[U Karst] Submission Acknowledgement

From: Ir. Agata Iwan Candra, MT. (jurnalonline@unik-kediri.ac.id)

To: aryastanaputu@yahoo.com

Date: Monday, February 13, 2023 at 02:56 PM GMT+8

Putu Aryastana:

Thank you for submitting the manuscript, "Grid Satellite Rainfall Products Potential Application for Determining Rainfall Thresholds for Landslide Occurrences over Bali Island" to U Karst. With the online journal management system that we are using, you will be able to track its progress through the editorial process by logging in to the journal web site:

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From: Agata Iwan Candra,ST.MT. (Scopus Id : 57218369367) (jurnalonline@unik-kediri.ac.id)

To: aryastanaputu@yahoo.com

Date: Wednesday, February 15, 2023 at 06:30 PM GMT+8

Dear Author.

Thanks for submitting the article on U Karst. Here I attach Editor Notes which contain instructions for correcting articles so that can continue for the review process.

We hope the author can fix it as soon as possible.

Best Regards,

Ir. Agata Iwan Candra, MT., IPM.
Chief Editor of U Karst

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EDITOR'S NOTES U Karst

TITLE OF MANUSCRIPT:

Grid Satellite Rainfall Products Potential Application for Determining Rainfall Thresholds for Landslide Occurrences over Bali Island

No	ITEMS		Eligible	Revised	Comment / Suggestion
1	**Title**				
	A	Capitalize each words	✓		
	B	Times New Roman 14 pt	✓		
	C	Bold	✓		
	D	Align Center	✓		
	E	Number of words	✓		
	F	Contribution on the Title		✓	There are no contributions on Title
2	**Author's / Authors' name**				
	A	Capitalize each words	✓		
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	A	Using Institution Email		✓	Recommended to use institutional email
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5	**Abstract**				
	A	Title: **ABSTRACT** (Font and form: Times new Roman, 11 pt, bold, capital)	✓		
	B	Text: Time New Roman 11 pt	✓		
	C	Text: Italic	✓		
	D	Text: Justify	✓		
	E	Text: 200-250 words	✓		
	F	Research Background		✓	Describe the problems that underlie the conduct of this research and the impact it has caused.
	G	The purpose of the research		✓	Explain the purpose of the research.
	H	Research method		✓	Add research methods conducted
	I	The finding of the research	✓		

	J	Contribution		✓	add research contributions that relate to research findings
	K	Keywords: 3-5 words or phrases	✓		
6	**Body text**				
	A	Time New Roman 12 pt	✓		
	B	Number of Pages 12 - 16	✓		
7	**Introduction**				
	A	Sub title: **INTRODUCTION (**Times New Roman 12 pt, bold, and Capitalize Each Words)	✓		
	B	The writer(s) state(s) the **urgency or problem** of the research	✓		
	C	The writer(s) state(s) the **state of the art** of the research	✓		
	D	The writer(s) state(s) the **Novelties** of the research	✓		
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8	**Methods**				
	A	Title: **RESEARCH METHODS**(Font size: 12, Times New Roman, bold, and Capital Letters)	✓		
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	C	Second sub heading: Times New Roman 12, Bold (if available)	✓		
		Please states the quality of approach, methods, techniques, and/or data of the research	Good		
9	**Results & Discussion**				
	A	Title: **RESULTS & DISCUSSION**(Font size: 12, Times New Roman, bold, and Capital Letters)	✓		
	B	First sub heading: Times New Roman 12, bold (if available)	✓		
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	D	Please states the quality of Results and discussion	The research results only reveal a basic description. Describe the results in detail		
10	**Tables**				
	A	The title of the table	✓		
	B	The style of the table	✓		
11	**Conclusion**				
	A	Title: **CONCLUSION** (Font size: 12 Bold in Capital Letters, Times New Roman)	✓		
	B	It answers all the purposes of the research	✓		
	C	Please states the quality of Conclusion	Present conclusions only on points that answer the research objective. After obtaining IMERG is the best? so what's the next step?		
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	A	Please states the readability of the English Note: The editor may give notes or comments on the paper	This paper is easy to read		
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	A	IEEEE	✓		
	B	Using reference manager	✓		
	C	The number of references is minimally 25	✓		
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	E	The citations are not from second sources e.g. (author, year in author, year)	✓		
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Grid Satellite Rainfall Products Potential Application for Developing I-D and E-D Thresholds for Landslide Occurrences over Bali Island

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A B S T R A C T

Grid Satellite Rainfall Products (GSRPs) present rainfall information on worldwide availability and different time pixel density have the potential to identify rainfall conditions for landslide occurrences because the rain gauge observations need to maintain, the coverage observation is not widespread enough, and limited in the mountain areas. The purpose of the present study is to analyze the potential application of Precipitation Estimation from Remotely Sensed Information Using Artificial Neural Networks (PERSIANN), the Integrated Multi-satellitE Retrievals for Global Precipitation Measurement (IMERG), and Global Satellite Mapping of Precipitation (GSMaP) in determining the mean rainfall intensities and duration (I-D); accumulated rainfall and duration (E-D) thresholds for landslide occurrences over Bali Island. The method used to develop I-D and E-D thresholds is the power-law equation and frequentist sampling method in various probability levels (5%, 10%, 20%, 30%, 40%, and 50%). The result shows that I-D and E-D thresholds established by GSRPs are generally lower than the threshold defined by rain gauge observations. Among the three GSRPs, IMERG is performing the best to establish the I-D and E-D thresholds for landslide phenomena. The present research contributes to allowing GSRPs to be an important additional data source that could be used to develop a local early alert system for landslide initiation.

1. Introduction

Bali province which is bordered by the sea has a complex terrain, where the border is a beach or flat area while the center part has a higher terrain with several mountains and hills [1]. Based on the National Disaster Management Agency of Indonesia, Bali is one of the provinces in Indonesia that has a high risk of natural disaster vulnerability. Landslide events are frequently occurring in Bali. The number of landslides in Bali took the first position in 2017-

Commented [A1]: The title should be short and write down what benefits are obtained after doing developing I-D and E-D

Commented [A2]: The abstract should be in order by describing :

1. The underlying problem needs to be done..
2. Objectives to be achieved in doing..
3. The method used in realizing the results.
4. The results obtained from the goals set in point 2.
5. Benefits/contributions from the results that have been obtained in point 4.

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Developing I-D and E-D Thresholds is a research process carried out. Of course, there is a goal to be achieved in conducting research. From the goal will realize the result.. From the results will emerge benefits that answer the problems that have been previously set.

Introduction, preferably in order, so that it is easy to understand anyone who reads

The introduction should be based on valid and reputable references

The order of introduction should describe from the beginning to the end of the paragraph in the following order, as follows:

1. Underlying problems the need for Developing I-D and E-D Thresholds implementation research
2. The results of the previous researcher are by the topic under study.
3. New existing findings from the research conducted.
4. The method used in realizing the results, of course, must be by the research objectives
5. Describe the objectives clearly, relevant to the research carried out
6. Pour out the results obtained following the objectives of point 5.
7. Describe the expectations/images/predictions of contribution/benefits from the results that have been obtained in point 6.

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2019 compared to other natural disasters (floods, earthquakes, volcanic eruptions, and strong winds) based on information from the Bali Province Regional Disaster Management Agency.

Furthermore, a landslide triggered by rainfall is a popular natural hazard regularly occurring around the world with serious impacts on property losses, fatalities, and environmental damages [2] [3]. Conforming to the World Health Organization in the range from 1998-2017, landslides have an impact on approximately 4.8 million population and cause more than 18 thousand mortalities [4]. The occurrences of landslides primarily provoked by rainfall infiltration are associated with rainfall duration, rainfall accumulation, and antecedent rain rate causing a rise in the soil pore pressure so that the shear stress of the soil decreases [5][6]. This is the most important cause of landslides. To reduce the risk of landslides, early alert systems for forecasting the landslide-triggering amount of rain were established at global and regional scales derived from different procedures and input raw data [7][8]. The prediction of rainfall-generated landslides calculates on physical or empirical approaches [9][10][11].

The physical approach can forecast the failures by examining the terrain information, soil formation, and environmental condition of the study region. Whereas in the empirical method, to evaluate the possibility of landslide occurrences is determined by analyzing previous rain rate occurrences that initiated landslides. Recently, empirical rainfall thresholds have been used to establish the early alert system of landslide occurrences on a global and regional scale [7]. The rainfall thresholds are categorized into three parts: (i) mean rainfall intensities and duration (I-D), (ii) accumulated rainfall and duration (E-D), and (iii) cumulative -mean intensity rainfall (E-I) [5][9]. The frequent rainfall thresholds used on multiple spatial scales are the I-D and E-D thresholds [12]. Hence, the I-D and E-D thresholds are chosen in the current study.

The accuracy of I-D and E-D thresholds is highly dependent on the quality of rainfall data as a primary input [13]. Reliable rainfall data used to define rainfall thresholds are obtained from rain gauge measurements. However, the spatial coverage of rain gauge stations which are very rare in remote areas and high terrain is a major issue in their use to develop rainfall thresholds for landslide occurrences. Recently, remote sensing platforms are capable to present global grid satellite rainfall products (GSRPs) at high spatial and temporal resolution. Various SPDs are accessible for their different retrieval algorithm, coverage areas (global or regional), spatiotemporal resolution, and utilized sensor instruments (visible, infrared, passive microwave, and combinations). GSRPs have the potential to be used to determine rainfall thresholds for landslide occurrences because it provides global rainfall estimates over remote areas, and complex topography, and have a high temporal resolution [1][14].

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The first potential GSRPs used to obtain the framework of global rainfall intensity-duration threshold for global landslide occurrences was the use of the Tropical Rainfall Measuring Mission (TRMM) Multi-satellite Precipitation Analysis (TMPA) datasets [15]. The first framework was upgraded by [16], who emphasize several issues in the original derivation because of the susceptibility map spatial resolution and the need to re-analyze the I-D threshold for a finer assessing regional climatology. A further study was achieved by [17] who used the Precipitation Estimation from Remotely Sensed Information Using Artificial Neural Networks (PERSIANN) to establish the global landslide forecast model. Moreover, [18] determined I-D thresholds from the TRMM dataset over the Garhwal Himalaya region in India. Afterward, [18] analyze the accumulative rainfall probability for landslide occurrences using a grid rainfall dataset from the global Hydro-Estimator of the National Oceanic and Atmospheric Administration (NOAA). In [19] compare the E-D threshold between rain gauge with TMPA and Climate Prediction Center morphing technique (CMORPH) datasets for debris flow occurrences in eastern Italian. Furthermore, [13] assess the performance of TMPA, PERSIANN, CMORPH, and Soil Moisture TO RAIN-Advanced SCATterometer (SM2RASC) datasets to determine the E-D threshold for landslide events over Italy. More currently, [12] used CMORPH to calculate the E-D threshold over the whole of China. The previous studies highly emphasize the potential of GSRPs in determining rainfall threshold. However, the past studies only derived I-D and E-D separately so that in the current study will analyze both I-D and E-D thresholds by using IMERG, GSMaP, and PERSIANN. Moreover, based on the author's knowledge, there are no previous studies in determining the rainfall threshold for landslide events using either rain gauge data or GSRPs over Bali Island. Therefore, it is important to develop the rainfall thresholds for landslide occurrences in Bali Island by using satellite-based rainfall datasets because the coverage of rain gauge stations in Bali Island is not widespread enough and is limited in the high terrain areas.

The present study aims to analyze the potential application of three GSRPs (i.e. PERSIANN, IMERG, and GSMaP) in determining the I-D and E-D thresholds for landslide occurrences over Bali Island. The expected results in this study are that GSRPs have the prospective to be used as an alternative to rainfall data in developing I-D and E-D thresholds. Therefore, the main contribution of the current study is the development of the I-D and E-D thresholds for landslide occurrences over Bali Island by using the different spatial-temporal resolutions of GSRPs (PERSIANN, IMERG, and GSMaP).

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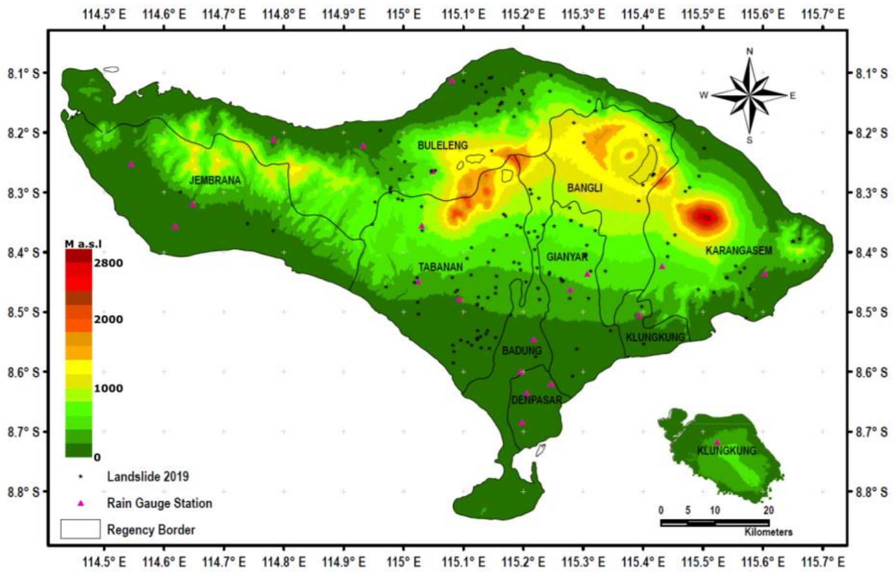
2. Research Method

2.1. Area of study

Bali is an Indonesian province that is enclosed east of Java and west of Lombok Island. It is located 8 degrees below the equator. Bali has a total area of 5620 km^2 and measures approximately 140 km by 80 km (**Figure 1**). As a result of its complex terrain and high rains, Bali Archipelago is highly prone to landslides. Bali has a drought period from May to October and a rainy period from November to April, which follows similar seasonal variations as Indonesia [20]. Relying on Balai Wilayah Sungai Bali-Penida (BWSBP) rain gauge information from 2015 to 2017, the amount of rain in Bali was defined to be approximately 180 mm/month; the greatest amount of rain happens from December to February, while the minimum amount of rain happens from July to August [1].



Source: Author's Compiles (ArcGIS, 2022).

Figure 1. Elevation Map of Bali and Landslide Events Position

2.2. Landslide data

The landslide events data is acquired from the Regional Disaster Management Agency of 8 regencies over Bali province. In this study, collected 66 landslide incidents were provoked by rainfall in 2019. The reference details for every landslide consist of the location (village or

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1. The research process, not the explanation of the definition/function of the method
2. Data, population and sample clearly (If using primary data from interviews or questionnaires)
3. Detailed instruments used in processing the data

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site) and the time when it happened (hour or date). The latitude and longitude of the landslide events were acquired by field surveying. **Figure 1** reveals the positions of landslides and the propagation of altitude in Bali.

2.3. Rainfall data

Two kinds of rainfall datasets were used to determine the rainfall thresholds: (i) rain gauge measurements and (ii) GSRPs (IMERG, GSMaP, and PERSIANN). The BWSBP Ministry of Public Works and Human Settlements of Indonesia provided the hourly rain gauge data. They only can provide 18 hourly rain gauge observation data for the completion in 2019. Because gauge measurements are not frequently near landslide locations, the author chose the gauge measurements closest to the site of every landslide incident.

The IMERG product is an upgrade of TRMM-TMPA that was later published and data available in global coverage from June 2000 to the present. Its algorithm is inter calibrations of all obtainable satellite microwave rainfall imagery, microwave-calibrated infrared imagery, ground rain gauge observations, as well as other potential rainfall guesstimates at high spatial and temporal scales across the entire quasi-global domain [21]. The present research used the final product of Level-3 IMERG half-hourly and 0.1° spatial resolution data from version-06B. The IMERG product is accessible online at https://gpm.nasa.gov/data/directory.

The GSMaP is a GSRP established from 2002 to 2007 by the Japan Science and Technology Agency in the Core Research for Evolutional Science and Technology (CREST) program, which was previously linked by the Japan Aerospace Exploration Agency (JAXA) [22][23]. The GSMaP technique integrates passive microwave and infrared imageries to generate a high-quality rainfall dataset [22][23][24]. The GSMaP_Gauge version 7 was used in the present study with the one-hour time resolution, 10 km x 10 km pixel size, and is easily downloaded into the JAXA official site (ftp://rainmap:Niskur+1404@hokusai.eorc.jaxa.jp/standard/v7/hourly_G/).

The PERSIANN was invented by the University of California Irvine’s Center for Hydrometeorology and Remote Sensing in collaboration with the NOAA, National Aeronautics and Space Administration (NASA), and the United Nations Educational, Scientific and Cultural Organization (UNESCO) program for the Global Network on Water and Development Information for Arid Lands (G-WADI). The PERSIANN retrieval algorithm rainfall estimates based on infrared imagery by an artificial neural network method [14]. In this study, the PERSIANN-CCS dataset with 0.04° spatial resolution and hourly time resolution was used, this dataset is free and accessible at https://chrsdata.eng.uci.edu/.

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2.4. Methods

A frequently used equation configuration of I-D and E-D thresholds for slope failure occurrences is the power-law correlation, defined as [5][25]:

$I = \alpha \cdot D^{-\beta}$

$E = \alpha \cdot D^{\beta}$

With:

I = the average rain rate (mm/hour)

E = the abundance of rain (mm)

D = the period of rainfall occurrences (hour)

α = the scaling factor

β = the slope variable

Based on the above formulation, this study used the frequentist sampling technique suggested by [10] to estimate the I-D and E-D thresholds for all GSRPs and gauge measurements. The I-D and E-D thresholds, in the present study, are determined at a 5%, 10%, 20%, 30%, 40%, and 50% exceedance level, which means that the probability of a landslide due to rainfall events not exceeding the rainfall thresholds is less than 5%, 10%, 20%, 30%, 40%, and 50%.

Two major processes were conducted in the features extraction of rainfall datasets for the recognition of landslides provoking rainfall occurrences. First, the catalog's landslide coordinates were geographically matched to satellite pixels and rain gauges. The GSRPs recognized the cell containing the landslide induction position, whereas the gauges assumed the single closest neighbor to the position of the landslide, as is normally accepted in gauge-based landslide-provoking rainfall prediction [26]. Second, the derived data series from every gauge/pixel could be produced to define and classify the rainfall occurrences that caused the landslides. The occurrences that happened mostly on the date of the landslide could be regarded, and a one-day no-rain occurrence was selected as the least interevent period [19]. Several past studies obtained 7 days of antecedent rainfall as an essential factor for initiating landslide occurrences [27][28]. Hence, the present study further analyzed rainfall total for 7 days (168 hours) before the start of rainfall events that initiated landslide occurrences.

3. Results and Discussions

The I-D and E-D threshold were inferred from the rain gauge, IMERG, GSMaP, and PERSIANN datasets by using the landslide occurrences during 2019 in Bali Island.

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It's a good idea to explain what results have been obtained... no need to explain the process

Discussion :
Explain how the results obtained answer/solve the problem that has been set out in the introduction

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3.1 Rainfall event conditions

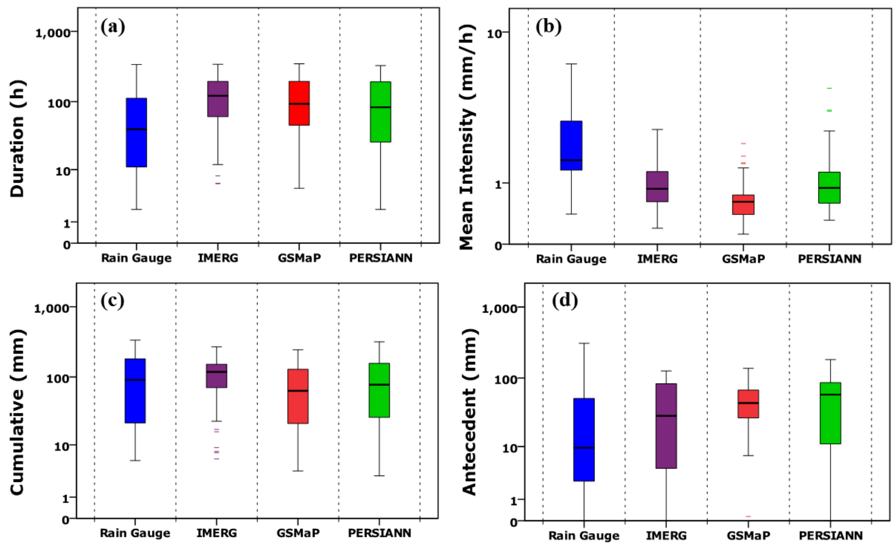
Table 1 shows the mean intensity, duration of rainfall occurrences, rainfall accumulation, and antecedent rainfall to trigger the landslide occurrences. The mean rainfall intensity for the rain gauge ranged from 0.41 to 6.68 mm/hour with an average of 2.16 mm/ hour, IMERG ranged from 0.20 to 2.66 mm/hour with an average of 1.12 mm/ hour, GSMaP ranged from 0.12 to 2.12 mm/hour with an average of 0.66 mm/hour, and PERSIANN ranged from 0.31 to 4.83 mm/hour with an average of 1.08 mm/hour. This indicates all GSRPs exhibited an underestimate of the average of rain-rate to provoke landslide events. The minimum rainfall duration triggers landslides of rain gauge and PERSIANN is equal (2 hours), while IMERG and GSMaP are more longers (6 hours and 5 hours, respectively). The maximum duration of rainfall occurrences triggering landslides from the gauge, IMERG, GSMaP, and PERSIANN is 339 hours, 341 hours, 347 hours, and 326 hours, respectively. This shows that the duration of rainfall that causes landslides detected by GSRPs and near-approximation rain stations is about 14 days or 2 weeks. The average rainfall duration of all GSRPs was confirmed higher with rain gauge observation. The maximum cumulative and antecedent rainfall of the rain gauge shows the highest compared to all satellite rainfall datasets. The average value of rainfall accumulation triggering landslides for all products reveals more than 75 mm, this indicates that the occurrence of landslides on the island of Bali in 2019 is more likely to be influenced by accumulated rainfall. The results of the current study are also strengthened by several previous studies in Indonesia which analyzed the accumulation of rainfall that initiated landslides with variations of 1, 3, 5, 10, 20, and 30 days [3][29][30].

Table 1. Rainfall events conditions

Products	Rainfall condition	Mean Intensity (mm/hour)	Duration (hour)	Cumulative rainfall (mm)	Antecedent rainfall (mm)
Rain Gauge	Average	2.16	64.73	105.80	36.63
	Max.	6.68	339.00	334.30	309.50
	Min.	0.41	2.00	5.60	0.00
IMERG	Average	1.12	132.58	116.26	44.42
	Max.	2.66	341.00	268.95	126.04
	Min.	0.20	6.00	5.97	0.00
GSMaP	Average	0.66	128.20	77.64	53.85
	Max.	2.12	347.00	244.36	136.76
	Min.	0.12	5.00	3.68	0.00
PERSIANN	Average	1.08	114.05	102.24	65.65
	Max.	4.83	326.00	317.00	182.00
	Min.	0.31	2.00	3.00	0.00

Source: Author's Analysis

Figure 2 reports the box plots of the duration of the rainfall event (**Figure 2a**), the mean rainfall intensity (**Figure 2b**), the cumulative rainfall (**Figure 2c**), and the antecedent rainfall (**Figure 2d**) calculated using the rain gauge and GSRPs responsible for the landslide occurrences. Inspection of **Figure 2a** reveals that the GSRP's rainfall duration has long duration compared with the rain gauge duration. **Figure 2b** shows that all satellite products generally underestimate the mean rainfall intensity that induces landslides measured by the rain gauge. However, the IMERG and PERSIANN show better performance in capturing mean rainfall intensity compared with GSMaP. From **Figure 2c** the cumulative rainfall for PERSIANN is comparable to that of a rain gauge, while IMERG and GSMaP show overestimate and underestimate, respectively. However, IMERG has a small deviation in capturing rainfall accumulation that initiates landslide events compared to other products. It might be due to the high temporal resolution of the IMERG can capture and apply in various potential studies [31][32]. All satellite rainfall datasets depict an overestimated antecedent rainfall (**Figure 2d**). This indicates that cumulative and antecedent rainfall is a dominant influence on the occurrence of landslides [6][27].



Source: Author's Analysis

Figure 2. Box Plots of Rainfall Condition: (a) Duration, (b) Mean Rainfall Intensity, (c) cumulative rainfall, and (d) Antecedent Rainfall

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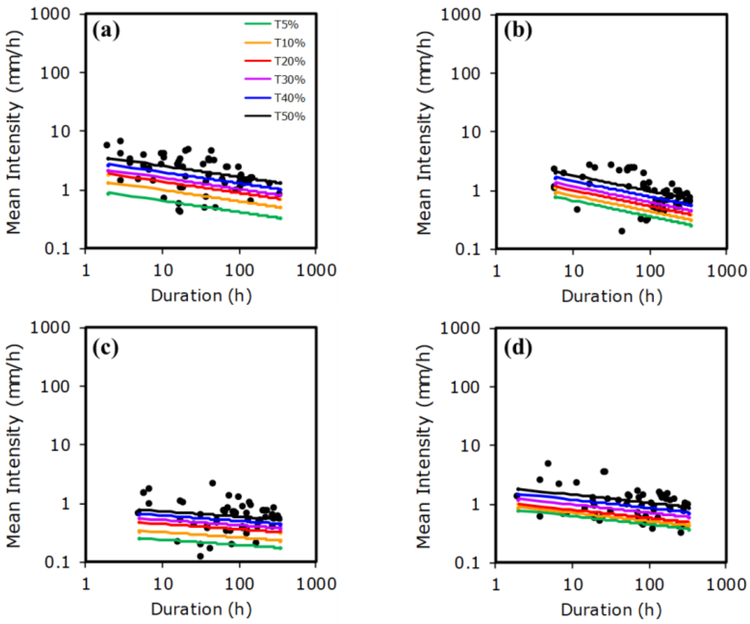
3.2 Rainfall thresholds

Figure 3 displays the I-D threshold at exceeding probabilities from 5% (T5%) to 50% (T50%) for the rain gauge (**Figure 3a**), IMERG (**Figure 3b**), GSMaP (**Figure 3c**), and PERSIANN (**Figure 3d**) datasets. The probability of every I-D threshold represents the potentiality of landslides when rainfall above the I-D curve happens. As presented in **Figure 3**, the I-D threshold of the GSMaP dataset is lower than other datasets. The IMERG threshold is relatively close to the I-D threshold determined by the rain gauge dataset, this might be due to the highest temporal resolution of the IMERG product. The accumulated half-hourly rainfall may produce a noteworthy overestimation of the rainfall needed to induce the landslide [13]. The slope of the PERSIANN demonstrated relatively similar to the rain gauge observation, this is might due to the highest spatial resolution of the PERSIANN dataset. However, the GSMaP rainfall thresholds exhibited the lowest compared to rain gauge, IMERG, and PERSIANN. This result indicates the GSRPs exhibited underestimated I-D threshold compared to the rain gauge observation.



Source: Author's Analysis.

Figure 3. (a) I-D thresholds for the rain gauge. (b) I-D thresholds for IMERG. (c) I-D thresholds for GSMaP. (d) I-D thresholds for PERSIANN

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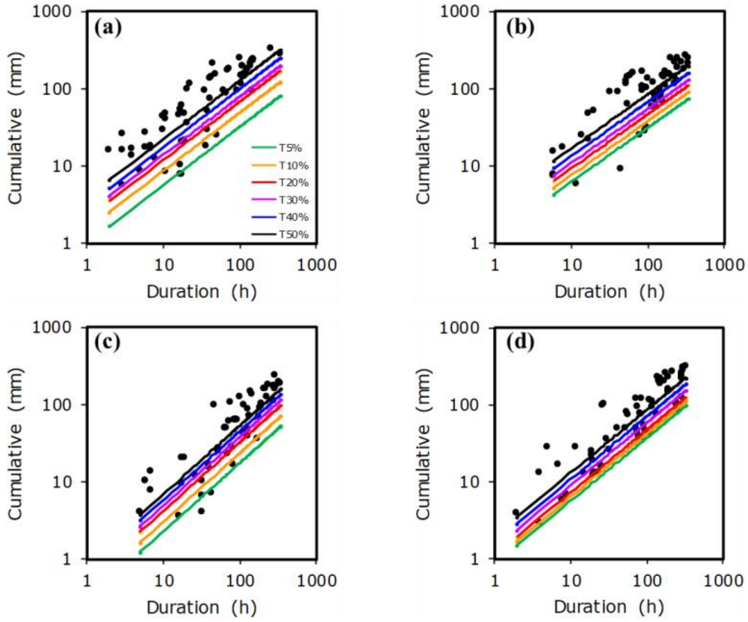
The E-D threshold at exceeding probabilities from 5% to 50% for the rain gauge, IMERG, GSMaP, and PERSIANN datasets are shown in **Figure 4a**, **Figure 4b**, **Figure 4c**, and **Figure 4d**, respectively. The slope of the E-D threshold of all GSRPs is comparable to that of a rain gauge, while the E-D thresholds of the three GSRPs tend to be lower compared to the rain gauge observation. The distribution of rainfall duration that causes landslides in IMERG products is more concentrated over more than 100 days (**Figure 4b**) when compared to evenly distributed rain stations (**Figure 4c**). All GSRPs produce a lower E-D threshold than those generated from rain stations. This is probably due to the GSRPs tending to underestimate capturing extreme rainfall [33] which is likely to provoke landslide events.



Source: Author's Analysis.

Figure 4. (a) E-D thresholds for the rain gauge. (b) E-D thresholds for IMERG. (c) E-D thresholds for GSMaP. (d) E-D thresholds for PERSIANN

3.3 Verification and prediction accuracy

The verification of landslide and no landslide occurrences for I-D and E-D thresholds at different exceeding probabilities are shown in **Figure 5a** and **Figure 5b**, respectively. Based on the verification results reveal most of the landslide events occur above the I-D lines for a

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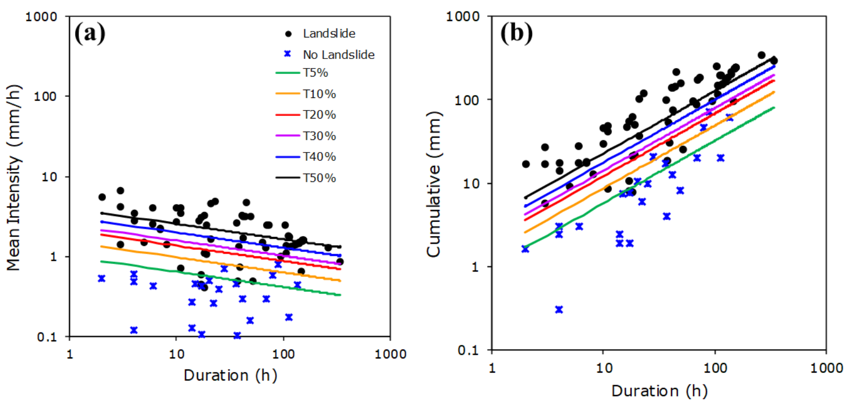
probability of 20% (red line in **Figure 5a**). On the other hand, most of the landslide events occur above the E-D lines for a probability of 30% (purple line in **Figure 5b**). Several previous studies have demonstrated that there is variability in the level of probability for the I-D and E-D thresholds [13][12][19][34].



Source: Author's Analysis.

Figure 5. (a) Verification landslide and no landslide for I-D threshold. (b) Verification landslide and no landslide for E-D threshold

The I-D and E-D thresholds equation derived from the rain gauge and GSRPs over Bali Island is tabulated in **Table 2**. **Table 2** also despite the relative differences of the threshold parameters in estimating mean rainfall intensity, cumulative rainfall, and rainfall duration. The differences between the GSRP's threshold variables from the rain gauge threshold variables are within 75%, with some datasets showing differences lower than 10%. All GSRPs underestimate the intercept parameter (α), while for the slope parameter (β) the IMERG dataset overestimates the I-D thresholds. The slope parameter of the E-D thresholds indicates that the IMERG underestimates, while both GSMaP and PERSIANN overestimate. The GSMaP has the largest deviation of all threshold variables (α and β) if compare to other GSRPs. Among the three GSRPs, IMERG has the lowest relative deviation of α compared with other datasets. PERSIANN dataset exhibited better accuracy of β in the I-D threshold, while IMERG demonstrated better performance in the E-D threshold.

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Table 2. Rainfall threshold equation and relative differences of intercept and slope parameters to the rain gauge

Threshold	Dataset	Equation	The relative deviation of α (%)	The relative deviation of β (%)
I-D	Rain Gauge	$I = 2.126 \cdot D^{-0.191}$	0.00	0.00
	IMERG	$I = 1.860 \cdot D^{-0.269}$	-15.94	40.84
	GSMaP	$I = 0.551 \cdot D^{-0.091}$	-75.10	-52.36
	PERSIANN	$I = 1.108 \cdot D^{-0.141}$	-49.92	-26.18
E-D	Rain Gauge	$E = 2.126 \cdot D^{0.753}$	0.00	0.00
	IMERG	$E = 1.860 \cdot D^{0.701}$	-15.94	-6.91
	GSMaP	$E = 0.551 \cdot D^{0.886}$	-75.10	17.66
	PERSIANN	$E = 1.108 \cdot D^{0.817}$	-49.92	8.50

Source: Author's Analysis

3.4 Comparison of rainfall thresholds

The I-D thresholds comparison with other regions of the world is shown in **Figure 6a** by [9], [35], and [36] have developed the world's I-D threshold for landslides with symbols in the form of dots, dash lines, and long dash lines, respectively. Furthermore, [37] and [38] established regional I-D thresholds in Taiwan (dash-dot lines) and Japan (dash double-dot lines), respectively. The I-D threshold calculated based on four rainfall datasets in the current study for the whole of Bali Island is lower than the I-D threshold in past studies, including the world thresholds [35][36], and the regional threshold in Taiwan [37], but higher than the world's I-D threshold was determined by [9]. The slope of the I-D threshold curve established in this study is similar to the slope examined in Japan by [38] but quite different from the slope revealed in [9], [35], [36], [37]. Among of three GSRPs, the IMERG dataset demonstrated the closest I-D threshold to the rainfall threshold set by [38] in Japan.

The E-D threshold curves are incomparable with other areas around the world as expressed in **Figure 6b**. In [35] and [39] established the world's E-D threshold for landslides as shown in **Figure 6b** with symbols in the form of dots and dash lines, respectively. Additionally, [13] and Brunetti et al. (2018) and [12] developed regional E-D thresholds over Italy (dash-dot lines) and China (dash double-dot lines), respectively. Comparing the present E-D threshold with other regions of the world displays that the E-D threshold for Bail Island is relatively close to the threshold for the world and Italy, but higher than the E-D threshold for China. The slope of the E-D threshold developed in the current study is relatively similar to the slope calculated in Italy and China, but slightly different from the E-D threshold reported by [35] and [39]. Comparison of the I-D and E-D thresholds in this study with previous studies

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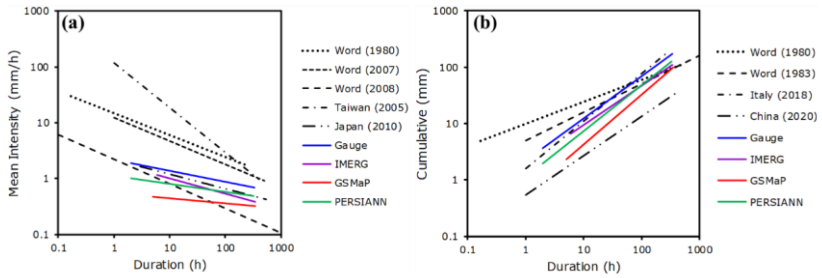
shows that the E-D threshold can reduce the uncertainty in satellite-based rainfall products, this indicates a high possibility of using the satellite rainfall datasets to establish the E-D thresholds.



Source: Author's Analysis.

Figure 6. Comparison rainfall thresholds with the past studies: (a) I-D thresholds, (b) E-D thresholds

4. Conclusion

Commented [A6]: The conclusion should contain:

1. Summarize, concise and clear results

2. An overview of the future benefits of the results that have been obtained.

The major advances in satellite remote sensing precipitation estimation over the last few decades has to lead the availability of various GSRPs with different coverage areas and space-time resolution. However, some previous assessment studies have demonstrated that GSRPs can be correlated with several errors [40], but they present the rainfall information on a global scale that is a possibility to use for assessing high-impact weather and natural disaster monitoring, such as landslides and flood monitoring. The intercomparison of three GSRPs (IMERG, GSMaP, and PERSIANN) to address the I-D and E-D threshold for the landslide occurrences in Bali Island was represented in this study. The I-D and E-D thresholds established by GSRPs are generally lower than the threshold defined by rain gauge observations. Among the three GSRPs, IMERG is performing the best to determine the rainfall threshold for landslide occurrences. The adjustment of the IMERG product by using the rain gauge dataset is important to analyze before applying it in assessing natural disaster monitoring, such as landslides and flood monitoring. On the other hand, the GSRPs be allowed to be an essential additional data source to establish a regional early warning system for landslide occurrence.

The accuracy assessment of GSRPs to determine the I-D and E-D thresholds in this study only uses the relative deviation of intercept and slope parameters. Further studies are needed to analyze the accuracy more objectively by using skill scores and receiver operating

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characteristic (ROC) analysis. The present study has limitations in the number of landslide events. Further studies are required for a large number of landslide events.

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