Jurnal Manajemen Hutan Tropika, *29*(1), 1–10, April 2023
EISSN: 2089-2063
DOI: 10.7226/jtfm.29.1.1

Scientific Article
ISSN: 2087-0469

Exploring Terrain Indices and Slope Morphometry for Trail and Campsite Planning on Mount Irau, Malaysia

Muhammad Shafeeq Sapian[1], Azita Ahmad Zawawi[1*], Thinaraj Balakrishnan[1], Mohd Hasmadi Ismail[2]

[1]Department of Recreation and Ecotourism, Faculty of Forestry and Environment, Universiti Putra Malaysia, UPM Serdang, Selangor, Malaysia 43400
[2]Department of Forestry Science and Biodiversity, Faculty of Forestry and Environment, Universiti Putra Malaysia, UPM Serdang, Selangor, Malaysia 43400

Received August 2, 2022/Accepted Februari 20, 2023

Abstract

Terrain analysis and elevation profiling are widely utilized in geographical studies where spatial information system is one of the foremost tools in assessing characteristic patterns of hiking trails and plain areas suitable for a campsite. The main objective of this study is to classify the landforms of Batu Gangan Forest Reserve by conducting a morphometric analysis of the digital terrain model (DTM) with a 10 m resolution. The classification process is based on calculating the topographic position index (TPI). Using TPI, the landscape was classified into slope position and landform categories. The delivered TPI landform classes are spatially correlated with the elevation, slope, LS factor, and topographic wetness of the mountain. Site observation was carried out to identify water sources, viewpoints, and their significance as suitable campsites and potential trails. An alternative trail was proposed to reduce the visitor impacts towards the main trail. The result suggested that the plains landform only covered 3.26% or 2.03 km^2 of the study area, where two potential campsites were identified. The method presented and research findings derived from the study are beneficial to support sustainable recreation resource planning, especially in a complex mountainous area. The study's findings and data will lead to proper forest use for recreational reasons consistent with conservation efforts.

Keywords: *landform, Mount Irau, recreation planning, sustainable, TPI, terrain analysis*

**Correspondence author, email*: *azitazawawi@upm.edu.my tel.: +60-397697171 fax.: +60-397693768*

Introduction

The implementation of automated techniques for landform classification has become quite common in scientific society (Tagil & Jenness, 2008; Grohmann et al., 2009; Ilia et al., 2013; McVicar & Körner, 2013; Rigol-sanchez et al., 2015; Skentos & Ourania, 2017). Consequently, landform elements such as mountains, hills, valleys, canyons, plateaus, plains, and other landform classifications have reduced the complexity of terrain units that can be easily described; this also provides more understandable information paths of land categories. Due to the earth's surface's complexity, landform classification emerged to quantify its forms into more manageable components (Mokarram et al., 2015).

The input data for landform classification consists of topographic maps, aerial photos, satellite imagery, and digital elevation models (DEM) or Digital Terrain model (DTM). Several studies have employed DEM/DTM for the automated mapping of landforms (Cone, 1998; Saadat et al., 2008; Verhagen & Drâguţ, 2012; Skentos & Ourania, 2017). Landforms are formed by small and simple elements that are topologically and structurally related. Using complex terrain parameters calculated from simple ones, such as topographic wetness index (Warner et al., 1989), stream power index (Pradhan & Buchroithner, 2012), and more complete landforms can be described. DEM/ DTM are the information base for extracting essential components and terrain parameters in geomorphologic studies. In this paper, the term DTM will be used to highlight the terrain factors. Terrain and landform analysis, together with additional information, such as surface geology and soil data, will help us to understand the region's topography and determine the most appropriate sites for various land uses. A better understanding of the method could be a pivotal point in conducting forest planning and achieving successful forest management. In addition, Zawawi et al. (2014) had previously introduced an approach to identifying terrain and landform analysis, Ming and Zawawi (2020) developed methods to extract terrain characteristics and terrain sensitivity due to slope gradient, elevation, and aspect.

In this study, the landforms of Batu Gangan Forest Reserve (Batu Gangan FR) were classified by calculating topographic position index (TPI). TPI was derived by conducting geometrical and topological analysis using local statistics (user-defined calculus area). Since both the geology and the ensuing topography significantly determine

Jurnal Manajemen Hutan Tropika, *29*(1), 1–10, April 2023
EISSN: 2089-2063
DOI: 10.7226/jtfm.29.1.1
Scientific Article
ISSN: 2087-0469

the landscape, the delivered TPI landform classes are related to the geological setting and terrain attributes (slope, valley depth, ruggedness) for further interpretation. Analysis of terrain indices and slope morphometry using GIS is significant in trail and campsite planning. It is an effective method to delineate areas concerning slope stability, which will influence recreation experience and hiking difficulties in a particular landscape (Forest Practice Code, 1999). The indices selected have been studied to be useful in prioritizing trail maintenance, recreational area design as well as resource condition reporting (Meadema, 2019). Furthermore, Becco et al. (2016) mentioned in their studies that GIS application provides guidelines for recreation planners in zone delineation involving conflict areas, resource classification and assisting management action (i.e identify areas suitable for development of activities and facilities).

With the help of GIS technology, terrain assessment may be done remotely. Terrain conditions around the trail of the study area may be extracted through DTM which might describe through several parameters, including altitude, slope, length-slope factor (LS factor), and topographic wetness index (TWI). Thus, TPI-based landform analysis will reveal the landform around the trail of the study area. As the study area is mountainous, manual analysis will be tough to carry out. According to Rahman (2014), GIS is useful to simplify forest resource evaluation, planning and management, where it is a powerful tool for integrating spatial, temporal, and attributive information (Hung, 2002). Vukomanovic et al. (2022), highlighted that advanced GIS and computing technology have a high capability to quantify recreational behaviour, tourist preferences and recreational impacts in protected areas, thus overcoming the challenges and limitations of monitoring techniques raised by Leung and Monz (2006).

The application of digital terrain assessment is proven to be time and cost-effective for long-term management purposes. Where trails and campsites studied could be efficiently examined and monitored (Olafsdottir & Runnstrom, 2013).

This study will apply GIS mapping to document trail characteristics and landform classification for Batu Gangan FR. The objective of this study is to establish an alternative method to identify site evaluation for forest planning. An alternative approach for terrain stability assessment and forest characterization method will be introduced.

Methods

Study area Mount Irau, as shown in Figure 1 was selected as the study site. Mount Irau is located within the Batu Gangan Forest Reserve, Cameron Highlands, Pahang State of Malaysia, with coordinates (N4.5289°, E101.3650°). High slopes and highly diversified terrain characterize the mountainous area. It is a forested area that acts as critical habitat for numerous plant and wildlife species and the headwaters of major rivers within the region. The general characteristics of Mount Irau are summarized in Table 1.

Mount Irau is the highest mountain in Cameron Highland, with an elevation of 2,110 m. It is categorized as an upper dipterocarp forest classification (Kumaran et al., 2011). This area is a popular spot for tourists, outdoor enthusiasts, and various stakeholders due to its beautiful surroundings that have massive potential for an economic generation. The mossy forest of Mount Irau in Cameron Highlands is prevalent with various terrain conditions, campsites, landslides, and carrying capacity issues which can be hazardous and often lead to disaster. Even though several existing research has been focused on the incidence of dangers, morphometric circumstances have gotten little attention, and their interaction with topography and

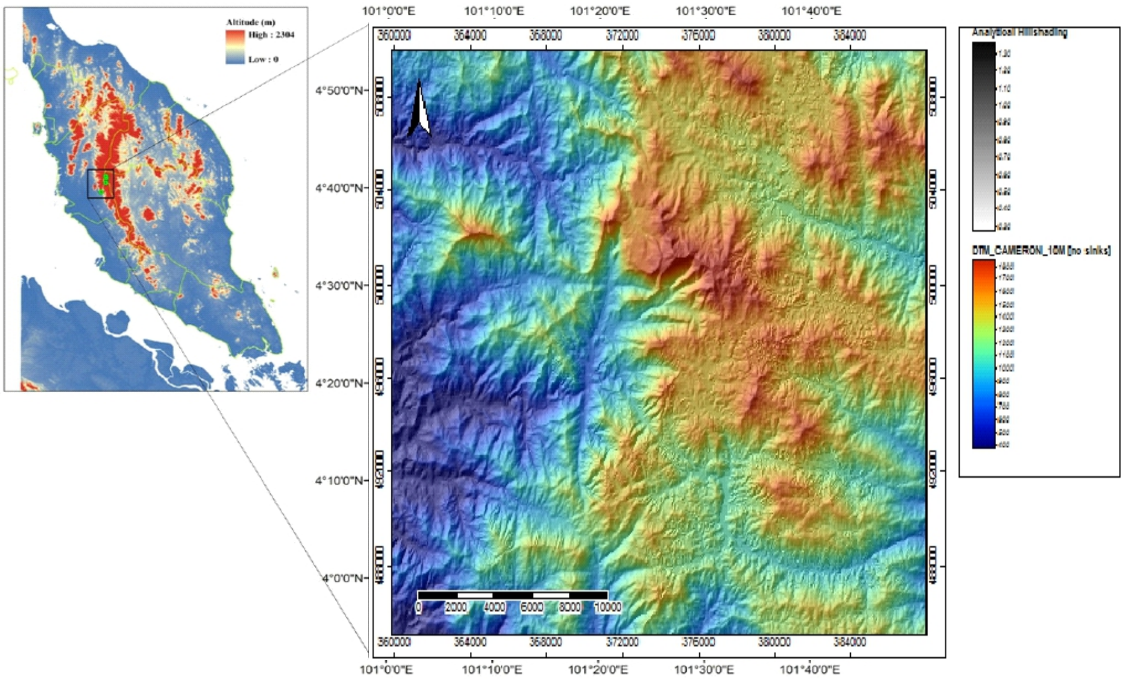


Figure 1 Map of Peninsular Malaysia and elevation profile of Mount Irau.

Jurnal Manajemen Hutan Tropika, *29*(1), 1–10, April 2023
EISSN: 2089-2063
DOI: 10.7226/jtfm.29.1.1
Scientific Article
ISSN: 2087-0469

campground management is not well known (Zalina, 2020). This study focused on Batu Gangan FR, an area where the main forested trail is located. The site covered the boardwalk of Mini Irau to the summit of Mount Irau, with elevations of 1,993 m and 2,110 m, respectively. Furthermore, the traditional ground survey method is complex, costly, and time-consuming in the case of Batu Gangan FR, concerning its rugged and mountainous terrain. Blending terrain analysis and geographical information systems (GIS) provides foresters with powerful tools for resource inventories and data analysis, and assists the management planning process, especially when addressing forest environment complexity (Sonti, 2015).

The study was conducted in three phases which are i) spatial data acquisition, ii) terrain and landform analysis, and iii) data interpretation (Figure 2).

Phase I: Spatial data acquisition Spatial data for this study were obtained from Jabatan Ukur dan Pemetaan Malaysia (JUPEM) and Jabatan Perhutanan Semenanjung Malaysia (JPSM). According to Hutchinson and Gallant (2000), DEM/DTM with a resolution of 5 to 50 m scale is suitable for various analyses, including soil, hydrological modeling, and terrain analysis. Figure 3 shows the spatial data image, while the respective information is summarized in Table 2.

Phase II: Terrain and landform analysis DTM data of Batu Gangan FR was extracted, and terrain parameters (elevation, slope gradient, length slope factor (LS factor), and Topographic Wetness Index (TWI) were computed within SAGA GIS software (Table 3, Figure 4). Slope expresses the terrain's surface inclination from either the horizontal or a local base level (Skentos, 2017). The calculation algorithm for the specific index consists of two significant steps; Interpolation of a channel network base level elevation, and subtraction of the channel network base level from the original elevations (Conrad et al., 2006).

Table 1 General characteristics of Mount Irau

Characteristic	Attribute	Source
Coordinate	N4.5289°, E101.3650°	Azita et al. (2020)
Area coverage	10.10 km^2	Azita et al. (2020)
Elevation	2,110 m	Matori et al. (2012)
Mean temperature	18.5°C	Azita et al. (2019)
Forest type	Upper Dipterocarp Forest	Kumaran et al. (2011)

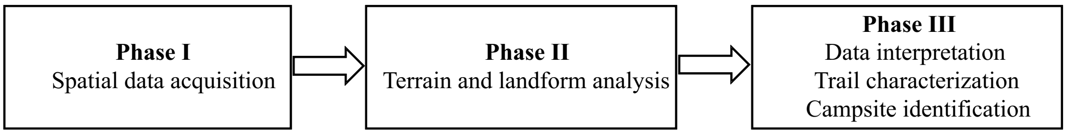
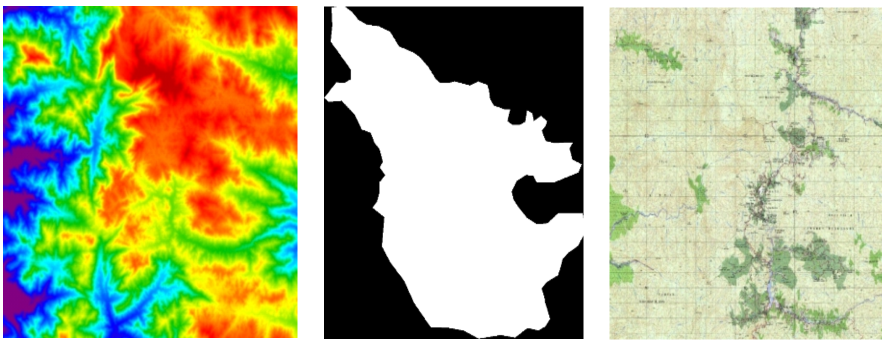


Figure 2 Research flow.



(a) (b) (c)

Figure 3 Spatial data for DTM (a), shape file of Batu Gangan Forest Reserve (b), and topographic (c).

Table 2 General information of data attributes

Spatial data	Resolution	Year	Source
DTM	10×10 m	2018	JUPEM
Shape file of Batu Gangan Forest Reserve	NA	2019	JPSM
Topographic map	5×5 m	2020	JUPEM

Jurnal Manajemen Hutan Tropika, *29*(1), 1–10, April 2023
EISSN: 2089-2063
DOI: 10.7226/jtfm.29.1.1

ISSN: 2087-0469

Table 3 Importance of respective terrain parameters

Features	Description	Significant
Elevation	Altitude of terrain above sea level	Local climate, vegetation
Slope gradient	Degree of sloping	Inclination level
LS factor	Effect of length and steepness of slope	Soil loss intensity, erosion rate
TWI	Surface wetness	Water accumulation, runoff propensity, soil moisture

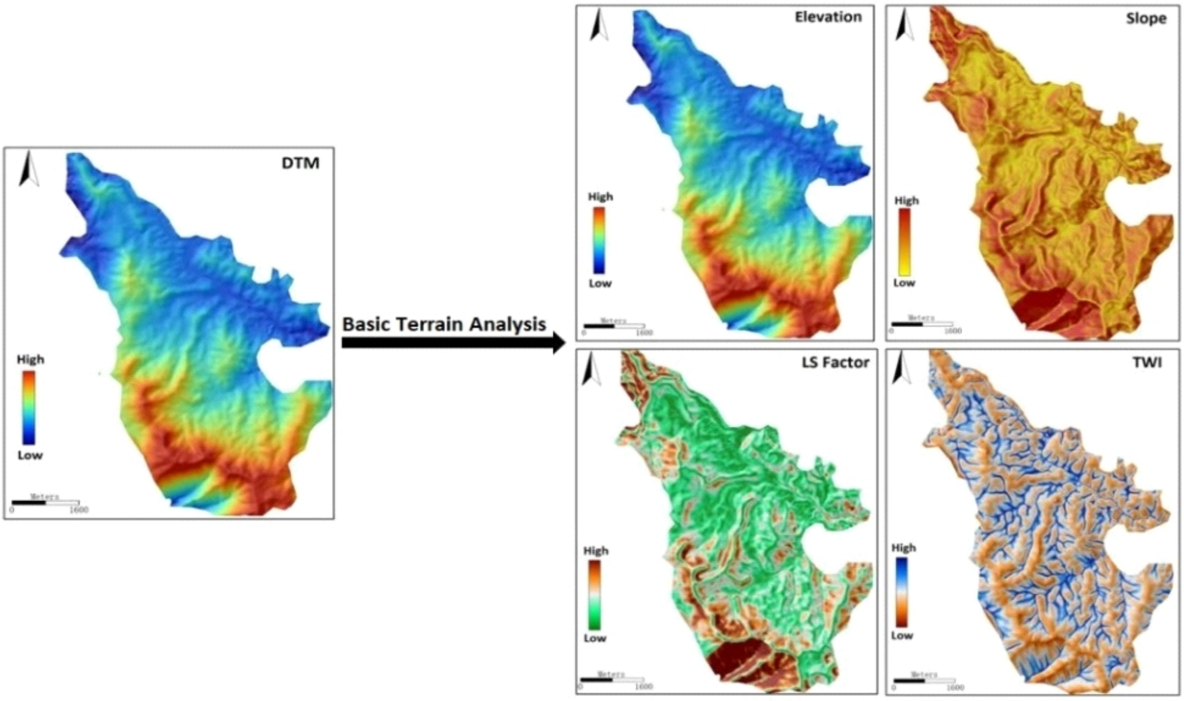


Figure 4 Process of map derivation for selected terrain parameters.

Landform classification using TPI Landform classification is an analysis designed to reveal a region's physical attributes (Abdullah & Abdulrahman, 2020). Landform classification can be computed digitally by using TPI. According to Weiss (2001), TPI landform classification is conducted by comparing the cell value of DTM with its neighboring cell to predict its landscape. In this study, TPI landform classification was applied to reveal the landform of Batu Gangan FR through an unsupervised classification (Figure 5). The method is adopted from Skentos & Ourania, (2017). It should be noted that TPI is scale-dependent, which means that the initial values are calculated using the size and form of the focal area, that may highlight or neglect important landscape characteristics. Guisan et al. (1999) propose the TPI calculation in the sequence. The calculation is the same as the difference in the mean calculation (residual analysis) proposed by Wilson and Gallant (2000). The bandwidth parameter for distance weighting is given as the percentage of the (outer) radius.

The analysis resulted in ten classes of landform elements which are streams, midslope drainages, upland drainages, valleys, plains, open slopes, upper slopes, local ridges, streams, midslope drainages, upland drainages, valleys, plains, open slopes, upper slopes, local ridges, and midslope ridges and high slopes.

Phase II: Data interpretation Phase III covers the discussion for identification of potential campsite and alternative trail.

Results and Discussion

Terrain characterization Table 4 shows the terrain characteristics of the study area, which are explained using elevation, slope, LS factor, and TWI. The minimum value (Min.) shows the lowest point, while the maximum value (Max.) shows the highest point of the respective terrain attribute. The mean value indicates the indicative character of the respective attribute, while the standard deviation (SD) indicates the range of data variation.

Major terrain variables characterized in the landform classes are presented in Figure 6. The topographic wetness index (TWI) is an index that is widely used to explain water

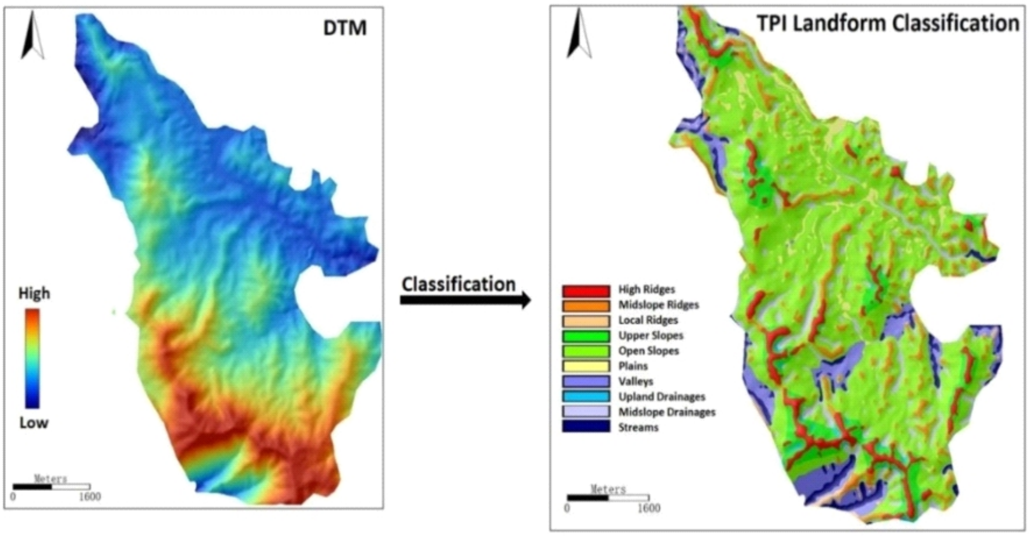


Figure 5 Simulation of TPI landform classification of DTM Batu Gangan Forest Reserve.

Table 4 Terrain characteristics of Batu Gangan

Attribute	Min.	Max.	Mean	SD
Elevation (m)	1,140.74	2,088.10	1,572.46	171.48
Slope (°)	0.00	56.22	19.16	9.53
LS factor	0.00	55.72	5.54	3.55
TWI	1.88	21.17	5.62	1.56

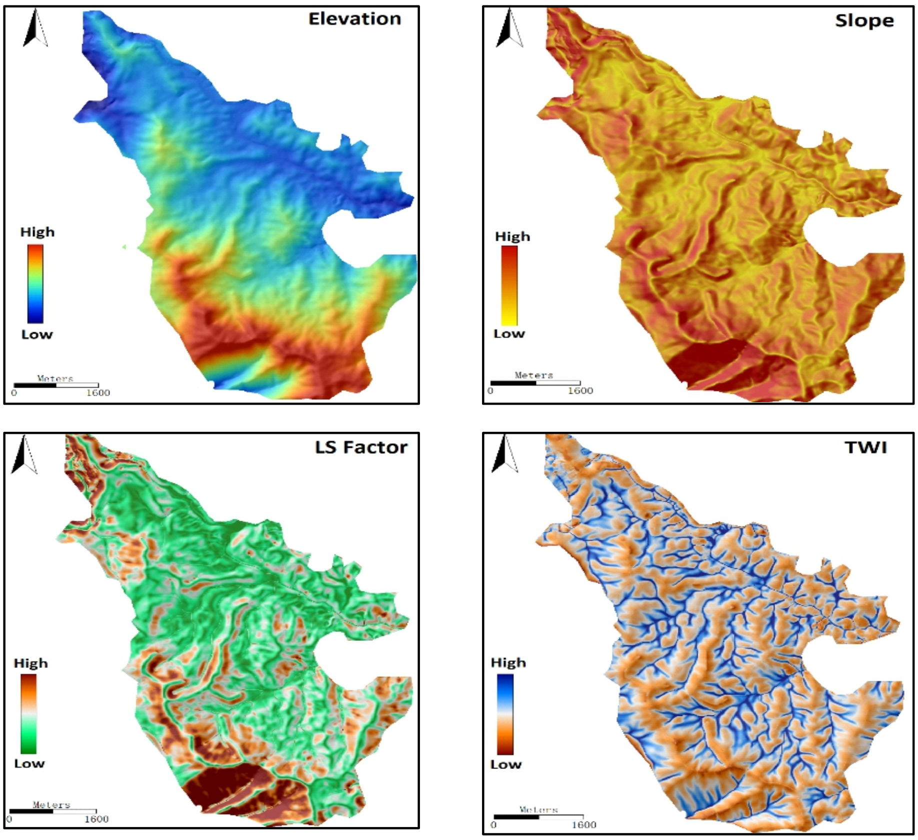


Figure 6 Major terrain variables characterized in the landform classes (a) elevation, (b) scope, (c) LS factor, and (d) topographic wetness index (TWI).

Jurnal Manajemen Hutan Tropika, *29*(1), 1–10, April 2023
EISSN: 2089-2063
DOI: 10.7226/jtfm.29.1.1

ISSN: 2087-0469

level, sediment content, and soil moisture in the area. This index is critical as it describes soil quality and potential land suitability of certain areas (Wilson & Gallant, 2000). The image shows the relationship between each variable and terrain steepness, where elevation, slope, LS factor, and TWI change as the terrain becomes steeper and more complex. All these terrain factors are crucial in understanding the topographical condition of the study site. The variable selection is also similar to a study by Muntasib et al. (2019) who indicated that a steep slope and erosion are among potential hazards on mountainous trail.

Results of terrain analysis using DTM indicate that the terrain in Mount Irau tends to express ungentle and rough conditions in the aspect of altitude, slope, LS factor, and TWI. Batu Gangan FR shows a high altitude with a mean value of 1572.46 ± 171.48 m which makes the hiker's trail in this region classified as very strenuous. Besides, the slopes of Batu Gangan FR are steep with a mean value of 19.16 ± 9.53° which exposes the hiker's trails to the risk of erosion. The value of LS factor shows a mean value of 5.53 ± 3.55 indicating that the Batu Gangan FR has a high risk of soil loss potential erosion site in terms of slope length and steepness while the value of TWI shows 5.62 ± 1.56 indicating that the area tends to be water accumulated and having a moderate risk of runoff propensity.

Landform characteristics and slope descriptions This section outlined the major landform elements of Batu Gangan FR according to the TPI modules. Figure 7 shows the study area's landform map, which was differentiated by dynamic colour coding. The study area was classified into ten landform types: high ridges, midslope ridges, upland drainage, upper slopes, open slopes, plains, valleys, local ridges, midslope drainage and streams, respectively, as shown in Figure 8. Different colors and patterns on the map denote significant landform features and describe the geographic location of major landforms.

Referring to Figure 8 and Table 5, the primary landform type in Batu Gangan FR is open slopes which cover 55.38% or 34.46 km^2 of the total forested area. A high percentage of open slopes should be expected from the study site as it is located in a mountainous area, and slope refers to the inclination of the surface. The formation of the mountain area is due to the plate tectonic process, which indicates the movement of the earth crust on a large scale and results in the surface protruding (Costa & Souza, 2018). As the mountainous area is the appearance of a protruded earth surface, the area seems reasonable to be covered by slopes with different degree levels. In addition, different landforms, including ridges and drainages, should be expected from the study area. On the other hand, the coverage of plains landforms should be rare in mountainous areas. TPI and landform patterns significantly impact soils by controlling water and sediment movement. Within the landform shape and structure lie very complex terrain features and characteristics. Elevation, slope, and aspect have been demonstrated to be beneficial predictors for the temporal and spatial distributions of variables such as precipitation and radiation, which highly influence vegetation growth and composition (Stage & Salas, 2007).

Slope profile morphometry of Mount Irau, Cameron Highland The description and slope level of the respective landform are summarized in Table 6, while the slope description is listed in Table 7. The slope refers to a horizontal surface's steepness (Department of Environment and Science, 2020). It describes the inclination or gradient of a surface and is expressed in the form of a degree. In the environmental aspect, terrain slopes enable natural processes, including sediment transportation and water movement, and induce hazards such as erosion, landslide, and surface runoff. Slope stability is essential in natural disaster management and land use planning (Reli et al., 2021). Different slope steepness leads to different rates of trail difficulty. According to the Australian Walking Track Grading System, the level of trail stability tends to decrease when the steepness increases (Department of Sustainability and Environment, 2011). The trail tends to become unstable when the slope steepness exceeds 5.7° , for example, in rocky areas and when encountering fallen debris. In order to ensure the safety of the trails, it is advisable to maintain the trail at a slope steepness of not more than 8.5° to avoid erosion (North Country National Scenic Trail, 1996).

Landform type and slope morphometry suitability for forest recreation planning: Campsite identification The required landform for potential campsites is the plain-type class. According to National Geographic (2011), plains refer to an area with relatively flat land. The campsite requires plains landform, which tends to exhibit flat and gentle terrain. However, flat and gentle terrain is not a typical landform in mountainous areas; as predicted, the plains landform only covered 3.26% or 2.03 km^2 of the total study area, and it is not located along the hiker's trail. Cesetti et al. (2010) claimed that due to the DTM resolution, a flat and safe target region is

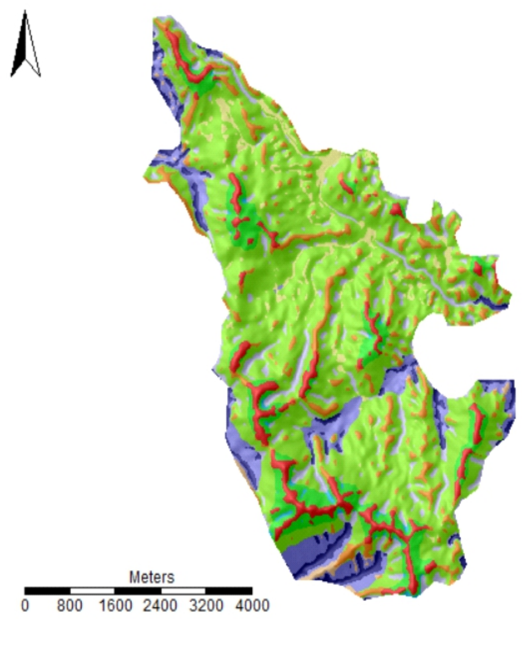


Figure 7 Landform elements from TPI classification analysis.

Jurnal Manajemen Hutan Tropika, *29*(1), 1–10, April 2023
EISSN: 2089-2063
DOI: 10.7226/jtfm.29.1.1

ISSN: 2087-0469

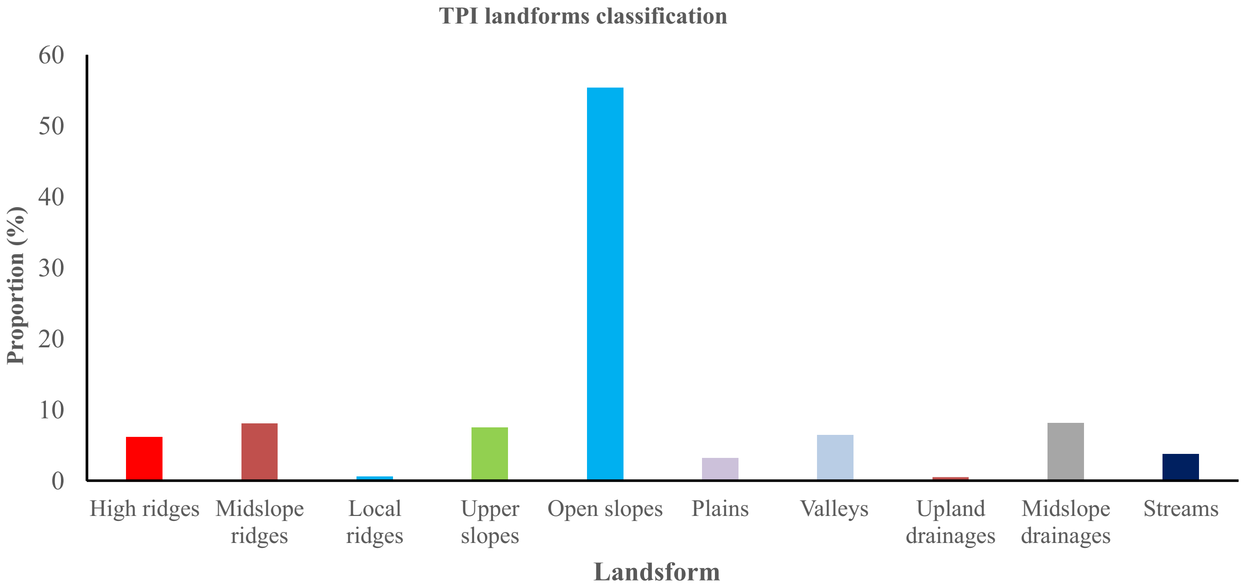


Figure 8 Percentage of landform coverage in Batu Gangan Forest Reserve.

Table 5 Area coverage and percentage of landform types in Batu Gangan Forest Reserve

Landforms	Area (km^2)	Proportion (%)
High ridges	3.83	6.15
Midslope ridges	5.03	8.08
Local ridges	0.38	0.62
Upper slopes	4.71	7.57
Open slopes	34.46	55.38
Plains	2.03	3.26
Valleys	4.02	6.45
Upland drainages	0.32	0.51
Midslope drainages	5.08	8.17
Streams	2.36	3.80
Total	62.22	100

not ensured to be found. This comment underlines the significance of gathering data in the field. Hence the ultimate decision in determining the potential campsite depends on the field verification. It should be noted that the sites will be chosen based on field decisions and on-site evaluations.

The result shows that open slopes landform covered the highest area in Batu Gangan FR. Natural topography can be used to limit the size of a campsite. A campsite should be established in an open space to enable any potential safety and rescue work, as per Choi and Dawson (2002). A tiny campsite is built in a gently sloping region with a 10–15% slope, using standard cut and fill techniques to create little benches for the tent and cooking area (Leung & Marion, 2004). Resistance to resource damage and site expansion is another important aspect of a good campsite location selection strategy. Campsites on flat, dry ground near water and trails have long been popular, but these sites are particularly vulnerable to resource and social influences (Leung & Marion, 2004). A similar study also reminds us that large, flat stream benches, gaps, and ridge tops are common camping spots, but they do not do much to prevent site multiplication. Furthermore, William and Marion (1995) suggested that a mountainous region, an area with limited access to water points and vegetation complexity limits the number of potential campsites. Careful considerations should be given in campsite selection, design, and construction to reduce further impacts and disturbance (Cole & Monz, 2003; Marion et al., 2020).

Trail characterization The Mount Irau route runs along ridge tops, and the upper slopes have experienced the worst erosion. Trail impacts are influenced by various user-related and environmental factors, according to Leung and Marion (1996), where intense impacts are studied to be concentrated spatially in a particular recreation site (Vukomanovic et al., 2022). Environmental factors are shown in many studies to be more relevant than user-related factors in determining the levels and rates of trail incision and the accompanying soil erosion. Soil erosion is a serious concern on the trail of Mount Irau where a landslide had been reported to occur near to summit at an altitude of 1,995 m. The trail had been closed from 07 January 2018 until now. This is due to the unsafe conditions and to avoid any risk of accidents for hikers. A trail rotation system can be applied using both the original hiking trail and the alternative trail, which will be beneficial to the recovery and conservation of the said area. Ground verification revealed that most of the trail degradation occurred at the ridge top, which is concentrated in muddy soil. The muddy trail becomes worse in the rainy season, contributing to disturbance and degradation, thus directly impacting hikers' experiences.

Table 6 Summarization of landform classes and slope level

Class code	Class type	Description	Slope level
1	Streams	Canyons, deeply incised streams	Moderate to low slope
2	Midslope drainages	Shallow valleys	Moderate slope
3	Upland drainages	Headwater	Extreme slope
4	Valleys	U-shaped valleys	Moderate to low slope
5	Plains	Plains	Flat areas to gentle slope
6	Open slopes	Open slopes	Moderate to strong slope
7	Upper slopes	Mesas, flat top hill	Moderate to strong slope
8	Local ridges	Hills in valleys	Moderate to strong slope
9	Midslope ridges	Small hills in plains	Moderate to strong slope
10	High ridges	Mountain tops	Extreme slope

Table 7 Slope description

Slope level	Gradient
Flat areas to gentle slope	Approximately 0–3°
Low slope	Approximately 3–5°
Moderate slope	Approximately 5–8.5°
Strong slope	Approximately 8.5–16.5°
Extreme slope	Approximately > 16.5°

Conclusion

The outcome shows that TPI is important in identifying accurate landform classes. Thus, the terrain condition in terms of altitude, slope, soil loss potential (LS factor), and runoff propensity (TWI) around the trail and landform of Batu Gangan FR is revealed. The landform classes obtained proved to be a very effective technique for determining different landform compartments within the Batu Gangan FR. Landform classifications using DTM and GIS are fast, feasible, and user-friendly, critical in assessing land characteristics, especially for an outsized region. The presented results and discussion integrated the geospatial approach for forest planning. With a deep understanding of the terrain characteristics, potential and specific constraints of the forest may well be detected. Information and method discussed in this study can be used to assist in planning park management for sustainable recreational purposes parallel with conservation activities in the country.

Acknowledgements

We want to thank Jabatan Perhutanan Semenanjung Malaysia (JPSM) for their cooperation during field assessment and *Jabatan Ukur dan Pemetaan Malaysia* (JUPEM) for the contribution of spatial data. Our gratitude also is extended to UPM Grant Scheme GP-IPS/2018/9663400 and GP-IPM/2017/9555200 for the financial support.

References

Abdullah, N. S. & Abdulrahman, A. I. (2020, February 4). Landform clarification using automated techniques in geographical information systems. https://doi.org/10.17605/OSF.IO/637A9

Becco, J. A., Hallo, J., Manning, R. E., Akers, J., Duh, S., Smith, C., ..., & Leung, Y. F. (2016). GIS applications. In J. Bass, & R. C. Burns (Eds.), *Outdoor recreation planning* (pp. 93–112). Sagamore Publishing.

Cesetti, A., Frontoni, E., Mancini, A., Zingaretti, P., & Longhi, S. (2010). A vision-based guidance system for UAV navigation and safe landing using natural landmarks. *Journal of Intelligent and Robotic Systems*, *57*, 233. https://doi.org/10.1007/s10846-009-9373-3

Choi, K. -Y., & Dawson, C. P. (2002). Attributes affecting campsite selection at two types of campgrounds in the Adirondack Park. *Proceedings of the 2002 Northeastern Recreation Research Symposium* (pp. 94–101). http://www.nrs.fs.fed.us/pubs/gtr/gtr_ne302/gtr_ne302_094.pdf

Cole, D. N., & Monz, C. A. (2003). Impacts of camping on vegetation: Response and recovery following acute and chronic disturbance. *Environmental Management*, *32*(6), 693–705. https://doi.org/10.1007/s00267-003-0046-x

Cone, J. (1998). Principles of geographical information systems by Peter A. *New Zealand Geographer*, *54*(2), 56–57. https://doi.org/10.1111/j.1745-7939.1998.tb02089.x

Conrad, O. (2006). SAGA-program structure and current state of implementation. In J. Böhner, K. R. McCloy, & J. Strobl (Eds.), *SAGA-analysis and modelling applications*. *Göttinger Geographische Abhandlungen 115* (pp. 39–52).

Costa, D. M. da, & Souza, E. R. (2018). Conceptions of mountain formation, folding, fault and the continental drift in geography textbooks between the decades of 1930 to 1960. *Terrae Didatica*, *14*(4), 349–354. https://doi.org/10.20396/td.v14i4.8654094

Department of Environment and Science, Queensland. (2020). *Terrain slope*. Wetland*Info*. https://wetlandinfo.des.qld.gov.au/wetlands/ecology/aq uatic-ecosystems-natural/estuarine-marine/itst/terrain-slope/

Department of Sustainability and Environment, Victoria. (2011). *Users guide to the Australian walking track grading system*.

Forest Practice Code of Bristish Colombia. (1999). *Mapping and assessing terrain stability guidebook* (2nd ed.). Bristish Colombia.

Grohmann, C. H., Smith, M. J., & Riccomini, C. (2009). Surface roughness of topography: A multi-scale analysis of landform elements in Midland Valley, Scotland. *Proceedings of Geomorphometry*, *2009*, 140–148.

Guisan, A., Weiss, S. B., & Weiss, A. D. (1999). GLM versus CCA spatial modeling of plant species distribution. *Plant Ecology*, *143*, 107–122. https://doi.org/10.1023/A:1009841519580

Hung, I , K. (2002). Using GIS for forest recreation planning on the longleaf ridge special area of the Angelina National Forest, East Texas [dissertation]. Texas: Stephen F. Austin State University.

Hutchinson, M. F. & Gallant, J. C. (2000). Digital elevation models and representation of terrain shape. In J. P. Wilson, & J. C. Gallant (Eds.), *Terrain analysis*. (pp. 29–49). John Wiley.

Ilia, I. K., Rozos, D. E., & Koumantakis, I. (2013). Landform classification using GIS techniques. The case of Kimi Municipality area, Euboea Island, Greece. *Bulletin of the Geological Society of Greece*, *47*(1), 264–274.

Kumaran, S., Perumal, B., Davison, G., Ainuddin, A. N., Lee, M. S., & Bruijnzeel, L. A. (2011). Tropical montane cloud forests in Malaysia: Current state of knowledge. In L. A. Bruijnzeel, F. N. Scatena, & L. S. Hamilton (Eds.), *Tropical montane cloud forests science for conservation and management* (pp. 113–120). Cambridge University Press https://doi.org/10.1017/CBO9780511778384.011

Leung, Y. F., & Marion, J. L. (1996). Trail degradation as influenced by environmental factors: A state-of-the-knowledge review. *Journal of Soil and Water Conservation*, *51*(2), 130–136.

Leung, Y. F., & Marion, J. L. (2004). Managing impacts of camping. In R. Buckley (Ed.), *Environmental impacts of ecotourism* (pp. 245–258). CABI Publishing. https://doi.org/10.1079/9780851998107.0245

Leung Y. F., & Monz, C. (2006). Visitor impact monitoring. *The George Wright Forum*, *23*(2), 7–10.

Marion, J. L., Wimpey, J., Arredondo, J., & Meadema, F. (2020). *Sustainable camping "Best management practices"*. U.S. Geological Survey, Virginia Tech Field Unit.

McVicar, T. R., & Körner, C. (2013). On the use of elevation, altitude, and height in the ecological and climatological literature. *Oecologia*, *171*(2), 335–337. https://doi.org/10.1007/s00442-012-2416-7

Meadema, F. (2019, March 1921). *The influence on layout on degradation of the Appalachian Trail* [Conference presentation]. Sustainable Trails Conference, Grand Junction, Colorado, United States. Retrieved from https://drive.google.com/file/d/13BHtDb9L5QIy3RzE8x8-vLl9E3bJ6BuQ/view

Ming, P. L. H., & Zawawi, A. A. (2020). Mapping potential landslide using digital terrain model: Application in Ringlet Forest Reserve. *The Malaysian Forester*, *83*(1), 28–37.

Mokarram, M., Seif, A., & Sathyamoorthy, D. (2015). Landform classification of Zagros Mountains using multiscale analysis of digital elevation models. *Malaysian Journal of Remote Sensing & GIS*, *4*(1), 30–48.

Muntasib, E. K. S. H., Nadhira, F., & Meilani, R. (2019). Hazard management in tourism: A case study of the Senaru-Sembalun Hiking Trail, Mount Rinjani National Park, Indonesia. *Jurnal Manajement Hutan Tropika*, 25(3), 199–208. https://doi.org/10.7226/jtfm.25.3.199

North Country National Scenic Trail. (1996). *A handbook for trail design, construction, and maintenance*. United States Department of the Interior.

Olafsdottir, R., & Runnstrom, M. C. (2013). Assessing hiking trails condition in two popular tourist destinations in the Icelandic highlands. *Journal of Outdoor Recreation and Tourism*, *3–4*, 57–67. https://doi.org/10.1016/j.jort.2013. 09.004

Pradhan, B., & Buchroithner, M. (Eds.). (2012). *Terrigenous mass movements: Detection, modelling, early warning and mitigation using geoinformation technology*. Springer. https://doi.org/10.1007/978-3-642-25495-6

Reli, S. N., Yusoff, I. M., & Ujang, M. U. (2021). Slope stability estimation using danger level approach for monitoring landslide prone areas. *Geografia*, *17*(4), 221–239. https://doi.org/10.17576/geo-2021-1704-16

Rigol-sanchez, J. P., Stuart, N., & Pulido-bosch, A. (2015). Computers & geosciences ArcGeomorphometry: A toolbox for geomorphometric characterisation of DEMs in the ArcGIS environment. *Computers and Geosciences*, *85*, 155–163. https://doi.org/10.1016/j.cageo.2015. 09.020

Saadat, H., Bonnell, R., Sharifi, F., Mehuys, G., Namdar, M., & Ale-Ebrahim, S. (2008). Landform classification from a digital elevation model and satellite imagery. *Geomorphology*, *100*(3–4), 453–464. https://doi.org/10.1016/j.geomorph.2008.01.011

Skentos, A. (2017). Topographic position index based landform analysis of Messaria (Ikaria Island, Greece). *Acta Geobalcanica*, *4*(1), 7–15. https://doi.org/10.18509/agb.2018.01

Skentos, A., & Ourania, A. (2017). Landform analysis using terrain attributes. A GIS application on the Island of Ikaria (Aegean Sea, Greece). *Annals of Valahia University of Targoviste, Geographical Series*, *17*(1), 90–97. https://doi.org/10.1515/avutgs-2017-0009

Sonti, S. H. (2015). Application of geographic information system (GIS) in forest management. *Journal of Geography and Natural Disasters*, 5(3), 1000145. https://doi.org/10.4172/2167-0587.1000145

Stage, A. R. & Salas, C. (2007). Interactions of elevation, aspect, and slope in models of forest species composition and productivity. *Forest Science*, *53*(4), 486–492. https://doi.org/10.1093/forestscience/53.4.486

Tagil, S., & Jenness, J. (2008). GIS-based automated landform classification and topographic, landcover and geologic attributes of landforms around the Yazoren Polje, Turkey. *Journal of Applied Sciences*, *8*(6), 910–921. https://doi.org/10.3923/jas.2008.910.921

Verhagen, P., & Drâguţ, L. (2012). Object-based landform delineation and classification from DEMs for archaeological predictive mapping. *Journal of Archaeological Science*, *39*(3), 698–703. https://doi.org/10.1016/j.jas.2011.11.001

Vukomanovic, J., Walden-Schreiner, C., Hipp, J. A., & Leung, Y. -F. (2022). GIS & T and recreation planning and management. In J. P. Wilson (Ed.), *The geographic information science & technology body of knowledge* (1st Quarter 2022 Edition). https://doi.org/10.22224/gistbok/ 2022.1.8

Warner, G. S., Nieber, J. L., Moore, I. D., & Geise, R. A. (1989). Characterizing macropores in soil by computed tomography. *Soil Science Society of America Journal*, *53*(3), 653–660. https://doi.org/10.2136/sssaj1989.03615995005300030001x

Weiss, A. D. (2001). Topographic position and landforms analysis [*Poster presentation*]. ESRI User Conference, San Diego, CA, United States.

Williams, P. B., Marion, J.L. (1995). *Assessing campsite conditions for limits of acceptable change management in Shenandoah National Park*. USDI National Biological Service, Virginia Tech Cooperative Park Studies Unit.

Wilson, & Gallant. (2000). *Digital terrain analysis in terrain analysis*: *Principles and applications*. John Wiley & Sons.

Zalina, M. S. (2020, August 20). #JOM! GO: Dreamy trek through Mossy Forest. *New Straits Times*. https://www.nst.com.my/lifestyle/jom/2020/08/617972/jom-go-dreamy-trek-through-mossy-forest

Zawawi, A. A., Shiba, M., & Jemali, N. J. N. (2014). Landform classification for site evaluation and forest planning: Integration between scientific approach and traditional concept. *Sains Malaysiana*, *43*(3), 349–358.