VOL 1, NO.1 (2021) 89-114
https://jagst.utm.my

JAGST

Journal of Advanced Geospatial Science & Technology

Advancing Landslide Risk Registers Via the Geospatial Metamodel Approach: A Review

Mohammad Sahrul Akmal Abd Sahrin, Mohd Faisal Abdul Khanan*
Department of Geoinformation, Faculty of Built Environment and Surveying,
Universiti Teknologi Malaysia, 81310 Johor Bahru, Johor, Malaysia.
*Corresponding author: mdfaisal@utm.my

Abstract- According to the United Nations (UN) World Risk Index 2020, Malaysia is at high risk of natural catastrophes and is highly exposed to them, but has a low vulnerability to them. This is due to Malaysia's geographical location at the edge of the Pacific Ring of Fire, which makes it relatively secure from earthquakes and volcanic eruptions. Large-scale landslides continue to occur in the country, mainly during the monsoon season. Landslide disasters in Malaysia are managed by several entities, coordinated by The National Disaster Management Agency (NADMA) where each entity has its particular landslide disaster management practices. Therefore, several concerns remain, such as inadequate documentation and decentralization of standards of procedure (SOP). This paper presents an implementation review of the current landslide risk register, focusing on the geospatial metamodel approach. A risk register is an active document that lists all the identified hazards in a region and the decisions taken to monitor and manage them. Initially, preliminary studies were conducted to identify the current practices of landslide disaster management in Malaysia. These include collecting geospatial data, such as LiDAR, aerial photographs (AP), existing landslide inventory maps, and SOPs for landslide non-structural mitigation activities. The geospatial metamodel consists of the concept and the relationship, which describes the domain with an additional geospatial element. To conclude, a risk register using the geospatial metamodel approach would enable NADMA to monitor and coordinate the landslide disaster management process more effectively.

Keywords - Risk register, Geospatial metamodel, Landslide inventory, Disaster, Mitigation

Article History: received 22 December 2020, accepted 4 June 2021, published 1 August 2021

How to cite: Sahrin, M.S.A.A, and Khanan, M.F.A (2021). Advancing Landslide Risk Registers Via the Geospatial Metamodel Approach: A Review. Journal of Advanced Geospatial Science & Technology 1(1), 89-144.

1. Introduction

The UN World Risk Index 2020 depicts Malaysia as highly exposed to natural disasters, but with low vulnerability to such events, placing the country at 72nd out of 181 countries (Behlert et al., 2020). This is based on Malaysia's geographical location at the edge of the Pacific Ring of Fire, meaning it is considered safe from seismic disaster and volcanic activity (Sulaiman and Siti, 2019). Despite this, a significant number of landslides still occur in Malaysia, mainly gravity-induced but also caused by heavy and prolonged rainfall, which reaches 700mm per month during the monsoon season (Hussin et al., 2015; Rahman and Mapjabil, 2017). Landslides in Malaysia generally happen in hilly and precipitous areas (Akter et al., 2019) but some occur on artificial slopes (Rahman and Mapjabil, 2017). For example, landslides at Kampung Pampang, Keningau claimed 302 lives on 26 December 1996 (Sardi, Mohamad Fazli, and Khamarrul Razak, 2019). A landslide can be defined as the movement of rock, debris, and earth down a slope by the action of gravity on steep slopes (Cruden, 1991; Cruden, 1996; Khanna and Bhagat, 2005.). According to Cruden (1996) and Varnes (2020), landslides can be categorized into six types, based on their material properties and the process (Refer to Table 1).

Table 1: Landslide classification based on process type and material (Cruden, 1996; Varnes, 2020)

Process type	**Type of material**		
	Rock	***Debris***	***Earth***
Topple	Rock topples	Debris topples	Earth topples
Fall	Rocks fall	Debris falls	Earth falls
Translational **Rotational**	Rocks slide Rocks Slump	Debris Slides Debris Slumps	Earth slides Earth slumps
Flow	Rocks flow	Debris flows	Earth flow
Spread	Rocks spread	Debris spreads	Earth spreads
Complex	Combination of two or more process types		

1.1 Landslide disaster management practices in Malaysia

Landslide disasters in Malaysia are managed by the Public Works Department (JKR) via the Slope Engineering Branch (CKC); the Department of Mineral and Geoscience (JMG); and the Malaysian Remote Sensing Agency (ARSM), currently merged into the Malaysian Space Agency (Agensi Angkasa Malaysia, 2021; Rahman and Mapjabil, 2017). Each entity has separate practices: the National Slope Master Plan (NSMP 2009 – 2023) (National Slope Master Plan, 2009; Rashid Ahmad et al., 2017); National Geospatial Terrain and Slope Information (NaTSIS) (Department of Mineral and Geoscience, 2016); and Electronic Slope (e-Slope) (Agensi Angkasa Malaysia, 2021).

The NSMP was established by JKR to reduce the risks and losses due to landslides across slopes nationwide from 2009 until 2023 (National Slope Master Plan, 2009; Abdullah, 2013). It provides an assessment for a national landslide mitigation program that involves activities at the national, state, and local levels and in both the public and private sectors. (Rahman and Mapjabil, 2017). Meanwhile, NaTSIS is a web-based platform that has been developed by the Department of Mineral and Geoscience Malaysia (JMG) (Department of Mineral and Geoscience, 2016). Its objectives are to prepare an integrated geospatial information system for managing landslides, terrains, and slopes across various government agencies (Department of Mineral and Geoscience, 2016). NaTSIS benefits Malaysia as it is a national referral center for gathering, analyzing, and disseminating geospatial information on landslides, terrains, and slopes (Department of Mineral and Geoscience, 2016). MYSA has developed a slope management system known as “e – Slope”, which consists of two modules, namely “the Slope Management Module”, and “Hill and Upland Development Module”. The Slope Management Module helps by providing slope details and related information for more efficient slope monitoring using satellite images (Agensi Angkasa Malaysia, 2021). The Hill and Upland Development Module assists the relevant authorities in monitoring and managing landslide incidents more efficiently, quickly, and systematically. NADMA is responsible for coordinating these different practices by ensuring an overall standard of procedure (SOP) is implemented in all phases of the disaster management cycle. Despite this, some issues remain, such as the decentralization of SOPs for landslide disaster management and weak documentation.

1.2 Issues with landslides disaster management practices in Malaysia

A number of issues can be identified. The first arises since JKR, JMG and MYSA have separate action plans and SOPs as part of their landslide disaster management practices. JKR (at federal, state, and district levels) is involved in five phases of disaster management (DM), from prevention, mitigation, preparedness and response until the recovery phase (Omar Chong and Kamarudin, 2017). JMG (at both federal and state levels) only focuses on the preparedness phase (Mohamad et al., 2015; Omar Chong and Kamarudin, 2017; Department of Mineral and Geoscience, 2017). MYSA has no specific activity for the stages of Disaster Risk Management (DRM) (Omar Chong and Kamarudin, 2017). A lack of coordination in executing Disaster Management Cycle (DMC) among government entities and a greater focus on the disaster response and preparedness stages explain why these issues have occurred (Omar Chong and Kamarudin, 2017).

The second issue relates to a poor documentation record. To date, between 1961 and 2021, over one hundred cases of landslides have been recorded in Malaysia (National Slope Master Plan, 2009; Izumi et al., 2019). However, only 90 cases were reported and the total number of human fatalities amounted to 755 (Rahman and Mapjabil, 2017; Izumi et al., 2019). Due to the insufficiency of records, it is assumed that previous records of landslides that occurred before 1960 may not be available. Even if records were available, they may be incomplete and/or damaged. The lack of an appropriate database of slopes and landslides in Malaysia is a major problem because decision making on landslide disaster management has, at times, been ineffective and difficult (Komoo and Aziz and Sian, 2011; Abdullah, 2013; Akter et al., 2019). To counter this, an inclusive landslide disaster management framework needs to be developed. This framework would centralize all SOPs for landslide risk management in Malaysia, along with a geospatial metamodel, into a landslide risk register.

This paper is organized into the following sections: Introduction, Materials and Method, and Results and Discussion. The introduction section presents the concept of landslides; work related to current landslide disaster management practices in Malaysia; the landslide risk register; the metamodel; and the geospatial metamodel. The materials and methods section elaborates on the proposed risk register solution and outlines the geospatial metamodel approach and possible related data. The results and discussion section presents the expected results from this research.

1.3 Risk Registers

A risk register is an active document (i.e., kept continuously up-to-date) that sets out all recognized risks (threats) at a particular location and the decision(s) taken on how to monitor and manage them (Lee and Jones, 2014). This definition is supported by the Organisation for Economic Cooperation and Development (2017), which states that a risk register contains a list of identified risks and related information to facilitate monitoring the risk assessment. A risk register could be in form of a table, spreadsheet or database. It generally comprises a statement of risk, the sources of risk, the area of impact, the element of risk with the assigned consequences, and the likelihood and level of risk (Australian Institute for Disaster Resilience, 2020). In terms of landslides, a risk register assists by screening and prioritizing landslide problems at the early stages of the landslide disaster management procedure, tracking landslide disaster management decision-making throughout the project, and facilitating the formulation of a landslide disaster management action plan (Lee and Jones, 2014).

1.4 Risk Registers in Malaysia

In Malaysia, the concept of risk registers is fairly new but preserved in rudimentary form in the risk assessment process (Lee and Jones, 2014). NADMA intends to develop a national risk register (NRR) to assess the potential impact of disaster risk on Malaysia and use it as a decision-making platform that involves a disaster mitigation program, development projects, and rescue operations (Bernama, 2020). The register would take into account information on disaster recovery trends, the population and economic activities that are at risk, and action plans for affected areas (Bernama, 2020). However, there are some issues regarding risk register documentation. Risk registers illustrate landslide records using attribute information only, without a geospatial element. Landslide-related data requires both geospatial and attribute information. Hence, it would be more effective if the landslide risk register can utilize the geospatial metamodel approach to facilitate current landslide disaster management practices in Malaysia. Geospatial Metamodel assist by centralizing SOP activity (Othman, Beydoun, and Sugumaran, 2014) with additional GIS elements, such as landslide inventory maps.

1.5 The Metamodel

A metamodel can be defined as a class collection that illustrates domain concepts representing domain entities, actions or states (Othman, Siti Hajar and Beydoun, 2013; Inan, Beydoun, and Pradhan, 2018). Classes and relations in a metamodel denote the set of concepts and rubric with which this concept interrelates (Inan, Beydoun, and Opper, 2017). Metamodel frequently use a high-level knowledge of structure that allows the creation of knowledge repositories with an apprehensible interface (Kaptan, 2014; Othman, Beydoun, and Sugumaran, 2014).

The process of creating a metamodel is known as metamodeling. Metamodeling is a central activity promoted by the efforts of the Object Management Group (OMG) in software development, which aims to create interoperable, reusable, and portable components of software and data that are model-based (Othman and Beydoun, 2010). Creating a metamodel requires six criteria: i) purpose – why it is used, ii) user – who should use it, iii) scope – which entities are addressed, iv) formality – whether can it easily interpreted by a computer, v) independence – whether it is independent of system implementation, and vi) understandability – whether it can easily be understood by professionals and experts (Fan et al., 2012).

1.6 The Metamodel framework

Metamodel can be classified into specific groups that include Unified Modeling Language (UML), Extensible Markup Language (XML), Common Warehouse Metamodel (CWM), Meta-Object Facility (MOF), among others (OMG, 2019). The concern of this paper is the MOF framework, which is commonly used in the Disaster Management Metamodel (DMM). MOF consists of four layers, which are M0 (Real world), M1 (Model), M2 (Metamodel), and M3 (Meta-metamodel) (refer to Figure 1) (Othman and Beydoun, 2016). The lowest level, M0, is dedicated to a user model / real-world domain (it is an instance of the model and called the information layer) (Othman and Beydoun 2013, 2016). The M0 layer describes how knowledge related to tactical activities is structured (Inan, Beydoun, and Pradhan, 2018). The M0 layer consists of the input, production, and output data of the digital process planning system (Yang et al., 2016). It is an instance of the model and directly interacts with the system users (Yang et al., 2016). In this case, the M0 layer refers to real-world data, that is, landslides data. The M1 layer is a “model elements” layer that defines a language describing information about a domain (Othman and Beydoun, 2013). The M1 layer comprises metadata that describes data in the information layer (Othman and Beydoun, 2016). The M1 layer also defines a language that describes the semantic domain. M1 knowledge from the M0 layer is abstracted too simplistic to describe the policy and planning context (Inan, Beydoun, and Opper, 2017). The M1 layer also can be modeled by or adapt to the M2 layer (Othman and Beydoun, 2013).

The M2 layer comprises a description of the structure and semantics of metadata (Othman and Beydoun, 2016). In the M2 layer, the knowledge is then abstracted at a conceptual level in which the relationship between the model layers is defined as instance and classifier (class or object) (Inan, Beydoun, and Opper, 2017). The lower layer MOF is an instance of, and should conform to, the higher layer; otherwise, the higher layer would instantiate the model from the lower layer (Inan, Beydoun, and Opper, 2017). The MOF is commonly used to support the implementation of the DMM due to its flexible exchange from the conceptual to the real world and vice versa (Inan, Beydoun, and Pradhan, 2018).

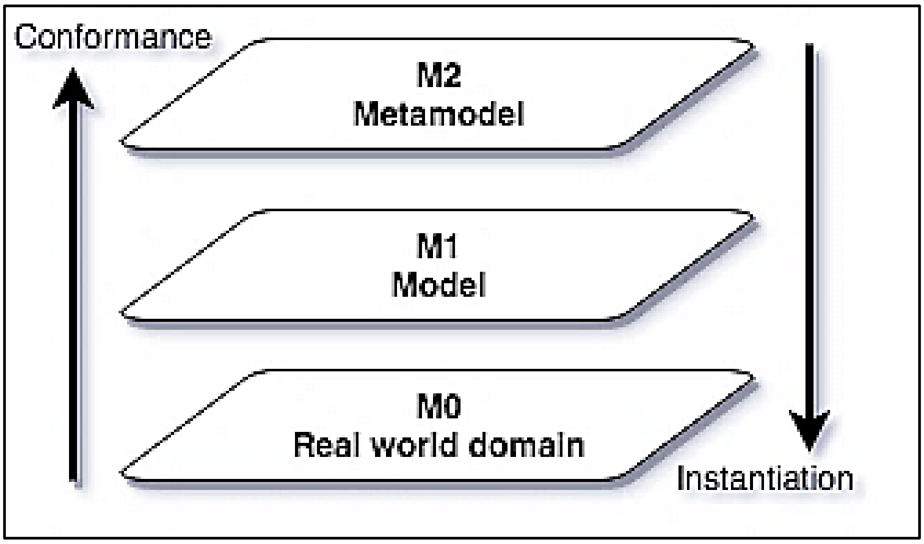


Figure 1: Meta-Object Facility (MOF) framework

1.7 The Disaster Management Metamodel (DMM)

The Disaster Management Metamodel (DMM) is a specific model that uses the metamodeling framework to support DM activities and phases. The development of the DMM was a solution to disaster issues such as data interoperability between various expert parties and government entities. Beydoun et al. (2009) stated that the benefit of unified metamodeling is that it provides better communication amongst practitioners and researchers in disaster management and the concept can be easily presented. In other words, unified metamodeling serves as an effective platform for sharing and integrating DM knowledge from varying sources (Othman and Beydoun, 2013). In this research, the MOF framework was used to implement the Landslide Disaster Metamodel. Numerous researchers, such as Othman and Beydoun (2013, 2016), Chen et al. (2015), Inan, Beydoun, and Pradhan (2018) and Nasir et al. (2018), have explored the topic of the MOF to support the development of DMM.

Othman and Beydoun (2013) proposed using the MOF framework as a core for developing the DMM. The metamodel serves as a guide for knowledge to be shared between DM experts and users. The proposed metamodel was validated and tested using two actual disaster scenarios: the 2011 Christchurch earthquake and the nuclear meltdown incident at Japan also in 2011. The benefit of using the DMM with the MOF framework is to facilitate global communication among different disaster emergency agents. It also provides guidelines for creating comprehensive DMMs and action plans.

Chen et al. (2015) adopted the MOF framework to develop a full life cycle natural disaster event metamodel (FLCNDEM). The FLCNDEM was endorsed and tested based on a flood event in Liangzi (LZ) Lake in Hubei, China from 1 July to 31 August 2010. The metamodel illustrates the class concept and map based on four different phases: diagnosis, preparedness, response, and recovery. Each map illustrates real-time changes in precipitation, water levels and the flooded area. The FLCNDEM is hugely significant to effective disaster detection, alert, response, and recovery. It also solves the problem of information from only one or two phases being covered.

Othman and Beydoun (2016) implemented the MOF framework in developing a system known as the "Disaster Management Knowledge Repository (DMKR)". The DMKR system consists of four sets of class concepts: mitigation, preparedness, response, and recovery. The class concepts were developed based on four phases of DM. Each class concept has a specific activity task and decision associated with it, which are stored in a database and visualized in the metamodel. The 2009 bushfire tragedy in Victoria, Australia was chosen to test the system. The system benefits DM practitioners by acting as a central tool for creating, organizing, and managing DM modeling knowledge. It also offers an overall picture of how all DM activities are executed.

Inan, Beydoun, and Pradhan (2018) applied the MOF framework in developing a decision support system (DSS) for DM. The hybrid knowledge between the top-down and bottom-up approach, coupled with the MOF framework, were used to deploy a Disaster Management Knowledge Analysis Framework (DM KAF). The DM KAF consists of three stages: customizing the Agent-Based Modeling (ABM) templates by applying the MOF framework, generating a specific disaster management plan (DISPLAN), and transferring the DISPLAN into the DMM-based repository. The 2017 Mount Agung volcano eruption in Bali, Indonesia was used to demonstrate the efficacy of the mechanism proposed and the resultant DSS. The Knowledge Analysis Framework (KAF) enables the knowledge element deposited in the repository to be structured in such a way that it can be used at any time in a DM event.

Nasir et al. (2018) adopted the MOF framework when developing an application known as the geospatial metamodel for non-structural mitigation of landslides (GeoMet). The metamodel was validated based on landslides from actual scenarios at Kundasang, Sabah, Malaysia. The result of GeoMet visualized the workflow model of non-structural mitigation activities which specifically involved from landslide inventory mapping to landslide risk mapping. However, the scope was limited to mapping landslide inventory only. The benefit of GeoMet is that it assists the responsible agencies during hazard occurrences and provides information about landslides. In addition, geospatial metamodel, coupled with landslide inventory maps, are practicable tools in preparing for and mitigating the impacts of landslide hazards.

Based on the literature surveyed, four out of five studies adopted the MOF framework from the M0 level until the M2 level (metamodel layer). Othman and Beydoun (2013, 2016), Inan, Beydoun, and Pradhan (2018), Nasir et al. (2018), and Chen et al. (2015) fully utilized all four levels (M0 level to M3 level). This is because the work of Chen et al. (2015) covered a wider scope of natural disaster events (NDE) and used different case studies. It is likely that more than one metamodel would need to be developed. This is unlike the other studies, which involved one specific disaster case study.

Geospatial elements, such as maps, need to be considered in the disaster management metamodel (DMM). Two out of five studies presented maps as the output of their disaster management metamodel, besides the metamodel itself (Chen et al., 2015; Nasir et al., 2018). Chen et al. (2015) illustrated a temporal flood map at Liangzi Lake, China, as one of the outputs of the FLCNDEM. Meanwhile, Nasir et al. (2018) presented a landslide inventory map of Kundasang, Sabah, Malaysia for non-structural mitigation activities. By contrast, the remaining studies only presented a conceptual version of a DMM.

It is possible to justify this: the MOF framework was commonly used to support the development of a DMM due to its flexibility in changing between the real and the conceptual. Generally, the MOF framework is implemented from the M0 level to the M2 level in modeling disasters (except in certain conditions that require full utilization, with all four levels). Secondly, few studies of the DMM apply a geospatial element such as a map (Nasir et al., 2018). Insufficient geospatial elements within the DMM acts as barriers to the production of landslide maps, hampering search and rescue (SAR) operations and making them challenging to conduct (Nasir et al., 2018).

Thus, reviewing the related work has resulted in a detailed description that outlines various studies of the disaster management metamodel (DMM) with the adoption of the MOF framework. The new concept of the Geospatial Metamodel will be explained in detail next.

1.8 The Geospatial Metamodel

A metamodel can be described as a model consisting of the concept and relation that represent the domain entities (Inan, Beydoun, and Pradhan, 2018). At present, no specific definition explains the geospatial metamodel concept. However, Frank (1998) and Wang et al. (2016) offered a detailed definition of a geospatial metamodel related to the GIS and geospatial decision models. The metamodel for GIS is a model of the GIS model (Frank, 1998).

The metamodel for GIS consists of an abstract, formalized model of the real world, a model of the data, an observation model, and the correspondence processes linking the world with the data and the model to functions of interest to a potential user (Frank, 1998). Figure 2 shows the concept of the metamodel for GIS. Letters are used with the denotation: W for world, D for data, o for observation operation, f for the function of interest to the user, q and u for the functions to determine the quality of the result of f, v for values, and e for errors (Frank, 1998). The data are the outcome of observations of the world, while outcomes of interest are computed with the function f (Frank, 1998).

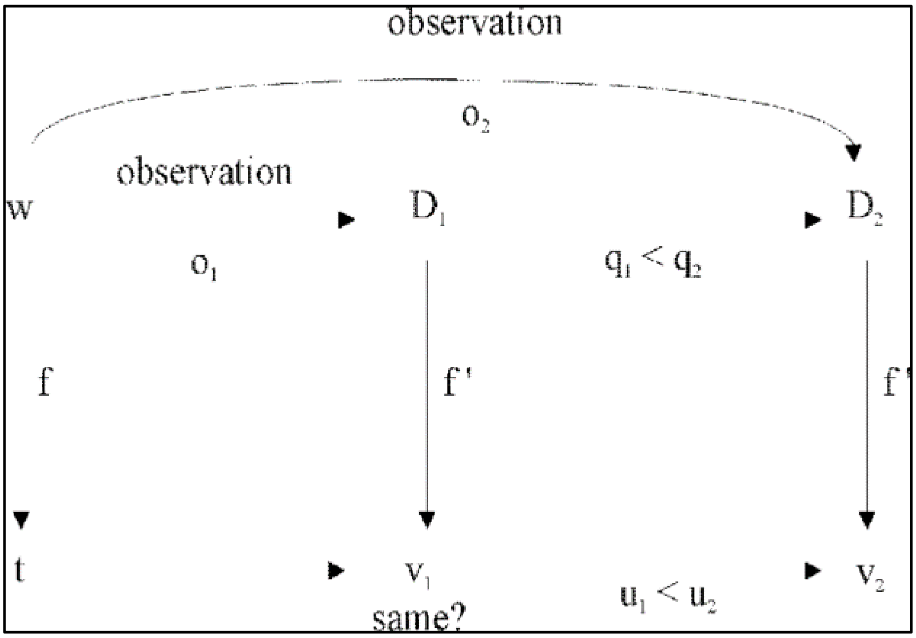


Figure 2: Metamodel for GIS (Frank, 1998)

Hence, data 1, D_1 are the outcomes of observation 1, O_1 of the world (Frank, 1998). D_2 results are obtained based on two approaches: i) directly from the outcomes of observation 2, O, and ii) function values to determine the quality of the result, f (Frank, 1998). If tolerance $q_1 < q_2$, then D_1 can be transformed into D_2 (Frank, 1998). This means that, if the quality of the result q_1 is less than a certain function tolerance of q_2, D_1 changes to D_2. The world is represented by a certain function of interest, f as t (true values) (Frank, 1998). The actual functions and values are not important in this model. The value derived from the observed data is, within tolerance, the same as the value directly measured (Frank, 1998). This type of metamodel permits the relationship between realities and geospatial data in GIS.

The geospatial decision metamodel defines the meta-modeling layers, basic components, metadata content, and information description structures, along with a set of unified rules and metadata standards that must be confirmed through geospatial decision modeling (Wang et al., 2016). Metamodeling layers are based on the metamodeling framework, known as the MOF. Based on the MOF, geospatial decision meta-modeling architecture consists of a hierarchy of four typical levels (M0 level to M3 level) (Wang et al., 2016). Each level is characterized as an instance of the level above (Wang et al., 2016). Figure 3 refers to the geospatial decision metamodel based on the MOF framework.

The M0 level grasps instances of the geospatial metamodel, the general analysis model and the professional application model (Wang et al., 2016). The M1 level indicates a model layer consisting of XML modeling language, which formalizes the information model and uses eleventh tuple information (Wang et al., 2016). These three kinds of information are described by the geospatial decision model of the M0 layer. This means that the information, language and metadata of the model in the M0 layer are described and mapped into the M1 layer. The M2 level is a metamodel layer that includes the formalization of the metamodel, the modeling facility metamodel and the information description metamodel, which describes the rules, facility constraints and metadata components (Wang et al., 2016). These three types of information are instances of and derived from the information model, XML, and eleventh tuple information, respectively, from the M1 layer (Wang et al., 2016).

The five basic metadata components include the tag, state, accessibility, structure, and services (Wang et al., 2016). To identify the available model quickly and precisely and select the appropriate model, these metadata components must be taken into account (Wang et al., 2016). The five basic metadata components constitute a reusable common information model (Wang et al., 2016). The detailed metadata content, expressed in the eleven tuples of information, consists of identification information, characteristic information, spatial information, dynamic information, performance information, working information, parameter information, algorithm information, service information, administration information, and constraint information (Wang et al., 2016).

However, the heterogeneous model has divergent features and it is necessary to extend some metadata content by including parameter and performance information (Wang et al., 2016). To extend this requires the establishment of specific information templates that are suitable for the geospatial decision metamodel (Wang et al., 2016). All these types of information above are defined in the Unified Modeling Language (UML) diagram (Wang et al., 2016). The benefit of the geospatial metamodel is that the geospatial decision model was developed by different entities and domains can be modeled by using the metamodel approach (Wang et al., 2016). In addition, combining the DMM with geospatial elements is an appropriate decision, since geospatial information is in high demand in risk and disaster management (Taib, 2014). Hence, this paper adopts both the concept and methodology of the geospatial metamodel approach from Wang et al. (2016) and Nasir et al. (2018) in advancing the development of a landslide risk register in Malaysia. The next section will discuss in detail the methodology workflow of this study.

2.0 Materials and methods

The methodology workflow of this study is divided into six phases, including preliminary studies, data acquisition, the conceptual design of a landslide risk register, the generation of a landslide inventory, and the development and validation of a geospatial metamodel. The methodology workflow is illustrated in Figure 4.

2.1 Preliminary studies (Phase 1)

Preliminary studies involved activities such as reviewing the issues concerning the current practice of landslide disaster management in Malaysia, the risk register and the metamodel. Work related to the study of metamodel for disaster management (DMM) that adopt the MOF framework was reviewed in the introduction.

2.2 Data Acquisition (Phase 2)

Data acquisition involved activities such as the collection of spatial and non-spatial data. Spatial data included Aerial Photograph (AP) imagery in the form of orthophoto, Airborne LiDAR data, and an existing landslide inventory map of Bukit Antarabangsa, Ulu Klang, Selangor. Non-spatial data refers to the SOP for landslides non-structural mitigation activities. Both spatial and non-spatial data were used to develop a landslide inventory map of Bukit Antarabangsa, a landslide risk register and a geospatial metamodel.

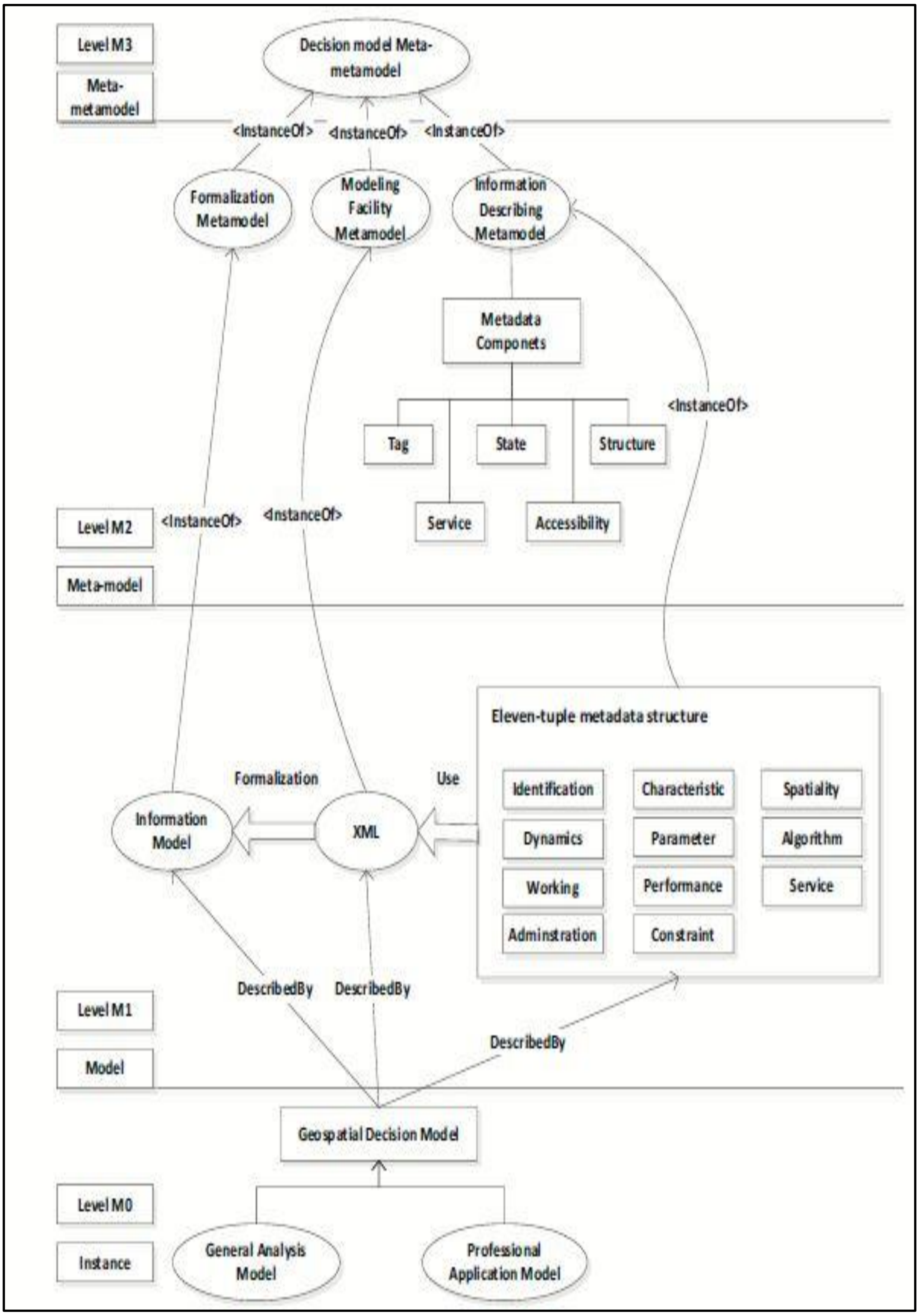


Figure 3: Geospatial decision metamodel based on the MOF framework (Wang et al. 2016)

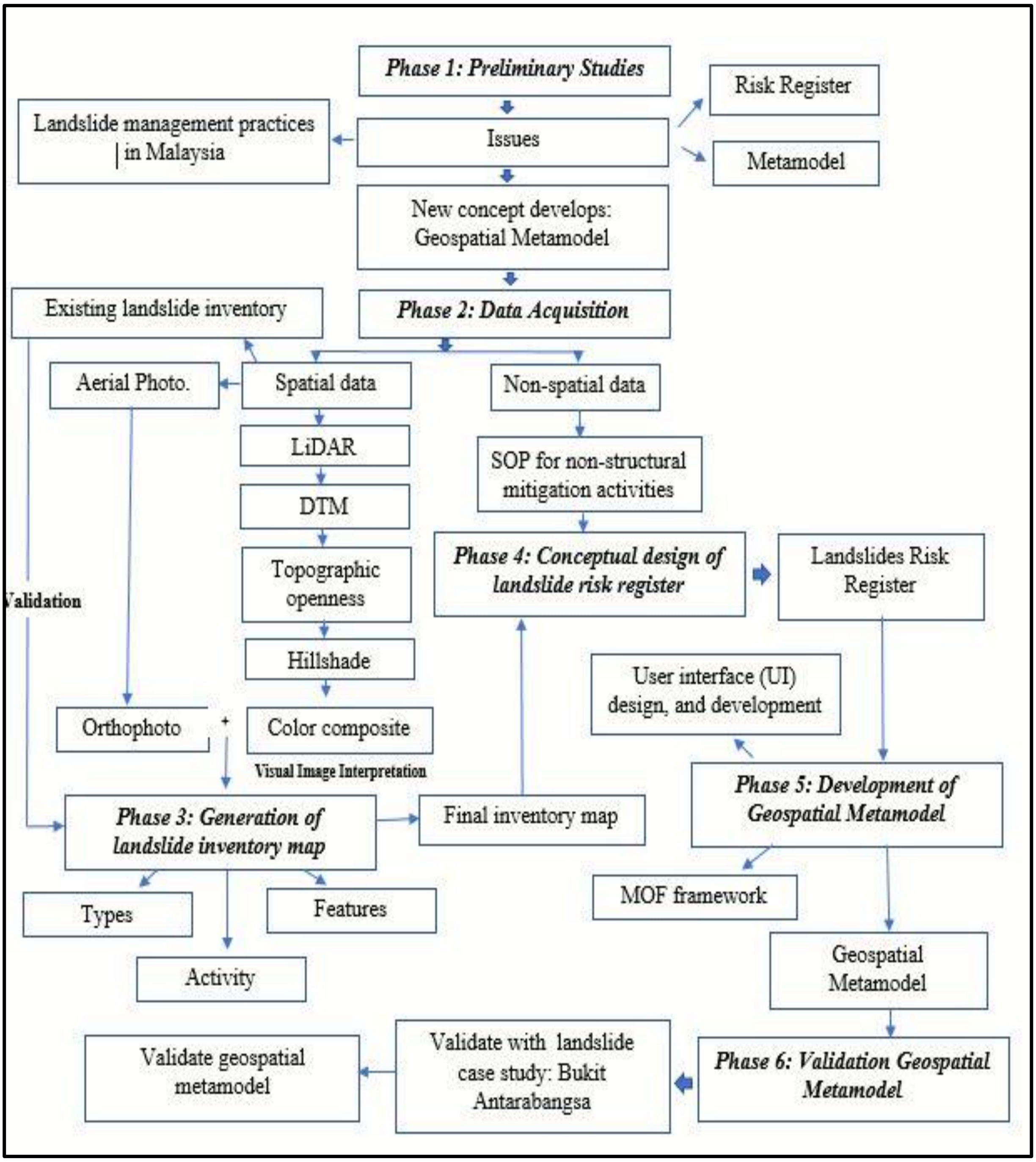


Figure 4: Methodology workflow for a landslide risk register with the geospatial metamodel

2.2.1 Aerial Photography (AP) images

Aerial photography is the technique of capturing images from an aircraft in flight with a camera mounted on it (Robinson and Erwad, 2016). AP images represent images of topographic and non-topographic features in the specific areas within aerial view. AP images were necessary for the generation of a new landslide inventory map of Bukit Antarabangsa, Ulu Klang, Selangor. It was crucial to identify a potential landslide site and map that location on the landslide inventory map. AP images were provided by the Department of Mineral and Geoscience (JMG) and the Department of Survey and Mapping (JUPEM), and certain policies and SOP had to be followed. Figure 5 indicates the orthophoto images from the AP imagery data.

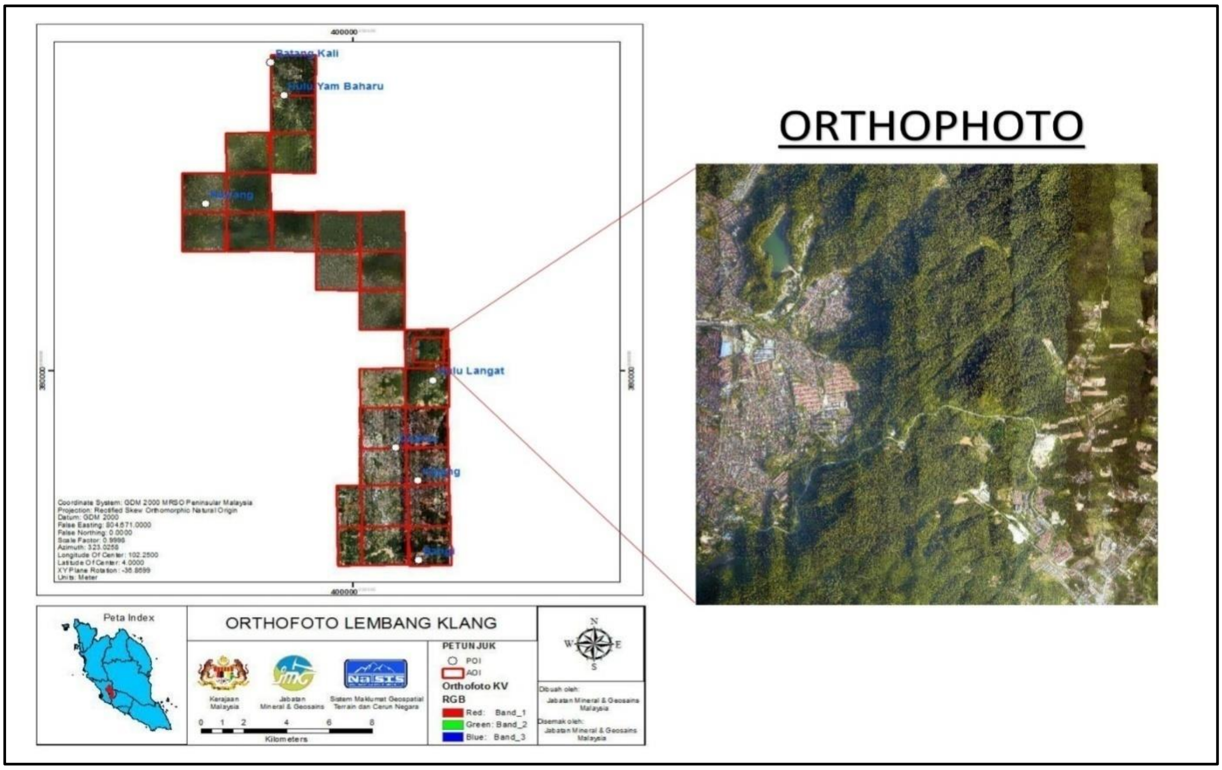


Figure 5: Example of an orthophoto of an area of the Klang Valley extracted from Aerial Photograph Imagery (Department of Mineral and Geoscience, 2016)

2.2.2 Airborne LiDAR data

LiDAR stands for Light Detection and Ranging. LiDAR is a remote sensing technique that uses light in the form of pulsed lasers to measure ranges to the earth (National Oceanic and

Atmospheric Administration, 2020). Airborne LiDAR data is a form of data crucial in mapping potential landslide areas due to its highly accurate visualization of topographic features. Hence, it is suitable for landslide inventory mapping work. A digital terrain model (DTM) was extracted from raw point cloud (National Oceanic and Atmospheric Administration, 2020) to derive information such as topographic openness, hill shades and color composites (Nasir et al., 2018). That information was overlaid with the AP (orthophoto) to identify and derive landslide inventory information such as the ID, types, activities, and features of landslides. JMG provided LiDAR-derived DTM data in raster dataset format. Figure 6 illustrates an example of a DTM extract using Airborne LiDAR.

2.2.3 The Existing Landslide Inventory Map

An existing landslide inventory map denotes information on landslides, such as their type, activity, structure, date of occurrences, relative age, magnitude, time and causes (Department of Mineral and Geoscience, 2016). An existing inventory map may derive from visual image interpretation, multi-temporal classification, or a digital elevation model (DEM) (Castellanos, 2008). The project team provided an existing landslide inventory map so it could be validated and compared with the new landslide inventory map. Data was given in shapefile format. Figure 7 shows an example of an existing landslide inventory map.

2.2.4 Landslide non-structural mitigation activities

Non-structural mitigation activities focus on reducing the impact of disasters through law and regulations, policy, action plan, education and awareness (Khanna and Bhagat, 2005). Legislation and policy activities, as well as landslide inventory mapping, are activities involved in non-structural mitigation phases. The information can be gathered in the form of government SOP documents from websites and also in landslide project reports.

2.3 Generation of the Landslide Inventory Map (Phase 3)

A landslide inventory is the basis for determining landslide susceptibility, hazard, vulnerability and risk. Without this, it would be impossible to predict the future behavior of these events. Discussed in the next section are activities such as data pre-processing, visual image interpretation and the validation of the new landslide inventory map using the existing map.

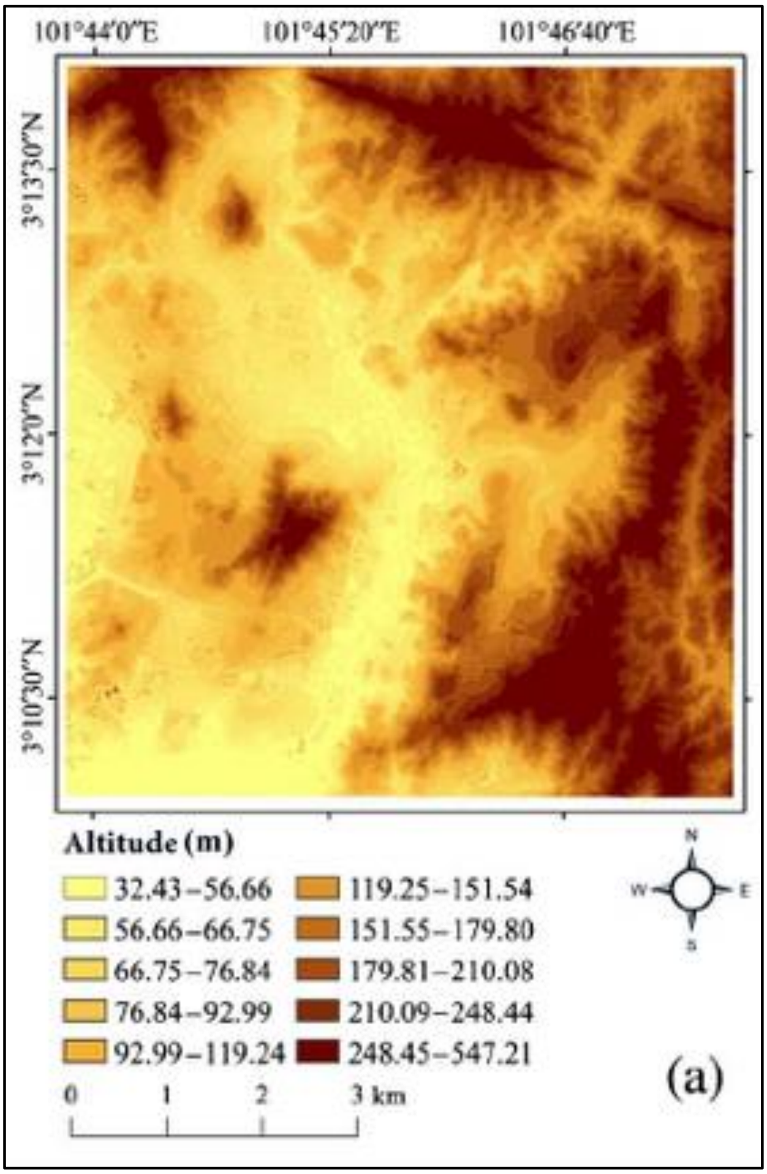
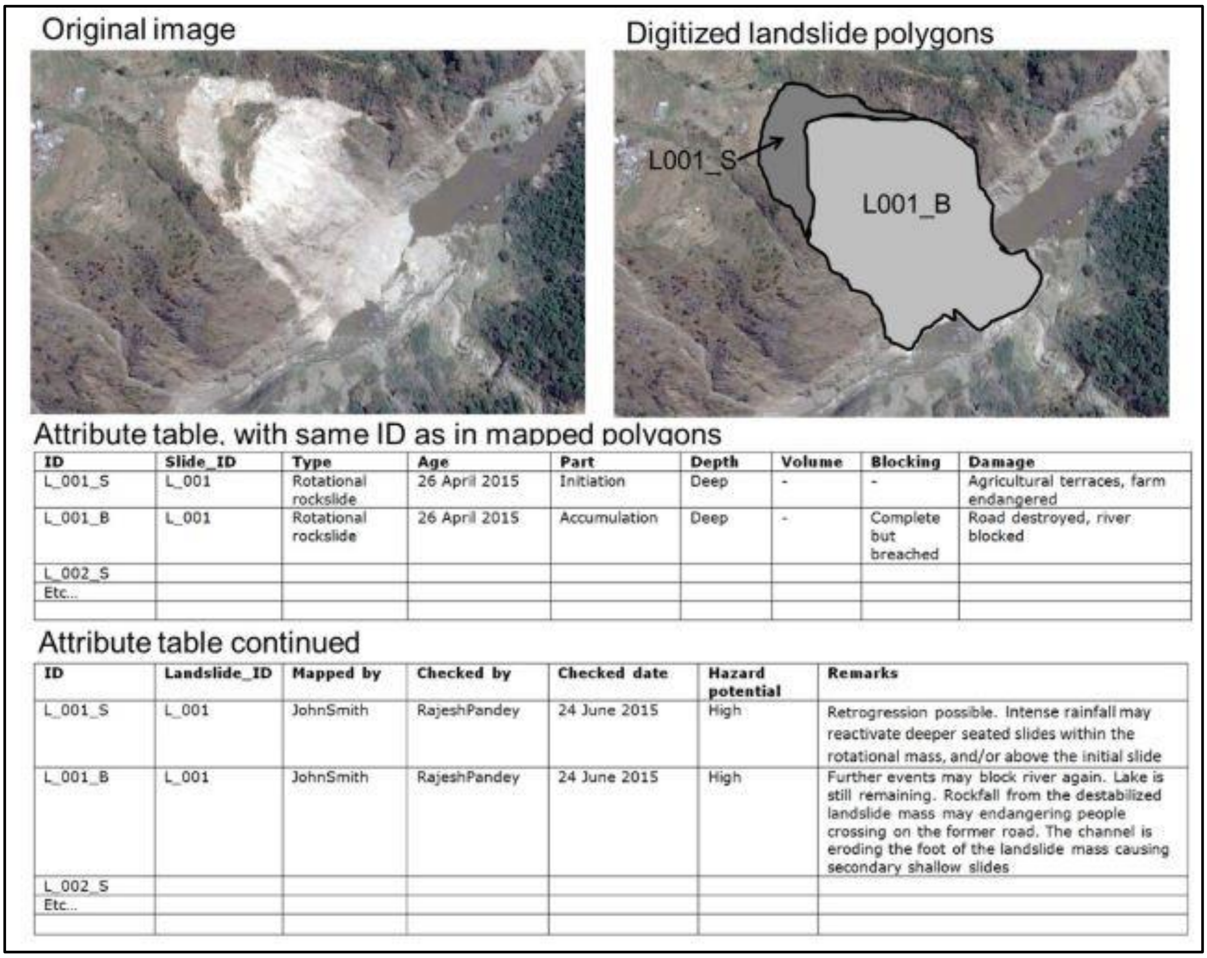


Figure 6: Example of a DTM of Bukit Antarabangsa, Ulu Klang, Selangor extracted from Airborne LiDAR data (Jebur, Pradhan, and Tehrany, 2014)



ID	Slide_ID	Type	Age	Part	Depth	Volume	Blocking	Damage
L_001_S	L_001	Rotational rockslide	26 April 2015	Initiation	Deep	-	-	Agricultural terraces, farm endangered
L_001_B	L_001	Rotational rockslide	26 April 2015	Accumulation	Deep	-	Complete but breached	Road destroyed, river blocked
L_002_S								
Etc...								

ID	Landslide_ID	Mapped by	Checked by	Checked date	Hazard potential	Remarks
L_001_S	L_001	JohnSmith	RajeshPandey	24 June 2015	High	Retrogression possible. Intense rainfall may reactivate deeper seated slides within the rotational mass, and/or above the initial slide
L_001_B	L_001	JohnSmith	RajeshPandey	24 June 2015	High	Further events may block river again. Lake is still remaining. Rockfall from the destabilized landslide mass may endangering people crossing on the former road. The channel is eroding the foot of the landslide mass causing secondary shallow slides
L_002_S						
Etc...						

Figure 7: Example of an existing landslide inventory map (Global Facility for Disaster Risk Reduction, 2014)

2.3.1 Data Pre-processing

Data pre-processing is a crucial aspect of extracting information into an appropriate form. In this study, data pre-processing included extracting information such as topographic openness, hill shades and color composites from the DTM based LiDAR. These three forms of information were generated using three different software packages: Integrated Land and Water System (ILWIS), System for Automated Geoscientific Analysis (SAGA GIS), and ArcGIS.

2.3.2 Visual Image Interpretation

Visual Image Interpretation was conducted by overlaying together the data for topographic openness, color composite, and hill shade with the orthophoto data in order to identify and digitize landslide inventory information such as landslide ID, type, activity, and features. Hence, four landslide inventory maps were produced for types of landslide, landslide activity, landslide features, and landslide inventory (a combination of type and activity).

2.3.3 Validation of the Landslide Inventory Map

The landslide inventory map was validated with the existing map to ensure its accuracy. The new landslide inventory map was overlaid with the existing map using ArcGIS software. The existing landslide inventory map was used to identify and analyze the similarity and difference percentage between the existing and the new landslide inventory maps. The percentage of similarity and difference was computed using the tabular intersection method in ArcGIS software.

2.4 Conceptual design of the Landslide Risk Register (Phase 4)

The conceptual design of the landslide risk register involves activities used for the conceptual, logical and physical models. The activities are identical in GIS database design since the landslide risk register deals with records, tables, attributes and spatial information. Designing the landslide risk register required some information on SOPs for landslide non-structural mitigation activities, records of previous major landslides in Malaysia and a landslide inventory map. Conceptual design is the first phase of a geospatial database, before the development takes place.

2.4.1 The Conceptual Model

The entity relationship diagram (ERD) and Unified Modeling Language (UML) are common approaches to conceptual design. The ERD is a flowchart that illustrates how objects or people inter-relate within a table in the form of "entities". ERD also comprises other elements such as spatial object type, topology indicators, spatial and non-spatial attributes, and cardinality. Figure 8 shows an example of an ERD.

2.4.2 The Logical Model

The logical model is the translation of the conceptual model into a logical table with specific entities that contain attributes, data type, attribute length, precision, and attribute description. The logical model focuses on logical relationships between objects. Common examples of the logical model are master data lists and GIS application forms. The logical model output becomes the input for the development of a landslide risk register.

2.4.3 The Physical Model

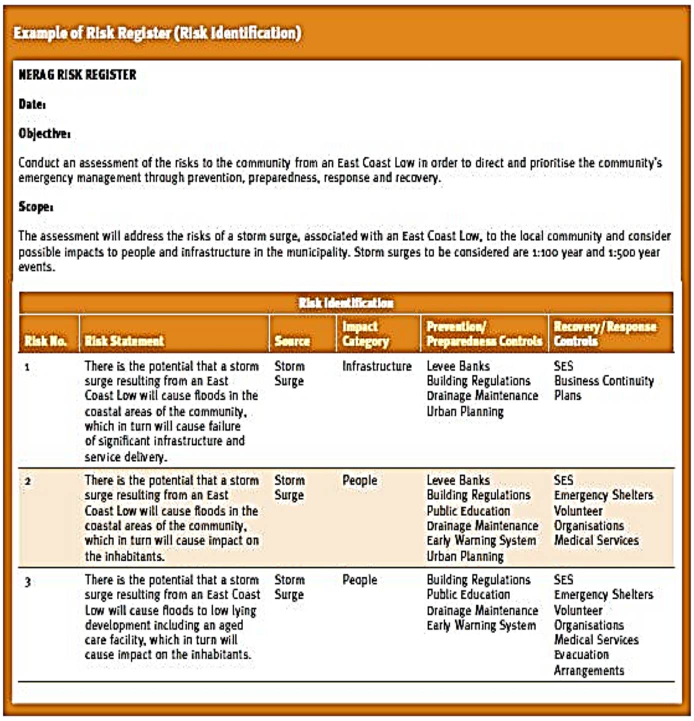
The physical model translates logical design into a precise physical landslide risk register. The physical model is used to estimate storage, in terms of specific storage allocation and the manner in which data is stored in a landslide risk register. In this study, the physical model covered specific tasks such as the creation of feature class, feature datasets, and project features in a suitable projection. After that, the landslide risk register was fully developed, utilizing information such as the SOP for landslides non-structural mitigation activities, records of previous landslides in Malaysia, and landslide inventory maps for specific areas. The information in the landslide risk register table was used for the development of the geospatial metamodel.

2.5 Development of the Geospatial Metamodel (Phase 5)

The geospatial metamodel for disaster management was developed to provide the users with information on SOPs for landslides non-structural mitigation activities, records of historical landslides and the landslide inventory map. Storing information in the metamodel required searching relevant websites and previous landslides projects. This information may include SOPs for landslides non-structural mitigation activities and records of previous landslides in Malaysia. The information above was recorded in the landslide risk register before the form was created.

2.5.1 Designing the user interface (UI) for the Geospatial Metamodel

The geospatial metamodel for the landslide risk register is a prototype application that provides the user with information on potential areas of landslides, records of previous landslides, and SOPs and action plans for non-structural mitigation measures. Microsoft Access (MS Access) was an appropriate tool to use in designing and developing a geospatial metamodel because this software is user-friendly: Microsoft Access has a feature that can create forms for UI design and development. Related information was stored in the form of a table (i.e., the landslide risk register) before the form was created (Nasir et al., 2018). The table was linked using a unique activity ID to ensure the data was shown in the correct form (Nasir et al., 2018). Then, the form was designed and created using MS Access software. Three main forms were created: the geospatial metamodel form, landslides non-structural mitigation workflow activities and records of previous landslides in Malaysia.



Example of Risk Register (Risk Identification)

NERAG RISK REGISTER

Date:

Objective:

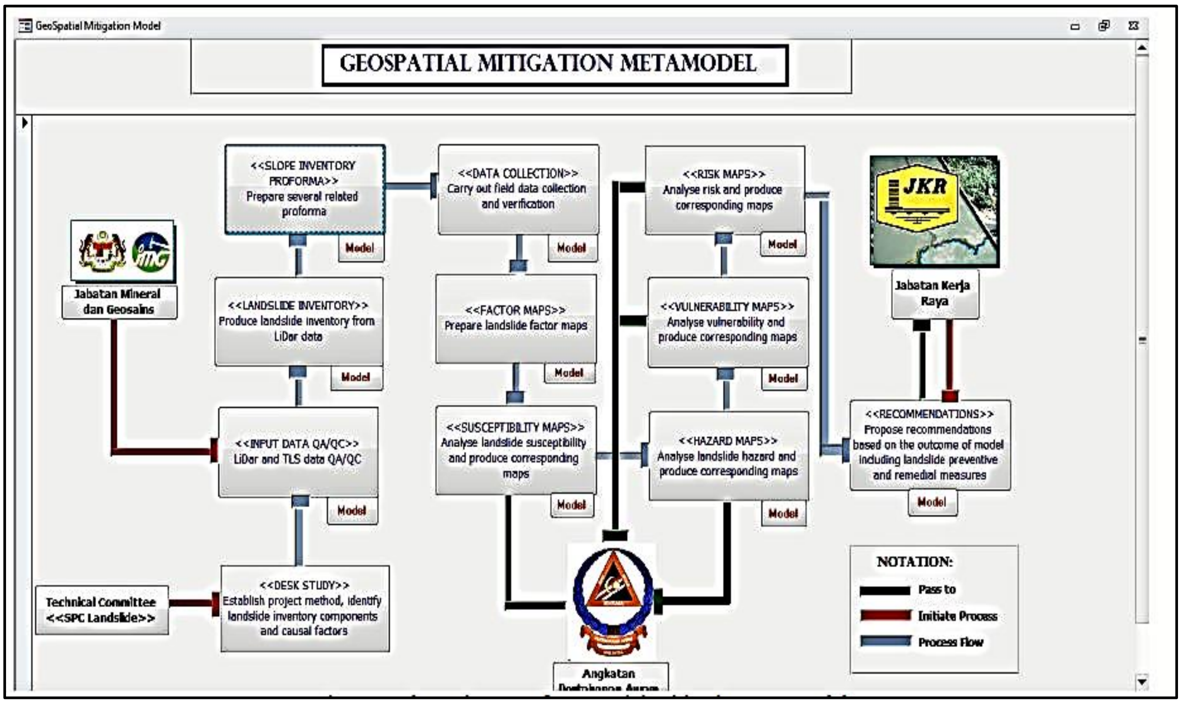
Conduct an assessment of the risks to the community from an East Coast Low in order to direct and prioritise the community's emergency management through prevention, preparedness, response and recovery.

Scope:

The assessment will address the risks of a storm surge, associated with an East Coast Low, to the local community and consider possible impacts to people and infrastructure in the municipality. Storm surges to be considered are 1:100 year and 1:500 year events.

Risk Identification					
Risk No.	Risk Statement	Source	Impact Category	Prevention/ Preparedness Controls	Recovery/Response Controls
1	There is the potential that a storm surge resulting from an East Coast Low will cause floods in the coastal areas of the community, which in turn will cause failure of significant infrastructure and service delivery.	Storm Surge	Infrastructure	Levee Banks Building Regulations Drainage Maintenance Urban Planning	SES Business Continuity Plans
2	There is the potential that a storm surge resulting from an East Coast Low will cause floods in the coastal areas of the community, which in turn will cause impact on the inhabitants.	Storm Surge	People	Levee Banks Building Regulations Public Education Drainage Maintenance Early Warning System Urban Planning	SES Emergency Shelters Volunteer Organisations Medical Services
3	There is the potential that a storm surge resulting from an East Coast Low will cause floods to low lying development including an aged care facility, which in turn will cause impact on the inhabitants.	Storm Surge	People	Building Regulations Public Education Drainage Maintenance Early Warning System	SES Emergency Shelters Volunteer Organisations Medical Services Evacuation Arrangements

(8a)



Figures 8a and 8b: Expected result of the Geospatial Metamodel for the Landslide Risk Register (Nasir et al. 2018; Australian Institute for Disaster Resilience, 2020)

The metamodel form displays a table and task activities for the landslide inventory map at three levels of the MOF framework (M0 level to M2 level) (Nasir et al., 2018). The landslide inventory map was imported into the geospatial metamodel and shows information about landslide locations, types, activities, and features (Nasir et al., 2018). The SOP for the landslides non-structural mitigation activities form displays the step-by-step procedure, from the desk study until the final hazard mapping was achieved (Nasir et al., 2018). Each SOP has a workflow model that describes the information about the procedures of each stage (Nasir et al., 2018). The records of previous landslides form display the list of major landslides in Malaysia from 1961 to 2021, along with the number of fatalities. The record is displayed in the form of a table in the geospatial metamodel.

2.6 Validation of the Geospatial Metamodel (Phase 6)

The geospatial metamodel that was created needs to undergo a validation process. NADMA will validate the metamodel based on real landslide disaster events at Bukit Antarabangsa, Ulu Klang, Selangor. Bukit Antarabangsa is one of the most landslide-prone areas in Malaysia, the most serious case being the “Highland Towers” incident in 1993, in which 48 people were killed (Rahman and Mapjabil, 2017). NADMA will assess the effectiveness of the geospatial metamodel based on certain criteria: i) storing and displaying accurate SOPs of the landslides non-structural mitigation activities workflow in the landslide risk register, ii) displaying records of previous major landslides in Malaysia, and iii) displaying a landslide inventory map of Bukit Antarabangsa, Selangor.

3.0 Conclusion

This paper presented the expected results of a landslide risk register via the geospatial metamodel approach at Bukit Antarabangsa, Ulu Klang, Selangor. The landslide risk register comprises information such as historical records of landslides in Malaysia and around Ulu Klang, Selangor, as well as SOPs and an action plan for landslides non-structural mitigation activities, including a landslide inventory map. The geospatial metamodel is preserved as a data model that visualizes all the information listed above within a comprehensive and centralized user interface (UI) application for landslide disaster events. The geospatial metamodel for the landslide risk register will be tested and validated based on real landslide scenarios at Bukit Antarabangsa, Ulu Klang, Selangor. Figure 8 shows the expected result of this study.

Acknowledgement

The author would like to acknowledge to Universiti of Teknologi Malaysia for support with funding under UTM Encouragement Research Grant (UTMER) Grant, No. Q. I130000.2652.17J58.

References

Abdullah, C.H., 2013. *"Landslide Risk Management in Malaysia"*. WIT Transactions on the Built Environment, 133, :255-265.

Agensi Angkasa Malaysia, MYSA. 2021. *"Pengoperasian Teknologi Angkasa Dalam Pemantauan & Pengurusan Fenomena Kejadian Tanah Runtuh."* Agensi Angkasa Malaysia (MYSA), accessed 14 April. http://www.mysa.gov.my/infografik2021-11/.

Akter, Ayesha, Megat Johari Megat Mohd Noor, Masa Goto, Shamsunnahar Khanam, Ahmed Parvez, and Md Rasheduzzaman. 2019. *"Landslide Disaster in Malaysia: An Overview."* International Journal of Innovative Research and Development 8. doi: 10.24940/ijird/2019/v8/i6/JUN19058.

Amin, Z.A.M., Abdullah, C.H. and Ngajam, S.Z., 2017, May. *"Public Awareness and Education Programme for Landslide Management and Evaluation Using a Social Research Approach to Determining "Acceptable Risk" and "Tolerable Risk" in Landslide Risk Areas in Malaysia"* (IPL-194, IPL-207). In Workshop on World Landslide Forum, :437-447. Springer, Cham.

Australian Institute for Disaster Resilience, . 2020. *"Australian Disaster Resilience Handbook Collection"*. In National Emergency Risk Assessment Guidelines. Melbourne, Australia.

Behlert, Benedikt., Rouven Diekjobst, Carsten Felgentreff, Timeela Manandhar, Peter Mucke, and Ludger Pries. 2020. *"World Risk Report 2020"*, edited by Lotte Kirch, Peter Mucke, Julia Walter and Leopold Karmann. Bundnis Entwicklung Hilft.

Bernama. 2020. "NADMA to develop national risk register " The Star. Accessed 4 April 2020. https://www.thestar.com.my/news/nation/2020/01/30/nadma-to-develop-national-risk-register.

Castellanos Abella, E.A., 2008. *"Basis of Spatial Landslide Risk Assessment"* (THESIS VERSION). *hdl: 1874/44087# AGGREGATION CHAPTER 2*, pp: 11-41.

Chen, Nengcheng, Wenying Du, Fan Song, and Zeqiang Chen. 2015. "FLCNDEMF: *"An Event Metamodel for Flood Process Information Management under the Sensor Web Environment."* Remote Sensing 7 (6). doi: 10.3390/rs70607231.

Cruden, D.M., 1993. Cruden, DM, Varnes, DJ, 1996, *"Landslide Types and Processes, Transportation"* Research Board, US National Academy of Sciences, Special Report, 247, :36-75.

Department of Mineral and Geoscience, . 2017. *"Slope Hazard and Risk Mapping. Malaysia: KSAASM"*.

Department of Mineral and Geoscience, JMG. 2016. *"National Geospatial Terrain and Slope Information System, NaTSIS."* Mineral and Geoscience Department, accessed 1 October. https://www.natsis.jmg.gov.my/en/FAQ2.jsp.

Fan, S., Zhao, J.L., Dou, W. and Liu, M., 2012. *"A Framework for Transformation from Conceptual to Logical Workflow Models"*. Decision Support Systems, 54(1), :781-794.

Frank, A.U., 1998. *"Metamodels For Data Quality Description"*. Data Quality in Geographic Information-From Error to Uncertainty, 192.

Global Facility for Disaster Risk Reduction, GFDRR. 2014. *"Caribbean Handbook on Risk Information Management (Data Management Handbook)"*. GFDRR, accessed 23 May. http://www.charim.net/datamanagement/43.

Hamill, M. and Goseva-Popstojanova, K., 2009. *"Common Trends in Software Fault and Failure Data"*. IEEE Transactions on Software Engineering, 35(4),: 484-496.

Hussin, H., Ghani, S.A.A., Jamaluddin, T.A. and Razab, M.K.A.A., 2015. *"Tanah Runtuh di Malaysia:Geobencana atau Geobahaya*. Jurnal Teknologi, 77(1).

ILWIS. 2018. "Main Page." Faculty of Geo-Information, Science and Earth Observation (ITC), accessed 5 June. http://ilwis.itc.utwente.nl/wiki/index.php/Main_Page

Inan, D.I., Beydoun, G. and Opper, S., 2018. *"Agent-Based Knowledge Analysis Framework in Disaster Management"*. Information Systems Frontiers, 20(4), :783-802.

Inan, D.I., Beydoun, G. and Pradhan, B., 2018. *"Developing a Decision Support System for Disaster Management: Case Study Of An Indonesia Volcano Eruption"*. International journal of disaster risk reduction, 31, :711-721.

Izumi, T., S. Matsuura, A. F. Mohd Yusof, K. A. Razak, S. Moriguchi, S Kure, M. H. Jamal, E. Motoyama, and L.M. Supar. 2019. *"Disaster Risk Report by IRIDES, Japan"*. Selangor Disaster Management Unit, Selangor State Government, Malaysia: Universiti Teknologi Malaysia.

Jebur, Mustafa Neamah, Biswajeet Pradhan, and Mahyat Shafapour Tehrany. *"Manifestation of Lidar-Derived Parameters in the Spatial Prediction of Landslides Using Novel Ensemble Evidential Belief Functions and Support Vector Machine Models In GIS."* IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing 8, no. 2 (2014), :674-690.

JKR. 2009. National Slope Master Plan Jabatan Kerja Raya Malaysia, PWD.

Kaptan, K., 2014. *"An Organizational Metamodel For Hospital Emergency Departments"*. Disaster medicine and public health preparedness, 8(5), pp.436-444.

Khanna, Bhagat. K. 2005. *"All You Wanted to Know About Disasters"*. New Delhi, India: New India Publishing Agency.

Komoo, I., Aziz, S. and Sian, L.C., 2011."*Incorporating The Hyogo Framework For Action Into Landslide Disaster Risk Reduction In Malaysia"*.

Lee, E.M. and Jones, D.K., 2014. *"Background to Landslide Risk Assessment"*. In Landslide Risk Assessment, pp: 1-20. ICE Publishing.

Mohamad, Z., Azahari Razak, K., Ahmad, F., Manap, M.A., Ramli, Z., Ahmad, A. and Mohamed, Z., 2015, April. *"Slope Hazard and Risk Assessment in the Tropics: Malaysia Experience"*. In EGU General Assembly Conference Abstracts, p: 7746.

NADMA, . n.d. "myDRR : *"Platform Kebangsaan dan Pelan Tindakan Pengurangan Risiko Bencana Malaysia"*. Prime Minister Department, accessed 05 December http://mydrr.org/about-mengenai/.

Nasir, N.S., Khanan, M.A., Othman, S.H., Rahman, M.A., Razak, K.A., Salleh, M.M., Umar, H.A. and Razak, A.A., 2018. *"Assimilating Geospatial Metamodel and Inventory Mapping for Non-Structural Mitigation of Landslide"*. International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, 42(4/W9).

National Oceanic and Atmospheric Administration, NOAA. 2020. "What is Lidar ? ." NOAA, accessed 20 May https://oceanservice.noaa.gov/facts/lidar.html.

National Slope Master Plan, . 2009. *"Sectoral Report National Slope Master Plan"*. In Sectoral Report: Policy and Institutional Framework ; Hazard Mapping and Assessment. Public Work Department.

OECD. 2017. *"National Risk Assessment : A Cross Country Perspective"*. Paris.

Omar Chong, N. and Kamarudin, K.H., 2017. *"Issues and Challenges in Disaster Risk Management in Malaysia: From The Perspective Of Agencies"*. Persidangan Geografi dan Alam Sekitar kali ke-6.

Othman, S.H. and Beydoun, G., 2010, August. *"A Disaster Management Metamodel (DMM) Validated".* In Pacific Rim Knowledge Acquisition Workshop, :111-125. Springer, Berlin, Heidelberg.

Othman, S.H. and Beydoun, G., 2016. *"A Metamodel-Based Knowledge Sharing System for Disaster Management"*. Expert Systems with Applications, 63, :49-65.

Othman, S.H., Beydoun, G. and Sugumaran, V., 2014. *"Development and validation of a Disaster Management Metamodel (DMM)".* Information Processing & Management, 50(2), :235-271.

Othman, Siti Hajar, and Ghassan Beydoun. 2013. *"Model-Driven Disaster Management." Information & Management 50* (5):218-228. https://doi.org/10.1016/j.im.2013.04.002.

Rahman, H.A. and Mapjabil, J., 2017. *"Landslides Disaster in Malaysia: An Overview"*. Health, 8(1), :58-71.

Robinson, Edward M. 2016. *"Chapter 9 - Special Photography Situations."* In Crime Scene Photography (Third Edition), edited by Edward M. Robinson, 455-586. San Diego: Academic Press.

Sardi, Mohamad Fazli, and Khamarrul Razak. 2019. *"Assessment of Effectiveness of Emergency Response Time during Landslide Event in Malaysia."* ASM Science Journal 12:1-19. doi: 10.32802/asmscj.2019.360.

Sulaiman, Siti. 2019. Is Malaysia Located In The Pacific Ring Of Fire? A Legal Perspective.

Taib, Abdul Kadir, 2014. *"The Importance of Geospatial Information for National Development".* International Convention Centre, Putrajaya.

Varnes, D. 2020. *"Chapter 2 Slope Movement Types and Processes."*

Wang, W., Li, P., Chen, N., Chen, Z. and Wang, C., 2016. *"A Geospatial Decision Meta-Model for Heterogeneous Model Management: A Regional Transportation Planning Case Study".* Arabian Journal for Science and Engineering, 41(3), :1077-1090.

Yang, B., Qiao, L., Zhu, Z. and Wulan, M., 2016. "*A Metamodel for the Manufacturing Process Information Modeling".* Procedia CIRP, 56, :332-337.