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Emerging Trends in Flood and Landslide Research: Single Vs Multi-Hazard Disaster Analysis Using GIS

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ABSTRACT

Floods and landslides, which cause significant loss of human life and economic loss, are the most reported catastrophic events worldwide. The Geographical Information System (GIS) has been recognized as one of the most effective tools in disaster related analysis. Therefore, this article uses GIS to review the development of landslide and flood research for the past 20 years. The main elements in this review are to scrutinize the trend and scope of studies related to disaster mapping around the globe. Amongst the criteria reviewed are; details of the study area, articles that received many citations, journals with high Impact Factor scores, scope breakdown based on single and multi-hazard analysis and the theme of the study. The methodology used in this Systematic Literature Review is based on the PRISMA guidelines. Results from the review found that studies related to disaster mapping are increasing every year. This trend is influenced by data availability, efforts to produce better disaster management, frequent disaster occurrences due to climate change and evolution of GIS to analyse spatial data. Nevertheless, articles related to multi-hazard analysis are still limited, and this study suggests conducting and publishing more studies related to multi-hazard assessment in the future. This review also shows that GIS has been used widely for various types of application in disaster analysis. Articles on disaster risk assessment have been the most common. This review will help other researchers in the field of disaster management to better understand the current trend of studies related to disaster mapping.

Keywords: Disaster; disaster risk management; GIS; flood; landslide

INTRODUCTION

The occurrence of hydrological extremes, particularly heavy rainfall that leads to devastating floods and landslides, is increasing every year. This scenario is worrying and can potentially be caused by global climate change (Shou & Lin 2016; Bathrellos et al. 2018; Kumar & Bhattacharjya 2020).

Floods and landslides are the most reported catastrophic events that occur around the world. These disasters cause significant loss in terms of economic and human lives and lead to disruptions to water supply systems, transportation, communications and infrastructure (Michael-Leiba et al. 2003landslide hazard (H; Khosravi et al. 2018). For example, from 2005 until 2015, it was reported that these disasters resulted in more than 700,000 people losing their lives, 1.4 million people being injured and about 23 million losing their homes. The total economic loss was estimated to be more than $1.3 trillion (United Nations 2015).

Disaster mapping using Geographical Information System (GIS) has been recognized as one of the most effective methods to identify a disaster-prone area and quantify the risk (Abdullah et al. 2018; Abdullah et al. 2019; United Nation 2015). GIS tools and software provide comprehensive mapping techniques that are able to classify, quantify and determine the risk and level of vulnerability of an area to disasters, i.e., floods and landslides.

Flood and landslide vulnerability mapping is very important for catchment management so that every development can be implemented in an environmentally sustainable manner (Tehrany Pradhan et al. 2014). Moreover, comprehensive disaster management planning needs to be implemented to reduce the risk of natural disasters, such as loss of human life and impact on the economy. All relevant parties involved in land use matters need to emphasize the aspect of the disaster hazard prediction map, since the early stage (Bathrellos et al. 2017). The government plays a crucial role in minimizing disaster risk with the collaboration of various parties, such as private agencies.

GIS was initially developed as a database to gather, manage and display spatial data. However, the advancement in technology and continuous improvement via research has significantly increased the capability of GIS to analyze spatial data, including determining hazard, quantifying risk and presenting the results via mapping (Sansare & Mhaske, 2020). In early 2000, mapping was frequently used to state the location of a disaster and to indicate locations prone to risk (Wieczorek 2000).

This systematic literature review (SLR) was conducted to discuss the evolution of the development of landslide and flood disaster mapping studies using GIS tools / software from the year 2000 to 2020. It is intended to provide a complete review of flood and landslide disaster mapping to assist researchers in determining research gaps for future studies. A set of questions, correlated to research pattern of disaster mapping using GIS, was formulated:

1. What is the trend and development of disaster analysis using GIS globally?
2. Who conducted the most research and gained the highest citation?
3. What has been the main scope of the research themes in disaster analysis?

The scope of this SLR includes the trends and scopes of single and multi-hazard studies. Single hazard is defined as the study of a single disaster, i.e., flood or landslide. Multi-hazard means assessment of both flood and landslide in an area, either through correlation between those hazards or joint risk assessment. Through our extensive literature review, we found that most research articles either; (1) treat hazards independently, or estimate the combined risk, without considering coincident or consecutive multiple hazards which could amplify consequences, or (2) evaluate the risk of multi-hazard scenarios at a high level based on statistical analyses, without investigating the actual interrelation among different hazards. Only limited work has considered the interactions between different hazards in the analyses.

MATERIALS AND METHODS

This SLR adapted the method suggested by (Moher et al. 2009) which consists of four major stages, namely; identification, screening, eligibility and documents included in the SLR. This study was conducted by searching for articles in the Web of Science database. Web of Science is selected because it is the most trusted research engine that has been used widely amongst researchers globally (K. Li et al. 2018).

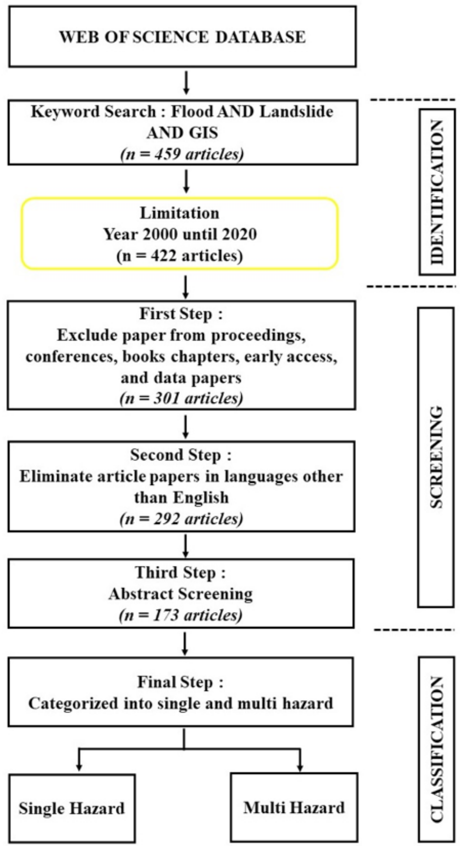

FIGURE 1. Flowchart of methodology following the steps proposed by PRISMA (2009)

IDENTIFICATION

The first stage is to identify articles that fulfill the three (3) keywords, namely "flood", "landslide" and "GIS". These keywords were selected to maximize results and ensure that all related papers are accounted for. This initial search resulted in 459 articles. These articles were further limited to publications within the year 2000 to 2020, in which 422 articles were found. All of these articles were used in the next screening.

SCREENING

The second stage involved three (3) steps in a screening process. The first step was to exclude papers from proceedings (100 articles), book chapters (10 articles), early access (10 articles) and data papers (1 article). Next, articles written in languages other than English were eliminated (9 articles). These nine (9) articles were written in French (1), Turkish (2), Italian (1), Malay (1), Portuguese (1) and Spanish (3).

A further 14 review papers were removed from the list before proceeding to the final step. The final step was abstract screening. Since this study focused on flood and landslide disasters, articles relating to other type of disasters, such as earthquakes, wildfires, prolonged cold hazards and others, were eliminated. From abstract screening, it was found that there were a few papers which did not discuss disaster mapping using GIS, these papers were excluded. Papers related to disasters in coastal areas were also excluded, since this study emphasizes disaster events on land and in mountainous areas only. This screening process resulted in excluding 105 articles.

ELIGIBILITY AND DOCUMENTS INCLUDED IN THE SLR

The 173 selected articles then underwent the third stage, i.e., document eligibility. This step segregates the papers into two major classifications, namely: single hazard or multi-hazard disaster analysis using GIS. The definition of single hazard is when only one type of disaster is included in the study, i.e., either flood or landslide, while multi-hazard is related to two or more disasters. It should be noted that, although disasters other than floods and landslides are not included in the scope of the study, if these disasters are studied together with floods and landslides, then it was included in the selection of articles for multi-hazard assessment. In this final stage, the scope of the study for each article was determined and divided into different themes. A flow chart of the methodology is illustrated in Figure 1.

RESULTS AND DISCUSSION

The results of this SLR are discussed based on several important criteria, such as the number of studies according to year (2000 to 2020), the number of studies based on the study area, which are further categorized into country and continent, publication in reputable journals, Journal Impact Factor score, and the number of citations for each article. Additionally, this review also evaluated research trends on the scope of disaster mapping involving single hazard disaster and multi-hazard disaster. This scope is emphasized to determine the tendency of researchers around the globe to assess the risk of disasters.

GLOBAL RESEARCH TREND

In general, the number of articles published every year from 2000 to 2020 shows a positive trend, with more than 20 articles published in each of the last 3 years (2018, 2019 and 2020), as illustrated in Figure 2. In the first 12 years (2000 – 2011), less than 10 articles were published annually. However, the number of articles has increased significantly since 2012. A total of 118 articles were published between 2015 and 2020 which is significantly more than the number of articles recorded between 2000 and 2014 (15 years) with a total of only 55 articles. The highest number of articles were recorded in 2020. This trend may be influenced by various factors, including data availability, efforts by researchers to produce better disaster management, frequent disaster occurrences due to unpredictable climate change around the globe and evolution and advancement of GIS as a tool to analyse spatial data. Floods and landslides are commonly reported around the globe; however, it is unclear which countries and continents are actively involved in conducting research in the said field. Therefore, the authors segregated the articles according to the geographical location of the study area, as shown in Figure 3. Based on the number of articles written, it can be seen that Continental Asia and Europe are the highest, with 90 and 65 articles, respectively. There are a small number of published articles with study areas in the continents of Oceania, Africa, North America and South America, i.e., 7, 4, 6 and 5 research articles, respectively. Although the Asian continent produces a high number of disaster mapping studies, Italy (located in the European continent) had the most articles.

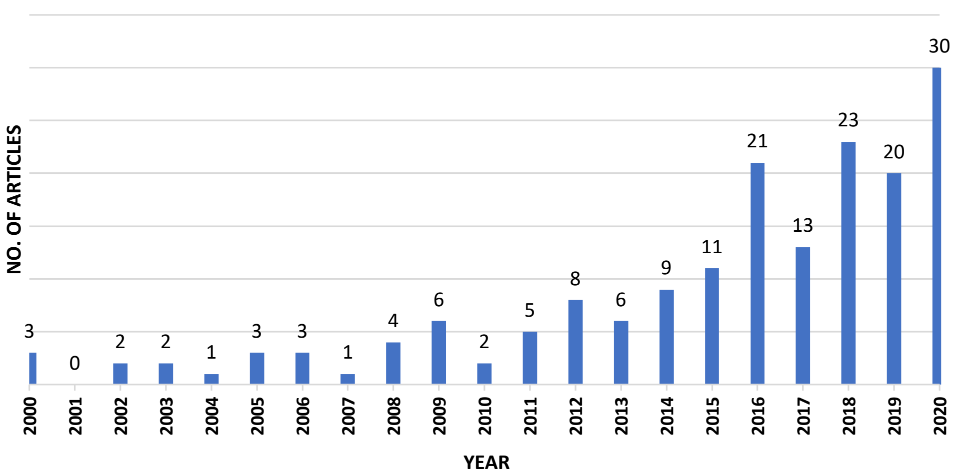

FIGURE 2. Number of published research articles by year 2000 – 2020

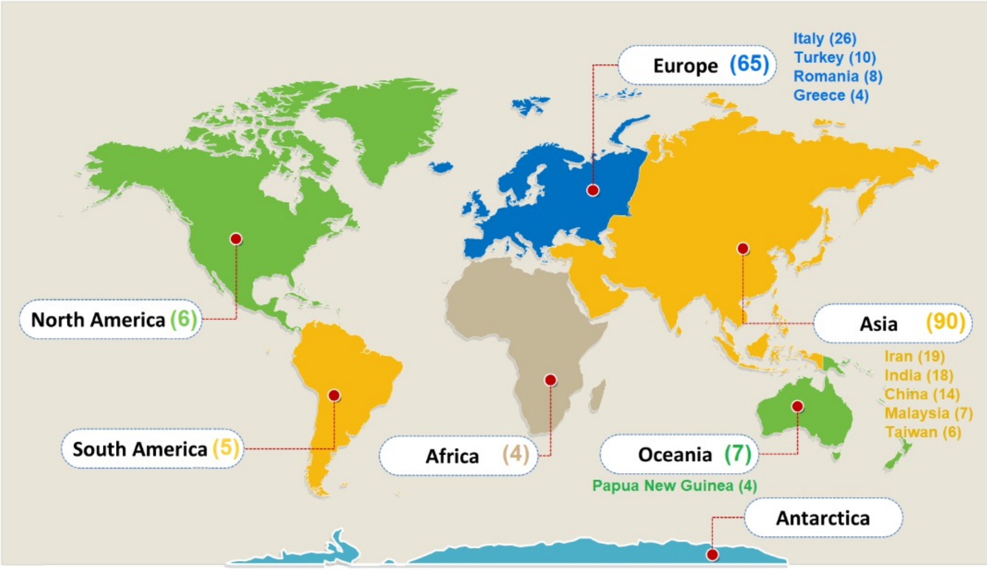

FIGURE 3. Number of published research articles by study area location 2000 – 2020

From the list of 16 countries that produced more than three (3) articles during the 20 years, countries from the Asian continent dominated the list, followed by the continents of Europe, Oceania and Africa. This study also found that there are two (2) articles in more than one (1) study area. The articles are "Integration of GIS with Remote Sensing and GPS for Disaster Mitigation" by (Khan, 2015) and "A collaborative (web-GIS) framework based on empirical data collected from three case studies in Europe for risk management of hydro-meteorological hazards" by (Aye, Sprague et al. 2016) which have three (3) locations of study each.

This review also determines the number of articles produced by a journal as well as the Journal Impact Factor score. The Journal Impact Factor score is very important because it indicates the reliability of a journal among researchers, since the number of citations are taken into consideration when the score of Journal Impact Factor is calculated. There are 13 journals that actively produced articles, which is more than four (4) articles during the study period. With reference to Table 1, Natural Hazards are the most active journal producing articles (17 articles). Other active journals include Environmental Earth Sciences, Natural Hazards and Earth System Sciences, Geomatics Natural Hazards & Risk, Science of The Total Environment, Journal of Hydrology, Geomorphology and CATENA, which produced at least five (5) articles in the same period. Nevertheless, there is a significant difference between the number of articles and the Journal Impact Factor. It was observed that the number of articles does not affect the impact factor of a journal. For instance, the journal Science of the Total Environment only produces about six (6) articles during the study period, although it has the highest impact factor among all the active journal lists. Another example is the journal Engineering Geology which only produced 4 articles related to disaster mapping, but has a high Journal Impact Factor of 4.779.

The scope of the journal also plays an important role in reviewing articles. Through the scope of the journal, researchers can focus on relevant topics, especially in the field of disaster management. Researchers can choose the suitability of a journal for publication of an article. This study also helps prospective researchers find suitable articles for the research gap, based on the list of journals.

TABLE 1. Journal Impact Factor according to journal and number of articles

Journal Name	Number of Articles (2000–2020)	Journal Impact Factor (2019)
Natural Hazards	17	2.427
Environmental Earth Sciences	10	2.180
Natural Hazards and Earth System Sciences	8	3.102
Geomatics Natural Hazards & Risk	6	3.333
Science of the Total Environment	6	6.551
Journal of Hydrology	5	4.500
Geomorphology	5	3.819
Catena	5	4.333

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Engineering Geology	4	4.779
Environmental Monitoring and Assessment	4	1.903
ISPRS International Journal of Geo-Information	4	2.239
Sustainability	4	2.576
Arabian Journal of Geosciences	4	1.327

This study also assessed the citation trends for each article. A high number of citations indicates that the article was used as a reference many times by other researchers. Amongst the total of 173 articles, this study listed 15 articles with the highest citation. Top of the list is an article entitled "Flood susceptibility mapping using a novel ensemble weights-of-evidence and support vector machine models in GIS". This study was done by three (3) researchers using a combination of weight of evidence and support machine models to develop a flood susceptibility map and was conducted in Terengganu, Malaysia in 2014.

The weight of evidence technique is used to determine the weight of each flooding factor and this result is used in the Support Vector Machine to determine the relationship between flood occurrences and the factors, together with floods and landslides, as a condition to be selected in this review study. The data showed that, out of the total of 173 articles reviewed in this study, 116 articles were written related to single hazard mapping, while the remaining 57 articles were written related to multi-hazard, as shown in Figure 4. A summary of articles according to the themes is listed in the Table 2.

SINGLE HAZARD

Initially, GIS was used to collect, arrange, and map the spatial information, but now it has the capability to analyze spatial data. In this review, the functions of GIS in disaster mapping were determined. The results show that studies integrated with GIS have several specific functions in disaster mapping. Therefore, to ease the discussion in this manuscript, the authors proposed that the specific functions in disaster mapping are categorised into seven (7) specific research themes. The themes are divided based on the abstract, objectives, and the results presented from the screened articles.

The specific themes and their description are listed below:

Identify – The main focus of this theme is identifying areas prone to disasters and hazards

Modelling / simulation – Disaster modelling / simulation (either flood or landslide) using appropriate applications and methods with integration of GIS.

Prediction – Prediction of landslide or flood disasters through spatial distribution.

Susceptibility / vulnerability mapping – Related to the susceptibility / vulnerability mapping for floods or landslides. Susceptibility map normally used to plan development in a potential area.

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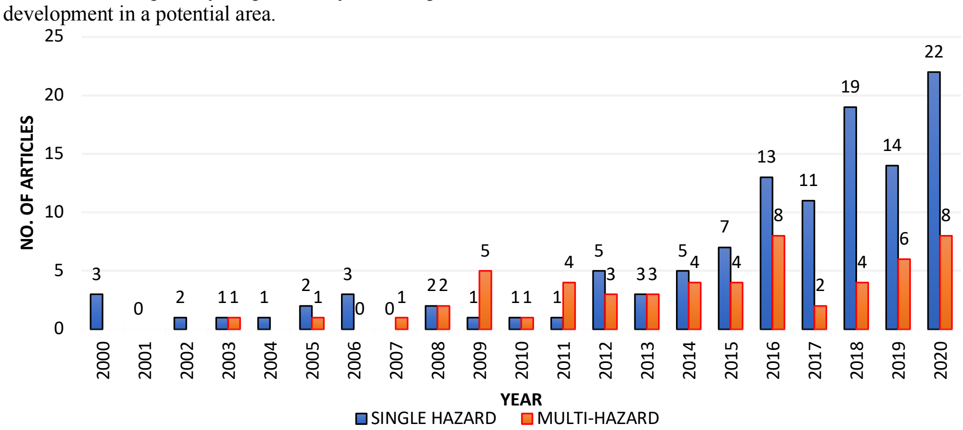

FIGURE 4. Comparison between single and multi-hazard papers 2000 – 2020

Risk assessment / hazard assessment – Estimation of inundation potentials downstream, debris-flow risk, landslide susceptibility, flood vulnerability, flood risk mapping using multi-criteria decision approach (MCDA), landslide risk, land use change risk, evaluate the possibility and probability of hazard characteristics, the pattern of occurrence of a disaster and the effects of disasters on an area.

Inventory / database – Studies conducted with the aim to collect disaster information for the purpose of database development. This database is produced to examine past events for the purpose of risk assessment. Among the examples of focus in this theme were established landslide inventory maps at medium (1: 25,000), regional (1: 100,000) and national (1: 500,000) scales and spatial information database

Comparison – The differences between the types of maps, the methods used when making prediction studies, and their effectiveness are categorized under this theme. For example, comparing landslide inventory maps, statistical and geomorphologically based density maps, landslide hazard maps, and performance of different approaches in disaster prediction.

MULTI-HAZARD

There were slight differences in the focus of the study for multi-hazard assessment, despite having similar themes to single hazard assessment. There are seven (7) research themes identified in this study:

Identification - The scope of this theme was to identify unsafe areas with a high risk of multi-hazard. This theme also explained areas where floods and landslides frequently occur and identified various dimensions of information that contribute to disasters.

Modeling / simulation - Assess the drawbacks in terms of prioritizing disaster mitigations by modeling five (5) different hazards (flood, heat, seismic, wind speed and landslide).

Prediction – evaluation of disaster predictions based on meteorological factors. In addition, other studies conducted produced multi-hazard probability maps as well as the occurrence of multi-disasters. The output from probability maps was verified by comparing the results with the landslide inventories together with geophysical and geotechnical maps. There are also studies that use different remote sensing and mapping technologies as tools for predicting the next disasters.

Susceptibility / vulnerability mapping – Study that combined several single hazard maps into a multi-hazard map. Multi-hazard susceptibility maps have many advantages. For instance, they can be used as a source of information for the purpose of land use planning before implementing a development (Muhamad et al. 2019). In addition, multi-hazard assessment maps could also make predictions of future occurrences (Skilodimou et al. 2019). The results of this map can also classify the areas prone to disaster according to hierarchy. This will make it easier for engineers, planners, and authorities to take appropriate planning and mitigation action in the specified area.

Risk assessment / hazard assessment - The relationship between risk, hazard and vulnerability can be expressed using the following concept:

RISK = HAZARD X VULNERABILITY

Decisions concerning the hazard being considered can be computed within GIS by employing rules based on geological and geomorphological aspects, potential effect of alpine natural hazards on water supply, disaster risk, disaster damage level, relationship between the risk parameters, level of vulnerability, potential natural hazard areas, ecological risk, geo-hydrological risk, risk map for mountainous, impact of human and geo-environmental to the hydrological hazards.

Comparison – Comparison of each contributing factor to the disasters. They ranked the factors according to the biggest contributors to a disaster using QGIS and Arc-GIS software in disaster mapping

Inventory / database – Evaluate the ability of GIS to correlate between textual and spatial information to produce databases for the future. Web-GIS decision support platform, impacts of hazards using Database Management System (DMS). In addition, there are articles that focus on the development of databases for disasters that caused personal harm, evacuees and displaced people, and the effect on the economy. Several articles were written purposely to develop web-GIS by using open-source geospatial software and technologies. The objective of this web platform is to guide the relevant parties in managing the disaster risk depending on their roles and responsibilities.

Figure 5 illustrates the number of articles for single and multi-hazard studies according to the specified research themes.

There are few articles which have more than one (1) theme which affect the overall number of articles. The highest recorded theme was risk / hazard assessment (67 articles) while the lowest was modelling and simulation (15 articles). Researchers tend to study risk assessment, as it is the most important preventive action to minimize the impact of disaster. From these findings, it can be concluded that researchers could focus more on the disaster modelling theme with the application of the latest technologies, such as Artificial Intelligence, in the future. Furthermore, themes such as disaster database and comparison method might be considered in future studies. This study is expected to assist researchers to discover gaps in disaster management using GIS.

WAY FORWARD

Based on the results of this study, articles related to multi-hazard disaster mapping using GIS were still low in number. There was a significant difference gap between single hazard disaster and multi-hazard disaster articles. Looking at the trend of the published articles, the number of articles for multi-hazard mapping is only nearly half from the entire articles related to disaster mapping. However, the number of articles published increase every year, which showed interest from researchers to study this topic.

The common focus of study in single hazard studies is risk assessment, while the data management / inventory theme got less attention among researchers. Towards the era of IR 4.0, data management is one of the important elements regarding the development of big data. Thus, themes for data management, such as the disaster information, correlation of disasters to climate change, losses caused by disasters, is recommended for future research. For multi disaster assessment, the comparison theme was still less published.

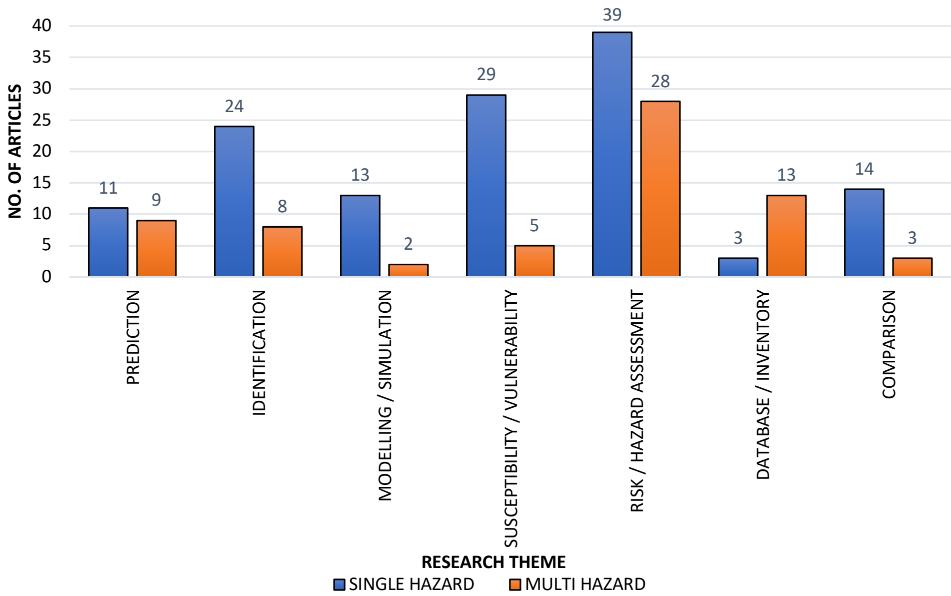

FIGURE 5. Number of articles according to the research themes 2000 – 2020

One of the interesting focusses of study is comparing the eligibility of open-source software (e.g. QGIS and GRASS GIS) and commercial software (e.g. ArcGIS and Global Mapper), when mapping. However, this study that has been conducted was to compare capabilities between QGIS and ArcGIS in terms of developing thematic maps and data analysis. Results showed that open-source software such as QGIS had the same output as commercial software like Arc-GIS (Sansare & Mhaske 2020).

In future research, consideration should be given to the comparison in terms of time consumed to analyze data, analysis tools, friendly user of the GIS software and many more. Due to rapid urbanization, extreme climate change, and emerging population growth, relevant authorities must look at the various natural threats regarding disaster risk reduction. Multi-hazard assessment is more relevant and holistic, as it accounts for many aspects, criteria, and perspectives in measuring the vulnerability of the study area. A combination of experts will contribute to a comprehensive database on multiple information relating to disaster hazards, risky area, etc. It may help many parties such as planners, government agencies, developers, engineers, and researchers as a reference during the development planning process and during the research related to disaster management.

CONCLUSIONS

This study aims to review previous studies related to disaster mapping using Geographical Information System (GIS). We discovered that the year 2020 recorded the highest number of articles compared to the previous years, while the continent of Asia is the most studied area in this review because, according to (United Nation 2020), the top ten (10) most disastrous occurrences in the world were dominated by countries from Asia. The title of the study that obtained the utmost citation was “Flood susceptibility mapping using a novel ensemble weights-of-evidence and support vector machine models in GIS” written by (Tehrany et al. 2014). For scope assessment, we divided disasters into single hazard and multi-hazard. There are seven (7) research themes for single hazard which were identification, modelling / simulation, prediction, susceptibility / vulnerability mapping, risk assessment / hazard assessment, inventory / database, and seven (7) research themes on multi-hazard. The themes for multi-hazard are identification, modelling / simulation, prediction, susceptibility / vulnerability mapping risk assessment / hazard assessment, inventory / database, comparison. The goal of this study is to help researchers in the field of disaster management make references related to disaster management using GIS applications.

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DECLARATION OF COMPETING INTEREST

None

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TABLE 2. Summary of scope of the study

Research Themes	Single Disaster	Researchers	Multi Disaster	Researchers
	Focus of Study		Focus of Study	
Identifying	Identify vulnerable areas to hazard	(Wieczorek.Pdf, n.d.), (Clerici & Perego, 2000), (P. K. Rawat, Pant, et al. 2012), (Popa et al. 2019), (Costache & Zaharia, 2017), (Das, 2018), (Bathrellos et al. 2018), (Sarkar & Mondal, 2020), (Khosravi et al. 2018), (Costache et al. 2019), (Kuniyal et al. 2020), (Negi et al. 2020)	Susceptible sites of a water supply system (WSS)	(Möderl et al. 2008)
	Identify hazard characteristic	(C. Audisio & Turconi, 2011), (Nguyen et al. 2013), (Rinaldi et al. 2016), (Ismail et al. 2017), (S. H. Peng, 2018), (Sarkar et al. 2020)	Identify hazardous / unsafe areas	(Chiara Audisio et al. 2009), (Ishida et al. 2011)
	Identify level of susceptibility	(Rawat & Sharma, 2012), (Ghosh et al. 2019)	Identify the flood and landslide spot	(Najafabadi et al. 2016), (Sansare & Mhaske, 2020), (C. Li et al. 2018), (Gaston, 2009), (Shrestha et al. 2016)
	Identify patterns of hazard	(Keller & Atzl, 2014)		
	Identify impacts of hazard	(Yulianto et al. 2015), (Keller & Atzl, 2014), (Al-Saady et al. 2016)		
Modelling / Simulation	Simulate the material descent through a cellular automata model	(Clerici & Perego, 2000)	Spatial distribution of five natural hazards in the context of the WHO/EMRO	(El Morjanil et al. 2007)
	Model the spatial distribution of rainfall-induced	(Abucay et al. 2012)	Modeling the natural hazards' implications on transportation network	(Toma-Danila et al. 2020)
	Landslide modelling	(Lai et al. 2013), (Bartelletti et al. 2015), (Bout et al. 2018), (Lin et al. 2017), (Mergili et al. 2018)	Predictive models for susceptibility mapping	
	Flood modelling	(Tien Bui et al. 2016), (Arabameri et al. 2020), (S. Elmahdy et al. 2020), (C. Y. Chen & Wang, 2017)		
	Spatial modelling	(Tehrany, Pradhan, & Jebur, 2015)		
	Assessment of landslide susceptibility models	(Paulín & Bursik, 2017)		
Prediction	Predicting spatial distribution of landslide hazard	(Mason & Rosenbaum, 2002), (Perotto-Baldiviezo et al. 2004), (Lee et al. 2017)	Future geohazard changes in a changing climate	(Jaedicke et al. 2008)
	Predicting spatial distribution of flood hazard	(Tehrany & Kumar, 2018), (W. Chen et al. 2019)		
	Prediction technique capability	(Tehrany, Pradhan, Mansor, et al. 2015), (Shafapour Tehrany et al. 2017), (Rezaei et al. 2020)	Multi-hazard probability map	(Yousefi et al. 2020), (Giardino et al. 2012), (Mirzaei et al. 2018), (Pourghasemi et al. 2019)
	Landslide activit	(Havenith et al. 2006)d, (Lee et al. 2019), (Lay et al. 2019)	Occurrence of multi-disaster	(S. I. Elmahdy & Mostafa, 2013), (Yanar et al. 2020), (Khan, 2015), (Augusto Filho et al. 2020)

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Susceptibility / Vulnerability Mapping	Produce flood / debris flow susceptibility map	(Tehrany, Lee, et al. 2014), (Khosravi et al. 2016), (C. Cao et al. 2016), (Youssef et al. 2016), (Samanta et al. 2018), (Harley & Samanta, 2018), (Lee et al. 2018), (Al-Juaidi et al. 2018), (Ali et al. 2019), (Siahkamari et al. 2018), (Das, 2018), (Kumar & Bhattacharjya, 2020), (Shafapour Tehrany et al. 2017), (Gudiyangada Nachappa & Meena, 2020), (Rahmati et al. 2016), (Roy et al. 2020), (Al-Abadi & Al-Najar, 2020), (S. Elmahdy et al. 2020), (Sarkar & Mondal, 2020), (Al-Abadi & Al-Najar, 2020), (Esper Angillieri, 2020)	Multi-hazard susceptibility map	(Bathrellos et al. 2017)Greece, (Skilodimou et al. 2019), (Nachappa et al. 2020)
	Produce Landslide susceptibility map	(Turer et al. 2008), (Meten et al. 2015), (Hashim et al. 2018), (Aghdam et al. 2017), (Lee et al. 2017), (Panahi et al. 2020), (Arabameri et al. 2019), (Can et al. 2005)	Multi-hazard exposure map	(Rahmati et al. 2019), (Dragicevic et al. 2011)
Risk Assessment / Hazard assessment	Inundation potentials downstream	(M. H. Li et al. 2002)	Geological and geomorphological aspects	(Duman, Can, et al. 2005)
	Debris-flow risk	(Gentile et al. 2008), (Negi et al. 2020), (C. Y. Chen & Wang, 2017)	Potential effect of alpine natural hazards on water supply	(Möderl et al. 2008)
	Landslide susceptibility	(Tošić et al. 2014), (Shou & Lin, 2016), (Sestras et al. 2018), (Liu et al. 2018), (Wang et al. 2018), (Rather et al. 2017)	Disaster risk	(Tüdeş & Yilmaz, 2009), (P. K. Rawat, Tiwari, et al. 2012), (Turconi et al. 2014), (Ciampalini et al. 2019), (Y. Peng et al. 2016), (Dragicevic et al. 2011), (Frigerio & Van Westen, 2010), (Möderl et al. 2008), (Sheikh et al. 2019)
	Flood vulnerability	(Luino et al. 2012)northwestern Italy, (Xiong, Li, et al. 2019)	Disaster damage level	(Lyu et al. 2018), (Petrucci & Polemio, 2003), (Aceto et al. 2016)
	Flood susceptibility	(Morelli et al. 2014), (Marconi et al. 2016), (Malik et al. 2020), (Romero & Cigna, 2020), (Y. Cao et al. 2020), (Janizadeh et al. 2019), (Tang et al. 2020)	Relationship between the risk parameters	(Ćosić et al. 2011)
	Flood risk assessment method	(Samanta et al. 2016), (Thongs, 2019), (Morea & Samanta, 2020)	Level of vulnerability	(Sdao et al. 2011), (de Almeida et al. 2016), (Mirzaei et al. 2018),(Soemabrata et al. 2018)
	Landslide / soil erosion risk	(Michael-Leiba et al. 2003), (Sujatha & Rajamanickam, 2015), (Karsli et al. 2009), (Al-Saady et al. 2016), (C. Y. Chen et al. 2010), (Donnini et al. 2017), (Biçer & Ercanoglu, 2020), (Xiong, Sun, et al. 2019), (Ebrahimzadeh et al. 2018)	Potential natural hazard areas	(Milevski et al. 2013), (Chou & Lee, 2014), (Turconi et al. 2015), (Nicu & Romanescu, 2016), (Milevski et al. 2017), (Furdu et al. 2013)
	Evaluate the possibility and probability of hazard	(Can et al. 2005), (Seijmonsbergen & de Graaff, 2006), (Cimini et al. 2016), (H. T. Nguyen et al. 2013), (Kain et al. 2018), (T. N. Nguyen et al. 2019), (Celik et al. 2006)	Geo-hydrological risk	(Petrucci et al. 2009)
	Risk Index	(S. H. Peng, 2018)	Risk map for mountainous	(Yousefi et al. 2020)
			Impact of human and geo-environmental to the hydrological hazards	(Aronica et al. 2012)

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... continued

Inventory / Database	Establish landslide inventory maps at medium (1:25,000), regional (1: 100,000) and national (1:500,000) scales	(Duman, Çan, et al. 2005)	Data entry for comparing information on different temporal and spatial scales	(Chiara Audisio et al. 2009)
	Spatial information database	(Vinet et al. 2019), (Ghosh et al. 2019)	Disaster database	(Santos et al. 2014), (Zêzere et al. 2014), (M. S. Rawat et al. 2015), (Sano et al. 2020), (Y. Peng et al. 2016)
			Web-GIS decision support platform	(Aye et al. 2015), Charrière, et al. 2016), (Aye, Sprague, et al. 2016), (Alfredo Mahar et al. 2017), (Frigerio & Van Westen, 2010)
			Impacts of hazards using Database Management System	(P. K. Rawat, 2012)
			Historical data on flood and landslide	(Salvati et al. 2009)
Comparison	Compare reconnaissance and detailed landslide inventory maps, statistical and geomorphologically based density maps, and landslide hazard maps	(Guzzetti et al. 2000)	Impact of effective factors on the occurrence of different natural hazards	(Pourghasemi et al. 2020), (Shrestha et al. 2016)
	Performances of different approaches	(Khosravi et al. 2016), (Tehrany et al. 2013), (Pham et al. 2020), (Tehrany & Kumar, 2018), (Al-Abadi & Al-Najar, 2020), (Lin et al. 2017), (Panahi et al. 2020), (W. Chen et al. 2020), (Khosravi et al. 2018), (Trigila et al. 2015), (Tehrany, Pradhan, et al. 2014)	Usage of QGIS and Arc-GIS software	(Sansare & Mhaske, 2020)
	Evolution of landslide occurrence	(Fan et al. 2018)		
	Changes in soil erosion rates	(Chinnasamy et al. 2020)		