ASSESSING THE INFLUENCE OF ANTHROPOGENIC CAUSAL FACTORS ON LANDSLIDE SUSCEPTIBILITY IN BUKIT ANTARABANGSA

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DEDICATION

I dedicate this to my mother Evas Stella Kantamu Mafigiri, and my brother Samuel, with whom I would have loved to share this special milestone had it not been for their untimely passing.

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ABSTRACT

The purpose of this study is to assess the influence of landslide causal factors related to anthropogenic activities on landslide occurrence in Bukit Antarabangsa, a township northeast of Kuala Lumpur in Ampang Jaya Municipal Council. Landslide disasters are a widespread phenomenon in Malaysia's Selangor region; with the study area being the site of numerous incidents that are frequently attributed to human-induced causes. The study implements a data-driven weight of evidence model to identify landslide causal factors that are most predictive of landslide occurrence based on an inventory of 20 landslides, and attempts to evaluate the extent to which these factors are driven by urban development. A total of 18 landslide causal factors are selected for analysis, 17 of which are used in the final analysis. The causal factors are categorized on four main groups, namely geological, geomorphological, hydro-tographical, and anthropogenic factors. Dichotomies between anthropogenic and non-anthropogenic factors are also made to understand the contribution of human-related factors on slope failures. The landslide causal factors, represented spatially as a set of factor maps were processed to determine factor classes for each landslide causal parameter, after which data was entered into a Bayesian weight of evidence statistical model to determine the contrast values for each factor class. The contrast values reflected the extent to which each causal factor class was predictive of landslide occurrences. These values were used to create weight maps for each factor class, which were combined to derive the landslide susceptibility index (LSI). The LSI values enabled visualization of the spatial distribution of landslide susceptibility across the study area based on a given combination of causal factors. Susceptibility maps were prepared for factor combinations including 1) only non-anthropogenic parameters and 2) all landslide causal parameters. Comparisons were made between these two combinations to determine the influence of human-induced factors on overall susceptibility, as well as analyses to determine the incremental effect that individual anthropogenic causal factors had on cumulative landslide susceptibility. The results indicated that collectively, the selected anthropogenic factors had a marginal influence on landslide susceptibility. However, within the anthropogenic factor group, land use land cover appeared to weigh significantly on landslide susceptibility, especially within the zone of the highest LSI values. This was followed closely by the influence of one distance to road factor class (147-218). Among the non-anthropogenic factors, lineament density, distance to lineament, slope, terrain ruggedness index (TRI), flow direction, aspect and terrain surface texture (TST) displayed the highest spatial correlation with landslide occurrence.

ABSTRAK

Tujuan kajian ini adalah untuk menilai pengaruh faktor penyebab tanah runtuh yang berkaitan dengan aktiviti antropogenik terhadap kejadian tanah runtuh di Bukit Antarabangsa, sebuah perbandaran timur laut Kuala Lumpur dalam Majlis Perbandaran Ampang Jaya. Bencana tanah runtuh adalah fenomena yang meluas di negeri Selangor Malaysia; dengan kawasan kajian menjadi tapak kebanyakan kejadian tanah runtuh yang sering dikaitkan dengan punca yang disebabkan oleh kegiatan manusia. Kajian ini mengguna pakai model pemberat berdasarkan bukti iaitu salah satu model berasaskan data untuk mengenal pasti faktor penyebab tanah runtuh yang paling berpotensi meramalkan kejadian tanah runtuh berdasarkan inventori 20 tanah runtuh, dan cuba menilai sejauh mana faktor ini didorong oleh pembangunan bandar, berkait dengan kegiatan manusia. Sebanyak 18 faktor penyebab tanah runtuh dipilih untuk dianalisis yang mana 17 daripadanya digunakan dalam analisis akhir. Faktor penyebab dikategorikan kepada empat kumpulan utama iaitu faktor geologi, geomorfologi, hidro-topografik dan antropogenik. Dikotomi antara faktor antropogenik dan bukan antropogenik juga dibuat untuk memahami sumbangan faktor berkaitan manusia terhadap kegagalan cerun. Faktor penyebab tanah runtuh, diwakili secara reruangsebagai satu set peta faktor yang telah diproses untuk menentukan kelas faktor bagi setiap parameter penyebab tanah runtuh, selepas itu data dimasukkan ke dalam model pemberat berdasarkan bukti jenis Bayesian untuk menentukan nilai kontras bagi setiap kelas faktor. Nilai kontras mencerminkan sejauh mana setiap kelas faktor penyebab meramalkan kejadian tanah runtuh. Nilai ini digunakan untuk mencipta peta pemberat bagi setiap kelas faktor, yang digabungkan untuk memperoleh indeks kerentanan tanah runtuh (LSI). Nilai LSI membolehkan visualisasi taburan reruang kerentanan tanah runtuh di seluruh kawasan kajian berdasarkan gabungan faktor penyebab. Peta kerentanan telah disediakan untuk kombinasi faktor termasuk: 1) hanya parameter bukan antropogenik dan 2) semua parameter penyebab tanah runtuh. Perbandingan telah dibuat antara kedua-dua kombinasi ini untuk menentukan pengaruh faktor yang disebabkan oleh manusia terhadap kerentanan keseluruhan, serta analisis untuk menentukan kesan tambahan yang disebabkan oleh faktor penyebab antropogenik individu terhadap kerentanan tanah runtuh kumulatif. Keputusan menunjukkan bahawa secara kolektif, faktor antropogenik yang dipilih mempunyai pengaruh kecil terhadap kerentanan tanah runtuh. Walau bagaimanapun, dalam kumpulan faktor antropogenik, faktor litupan guna tanah kelihatan memberi kesan yang ketara terhadap kerentanan tanah runtuh, terutamanya dalam zon dengan nilai LSI tertinggi. Ini diikuti rapat dengan pengaruh jarak terhadap kelas faktor jalan raya (147-218). Antara faktor bukan antropogenik, ketumpatan garisan, jarak ke garisan, cerun, indeks kekasaran rupa bumi (TRI), arah aliran, aspek dan tekstur permukaan rupa bumi (TST) menunjukkan korelasi reruang tertinggi dengan kejadian tanah runtuh.

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LIST OF ABBREVIATIONS

AUC	-	Area under curve
GIS	-	Geographical Information System
LSI	-	Landslide Susceptibility Index
LULC	-	Land use land cover
ROC	-	Receiver Operating Characteristics
SPI	-	Stream Power Index
TRI	-	Terrain Ruggedness Index
TWI	-	Topographic Wetness Index
VRM	-	Vector Ruggedness Measure
WoE	-	Weight of Evidence

LIST OF SYMBOLS

C	-	Contrast value
W-	-	Negative weight
W+	-	Positive weight

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CHAPTER 1

INTRODUCTION

1.1 Background to the Study

A landslide is defined as a "movement of a mass of rock, earth or debris down a slope" (Cruden, 1991). Landslides displace thousands of people and cause numerous fatalities and loss of productive assets all across the world. Landslides are common in hilly and mountainous parts of Malaysia, and result in major losses of economic and environmental resources, including human fatalities (Akter et al., 2019). In spite of this, it remains difficult to predict landslide occurrence spatially and temporally with a level of accuracy needed to prevent such losses. This is because unlike earthquakes and volcanic eruptions that can be pegged to a specific location, landslides are the result of localized processes and rarely occur in the exact same location (Van Westen et al., 2006). Added to this problem is the widely varying range of natural and human-induced factors that influence each slope failure, even within the same region (Fell et al., 2008). Therefore, it is often necessary to examine these occurrences within their unique geographical and environmental context to build a comprehensive understanding of landslide susceptibility, hazard and risk.

Landslide occurrence in Malaysia has been attributed to a number of factors, the most notable among these being design errors due to insufficient site-specific ground investigation (Haliza and Jabil, 2017). The prevalence of man-made causal factors ties in with Malaysia's rapid urbanization and development of highland and hilly terrain (Nor Diana et al., 2021), and points to a possible trend towards development beyond control of land use. Conventional methods of landslide risk reduction typically involve implementation of engineering controls that carry a substantial financial cost and environmental impact. This despite studies indicating significant improvements to factor of safety due to reinforcement by planting of woody vegetation (Haliza and Jabil, 2017). Numerous studies on landslide risk focused on

geological, geomorphological, hydro-topographical factors, although the hydrological effect of vegetation on rainfall-induced landslides has been rarely assessed (Gonzalez-Ollauri and Mickovski, 2017). Risk reduction strategies have utilized a number of spatial information approaches to identify landslide-prone areas and assess potential damage during planning of urban and infrastructural development.

Geographical Information Systems (GIS) are applied to landslide disaster preparedness primarily through geospatial mapping to determine an area's landslide susceptibility, hazard and risk, which enables planning authorities to carry out appropriate zonation for urban development based on landslide risk. GIS also allows disaster management agencies to carryout strategic level analyses of landslide occurrence thanks to the ability of geospatial techniques to integrate varying datasets at across a wide geographical scale. Geospatial methods provide a set of diverse and scalable tools for basic and advanced assessment of landslide susceptibility, hazard and risk, and a mechanism for development and sharing of landslide inventories. Landslide inventory mapping provides historic information on landslide occurrences and enables experts to gain further insight into their unique characteristics. The inventories are typically compiled in a GIS-based risk assessment system with environmental factors, triggering factors and landslide occurrences comprising some of the input data (Van Westen et al., 2006). The inventory is a first and often critical phase of the risk assessment process. It is followed by the landslide susceptibility phase, which seeks to assess the proneness of a given area to landslide occurrence.

This study focuses on landslide susceptibility, which is typically the first stage of landslide risk management (Fell et al., 2008). Landslide susceptibility addresses the question of "where could landslides occur?", and can be seen as an estimation of the spatial probability of landslide occurrence at a given location (Fell et al., 2008; Günther, 2007). Landslide susceptibility informs subsequent studies of landslide hazard (when do what landslides occur?) and landslide risk (what consequences do landslides have?) (Günther, 2007). GIS has become a popular method for assessing statistical landslide susceptibility (Van Westen et al., 2006). To date, there have been a number of studies on landslide susceptibility in Peninsular Malaysia, the majority of which have focused on natural (i.e. geological, geomorphological, hydro-

topographical) and, to some extent, anthropogenic factors. What remains less clear is the link between slope instability possibly attributed to anthropogenic causal factors related to urban development and landslide occurrence.

1.2 Problem Statement

In Malaysia, numerous studies have been carried out on landslide mapping and risk zonation; however, few have focused on aspects such as causal factor analysis, sensitivity analysis and socio-economic characterization (Akter et al., 2019). This challenge has been observed despite a growing acknowledgment that landslide occurrence is being driven by natural as well as anthropogenic factors.

Land urbanization has been linked to an increased likelihood of landslides, largely due to physical disturbances that result in reduced vegetation cover and cutting of natural slopes (Li et al., 2017). While urbanization on its own does not necessarily increase the likelihood of landslide occurrences, the pressure for more land can lead to building in areas that are susceptible to landslides (Klimeš and Novotný, 2011).

The area of study, Bukit Antarabangsa in Ampang Jaya Municipal Council (MPAJ), is one of the most landslide-prone regions in Malaysia, and recorded six landslide events in the period from 1993 to 2014 (Akter et al., 2019). The consequences of landslide occurrences in this area range from damage of roads and residential property to loss of life (Nor Diana et al., 2021). Bukit Antarabangsa is also a rapidly growing peri-urban area with considerable hillside development. Recent studies of this area have highlighted construction design errors and precipitation as main causal factors of landslide occurrence (Jebur et al., 2014; Kazmi et al., 2017). However, the rapid urban development of the area, and subsequent increase in surface runoff could play a role in the area's proneness to slope failure (Haliza and Jabil, 2017). The study area, much like the rest of Malaysia, enjoys a tropical climate with high annual rainfall playing a significant role in landslide events (Akter et al., 2019). Landslide occurrences have also been attributed to human practices such as

construction of roads without adequate grading of slopes, poorly planned alteration of drainage patters and disturbing of old landslides (USGS, 2021).

In Bukit Antarabangsa, improper planning and the continued development of hilly areas have been cited as contributing factors arising from human activity (Shafie et al., 2013). While the geology of the area remains fairly stable, the ongoing urban expansion has led to deforestation, which has in turn exacerbated weathering and erosion (Hassaballa et al., 2014). It is worth noting, however, that MPAJ has taken significant steps to mitigate landslide risk through planning development controls that establish criteria for developing within certain slope and altitude classes.

1.3 Research Goal

This research seeks to assess the influence of anthropogenic causal factors on landslide susceptibility in a landslide prone area using a data-driven geospatial method. It seeks to determine whether or not approaches that address housing and infrastructure development can provide a basis for sustainable, low-cost landslide risk reduction in urbanized areas.

1.4 Research Objectives

The research objectives of the study are outlined as follows:

(a) To identify causal factors that have a significant influence on landslide occurrence in Bukit Antarabangsa including factors related to anthropogenic activities.

(b) To implement an analytical model for assessing the influence of anthropogenic causal factors on landslide susceptibility in Bukit Antarabangsa.

(c) To evaluate the data-driven model for assessing landslide susceptibility and the influence of anthropogenic causal factors.

1.5 Research Questions

The research questions for the study are outlined as follows:

(a) Which causal factors have been attributed to historical landslide occurrence in Bukit Antarabangsa?

(b) How have landslide occurrences in the Bukit Antarabangsa been affected by anthropogenic factors?

(c) Which analytical technique reliably enables assessment of the influence of landslide causal factors on landslide events?

(d) How shall the analytical model be constructed and implemented?

(e) How reliable is the model in predicting the likelihood of landslide occurrence for each causal factor?

(f) What is the incremental effect of anthropogenic causal factors on the cumulative susceptibility to landslide occurrence?

1.6 Study Area Scope

The choice of Bukit Antarabangsa as the area of study is owed largely to its prominence as one of the major hot spots of landslide occurrence in Malaysia. The township is situated in Klang Valley, which is an economic powerhouse in the region and as a result continues to experience rapid urban expansion in spite of landslide prevalence. This therefore made it an interesting case to investigate issues arising from the overlap of urban development and landslide susceptibility.

The study covers a 1.15 square kilometre area in the township of Bukit Antarabangsa on the northeastern extent of Ampang Jaya Town Council. This specific area was selected for its high density of landslides. Bukit Antarabangsa is a hillside township located in Ulu Klang District, Selangor State, and is under the jurisdiction of Ampang Jaya Municipal Council. It is cantered at geographic coordinates 3°12′00″ north latitude and 101°46′01″ north of Kuala Lumpur (Figure 1.1). The township has witnessed a rapid increase in infrastructure development owing largely to its proximity to Kuala Lumpur (Hassaballa et al., 2014). The study area covers approximately 73 square kilometres, and forms a narrow ridge that extends in the northeast-southwest direction with a maximum elevation of 230 m (Chigira et al., 2011). The landscape is characterized by rolling hilly terrain with a network of streams and rivers. Land use in the area includes flat terrain at peat swamp forest, grassland, ex-mining, and scrub area, and a hilly expanse of natural forest ranging between 0 and 420 m above sea level (Lee and Pradhan, 2007).

Bukit Antarabangsa is a well-known landslide prone area and was selected for this reason. Recent significant events include December 1993, May 1999, November 2002 and December 2008 (Chigira et al., 2011; Hassaballa et al., 2014). Several investigations conducted in the period following these incidents indicated that the landslide was the result of several factors such as loose soil from earth dumping during construction, a rise in ground water level due to extended rainfall in the months prior to the failure, sustained soil creep that expanded the existing cracks and created new tension cracks as well as heavily leaked active water pipe as a result of soil creep (Ismail et al., 2019). The 1993 landslide was responsible for the collapse of the Highland Tower condominium, which led to 48 fatalities. The occurrence of this landslide was partly attributed to presence of weathered granitic material which is porous, friable and inherits relict planes of weakness from the parent rock (Chigira et al., 2011). The 1999 landslide took place near Athenaeum Tower condominium. It did not result in any fatalities but cut off the access road to Bukit Antarabangsa and left many people trapped inside their homes. The failure was attributed to non-adherence to the minimum factor of safety requirements, inadequate slope drainage, weak material in the slope body, subsurface saturation by rainwater, vegetation removal due to dumping, and internal erosion of fill materials (Ismail et al., 2019; Kazmi et al., 2017). The landslide of 2008 occurred only 1.4 kilometres from the Highland Tower

site and resulted in five fatalities, blocking of the access road, and confining of approximately 2,000 inside their homes. Contributing factors included presence of loose soil from earth dumping during construction, damaged or poorly maintained drainage, leaking from underground water supply lines and prolonged rainfall.

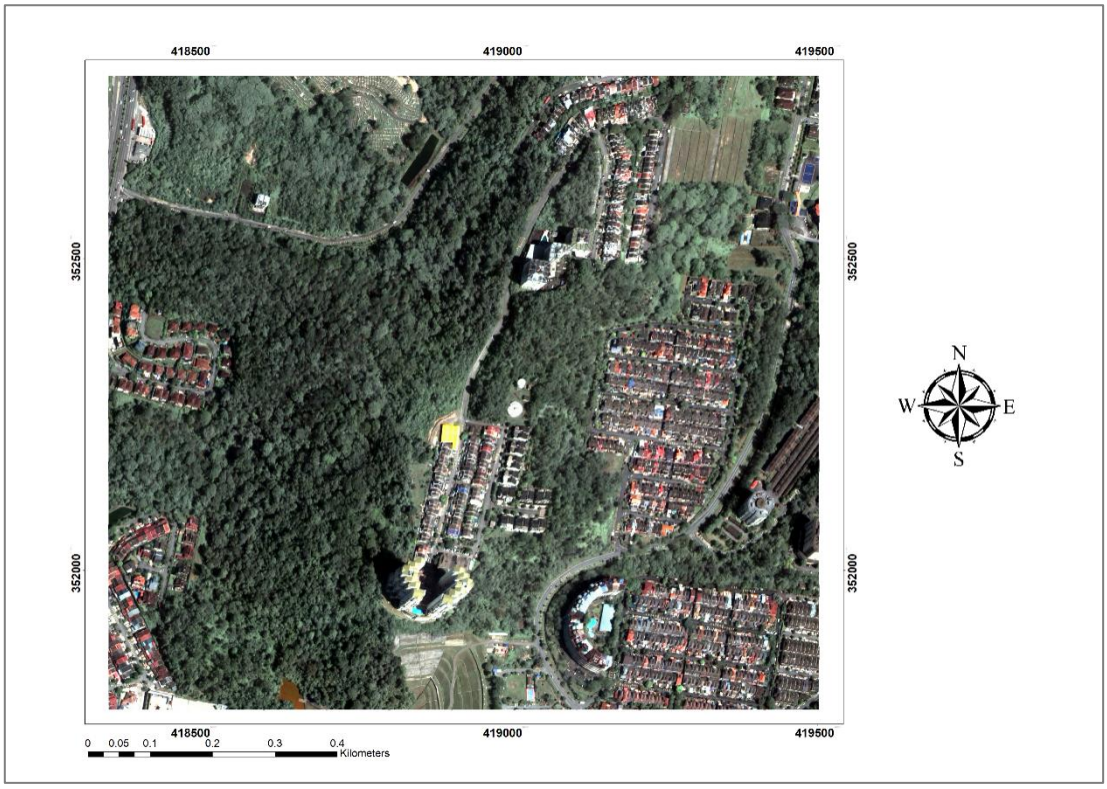

Figure 1.1: Study Area

Geologic conditions specifically rock type have a significant influence on landslides for instance earth flows and earth slides are more likely to occur in geologic settings characterized by fine-grained materials such as shale and unconsolidated alluvium (Liu et al., 1992; Ohlmacher, 2000). The geologic setting of the study area is characterized by granitic rock, phyllite and schist, and limestone with minor intercalations of phyllite, with most landslides occurring on granitic rock formations (Lee et al., 2014). With a few exceptions in northern Europe and North America, granitic rocks in particular are known to be prone to weathering and thus are susceptible to landslide occurrence (Chigira et al., 2011).

Geological factors include parameters such as rock types, weathering, discontinuities, structural aspects and faults. The landslide susceptibility mapping considers two geological factors namely lineament density and distance to lineament.

1.7 Research Significance

Preparation of landslide susceptibility maps is crucial for safe and economic planning of urban developments (Polykretis et al., 2015). These maps enable planners to determine land use restrictions within historically landslide-prone areas. As urban areas sprawl farther into hilly and mountainous terrain, it is necessary to understand the degree of exposure to landslide hazards in order to minimize the cost of living in landslide-prone areas (USGS, n.d.).

This research proposes a method for evaluating the importance of anthropogenic activities on the susceptibility of urbanized areas to landslides. It aims to integrate human-induced triggering causal factors into the landslide susceptibility mapping process for hillside urban development. This is achieved by comparing the importance of causal factors on landslide susceptibility in built-up and non-built-up areas. The study anticipates that information generated will contribute to a more holistic approach to landslide susceptibility mapping in urban areas– one that enables planners to evaluate development constraints based on geo-environmental and anthropogenic causal factors.

This research differs from previous studies in its focus on anthropogenic landslide causal factors and the human activities that influence them. Therefore, it is envisaged that the research will benefit the following stakeholders:

1. Jabatan Kerja Raya (JKR) or Malaysian Public Works Department)
2. Jabatan Mineral dan Geosains (JMG) or Department of Mineral and Geoscience
3. Majlis Perbandaran Ampang Jaya (MPAJ) or Ampang Jaya Municipal Council
4. Angkatan Pertahanan Awam Malaysia (APM) or Malaysian Civil Defence Department

5. National Disaster Management Agency (NADMA)

1.8 Thesis Structure

This thesis adopts the structure outlined as follows:

Chapter 2 highlights the findings of established research on landslides and landslide susceptibility mapping. It also defines key terms used in this thesis, and reviews the existing literature to gain insights into theories, concepts and methods employed in recent research.

Chapter 3 outlines the methods and resources that the researcher used to gather and analyse data, and provides justification for the selected approach. Specifically, it highlights the suitability of the approach in addressing the research questions as well as its limitations. It goes on further to discuss how such limitations might be addressed.

Chapter 4 presents the findings of the study in relation to the research questions, and presents an outline of answers that were found. This includes a number of visualized results. This chapter also presents an analysis and interpretation of the data gathered and determines the meaning of the results.

Chapter 5 highlights whether the research objectives were achieved, and points out any outstanding limitations, lessons learned and suggestions for future research.

1.9 Chapter Summary

This chapter provides an overview of the research which seeks to better understand the link between human-induced landslide causal factors and landslide susceptibility in the township of Bukit Antarabangsa, a known landslide hot spot in Malaysia. It highlights existing research that points to a prevalence of human-related factors in contributing landslide occurrences, and proposes the development of a data-driven approach for assessing the influence of anthropogenic causal factors on landslide susceptibility. Additionally, it provides an overview of the study area and its history of landslide incidents and identifies possible beneficiaries of this research.

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