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Landslide Analysis Approaches in Tropical Environment Region for Disaster Risk Reduction

Muhammad Afiq Abdul Kahar[1]*, Hamzah Hussin[1], Nadia Ramli[1] and Muhammad Fahmi Abdul Ghani[2]

[1] Department of Geoscience, Faculty of Earth Science, Universiti Malaysia Kelantan, 17600 Jeli, Malaysia

[2] Smartmap Insights Sdn Bhd, Unit B1-02-08, Block 1, Perniagaan Temasya, No. 13, Jalan U1, 67, Persiaran Kerjaya, 40150 Shah Alam, Selangor, Malaysia.

*E-mail: afiqkahar98@gmail.comy

Abstract. Landslides are natural disasters that befall practically in almost every country worldwide. Since the behaviour of the Earth is varied and the influencing factors that induce landslides are not constant, there seems to be no precise technique for assessing and forecasting the occurrence of landslides. This study selected the Cameron Highlands district, situated in Pahang, Malaysia, which accentuates reviewing numerous methods by the preceding local researcher to analyse and assess landslide incidence. A country like Malaysia is highly vulnerable to landslides due to its geographical features of high and lowlands, relatively intense precipitation, and locality in the distribution of tropical rain forests typified by dense vegetation, hot and humid temperatures throughout the year. In comprehending the landslide, most prior researchers employed numerous approaches and methods, where three qualitative methods (acceptable accuracy), two semi-quantitative methods (78% to 86% accuracy) and five quantitative methods (86% to 98% accuracy) were identified. These methods appraise multiple parameters and employ various techniques for factor research and understanding, where each method has its own set of benefits and shortcomings. The diversity of the landslide scale requires specific research in determining landslide mapping, whether by inventory, susceptibility, hazard, or risk. An application of the programme and software platform can forecast the accuracy of landslide occurrence modelling for future landslide mitigation planning. Based on the review findings, GIS and remote sensing play a crucial part in translating spatial data for more accessible analysis in furthering the research, as supported by field survey results. Each method comprising various techniques indicates that overall accuracy is applicable for the landslide analysis approaches.

1. Introduction

The highlands are fragile and environmentally sensitive, where landslides are the most frequent dominant geohazards. In Malaysia, landslides are the second greatest threat of natural disasters after floods [1]. Natural geohazards are generally related to mass wasting in Malaysia's tropical highlands terrain, which heavy and prolonged rainfall usually triggers. The Malaysian Meteorological Department revealed that the monsoon season from November until March increases the frequency of landslides yearly. Thus, it also occurs in months other than the monsoon season. Due to rapid infiltration, intense rainfall indirectly raises groundwater content and pore water pressure [2], where most landslides often arise in slope cuts or embankments made along roads and in homes located in upland areas [3]. The development of population, natural factors, geotechnical and anthropogenic factors contribute to

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landslides event [4]. On an annual basis, shallow landslides ensue in Malaysia, typically less than a deep (4m) against the slide surface or less than a thick (5m) [5], and transpire throughout or after intense rainfall. In Malaysia, deep-seated landslides, debris flows, and geologically controlled failures, including wedge failure and rockfall, are other high-risk landslides or slope failures [4]. The updated list from a study by the Malaysian Public Works Department (JKR) indicates 721 deaths from 1961 to 2019, with 91 significant landslides overall [6]. Uncontrolled rapid development in Malaysia has resulted in environmental degradation, contributing to environmental disasters like landslides [7]. Among the highlands in Malaysia, perhaps the Cameron Highlands area has suffered the most detrimental landslide consequences due to uncontrolled development [8]. The land use in this area has turned forests into areas for agriculture (tea and vegetable), housing area, roads, logging, resettlement of natives, and other infrastructure development that persist co-occurrence ensues every year. An assessment is critical based on a scientific method in defining places prone to landslides by analysing previous data such as terrain, geological features, and human activities that contribute to geohazard and identifying the reason for the occurrence [9]. Scrutiny of the literature record exposes that qualitative, semi-quantitative and quantitative methods are designated to identify various landslide scales [10]. The focal goal of this article's writing is to review the existing methodologies and approaches for studying landslides, chiefly in the Cameron Highlands, Pahang, Malaysia, which has a high yearly landslide frequency.

2. Collection of landslide data via technology and proforma

The progression of remote sensing and GIS technology nowadays makes it feasible to modify, gather and incorporate a wide range of spatial data from distinct areas, such as structure, geology, slope characteristics, surface cover and other factors which are utilised later to determine the landslide zone through the detailed analysis performed. Landslide inventory interprets landslide mapping commonly used by local scientists [11], acquiring two sources: aerial photographic interpretation and field inventory. The production of landslide maps comes in diverse forms, including mapping towards the landslide inventory, susceptibility, hazard, and risk [5], which are predominately covered by scientists and entail comprehensive data for modelling framework. Remote sensing is a cutting-edge technology for detecting objects remotely. It is used chiefly as a reconnaissance tool to identify previous or current landslides in exposed areas. Until now, remote sensing has thrived due to advanced sensor systems resulting in satellite technology. Landslide identification is also executed based on indicators involving geomorphology, topography, water body and vegetation guide landslides on natural slopes [12], especially in the terrain of humid tropical regions [11]. Landslide inventory mapping includes the data collection of aerial surveys, which typically use change detection and image combination techniques through remote sensing technology with software support. Indeed, it involves historical data and a ground survey that is vital in assisting researchers in predicting impending landslides in the future and analysing various landslide scales [13]. A proforma sheet is used in most countries to inspect landslide sites, focusing on critical data capture for landslide information and geomorphological condition. The preparation of proforma sheets varies for each country and records entirely probable slope structures and circumstances that may lead to instability [6, 14]. Other researchers applied the proforma sheet to notify landslide database providers, like in China [15] and act as form sheets that include a reference guide for landslide hazard mapping in Andean countries [16]. Landslide susceptibility and hazard zonation data gathering differ significantly from landslide inventory data collection. Landslide hazard assessment usually necessitates specific uses such as spatial and temporal detail in landslide information archives and site surveys for identification [17]. In contrast, landslide susceptibility requires only spatial information [18]. The projected damage, losses of lives, and fatalities caused by landslides are called landslide risks. Landslide risk mapping is much less prevalent than landslide susceptibility or hazard mapping, which is more intricate since it comprises the exposure of hazard, risk element and vulnerability products [10]. Quantitatively assessing landslide risk remains problematic, especially since the required information to quantify hazard and susceptibility correctly is not always obtainable

Table 1. The contrast of landslide evaluation methods in the Cameron Highlands.

Method	Analysis techniques	No. of landslides	No. of Parameters	Accuracy	Ref.
Qualitative	Inventory, geomorphological	N/A	3	Satisfactory and reliable results	[11]
Qualitative	Inventory, geomorphological	207	3	Satisfactory and reliable results	[19]
Qualitative	Inventory, geomorphological	152	4	Satisfactory and reliable results	[21]
Semi-quantitative	Weighted overlay	320	9	93%	[1]
Semi-quantitative	AHP	50	10	78%	[25]
Quantitative	ANN	324	10	83%	[3]
Quantitative	USLE, Bivariate statistical	625	6	70%	[26]
Quantitative	RF, LR, LMT	152	7	LR (90%), LMT (92%), RF (88%)	[27]
Quantitative	RF, ACO, CFS	43	5	CFS (89.28%), RF (85.59%), ACO (86.74%)	[28]
Quantitative	KNN, SVM, DT	104	7	KNN 0.944 (± 0.03), SVM 0.943 (± 0.04), DT 0.978 (± 0.03)	[29]

3. Qualitative approach method

Findings of information by inventory and geomorphic analysis are an adaptation of qualitative methods in assessing the presence of landslides. The qualitative approaches express the landslide's prone levels in descriptive phrases based on expert decisions. The direct approach comprises geomorphological analysis that indicates mapping implementation in the context of susceptibility and landslide hazards through remote sensing and data acquisition from field input discoveries. Procurement of historical sources, archives documents, and newspapers by retrieving from an inventory analysis also includes the study of aerial photos and a field inspection of selected places. As a result, the qualitative method arguably includes procedures reliant on experts' human judgments (heuristically) [11].

3.1. Inventory and geomorphological analysis techniques

A well-known individual [11] is one of the local scientists in Malaysia who entails a geomorphological assessment of historical landslides in the Cameron Highlands, as illustrated in Table 1, where the descriptions of the identification features of an old landslide consist of direct field observations and remote sensing images. Landslides typically alter the topographic surface's shape, position, or appearance. Thus, the physical appearance of a landslide, particularly in humid tropical settings, usually does not persist long and is swiftly eroded and weathered away, followed by secondary vegetation cover, which makes its detection in the field or by remote sensing challenging. Therefore, understanding the patterns of regional or local structures is beneficial in identifying and mapping old landslides. Geomorphological processes on the Earth's surface produce geomorphic cycles that explain the stage of landslide evolution according to its relative age, whether young, adult or old. Old landslide scars, covered by vegetation or plantation crops, are the source of these landslide geohazards on these natural slopes, as is frequent in the Cameron Highlands hills. Evolutionary stage and geomorphic cycle classification of natural slope landslides in Malaysian tropical highland areas rewritten by the preceding local researcher [11] became the primary guide in analysing past landslides in Cameron Highlands. This research demonstrates that each landslide represents a high-risk geohazard. Its existence requires immediate attention since human actions and severe weather can reactivate past landslides, forming new geohazards.

In the Cameron Highlands, the intensification of agriculture in highlands terrain plays a part in the rising frequency of landslides [19]. Remote sensing data, such as Interferometric Synthetic Aperture Radar (IFSAR, also known as InSAR) with a resolution of 350 × 350m^2, evaluates the study area's geomorphology, and the usage of aerial imagery could ascertain anthropogenic landslide features for better systematic landslide mapping. Due to remote sensing research and field mapping, 207 landslide incidents have been recorded, with 164 (79.22%) of the widespread landslides documented induced by human activities and further potential to befall greater than 15° slope angles. The detected landslides are categorised based on landslide materials, movement pattern and landslide size [20]. Besides, the emphasis of this study refers to a causal approach consisting of slope gradients, geology or lithology, and land use aspects. According to the findings, anthropogenic activities and landslide events interact significantly in the study area, where a distinction between poor agricultural and forested management revealed contradictory results on landslide frequency. Scientists [21] utilise the IFSAR, Google Earth imageries, and substantial field mapping to produce a landslide inventory (Table 1). The procurement of two photographs of Sentinel-1 satellite datasets from several dates and topographic locations for this research allows for comparing phase values in two InSAR satellite images [22]. The application of Google Earth in assisting IFSAR is beneficial, mainly in georeferencing and digitising the landslide. By overlapping the result of an interferogram from Sentinel-1 onto Google Earth, it can identify the sign of a landslide, and from the validation through GPS, the researcher considered about 30 landslide locations from 152 landslide events by field mapping-based, which is reliable and applicable in detecting landslide, notably in Malaysia's tropical rainforest highlands.

4. Semi-quantitative approach method

The involvement of Multicriteria Decision Making (MCDM) has become prevalent and trendy in its use [23] when examining the diverse aspects of landslide occurrence as the year progresses. MCDM constitutes a procedure by converting and merging geographic information (map parameters) with subjective opinions (ambiguity and judgement) to generate relevant information for decision-making. Semi-quantitative methods result from qualitative methods that adhere to expert knowledge, then modified to weigh and define spatial variables. In regional-scale worldwide studies, semi-quantitative methods have proven dependable and practical for landslide inquiry by mathematically processing and overlaying the existing maps. The following is the approach used for the semi-quantitative method, as shown in Table 1.

4.1. Weighted overlay analysis techniques

The Weighted Overlay approach [1] encloses the application of the GIS platform to generate LSM in Cameron Highlands. Nine spatial information includes a slope, aspect, curvature, elevation, land use, proximity to locality (road, river or lake, lineament) and lithology to produce static model layers for future processing priorities. The raster data from the SPOT 2 (10-20m) and Landsat 7 (15-30m) are applied to create the static model's land cover feature and a series of land surface temperatures (LST) of the dynamic model feature that henceforth is essential for constructing the landslide susceptibility map (LSM) model. The RMS (0.546) of the 10 GCPs become benchmarks and references for georeferencing, which is appropriate for this study. Besides, a landslide inventory map (LIM) is created from field study and validation of the satellite (SPOT 2) photos. This map is necessary for giving consideration when allocating weight values. An approach to assigning the weight value is the same as the previous researcher by placing 1(very low) to 5(very high). The result showed that the LHM is classified into five divisions from very high to very low hazards, with greater precision (70-93%) based on a resolution comparison of very high resolution (VHR) and High resolution (HR) covering the combination of high to very high landslide hazards overall.

4.2. AHP analysis techniques

Analytical Hierarchy Process (AHP) is also a method of the MCDM model which accentuates expert knowledge from the perspective of a comparison scale [24] to produce the LSM in Cameron Highlands

[25]. Ten parameters are critical in this study; nine of them are the same as those used by the previous researcher [1], while the other is rainfall. The remote sensing data of Landsat 8, ALOS Palsar and Sentinel-2 are drawn via ArcGIS and Erdas Imagine software to construct parameters covering the identification of 50 active landslides that portrays 18% of it from high susceptibility and 82% from moderate susceptibility areas. Research findings for the landslide inventory map (LIM) are obtained from the historical and field data collection to contrast the LSM analysis with an area under the curve (AUC), which demonstrates 78% correctness of the landslide forecast.

5. Quantitative approach method

The quantitative technique refers to an approach involving statistical, deterministic, probability, and artificial intelligence. Typically, it denotes the mathematical estimation for the landslide zonation scale scrutiny. As indicated in Table 1, the analysis techniques are described according to their usage based on diverse preceding researchers, which is divided into five subsections as follows.

5.1. ANN analysis techniques

Landslide study [3] implements the Artificial Neural Network (ANN) to produce LSM in the Cameron Highlands by the back-propagation training algorithm until the minimal error is achievable and capable of producing weight towards predicting an output from the inputs. Thus, the programming platform of MATLAB is utilised for the ANN modelling. This study has ten parameters, eight generated from spatial information similar to prior research [1] and the other two from remote sensing data. The remote sensing applied in this work is SPOT 5, used for preparing the land cover and normalised difference vegetation index (NDVI) parameters. In the research area, landslide detection by eye inspection asserts the usage of aerial photographs, SPOT 5, and previous reports to indicate a recent landslide towards creating a LIM with 324 landslides covering 29.3km^2. Based on the research outcome, the slope feature is assumed to be very crucial in causing a landslide, with the highest weight (0.205) at an angle (15°-35°), which is more susceptible. The LSM has five categories, identical to the researcher [25], and the ANN effectively identifies landslide pixels (83%), indicating a high level of performance.

5.2. USLE and Bivariate Statistical analysis techniques

The Universal Soil Loss Equation (USLE) and Bivariate Statistical Analysis suggested by scientists [26] are applied to construct modelling soil erosion and landslide in the Cameron Highlands. Six USLE input parameters involving rainfall erosivity (R), soil erodibility (K), Topographic (LS), Land Cover Management (C) and Conservation Factors (P) are applied to generate four stages (very low to high) of the soil erosion map. When modelling landslides, geology, slope, and average annual rainfall are essential variables and play a key role in determining landslide size. In ArcGIS, bivariate statistical analysis is being used to provide statistics regarding areas at risk of landslides. Much of the data is modelled using a software package in the form of maps. Due to this approach, 625 landslide incidents are created for the analyses, with 48.16% occurring in crop production farming areas and 52% occurring in agriculture-associated zones. Furthermore, over 75% of landslides in agriculture activity regions are thought to have happened under sheltered farms, whereas 17.94% originated in terracing farmlands.

5.3. RF, LR and LMT analysis techniques

LSM by the researcher [27] focuses on the random forest (RF), logistic regression (LR), and logistic model tree (LMT) and covers the aspect of AI and multivariate analysis [18]. From the study preference, the analysis of a landslide in Cameron Highlands undergoes a two-stage analysis; detecting a landslide from remote sensing and LSM modelling based on machine learning of RF, LR and LMT. Incorporating InSAR, Google Earth, and field verification created landslide inventory maps through the software platform, namely SNAP, ENVI, and SAGA GIS. 20% of 30 landslide locations are used as a validation input, while 80% of 122 landslide locations are for the training input attributed to the LIM. Landslides inventory is recorded via surface deformation maps (phase, unwrapped, and coherence bands), including the field's InSAR participation and GPS evaluation. Seventeen factors are derived from the DEM, geology, soil, rainfall and road networks undergoing the RF, LR and LMT modelling. The LR classified LSM into four categories, indicating a very high susceptibility area of 22% (18.2 km^2) to a low susceptibility area of 32% (25.7 km^2). Meanwhile, The LMT model shows the same classification as the LR model, but the area has a very high susceptibility of 24% (19.1km^2) to a low susceptibility of 30% (24.7km^2). A similar susceptibility distribution is demonstrated by the RF model, with a very high susceptibility of 26% (21.2 km^2) to low susceptibility of 25% (20.0 km^2). The Friedman and Wilcoxon tests illustrate RF (2.20), LMT (2.07) and LR (1.73), as well as the ROC curve from the highest AUC of 0.90 (both LR and LMT model) to 0.88 for the RF model. The statistical metrics (specificity, sensitivity, accuracy, PPV, NPV, and RMSE) evaluate the model's capability, where commencing with the RF's highest specificity (71.43%) and accuracy (70%), whilst LMT displays the highest sensitivity (68.75%). Besides, the RMSE shows the value of 0.4(both LR and RF models) and 0.3(LMT model). According to the researcher's findings, all models are effectively trained. However, in some research, LR and RF are robust algorithms that are much more effective for landslide prediction. Therefore, the LMT is more appropriate in this study, making it an appealing technique for shallow landslide identification, especially in the Cameron Highlands tropical surrounding.

5.4. RF, ACO and CFS analysis techniques

The previous researchers [28] recommend using the method of RF, ant colony optimisation (ACO) and correlation-based feature selection (CFS) to detect the shallow and deep-seated landslides in the Cameron Highlands region. The data encompassing in this study includes LiDAR usage, where DEM is retrieved to produce aspect, slope, height, intensity and hillshade. In addition, the orthophoto obtained from airborne laser scanning is georeferencing, and correcting process is initiated for other GIS processing purposes. The Fuzzy-based Segmentation Parameter Optimiser (FbSP optimiser) is used to acquire parameters such as shape, scale, and compactness at various segmentation stages, with the excellent value obtained being 0.4,75.52 and 0.5. The application platform utilised in this study includes the Statistica Trail software, Weka 3.8 software and R statistical programming.

The findings of the feature identification algorithms revealed that CFS (89.28%) had the optimal configuration, which increased the discrimination for both two types of landslides in the research area: shallow and deep-seated. Otherwise, ACO (86.74%) and RF (85.59%) exhibited good accuracy but substantially less than the CFS. The effectiveness of the methods mentioned above in distinguishing between two types of landslides, deep-seated and shallow-seated, is examined using a random forest (RF) classifier. The cumulative precision in shallow (70.44%) and deep-seated (73.54%), respectively, throughout the qualitative performance assessment of random forest (RF). These findings are achieved whenever 70% of the training data set and all attributes are used to train the RF classifier. The CFS approach used the quantitative appraisal of shallow landslides with accuracy (87.54%). Likewise, the deep-seated datasets had an accuracy (89.9%) for the deep-seated of 70% training data. From the research discoveries, the usage of the LiDAR and orthophoto of best quality resolution with FbSP Optimizer augment the overall accurateness of the system to delineate borders towards landslide kinds. Adding a feature identification and selection approach boosts the accuracy rate, reduces computing time, and improves the generalizability of the research results. Furthermore, the findings' generalizability demonstrates that selecting features with CFS (ideal setup) and RF classifier in the constructed landslide inventory map produces reliable results with improved process and efficiency.

5.5. KNN, SVM and DT analysis techniques

A researcher [29] applied k-nearest neighbour (KNN), support vector machine (SVM) and decision tree (DT) for the LSM model training subdividing approach. The inventory data for landslides is assembled from SPOT 5 panchromatic, aerial photographs and airborne laser scanning images, where the old and recent landslides are recognised. This study identified 104 landslides and simultaneously identified the landslide inventory. Thus, this research generates a non-landslide specimen of 208 non-landslide samplings. The platform for analysis in this study relies on ArcGIS and Python programming libraries (Numpy, Scikit-learn, Pandas). Determination of parameters is based on seven selective sources, which incorporate DEM (altitude, slope and aspect) from LiDAR, SPOT 5 (land cover) from maximum likelihood classification, and three-source distance computation (road, river, lineament) from Euclidean distance approaches. Map creation of each parameter mentioned above, indicating landslide triggering feature that displays 87.20% accuracy results from field assessments. The inventory information curve (IIC) is a graphical depiction of the data stored in a database of inventories. AUIIC (area under IIC) is calculated for the landslide, non-landslide, and combined curves. As for this research, the landslide specimens have a lower AUIIC (0.216) than the non-landslide samples (0.275) due to landslide specimens being all acquired within the landslide's boundaries.

In contrast, non-landslide measures are taken from the external environment (including structures, vegetation and water source). KNN is an approach for categorising objects according to the closest training in the feature space with an overwhelming vote of its neighbours to classify an object. SVMs are data-dependent models, meaning their capacity is tuned to reduce both error test and computational intricacy. Besides, The DT is an information mining algorithm for classification that most researchers frequently use to forecast landslide susceptibility classes. The impact of inserting noise into landslide inventory records confirms that noise significantly impacts DT (0.06 to 0.13, there is a significant rise), although SVM (0.08) and KNN (0.05) are less sensitive to it. To mitigate the effects of the noise, SVM or KNN are recommended. These findings imply that IICs are excellent ways of evaluating the reliability of inventory records before constructing models and act as a promising technique for estimating the accuracy of susceptibility models.

6. Conclusion

In conclusion, this research provides a broad overview of the methods and approaches proposed by the previous researcher for examining the various landslide mapping techniques analysis. In Cameron Highlands, Pahang, Malaysia, this research covers qualitative, semi-quantitative, and quantitative approaches for identifying the distinct landslide scales. Landslide mapping techniques typically have four significant stages: information collection, pre-processing, processing, and outputting. These stages are stated in this paper and the methodology used to conduct it. As the study revealed above, there is no precise approach for creating a landslide map in the Cameron Highlands area. Hence, each researcher employs diverse methods and solutions to locate the landslide.

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