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Landslide Detection Using Analysed UAV Imagery

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ABSTRACT

Landslide is one of the disasters that often occur in Malaysia. It causes thousands of injuries and death records. Plus, a lot of money has been spent on search and rescue purposes and upgrading utilities to prevent landslide occurrence. Malaysia's climate, categorized as equatorial, is hot and humid throughout the year. Malaysia has been exposed to an average rainfall of 250cm in a year as rainfall has been the main contributor to landslide occurrence. Thus, an early warning system can be convenient to reduce the hazard risk. This research used Unmanned Aerial Vehicles (UAVs) or drones embedded with RGB cameras to capture data. UAVs or drone is a part of technology revolutionary. The UAV has been widely used in different industries including agriculture, mining, land surveyor, and search and rescue. With the UAV capability, in this research, the UAV is used to measure the slope of the earth by capturing orthomosaic data and will be required to process using Geographical Information System (GIS) software to gain access to other data such as imaging data and digital surface model (DSM). With the capability of Pix4D software, the imaging data such as thermal and spectral imaging can be generated. The data will be compared with rainfall data from Jabatan Meteorologi Malaysia to compare the effect of rainfall on slope conditions. The data for the result will be a great contribution to the early warning system as it contributes towards the accuracy of landslide prediction based on the volume of rainfall.

1. Introduction

Landslides are one of the natural events that occur at the mountain or high-level ground area. Between the years 2007 and 2015, according to NASA's Global Landslide Catalogue, 7000 cases of rainfall-triggered landslides involved more than 25000 death records worldwide. Landslides are perhaps one of the most daunting natural hazards to predict because the variables influencing slope stability vary so widely in space and time. Aside from that, significant advances in precipitation prediction, high-resolution imagery, and elevation maps increase our ability to estimate the danger of rainfall-triggered landslides in real time. An early warning system can be defined as an information

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system of hazard monitoring, forecasting and estimation, disaster risk analysis, communication, and readiness activities structures, and procedures that allow individuals, communities, authorities, companies, and others to take timely steps to reduce catastrophe risks as part of disaster scenarios [1]. Through this system, the loss of human life can be reduced [2].

With the application of the current advanced Geographic Information System (GIS) and remote sensing technology, the assessment and area of slope hazard can be mapped throughout the area. GIS is a computer-based system for recording, storing, capturing, analysing, and data display [17]. GIS is distinguished from other spatially related systems by its computational capacity, which enables modelling operations on spatial data. Spatial data in GIS databases are primarily generated through remote sensing by the direct import of images and classified images, but it is also generated through traditional map generation using photogrammetry (e.g., topographical maps) [3]. Remote sensing data is valuable because of its synoptic vision, repeated coverage, and real-time data collection. As a result, digital data in the form of satellite imagery enables precise measurement of various land cover/land use categories and aids in the establishment of a spatial data network, which is critical in tracking urban growth and land use studies [4]. Recent advancements in drone or Unmanned Aerial Vehicle (UAV) technology have launched significant new potential in the field of remote sensing so that drones can be considered the third generation of platforms producing remotely sensed data of the Earth's surface [5]. As a result, remote sensing is an essential component of GIS, and it is difficult to function without it.

Moreover, landslides in Malaysia are mainly caused by heavy and continuous rainfall, much of which is correlated with monsoon runoff. Climate and developing areas have led to land loss in the mountainous terrain, resulting in increased rock erosion and soil degradation caused by rainwater and landslides [6]. In general, urban construction in mountainous areas with a possibility of rainfall, steep terrain, and inconsistent slope structures have been recognized as the main factors that cause landslides [18], while rainwater slows down and triggers flash floods on low slopes. Landslides are common in Malaysia, especially in hilly areas such as Ulu Kelang, Selangor. Landslide damages and deaths in Malaysia are often caused by the country's rapid urbanization and economic growth. People also expanded their economic activities into the highlands and hilly regions due to a lack of suitable low-lying areas. The clearance of mountain areas for high-rise constructions rapidly increases the risk of landslides [7]. Because rainfall is the most significant physiological mechanism for causing landslides around the world, the relationship between landslides and rainfall has been hesitantly established over the past several decades by deciding rainfall benchmarks or thresholds. For example, when certain rainfall conditions (cumulative rainfall, intensity) are met or exceeded, they may trigger a landslide event [8]. Physical and mathematical approaches can be used to assess rainfall thresholds. Rainfall spreads into the slope and changes the tension of the pore water, lowering tensile force and potentially causing the slope to collapse. Scientific methods can be used to study these physical processes, and the essential rainfall value can be calculated [9]. The landslides are largely focused on empirical rainfall parameters at a broad scale, which are the intensity-duration (I-D) of the rainfall, event-duration threshold (E-D), antecedent rainfall threshold, and combined threshold. I-D and E-D were the common thresholds being used globally [10].

Landslide early warning systems are constantly becoming popular around the world, due to their lower economic and environmental costs compared to standard methods, the continuous emergence of local landslide detection technologies, and the increased availability of accurate databases to calibrate warning models [11,12]. Aside from that, the framework seeks to reduce the risk of loss of life and other negative consequences of landslide events by warning people, families, and organizations impacted by a landslide to plan and react appropriately in enough time to lower the potential for harm or loss. As a result, it is critical to establish a standardized norm for landslide early warning systems that emphasizes the involvement of the community and social aspects in general.

The objective of the research is to capture data on the landslide area using a UAV or drone Nowadays, UAVs are being used in various industries or applications such as agriculture, mining, forestry geospatial mapping, or any application that needs information from the top views [13]. Although the UAV is intended to be a generic remote sensing (RS) instrument, most RS data processing and analysis methods are still ad hoc to applications [14]. The data is then analysed using GIS software such as ArcGIS and Pix4D. The analysis process is important to identify the development of the system from different points of view. The method of capturing the data of landslide area by deploying a UAV or drone at an altitude of 100m above facing toward landslide prone area [20]. The data is captured using an RGB camera embedded in the drone. Besides that, the analysed data from the drone will be compared to rainfall data by Jabatan Meteorologi Malaysia. Aligned with the aim of the study, the data will contribute towards early warning system accuracies, and reduce the hazard risk of a landslide. Also, the aim of the study is to provide insight into the relationship between rainfall and slope conditions which can contribute to future efforts to prevent and mitigate landslides in Malaysia.

2. Methodology

For this research, the area of study is Bukit Antarabangsa and Jalan HillView which were in Ulu Klang, Selangor. Ulu Klang was part of the location undergoing urbanization. Therefore, the area is developing rapidly with buildings and other infrastructures. In Malaysia, Ulu Klang was known as a landslide-prone area due to frequent landslide occurrences since 1990.

In the framework, it consists of hardware and software parts. With the use of UAV, ortho-mosaic data or top-view images can be collected with ease and transferred to the computer for further analysis [19]. The time interval of data capture by the UAV was 1 week for both locations. Figure 1 and 2 shows the location of the study area.

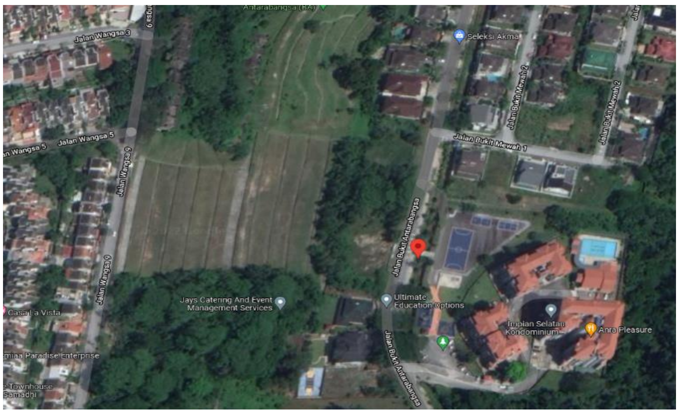

Fig. 1. Location of Bukit Antarabangsa, Ulu Klang, Selangor

Fig. 2. Location of Jalan HillView, Ulu Klang, Selangor

DJI Phantom 4 Pro V2 was used to gather data from the study area. DJI Phantom 4 Pro V2 is a small quad-rotor type drone that is easy to use and control, thus, the high-quality camera helps a lot in gathering high-quality images up to 4K resolution. Plus, DJI Phantom 4 Pro V2 is capable of flying at an altitude of more than 100m, therefore, it is capable of flying higher than the average building in the area.

As for the software, GIS software from Pix4D was recommended for this research, due to its user-friendliness and the compatibility of the software with the DJI system to create a smooth working and data-collecting experience. For the flight system, Pix4D Capture was used in iPad or tablet to transfer the mission plan to the UAV.

As for the processing software in the computer, Pix4D Mapper or Pix4D Cloud was used to process and analyse data gathered by the UAV. The software generates 3D model mapping which includes cloud-point, triangle mesh, and DSM data and also imaging data even though the camera used is RGB camera [15,16].

UAV flight operations conducted at the study area legally with permission from the authorised agency. Figure 3 shows the block diagram on UAV flight operation. A flying permit is required in order to perform the flight operation for safety and legal reason. The authorised agencies were local Municipal Council, Jabatan Ukur dan Pemetaan Malaysia (JUPEM) and Civil Aviation Authority of Malaysia (CAAM). Total duration of applying the permit was roughly 2 months.

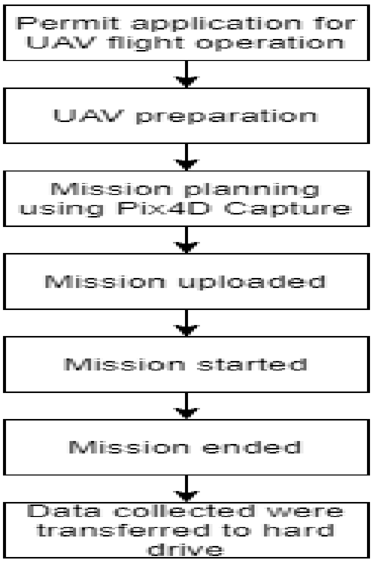

Fig. 3. Block diagram of UAV Flight Operation

Figure 4 shows a single grid mission plan created in the Pix4D Capture application before being executed into the UAV. Figure 5 shows a double grid mission plan which was also created in Pix4D Capture. In Figures 4 and 5, the mission plan was executed at Jalan Hillview. A double grid mission was chosen to be uploaded into Pix4D Mapper for data processing due to its accuracy from more capture points than a single grid mission and camera elevation of 70°.

Fig. 4. Single grid mission plan at Jalan HillView

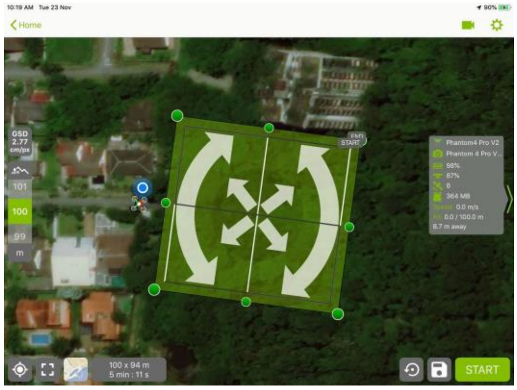

Fig. 5. Double grid mission plan at Jalan HillView

After data collecting, the data was transferred to laptop directly from the UAV's memory card. The data was also backed up in the tablet to avoid data corruption during data transfer.

Pix4D Mapper/Cloud is next generation photogrammetry software that was designed to work with UAVs and turn a large number of images into accurate point cloud, DSMs and Otho mosaics data. Figure 6 shows the block diagram of data processing using the Pix4D software.

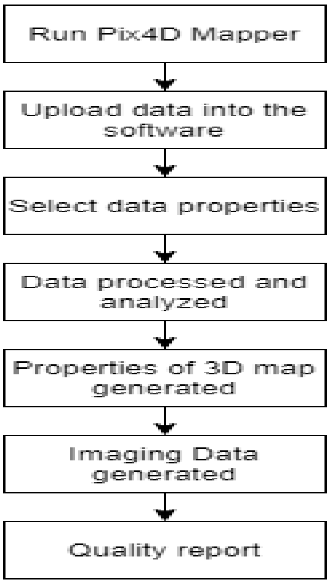

Fig. 6. Block diagram of data processing using Pix4D software

The process of data analysing using Pix4D may take up to 2 hours per data set. Imaging data generated were spectral imaging and thermal imaging. The imaging data were generated using value of pixel derived from reflectance map that was generated before the imaging data. Reflectance maps compile all the pixel value of the whole map captured into a single function.

3. Results

This section discussed the results obtained from government organizations, collected data from UAV, analysed spatial data and imaging data.

3.1 Trendline of Rainfall

Daily rainfall data from 23 November 2021 until 14 December 2021 were plotted in graph. This would show how much precipitation does the soil contain throughout the date. Figure 8 shows the trendline of uprising value of rainfall in mm and as per Figure 7, it also shows the daily rainfall data in millimetre (mm) from 23 November 2021 until 14 December 2021. Means the increasing volume of rain water in the soil as the day goes on with the initial of rainfall were assumed as 0mm in 23 November 2021. At the exact study area, until 14 December 2021, total amount of 194.40mm of rain water has been absorbed by the soil. As on 14 December itself was 9.20mm of rainwater.

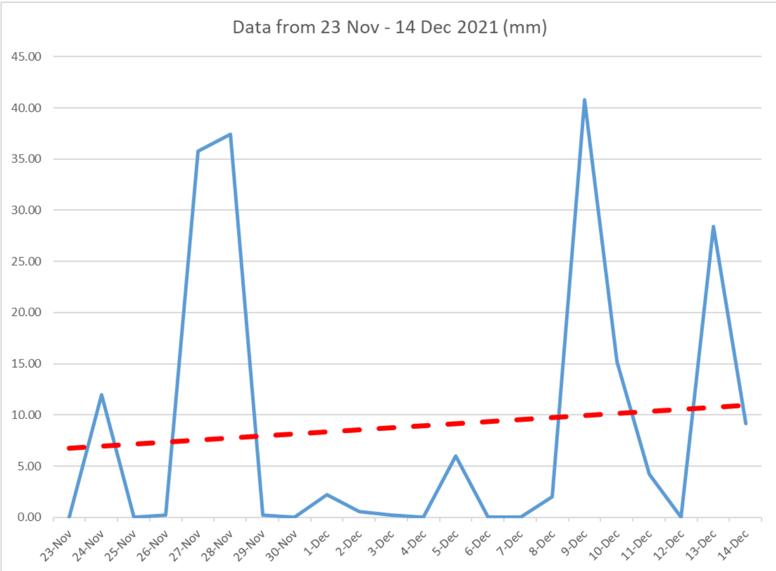

Fig. 7. Trendline of rainfall data from 23 Nov 2021 - 14 Dec 2021

3.2 Imaging Data for Study Area 1 and Study Area 2

By using the image captured by UAV and uploaded to Pix4D Mapper, the image was analysed as per required and was able to extract the imaging and spatial information.

3.2.1 Study area 1

Study area 1 as shown in Figure 8 was used as our location to conduct the research. It is a location with the history of landslide at Ampang. The map was taken on 23 November 2021 at Bukit Antarabangsa.

Fig. 8. Study area 1 in Bukit Antarabangsa on 23 November 2021

i. 23 November 2021
Figure 9 is the spectral imaging data that was generated during the process of generating the DSM. Spectral imaging was extracted using a reflectance map which was analysed using the data captured by UAV.

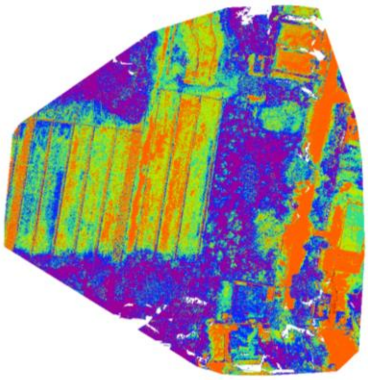

Fig. 9. Study area 1 spectral map on 23 November 2021

The spectral rate differences were indicated as shown in Figure 10. As orange shows the highest rate of reflection while purple shows the lowest rate of reflection.
Spectral index in percentage (%):
Orange: 33.57%
Green: 9.02%
Teal: 8.55%
Blue: 10.89%
Purple: 37.94%

With a high purple index, the area contains high precipitation. On the slope, the part of the colour index is green, teal, and blue which in conclusion water precipitation exist in the soil.

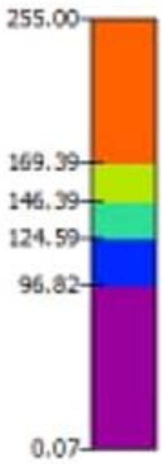

Fig. 10. Spectral colour codes

Figure 11 is the thermal imaging data that was generated during the process of generating the DSM. Thermal imaging involves temperature detection using pixel format from the reflectance map.

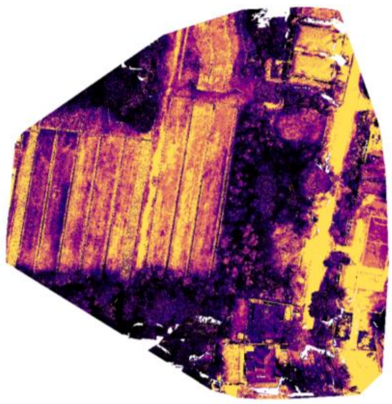

Fig. 11. Study area 1 thermal map on 23 November 2021

The difference in temperature of the surface was indicated using the index given in Figure 12. The pale-yellow area has the highest surface temperature while the dark purple has the lowest surface temperature.

Thermal Index in percentage (%):

Pale yellow: 33.57%

Light purple: 9.02%

Purple: 8.55%

Slightly dark purple: 10.89%

Dark purple: 37.94%

With a dark purple index, the area contains high precipitation. On the slope, the part of the colour index is light purple, purple, and slightly dark purple which in conclusion water precipitation exists in the soil.

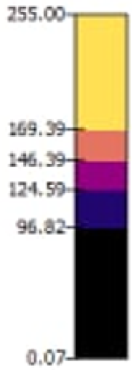

Fig. 12. Thermal colour code

ii. 14 December 2021

Figure 13 is the spectral imaging data that was generated during the process of generating the DSM. Spectral imaging was extracted using a reflectance map which was analysed using the data captured by UAV.

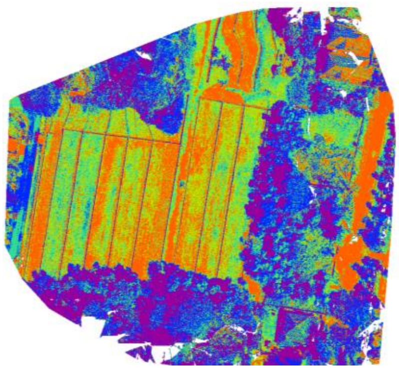

Fig. 13. Study area 1 spectral map on 14 December 2021

The spectral rate differences were indicated as shown in Figure 14. As orange shows the highest rate of reflection while purple shows the lowest rate of reflection.
Spectral index in percentage (%):

Orange: 30.25%

Green: 10.8%

Teal: 14.24%

Blue: 19.67%

Purple: 25.04%

On the slope, the part of the colour index is green, teal and blue slightly higher than the result during the 1st flight which in conclusion water precipitation in the soil during the 2nd flight is higher than 1st flight.

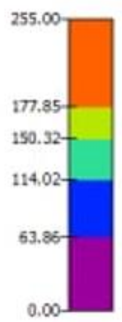

Fig. 14. Spectral colour codes

Figure 15 is the thermal imaging data that was generated during the process of generating the DSM. Thermal imaging involves temperature detection using pixel format from the reflectance map.

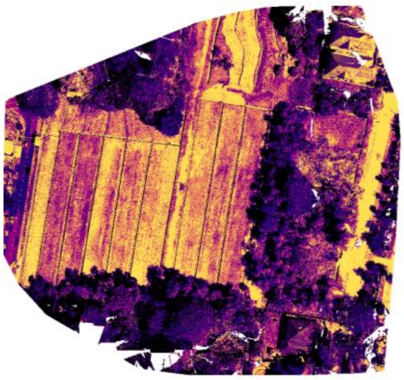

Fig. 15. Study area 1 thermal map on 14 December 2021

The difference in temperature of the surface was indicated using the index given in Figure 16. The pale-yellow area has the highest surface temperature while the dark purple has the lowest surface temperature.
Thermal Index in percentage (%):
Pale yellow: 30.25%
Light purple: 10.8%
Purple: 14.24%
Slightly dark purple: 19.67%
Dark purple: 25.04%

On the slope, the part of the colour index is light purple, purple and slightly dark purple are slightly higher than the result during the 1st flight which in conclusion water precipitation in the soil during the 2nd flight is higher than 1st flight.

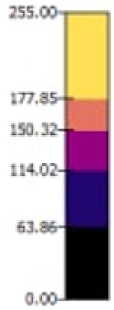

Fig. 16. Thermal colour code

Based on the comparison of spectral and thermal imaging of the 2 flight sessions. It is concluded that during the 1st flight session, the study area has a larger area with high reflective and high-temperature difference which indicate the soil was drier and less humid than on the 2nd flight session.

3.2.2 Study area 2

Study area 2 as shown in Figure 17 was used as our location to conduct the research. It is a location with a history of landslides at Ampang which is the Highland Tower disastrous event. The map was taken on 23 November 2021 at Bukit Antarabangsa.

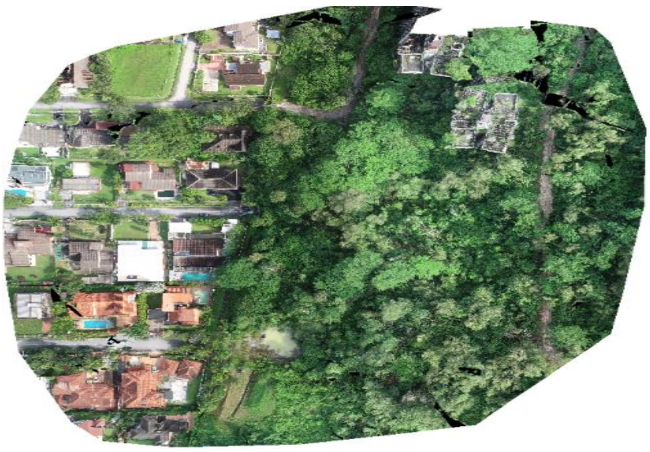

Fig. 17. Study area 2 in Jalan HillView on 23 November 2021

i. 23 November 2021
   Figure 18 is the spectral imaging data that was generated during the process of generating the DSM. Spectral imaging was extracted using a reflectance map which was analysed using the data captured by UAV.

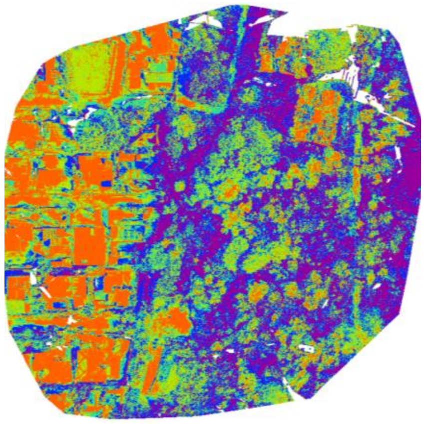

Fig. 18. Study area 2 spectral map on 23 November 2021

The spectral rate differences were indicated as shown in Figure 19. As orange shows the highest rate of reflection while purple shows the lowest rate of reflection.
Spectral index in percentage (%):
Orange: 40.49%
Green: 16.56%
Teal: 13.8%
Blue: 10.93%
Purple: 18.22%

With a high purple index, the area contains high precipitation located on the slope which is on the right side of the map.

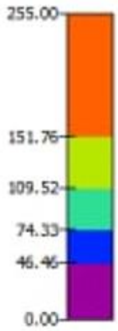

Fig. 19. Spectral colour codes

Figure 20 is the thermal imaging data that was generated during the process of generating the DSM. Thermal imaging involves the temperature detection using pixel format from the reflectance map.

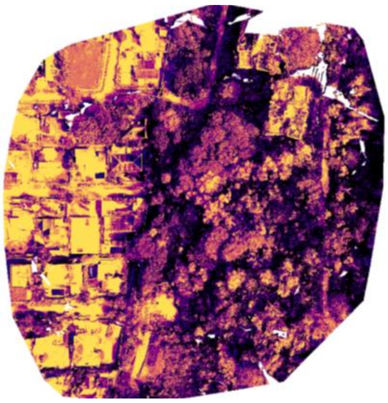

Fig. 20. Study area 2 thermal map on 23 November 2021

The difference in temperature of the surface was indicated using the index given in Figure 21. The pale-yellow area has the highest surface temperature while the dark purple has the lowest surface temperature.
Thermal Index in percentage (%):
Pale yellow: 40.49%
Light purple: 16.56%
Purple: 13.8%
Slightly dark purple: 10.93%
Dark purple: 18.22%

With a high dark purple index, the area contains high precipitation located on the slope which is on the right side of the map.

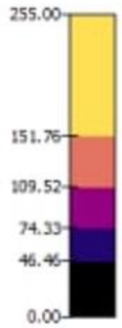

Fig. 21. Thermal colour code

ii. 14 December 2021
Figure 22 is the spectral imaging data that was generated during the process of generating the DSM. Spectral imaging was extracted using a reflectance map which was analysed using the data captured by UAV.

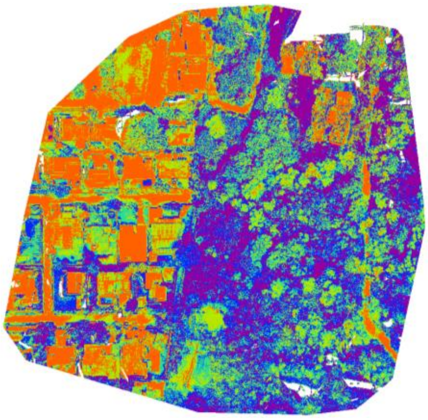

Fig. 22. Study area 2 spectral map on 14 December 2021

The spectral rate differences were indicated as shown in Figure 23. As orange shows the highest rate of reflection while purple shows the lowest rate of reflection.
Spectral index in percentage (%):

Orange: 36.72%

Green: 15.27%

Teal: 9.9%

Blue: 9.55%

Purple: 28.57%

On the slope (right side of the map), most of the map was a purple colour index which is higher than the result during the 1st flight in conclusion water precipitation in the soil during the 2nd flight is higher than the 1st flight.

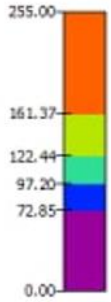

Fig. 23. Spectral colour codes

Figure 24 is the thermal imaging data that was generated during the process of generating the DSM. Thermal imaging involves temperature detection using pixel format from the reflectance map.

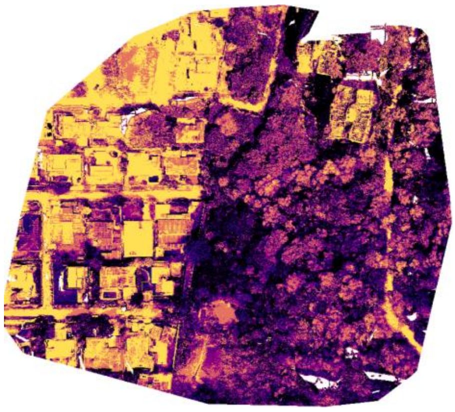

Fig. 24. Study area 2 thermal map on 14 December 2021

The difference in temperature of the surface was indicated using the index given in Figure 25. The pale-yellow area has the highest surface temperature while the dark purple has the lowest surface temperature.
Thermal Index in percentage (%):
Pale yellow: 36.72%
Light purple: 15.27%
Purple: 9.9%
Slightly dark purple: 9.55%
Dark purple: 28.57%

On the slope (right side of the map), most of the map was dark purple colour index which is higher than the result during the 1st flight which in conclusion water precipitation in the soil during the 2nd flight is higher than 1st flight.

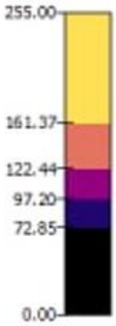

Fig. 25. Thermal colour code

Based on the comparison of spectral and thermal imaging of the 2 flight sessions. It is concluded that during the 1st flight session, the study area has a larger area with high reflective and high-temperature difference which indicate the soil was drier and less humid than on the 2nd flight session.

3.3 Slope Elevation Differences

Figure 26 and 27 shows the slope elevation graph of the Bukit Antarabangsa study area 1 on 23 November 2021 and 14 December 2021.

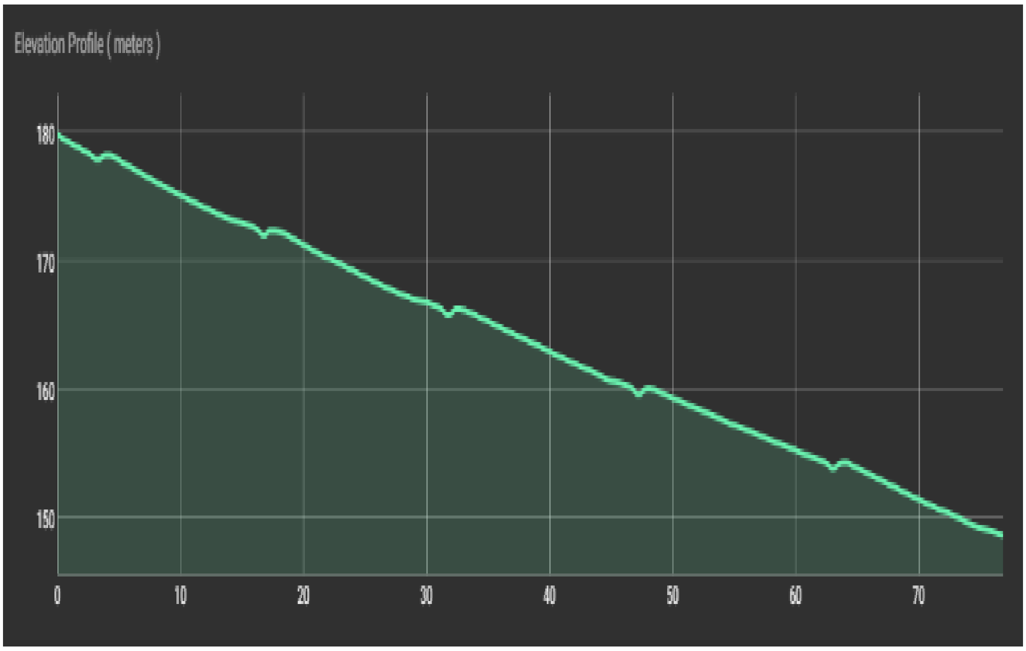

Fig. 26. Slope elevation graph of Bukit Antarabangsa study area on 23 November 2021

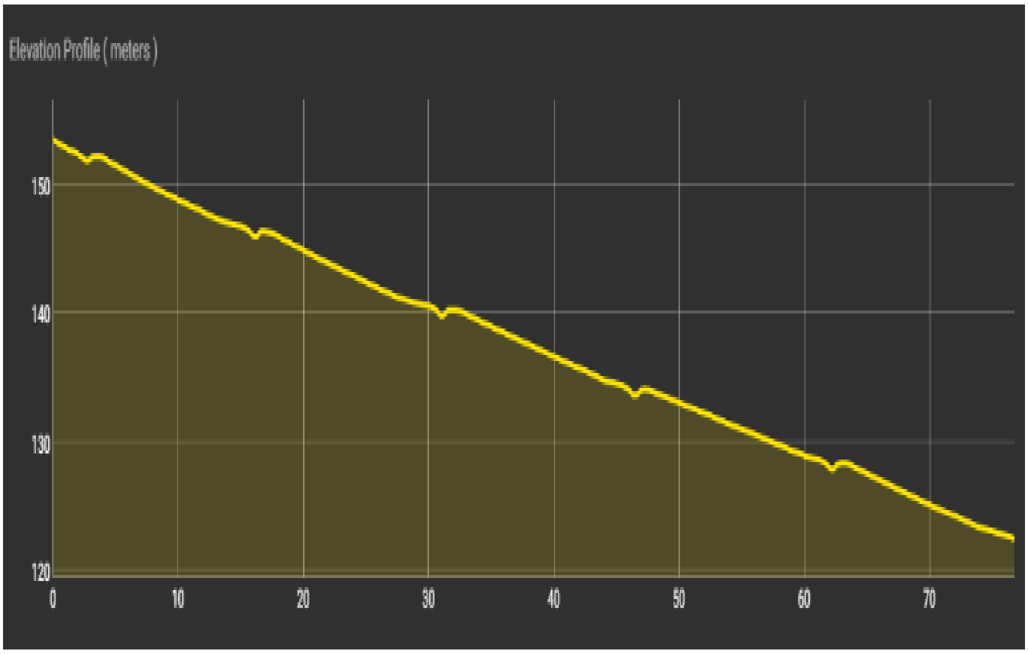

Fig. 27. Slope elevation graph of Bukit Antarabangsa study area on 14 December 2021

Figure 28 and 29 shows measurement information of the slope elevation graph of the Bukit Antarabangsa study area 1 on 23 November 2021.

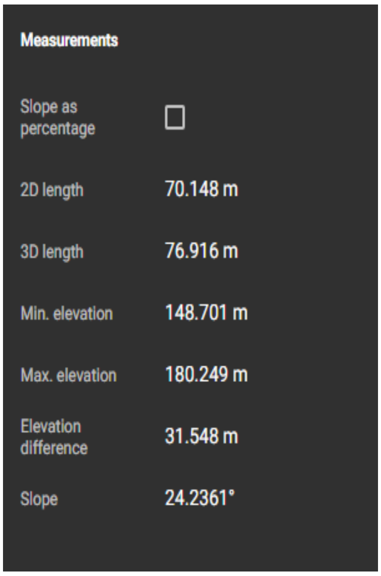

Fig. 28. Measurement information of the slope elevation graph of Bukit Antarabangsa study area on 23 November 2021

Fig. 29. Measurement information of the slope elevation graph of Bukit Antarabangsa study area on 14 December 2021

Meanwhile, Figures 30 and 31 show the slope elevation graph of the Jalan HillView study area 2 on 23 November 2021 and 14 December 2021.

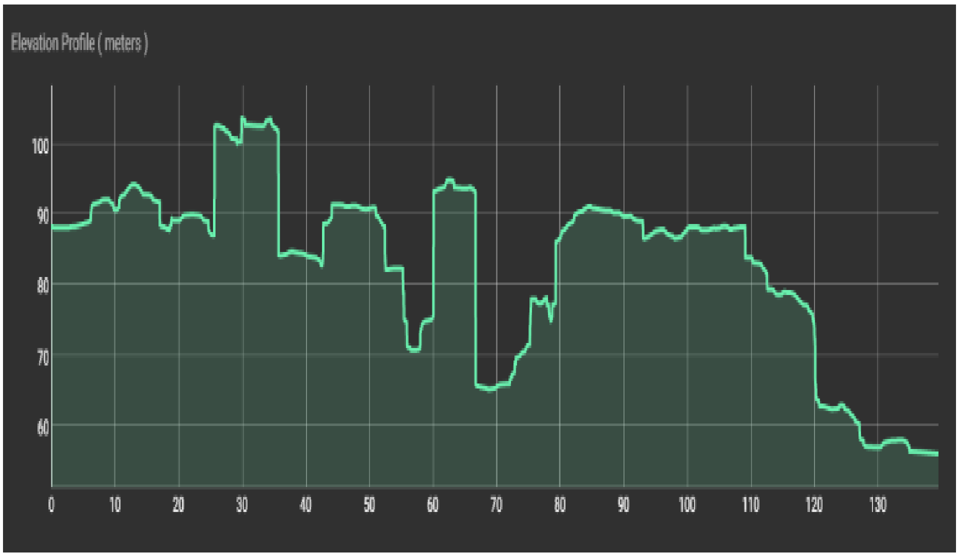

Fig. 30. Slope elevation graph of Jalan HillView study area on 23 November 2021

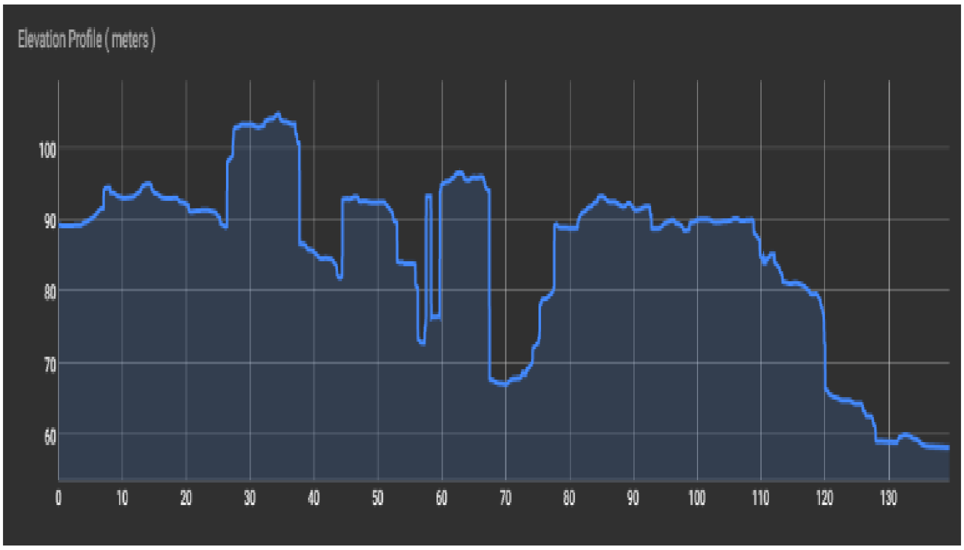

Fig. 31. Slope elevation graph of Jalan HillView study area on 14 December 2021

Figures 32 and 33 show measurement information of the slope graph of Jalan HillView study area 2 on 23 November 2021 and 14 December 2021.

Fig. 32. Measurement information of the slope graph of Jalan HillView study area on 23 November 2021

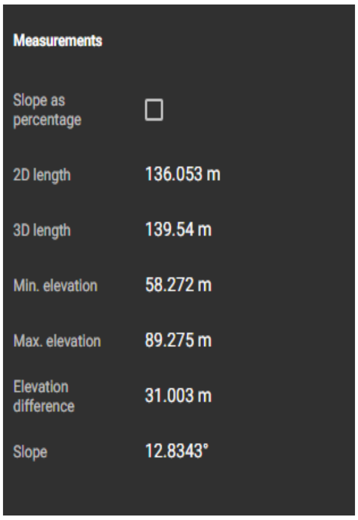

Fig. 33. Measurement information of the slope graph of Jalan HillView study area on 14 December 2021

Based on the analysed data and their comparison is summarized in Table 1 below. Study area Jalan HillView has the most slope changes which are 0.4583° with 3.45% changes in slope angle while study area Bukit Antarabangsa has 0.2865° slope difference with only 2.45% changes.

Table 1
Data comparison between 2 different flight times

Study Area	Slope Angles (°)		Slope Changes (°)	Slope Changes (%)
	23-Nov-21	14-Dec-21		
Bukit Antarabangsa	24.2361	23.9496	0.2865	-2.45
Jalan HillView	13.2926	12.8343	0.4583	-3.45

4. Conclusions

Landslides are one of the most dangerous natural disasters. Many organizations and research teams throughout the world have been working to evaluate and assess the dangers and risks of landslides, as well as discover solutions to landslide problems. With remote sensing technology, a variety of data can be gathered in a short time and landslide occurrence can be analysed even deeper. The purpose of this research is to conduct data gathering and data analysis from a different point of view and use existing technologies to indicate and create a threshold for landslide occurrence. Thus, could be used for developing a much more accurate landslide early warning system that would be benefits Malaysians, especially Ulu Klang residents.

For future recommendations, it would be better if continuous flight can be conducted to gain continuous data. This will greatly boost the accuracy of slope changes due to rainfall. Thus, the trend of slope changes can be predicted monthly or daily, and it is useful for the future development of landslide early warning systems.

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