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Conceptual Development of a Geographical Information System (GIS) Database for Earthquake Risk Assessment

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ABSTRACT

Geographic Information Systems (GIS) play a pivotal role in earthquake risk assessment, providing a comprehensive framework for understanding, analyzing, and mitigating the impact of earthquakes. This article explores the integration of GIS conceptual design with Entity-Relationship (ER) diagram development, enhancing the spatial database design for earthquake risk assessment. The complexity of earthquake events introduces challenges in designing a conceptual model that accounts for their dynamic nature, including aftershocks and evolving seismic patterns, demanding a framework capable of capturing these layered interactions. Achieving high spatial resolution to address localized risks while managing large datasets adds another layer of complexity, necessitating careful design considerations. The goal of this research is to develop a GIS-based conceptual design for earthquake risk assessment. This involves identifying essential spatial and attribute data; conducting a systematic review and user requirement analysis; and developing an ER diagram to represent the conceptual structure. The resulting model organizes data into three core modules: the hazard layer, cadastral layer, and potential risk layer. The cadastral layer supports both hazard and risk analyses. The hazard layer incorporates fault lines, historical earthquake data, geology, and seismic zones, aiding in land-use planning and emergency responses. The potential risk layer produces seismic vulnerability maps that encompass social, economic, physical, and environmental aspects. These outputs contribute to determining the earthquake risk levels for both populations and constructions, providing valuable insights for risk assessment and management. By integrating ER diagram development, this approach enhances data organization and supports more effective earthquake risk management through a robust and scalable GIS framework.

Keywords: GIS conceptual design; earthquake risk assessment; ER diagram

INTRODUCTION

Earthquake-related challenges are worldwide occurrences that demand optimal resolution strategies. Often, the aftermath of an earthquake leads to widespread devastation, causing both economic and social harm, including loss of life. Consequently, interventions in disaster management are orchestrated to furnish lasting safeguards against disasters, primarily for preventive objectives. The mitigation process, conceived as a proactive strategy, seeks to diminish the adverse effects of disasters on societies, individuals, and the environment. Preparedness entails proactive measures implemented before a disaster unfolds, aiming to anticipate, respond to, and navigate the consequences of the impending disaster (Bahari et al. 2025).

An earthquake, being an unforeseeable natural disaster, necessitates significant actions in earthquake management to mitigate its effects. This process involves addressing the complex interplay of social, economic, and physical elements within a community, encompassing the construction of structures in areas susceptible to earthquake hazards (UNDRR 2021; UNISDR 2015). Collaboration among administrators, planners, disaster response agencies, engineers, architects, and the community is essential for efficacious earthquake risk management. Earthquake risk management has proven indispensable across all disaster phases—pre, during, and post. In non-emergency contexts, an earthquake risk plan aids city planners in formulating land-use policies for high-risk areas, assists Public Works Departments in locating infrastructure within the risk zone, and enables disaster response agencies to refine their response strategies.

During and after an earthquake, this type of plan assists emergency teams in identifying vulnerable areas, determining safe evacuation locations, and allocating limited emergency resources like shelter, aid, food, and water based on priority. Post-disaster, insurers can reassess properties, authorities can utilize contingency plans, and resource allocation for recovery can be determined. Effective earthquake risk management brings numerous other benefits.

The spatial information system is crucial for assessing earthquake risks as it facilitates spatial modeling, allowing the creation and visualization of models that represent hazards and illustrate the ramifications of these hazards in terms of risk and planning. Often conveyed through maps, spatial information enhances comprehension of the geographical context of a disaster by addressing essential questions related to the disaster situation, such as the who, what, where, why, and how. GIS offers functionalities that swiftly adjust the statistical representation of data, generating thematic maps that aid users in comprehending the development and causation of a disaster situation (Tomaszewski 2015).

The aspects of ‘what’ and ‘when’ within a map hold particular significance in depicting the dynamics of a disaster. For instance, questions like “What is the extent of the disaster?” or “When will the disaster rescue team reach the disaster area from the disaster center?” are pivotal. On the other hand, the ‘why’ and ‘how’ aspects focus on the role of maps in aiding decision-making and reasoning in disaster management. For instance, manipulating a basic operation, such as controlling the data layer (turning it on and off), empowers users to make comparisons and gain insights into how a disaster unfolded. The interactions between the map reader and the map itself contribute to insights, reasoning, and decision-making, encompassing the ‘how’ and ‘why’ aspects of a disaster.

GIS holds significance across all stages of disaster management, encompassing preparedness, mitigation, response, rescue, and recovery (Khan et al. 2023; Manfré et al. 2012). In the realm of planning and preparedness, GIS is instrumental in tasks such as crafting evacuation routes, delineating evacuation zones, and conducting scenario modeling. These simulations address hypothetical scenarios, aiding in the development of disaster capacity and readiness (Mili et al. 2017; Shadmaan & Popy, 2023; Tomaszewski, 2015; Walker et al. 2014). Moreover, GIS facilitates the seamless creation and updates of maps highlighting vulnerable areas in earthquake risk assessment. The earthquake risk or damage potential of a region results from the interplay between seismic hazard and vulnerability. Utilizing GIS, one can easily visualize the spatial distribution of population exposure, the built environment, community resilience, and adaptive capacity, thereby offering convenient graphical inputs and outputs. The application of the GIS tool for multi-hazard risk assessment is illustrated in Figure 1.

At the international level, various GIS-based frameworks for earthquake risk assessment have been created, each emphasizing different components of risk management. For instance, the HAZUS framework devised by FEMA in the United States provides standardized methodologies for assessing potential earthquake losses, although it mainly relies on predefined data models with limited flexibility in database customization (FEMA, 2018). The Methods for the Improvement of Vulnerability Assessment in Europe (MOVE) framework approaches the multi-dimensional nature of vulnerability and risk as a combination of exposure, susceptibility, and resilience components (Birkmann et al. 2013). Beyond Europe, approaches such as the Integrated Earthquake Safety Index (IESI) and Relative Seismic Risk Index (RSRi) have been applied, particularly in the Tehran region, to combine hazard, vulnerability, and response capacity into a holistic seismic risk assessment (Hajibabaee et al. 2014; Mili et al. 2017). Compared to these existing approaches, our study contributes to the field by integrating ER diagram development into the conceptual design of GIS for earthquake risk assessment. This integration ensures a systematic structuring of spatial and non-spatial entities, enhancing data organization, scalability, and adaptability for local settings.

Earthquake risk assessment using Geographic Information Systems (GIS) represents a powerful and comprehensive approach to understanding and mitigating the impact of seismic events. GIS leverages spatial data and analytical tools to integrate various layers of information, providing a holistic view of the factors contributing to earthquake risk. GIS enables the mapping of seismic hazards, incorporating data on fault lines, historical earthquake occurrences, and ground shaking intensities. By overlaying this information with critical infrastructure and population density maps, analysts can identify areas prone to higher earthquake risk (Sauti et al. 2022). This spatial analysis is instrumental in prioritizing resources for preparedness, response, and recovery efforts.

One key aspect of earthquake risk assessment through GIS is the evaluation of structural vulnerability. GIS facilitates the creation of detailed building inventories and the integration of structural characteristics, construction materials, and vulnerability assessments. This information aids in identifying structures that are more susceptible to damage during an earthquake, enabling targeted interventions and retrofitting measures.

Moreover, GIS plays a crucial role in assessing socio-economic vulnerability. By incorporating demographic data, land-use patterns, and socio-economic indicators into an analysis, GIS helps identify vulnerable populations and areas with limited resources for coping with and recovering from seismic events. This knowledge informs emergency response planning and community resilience strategies. Furthermore, GIS supports scenario modeling and simulation, enabling planners to anticipate the potential impacts of various earthquake scenarios. This proactive approach assists in developing and testing emergency response plans, identifying evacuation routes, and optimizing resource allocation based on different seismic intensities and affected areas.

The design of the GIS database was one of the important tasks to achieve in order to meet the requirements of applications utilized by the proposed users. The principles of the GIS database design involved organizing a multiple thematics layer for a common geographical area. The geographical data collection comprised homogeneous features of class layers, including points, lines, polygons, rasters, and surfaces. Moreover, the design aimed to create a comprehensive database framework, enabling a holistic perspective of the database for defining and evaluating interactions and links between elements. It also sought to identify potential bottlenecks and problematic areas, facilitating consideration of alternative designs. The design aimed to determine the necessary correct data while filtering out irrelevant information. Additionally, it aimed to define update procedures that would allow the merging of updated data in the future.

Generally, the three key elements in the GIS database design comprise the conceptual design needed to determine the application requirements based on the end user utilization. Subsequently, the logical design specified the logical structure of the database elements for a particular GIS software package. Finally, the physical design, involving hardware and software characteristics, required consideration of the file structure, memory and disk space, access, and speed. Each stage of the database design was closely interrelated, and a detailed and lengthy process was required to ensure success and prevent the failure of GIS project applications when used by organizations.

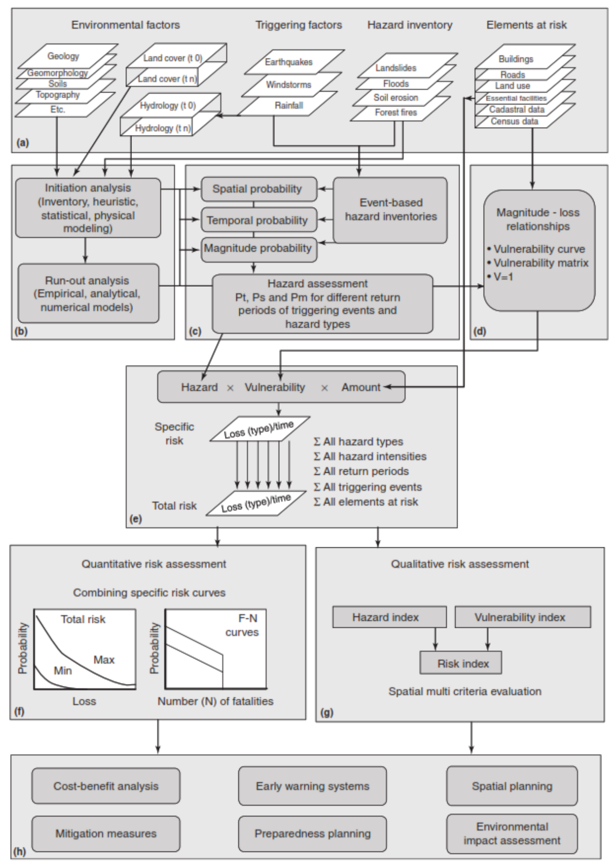

FIGURE 1. GIS framework for assessing risks from multiple hazards (Van Westen 2013)

This article aims to propose a GIS-based conceptual design for earthquake risk assessment. To address this, the following research objectives were pursued: first, to identify the entities, attributes, and relationships involved in earthquake risk assessment; and, second, to design and develop an ER diagram specifically tailored for earthquake risk assessment.

METHODOLOGY

GEOSPATIAL DATABASE DEVELOPMENT

The creation of the GIS-based earthquake risk assessment followed the established procedure outlined in the System

Development Life Cycle (SDLC). The SDLC is a structured approach to developing an information system database that aligns with user requirements. In essence, a database is a well-organized collection of data, with each piece of information interconnected or related to other datapoints within the set. Typically, the SDLC encompasses key stages and activities in the system development process, commencing with problem identification, progressing to the analysis of user requirements, and advancing through system development, which includes database design and programming. The procedures are in sequence, as the results of each stage form the input for the next stage of the system development life cycle. The stages of the process are shown in Figure 2.

PRELIMINARY STUDY

The initial phase in the process of assessing the need for an upgrade or replacement of the existing earthquake risk assessment database is the preliminary study. This stage involves a thorough examination to define the primary problem areas within the domain of earthquake risk assessment. This type of study entails investigating, identifying, prioritizing, and organizing the issues that necessitate attention. Subsequently, a comprehensive work plan was devised to address the shortcomings in the current system. This plan specifically focuses on the integration of GIS technology into the earthquake risk assessment database, aiming to enhance its capabilities and effectiveness.

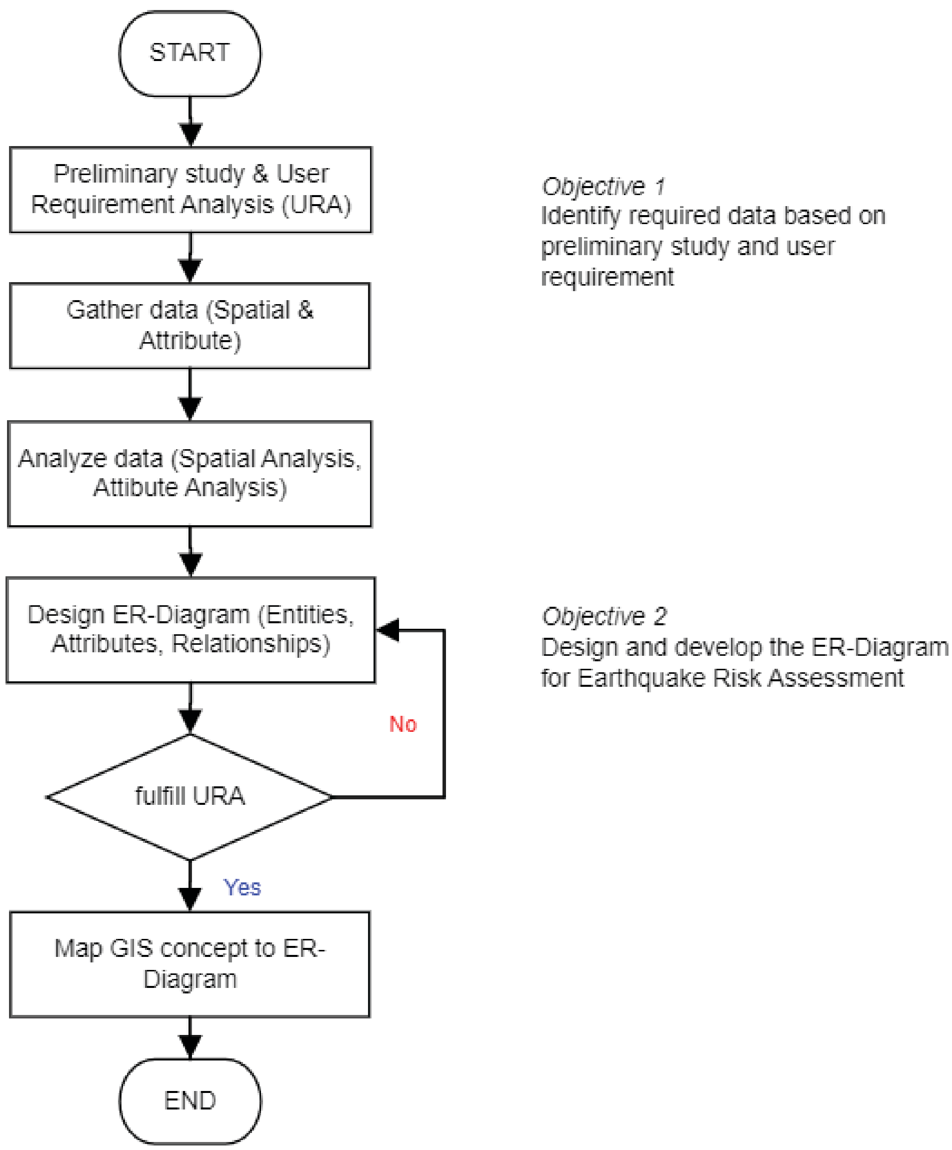

FIGURE 2. Methodology of GIS database development

USER REQUIREMENT ANALYSIS (URA)

The integral part of developing an information system is to understand the needs and requirements of its users (Stefanou, 2022). Therefore, the first step was to identify the user group or stakeholders for this study. The teams thus identified were the Malaysian Meteorological Department (MET Malaysia), National Disaster Management Agency (NADMA), and Mineral and Geoscience Department Malaysia (JMG), all of which are community-based disaster risk management (CBDRM) bodies responsible at the pre-disaster stage for the mitigation and preparedness of an earthquake disaster event (Chong & Kamarudin, 2017). The application of the needs assessment analysis consisted of four steps, as shown in Figure 3. Once the users had been recognized, interview sessions were carried out to gain information about their needs or requirements that might be met by the new system. The objective of these sessions was to identify issues that needed to be tackled. The user needs and requirements identification process and the evaluation activities process were done in parallel to generate new ideas and define the strengths and weaknesses of the current situation in the earthquake management system. If users and system developers had a thorough understanding, this would contribute to the success of the new system application. Finally, the requirement specification was the primary reference within the process of designing and developing the database system (Sauti et al. 2023).

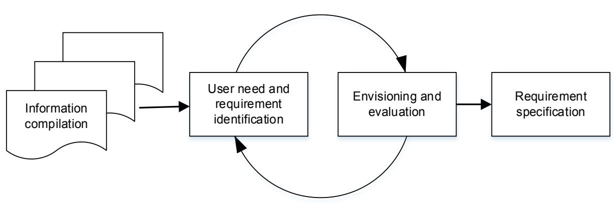

FIGURE 3. URA (Maguire & Nigel 2002)

PREPARATION OF CONCEPTUAL DATABASE DESIGN AND DEVELOPMENT

Database design is a crucial aspect of developing an earthquake risk assessment to produce a database schema that describes the database structure, data types, and constraints on the database. The database construction consisted of the conceptual design, logical design, and physical design. Generally, conceptual design is a process of data modeling used to represent the geographical data in a database (Hapizah Musa et al. 2018). In this study, the ER diagram approach was used to represent the group of entities within a database system and the relationships between these entities (Carvalho et al. 2023).

The ER diagram functions as a schematic for illustrating relationships across spatial entities, characteristics, and layers within a GIS database. The diagram ensures a systematic and coherent representation of spatial data by directly mapping GIS ideas into ER components. This provides a solid foundation for database construction and subsequent analysis. The internal structure of an entity encapsulates information such as the entity name, supplementary details indicating the spatial object type (point, line, or polygon), a code denoting the topology, and a code specifying the encoding of the spatial entity through coordinates. The basic entity symbol for a spatial object is shown in Figure 4.

In this phase, all the entities related to the earthquake risk assessment database were mapped to represent the spatial relationships between them. For example, the epicenter-fault line relationship represented a one-to-many relationship, whereby many epicenters were located near a fault line (Figure 5).

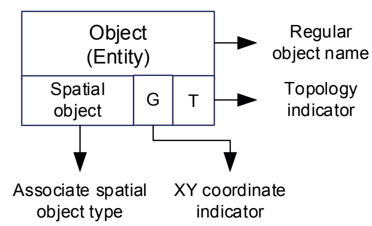

FIGURE 4. Entity symbol for a spatial object (adopted from Chen (1976))

The logical design provides a detailed description of the data, irrespective of its physical implementation in the database. Characteristics of logical data models encompass all entities and their interrelationships. Each entity's attributes are articulated in logical schemes, offering comprehensive and detailed information (see Figure 6).

The physical design is the last process after creating the logical design when developing the database. The physical design defines how data are stored in the database to optimize performance while ensuring data integrity by avoiding unnecessary data redundancy. The design displays the structures of all the tables, encompassing details such as column names, column data types, column constraints, primary keys, foreign keys, and the relationships between tables.

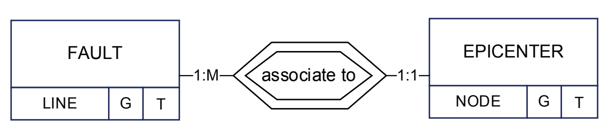

FIGURE 5. Illustrating the spatial relationship between fault and epicenter

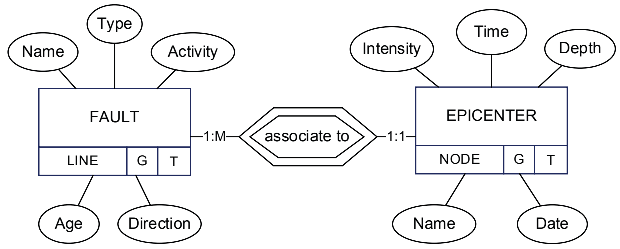

FIGURE 6. Spatial relationship between fault and epicenter associated with attribute data

RESULTS AND DISCUSSION

DATA ACQUISITION AND ORGANIZATION

A systematic literature review was conducted on disaster management, earthquake risk management, earthquake risk assessment, and GIS technology application in earthquake risk management and measurement. This process helped to identify, consider, and synthesize all the empirical evidence that met specified eligibility criteria to answer a given research question.

In constructing the research aim, research questions, and research objectives, a brainstorming bursting technique (5W1H) was used to analyze the study topic systematically and comprehensively (Kim et al. 2022). The 5W1H (who, what, where, when, why, how) technique guides questions from multiple angles and enables answers to be found through one approach to a cause-effect analysis (see Table 1).

TABLE 1. Cause-effect analysis utilizing the 5W1H approach

5W1H	Descriptions
WHO is at risk and responsible?	A population affected in earthquake events Agencies related to earthquake management: MET Malaysia, JMG, NADMA, and National Geospatial Centre (PGN)
WHAT is earthquake risk assessment?	Evaluation of potential earthquake losses and damage to population, structures, and other entities
WHEN is earthquake risk tangible?	Earthquake risk assessments are needed in earthquake management to measure the social, economic, and environmental impacts of an earthquake for a specific period and location
WHERE does earthquake risk take place?	Focusing on earthquake-prone regions in Malaysia (Sabah and Pahang)
WHY is earthquake risk important?	The basis for any plan for disaster mitigation and preparedness Reduce loss of life and property by improving the ability of decision-makers in regard to planning and managing risk
HOW to measure earthquake risk?	Earthquake risk assessment, Risk = Hazard x Vulnerability (exposure, resilience, and capacity)

Secondary data from related agencies were gathered to support the study. These data were analyzed using the meta-analysis method to ascertain the critical problems in earthquake risk assessment (Lee et al. 2013; Paul & Barar, 2022). Information sourced from various federal government agencies underwent collection and systematic organization based on the modular application within the database. Notable contributors to this dataset included PGN, MET Malaysia, JMG, and the Department of Statistics, Malaysia (DOSM). The seismic event epicenter data originated from a local agency, MET Malaysia, while information was also incorporated from international earthquake monitoring websites, specifically those of the Incorporated Research Institutions for Seismology (IRIS) and the United States Geological Survey (USGS). Census data spanning the period 2010 to 2020 were also gathered. To provide the data with clarity and structure, a comprehensive table was created (see Table 2), detailing the entities, attributes, formats, and sources. Recognizing the paramount importance of data in the success of GIS applications, a meticulous identification process was employed based on data types (spatial or attribute) and data formats (vector or raster).

TABLE 2. List and details of data and sources

No	Module	Entity	Year	Attribute	Format	Source
1	Hazard	Fault	2012	Fault name, length, age, slip sense, fault class, slip rate, dip direction, zone	Line- vector	JMG
2		Epicenter	2016	Intensity, latitude, longitude, depth (km), type, date, time (UTC), distance (km), pictures of related earthquake, historical earthquake	Point- vector	MET Malaysia/ IRIS/ USGS
3		Seismic zone	2016	Zone category, area, type	Polygon- vector	JMG
4	Cadastral layer	State map	2020	State name, area	Polygon- vector	PGN
5		Country	2020	Country name, area	Polygon-vector	PGN
6		District	2020	District name, area	Polygon-vector	PGN
7		Road	2020	Road name, category	Line - vector	PGN
8		Administration Boundary	2012	Name, boundary type, boundary status	Line - vector	PGN
9		Slope (DEM)	2012	x, y, z	Raster image	PGN
10	Potential risk zones	Land use (Agriculture)	2015	Category, Type	Polygon- vector	PGN
11		Building	2015	Building name, type, category	Polygon- vector	PGN
12		Residential	2015	Name, type	Polygon-vector	PGN
13		Public facilities (police station, fire station, and others)	2012	Name, type, category	Point / polygon - vector	PGN
14		School	2017	Name, Type	Point / polygon - vector	PGN
15		Hospital	2020	Name, Type	Point / polygon - vector	PGN
16		City	2020	City name, number of the population, GDP	Point- vector	PGN
17		Population / Census	2020	Total population, female residing, residing age less than 15 years old, residing more than 65 old, number of households, household residence, disabilities occupant, gross income, population growth, poverty level, telecommunication services and equipment	Polygon-vector	DOSM

ER DIAGRAM FOR EARTHQUAKE RISK ASSESSMENT

The initial and pivotal phase in the development of a database is the conceptual design, representing a crucial step in establishing the application requirements and determining the ultimate goals of the database. Unlike relying on specific hardware and software, the conceptual design offers a theoretical definition of a database. It outlines the relationships between entities, compiles a list of attributes, and identifies constraints within a given problem domain. In the context of earthquake risk assessment, the entity-oriented data model places significant emphasis on capturing geographical features that faithfully mirror real-world scenarios.

The meticulous conceptual design process involves the careful identification of logical views and distinct entity levels, the definition of entity attributes, and the establishment of relationships among entities. The resulting ER diagram, illustrated in Figure 7, provides a comprehensive overview of the modeling system for earthquake risk assessment.

The determination of earthquake risk assessment indicators is a crucial step toward developing an effective

Entity-Relationship (ER) diagram aimed at comprehensive risk assessment and management. Each indicator plays a vital role in understanding the potential impacts of earthquakes on different aspects of society and infrastructure.

Fault lines serve as fundamental indicators of seismic activity, representing areas where tectonic plates interact and seismic stress accumulates. In the development of the ER diagram, fault lines formed a primary entity influencing the distribution and severity of earthquake hazards. By linking fault lines to other entities such as seismic zones, residential buildings, and critical infrastructure, the ER diagram can capture the spatial relationship between fault activity and vulnerability.

Road networks are critical components of disaster response and evacuation strategies, particularly during events such as earthquakes. Incorporating road networks into the ER diagram enables the assessment of accessibility and connectivity, particularly in areas prone to seismic hazards. By linking road networks to other entities such as schools, healthcare facilities, and emergency response centers, the ER diagram facilitates the evaluation of evacuation routes and logistical challenges in disaster scenarios.

Census data provide valuable demographic information that helps assess population distribution and vulnerability to earthquakes. Integrating census data into the ER diagram enables the identification of high-density residential areas, socioeconomic disparities, and vulnerable populations. By linking census data to entities such as residential buildings, schools, and healthcare facilities, the ER diagram can inform targeted interventions and resource allocation to support vulnerable communities.

To validate the ER diagram, entity and attribute verification was performed to ensure it would fulfill the user requirements (Ma et al. 2023). All the necessary and correct entities and attributes were aligned with the stakeholders. Relationship validation was conducted to accurately represent the relationships between entities, including their cardinality (one-to-one, one-to-many, and many-to-many). Subsequently, normalization rules were applied to eliminate any redundancy and confirm data integrity, as well as to check for any anomalies, including those related to insertions, updates, or deletions. Review sessions with stakeholders were conducted to gather feedback and refine the ER diagram.

Finally, detailed documentation comprising clear explanations of the entities, attributes, and relationships was produced. Additionally, a final validation step was included to ensure the ER diagram aligns with the user requirements.

Critical infrastructure such as schools, healthcare facilities, police stations, and fire stations are essential for emergency response and recovery efforts during earthquakes. Including these entities in the ER diagram would enable the assessment of their spatial distribution, capacity, and resilience to seismic hazards. By linking critical infrastructure to road networks and population centers, the ER diagram helps to, first, identify areas with inadequate access to emergency services and, second, prioritize mitigation measures.

Residential buildings represent a significant type of exposure to earthquake risks, particularly in urban areas with high population density. Incorporating residential buildings into the ER diagram enables the assessment of their vulnerability to seismic hazards and the identification of areas at high risk of structural damage. By linking residential buildings to fault lines, road networks, and census data, the ER diagram supports decision-making processes related to building codes, retrofitting initiatives, and land-use planning.

Telecommunication infrastructure is vital for communication and coordination during earthquakes, facilitating emergency response and recovery efforts. Integrating this infrastructure into the ER diagram allows for the evaluation of its resilience to seismic hazards and the identification of critical communication nodes. By linking telecommunication infrastructure to road networks and emergency response centers, the ER diagram supports efforts to maintain connectivity and information exchange during disasters.

Seismic zones delineate areas with varying levels of susceptibility to seismic hazards, guiding land-use planning and development. Incorporating these zones into the ER diagram enables assessments of their influence on vulnerability and risk exposure across different sectors. By linking seismic zones to fault lines, critical infrastructure, and agricultural areas, the ER Diagram supports efforts to implement zoning regulations, building codes, and resilience measures tailored to specific seismic risk profiles.

Agricultural areas are essential for food security and economic stability, making them critical considerations in earthquake risk assessment and management. Including agricultural areas in the ER diagram enables the evaluation of their vulnerability to seismic hazards and the identification of risks to crop production and livelihoods. By linking agricultural areas to road networks, census data, and critical infrastructure, the ER diagram supports efforts to enhance resilience and adaptive capacity in rural communities.

In conclusion, the determination of earthquake risk assessment indicators lays the foundations for the development of an informative and actionable ER diagram. By integrating fault lines, road networks, census data, critical infrastructure, seismic zones, and agricultural areas, the ER diagram provides a comprehensive understanding of earthquake risks. It also supports informed decision-making processes aimed at enhancing resilience and reducing vulnerabilities in at-risk communities.

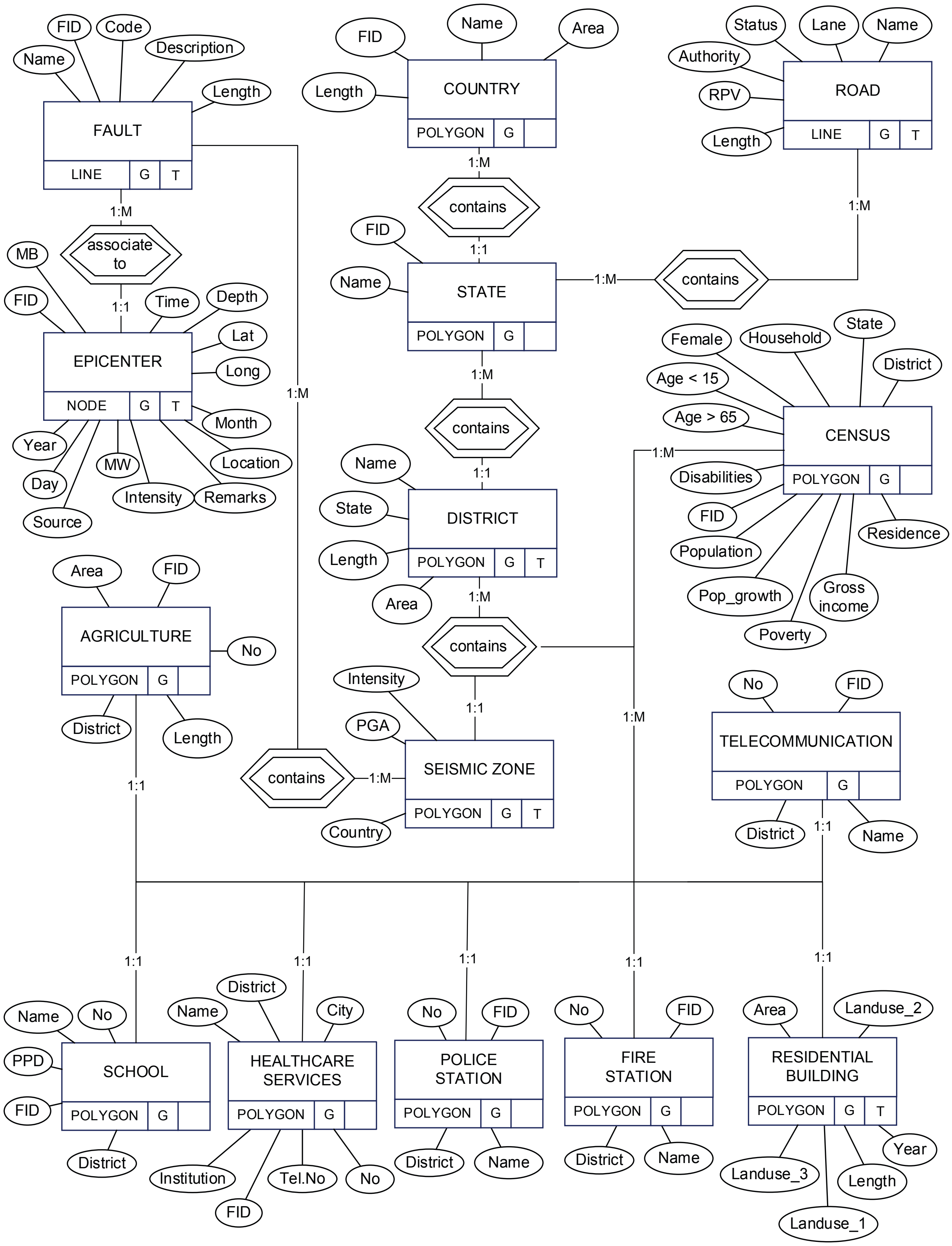

FIGURE 7. Comprehensive ER diagram for GIS-based earthquake risk assessment

CHALLENGES IN DEVELOPING AN ER DIAGRAM IN THE MALAYSIAN CONTEXT

Varied seismic activity and topographical variability present unique challenges and require specific approaches in data collection and the development of ER diagrams for risk assessment. Malaysia's geographical diversity includes regions with different levels of seismic activity. Peninsular Malaysia experiences lower seismic activity than East Malaysia, which is closer to seismically active regions. This regional context necessitates tailored approaches in both acquisition and model design.

A significant difficulty is the restricted access to high-resolution and historical seismic data, especially in regions with infrequent earthquake events. This data sparsity can undermine the accuracy and reliability of ER diagrams employed for risk modeling (Boardmix 2023). Collaborative initiatives with local agencies, like MET Malaysia, academic institutions, and international seismic databases, are crucial to enrich the dataset. Moreover, remote sensing technologies and crowdsourcing data platforms can be utilized to address deficiencies in spatial and temporal data.

Most risk assessment models used globally are designed based on local conditions and expert judgments, making them unsuitable for universal application due to the complex nature of risk assessment. ER diagrams must be adaptable in order to account for regional differences in seismic activity. Customizing data models and risk assessment methodologies to suit the specific needs of each region is essential (Mili et al. 2017).

CONCLUSION

This article provides an in-depth exploration of the integration of ER diagram development with GIS conceptual design for earthquake risk assessment. By elucidating the symbiotic relationship between these two approaches, the aim is to guide practitioners, researchers, and educators in creating more organized, efficient, and effective GIS systems for earthquake risk management. In conclusion, the integration of ER diagrams into GIS conceptual design represents a cornerstone of spatial data organization. From mapping GIS concepts to optimizing queries and enhancing maintenance efficiency, ER diagrams offer a holistic framework for building resilient GIS databases. This integration not only streamlines data management but also fortifies the foundation for effective spatial analyses, contributing to the overall success of GIS applications.

For future directions and improvements based on the ER diagram elements related to critical infrastructure during earthquakes, several areas can be explored to enhance the diagram's comprehensiveness and utility for disaster management and planning. One key area is dynamic risk assessment, which involves incorporating real-time data from sensors and satellite imagery related to earthquake activity and infrastructure conditions.

This integration could enable proactive mitigation measures and improve the responsiveness of a risk assessment. Additionally, expanding the ER diagram to include environmental and social vulnerability indicators, such as flood zones, landslide-prone areas, and regions affected by liquefaction, could provide a more holistic view of earthquake risks. By focusing on real-time data integration and enhanced social and environmental vulnerability assessments, the proposed ER diagram could significantly enhance earthquake preparedness and resilience in the future, offering a robust tool for disaster management and planning.

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DECLARATION OF COMPETING INTEREST

None.

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