**SINERGI** Vol. 29, No. 2, June 2025: 547-554
http://publikasi.mercubuana.ac.id/index.php/sinergi
http://doi.org/10.22441/sinergi.2025.2.024

# Experimental study of rainfall intensity on silty sand slope

**Jestin Jelani[1*], Zuliziana Suif[1], Nordila Ahmad[1], Muhammad Jazil Rabbani Muhammad Sadiq Rabbani[2], Nurul Afiffah Khairulazman[1]**
[1]Civil Engineering Department, Engineering Faculty, National Defence University of Malaysia, Malaysia
[2]Malaysia Armed Forces, Malaysia

***Abstract***
*Malaysia, located in the tropical region, is blessed with an abundance of rainfall, particularly during the monsoon season. Previous studies have shown that major landslide occurrences in Malaysia are primarily caused by frequent and prolonged rainfall. This study is conducted to investigate the effect of different rainfall intensities on the silty sandy slope through a small-scale slope model. The soil samples were collected from Bukit Tabur, Kuala Lumpur, Malaysia, to construct a 60° slope model. A continuous rainfall intensity of 50, 100, and 150 mm/hour was considered in the study to determine the type and duration of failure. Two cameras were positioned at the front and side of the slope model to capture the elapsed time since the onset of rainfall. The gullies failures were observed in all experiments. It is due to the soil on the slope surface reaching nearly full saturation, causing runoff water to move down the slope and drain downstream, resulting in surface erosion. Such a failure mechanism agreed well with the failures (formed gullies) recorded on the downstream slope of the Bukit Tabor after high-intensity rainfalls. The time of failure for different rainfall intensities was compared to the highest rainfall intensity. The duration of slope failure for 50 mm/hr and 100 mm/hr is approximately 30% and 5% slower than that of rainfall intensity at 150 mm/hr. The results suggest that the slope is more prone to failure with higher rainfall intensities.*



***Keywords:***
*Erosion;*
*Gullies;*
*Rainfall Intensity;*
*Silty Sand;*
*Small Scale Test;*

***Article History:***
*Received: November 20, 2024*
*Received: December 23, 2024*
*Accepted: January 22, 2025*
*Published: May 17, 2025*

***Corresponding Author:***
*Jestin Jelani*
*Civil Engineering Department, Engineering Faculty, National Defence University of Malaysia, Malaysia*
*Email: jestin@upnm.edu.my*

## INTRODUCTION

During the last few decades, Malaysia has consistently experienced devastating landslide incidents. Most of the landslides occurred in developed hillside areas due to the disturbance to the intrinsic and extrinsic characteristics of natural slopes [1][2]. Among the disturbances are excavation and cutting, removal of vegetation, changes in natural drainage patterns, and added weight and load, to name a few [3][4].

In tropical regions like Malaysia, where the soil deposits are mainly residual soils, massive landslides are attributed to frequent and prolonged rainfalls, in many cases associated with monsoon rainfalls. With high annual rainfall intensity around 2000 to 2500 mm, rainfall-induced landslides are among the most frequent natural disasters [5]. The dual combinations of hillside development and rainfall contribute significantly to landslides. Table 1 shows rainfall-induced landslide incidents in Malaysia from 1990 to 2021, of which most cases occurred in developed areas.

The impact of rainfall on slope stability is determined by the duration and intensity of the rain. Rainfall seepage through unsaturated residual soil was found to considerably affect the pore water state of a slope [6]. Soil strength continues to deteriorate when precipitation infiltrates through the slope surface into the soil’s pores, resulting in slope instability. The slope may become less stable when the pore water pressure rises [7].

Table 1. Historical rainfall-induced landslide in developed areas from 1993 to 2021

| No. | Location | Date | Ref |
|---|---|---|---|
| 1 | Highland Tower | 1993 | [13] |
| 2 | Keramat Permai | 1995 | [5] |
| 3 | Kampar Perak | 1996 | [13] |
| 4 | Bukit Antarabangsa | 1999 | [5] |
| 5 | Taman Hillview | 2002 | [13] |
| 6 | Bukit Lanjan | 2003 | [4] |
| 7 | Gua Tempurong | 2004 | [4] |
| 8 | Taman Zooview | 2006 | [5] |
| 9 | Bukit Antarabangsa | 2008 | [14] |
| 10 | Wangsa Height | 2009 | [5] |
| 11 | Ukay Club Villa | 2010 | [5] |
| 12 | Setiawangsa | 2012 | [15] |
| 13 | Bukit Aman | 2013 | [15] |
| 14 | Karak Highway | 2016 | [13] |
| 15 | Tanjung Bungah | 2017 | [13] |
| 16 | Genting Highland | 2019 | [13] |
| 17 | Kemensah Height | 2021 | [16] |

Soil with higher permeability will allow rainfall seepage to penetrate the wetting zone deeper and more quickly, resulting in a greater loss of matrix suction between soil particles, thus increasing wetting zone penetration [8].

Many studies have been conducted to investigate rainfall intensity and slope failure through a small-scale experimental test. Kanule et. al. [9] studied cohesion, internal friction angle, and pore-water pressure modulated by rainfall affecting slope stability. The constructed slope dimensions are 80 cm in height with angles of 30°, 40°, and 60° using silty sand soil. The slopes were subjected to rainfall intensity of 45 mm/hr. Susinov et. al. [10] studied infiltration rate and failure mechanism of sandy soil slope with rainfall intensity of 28 mm/hr. A box model with a size of 4 m in height, 3 m long, and 2.5 m in width was used. Do et. al. [11] studied the critical slope angle (i.e., 55°, 59°, 63°, and 67°) to determine the threshold value of sudden slope failure with varied rainfall intensity. In more recent research by [12], critical slope inclination with a value greater than 1.2 of friction angle was proposed to prevent collapse during rainfall. The experimental box has a length, width, and height of 2.2, 0.8, and 1.0 m, respectively, to form three different slope angles (30°, 45°, and 60°). The slopes are subjected to rainfall intensity of 20 mm/hr to 50 mm/hr.

Although many studies have been conducted to investigate the mechanism of rainfall-induced slope failure, limited compelling experimental studies have been conducted on the relationship between rainfall intensity and duration with type of slope failure. In this study, the effect of rainfall intensity on the residual soil slope of Bukit Tabur, Malaysia, is conducted to determine the mode of failure, critical slip surface formation, slope deformation, and duration of slope failure due to tropical rainfall intensity of 50, 100 and 150 mm/hr.

## STUDY AREA

Bukit Tabor is in Hulu Kelang, Selangor, approximately 15 km away from Kuala Lumpur city centre, as shown in Figure 1. It has a unique geological formation known as Klang Gates Quartz Ridges that is made of quartz dyke and runs 14 km long within Kuala Lumpur - Selangor. The geological composition of Bukit Tabor consists primarily of granitic rock. Since the site is close to the foothills of Titiwangsa Mountain Range, it provides impressive views of Kuala Lumpur, making it an exclusive development area for residential housing, resorts, and commercial use. This has posed challenges for developers, leading some to encroach onto highlands in hilly areas. Consequently, many landslide incidents have been reported within the study area for the last two decades. There were concerns about the condition since Bukit Tabor experiences significant annual rainfall, averaging 2,400 mm per year, which could impose a risk of landslides.

## METHOD

### Soil sample collection and Laboratory Testing

Residual soils were collected from a natural slope of Bukit Tabor in Malaysia. Disturbed and undisturbed soil samples were stored in sealed plastic bags to preserve natural moisture content. The undisturbed soil samples were taken at an approximate depth of 0.7 m. In contrast, the disturbed samples were brought back to the laboratory and air-dried for a few weeks (Figure 2). Sieving analyses were performed on the sample to determine particle size distribution. As the soil contains fine soil particles of less than 0.063 mm, hydrometer analysis is used. Among other laboratory tests that were conducted were particle density, shear strength, and compaction tests. Table 2 lists the types of testing undertaken and the standards used in this study.

### Experimental Work

The dimensions of the acrylic box are shown in Figure 3. Additional steel bracings were added to the side of the acrylic box to avoid bulging and cracks. It was elevated 16 cm from the floor to form an inclined angle of 6° to avoid water puddling. A modified 15 mm diameter PVC pipe attached with eight water sprinklers was installed above the box to provide artificial rainfall. A drainage is constructed at the front to channel excess water properly.

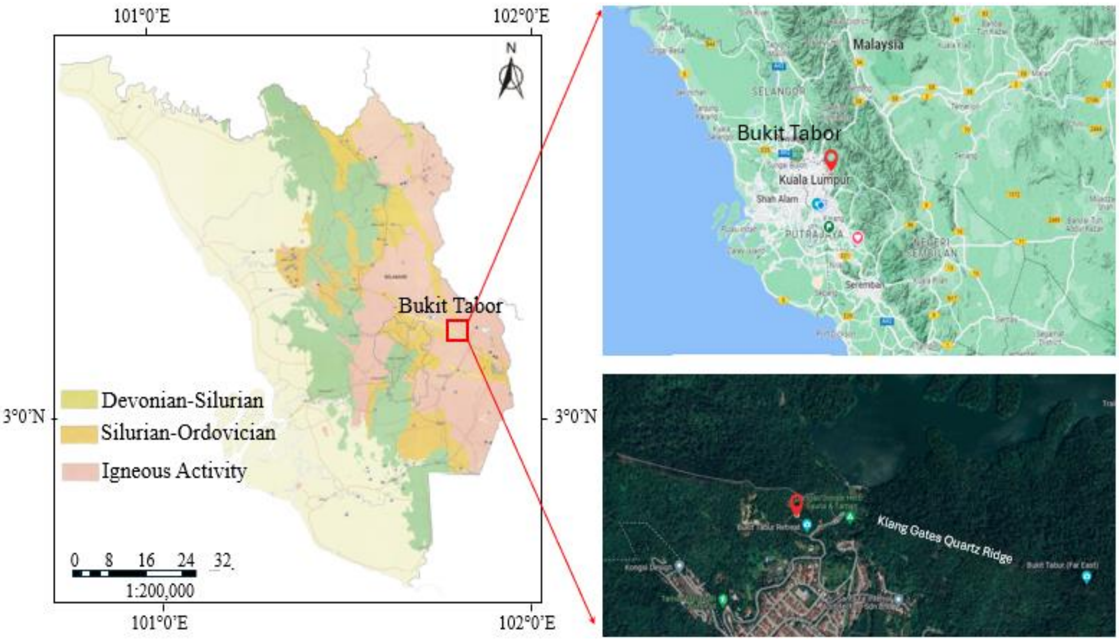



Figure 1. Location of study area

Figure 2. Samples were air-dried

Table 2. Laboratory Testing Standard

| Test | Description | Standard/specification |
|---|---|---|
| Sieve Analysis | Disturbed | BS1377:1990, Part 2, Clause 9.5 |
| Hydrometer | Disturbed | BS1377:1990, Part 2, Clause 9.5 |
| Atterberg Limit | Disturbed | BS1377: 1990, Part 2, Clause 4 |
| Soil Density | Disturbed | BS 1377: 1990, Part 4, Clause 8.3 |
| Drained Shear Box | Undisturbed | BS1377: 1990, Part 2, Clause 8.3 |
| Soil compaction | Disturbed | BS 1377-4: 1990, Part 4. |

The model slope face angle was created at 60°, representing the average slope angle of Bukit Tabor. The soil is compacted for each 5.0 cm layer thickness using a hand temper to achieve 60% relative density. Concrete bricks were located on the downstream face to support the soil mass. A transparent plastic sheet was attached to the outer faces of the box to observe the slip surface.

A continuous rainfall duration is adopted in this study at a rate of 50, 100, and 150 mm/hr using a rainfall simulator. Two digital cameras were used to capture the initiation and movement of the failure (at the front and side of the box). The experimental test is presented in Table 3.

## RESULTS AND DISCUSSION

### Laboratory Test Results

Results the particle size distribution of Bukit Tabor's soil was determined using a combination of sieving and hydrometer. The result is shown in Figure 4. The soil comprises 55% sand, 27% silt, 16% clay, and 2% gravel; it is, therefore, classified as silty SAND. The Atterberg limit of soil, i.e., Liquid Limit, Plastic Limit, and Plastic Index, are 43%, 27%, and 16%, respectively, thus classifying the soil as having low plasticity. The specific gravity of solid soil particles is 2.62 Mg/m$^3$, determined by the pycnometer method.

Figure 5 shows the result of the proctor test, where the maximum dry density of the soil is 1,906 kg/m$^3$ at an optimum moisture content of 10.3%.

Table 3. Experimental Test

| Test No. | Slope Angle (Degree) | Average Rainfall Intensities (mm/hr) | Rainfall Duration |
|---|---|---|---|
| 1 | 60 | 50 | Continuous |
| 2 | 60 | 100 | Continuous |
| 3 | 60 | 150 | Continuous |

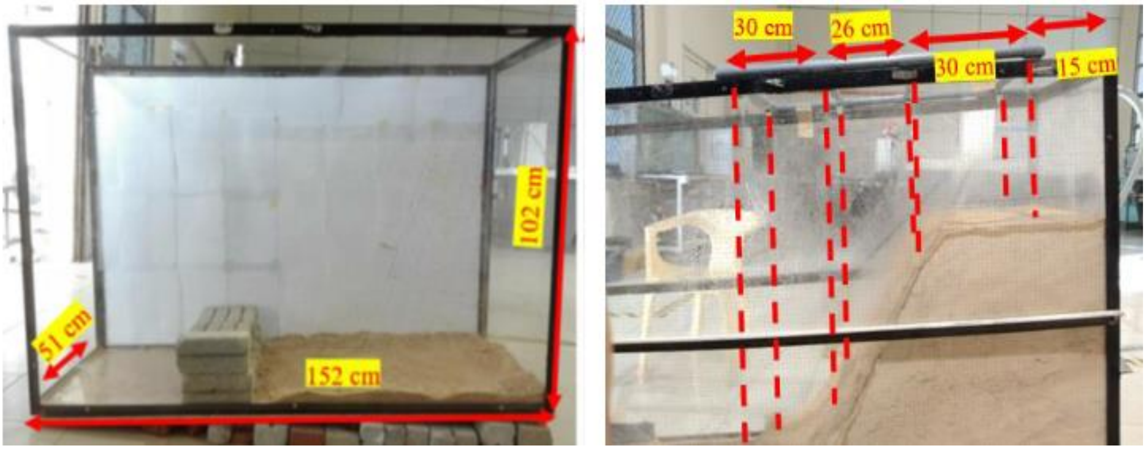


Figure 3. The size of the acrylic box and the location of the water sprinklers

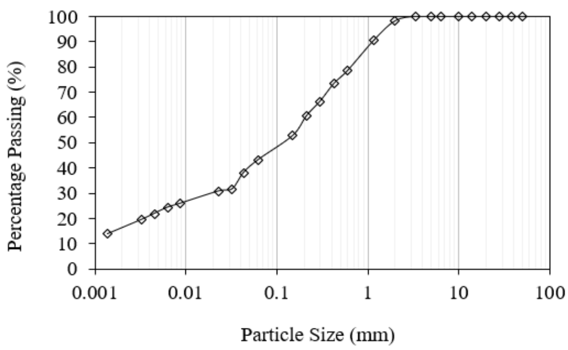


Figure 4. Particle-size distribution of Bukit Tabor soil

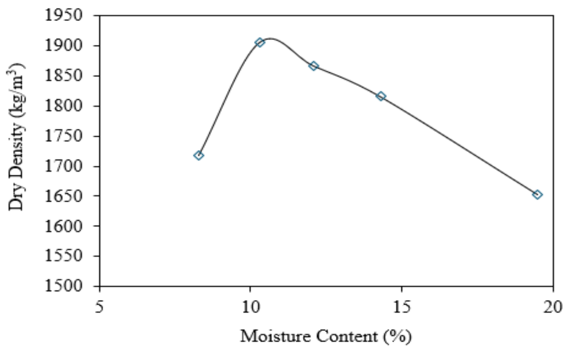


Figure 5. Soil compaction test result

The relative density, R, is 60%, determined from (1), where R, $\gamma_{box}$, and $\gamma_{lab}$ is the relative density, the density of soil in the acrylic box, and the maximum density of soil when compacted using the proctor test.

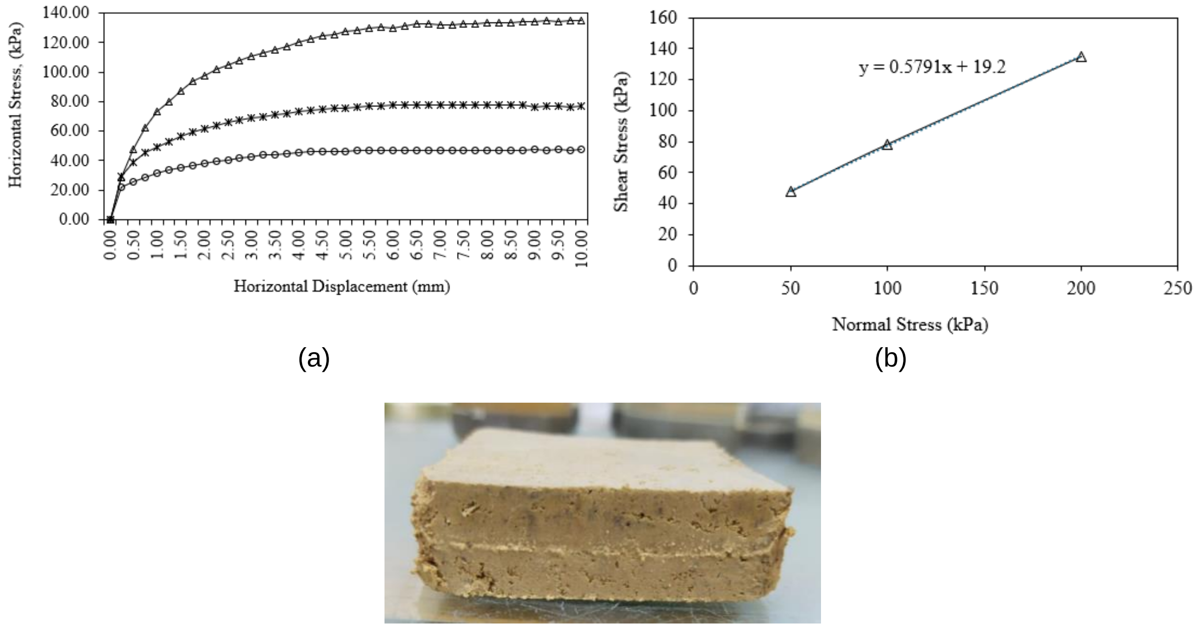
The drained shear box test was conducted at three different normal stresses, 50, 100, and 200 kPa for samples A, B, and C, to determine the Mohr-Coulomb strength parameter. The strain rate applied is 0.25 mm/min. The effective cohesion, c', and angle of internal friction, φ', were 19 kN/m$^2$ and 30°, determined from Figure 6.

$$Relative\ Compaction, R\ (\%) = \frac{\gamma_{box}}{\gamma_{lab}} \tag{1}$$

## Experimental Test Results

An analysis was carried out to investigate the effect of different rainfall intensities on the type and duration of failure of the Bukit Tabor soil slope. The time t = 0 second represents the initiation of rainfall. The signs of failure in all experiments were observed at 30-, 60-, and 90-minute intervals.

After the onset of rainfall, it was observed that seepage water gradually infiltrated into the slope for all experiments 1, 2, and 3. Figure 7 shows the final seepage condition from the side view of the slope before failure takes place. The difference was only the depth of the seepage. For experiment 1, the depth of seepage is more compelling due to the time exposure to rainfall is the highest. It took 107 minutes to cause the slope to fail. For experiments 2 and 3, the depth of seepage showed no significant difference as the exposure time before failure was 85 and 81 minutes, respectively. This implies that the seepage under low intensity and long duration is greater than that of high intensity and low duration [17][18].




(a) (b)

(c)

Figure 6. Drained shear strength test (a) Stress-displacement graph (b) shear strength of soil (c) failed sample

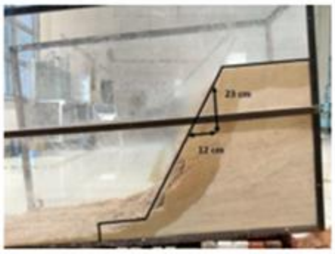
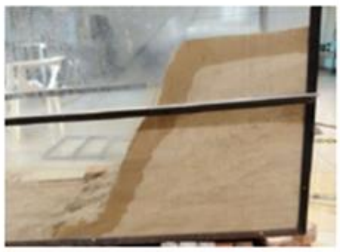
| **Rainfall Intensity (mm/hr)** | **50** | **100** | **150** |
|---|---|---|---|
| Seepage condition |  |  |  |
| Duration | Soil collapse at *t*=107 minutes | Soil collapse at *t*=85 minutes | Soil collapse at *t*=81 minutes |

Figure 7. Seepage conditions from the side view

The first sign of failure in all experiments was observed at t = 30. It appeared at the middle and toe of the slope (Figure 8). The difference between them was only the size of the failure, which was very small in experiment 1 (the lowest intensity was 50 mm/hr). Experiments 2 and 3 show more compelling failure. When t = 60, the slope with high rainfall intensities reached nearly full saturation, and failure occurred more prominently at the middle and toe. The runoff water begins to move down the slope surface and drain through the downstream holes. This causes concentrated surface flows, which erode the slope surface [19][20]. Such a failure mechanism agreed well with the failures (formed gullies) recorded on the downstream slope of the Bukit Tabor after high-intensity rainfalls.

As the rainfall continued, the soil started to recumbent due to excessive erosion at the toe of the slope, which took approximately 107, 85, and 81 minutes for experiments 1, 2, and 3. With increasing rainfall intensity, the time of failure decreases [21, 22, 23]. In comparison to that 100 mm/hr rainfall intensity, the duration of slope failure for 150 mm/hr intensity occurs 4% faster. Meanwhile, for 100 mm/hr intensity, the slope failure duration is 20% faster than that of 50 mm/hr.

| Exp no | Rainfall Intensity (mm/hr) | Before | After | | |
|---|---|---|---|---|---|
| | | | t=30 minutes | t=60 minutes | t=90 minutes |
| 1 | 50 |  |  |  |  |
| 2 | 100 |  |  |  |  |
| 3 | 150 |  |  |  |  |

Figure 8. Experimental progress from the front view

The results are congruent with the study conducted by [24, 25, 26, 27], which showed that the slope is prone to failure with higher rainfall intensity.

## CONCLUSION

This paper investigated the effect of different continuous rainfall intensities of 50, 100, and 150 mm/hour on a 60° slope model using Bukit Tabor soil. It was observed that gullies' failure occurred in all experimental tests. The failure is due to soil on the slope surface reaching nearly full saturation, causing runoff water to move down on the slope surface and, consequently, causing surface erosion. Such a failure mechanism agreed well with the failures (formed gullies) recorded on the downstream slope of the Bukit Tabor after high-intensity rainfalls. The time of failure for different rainfall intensities was compared to the highest rainfall intensity. The duration of slope failure for 50 mm/hr and 100 mm/hr are approximately 30% and 5% slower than that of rainfall intensity of 150 mm/hr. The results imply that the slope is prone to failure with higher rainfall intensity.

## ACKNOWLEDGMENT

The authors wish to thank the National Defence University of Malaysia for funding and supporting this project under the grant, with project code: UPNM/2023/GPJP/TK/2.

## REFERENCES

[1] S. Gue and C. Liong, "Is the ground in Ulu Klang unstable?," *Jurutera*, pp. 32–33, 2007.

[2] F. A. Samah, "Landslides in the Hillside Development in the Hulu Klang, Klang Valley," in *Post-graduate Seminar*, 2007, pp. 148–162.

[3] A. S. Ahmad Ishak, J. Jelani, S. Y. Wong, Z. Suif, and A. L. Ahmad Mazuki, “Experimental and Numerical Study on the Behaviour of Silica Sand Slope Model,” *Jurnal Teknologi (Sciences & Engineering),* vol. 86:1, no. 2024, pp. 165–173, 2023, doi: 10.11113/jurnalteknologi.v86.20463

[4] A. S. Ahmad Ishak, J. Jelani, S. Y. Wong, Z. Suif and A. L. Ahmad Mazuki, “Stability Analysis of a Silica Sand Slope Model Subjected to Surcharge Load Using LEM and FEM Methods”, *International Journal of GEOMATE*, vol. 7, no. 21, pp.121–135, 2024 https://doi.org/10.21660/2024.121.g13442

[5] M. L. Lee, K. Y. Ng, Y. F. Huang, and W. C. Li, “Rainfall-induced landslides in Hulu Kelang area, Malaysia,” *Natural Hazards*, vol. 70, no. 1, pp. 353–375, Jan. 2014, doi: 10.1007/s11069-013-0814-8.

[6] D. Hu, S. Kato, and B. S. Kim, “Evaluation Of Infinite Slope Stability With Various Soils Under Wet-Dry Cycle,” *International Journal of GEOMATE*, vol. 26, no. 115, pp. 89–99, 2024, doi: 10.21660/2024.115.g13306.

[7] M. Mukhlisin, S. J. Matlan, M. J. Ahlan, and M. R. Taha, “Analysis of rainfall effect to slope stability in Ulu Klang, Malaysia,” *Jurnal Teknologi (Sciences & Engineering)*, vol. 72, no. 3, pp. 15–21, 2015, doi: 10.11113/jt.v72.4005.

[8] H. Heyerdahl, “Influence of extreme long-term rainfall and unsaturated soil properties on triggering of a landslide-a case study,” *Natural Hazards Earth System and Science*, pp. 1–43, 2017, doi: 10.5194/nhess-2017-410.

[9] J. Kanule, W. Ng’etich, and S. Rotich, “Computational and experimental study of a hydro-dynamical landslide model based on laboratory flume tests,” *Environmental Research Communications*, vol. 1, no. 12, 2019, doi: 10.1088/2515-7620/ab50f6.

[10] B. Susinov, S. Abazi, and J. Josifovski, “Physical modelling of rainfall-induced slope instabilities in unsaturated silty sand 1 Introduction 2 Model preparation,” *26th European Young Geotechnical Engineers Conference (EYGEC2018)*, Graz, Austria, 2016, no. 2016, pp. 309–318.

[11] X. K. Do, K. Jung, G. Lee, and R. K. Regmi, “A Study on Rainfall Induced Slope Failures: Implications for Various Steep Slope Inclinations,” *Journal of the Korean Geoenvironmental Society*, vol. 17, no. 5, pp. 5–16, 2016, doi: 10.14481/jkges.2016.17. 5.5.

[12] C. Gallage, T. Abeykoon, and T. Uchimura, “Instrumented model slopes to investigate the effects of slope inclination on rainfall-induced landslides,” *Soils and Foundations*, vol. 61, no. 1, pp. 160–174, 2021, doi: 10.1016/j.sandf.2020.11.006.

[13] N. A. Majid, M. R. Taha, and S. N. Selamat, “Historical landslide events in Malaysia 1993-2019,” *Indian Journal of Science and Technology*, vol. 13, no. 33, p. 3387, 2020, doi: 10.17485/IJST/v13i33. 884.

[14] D. Kazmi, S. Qasim, I. S. H. H. Thu, and H. Vu, “Analytical study of the causes of the major landslide of Bukit Antarabangsa in 2008 using fault tree analysis,” *Innovative Infrastructure Solutions*, vol. 2, no. 1, pp. 1–11, 2017, doi: 10.1007/s41062-017-0105-4.

[15] N. I. Ismail and W. Z. W. Yaacob, “An investigation of landslides in Bukit Aman and Puncak Setiawangsa, Kuala Lumpur, Malaysia,” in *AIP Conference Proceedings*, American Institute of Physics Inc., Apr. 2018. doi: 10.1063/1.5027946.

[16] J. Jelani, M. S. S. Abdul Rahman, S. Sojipto, M. S. W. Wan Mohamed Sabri, L. Min Lee, and N. Ahmad, “Geotechnical Investigation of a Landslide Incident in Hulu Kelang, Malaysia,” *International Journal of GEOMATE*, vol. 27, no. 120, pp. 138–145, 2024, doi: 10.21660/2024.120.g13382.

[17] H. Wang *et al.*, “Analysis of deformation mechanism of rainfall-induced landslide in the Three Gorges Reservoir Area: Piansongshu landslide,” *Scientific Reports*, vol. 14, no. 1, Dec. 2024, doi: 10.1038/s41598-024-60590-w.

[18] L. Li, Y. Li, and Y. Xu, “Instability evolution of expansive soil slope due to short duration-varying intensities of rainfall,” *Engineering Failure Analysis*, vol. 161, no. 108313, Jul. 2024, doi: 10.1016/j.engfailanal.2024. 108313.

[19] X. Xu, F. Zheng, and G. V. Wilson, “Flow hydraulics in an ephemeral gully system under different slope gradients, rainfall intensities and inflow conditions,” *Catena (Amst)*, vol. 203, no. 2021, Aug. 2021, doi: 10.1016/j.catena.2021.105359.

[20] X. Xu, F. Zheng, G. V. Wilson, and M. Wu, “Upslope inflow, hillslope gradient and rainfall intensity impacts on ephemeral gully erosion,” *Land Degradation & Development*, vol. 28, no. 8, pp. 2623–2635, Nov. 2017, doi: 10.1002/ldr.2825.

[21] X. Liu and Y. Wang, “Analytical solutions for annual probability of slope failure induced by

rainfall at a specific slope using bivariate distribution of rainfall intensity and duration," *Engineering Geology*, vol. 313, Feb. 2023, doi: 10.1016/j.enggeo.2022.106969.
[22] N. H. Do *et al.*, "Mechanism of a rainfall-induced landslide in a large-scale flume experiment on a weathered granite sand," *Geoenvironmental Disasters*, vol. 11, no. 1, Dec. 2024, doi: 10.1186/s40677-024-00280-x.
[23] D. Kalaimani and G. Srinivasan,"Strength and durability properties of concrete made with recycled coarse aggregate and seashore sand," *Sinergi*, vol. 28, no. 1, pp. 115-128, 2024, doi: 10.22441/sinergi.2024.1.012
[24] Z. Li and Z. Yin, "Failure pattern of dispersive soil slopes under the action of rainfall conditions," *Alexandria Engineering Journal*, vol. 104, pp. 193–210, Oct. 2024, doi: 10.1016/j.aej.2024.06.045.
[25] X. Liu, Y. Wang, and A. K. Leung, "Probabilistic back analysis of rainfall-induced slope failure considering slope survival records from past rainfall events," *Computers and Geotechnics*, vol. 159, Jul. 2023, doi: 10.1016/j.compgeo.2023.105436.
[26] S. N. Hamizak et al., "Experimental investigation on slope runoff, sediment, and hydraulic parameters under different underlying surface," *Sinergi*, vol. 29, no. 1, pp. 252-258, 2025, doi: 10.22441/sinergi.2025.1.023
[27] Z. Guo, Q. Huang, Y. Liu, Q. Wang, and Y. Chen, "Model experimental study on the failure mechanisms of a loess-bedrock fill slope induced by rainfall," *Engineering Geology*, vol. 313, Feb. 2023, doi: 10.1016/j.enggeo.2022. 106979.