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Landslide Inventory Database for Hazard Assessment in the Alborz Mountains, Iran

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***Abstract*:** This study presents a detailed inventory database of landslides in the Alborz Mountains, compiled through a combination of satellite imagery, historical records, aerial photographs, and field surveys. The database encompasses critical information on the location, type, size, mechanism, and triggering factors of landslides, alongside their environmental and societal impacts. Covering an area of approximately 2,500 km², the inventory documents 2,984 recorded landslides. To ensure accessibility and usability, the dataset is provided in a standardized format, complete with metadata and quality control details, facilitating its application and reuse by researchers and practitioners. This comprehensive resource is designed to support a wide range of applications, including landslide susceptibility mapping, hazard assessment, and land-use planning. The database serves as a crucial tool for improving the management of landslide risks in the Alborz Mountains and comparable regions. By offering a reliable and organized compilation of data, it aids in identifying vulnerable areas, assessing hazards, and guiding sustainable land-use strategies. Additionally, the dataset promotes collaboration and data sharing within the scientific community, enabling further research and development in landslide risk management. This initiative underscores the importance of data-driven approaches to natural hazard mitigation and highlights the potential societal benefits of open and reusable research data. The inventory represents a significant step toward enhancing our understanding of landslide dynamics and fostering resilience in regions prone to such geological hazards.

Keywords: Landslide inventory, Geohazards, Alborz mountains, hazard assessment, Susceptibility mapping.

I. INTRODUCTION

Landslides are considered as one of the most frequent geo-hazards that occurs in the various part of Iran especially in Alborz Mountains which has significantly impact on human settlements, urbanisms, facilities, infrastructure, forests, natural resources and ecosystems (Aghdam et al., 2016; Asadi et al., 2019; Azarafza et al., 2021). This Mountain is stretching for approximately 1200 km from the border with Azerbaijan in the northwest to the Khorasan Province in the northeast (Mohsen, 2022). The importance of proper, accurate and comprehensive understanding regarding landslides can provide a chance to mitigate the hazard risks by conducting appropriate development plans and risk reduction strategies (Daviran et al., 2023).

However, accurate and up-to-date inventories of landslides in the studied region are often lacking or incomplete, hindering the development of effective hazard risk reduction and management strategies (Chen et al., 2019; Karaman et al., 2022; Pacheco Quevedo et al., 2023). Recent advances in remote sensing and geographic information systems (GIS) have provided new opportunities for compiling landslide inventories in a systematic and efficient manner (Zhao et al., 2022). Therefore, this study aims to present a comprehensive landslide inventory database for the Alborz Mountains of Iran, based on multi-source data and standardized procedures.

As is known, landslide inventory databases are an essential tool for assessing the hazard risks posed by landslides and for developing effective risk reduction and mitigate the risk-ability as geo-hazard management strategies (Mohsen, 2022). Such databases typically contain information on the location, extent, type, and triggering factors of landslides, as well as their impact on the environment and human settlements (Azarafza et al., 2018). The data are usually compiled from multiple sources, including remote sensing, field surveys, and historical records (Nikoobakht et al., 2022; Shao & Xu, 2022).

One advantage of landslide inventory databases is that they provide a comprehensive and systematic approach to landslide mapping, which enables accurate hazard assessment and facilitates the identification of high-risk areas (Azarafza et al., 2018). However, landslide inventory databases also have some limitations. One limitation is that they rely on the availability and quality of the input data, which can vary depending on the location and time period of the inventory (Nikoobakht et al.,

2022). For example, in some regions, historical records may be incomplete or unavailable, and remote sensing data may be affected by cloud cover or other environmental factors (Mohsen, 2022). Another limitation is that landslide inventories can be time-consuming and resource-intensive to compile, especially in areas with rugged terrain or limited accessibility (Daviran et al., 2023). Despite these limitations, landslide inventory databases remain an important tool for improving our understanding of landslide hazards and for developing effective risk reduction and management strategies (Chen et al., 2019).

This study presents a comprehensive landslide inventory database for the Alborz Mountains of Iran, covering an area of approximately 2,500 km^2 and including landslides that includes 2,984 landslides that recorded. The inventory was compiled based on satellite imagery, aerial photographs, historical development, and field surveys, providing information on the location, type, size, and triggering factors of landslides, as well as their impact on the environment and urbanism. The dataset is provided in a standardized format, along with metadata and quality control information, to facilitate its use and reuse by the scientific community. The dataset can be utilized for various purposes, such as landslide susceptibility mapping, hazard assessment, and land use planning, and can contribute to improving the management of landslide risks in the Alborz Mountains and other similar regions. The use of multi-source data and standardized procedures enhances the accuracy and reliability of the inventory, enabling it to serve as a baseline for future studies on landslide dynamics and impacts in the region.

In the context of the Alborz Mountains of Iran, the landslide inventory database presented in this study has several important implications. Firstly, it provides a comprehensive and up-to-date inventory of landslides in the studied region, based on a standardized and systematic approach that implemented in GIS (Sheikholeslami, 2018). This inventory can be used to improve landslide susceptibility mapping and hazard assessments, which can help to reduce the risk to sustainable developments, geo-hazard mitigation and risk assessment, and urban-planning (Wang et al., 2021; Karaman et al., 2022). Secondly, the inventory database provides a baseline for future studies on landslide dynamics and impacts in the region, which can contribute to a better understanding of the mechanisms and causes of landslides in the Alborz Mountains. Finally, the standardized format of the dataset and its can facilitate the use of the dataset in other studies and applications (Asadi et al., 2019), which can promote collaboration and knowledge sharing among the scientific community and stakeholders.

Despite the advantages of the landslide inventory database, there are also some challenges that need to be addressed. One challenge is the availability and quality of input data, which can vary depending on the location and time period of the inventory (Wang et al., 2021). Historical records may be incomplete or unavailable, and remote sensing data may be affected by cloud cover or other environmental factors. Another challenge is the time-consuming and resource-intensive nature of compiling the database, especially in areas with rugged terrain or limited accessibility. Finally, the accuracy of the database may be limited by the scale of the mapping, as small-scale landslides may not be detectable using the available data (Shao & Xu, 2022; Daviran et al., 2023).

Generally, the efforts have been made to compile comprehensive databases of landslides in order to improve our understanding of their distribution and characteristics (Gaidzik & Ramírez-Herrera, 2021). This database is allowed to globally understand the main triggering factors that affected the landslide occurrences and comparison of events in distinct geological settings with geo-unit specifications (Zhu et al., 2019; Shokri et al., 2020).

However, extensive landslide characterization and providing the proper link between the occurred events and general plate tectonic activity in continental level is still lacking where adequate characterization of landslides depends on the quality of available data (Farahi et al., 2020). Tectonically, the mountains are part of the larger Alpine-Himalayan orogenic belt, which extends from the Atlas Mountains in North Africa to the Himalayas in South Asia (Ghorbani & Ghorbani, 2021). The tectonic history of the Alborz Mountains is complex, involving multiple episodes of deformation and uplift that have occurred over the past 50 million years (Shokri et al., 2020). This mountains are located at the boundary between the Eurasian Plate and the Central Plate, which are converging at a rate of approximately 2 to 3 cm/year. The collision between these two plates has results various folding, faults, geo-structures, earthquake events, and landslides (Farahi et al., 2020).

The tectonic activity in the Alborz Mountains has had significant geological and geomorphological consequences, including the formation of numerous anticlines and synclines, as well as the development of extensive alluvial and colluvial deposits (Alaminia et al., 2021). The studied Mountains are also prone to seismic activity, with several significant earthquakes having occurred in the area over the past century (Farahi et al., 2020). These activities in overall perspective provide suitable conditions regarding landslide occurrences (Alaminia et al., 2021) which make various regions of the Alborz Mountains (Sheikholeslami, 2018).

Figure 1 global deformation, geo-activities and earthquake recorded in studied mountains in Iran. This map indicates the major geological structures and recorded earthquakes. Elevation changes were generated using a 30m resolution from the digital elevation model (DEM) data. Also, geological identification of the studied mountains is provided in Figure 2. Landslide susceptibility and slope instability studies conducted on the study area indicate that large extents of the ground movements and landsliding has been identified various are prone regions to failures (Mokhtari & Abedian, 2019; Ngo et al., 2021).

As stated, the landslide inventory database developed for the Alborz Mountains provides a comprehensive dataset of landslides in the region, with information on their location, extent, type, and triggering factors (Ghassemi, 2004). The database includes a total of 2,984 landslides, covering an area of approximately 2,500 km^2, and is based on a standardized and systematic approach that enables accurate hazard assessment and identification of high-risk areas (Hussain et al., 2022). The database also includes information on the impact of landslides on the environment and settlements, which can be used to develop effective risk reduction and management strategies (Shahri et al., 2019; Saha et al., 2021; Rosser et al., 2021; Mao et al., 2021).

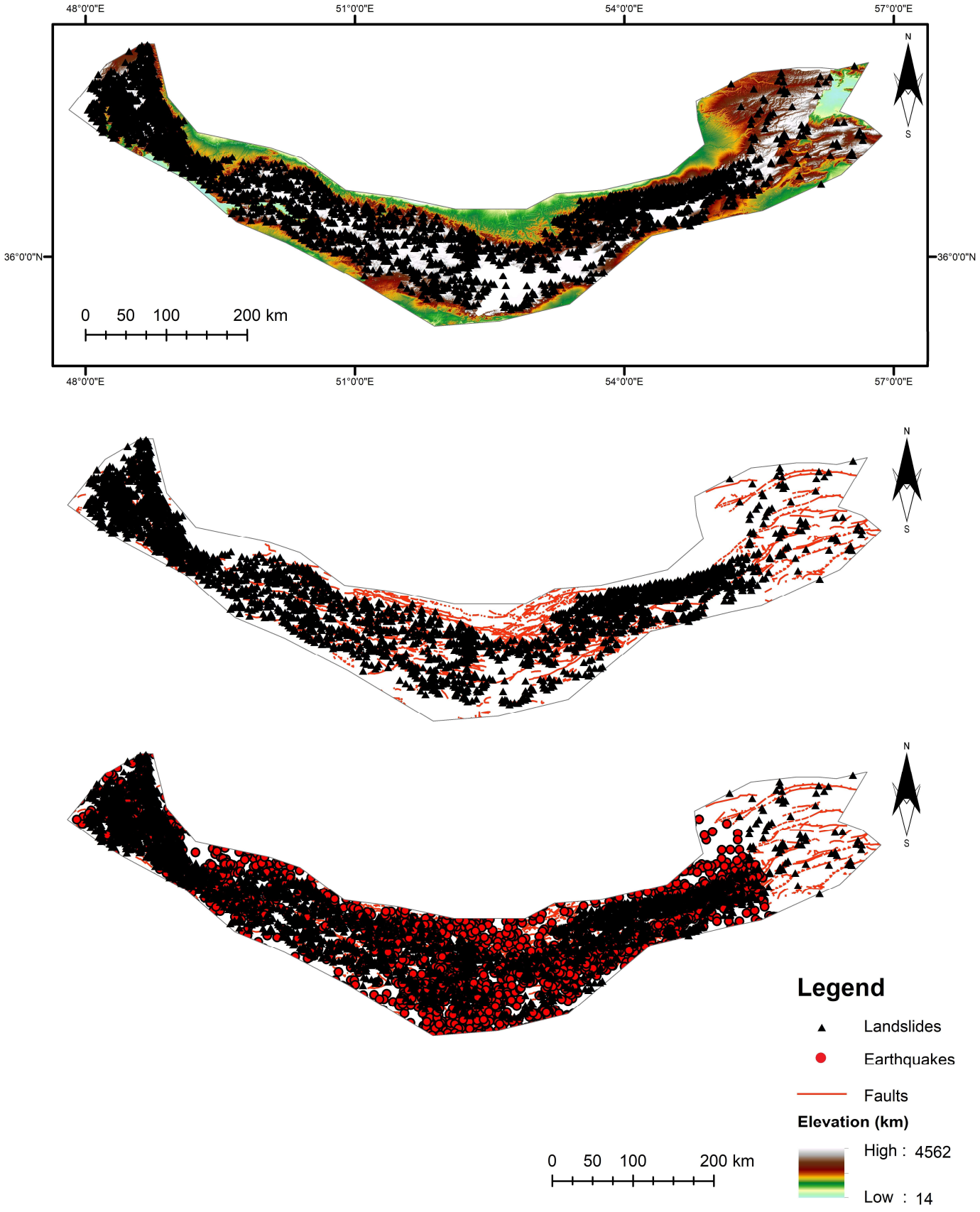

Fig. 1 Map of the study mountains East to West shown as a topographic gradient raster

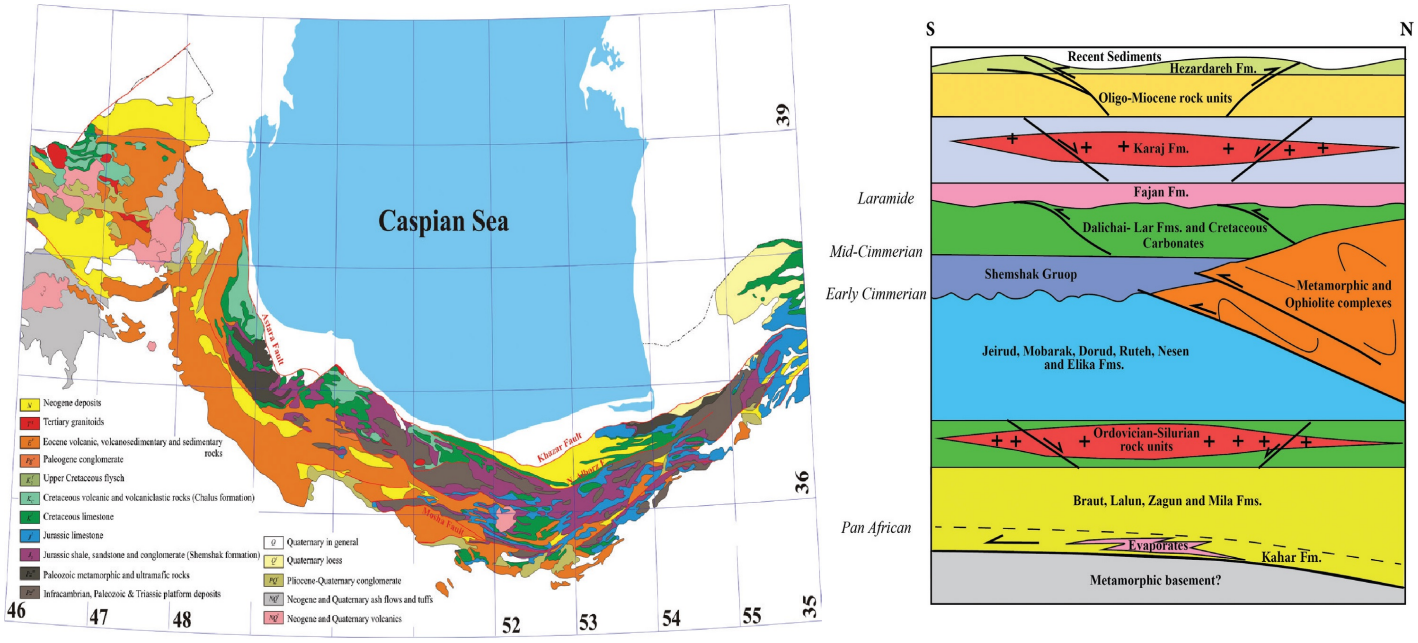

Fig. 2 Map of global geological units' identification for the extended Alborz Mountains (Ghassemi, 2004; Saha et al., 2021)

Workflow diagram of the landslides inventory mapping in Alborz Mountains is presented in Figure 3. Regarding this figure it can be stated that there are various stages that utilized to provide such database where can be classified into the several stages includes data collection, data pre-processing, landslide mapping and characteristics, events' data integration, and databases analysis. The first step in the landslide inventory mapping process is to collect and compile all available data on landslides in the study area. This includes historical records, remote sensing data, and field observations. The data should be organized and standardized to facilitate the mapping process. The next step is to pre-process the data to prepare it for mapping. This involves georeferencing the data and converting it into a standardized format, such as a GIS layer. The data should also be checked for quality and completeness. The mapping process involves the identification and delineation of landslides in the study area. This can be done using visual interpretation of aerial photos, satellite imagery, and other remote sensing data. Field observations may also be necessary to verify the presence of landslides and their boundaries. Once the landslides have been mapped, the data should be integrated with other relevant datasets, such as topography, geology, and land use. This can help to identify the factors that contribute to landslide occurrence and to develop more accurate susceptibility models. The final step in the landslide inventory mapping process is to analyze the data to identify patterns and trends in landslide occurrence. This can involve statistical analysis, spatial analysis, and modeling.

It should be stated that the workflow diagram for landslide inventory mapping in the Alborz Mountains is a cyclical process, meaning that the results of the analysis can inform future data collection efforts and update the inventory database. This process is a systematic approach from collecting to analysis of landslides which can help to ensure the accuracy and reliability of the data and can facilitate the development of effective landslides risk reduction.

II. Materials and Methods

The following section outlines the methodology workflow that was employed for acquiring and preparing the data. As previously mentioned in the workflow chart (Figure 3), there are several implementation stages that are considered in this database preparation. The collected data was acted in several steps that can be stated as literature review, remote sensing data, field observations, and GPS surveying. The main data resources that used in the collecting data are DEM, aerial photographs, satellite imagery, and GPS coordination data. These steps were set in four main phases including data loading, the manual digitizing of landslide features, landslide characterization and visualization. Figure 4 is provide a schematic representation of landslide characterization and features that provided in this research.

Data loading phase: First by reviewing the literature, available data on landslides in the study area is identified and compiles such as historical records, published reports, and academic articles from 2000 to 2021. These data are enriched by using aerial photographs, satellite imagery like Landsat TM, ETM^{+} and DEM data were used to identify and delineate landslides in the study area. The various satellite imageries can be obtained from EarthExplorer (https://earthexplorer.usgs.gov/), EarthDATA (vertex.daac.asf.alaska.edu), GloVis (https://glovis.usgs.gov), public archives, or through other purchasing from commercial vendors. Field observations with GPS recording for large scale available survey, we able to modified the location and magnitude of the components in landslide inventory mapping. These observations involve visiting the study area and visually identifying and documenting landslides and related features such as scarp faces, debris fields, topographical irregularities, and failure mechanisms in limited scale. For this work, we used the XYZ data version of recording to anticipate the failures scale.

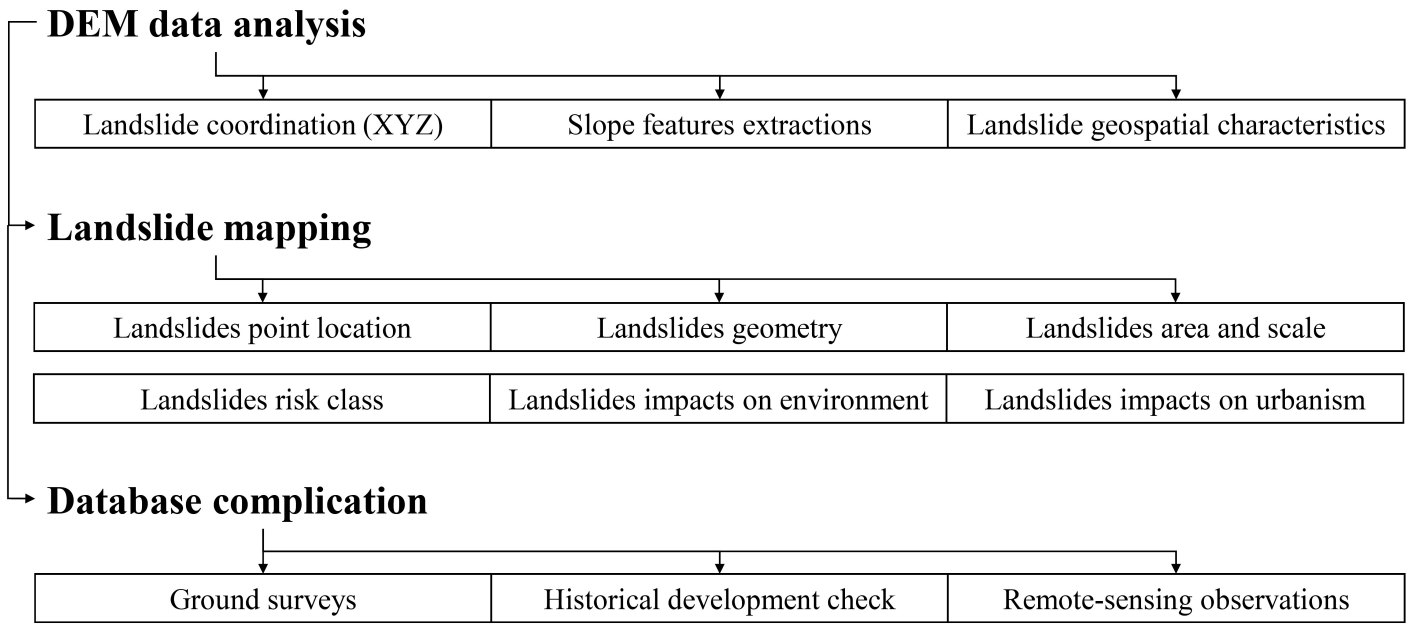

Fig. 3 Flowchart of the analysis process

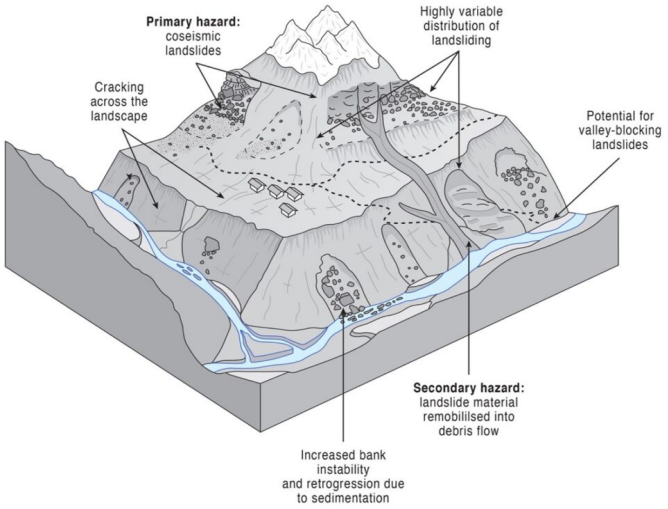

Fig. 4 Schematic diagram of landslide parameters, features and characteristics that considered as basic in this study; not to scale (adapted from Rosser et al., 2021)

Manual digitizing of landslide features phase: Once the data has been collected, it needs to be prepared for mapping by converting it into a standardized format, such as a GIS layer as tabulated in CSV. This involves georeferencing the data to a common coordinate system, digitizing the data, and organizing it into attribute tables. The data should also be checked for quality and completeness, with any errors or inconsistencies corrected before proceeding with the mapping process. The manual digitizing of landslide features is a process of identifying and tracing landslide boundaries and related features, using ArcGIS v10.4 software and spreadsheet tools. We involved manually selecting and marking points and digitizing the landslides' location by using GIS features to create a vector-based representation of the landslide events in Alborz Mountains. The resulting data was used to create a landslide inventory map. Manual digitizing is a time-consuming and labor-intensive process, as it requires a high level of accuracy and attention to detail. Lack of the several data and not-digitized information regarding various landslides was the main limitations that we faced during this phase. However, conducting manual import of landslide features can provide information that may not be captured by automated techniques, particularly in complex terrain or areas with low-resolution remote sensing data, but using manual digitizing process has extensive checking and validation of the landslide data. Quality control and assurance of the digitized data to ensure accuracy and completeness is the main concern that we faced with during providing the landslide database.

Landslide characterization phase: for provide the characterization and features of recorded landslides that refer to the physical attributes including their size, shape, type, and movement mechanisms; all collected information was categorized and classified in various groups. These groups are contain key features such as type of movements, dimension (shape and size), location (longitude and latitude), triggering mechanisms, geological structure, type of required mitigation, potential damages for settlement or environment, topographic properties, special attributes and remarks. By constraining calculations within each individual landslide limit, the class of each landslide features are identified, labelled and categorized in unique temporospatial ID.

Visualization phase: The final stage of database preparation was compiled in a spreadsheet (CSV/ XLS) and rastered information layers in GIS for the Alborz Mountains. Figure 5 provides the desired outcomes from landslide features data visualization in studied mountains. This chart method was recommended to show trends and patterns in landslide events and risk rate used to identify areas of high landslide susceptibility and inform risk management strategies.

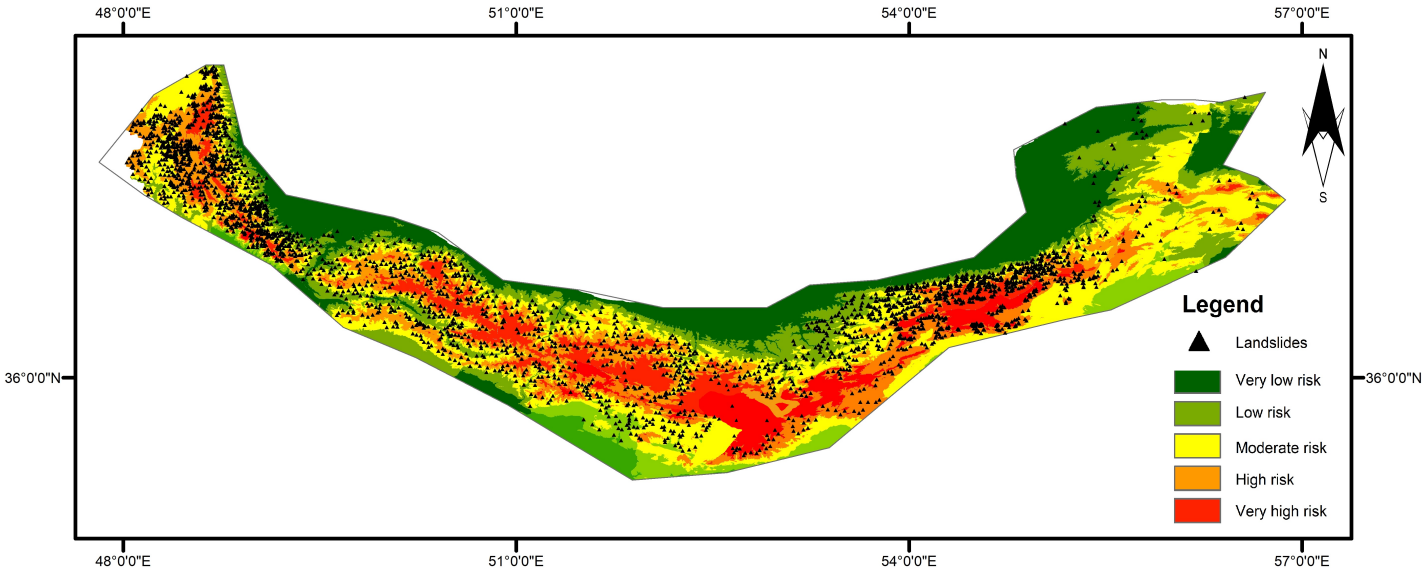

Fig. 5 Data visualization for studied mountains

III. Data Records

The landslide inventory for the Alborz Mountains provides comprehensive and detailed data on landslides in the region, including their locations, types, and movement mechanisms. This database plays a critical role in understanding landslide dynamics, risk assessment, and mitigation strategies. It incorporates a wealth of geo-structural data represented in various formats, enabling a multidimensional analysis of landslide phenomena. At the core of the inventory are a series of shapefiles that document the spatial distribution of landslides, faults, and earthquake locations, along with associated attributes like event magnitude, size, and areas impacted. These files utilize point, line, and polygon formats to represent geo-structural features accurately. Complementing the shapefiles are GeoTIFF files, which provide baseline geographic and environmental data, including DEM, topography, geological units, and land-cover layers. Together, these datasets offer a detailed geospatial framework for analyzing landslide occurrences. In addition to the spatial data, the inventory includes detailed records organized in Microsoft Excel spreadsheets. These spreadsheets catalog 2,984 individual landslides, encompassing a total affected area of approximately 2,500 km^2. Each landslide entry has been normalized and classified based on various attributes, ensuring consistency and reliability for further analysis. The classification system allows researchers to identify patterns and correlations, such as the relationship between landslide types and specific geo-structural features.

The integration of diverse data formats (i.e. shapefiles, GeoTIFF layers, and spreadsheets) makes the inventory a versatile tool for researchers and policymakers. For example, the shapefiles enable spatial mapping and visualization, while the spreadsheets provide numerical and categorical data for statistical analysis. The GeoTIFF layers, on the other hand, serve as a foundation for advanced modeling and simulations, such as landslide susceptibility mapping and hazard prediction. Generally, the landslide inventory for the Alborz Mountains is a vital resource for understanding the complex interplay of geological, topographical, and environmental factors contributing to landslides. By offering a standardized and comprehensive dataset, it facilitates detailed analyses and supports the development of effective landslide risk management strategies in this geologically active region.

IV. Technical Validation

The technical validation of landslide inventory mapping in the Alborz Mountains is an important part of this research to ensure the accuracy of collected, check the performance of task, and reliability of the landslides inventory database. This involves implementing quality control measures and validation checks to identify and correct errors or inconsistencies in the data. The validation approach that is considered in this research is based on data-driven decision-making based on expert check and review methods. This procedure can be implemented in several steps that were summarized below:

- Ground investigation and field validation which is the conventional approaches for technical validation in landslide inventory mapping. We used field data and GPS survey to verify the remote-sensing and historical development records. This method entails verifying the accuracy of the landslide locations and other data through field surveys and ground-based observations.
- Statistical analysis is another approach that we use to validation of landslide inventory mapping. This approach involves analyzing the frequency and distribution of landslides and comparing this with other data sources such as historical records or geological maps.

To sum up, there are two validation procedures that we followed to deliver landslide validation inventory mapping database. Quality control measures and validation checks that are

conducted in this research are employed to increase the accuracy and reliability of data.

Ground investigation and field validation: Ground trothing or investigation is one of the well-known traditional methods that used for technical verification in inventory mapping of landslides. Using this method is considered the site walkover and ground-based observations as the baseline of reliability validation for accessible geospatial data and landslide records. Also, field validation provides an opportunity to assess the quality of the data directly and improve the overall accuracy of the inventory. This validation includes visual inspection of landslide features, field measurements of slope stability and soil characteristics, and documentation of the landslide type, size, and activity status. The use of GPS to ensure the quality and reliability of the data (Shahri et al., 2019).

Statistical analysis validation: This method was used for technical validation in landslide inventory mapping as well which involves analyzing the frequency and distribution of landslide events in the study's mountains. This method is a comparative method to understand the database is undertaking more data such as historical records or geological maps. Also, if there is any link between the landslides that recorded in Alborz Mountains with triggering factors highlighted accordingly. Statistical analysis can provide insights into potential data gaps or areas for further investigation, thereby ensuring the accuracy and reliability of the data (Ghassemi, 2004).

V. Conclusion

The landslide inventory database presented in this study can be used for various technical and educational purposes. It can also serve as a baseline for future studies on landslide dynamics and impacts in the Alborz Mountains (Iran), with appropriate acknowledgement of the sources and to follow proper citation practices when using the dataset in research or other publications. The majority of the work was produced using ground survey, remote-sensing (satellite imagery), aerial photographs, and historical development check and mapping was provided by ArcGIS v10.4. It is important to consider the temporospatial resolution of the dataset when using it for specific applications. We used common information with ±30 m resolution. Scientists and researchers are encouraged to contribute to the ongoing development of this dataset by enhancing our understanding of the existing mapped features or by introducing new features as needed. This collaborative effort can help to improve the accuracy and usefulness of the dataset for a range of applications, from natural hazard assessments to land-use planning and beyond.

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Authors' contributions

Amin Yeganeh, Ramin Nazari and Pejman Tagizadeh conducted the main data analysis, contributed to the data collection, preprocessing and interpretation. Dengchao Zhu and Pejman Tagizadeh were responsible for drafting the initial manuscript. Zhao Chen performed checks, supervision, conceptual guidance, and critical revision of the manuscript. All authors read and approved the final manuscript.

Conflict of interest

The authors have not disclosed any competing interests.

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