to Google Maps directly to each location respectively. The fourth page is the profile page. A user who wants to change or edit their profile will use this page, the same process as the registration process. Table II shows the data analysis in June of 2023.

TABLE II. DATA ANALYSIS OF JUNE 2023

Date	1-day rainfall (mm)	3-day cumulative rainfall (mm)	30-day cumulative rainfall (mm
1/6/2023	2.23	6.81	193.93
2/6/2023	0.63	5.32	166.51
3/6/2023	5.13	7.99	154.85
4/6/2023	0.27	6.03	159.56
5/6/2023	41.2	46.6	194.88
6/6/2023	89.2	130.07	172.06
7/6/2023	2.1	132.5	160.84
8/6/2023	0.42	91.72	162.45
9/6/2023	22.39	24.91	162.01
10/6/2023	1.87	24.68	186.3
11/6/2023	66.98	91.24	186.99
12/6/2023	89.76	158.61	250.83
13/6/2023	3.9	160.64	348.19
14/6/2023	17.8	111.46	352.17
15/6/2023	6.78	28.48	363.77
16/6/2023	2.87	27.45	366.01
17/6/2023	1.34	10.99	368.68
18/6/2023	2.69	6.9	367.65
19/6/2023	0.94	4.97	362.49
20/6/2023	0.67	4.3	362.94
21/6/2023	0.88	2.49	342.54
22/6/2023	2.12	3.67	337.45
23/6/2023	0.19	3.19	326.59
24/6/2023	1.03	3.34	326.09
25/6/2023	0.94	2.16	315.13
26/6/2023	12.98	14.95	308.02
27/6/2023	2.12	16.04	296.22
28/6/2023	0.07	15.17	290.02
29/6/2023	2.57	4.76	289.91
30/6/2023	1.09	3.73	292.04

Based on Table II, the lowest rainfall value for 1-day rainfall is on 28th June 2023 with only 0.07mm while the highest is on 11th June 2023 with 89.76mm. For 3-day rainfall data, the lowest rainfall value is on 25th June 2023 with a value of 2.16mm and the highest value of rainfall is on 13th June 2023 with 160.64mm. Meanwhile, for 30-day rainfall data, the lowest value is on 3rd June 2023 with a value of 154.85mm while the highest is on 17th June 2023 at 368.88mm.

B. Warning Level of Landslide

RLEWS has three separate warning levels: normal, attention, and alarm. The warning levels are dependent on rainfall threshold levels, which create a scenario of hazard map and warning state issued.

1) Low Warning Level of Landslide: On 9th July 2023, the rainfall threshold analysis is plotted in a graph to monitor the potential landslide as shown in Fig. 8. The warning level is Low. The E3-E30 graph is divided into four limitation lines which are low, moderate, and high. A green line is for a low-moderate limit, a yellow line is for a moderate limit and a red line is for a high limit. The 1-day rainfall is 22.39mm, the 3-day rainfall is 24.91mm and the 30-day rainfall is 162.48mm. The landslide hazard for all four locations Taman Zooview, Ukay Perdana, Taman Kelab Ukay, and Taman Bukit Jaya is low. This indicates that in normal warning levels, no warning state is issued. Thus, the hazard map was created in this scenario and shows a low and moderate hazard zone with a low probability of landslides. The rainfall rate for this situation is stated as having a low rainfall distribution.

Fig. 8. Analysis page for low warning level of landslide occurrence

2) Moderate Warning Level of Landslide: On 7th July 2023, the rainfall threshold analysis is plotted in a graph to monitor the potential landslide as shown in Fig. 9. The warning level is Moderate. The 1-day rainfall is 2.1mm, the 3-day rainfall is 132.5mm and the 30-day rainfall is 172.06mm. The landslide hazard for Taman Zooview is moderate, low for Ukay Perdana, moderate for Taman Kelab Ukay, and high for Taman Bukit Jaya. A hazard map showing low, moderate, and high hazard zones incorporated an attention warning level. In this case, there was a location that showed a precautionary warning of an unstable slope as well as a prediction of minor landslide occurrences in an area with a high hazard level.

Fig. 9. Analysis page for moderate waning level of landslide occurrence

3) High warning level of landslide: On 12th June 2023, the rainfall threshold analysis is plotted in a graph to monitor the potential landslide as shown in Fig. 10. The warning level is High. The 1-day rainfall is 89.76mm, the 3-day rainfall is 158.61mm and the 30-day rainfall is 250.83mm. The landslide hazard for Taman Zooview is low, low for Ukay Perdana, moderate for Taman Kelab Ukay, and high for Taman Bukit Jaya.

In the high-hazard zone, a warning signal was issued, but there was no warning signal in the low and moderate-hazard zones. However, when rainfall levels reach the limit, these areas will be subjected to continuous monitoring. In this condition, the rainfall distribution has started to impact slope stability, particularly in high-susceptibility areas.

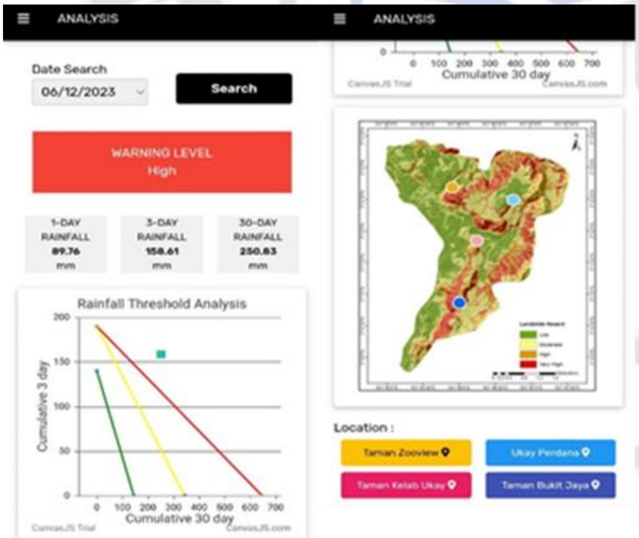

Fig. 10. Analysis page for high warning level of landslide occurrence

C. *Rainfall Cumulative Pattern*

1) 1-day cumulative rainfall: Fig. 11 shows the rainfall pattern of 1-day cumulative rainfall in June 2023 where the highest cumulative rainfall is 89.76mm on 12th June 2023 while the lowest is 0.19mm on 23rd June 2023.

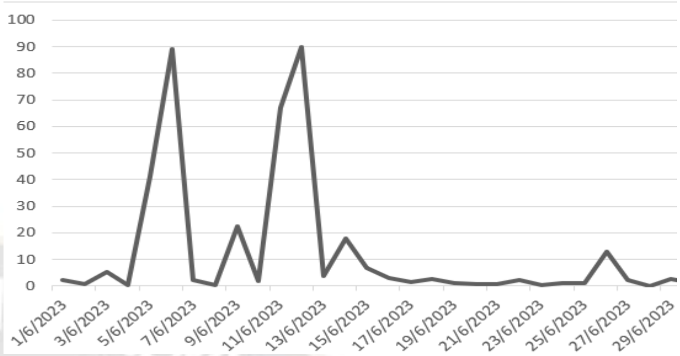

Fig. 11. Rainfall pattern of 1-day cumulative rainfall of June 2023

Table III shows a 1-day cumulative rainfall on the 12th, 23rd, and 26th June 2023, of which 89.76mm is the highest value, 0,19mm is the lowest and 12.86mm is the median on the 26th June 2023.

TABLE III. DATA ANALYSIS OF JUNE 2023

Date	1-day cumulative rainfall (mm)
12 June 2023	**89.76**
23 June 2023	**0.19**
26 June 2023	**12.98**

2) 3-day cumulative rainfall: Fig. 12 shows the rainfall pattern of 3-day cumulative rainfall in June 2023 where the highest cumulative rainfall is 160.64mm on 13th June 2023 while the lowest is 2.16mm on 25th June 2023.

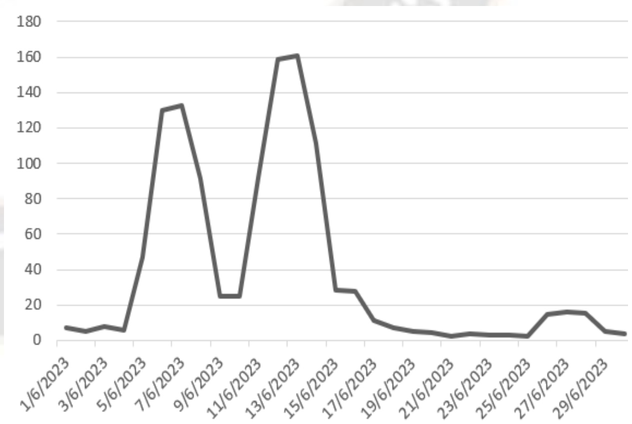

Fig. 12. Rainfall pattern of 3-day cumulative rainfall of June 2023

Table IV shows a 3-day cumulative rainfall on the 5th, 13th, and 25th of June 2023, of which 160.64mm is the highest value, 2.16mm is the lowest and 46.6mm is the median on the 5th of June 2023.

TABLE IV. DATA ANALYSIS OF JUNE 2023

Date	3-day cumulative rainfall (mm)
5 June 2023	46.6
13 June 2023	160.64
25 June 2023	2.16

3) 30-day cumulative rainfall: Fig. 13 shows the rainfall pattern of 30-day cumulative rainfall in June 2023 where the highest cumulative rainfall is 368.68mm on 17th June 2023 while the lowest is 154.85mm on 3rd June 2023

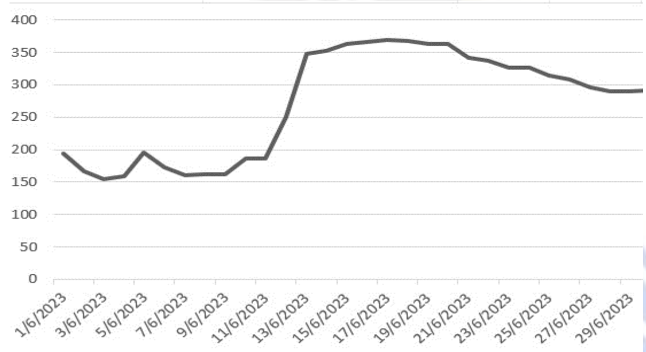

Fig. 13. Rainfall pattern of 30-day cumulative rainfall of June 2023

Table V shows a 30-day cumulative rainfall on the 3rd, 12th, and 17th of June 2023, of which 158.61mm is the highest value, 3,19mm is the lowest and 46.6mm is the median on the 12th of June 2023.

TABLE V. DATA ANALYSIS OF JUNE 2023

Date	30-day cumulative rainfall (mm)
3 June 2023	154.85
12 June 2023	250.83
17 June 2023	368.68

D. Description of this landslide early warning system

Fig. 14 is the last page, which is the info section, this section shows the description of this landslide early warning system as a monitoring tool of landslide to notify if there are any warning signs observed from potential landslide occurrences in Ulu Kelang, Selangor. It also consists of Ulu Kelang, Selangor's map location, and acknowledgment of the NASA and Malaysian Space Agency (MYSA) for providing GPM satellite data.

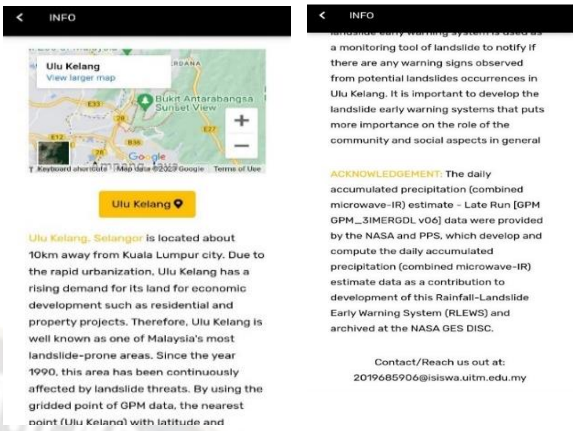

Fig. 14. Info page

IV. CONCLUSIONS

A Rainfall-landslide early warning system (RLEWS) that may be used as a monitoring tool for Ulu Kelang residents is the goal of this project. Additionally, this system will assist the locals in being more aware of any warning indications associated with probable landslides and in providing information when a landslip occurs in locations. The development of landslide early warning systems that have an emphasis on community involvement and social aspects, in general, is crucial. The landslide–rainfall hazard map model can be used to develop RLEWS that can predict, detect, and monitor landslide events. RLEWS which provides information about the location, timing, and magnitude of landslide occurrences was established using remote sensing and GIS techniques. RLEWS may be used as a mobile application to provide notifications and raise awareness for residents in Ulu Kelang, Selangor. It also enables remote monitoring of the environment over large regions at minimal cost, as well as long-term solutions in prediction, detection, and monitoring systems.

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