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Determination and Evaluation of Landslide-Prone Regions of Isparta (Turkey): An Urban Planning View

Aynur Uluç Keçik [1,*], Canan Çiftçi [2], Şirin Gülcen Eren [1], Aslı Tepecik Diş [3] and Agatino Rizzo [4,5]

[1] Department of City and Regional Planning, Faculty of Architecture, Süleyman Demirel University, Isparta 32260, Turkey; sirineren@sdu.edu.tr
[2] Department of Geophysical Engineering, Faculty of Engineering, Süleyman Demirel University, Isparta 32260, Turkey; cananciftci@sdu.edu.tr
[3] School of Architecture and Built Environment, KTH Royal Institute of Technology, 10044 Stockholm, Sweden; atdis@kth.se
[4] Architecture Research Group, Department of Civil, Environmental and Natural Resources Engineering, Luleå University of Technology, 97187 Luleå, Sweden; agatino.rizzo@ltu.se
[5] Department of Architecture, School of Arts, Design and Architecture, Aalto University, 11 000 Aalto, Finland
* Correspondence: uluc.aynur@gmail.com

Abstract: Landslides represent a significant hazard affecting human life and property and threaten the sustainability of human settlements. They are among the most critical threats after earthquakes in Turkey. In 2020, 107 landslide events occurred in Turkey. Implementing proper policies, strategies, and tools for landslide risk mitigation remains challenging for urban planning institutions. In the plan preparation phase, urban planners and plan-making authorities, agencies, or institutions may overlook landslide risks due to a lack of data or related studies. Therefore, this article aims to develop a novel spatial analysis for identifying landslide-prone areas at the provincial level from an urban planning perspective. The analysis is compared to the approved upper-scale plan, and the results are used to build a more robust understanding of landslide risks for sustainable urban development. Isparta Province is selected as the study area, as it has active landslide areas. The methods used include a literature survey including internet sources, newspapers, plans, articles, and other research projects and a case study utilizing a GIS spatial analysis. The spatial analysis using GIS is based on three landslide inventories currently available in Turkey. This spatial analysis is developed to determine landslide-prone regions by considering thematic layers, triggering factors, and vulnerability inputs. As a result of this analysis, five landslide-prone areas in Isparta Province are determined. When these regions are compared to the upper-scale plan that covers the province, it is found that land use and planning decisions have neglected landslide risks, and urban areas are at high landslide risk. Several specific principles and strategies, such as a spatial inventory database and an integrated planning approach including landslide-prone areas, are stated with a reliable spatial analysis to assess landslide-prone areas on a regional scale, which can be applied later in any city and region of Turkey.

Keywords: landslide; urban planning; sustainability; GIS; spatial analysis; Isparta (Turkey)

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1. Introduction

A landslide is defined as the movement of a mass of rock, earth, or debris down a slope [1]. This complicated geomorphological occurrence is the movement of soil, rocks, and organic elements in the direction of gravity [2]. In addition to slides, landslides can also include collapses, flows, topples, and spreads [3]. The interactivity of multiple factors, such as earthquakes, heavy precipitation, geology, land use, slope morphology, groundwater levels, vegetation density, and anthropogenic activities, can trigger landslides [4,5]. The frequency of landslides is also experiencing a rise as a result of rapid urbanization [6,7]. Landslides are primary or secondary hazards. They can be secondary hazards if following rainfalls and earthquakes. They create risks measured by the probability and severity of an adverse effect on health, property, or the environment [8]. It becomes a disaster if the necessary precautions are not taken while preparing all types and scales of spatial plans. They have a significant global impact, resulting in more than 26,000 fatalities, displacing approximately 2.5 million people, and incurring economic losses totaling USD 40 billion [9]. The World Bank the Global Landslide Hazard Map Final Project Report [10] presented the estimated average annual number of significant rainfall-triggered landslides (1980–2018) to be the highest in the USA (36,150) and China (35,280), and earthquake-triggered landslides are the maximum in China (20,950) and the Kyrgyz Republic (11,070).

Disaster risk reduction should be incorporated into climate and disaster risk-informed policies and programs and create coherence with the 2030 Agenda for Sustainable Development to meet the challenge of systemic risk. Therefore, better risk knowledge is needed to build a more robust understanding of the risk in sustainable development and make risk-informed decisions and investments [11]. The impact of landslides, like other types of disasters, on sustainable development and local economies has been noted [12]. Along this line of thought, the UNDRR (2023) announced several recommendations to achieve sustainable development for policymakers: shifting to anticipation, prevention, and risk reduction; integrating and aligning risk reduction across the Sustainable Development Goals; investing in the prevention of disasters at all levels; and creating a strategic, forward-looking plan for transformative change. A lack of landslide maps that can be used for urban planning has been detected [13].

Turkey is one of the countries highly affected by landslide events in Europe [14]. Turkey's geological features, topographic structure, and climatic characteristics are conducive to landslides, resulting in a significant loss of life and property [15]. Due to climate change and global warming, the frequency of floods has increased, and heavy rainfalls are exercised. These increase the number of landslides and areas affected. The country is situated on active earthquake fault lines that trigger landslides. In 2020 alone, 107 landslide events occurred in Turkey [16]. The occurrence level of fatal landslide events in Turkey from 1929 to 2019 was analyzed [17]. The study revealed the identification of 389 landslide events, which resulted in the loss of 1343 lives. Isparta Province, the case study area, is subject to earthquakes and active landslides. Our analysis of the upper-scale spatial plan reveals that there is insufficient consideration of landslides and spatial landslide inventory. This oversight represents a significant gap in the planning process, as it overlooks a crucial factor that can profoundly impact human settlements. Within the context of spatial and urban planning, settlement site selection, the construction of roads on river basins, fault lines, slopes, and aspects within the context of spatial planning were investigated in this case study.

Despite the importance given to landslides as a type of disaster, there are limited scientific studies on the issue in relation to sustainability, urbanization, and spatial planning. Studies have generally concentrated on landslide susceptibility [18], landslide mapping [10], susceptibility mapping [19,20], mapping with unmanned aerial vehicles [21–23], the particle finite element method [2,24,25], three-dimensional modeling [26,27], and numerical models [28]. Many other methods and models have also been applied, such as multi-criteria analysis, a physical slope model, and the probabilistic method. However, these studies concentrated on determining the hazard areas, disaster-prone areas, and potential risk areas.

Urban planning plays a crucial role in managing landslide risk [29–31]. The most efficient way to mitigate the risk of landslide-related losses is by spreading information about landslide locations and hazards while implementing effective spatial planning [31]. During the plan preparation phase for landslide-prone areas, necessary measures and precautions can be taken. All types and scales of urban planning documents must consider data about how landslides are distributed across an area to prevent landslides [32].

The spatial analysis developed in this study is implemented in Isparta at the provincial level. The relations of spatial plans, landslides, and sustainability are assessed, whether the risk of landslides was included or not, and how the relationship between those aspects is related to the region's sustainable development, since the relationship between urban planning and landslide risk is critical in developing sustainable and resilient human settlements. This natural event threatens the sustainability of human settlements and impacts the land, society, and cities. It is a problematic subject area for urban planning. Hazards and risks should be decreased to achieve sustainability and livability [33]. A landslide risk mitigation approach can contribute to a resilient future.

In contrast to this understanding, the current planning practice in Turkey falls short of attaining sustainability due to the absence or outdated nature of integrated spatial landslide data during the planning phases, as discussed in the Isparta case. As a result, landslide-prone regions are overlooked when formulating land use decisions and spatial plans, resulting in elevated risks to human settlements and the potential loss of life and property. The absence of a comprehensive examination of the relationship between landslides and spatial planning exacerbates the issue. Thus, a pressing need arises to investigate the methods for determining landslide-prone regions and explore how the obtained results should be effectively integrated into relevant plans and planning processes.

2. Materials and Method

2.1. The Methodology of the Study

This article applies the case study method with a mixed analysis method. Here, a method of determining landslide-prone regions based on specific criteria is developed through spatial analysis. This spatial analysis is a pioneering effort that integrates urban planning and geological perspectives. The identification of landslide-prone regions is envisaged by interpreting geological data so that the planning institution can utilize and compare it with relevant-scale spatial plans, which can ultimately contribute to the sustainability of settlements.

Landslide data specific to Isparta Province were utilized; 3612.60 hectares of the landslide area from [34], four landslide events in point data from [35], and three fatal landslide events as point data from [36] were evaluated in this research. Landslide-prone regions are defined regarding the existence of landslide areas with the parameters defined in the study, including geological setting, seismicity, slope, aspect, water sources, landslide inventory, and land use data. Elevation data for Isparta Province were used to create terrain slope and aspect maps using QGIS 3.32 lima software. Landslides were correlated with earthquakes occurring in the region between 1900 and 2023, as well as the geological characteristics of the area. Furthermore, a land use map was synthesized with information on earthquakes, faults, and rivers. In the generated map, five areas with landslide clusters were identified, and interpretations were made based on their proximity to faults, rivers, and settlements. Additionally, slope, aspect, and lithology distributions for landslide areas were determined using the QGIS program, and statistics were provided.

A comparison of landslide-prone regions with the related upper-scale plan land use and planning decisions was made. Moreover, a critical evaluation of upper-scale planning decisions and land use decisions regarding these identified regions was made in the context of sustainability from an urban planning perspective.

2.2. The Study Area

This research focuses on Isparta Province (Figure 1). Isparta Province's total area is 893,307 ha [37], and its population was 445,325 people for the year 2022, according to the address-based population registration system [38]. The highest altitude in the province reaches a maximum of 2950 m.

Isparta is located in the southwestern part of Turkey and is a complex zone regarding tectonic and geologic features. Other than its geological and geomorphological features, the climatic characteristics create a high risk of earthquakes, landslides, rockfalls, floods, avalanches, and fires [35]. Earthquakes and landslide events happen throughout the province. The region is surrounded by active faults like the Burdur Fault Zone and Akşehir Fault Zone and is known as the "Isparta Angle" (Figure 1).

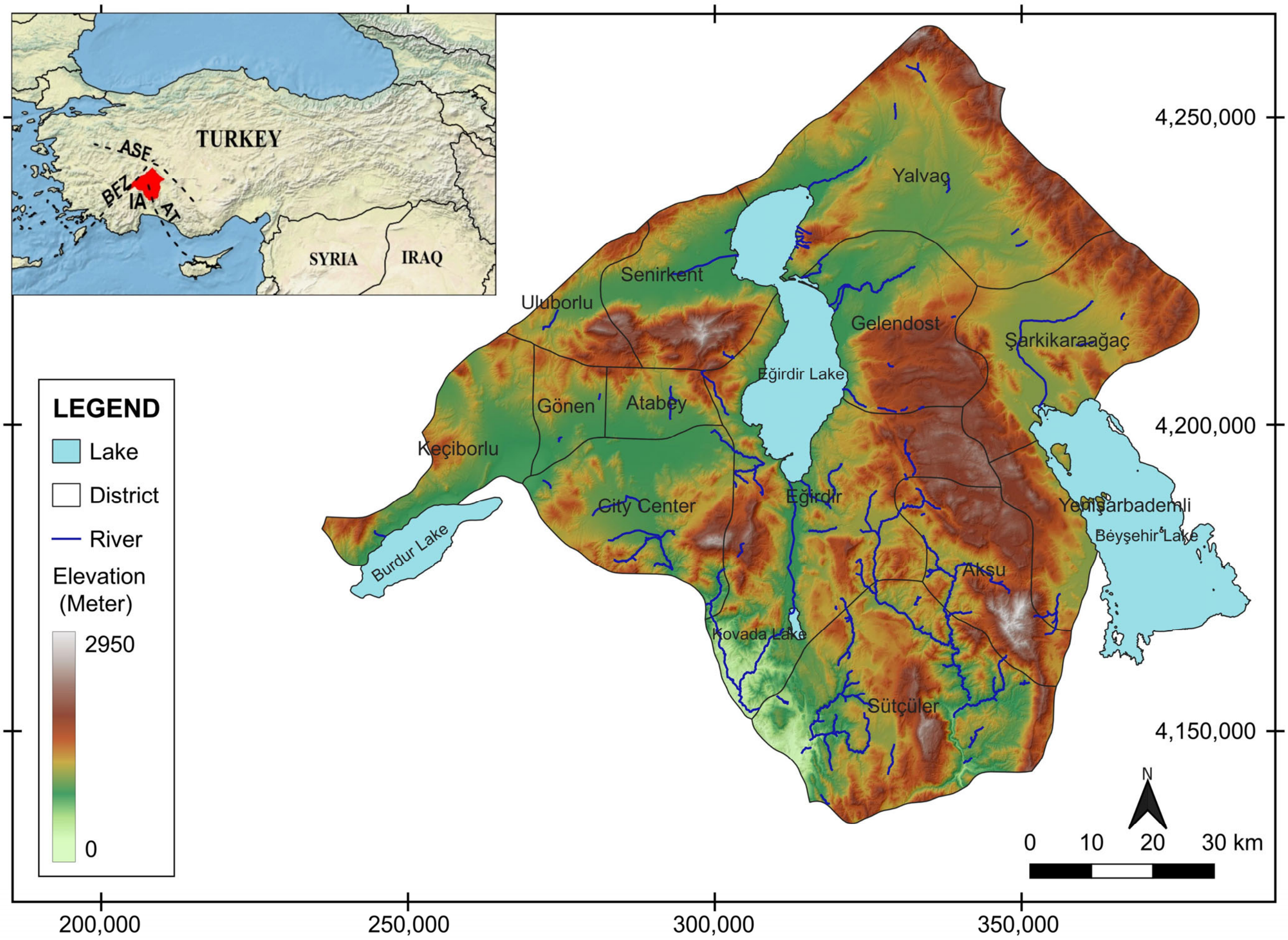

Figure 1. The study area: Isparta and its elevation. BFZ: Burdur Fault Zone, AFZ: Akşehir Fault Zone, IA: Isparta Angle, and AT: Aksu Thrust.

The province has active landslide events, a high potential for earthquakes and landslides, and a comparable upper-scale spatial plan. In addition to the literature survey on landslides, Isparta planning practice, internet sources, newspapers, IRAP, 1/100,000 plans, articles, and other research projects were also analyzed.

There have been several studies focused on the landslide hazard in Isparta. These studies focused on identifying areas at risk of landslides and developing mitigation strategies. Settlement areas in Isparta, especially near mountainous regions, are exposed to the potential hazards of mass movements [39]. Similarly, landslide risks and hazards in the Isparta region, specifically for the mountain road between Isparta and Burdur, were assessed [40]. A landslide susceptibility assessment of the Yaka Region (Gelendost, Isparta) was conducted using a logistic regression method accompanied by geographic information systems [41]. On the other hand, studies related to landslide risk mitigation for Isparta at the provincial scale are limited in terms of the assessment scale and comparison of landslide areas with the current regional spatial plans. The assessment should have covered the provincial scale to see all the landslide areas in Isparta in order to compare them with approved regional spatial plans. In addition, the current Provincial Disaster Risk Reduction Plan (IRAP) is insufficient due to the inability to provide spatial landslide data that can be used in upper-scale plans. The comparative analysis of landslide-prone areas and spatial plan in this study serves as a critical evaluation tool, shedding light on the factors influencing land use decisions within landslide-prone areas and providing insights into the optimal development strategies.

As the administrative boundaries are considered, cross-cutting landslide areas are neglected. Multi-hazards are also excluded. Landslide seasonality is excluded, as there is no available data. Recent landslides in Isparta Province are presented in Table 1.

Table 1. Recent landslides in Isparta.

Landslide Event	Date
Senirkent Landslide	13 July 1995  A photograph from the news [42].
	Damage Seventy-four people died, and 209 houses were damaged or destroyed [42].
Güneyce Village Landslide	29 December 2012  A photograph from the news [43].
	Damage Forty-eight injuries, and 18 houses were at risk [43].
Eğirdir Landslide (İmaret Neighborhood)	2022  Photographs of the landslide area (Uluç Keçik Archive 2023).
	Damage Two hundred and ten dwellings, distributed among 14 residential blocks, were at risk. Landslides were triggered by intense precipitation and the subsequent melting of snow [44].

2.3. The Data and the Spatial Analysis

A GIS-based spatial analysis was made for this research based on three landslide inventories or studies currently available in Turkey: The General Directorate of Mineral Research and Exploration (Maden Tetkik ve Arama Genel Müdürlüğü (MTA)) landslide data, Disaster and Emergency Management Presidency (Afet ve Acil Durum Yönetimi Başkanlığı (AFAD)), Isparta Provincial Disaster Risk Reduction Plan (İl Afet Risk Azaltma Planları (IRAP)), and data of the studies of [17,36] as area data or point data.

The lack of coherence and limited accessibility of landslide inventories across European countries has led to the delayed recognition of landslide events and their impacts [12]. This issue is also applicable in the context of Turkey. In this research, one significant challenge encountered was the limited data availability. The absence of a systematic spatial inventory of landslides in Isparta posed a hurdle. When examining fatal landslides in the study area, no evidence of them being triggered by earthquakes as secondary landslides were obtained. However, due to the lack of recent information on landslide data obtained from the MTA inventory and Isparta IRAP, the occurrence of secondary disaster situations could not be determined.

In the Isparta case, 3612.60 hectares of the landslide area from [34], four landslide events in point data from [35], and three fatal landslide events as point data from [36] were evaluated. These three data were used since no single spatial database included all landslide events in Isparta. After spatializing the landslide events, landslide-prone regions have been identified as areas with the highest number of landslides, the existence of parameters, and areas close to settlements. Fault lines and rivers are assessed in the study by defining buffer zones around them. Buffer zones were created with 200 m intervals up to 800 m along fault lines and 100 m intervals up to 600 m along river data. The relationship between these buffer zones and the geological structure of the urban areas, the region, and the province was examined.

Provincial Disaster Risk Plans prepared for 81 provinces of Turkey by AFAD are also made for Isparta. Isparta IRAP, published in 2021, includes strategies and actions for earthquakes, floods, fires, meteorological disasters, climate change, and mass movements. This plan states that, despite having a lower population exposure to mass movements, dispersed settlements are still at landslide risks due to their lack of suitability assessments. The southern/southeastern regions of Isparta, known for their high potential for mass movements, also experience the highest precipitation and face geological disadvantages. The elevated earthquake risk further amplifies the danger of mass movements [35]. Mass movements (landslides, rockfalls, and avalanches) and related scenarios are presented in Section 2.5 of IRAP.

The data used for the spatial analysis of landslide-prone regions in the Isparta Region are collected from various resources and are presented in Table 2.

Table 2. Data sources and types.

Data	Source	Type
Elevation, Slope, and Aspect	Open topography, Copernicus GLO-30 Digital Elevation Model (COP30) (https://opentopography.org/ (accessed on 17 November 2022)) [45]	Raster
Road, waterway, and lake	Geofabrik, Open Street Map Data (download.geofabrik.de (accessed on 17 November 2022)) [46]	Line
Political Map of Turkey	https://www.diva-gis.org/gdata (accessed on 17 November 2022) [47]	Polygon
Lithology (Geology)	Akbaş et al., 2011 (http://yerbilimleri.mta.gov.tr/home.aspx (accessed on 17 November 2022)) [48]	Raster
Fault	Emre et al., 2013 (http://yerbilimleri.mta.gov.tr/home.aspx (accessed on 17 November 2022) [49]	Line

Table 2. *Cont.*

Data	Source	Type
Earthquake	Boğaziçi University Kandilli Observatory and Earthquake Research Institute Regional Earthquake-Tsunami Monitoring Center (http://www.koeri.boun.edu.tr/sismo/2/en/ (accessed on 23 February 2023)) [50]	Point
Land Use	Corine Land Cover (CLC) (2018). (https://land.copernicus.eu/pan-european/corine-land-cover/clc2018 (accessed on 15 May 2023)) [51]	Raster
Past Landslide Events	Duman et al. (2011) [34] Görüm and Fidan (2021) [36] Isparta IRAP (2021). Provincial Disaster Risk Plan by the Disaster and Emergency Management Presidency [35]	Polygon Point Point

During the investigation of fatal landslides within the study area, no indications were discovered to support the hypothesis that they were triggered as secondary landslides by earthquakes. Nevertheless, the absence of temporal data in the landslide information acquired from MTA and IRAP prevented the identification of potential occurrences of secondary disaster events.

This article presents a spatial analysis using an advanced tool like GIS that allows for investigating landslide-prone regions to guide development in safer areas. It is crucial in conducting a landslide analysis using a GIS environment [52]. It provides insights into the geological and environmental factors contributing to slope failure, aids in creating hazard maps to identify high-risk areas, enables the estimation of the probability of future landslides, and informs the design of mitigation measures. By leveraging GIS technology, the spatial information associated with landslides has been accurately registered and integrated into a geospatial database that enables the comprehensive analysis, visualization, and evaluation of landslide-related data. The georeferencing of landslides was performed by using QGIS 3.28 software.

Turkey's diverse urban landscape spans from bustling metropolises to small villages, each with its unique culture and history. Based on the UN HABITAT principles, under national legislation, the country categorizes settlements as urban (provincial and district centers) and rural (towns, municipalities, and villages). In 2012, the establishment of metropolitan municipalities in 14 provinces transformed towns and villages in 30 provinces into neighborhoods under district municipalities, granting them urban status. However, Isparta's central city did not receive metropolitan status, maintaining the urban–rural distinction.

Turkey's urbanization process differs significantly from developed countries [53], shaped by factors like natural disasters, migration, sectoral development, and capital investments, leading to population shifts. This and natural population growth have resulted in irregular and problematic urbanization. Isparta City transitioned from a compact to a sectoral form, while district and municipal settlements remained compact, and lives continued in rural settlements. Recent uncontrolled population growth due to external migration has accelerated urbanization. This study assesses the landslide inventory of Isparta and the relation between active landslide regions, as well as landslide-prone regions and human settlements.

This study was uniquely conducted at a specific scale due to the available data limitations. While more precise landslide-exposed zones are recommended to be assessed at a 1/25,000 scale [29], this scale is not suitable for upper-scale assessments used in regional planning studies. For these broader investigations, it is crucial to begin with a detailed analysis at smaller scales like 1/100,000 or 1/50,000 using a binary assessment (yes/no) without evaluating the magnitude [29]. Such an approach is valuable for overall planning objectives, where natural hazards are just one of several considerations [29]. Additionally, when data on landslide frequency are lacking or unreliable, susceptibility zoning is a preferable choice over quantitative hazard and risk zoning [54]. In this sense, this paper defines landslide-prone areas of Isparta.

The importance of choosing a parameter appropriate for the specific area under a study of approximately 1500 randomly selected publications has been revealed [55]. Accordingly, this spatial analysis was developed from an urban planning point of view to determine landslide-prone regions by considering the thematic layers (i.e., slope, aspect, elevation, and lithology); triggering factors (i.e., past earthquake events); and vulnerability inputs (distance to roads, distance to settlement, and land use). The characteristics of the study area and the existence of landslide events in relation to those parameters determined the selection of the parameters. It should also be stated that, in every planning process, those parameters are assessed. The spatial approach developed in this study can provide an assessment tool for planning analyses.

In this study, four main steps are followed: collecting parameter data, evaluating the thematic maps and preparing a synthesis showing landslide-prone regions that can direct planning studies (Figure 2). The methodology is based on a heuristic method. The rationalized approach referred to as "non-weighted bounded indicators" relies on the integration of overlapping thematic maps representing conditioning factors for mass movement [56]. This approach is also used for determining landslide-prone regions in Isparta. Different from [56], as it was focused on the quantification of a susceptibility index for each individual index, this study simply evaluated the togetherness of the multicriteria defined.

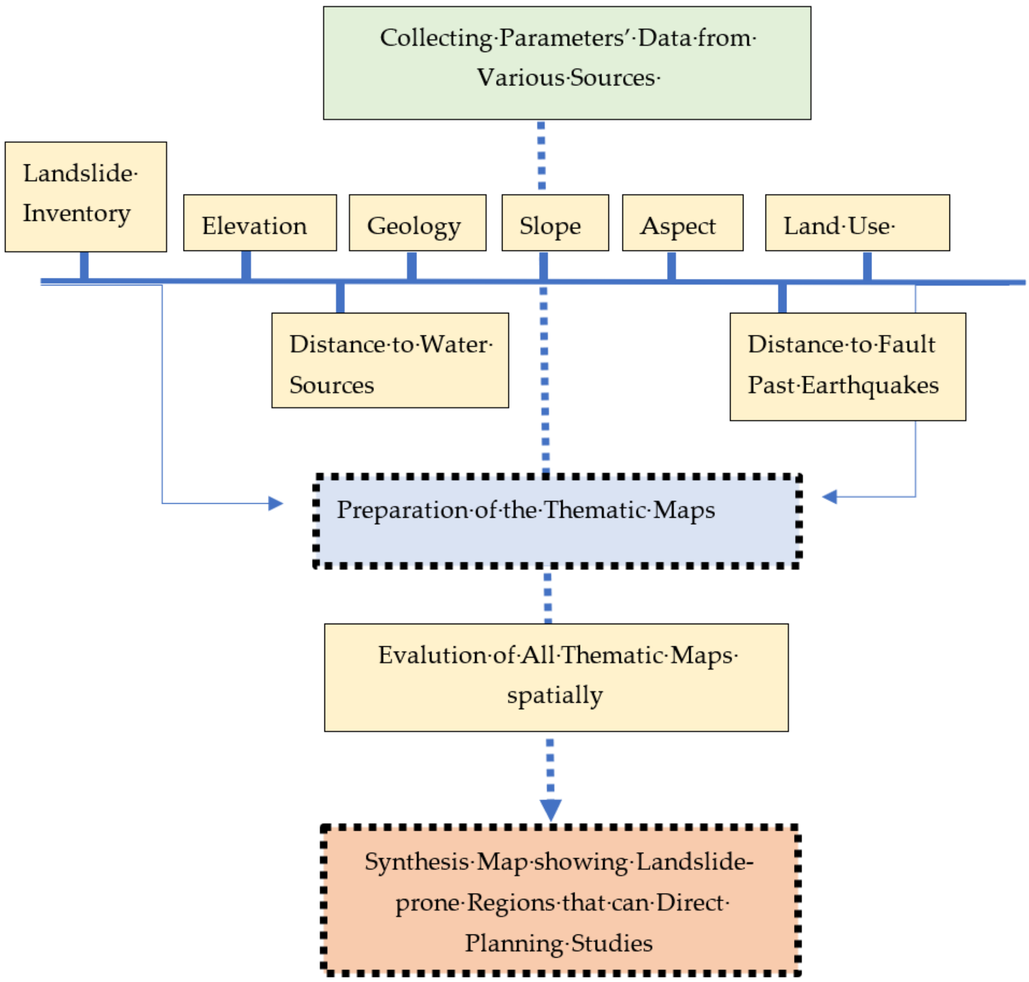

Figure 2. Workflow of the research.

In order not to increase the uncertainty, no ranking or weight was given to any parameter. This study accepted the assumption that future landslides will occur under circumstances resembling past event patterns.

2.3.1. Geological Setting

To the north of the Antalya Gulf, the Taurus Mountains form an inverted V-shape by extending northward, and this region is called the Isparta Fold or the Isparta Angle [57] (Figure 3). The eastern branch of the Isparta Angle consists of the Central Taurus Mountains, while the western branch consists of the Western Taurus Mountains. These two Taurus Mountains unite at the north of Lake Eğirdir-Hoyran.

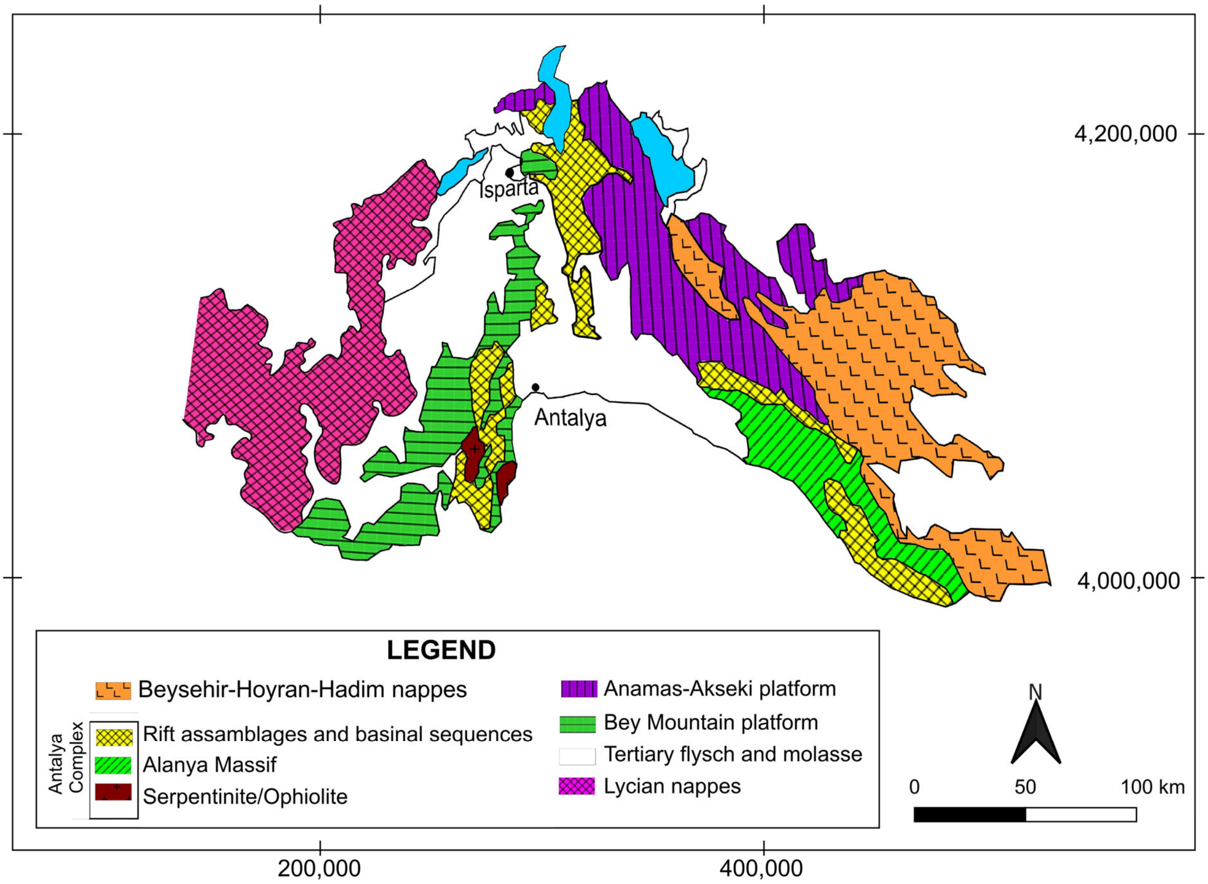

Figure 3. General geological map of Isparta and its surroundings (modified from [58]).

The study area consists of stratigraphic formations, including autochthonous and allochthonous units. The lithological units present in the province are depicted in Figure 4. Upon examining the lithological map, it is observed that the dominant geological units in the area are clastics and carbonates, clastics, neritic, pelagic, and lacustrine limestones. The percentage variations of landslides occurring are attributed to lithology and are given in Figure 5, revealing that clastics and carbonates exhibit the highest landslide percentage at 35%.

Lithological composition plays a significant role in landslide occurrence, with clastics and carbonates exhibiting the highest percentage of landslides in the study area. The dominance of Mesozoic-aged carbonate rocks, along with Tertiary-aged sedimentary and volcanic rock units, contributes to the instability of slopes. Understanding the lithological characteristics of the area is crucial for identifying high-risk zones and implementing appropriate mitigation measures.

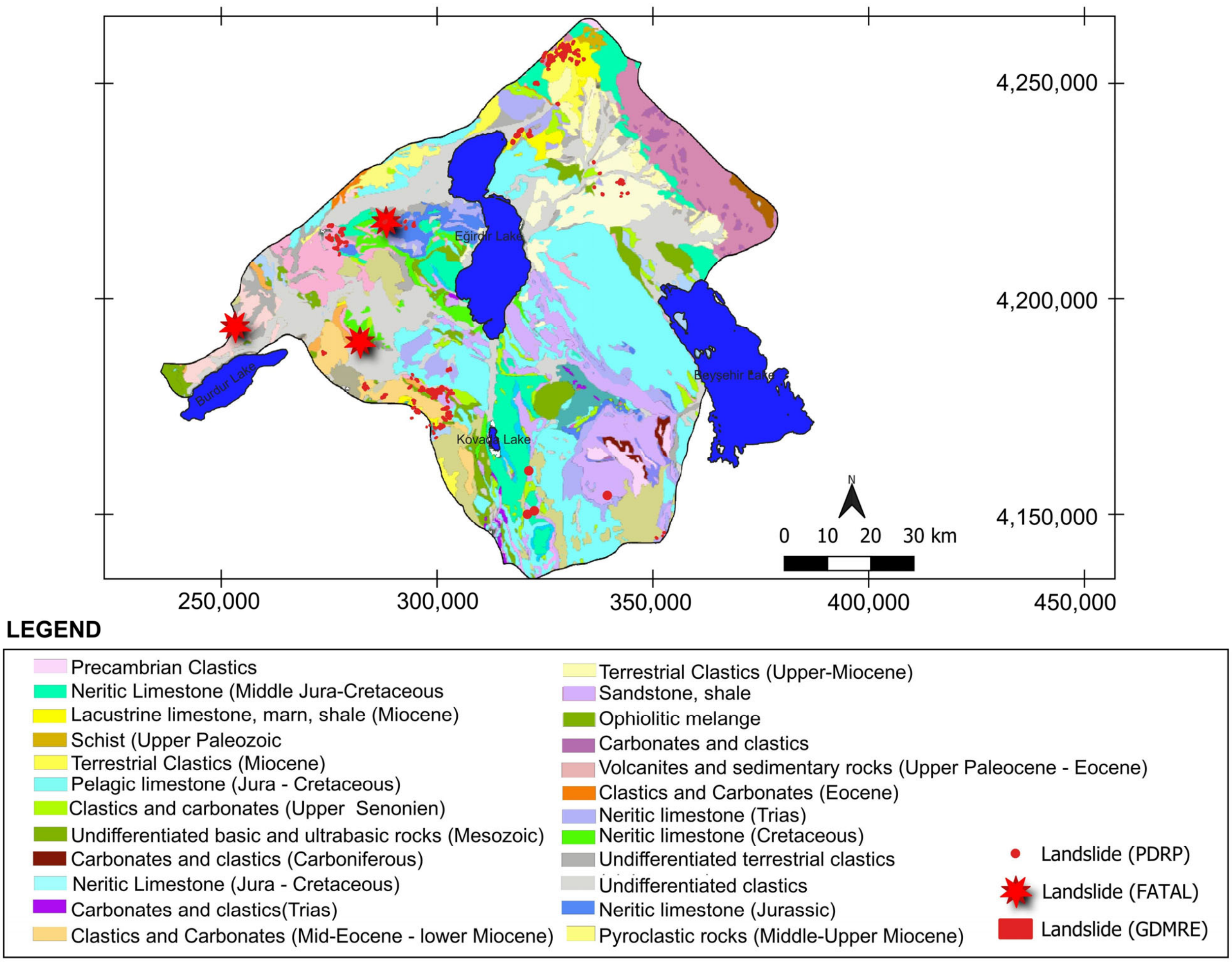

Figure 4. Geological map of Isparta (retrieved from [48]).

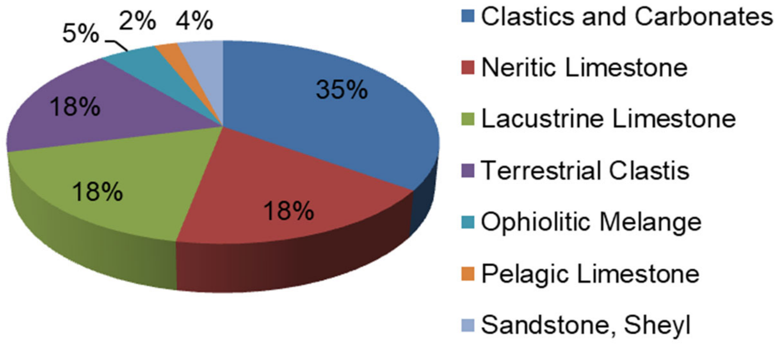

Figure 5. The percentages of landslides according to lithology.

2.3.2. Seismicity—Fault Lines and Past Earthquake Events

Landslide events are observed within proximity of around 100 m to tectonic features such as thrusts, overthrusts, and faults [59]. As the distance from these tectonic features increases, the occurrence of landslides gradually decreases. Isparta Angle and the surrounding area are complex regarding their tectonic and geologic features. The region is surrounded by active faults like the Burdur and Akşehir Fault Zones (Figure 6). These have produced many destructive and micro-level faults throughout history.

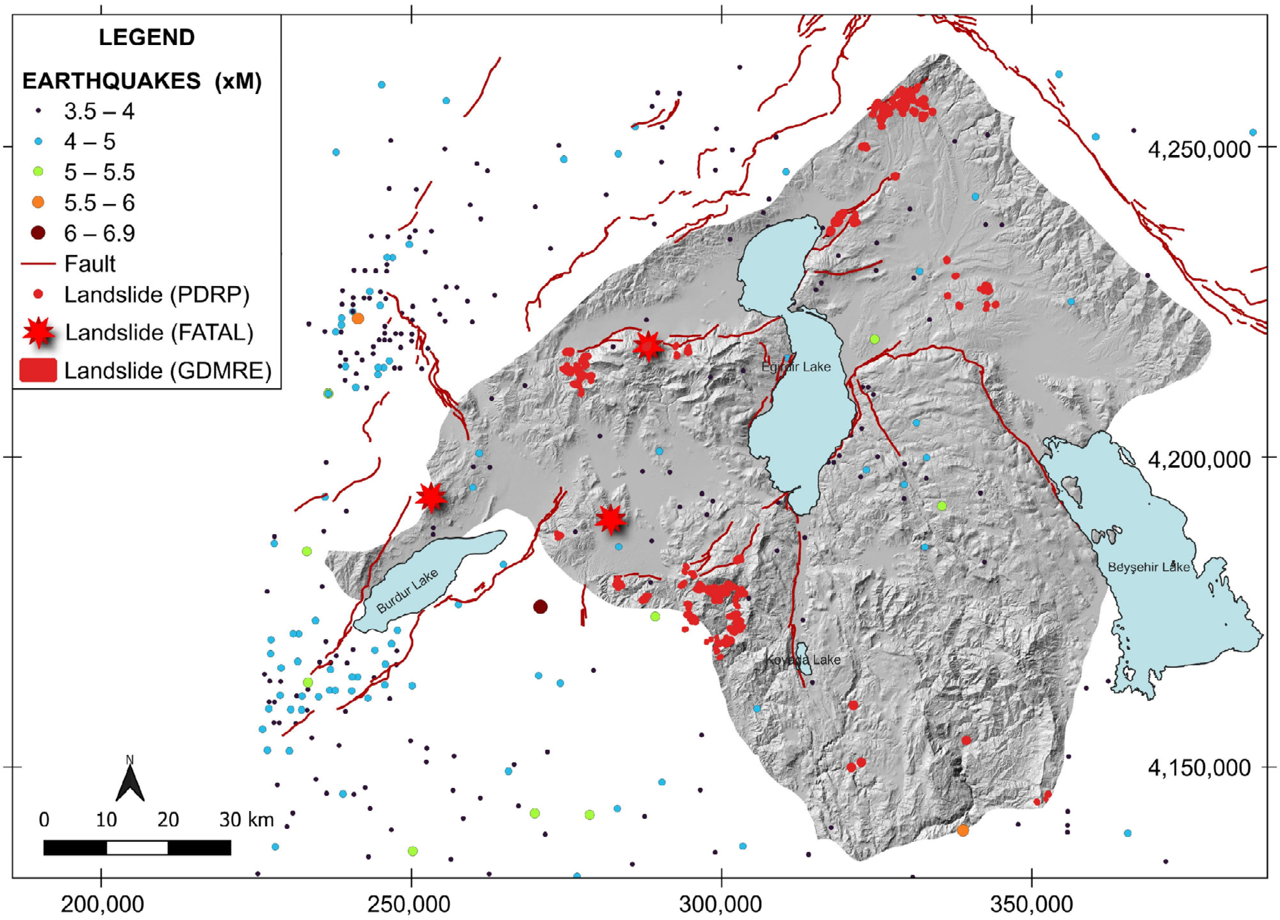

Figure 6. Past earthquake events between 1900 and 2023 and fault lines.

In the context of this study, for the area between longitudes 29.9–31.7° E and latitudes 37.3–38.5° N, which includes Isparta and its surroundings, a total of 399 earthquakes with a magnitude greater than 3.5 from 1900 to 1 February 2023 were examined by the authors. The spatial distribution of the earthquakes that occurred in the province is shown in Figure 6. Within the defined area, it was determined that there were five earthquakes with a magnitude of 5.5 or higher, 145 earthquakes between magnitudes 4 and 5.5, and 249 earthquakes between magnitudes 4 and 3.5.

Given the study area's geographical characteristics, determined by the surrounding faults and a history of significant seismic activity, the possibility of earthquakes triggering landslides cannot be discounted. An inventory covering this data is absent for Isparta. It is crucial to consider the destructive consequences of potential earthquakes and the potential for induced landslides when assessing the proximity of residential areas to fault lines since there are landslide areas near fault lines.

Seismic activity is another critical factor influencing landslide hazards. The presence of active faults, such as the Burdur and Akşehir Fault Zones, indicates the tectonic complexity of the region. This study revealed that landslides were predominantly observed near tectonic features, suggesting a correlation between fault lines and landslide occurrences. Monitoring and assessing seismic activity is essential for identifying areas prone to landslides and improving hazard management strategies.

2.3.3. Slope and Aspect

There is a consensus among researchers that the slope is an essential input parameter in landslide susceptibility analyses. Based on the research findings, the slope is a highly preferred choice among the various parameters [55]. It is widely accepted that the steeper the slope angle, the higher the risk of landslides [20]. The available literature demonstrated a consensus among researchers regarding the importance of incorporating the slope as a fundamental determinant in the initiation of landslides, thus establishing its widespread use as a parameter in evaluating landslide susceptibility [55]. The slope exhibits the most significant influence and indispensability concerning landslide susceptibility [55]. A slope map of Isparta is given in Figure 7.

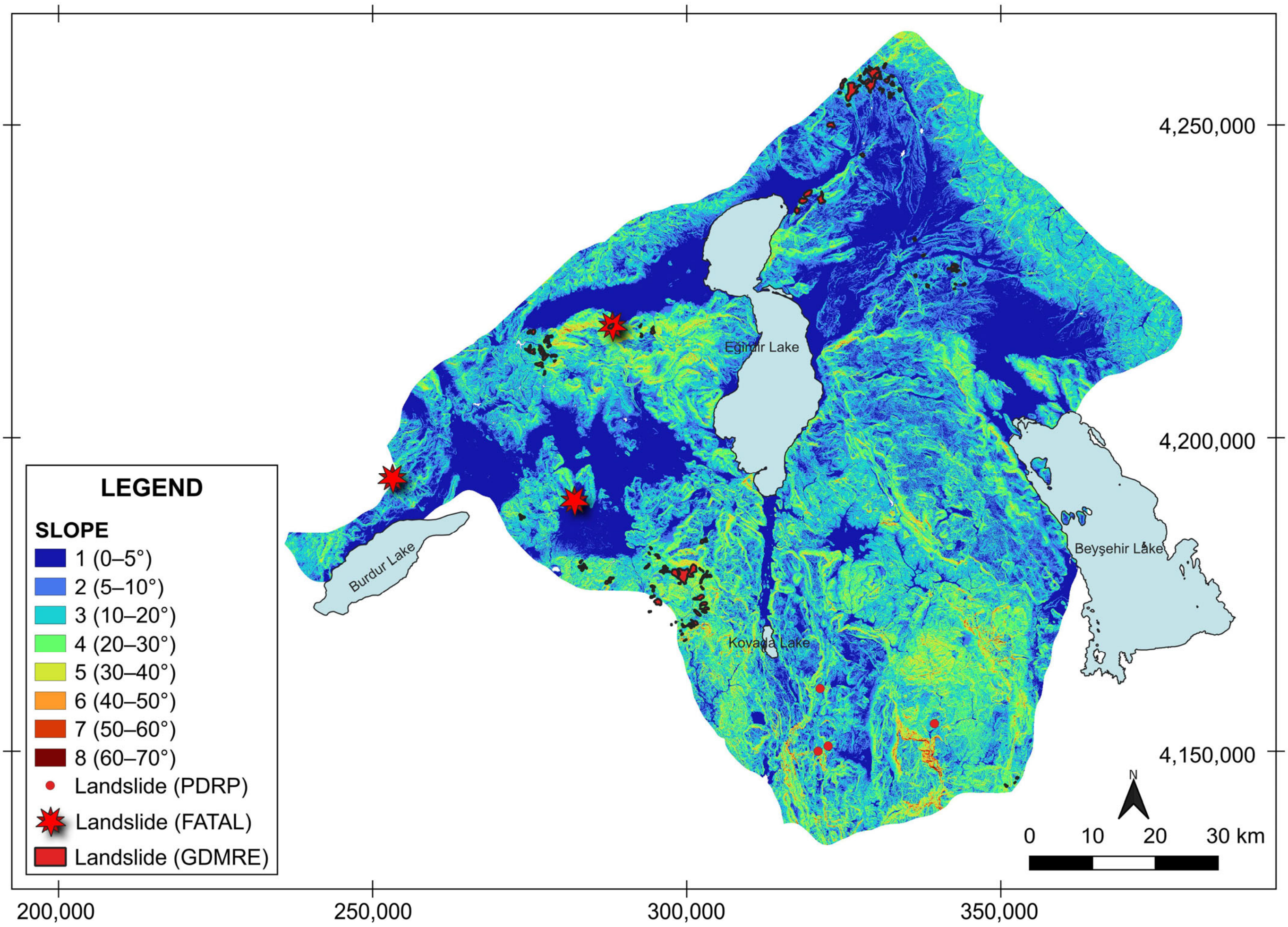

Figure 7. Slope map of Isparta.

The slope characteristics of the study area have been divided into five distinct categories, as illustrated in Figure 8. Upon analyzing the distribution of landslides based on slope percentages, it has been determined that the highest occurrence of landslides, comprising 64% of the total, is attributed to slopes within the range of 10–20°. Furthermore, slopes ranging from 5 to 10° accounted for 22% of the recorded landslides.

The study area was categorized into four groups based on azimuth angles and reclassified, as presented in Figure 9. When examining the percentage variations of landslides according to aspect, it was determined that the highest occurrence of landslides, at a rate of 38%, was associated with lithologies exhibiting a northern aspect. Following this, west-facing lithologies accounted for 26% of the landslides, east-facing lithologies constituted 20%, and south-facing lithologies accounted for 16% in descending order (Figure 10).

Slope angle is a widely recognized parameter in landslide susceptibility analyses. Steeper slopes are associated with a higher risk of landslides, emphasizing the importance of considering the slope as a fundamental determinant in landslide assessments. This study classified slopes into different categories based on the aspect angles, revealing that lithologies with a northern aspect had the highest occurrence of landslides. This information can guide urban planning and development to minimize landslide risks and determine vulnerable areas.

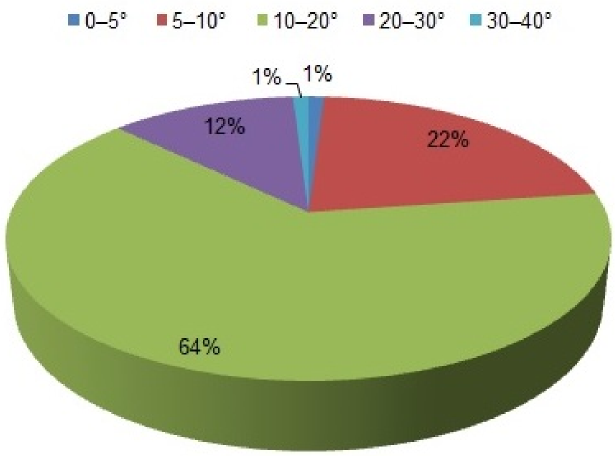

Figure 8. The percentages of landslides according to slope.

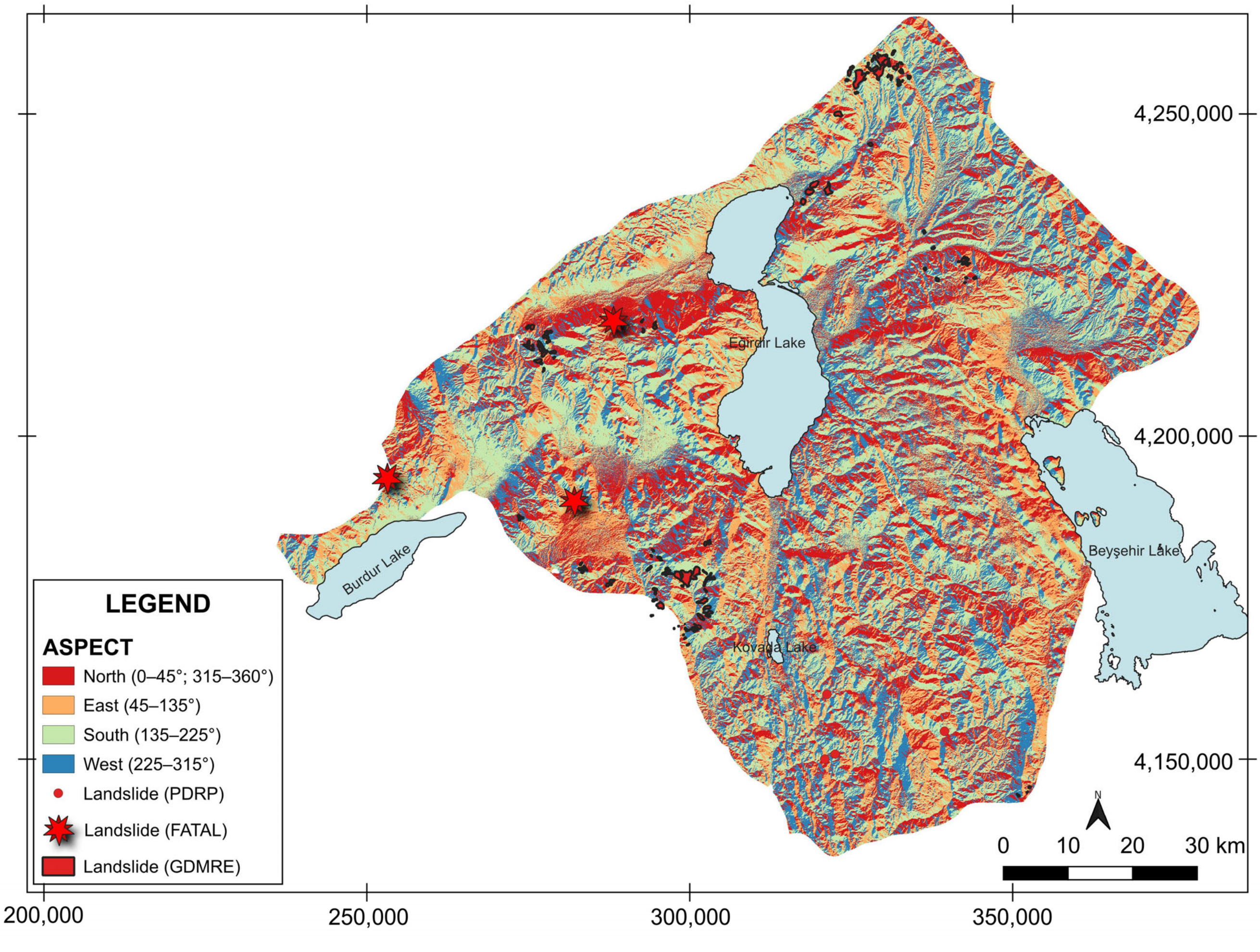

Figure 9. Aspect map of Isparta.

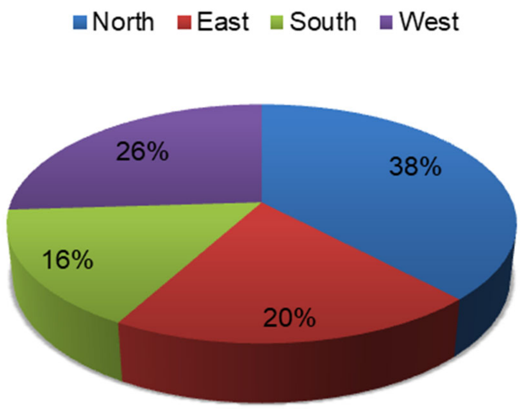

Figure 10. The percentages of landslides according to the aspect.

2.3.4. Water Sources

Researchers generally agree that the susceptibility to landslides decreases as the distance to rivers increases because rivers can have a detrimental effect on the stability of the soil, either by saturating certain materials with water or eroding the base of the slope [20]. Isparta is one of the provinces that has many water sources. The province is located in the "Göller Bölgesi" (Lakes Region). The province has various active faults appearing as springs, brooks, and rivers, and many floods are exercised. Urban settlements are located on river basins, and the names of those settlements are given in the synthesis map of this study.

The study involved the establishment of buffer zones along the rivers, with intervals of 100 m up to 600 m. The search focused on examining the correlation between these buffers and the geological composition of the province. Based on the study's defined parameters, five areas prone to landslides were identified. Water sources, such as rivers and lakes, have a complex relationship with landslide susceptibility. While the literature lacks consensus on the distance of stream networks or lakes regarding landslide occurrence, it is generally agreed that the proximity to rivers can increase the vulnerability of slopes. Rivers can saturate materials with water or erode the base of slopes, compromising their stability. Evaluating the influence of water sources on slope vulnerability and establishing appropriate buffer zones are crucial for effective landslide hazard management.

2.3.5. Landslide Inventory

Creating a map of landslides that have occurred in the past, also known as landslide inventory mapping, can be utilized to identify areas prone to landslides and assess their risks [60–62]. As stated in the Method section, data from three sources were gathered to form the landslide inventory of Isparta. The landslide inventory of Isparta and the relation of active landslide regions and prone regions and their relations to human settlements are given in Figure 11. The data collected from the Isparta case consisted of information about the area affected by landslides, specifically covering 3612.60 hectares [34]. Additionally, four individual landslide incidents were examined from the Isparta IRAP [35]. Furthermore, three landslide events resulted in the loss of lives [36].

Creating a landslide inventory map based on past landslide events is essential for assessing the risk and susceptibility of specific areas. Conveying the results of landslide maps to decision-makers and planners is a crucial step in facilitating informed choices regarding land use decisions and disaster preparedness. This transfer of information also supports the development of proactive strategies to mitigate landslide-related risks [63].

This mapping provides insights into the geological and environmental factors contributing to slope failure, enabling the identification of high-risk zones and the estimation of future landslide probabilities.

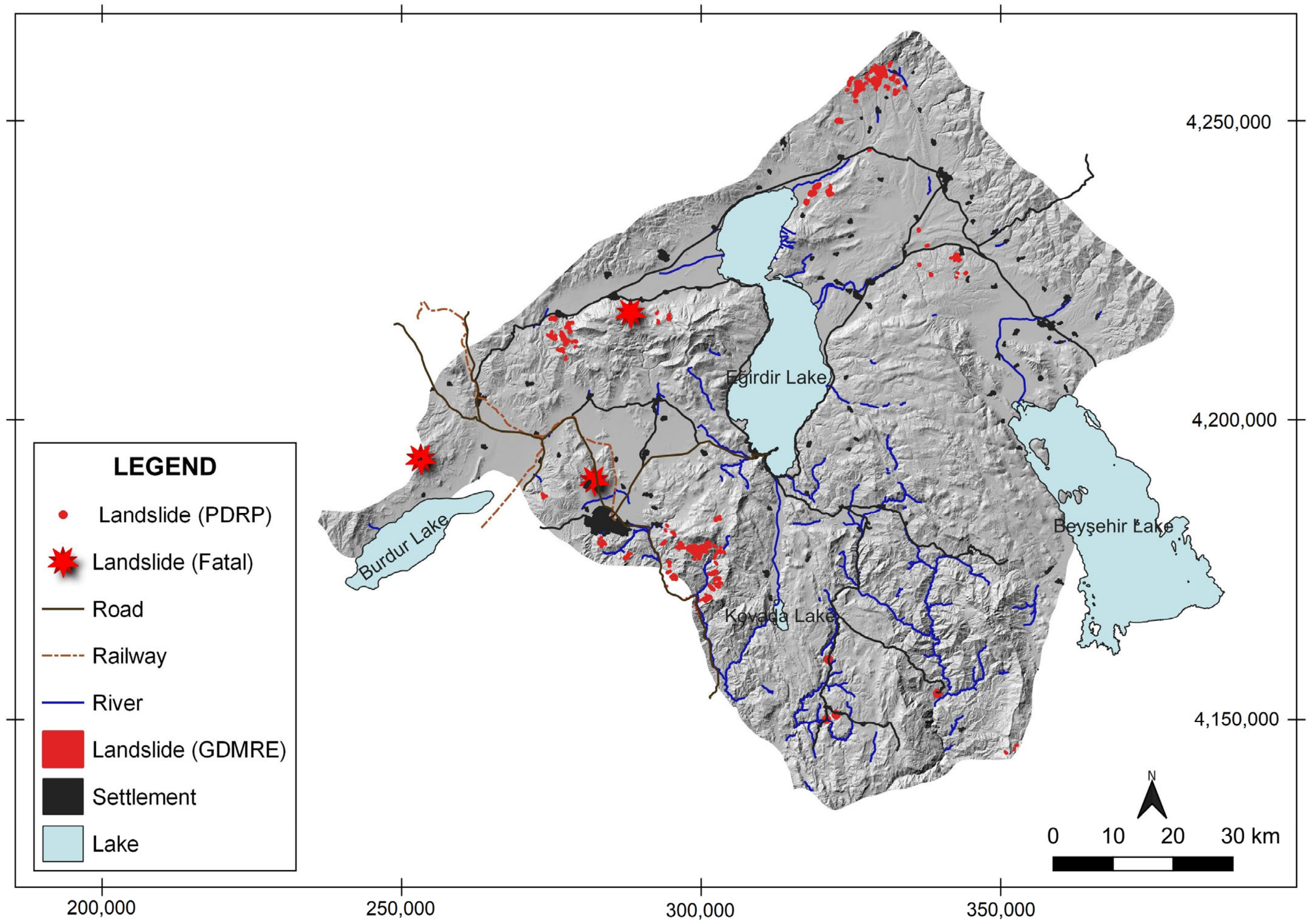

Figure 11. Landslide inventory and the relation of landslides and human settlement areas (PDRP: Provincial Disaster Risk Plan, GDMRE: MTA).

The study highlighted significant landslide events in Senirkent and Güneyce, emphasizing the importance of incorporating historical data into landslide risk management strategies. The Isparta IRAP states that a landslide is expected in Sütçüler due to long-lasting and persistent rainfall and large temperature differences between night and day. In the event of a disaster, it is expected that issues such as housing, animal shelter and feed storage, and the repair of damaged infrastructure will arise. The mentioned report described the worst-case scenario, triggering slope instability due to inappropriate construction, lack of preventive measures, or relocation in the Imaret neighborhood of Eğirdir. This scenario is based on the occurrence of a moderate-scale earthquake.

2.3.6. Land Use

Several studies have assessed land use as a parameter in landslide risk management [64–66]. Land use transformation has gained global recognition as a paramount factor influencing the occurrence of rainfall-induced landslides [65]. Land use maps must be prepared to understand which land uses are at risk. The hazard level can also be understood, and necessary precautions can be taken.

The CORINE land use map was used to categorize land uses into several classes: settlements, industrial, airports, mineral extraction sites, urban green areas, forest areas, bare rocks, marshes, and water sources. In this phase, the existing land cover classes were rearranged to align with the specific objectives of the research. In addition to this classification, road networks, including first, second, and third degrees, were added to the

CORINE land use map. Settlement and archeological sites near landslide areas were also added (Figure 12).

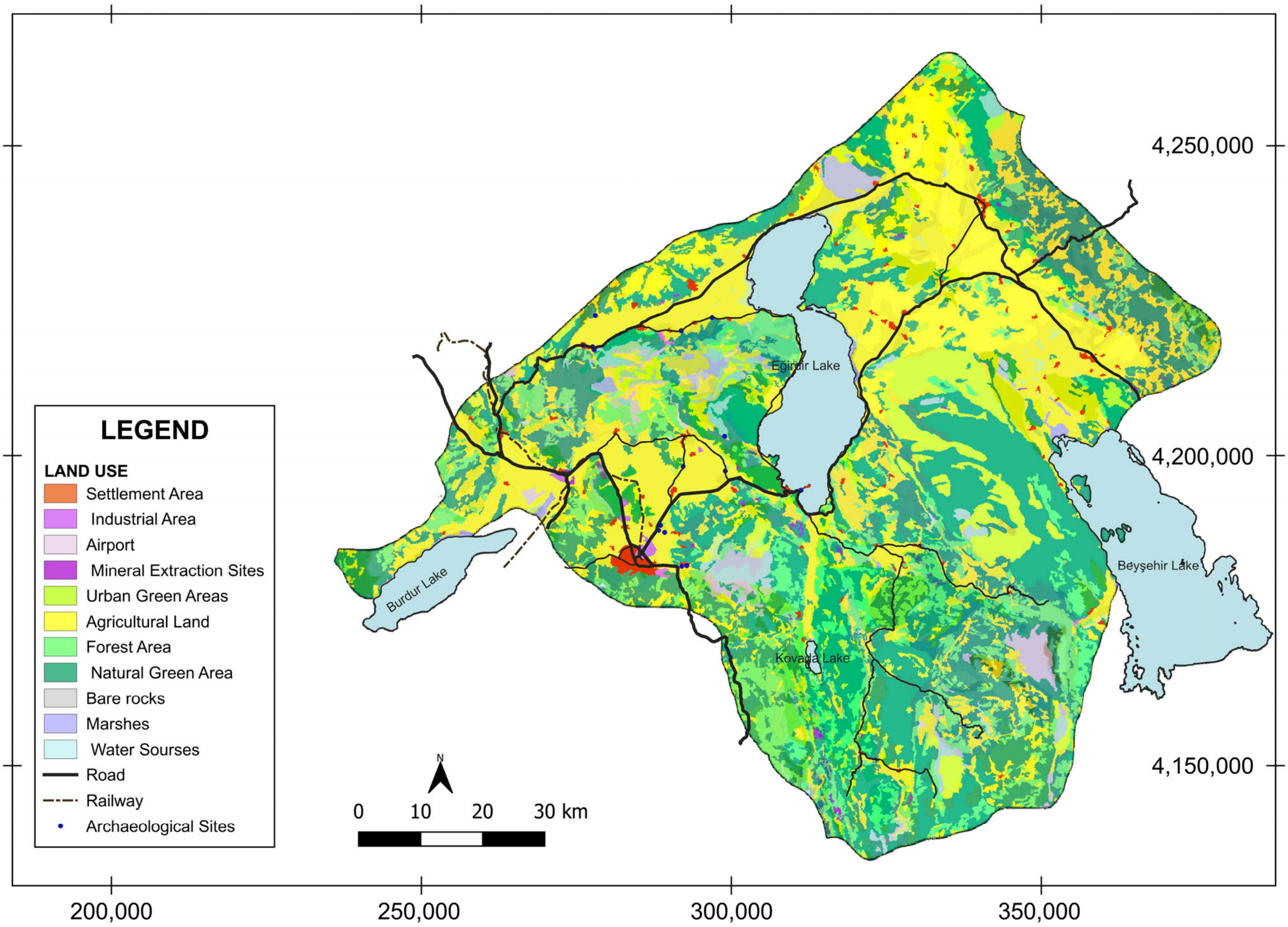

Figure 12. Land use map of Isparta.

Within the boundaries of Isparta Province, the spatial composition can be delineated based on land use categories. Agricultural land, forest areas, natural green areas, mineral extraction sites, bare rocks, marshes, settlements, and water sources exist in the province.

Land use change is recognized as a crucial factor influencing the occurrence of rainfall-induced landslides. The CORINE Land Cover Program was utilized to classify land use in the research area, including settlement areas, industrial areas, forests, and water sources. Understanding the spatial composition of land use, such as the dominance of forested regions, agricultural land, and settlements, helps identify areas where land use practices can contribute to landslide risks.

3. Results

This study conducted a GIS-based spatial analysis using three different landslide datasets for Isparta. Multiple data sources were necessary, since no single database contained all the landslide events in this province. After spatializing the landslide events, the study identified five landslide-prone regions based in areas with the highest number of landslides, the existence of the parameters defined in this study, and landslide areas close to settlements.

Twelve landslide disaster-prone areas are defined in Isparta IRAP [35]. Five of them are in Isparta's Central District, five are in Sütçüler District, one is in Uluborlu, and one is in Yalvaç District. In addition, 3612.60 hectares of the landslide area [34], four landslide events in point data [35], and three fatal landslide events as point data [36] were investigated in this research. This study's spatial analysis covered human settlements, including urban and rural settlements, in Isparta. At this point, being a spatial database, it differed from Isparta IRAP.

3.1. Landslide-Prone Regions in Isparta

A synthesis of parameters and landslide-prone regions in Isparta was assessed by superposing the various parameters defined in this study (Figure 13). Superposed layers with data on past landslide events provided landslide-prone regions. Accordingly, five landslide-prone regions at the upper scale were determined by the spatial analysis of the parameters and are given in detail in Figure 14a–e. The landslide-prone regions were selected according to the distribution of landslide areas, past landslide events, fault lines and earthquakes, slope, and aspect. In addition, the existence of settlement areas near past landslide events was considered.

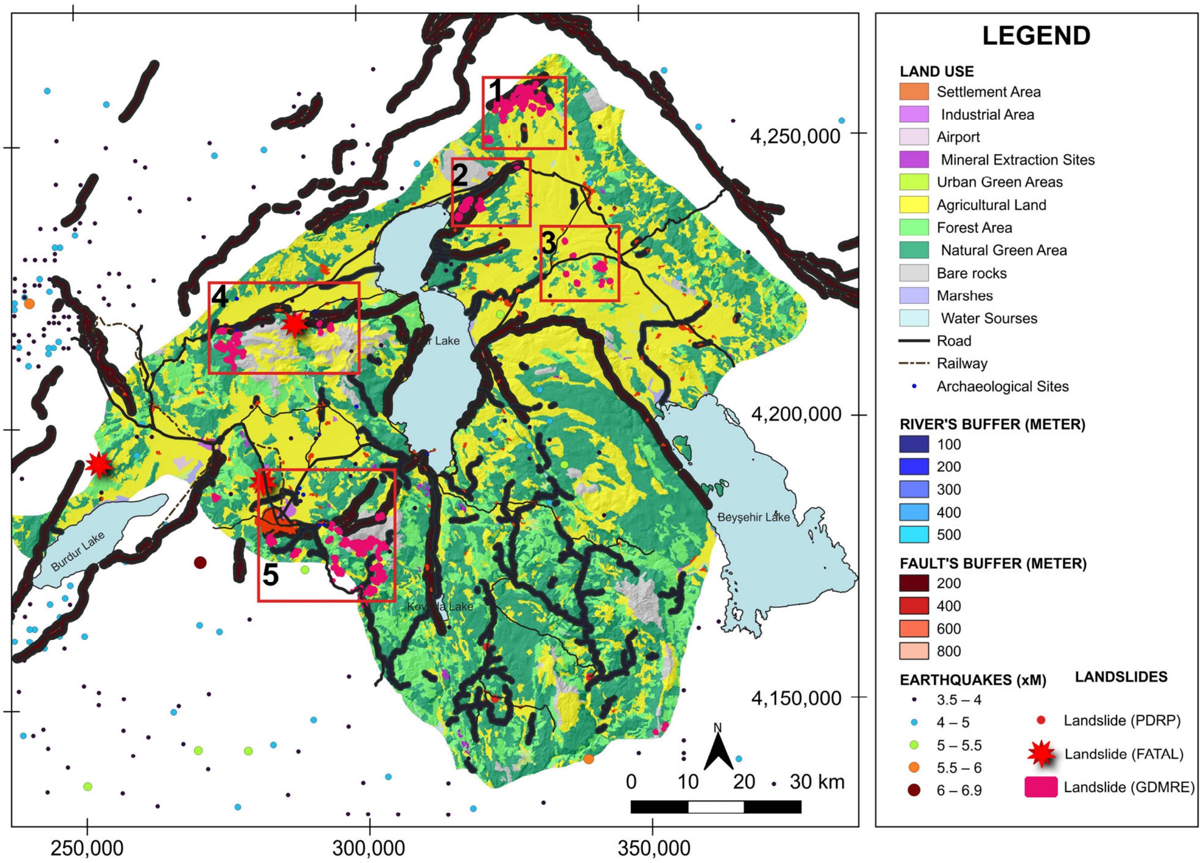

Figure 13. Synthesis of parameters and landslide-prone regions in Isparta.

Slope ranges and aspect directions are presented by region in Tables 3 and 4.

Table 3. Slope ranges in landslide-prone areas.

Slope Range	Class	Region 1 (R1) Slope (%)	Region 2 (R2) Slope (%)	Region 3 (R3) Slope (%)	Region 4 (R4) Slope (%)	Region 5 (R5) Slope (%)
0–5°	1	-	-	8	-	-
5–10°	2	48.5	33	67	4	4
10–20°	3	48.5	50	25	81	81
20–30°	4	3	17	-	11	15
30–40°	5	-	-	-	4	-

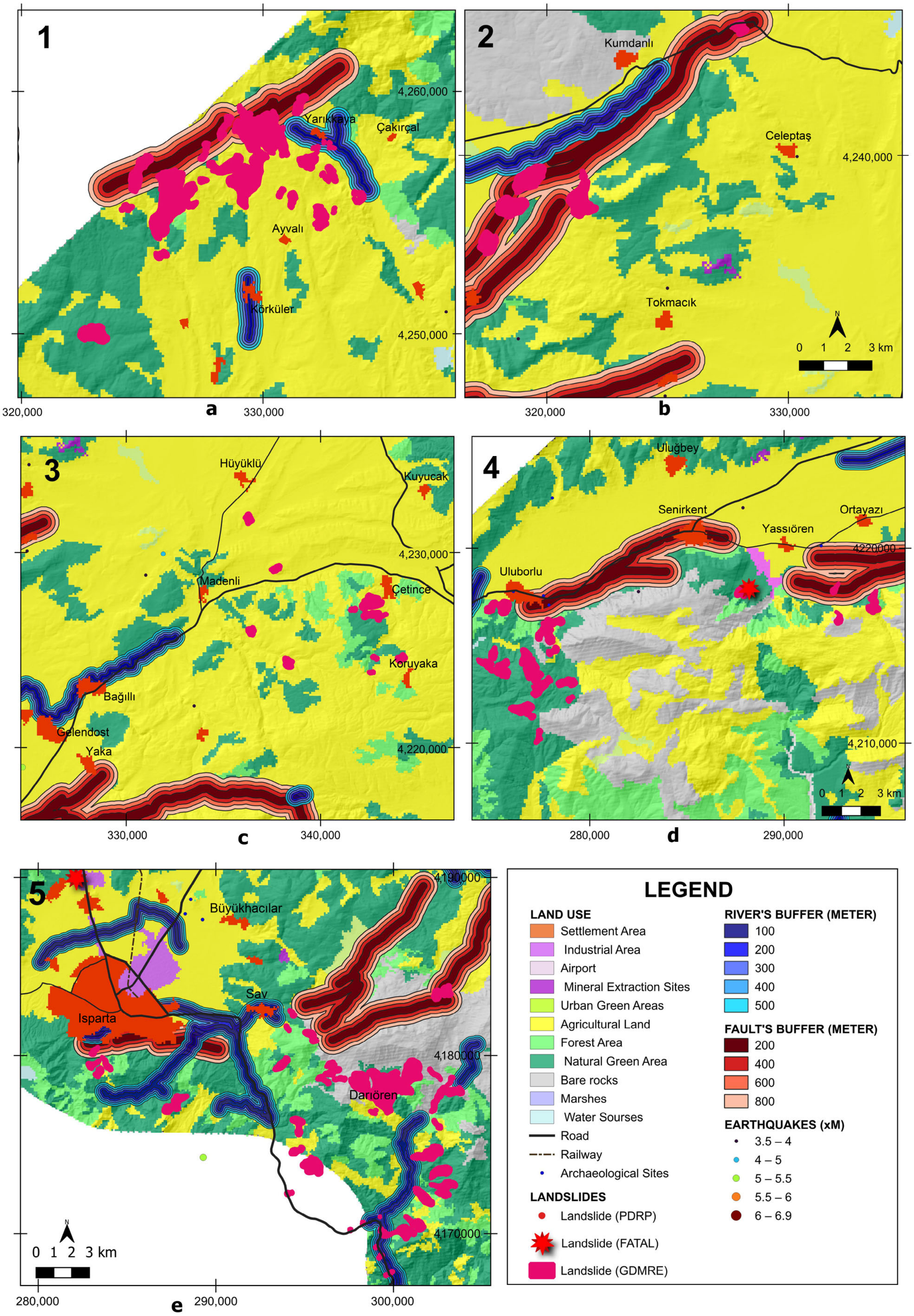

Figure 14. (**a**–**e**). Landslide-prone regions in Isparta.

Table 4. Aspect directions in landslide-prone areas.

Class	Direction	Region 1 (R1) Aspect (%)	Region 2 (R2) Aspect (%)	Region 3 (R3) Aspect (%)	Region 4 (R4) Aspect (%)	Region 5 (R5) Aspect (%)
1	North	27	67	10	67	26
2	East	30	-	40	7	17
3	South	37	-	20	4	13
4	West	6	33	30	22	44

3.2. First Landslide-Prone Region

Figure 14a presents the first landslide-prone region. This region is covered with fault lines and landslide areas. The landslide areas cover 1142.75 ha in this region. Four villages are included: Yarıkkaya, Çakırçal, Ayvalı, and Körküler. As seen in Figure 14, Körküler and Yarıkkaya are settled on the river basin. In addition, Yarıkkaya is near fault lines. The populations of those villages in 2022 were as follows: Yarıkkaya: 460, Çakırçal: 162, Ayvalı: 416, and Körküler: 1099.

Many landslides occur in this region within the 800 m buffer zone of faults and the approximately 500 m buffer zones of riverbeds. The analysis derived from the slope map indicated that landslides predominantly occurred within the 5–10° slope range, accounting for 48.5% of the occurrences, and within the 10–20° slope range, accounting for 48.5%. Furthermore, the orientation analysis revealed that landslides exhibited a predominant aspect toward the south direction, accounting for 37% of the observed cases.

3.3. Second Landslide-Prone Region

In the second region (Figure 14b), a 354.70 ha landslide-prone area exists. Kumdanlı, Celeptaş, and Tokmacık Villages form the second region. As observed in Region 2, it is evident that the 800 m buffered fault line and the 500 m buffered riverbed coincide in the same region. In addition, landslides are concentrated around the 800 m vicinity of the fault line. The population of those villages in 2022 was as follows: Kumdanlı: 1186, Celeptaş: 322, and Tokmacık: 706. Kumdanlı is close to fault lines, rivers, and landslide areas. The analysis derived from the slope map indicated that landslides predominantly occurred within the 10–20° slope range, accounting for 50% of the occurrences. Furthermore, the aspect analysis reveals that landslides were predominant in the north direction, accounting for 67% of the observed cases.

3.4. Third Landslide-Prone Region

The third region has a 176.22 ha landslide area (Figure 14c). Gelendost, Bağıllı, Yaka, and Koruyaka are situated in this region. The population of those settlements in 2022 was as follows: Gelendost: 5279 (central district), Bağıllı Village: 569, Yaka Village: 1552, and Koruyaka Village: 873. Gelendost and Bağıllı are on river basins, while Yaka is on fault line buffers. Çetince and Koruyaka Villages are very close to landslide areas. It was observed that landslides do not occur around the 800 m buffer zone of faults or the 500 m buffer zone of riverbeds. The analysis derived from the slope map indicated that landslides predominantly occurred within the 5–10° slope range, accounting for 67% of the occurrences. Furthermore, the aspect analysis revealed that landslides were predominant in the east direction, accounting for 40% of the observed cases.

3.5. Fourth Landslide-Prone Region

The fourth region (Figure 14d) has 564.28 ha landslide areas. The population of those settlements in 2022 was as follows: Uluborlu: 5635 (central district), Senirkent: 4548 (central district), and Yassıören Village: 386. It was observed that landslides, in frequency, did not primarily occur on the fault and river buffers. However, they were found within the 800 m buffer zone of faults. The analysis derived from the slope map indicated that landslides predominantly occurred within the 10–20° slope range, accounting for 81% of the occurrences. Furthermore, the aspect analysis revealed that landslides were predominant in the north direction, accounting for 67% of the observed cases.

3.6. Fifth Landslide-Prone Region

The fifth region (Figure 14e) has the largest landslide area of 1374.63 ha. The population of those settlements in 2022 was as follows: Isparta: 445.325 (central district), Sav: 1026, and Darıören Village: 350. Many landslides occurred within the 800 m buffer zone of faults and approximately 500 m buffer zones of riverbeds. The analysis derived from the slope map indicated that landslides predominantly occurred within the 10–20° slope range, accounting for 81% of the occurrences. Furthermore, the aspect analysis revealed that landslides exhibited a predominantly west directional aspect, accounting for 44% of the observed cases.

Detailed spatial landslide risk management studies should be conducted at a larger planning scale for these five landslide-prone areas. When examining these five areas, it was observed that landslides generally occurred in weak zones on fault lines and riverbeds. From a planning perspective, considering these parameters is paramount in preventing the potential loss of life and property caused by earthquakes and landslides.

4. Discussion

Five discrete landslide-prone regions within the study area were assessed, and each was marked by distinctive attributes and contributing elements to landslide occurrences. These findings yield valuable insights into the geographical distribution of landslides and play a pivotal role in the formulation of effective risk management strategies. For years, cities worldwide, both developed and developing, facing landslide risks have enforced and periodically revised local planning regulations to guide their development [29].

The analysis showed that there are both urban and rural settlements located in landslide-prone regions. In addition, there are fault lines that pass those settlements. In addition, in Uluborlu, which is one of the towns in Isparta, the urban development direction is through landslide-prone regions.

In this sense, the role of upper-scale spatial planning in managing landslide risks is very significant. As stated by [32], regional land use plans must incorporate data on landslide patterns. To prevent unnecessary expenditures, municipal authorities rely on past landslide incidents and the resulting damage to formulate local policies that limit construction in areas prone to landslides. In the Isparta case, there is a 1/100,000 scale Antalya-Burdur-Isparta Planning Region Environmental Territorial Plan (Antalya-Burdur-Isparta Planlama Bölgesi 1/100,000 ölçekli Çevre Düzeni Planı). Although its existence is a significant contribution to the sustainability of Isparta Province, it has some limitations in terms of considering landslide risk mitigation.

Comparison of Upper-Scale Spatial Plan Land Use Decisions and Landslide-Prone Regions of Isparta

The upper-scale plan covering the provincial area is the 1/100,000 scale Antalya-Burdur-Isparta Planning Region Environmental Territorial Plan approved by the General Directorate of Spatial Planning of the Ministry of Environment, Urbanism and Climate Change on 23 March 2015. The plan covers Antalya, Isparta, and Burdur Provinces and their section of the plan (Figure 15). The plan has been annulled seventeen times before today. Two of the plan amendments (2022) were related to Isparta Province.

This upper-scale spatial plan is a blueprint for sustainable development. It outlines objectives, strategies, and spatial intervention approaches. The plan ensures orderly and balanced development and considers the balanced utilization of resources, historical development, and land use decisions while preserving the region's unique identity.

Based on the comparison of the 1/100,000 scaled Environmental Territorial Plan with the land uses in landslide-prone regions, the following results have been identified:

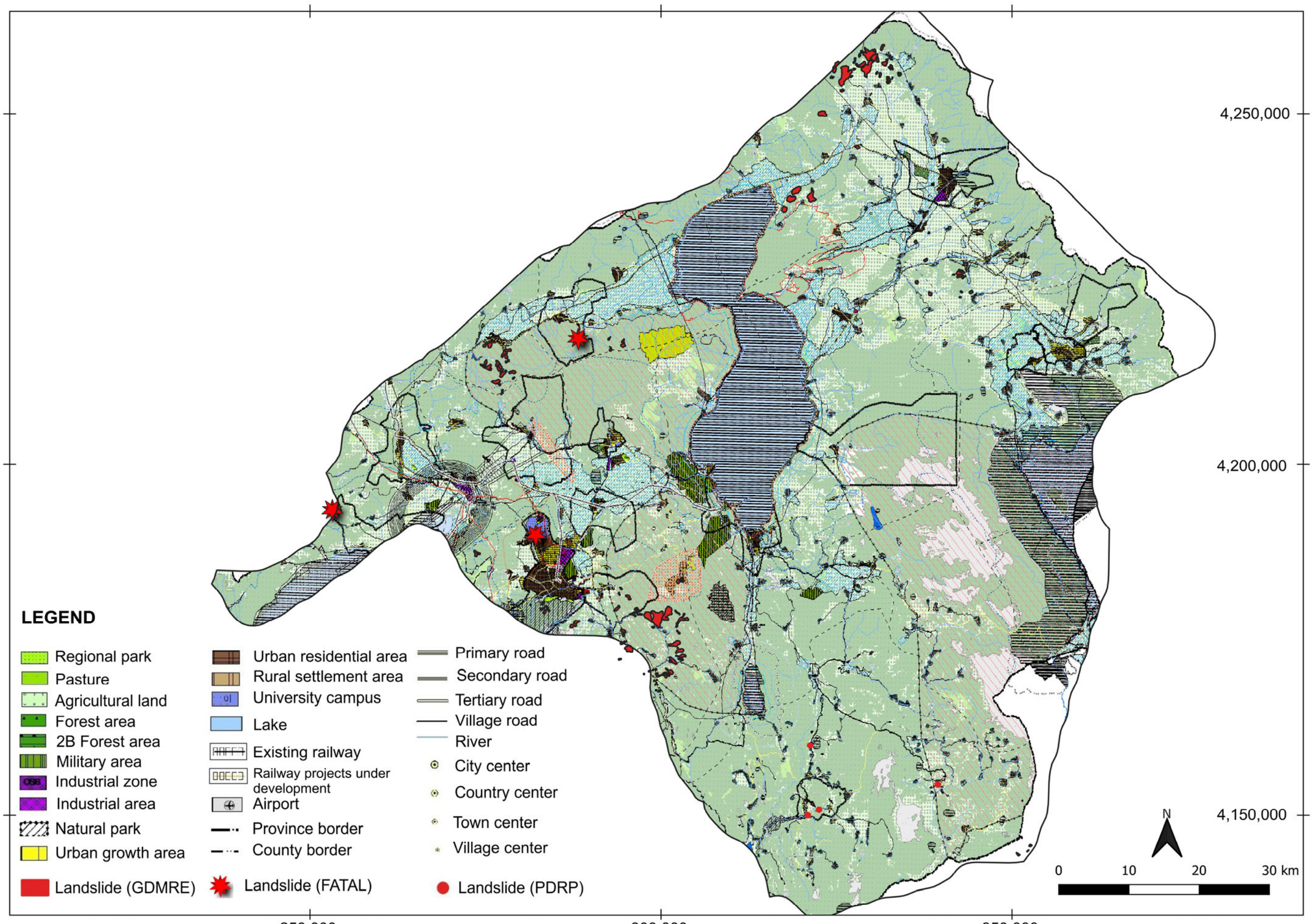

Figure 15. The 1/100,000 scale Antalya-Burdur-Isparta Planning Region Environmental Territorial Plan (Isparta section is cropped from the Territorial Plan).

In the First Region: The settlement of Körküler, located in the northwest of Sağırköy, is entirely within the landslide-prone area. Most of the landslide areas consist of meadows, wetlands, agricultural, and forest lands, and they are integrated with fault lines. Therefore, earthquake-triggered landslides are likely to occur in Sağırköy, putting the area at risk. It is recommended to relocate the settlement to a safer area.

In the Second Region: The Kumdanlı, Celeptaş, and Tokmacık settlements are at risk of landslides to the north. Gökçeali is exposed to both earthquake and landslide risks, while Yukarıtırtır faces earthquake risks. Necessary precautions should be taken in these areas to mitigate the risks.

In the Third Region: Numerous small-clustered settlements are concentrated in the area, some of which are also at risk of landslides associated with active fault lines. The Hüyüklü, Bağıllı, Madenli, Koruyaka, and Çetinceli settlements are located in landslide-prone areas. It is essential to prohibit settlements in risky directions to prevent development in hazardous landslide areas. The existing urban plans should be revised accordingly, including the upper-scale environmental plans.

In the Fourth Region: The southeastern urban development areas of Uluborlu are located in a landslide-prone zone. Additionally, active fault lines pass through the same area, increasing the risk of earthquake-triggered landslides. It is recommended to relocate the urban development areas in a different direction.

In the Fifth Region: Savköy, situated within a steep and narrow valley, is at risk of landslides. The settlement's development should be carefully managed and controlled.

In the hillside areas of the Darıören settlement to the north, a substantial portion of the forested area is prone to landslides. Therefore, any tourism-related development in this direction should be avoided.

These findings and recommendations are based on comparing the Environmental Planning Map and land use in landslide-prone regions. It is crucial to act upon these results to ensure the safety and sustainable development of the respective areas.

5. Conclusions

Spatial planning can be vital in managing landslide risks and reducing their impact on lives, property, infrastructure, and the local economy. Protecting people and property from landslides can be possible by determining landslide-prone regions and incorporating landslide-risk regions into spatial plans and planning decisions. Spatial plans are essential tools for risk and hazard reduction.

This study has outlined the key parameters for identifying landslide-prone regions on a provincial scale. This research presented major parameters such as elevation, land use, past earthquakes and landslide events, lithology, slope, aspect, and water sources that are critical in identifying landslide-prone areas. By integrating these parameters into spatial planning and development processes, urban planners and decision-makers can identify landslide-prone areas, implement appropriate mitigation measures, and develop sustainable and resilient human settlements in Isparta at the provincial scale.

Moreover, a spatial landslide inventory, produced using various data sources, has been created in QGIS that can easily be integrated into planning studies. The evaluated landslide parameters have been discussed in conjunction with the approved spatial plan for Isparta Province. Upon comparison of the regions identified through spatial analysis with the upper-scale plans, it has been evaluated that there are many rural settlements that stay in landslide-prone areas and there are also fault lines that pass through some of those settlements. In addition, the urban development direction of Uluborlu should be relocated in a different direction to mitigate landslide risks.

In addition, it assessed that considering the Provincial Disaster Risk Reduction Plan of Isparta (IRAP) must be a legal obligation for urban planners and responsible public authorities involved in plan preparation and approval. However, due to inadequate landslide risk assessments, there are areas for improvement in identifying risks, preparing plans with sensitivity to these risks, and ensuring the sustainability of settlements. IRAP still remains an informative document rather than providing a spatial analysis that directs upper-scale planning studies. Landslide-prone regions absent in the IRAP must be determined before the plan preparation phase, and binding legislation must be prepared. There must be forced action for landslide disaster management in the new plan preparation (including revisions). A comprehensive approach is needed to manage landslide risks, hazards, and hazard-prone land use decisions to realize the above-stated principles for achieving sustainable urban development. This approach should include policy measures and a spatial analysis at different planning scales. The integrated planning framework and the National Landslide Spatial Inventory Database are also essential.

The Isparta spatial landslide inventory in this study shows the areas affected by landslides, specifically covering 3612.60 hectares, four individual landslide incidents from the Isparta IRAP, and three landslide events that resulted in the loss of lives. With the spatial analysis developed here, landslide-prone areas of Isparta have been identified. However, the spatial analysis also indicated deficiencies in the data format, updates, creation, and in the collection processes. The fragmented landslide data of Isparta Province challenges the assessment of landslide risks and sustainable development of the region.

In addition, the UNDRR's (2023) proposals offer a comprehensive roadmap for policy-makers in navigating sustainable development and resilience. By prioritizing anticipation, prevention, and risk reduction across the Sustainable Development Goals, societies can enhance their resilience against disasters. Strategic resource allocation for disaster prevention underscores the dedication to present and future generations' safety. Overall, a proactive, visionary approach is crucial for driving transformative change toward a more sustainable, livable, and resilient future.

The assessment employed in this study is suitable for determining and evaluating landslide-prone regions that direct upper-scale strategic and spatial planning. The outcomes of this study can offer valuable insights for local administrations with landslide-prone regions in their territories. However, it should be noted that this study was based on a provincial-scale analysis of landslides. For more accurate and detailed research, larger-scale analyses, including 1/25,000 and 1/5000, should be conducted.

In conclusion, this discussion highlights the importance of integrating landslide hazard management with urban planning in Isparta. Moreover, it is necessary that the Provincial Disaster Risk Reduction Plans encompass spatial data that can be effectively integrated into urban planning processes. Further research, and the integration of landslide risk mitigation into urban planning and spatial landslide inventory, are essential to developing comprehensive policies, tools, and strategies for mitigating landslide risks in Isparta and similar regions.

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