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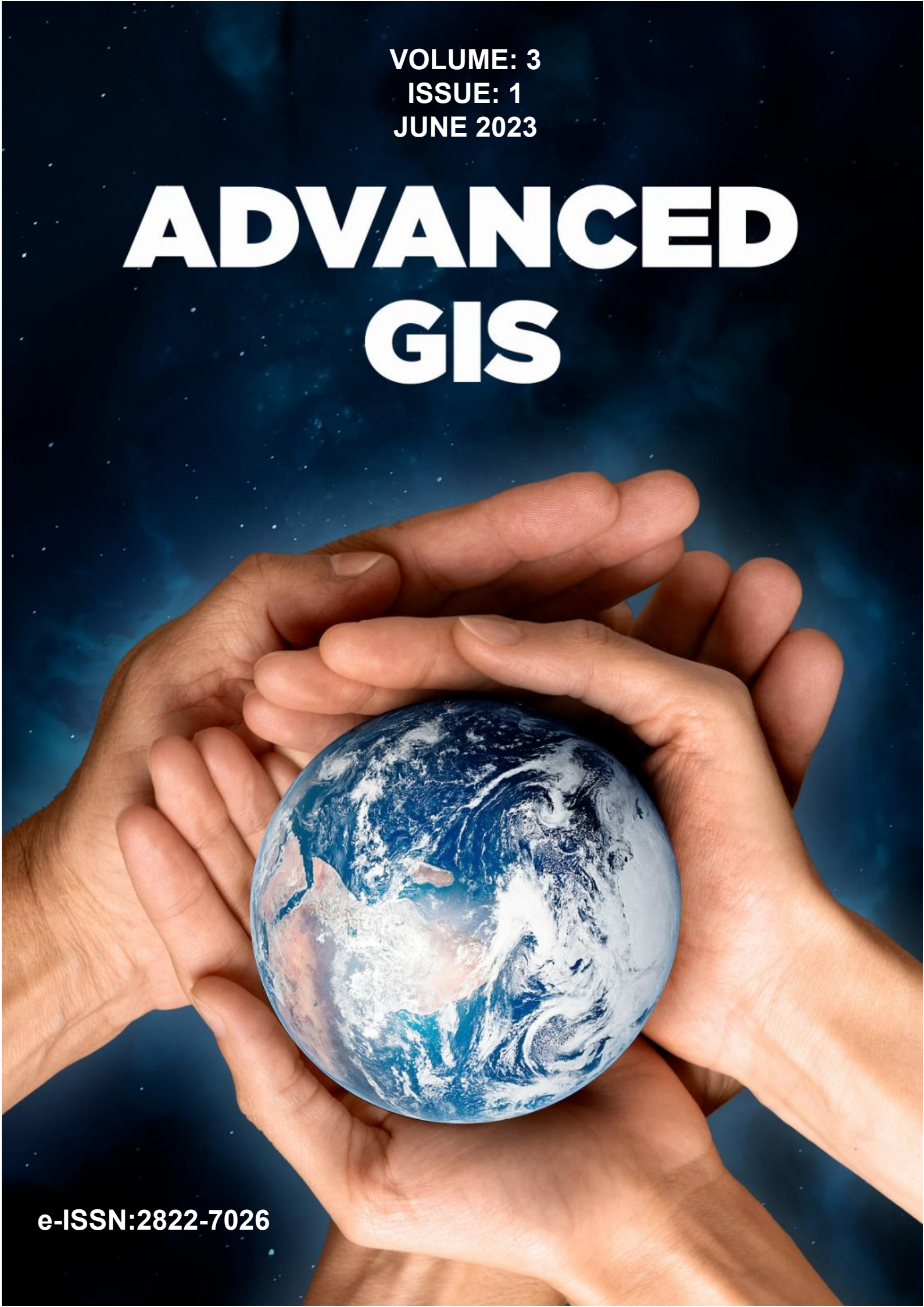

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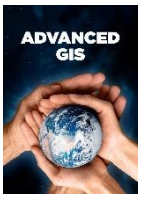

Identifying impervious surfaces for rainwater harvesting feasibility using unmanned aerial vehicle imagery and machine learning classification

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ABSTRACT

As global demand for clean, reliable water sources continues to increase amid a growing population and the impacts of climate change, effective water conservation and collection methods are more important than ever. Rainwater harvesting has long been a reliable technique for capturing and preserving water, and recent advances in geographic information systems (GIS), unmanned aerial vehicle (UAV) remote sensing, and machine learning (ML) image classification have significantly improved our ability to accurately assess the potential for rainwater harvesting. This study leveraged these technologies to evaluate the feasibility of rainwater harvesting at the Osmanbey Campus of Harran University, using UAV imagery and ML classification techniques to identify suitable surfaces for collection. The results showed that it is possible to irrigate a grass area of 4417 square meters daily for a year using the potential harvested rainwater in the study area, demonstrating the significant potential of rainwater harvesting as a sustainable water source for irrigation purposes.

1. Introduction

Turkey is a water-scarce country, with an average of only approximately 1500 cubic meters of water available per person per year, significantly lower than the global average of around 7000 cubic meters per person per year (Alparslan et al., 2008; Şahin & Manioğlu, 2011; Yiğit et al., 2020). This limited water availability poses a significant challenge for the country and its people, making it essential to prioritize water conservation and collection efforts. Water resource management strategies such as rainwater harvesting can play a key role in addressing this issue and ensuring a sustainable supply of water for the country's needs.

Rainwater harvesting is a widely used technique for collecting and storing water for various purposes, such as irrigation and household use (Boers & Ben-Asher, 1982). With the advancement of Geographic Information Systems (GIS) and remote sensing technologies, methods for assessing rainwater harvesting potential have also evolved. The use of image acquisition techniques, such as Unmanned Aerial Vehicles (UAVs) and Machine Learning (ML) image classification algorithms, has further facilitated this process by providing high-resolution imagery and automating the classification of features relevant to rainwater harvesting. These technologies have made it possible to quickly and accurately assess the potential for rainwater harvesting in various locations, enabling more efficient and effective water resource management.

There have been numerous studies in the literature that have utilized GIS and remote sensing techniques to assess rainwater harvesting potential (Mbilinyi et al., 2007; Mwenge Kahinda et al., 2009; Campisano et al., 2017; Hari et al., 2018; Shokati et al., 2021). Many of these studies have focused on the potential for rainwater harvesting from urban building roofs, but it is important to note that different building complexes may require different methods for assessing rainwater harvesting potential. It is crucial to consider the specific characteristics and needs of each site in order to accurately assess the potential for rainwater harvesting and optimize water resource management strategies. Recent studies have also shown that the combination of UAV images, farm maps, and machine learning can provide a rapid and reliable method for analyzing cultivated areas of crops (Lee et al., 2021). This technique has also been applied at the community level for land classification and mapping using satellite remote sensing and UAV surveying (Meng et al., 2021). Furthermore, the use of optical UAV tilt photogrammetry combined with machine learning algorithms has been demonstrated as a low-cost, high-efficiency, and high-precision method for

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tree species classification (Wang et al., 2021). In addition, a meta-analysis of agro-environmental monitoring studies has shown that the application of machine learning algorithms to UAV imagery produces fast and reliable results (Eskandari et al., 2021). Moreover, when estimating crop above-ground biomass using UAV RGB remote-sensing systems alone, the use of optimized vegetation indices and advanced algorithms such as machine learning technology has been shown to provide high performance (Niu et al., 2021).

This study aims to assess the rainwater harvesting potential of a building complex located in the Harran University Osmanbey Campus using GIS and a combination of UAV imagery and ML classification techniques. In addition to roofs, the potential for rainwater harvesting from marble surfaces on the ground between the building blocks was also considered in the calculation. The results of this study can provide valuable insights for optimizing water resource management strategies and maximizing the potential for rainwater harvesting at this site.

2. Study Area

The study area for this research is a building complex located on the Harran University Osmanbey campus, comprising the Faculty of Engineering and the GAP YENEV (GAP Renewable Energy Research Center) (Figure 1). This complex provides a relevant and representative case study for assessing the potential for rainwater harvesting in urban environments, given its diverse mix of roof and paved surfaces. The results of this study can provide valuable insights for optimizing water resource management strategies and maximizing the potential for rainwater harvesting at this site and similar locations.

Figure 1. Location of the study area

3. Method

The process of calculating rainwater harvesting potential for various impervious surfaces, such as roofs and paved areas, typically involves several key steps (Figure 2). First, images of the study area are obtained using UAVs. Next, an orthophoto of the study area is generated, which is a georeferenced image that has been corrected for distortions caused by the terrain and the orientation of the camera. ML classification is then performed using predefined parameters to identify and classify different features in the images. The area of each class is calculated, and the rainwater harvesting potential is determined based on the results of the classification and area calculations. These approaches can provide a robust and accurate assessment of the potential for rainwater harvesting and inform the design and optimization of water resource management strategies.

Figure 2. The overall methodology of the study

In this study, images of the study area were acquired using a DJI Mavic 2 Pro UAV at an altitude of 80 meters, with a 70% overlap on both sides. Orthophotos were generated from these images using the Agisoft software package.

To accurately classify the different surface types within the images, this study applied a pixel-based support vector machine (SVM) classification algorithm, a ML technique that has been demonstrated to be efficient and accurate in previous research. SVM is a well-known classification algorithm in machine learning that has been widely applied in various fields including remote sensing image classification. SVM is a supervised learning algorithm that is used for both regression and classification problems. In pixel-based SVM classification, each pixel in an image is considered as an

individual sample, and the features extracted from each pixel are used as inputs to train the SVM model. The SVM algorithm then separates the different classes of pixels by constructing a hyperplane in the feature space that maximizes the margin between the classes. The margin is defined as the distance between the hyperplane and the closest samples from each class. The SVM algorithm finds the hyperplane that separates the classes with the largest margin, which is referred to as the maximum margin hyperplane.

In the study, five surface types were identified: soil, green, metal roof, concrete, and marble. While all of these surfaces have different behaviors in terms of rainwater flow, only the metal roof, concrete, and marble classes, which are impervious surfaces, were considered in the calculation of rainwater harvesting potential. The concrete and marble classes were merged due to their similar spectral reflectance and flow coefficient. This approach allowed for a more accurate assessment of the potential for rainwater harvesting in the study area.

The rainwater harvesting potential for both the metal roof and concrete & marble areas was calculated using Equation 1. This equation takes into account the surface area, rainfall intensity, and flow coefficient for each surface type, as well as the desired volume of water to be harvested.

$$rainwater\ harvesting\ potential\ (m^3) = (area \times precip \times coeff \times filter)/1000 \quad (1)$$

The rainwater harvesting potential for each surface type is calculated using Equation 1, which considers the surface area, average annual precipitation, flow coefficient, and filter efficiency coefficient. The surface area is the area of the specific surface type being considered, while the precipitation term represents the average annual rainfall in millimeters for the study area, which is 460.1 mm for the Şanlıurfa region (TSMS, 2022). The flow coefficient represents the ability of the surface to allow rainwater to flow and be collected, and the filter efficiency coefficient accounts for any losses due to filtration. The filter efficiency coefficient, which is defined by German standards in DIN (1989) and has been used in some studies investigating rainwater harvesting potential (Erdoğan, 2002; Yiğit et al., 2020), is typically set to a value of 0.9. The flow coefficients for the various surface types utilized in this study are presented in Table 1.

Table 1. The flow coefficients for surface types (DIN, 1989)

Class	Flow Coefficients
Metal Roof	0.9
Concrete	0.7
Marble	0.7

4. Results

In this study, 172 images were obtained through a carefully planned and executed UAV flight, the details of which are described in the methods section. These images were used to create an orthophoto of the study area, as shown in Figure 3. This orthophoto served as the basis for further analysis and interpretation of the data.

Figure 3. Orthophoto of the study area

Figure 3 displays the layout of the engineering faculty, which includes multiple blocks and a circular building on the left. The ground between the blocks is paved with marble, providing additional opportunities for rainwater collection beyond the roofs of the buildings. To accurately assess the potential for rainwater harvesting, it is necessary to classify the various surfaces within the complex. The design of the faculty, as depicted in the figure, presents opportunities for rainwater collection from a range of sources. Thus, the SVM algorithm, a commonly used ML classification method for geospatial images, was employed. The algorithm parameter for the maximum number of samples was set to 500 per class. The radial basis

function (RBF) was used as kernel type to map the input data into a higher-dimensional feature space. An optimal gamma parameter was used in conjunction with the RBF kernel to control the shape of the decision boundary. These parameters were chosen to ensure optimal performance of the SVM algorithm in the classification of the geospatial images. The sample statistics for the training model are presented in Table 2.

Table 2. The train samples statistics

Class	Num. of Samples	Pixels (%)
Green	12	13.23
Soil	11	4.79
Metal Roof	5	16.63
Concrete-Marble	42	65.34

Figure 4 presents the classified image of the study area, divided into four distinct surface types.

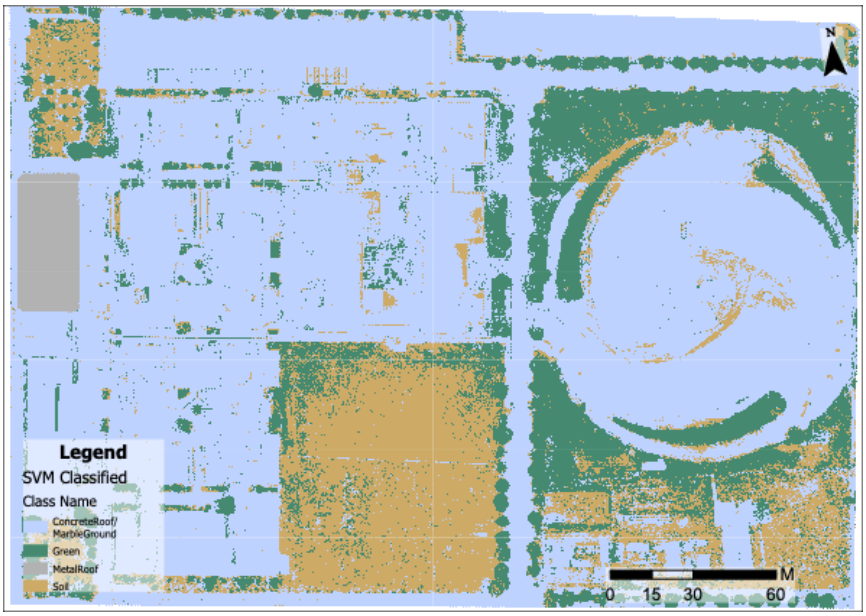

Figure 4. The classified image of the study area

To identify potential areas for rainwater harvesting, it is necessary to calculate the areas of the various surface types present within the study area as impervious and pervious. Using the classified image obtained in this study, the relevant surface types reclassified as impervious, impervious-metal, and pervious (Figure 5).

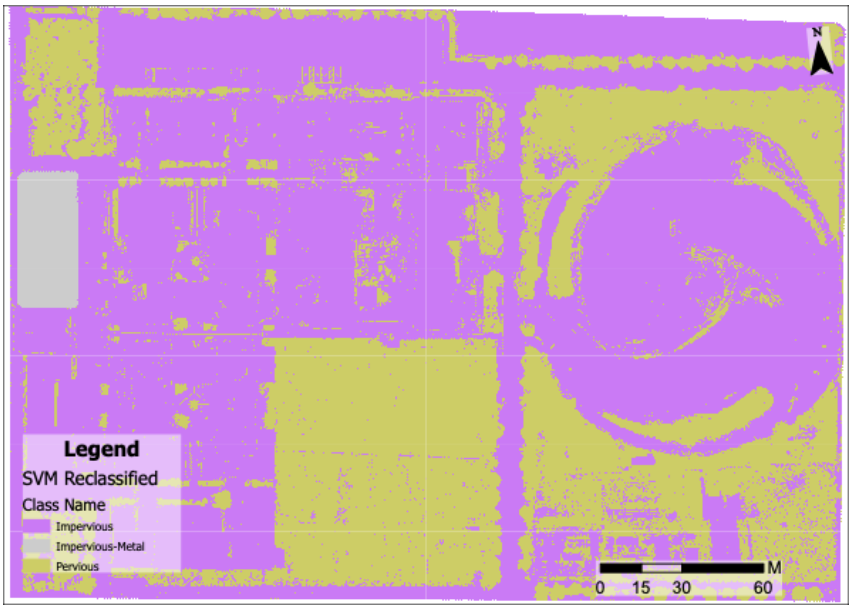

Figure 5. Reclassified image according to the perviousness of the surfaces.

The areas of these surfaces were calculated and presented in Table 3. This information allows for the assessment of the potential for rainwater harvesting within the study area based on the distribution and extent of these impervious and pervious surface types.

Table 3. The area and the ratio of the surface types

Class	Area (m^2)	The ratio of total area (%)
Impervious	41668.55	63.3
Impervious-Metal	1119.06	1.7
Pervious	23039.48	35.0
TOTAL	**65827.09**	**100**

Using Equation 1, the potential for rainwater harvesting was calculated for the concrete & marble and metal roof surface types. The results of this calculation are presented in Table 4. This information allows for the assessment of the feasibility of rainwater harvesting for these specific surface types within the study area.

Table 4. The rainwater potential

Class	Rainwater harvesting Potential (m^3)
Impervious	12078
Impervious-Metal	417
TOTAL	**12495**

It is estimated that a total of 12495 cubic meters of rainwater could potentially be harvested from the study area. By utilizing this water resource, it would be possible to irrigate approximately 4417 square meters of grass daily, based on the average daily water requirement of 7.75 cubic meters per 1000 square meters of grass reported in previous studies (Erdoğan, 2002; Yiğit et al., 2020). This potential for daily irrigation over the course of a year demonstrates the significant benefits of rainwater harvesting in the study area. The results indicate that the amount of water obtained is sufficient for irrigating a significant portion of the green areas surrounding the buildings.

5. Discussion

The images used for classification in this study were acquired in the afternoon, resulting in shadows that may have influenced the classification results. It is important to note that the time of image acquisition can significantly impact the accuracy of classification, with images taken closer to noon likely to have fewer shadows. Future studies should consider the time of flight as an important factor in the acquisition of images for classification purposes.

The SVM algorithm is a popular choice for the ML classification of geospatial images. However, the performance of this algorithm can be influenced by certain parameters, including the kernel type, gamma value and maximum number of samples per class. These parameters can either be set to default values or determined through empirical testing. In this study, various combinations of these parameters were evaluated through visual accuracy comparison, and the optimal settings were selected for use. While the study area in this research was relatively small, the sample size used for training was sufficient to accurately cover the different surface types and could potentially be applied to larger areas with similar success.

The accuracy of the classification method was not formally assessed in this study as the primary aim was to determine the potential for rainwater harvesting. However, a visual accuracy comparison was conducted to ensure the reliability of the results. Besides, the metal roof area, which can be measured with relatively higher accuracy compared to other areas, was measured and compared in the orthophoto and classified image. The result showed an accuracy of percentage99. Although this value is not valid for the whole area, it is an indication that this method performs a near-perfect classification for easily distinguishable objects. While it is generally advisable to include formal accuracy assessment in research, the specific goals of this study and the relatively small size of the study area made a visual comparison sufficient for the calculation of rainwater harvesting potential.

The collection and storage of rainwater on marble surfaces may present unique challenges compared to building roofs. To address these challenges and facilitate the accurate planning of rainwater storage systems, high-resolution digital elevation models derived from UAV imagery can be used to identify runoff directions and accumulation patterns on marble surfaces. This information is essential for the effective design and implementation of rainwater storage systems on marble floors.

The combination of ML and UAV techniques with GIS provides fast and effective solutions for identifying rainwater harvesting potential, thereby rendering them applicable in this area of study

6. Conclusion

The present study employed a UAV flight to gather high-resolution images of a building complex, which were subsequently used to create an orthophoto of the study area. Through the application of the SVM algorithm, the orthophoto was classified to identify the various surface types within the complex. By analyzing the classified image, the impervious surfaces, including building roofs and ground marble areas, were quantified and used to calculate the potential for rainwater harvesting within the complex. This methodology demonstrates the usefulness of combining UAV imagery and ML techniques in evaluating the feasibility of rainwater harvesting and similar applications.

Although there are numerous studies involving ML and UAV techniques, their application for assessing rainwater harvesting potential is still rare, especially with regards to ground surfaces adjacent to the roof area. Therefore, the combination of these techniques with GIS represents a promising approach to accurately estimate rainwater harvesting potential and should be further explored in future research.

The combination of UAV imagery and ML algorithms allows for rapid assessment of various applications, including the determination of rainwater harvesting potential. Additionally, this method can be utilized in a range of other applications, such as the installation of solar panels on roofs, monitoring of landscapes, and detection of land use and land cover. The use of ML in the classification of UAV imagery offers a versatile and efficient solution for these and other endeavors.

Author Contributions

The study was carried out by a single author.

Statement of Conflicts of Interest

There is no conflict of interest.

Statement of Research and Publication Ethics

Research and publication ethics were complied with in the study.

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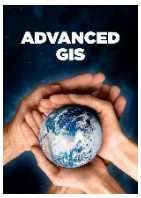

Risk assessment of Rawal dam outburst flood using integrated hydrological and geo-spatial approaches

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ABSTRACT

This study is an effort of Rawal Dam outburst flood risk assessment using integrated hydrological and geo-spatial approaches. Satellite data sets including Advanced Space borne Thermal Emission and Reflection Radiometer (ASTER) Global Digital Elevation Model (GDEM) and Landsat-8 image having 30 m spatial resolution were downloaded from United State Geological Survey (USGS) geo-database. Watershed modeling was applied to delineate the catchment area and drainage geo-visualize network. Spatial hydrological model was utilized to the vertical and horizontal profile of estimated flood in the downstream areas in case of dam breaching. Similarly, Google Earth Pro was used to calculate lake volume. The estimated flood has depth of more than 15 m. Downstream areas are at high risk. The results of the study can assist disaster management authorities and decision-makers in devising location specific effective flood risk reduction strategies in the region.

1. Introduction

Globally, flood is one of the destructive hazard causing damages to the properties, economies and lives (Mahmood & Rani, 2022). Around 70% of the human population is living in or in the proximity of flood hazard zones (Aksoy et al. 2016). Flood is the abnormal behaviour of the river with heavy discharge comparatively more than the river's channel capacity leading to inundation of the adjacent dry areas. Similarly, Geo-morphometric characteristics and surface runoff are the main factors of flash flood genesis (Mahmood, 2019). The high intensity rainfall and melting of snow and glaciers add huge volume of water beyond the channel's capacity and cause overtopping (Mahmood & Ullah, 2016; Mahmood et al., 2016). The frequency and magnitude of floods has been increased because of climatic variability and changing trends of economic activities. The increase in investment in flood prone areas has increased flood risk (Mahmood & Rani, 2018; Mahmood & Hamayon, 2021). The frequency and intensity of extreme rainfall events are still on rise. Pakistan is exposed to hydro-meteorological, geological and biological hazards (Mahmood et al., 2019; Gull & Mahmood, 2022). Flood is one of the hydro-meteorological hazards and may lead to dam lake outburst flooding.

Generally, most of the recent studies consider either the probability analysis of dam overtopping or estimation of economic loss estimates caused by dam failure (Mo & Liu, 2010). Some studies are; Aboelata et al. (2003) used GIS model and estimated dam risk failure and life loss. de Béjar (2011) discussed more about risk of barriers in watershed-reservoir-dam systems being overtopped by floods. They converted a haphazard representation of the hourly rain from the storm into effective surface runoff, containing losses from surface retention, interception, and evaporation. They compared the annual maximum series models' overtopping probability to those based on monthly maximum series models. Zhong et al. (2011) suggested a risk-based analysis approach for assessing the risk of hydrological factors, seepage and bank slope failure, respectively, and for evaluating the integrated risk by coupling these factors. Li et al. (2012) developed a LHS-MC method to appraise dam burst risk. A new evaluation model built on the interval analytic hierarchy process (IAHP) and the expansion of methodology for improved outcomes was presented by Zhang et al. (2013). The interval data improves the degree of risk identification confidence for hydropower projects. Yang et al. (2013) proposed a systematic strategy for the assessment of inundation risks brought on by the construction and breach of landslide dams, which included the evaluation of the

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likelihood of a breach, the risk of inundation upstream and downstream, and the classification of flood hazards. Du et al. (2020) examined the risk of tailings dams using InSAR time series technique. Psomiadis et al. (2021) used the HEC-RAS technique and satellite data to estimate the danger of dam outburst and flood wave. The importance of risk assessment of ageing dams portfolio was emphasized by Concha Larrauri et al. (2023).

Flood overtopping risk contains the probability that the water level exceeds the dam and the associated consequences caused by the dam accidents, in the design reference period. From the view of probability theories, it synthesizes disciplines of reliability math, stochastic hydrology, stochastic hydraulics, engineering economics, and social statistics and so on, to make the best of the balance between flood control and flood utilization benefits (Zhang & Tan, 2014). The risk of dam lake outburst flooding is also increasing because of increasing intensities of rainfall leading to unprecedented discharge in the river channel. The high-level discharge can overtop the dam or may lead to dam burst. Therefore, the aim of this study is to assess the risk of Rawal Dam outburst flooding in downstream areas using integrated hydrological and geo-spatial approaches.

The risk of dam lake breach and the related effects brought on by dam accidents are included in the flood overtopping risk during the design reference period. Making the most of the balance between flood control and flood utilisation benefits requires taking into account probability theories, stochastic hydrology and hydraulics, engineering economics, sociological statistics, and other factors (Zhang & Tan, 2014). Because of the intensifying rainfall that is causing an exceptional discharge in the river channel, the probability of dam lake outburst floods is also rising. The high-level discharge may cause the dam to burst or cause it to topple. The purpose of this study is to evaluate the potential for flooding caused by an outburst at Rawal Dam using integrated hydrological and geospatial methodologies.

2. Study Area

Relatively, Rawal dam is located in Margalla Hills and covering an area of 8.8 km^2 (Samad et al., 2016). The government of Pakistan constructed it in 1962 on the Korang River along with some other small streams originating from Margalla Hills (Ahmed et al., 2021). It is the partly arched gravity dam with crest level 534 m and crest length 210 m (Figure 1). Water may be discharged at a rate of 80,000 cusecs (cubic feet per second) via eight Ogee gated spillways. It is able to command an agricultural area of 500 acres (2 km^2). The live storage capacity of Rawal dam is 37,500-acre feet (ft) and the dead storage capacity is 45,00-acre ft with a gross capacity being 42000-acre ft. Its saddle length is 6,991 ft (2,131 m) and its height of 24 ft (7.3 m). Whenever there is an increase in water level of more than its capacity its spillways get open (Mateen & Garstang, 2008). The left bank canal of Rawal dam is Shahana Disty with a capacity of 40 ft^3/s used for irrigation purposes and the right bank canal of it is Ojri Disty with a capacity of 70ft^3/s supplying 100-acre ft of drinking water to Rawalpindi. Four main and 43 tributary streams from the Margalla Hills feed Rawal Lake in a typical rainfall year. The flash and riverine floods are generated by heavy rains in catchment regions of major and other tributary streams.

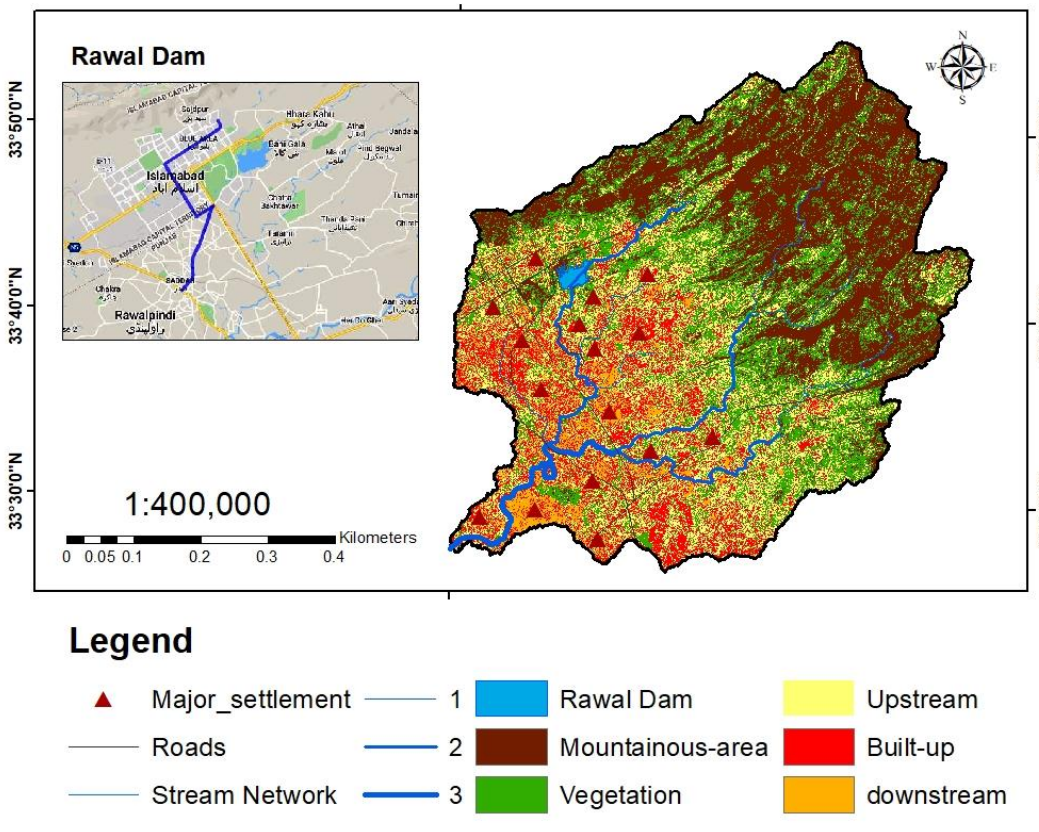

Figure 1. Location of the study area

3. Research Methodology

Advanced Space borne Thermal Emission and Reflection Radiometer (ASTER) Global Digital Elevation Model (GDEM) and Landsat-8 image having twelve distinct bands covering having 30m spatial resolution is downloaded from the USGS Earth explorer open source geo-database. Watershed modeling was applied to delineate the catchment area and drainage geo-visualize network. Spatial hydrological model was utilized to the vertical and horizontal profile of estimated flood in the downstream areas in case of dam breaching after (Mahmood, 2019; Mahmood & Rahman, 2019a, b). Similarly, Google Earth Pro was used to calculate lake volume.

Watershed of the study region is delineated by utilizing GDEM as input spatial data in Geographical Information System (GIS) environment. The ASTER GDEM was selected as input data for this study because of its accuracy and better output. Hydrology tool of Spatial Analyst of ArcGIS is used in to simulate elevation data. By applying Fill, Flow Accumulation and Flow Direction operations, the drainage network and watershed boundary was extracted (Figure 2).

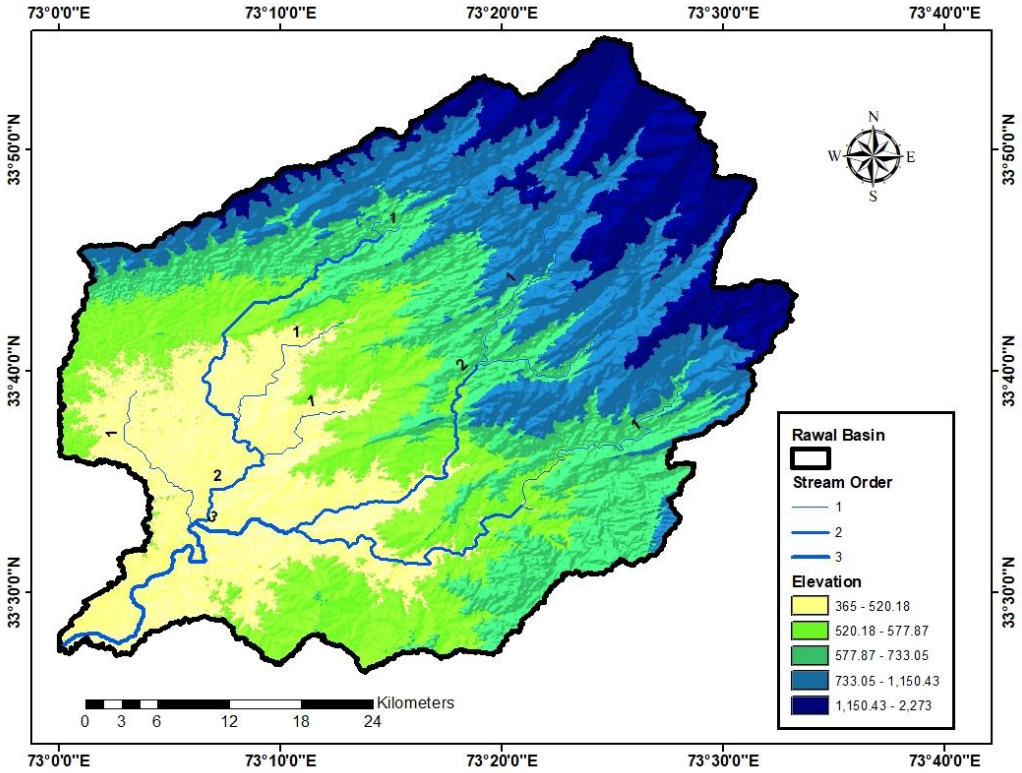

Figure 2. Rawal watershed and upstream and downstream region of Rawal

3.1. Lake volume calculation

First, Rawal Dam was digitized using Google Earth Pro and saved the polygon in Keyhole Markup Language (KML) format. GPS Visualizer is used to converting KML data into elevation data and then imported it into ArcGIS. By using GPX to feature tool data was converted into feature. After that, Triangular Irregular Network (TIN) was created by converting GDEM to TIN. In the last step, the surface volume 3D-Analyst tool was selected and TIN was used as input data and the lake volume gets calculated.

3.2. Horizontal and vertical profile of flood

Hydrologic and hydraulic characteristics of the downstream areas were modelled by employing HEC-RAS and HEC-GeoRAS spatial hydrological model (Demir & Kisi, 2016; Mahmood et al. 2019). Then simulated data was imported into ArcMap for processing, and the horizontal and vertical profile of the estimated flood in downstream areas was geo-visualized. HEC-GeoRAS is used to create river geometry by using GDEM as input data. The river geometry includes river centreline, riverbanks (left and right), flow route lines and channel cross sections (XS-Cut lines) with intervals of 1000m and breadth of 1500m (Figure 3). A total of 50 cross-sections were generated. The geometric data tool of HECRAS generated the vertical profile of the flood with the help of cross sections. Then from the steady flow data, spatial extent and flood depth were geo-visualized. Manning's roughness coefficient "n" value of the river channel is resolute by applying Chow (1959) method. The "n" for the riverine zone of Rawal Dam is 0.02 presenting the confrontation to flood flow in the channel and flood plain. The "n" is also used as input data in the geometric data tool.

Weighted overlay analysis technique is implemented and cumulative flood risk is geo-visualized in ArcGIS environment.

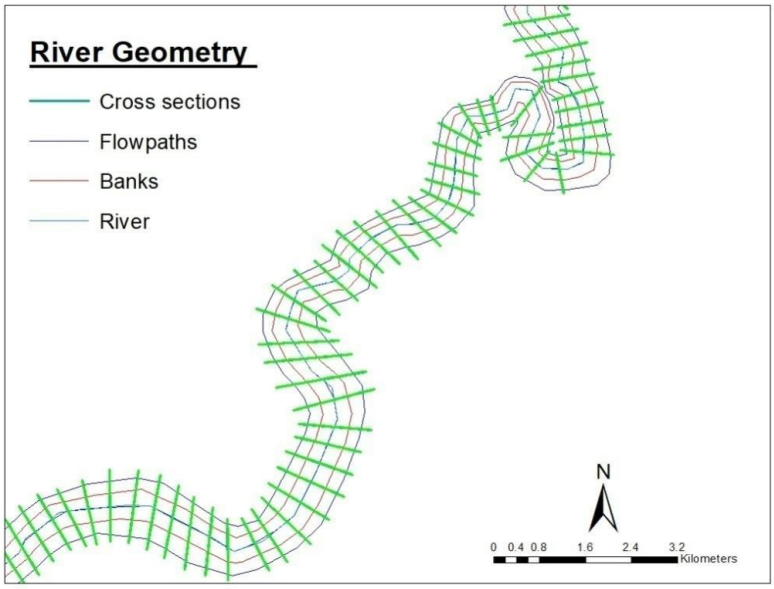

Figure 3. Geometry of the selected reach developed in HEC-Geo-RAS

4. Results and Discussion

The area exposed to dam lake outburst floods in downstream of Rawal Dam has diversity in topography, human activities and population density. The drainage pattern, gradient and nature of the river channel also variation. These factors further intensify flood risk. The detail of the estimated flood spatial extent and vertical profile is given in the following section.

4.1. Spatial extent and vertical profile of predicted flood

The vertical profile means depth of the predicted flood is ranging from 3 to 15 m. The depth depends on the nature of valley and huge discharge from upstream. The estimated depth in main channel is more than10 m from dam to downstream areas whereas the variation in depth is geo-visualized on both side of the channel (Figure 4). The spatial extent of flood also varies along the channel. The extent is maximum in the downstream areas (Figure 5). The study area has diverse topography. The elevation is ranging from 300m to 2200m above mean sea level. Elevation is decreasing from northeast to southwest direction. The higher-level stream order is third.

The spatial extent of apparent flood peak is variable along the selected reach of Rawal Dam. The extent of flood increases towards downstream. The maximum spatial extent of predicted floods in the downstream is because of increasing width of the river. The downstream area has high population density with major human settlements.

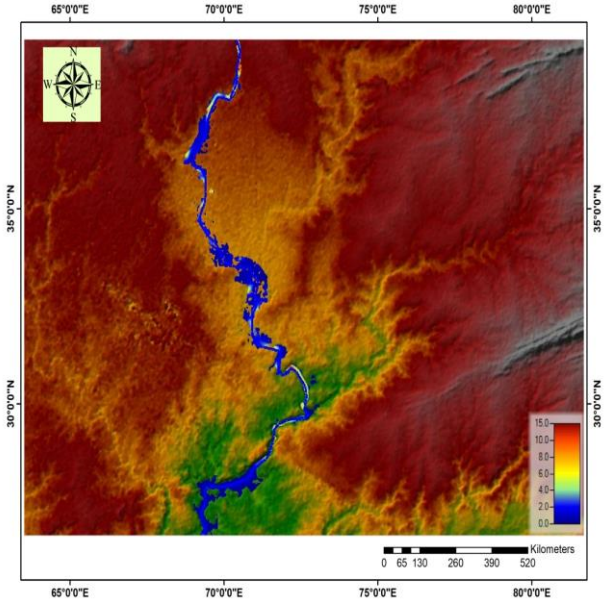

Figure 4. Vertical profile of Rawal basin

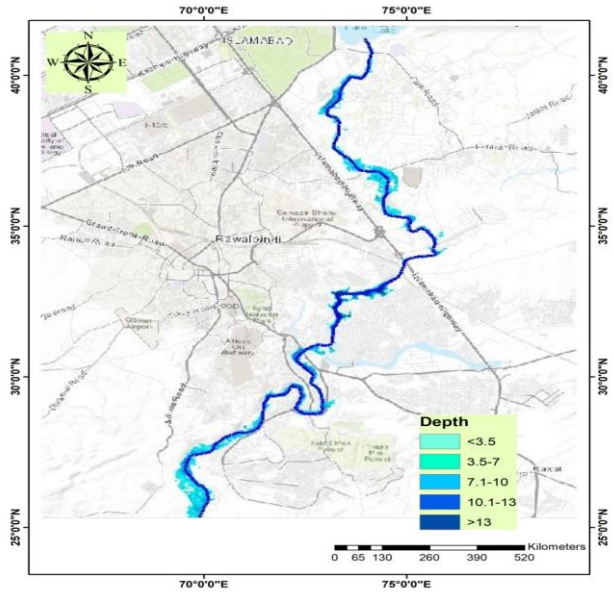

Figure 5. Vertical and horizontal profile of estimated flood developed in HEC-RAS

4.2. Flood risk zones

The risk of flood and potential socio-economic and physical damages in the downstream areas is prevailing. In the study region, human settlements, agricultural land, road and bridges are exposed to flood. Based on the flood risk, the areas downstream of the dam are categorized into three zones the upper zone, the middle zone and the lower zone. The risk is very high in the upper and lower zone whereas in the middle zone flood risk is lower comparatively whereas in some sections of the reach moderate and low risk also prevail. The spatial extent of the flood is maximum in the lower zone because the river channel is wide and built-up land is more with high population density. The major human settlements exposed to flood include Rawal Town, Rawal Dam Colony, Chak Shehzad, Morian, Margala Town, Phase-I & II of Margala Town, NARC colony, Burma Town, National Agriculture Research Institute, Koral Town, Ghauri Town, Hussain Abad, The human settlements located in the high-risk zone are Gulberg Marque, Koral Town and NARC colony (Figure 6).

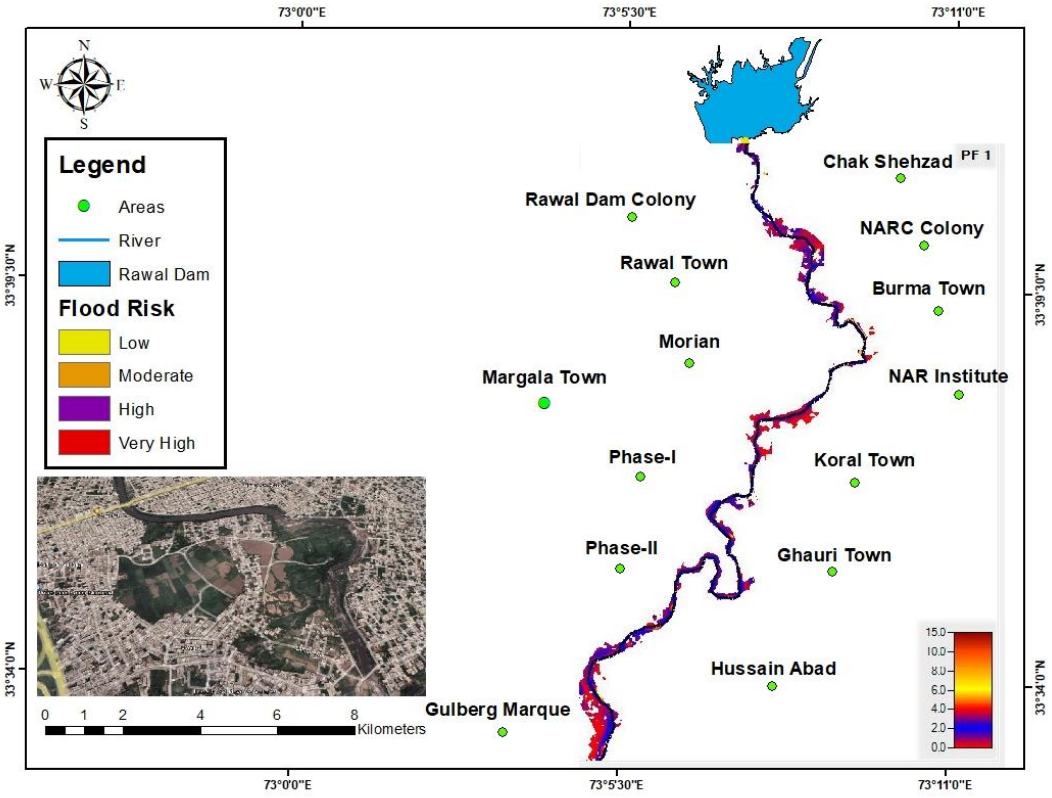

Figure 6. Flood Risk Zones

Analysis revealed that the risk of flood is increased with increasing high magnitude rainstorm event generating flash floods in the upstream areas posing risk dam lake outburst floods. Saeed et al. (2011) also narrated that that sedimentation has decreased the storage capacity of Rawal Lake by 34%. Effective soil erosion risk reduction measures in the higher catchment areas can lessen siltation in river channels and dams (Mahmood & Atiq, 2022). In a similar vein, dams may be overtopped by high discharge flash floods. Even the opening of spell ways can lead to flood in the downstream areas. Shaktawat & Vadhera (2021) concluded that risk management of hydropower projects is the need of time. Similarly, Concha Larrauri et al. (2023) stressed that risk assessment of aging dams is highly important. It is recommended that risk assessment of all dams need to be carried out and dam-specific flood risk reduction plan should be reinforced. This will reduce the risk of dam lake outburst floods and potential damages. In this aspect, flood risk reduction (FRR) is essential to minimising the damaging effects of floods.

High-resolution satellite imageries and field measurements can further enhance the results of the study. Similarly, determining vulnerability of the community will assist the disaster management authorities in policy and decision-making. Further studies on vulnerability and exposure to floods are recommended.

5. Conclusion

The study concludes that risk of dam lake outburst floods is prevailing in the downstream areas. The downstream areas are characterized by high population density and economic activities. Alongside, physical infrastructure and properties are exposed to floods. The high intensity rainfall events and decreasing capacity of the lake are the main risk factors.

Plantation in the upper catchment areas is recommended to decrease the intensity of rainfall, surface runoff and soil erosion. Removal of silt, clay and sand from the reservoir is also recommended to increase the capacity of the dam. In the entire Rawal Basin,

installation of Sensor based hydro-gauging stations and automatic weather stations are also highly recommended to provide real-time data. This may help to reduce the risk of floods. Further studies on vulnerability and exposure to floods are recommended.

Author Contributions

The contributions of the authors of this article is equal.

Statement of Conflicts of Interest

There is no conflict of interest between the authors.

Statement of Research and Publication Ethics

Research and publication ethics were complied with in the study.

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Landslide susceptibility analysis with multi criteria decision methods; a case study of Taşova

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ABSTRACT

Natural or artificial based disasters threaten to humans. In order to minimize the loss of life and property that may occur after a disaster, various studies are carried out. One of these studies is disaster risk maps. To produce disaster risk maps, the criteria which affecting the disasters should be determined. In order to evaluate more than one criterion Multi-Criteria Decision Making Methods (MCDM) and Geographical Information Systems (GIS) are used. MCDM methods are used both to weight criteria and to rank among alternatives. In the current study Taşova district of Amasya province is used as study area and two different Landslide Susceptibility Maps were produced based on Analytical Hierarchy Process (AHP) and Full Consistency Method (FUCOM) for this region. A total of twelve criteria were determined for production of risk map and raster data was produced by performing various spatial analyzes for the current criteria. Two different landslide susceptibility maps were obtained by giving criterion weights to the generated raster data. It was observed that, Risk-free area, low risk area and high risk area rates are almost equal, but medium risk area and risk area rates are different in two different weighting methods.

1. Introduction

Nowadays, studies are carried out to produce disaster risk maps in order to reduce the loss of life and property in disasters. The studies are aimed at pre-disaster vulnerability analysis and post-disaster evacuation resistance analysis. When these objectives are combined, disaster risk maps will emerge. There are many known disaster types and multiple criteria affecting these disasters. It is very difficult to evaluate these criteria at the same time. Therefore, Multi-Criteria Decision Making Methods are needed. Multi-criteria decision-making (MCDM) is a method that enables the selection of the best choice among the criteria applied simultaneously and more than once (Zahedi, 1986; Ishizaka & Labib, 2009; Kabak et al., 2018; Arslankaya & Göraltay, 2019; Boyacı, 2020). Before evaluating the criteria, spatial analysis of the data should be done. After the spatial analysis of the data is done with Geographic Information System (GIS) or Remote Sensing (RS) methods, weights are assigned to the criteria with a determined criterion weighting method. The criterion with the highest weight will affect the risk map more, while the criterion with the least weight will affect the risk map less. Thus, more results that are reliable will be obtained.

The most common risk analyzes in the literature review are landslide susceptibility analysis, flood risk, earthquake, forest fires, and tsunami risk maps. One of these risk maps is landslide susceptibility analysis. (Gökkaya, 2014; Cankaya, 2016; Acar, 2019)

Considering the damage and losses caused, landslides, which are in the second place after earthquakes in Turkey, have caused many losses of life and property until today (Acar, 2019). According to the Ergünay (2007), since the beginning of the 20th century a total of 89500 house affected by landslides and rock falls in Turkey which is 14% of all natural disasters. A landslide is a situation where rock, soil or pieces of land shift or move noticeably down the slope due to gravity or external factors such as earthquakes, heavy rains. (Disaster Management Dictionary). Although a landslide is a natural disaster, the human factor also triggers it. Examples of human factors such as unknowingly felling trees, unauthorized mining, inadequate retaining walls on the roadside. Therefore, it allows to determine the places with landslide risk and to act carefully in those areas. Thus, the loss of life and property is minimized.

Different kind of MCDM techniques were used in landslide studies, Analytical Hierarchy Process (AHP) is one of the most used method. Landslides are affected many factors, and all factors have different weight on landslide. In the current study, it was focused to determine weight of the factors which affect landslides using two different methods which are Full Consistency Method (FUCOM) and the AHP method. To achieve this, two different maps were produced based on both

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methods of landslide susceptibility analysis for the Taşova district of Amasya province.

2. Material and Method

In this section, the study area described, AHP and FUCOM methods are shortly explained, and criteria for landslide susceptibility analysis are determined.

2.1. The study area

The study was carried out in in Taşova district of Amasya province. Taşova is located on 40° 46' 36" north latitude and 36° 13' 12" east longitude (Figure 1). The District has an area of 1051 km². The lowest altitude is 170 m where Karlık Stream meets Yeşilırmak. The highest altitude is Cami Hill, located in the South of Esençay Village, 1956 m. Regional landslides have been observed during times of heavy rainfall.

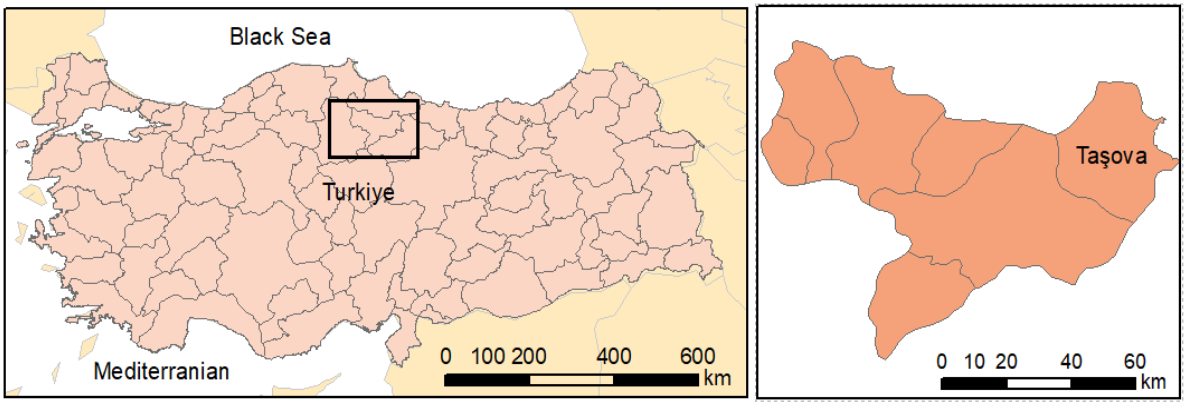

Figure1. Study area

2.2. Analytical hierarchy process (AHP)

The AHP method was developed by Thomas Saaty in 1980 that provides a basis for comparing decision-making criteria in a mathematical structure by creating a hierarchical structure.

Organizing goals, attributes, issues, and stakeholders in a hierarchy serves two purposes; first provides an overview of the complex relationship vessels inherent in the situation, second helps the decision maker to assess whether the problems at all levels are of the same magnitude, so that they can accurately compare these homogeneous elements (Saaty, 1994).

In the first stage of the method, a hierarchical model is created which shows the relations between the aim, criteria and alternatives to be obtained by taking expert opinion for the solution of the problem.

In the second stage, each criterion is compared with other criteria and values are assigned according to the importance scale in Table.1 prepared by Saaty. In line with these values, the degree of importance of the criteria to each other is filled according to the pairwise comparison matrix in Table 2. With these values, *nxn* dimensional pairwise comparison matrix is created for n criteria.

Each criterion is evaluated mutually, ignoring the other criteria. Evaluation of the criteria in this way is advantageous in cases where the number of criteria is high (Yılmaz, 2010).

Table 1. Significance Scale by Saaty

Importance Values	Value Definitions
1	Equal Importance
3	A little more important
5	Quite Important
7	Very Important
9	Highly Important
2,4,6,8	Intermediate values

Table 2. Pairwise Comparison Matrix (aij) (Ci: Criterion, i: 1, 2…n)

	C1	C2	C3	….	Cn
C1	a11	a12	a13	…	a1n
C2	a21	a22	a23	…	a2n
C3	a31	a32	a33	…	a3n
….	….	….	….	…	….
C4	an1	an2	an3	…	ann

The third step is to determine the weights of the criteria. In the pairwise comparison matrix, the sum of each column is taken and divided by each element in the column and matrix B is obtained. If we divide the row sum of matrix B by the number of criteria, that is, if the arithmetic average of the row is taken, the weights of each criterion will be found (Equation 1).

$$W_i = \sum_{j=1}^{n=1} b_{i,j} \quad (1)$$
$$i = 1, 2, 3 \dots n; j = 1, 2, 3 \dots n$$

The consistency ratio (CR) of the measures is calculated in the last step. If the consistency ratio (CR) is less than 0.1, the comparisons are consistent; else, the comparisons are inconsistent (Equation 2-4). That is, the closer the CR is to zero, the higher the consistency of the decision matrix (Jian-Zhong et al., 2008). No matter how mathematically consistent the AHP has in itself, the realism of the results will depend on the consistency of the judgment of the decision maker in the one-to-one comparison between the criteria (Yılmaz, 2010).

$$[C_{ij}]_{nx1} = [a_{ij}]_{nxn} x [w_{ij}]_{nx1} \quad (2)$$
$$[d_{ij}]_{nx1} = [C_{ij}]_{nx1} / [w_{ij}]_{nx1} \quad (3)$$

$$\lambda = \frac{\sum_{j=1}^{n} d_i}{n} \quad (4)$$

a_{ij}: Pairwise comparison matrix
w_{ij}: Weight vector of criteria
C_{ij}: Column Vector
d_{ij}: Consistency Vector
λ: Base value

The basic value (λ) is calculated with the help of matrices in Equation 2 and Equation 3. Finally, the randomness indicator (Rl) is selected from table 3 prepared by Saaty according to the number of criteria.

Table 3. Saaty's Randomness Indicator

n	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RI	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.48	1.56	1.57	1.59

With the randomness indicator (Rl) and λ (basic value), the consistency ratio (CR) is calculated (Equation 5).

$$CR = \frac{\lambda - n}{(n-1)xRI} \quad (5)$$

2.3. Full consistency method (FUCOM)

The Full Consistency Method (FUCOM) method is one of the criteria weighting methods developed by Pamučar, Stevic and Sremac in 2018. The FUCOM algorithm is based on the pairwise comparisons of criteria, where only the *n – 1* comparison in the model is necessary. The model implies the implementation of a simple algorithm with the ability to validate the model by determining the deviation from full consistency (DFC) of the comparison. The consistency of the model is defined on the basis of the satisfaction of mathematical transitivity conditions. One of the characteristics of the developed new method is the lowering of decision-makers' subjectivity, which leads to consistency or symmetry in the weight values of the criteria (Pamučar et al., 2018).

The FUCOM method takes place in three stages. At the first stage, decision makers are asked to rank n criteria from the most important to the less important criteria (Equation 6).

$$C_{j(1)} > C_{j(2)} = C_{j(3)} > \cdots > C_{j(n)} \quad (6)$$

In the second stage, the comparative priorities of the criteria ranked by the decision makers in order of importance *(φ n/ (n+1)* the comparative priority vector with n-1 elements is obtained (Equation 7).

$$\varphi = \{\varphi_{1/2}, \varphi_{2/3} \dots \varphi_{n/n+1)}\} \quad (7)$$

In the FUCOM method, the decision maker(s) can use integers, decimals or values of certain scales for comparisons of criteria. This provides flexibility to decision makers in the evaluation of criteria. (Ayçin & Aşan, 2021)

In the last stage, the following two conditions must be met in order to calculate the criteria weights.

Condition 1: The ratio of the weights of the two criteria to each other should be equal to the priority value in the pairwise comparison (Equation 8).

$$\frac{w_n}{w_{n+1}} = \varphi_{n/n+1)} \quad (8)$$

Condition 2: The final values of the weight coefficients must satisfy the mathematical transitivity condition. Since *φ n/ (n+1) × φ (n+1)/ (n+2) = φ n/ (n+2)* and $\varphi_{n/(n+1)} = \frac{w_n}{w_{n+1}}$ are $\frac{w_n}{w_{n+1}} \times \frac{w_{n+1}}{w_{n+2}} = \frac{w_n}{w_{n+2}}$ must satisfy the mathematical equation. If we combine the two equations, we get equation 9.

$$\varphi_{n/n+1)} x\, \varphi_{n+1/n+2)} = \frac{w_n}{w_{n+2}} \quad (9)$$

Full consistency is achieved if the conditions in equation 8 and Equation 9 are met for criterion weighting. Full consistency, consistency deviation (min (DFC(X))) is expected to be minimal. Maximum consistency is achieved if the deviation from full consistency is zero (0).

Finally, using the expressions in equation 10 to find the criterion weights, linear programming model and solutions can be made with programs such as Excel Solver or MATLAB with simple codes.

$$\begin{aligned} &Min\ X \\ &\left|\frac{w_{j(n)}}{w_{j(n+1)}} - \varphi_{n/n+1)}\right| \le X, A_j \\ &\left|\frac{w_{j(n)}}{w_{j(n+2)}} - \varphi_{n/n+1)} x \varphi_{(n+1)/n+2)}\right| \le X, A_j \\ &w_j > 0, A_j \\ &\sum_j w_j = 1 \end{aligned} \quad (10)$$

2.4. Determination of criteria and criterion maps

Determining of the criteria is one of the most important phase of producing risk map. The criteria are the decision components used in the evaluation of alternatives to reach the goals. It should be known that each criterion included in the decision problem is effective in the decision process, as well as the criteria not addressed in the problem have an indirect effect on the decision output (Yildirim, 2019).

Slope, lithology, land use potential or vegetation, slope direction, distance to main faults, drainage and relative height are the parameters often used in the risk studies (Gökçeoğlu & Ercanoğlu, 2001).

In the current study; slope shape, slope, elevation, aspect, lithology, precipitation, proximity to the river, proximity to the road, NDVI (Normalized Difference Vegetation Index), land use, soil type, fault line were used as the criteria which affect to the landslide. The raster data of each criterion were prepared by performing various spatial analyzes with the ArcGIS software.

a) Elevation: It has been reported that the height conditions of the topography are also an effective factor in the formation of landslides. Because the determination of the heights of the landslides occurring in any region

can be accepted as a data that can only give a preliminary idea. On the other hand, it has been suggested that landslides tend to occur more in high altitude areas. (Özşahin, 2015) The highest value of the region is 1956, and the lowest value is 170. A total of five classes were created in these value ranges.

b) Slope: The general tendency among researchers is that as the slope increases, the sensitivity to landslides will also increase (Gökçeoğlu & Ercanoğlu, 2001). The slope in the region varies between 0-62°.

c) Slope shape: In the studies, the effect of the shape of the slope on the landslide susceptibility was examined, but some researchers said that more landslides occurred on concave slopes, while some researchers suggested that more landslides occurred on convex slopes.

In addition, statistical evaluation of this parameter is quite difficult. Because during a landslide, the initial appearance of the slope is often distorted and this may lead to erroneous assessments during data collection. (Gökçeoğlu & Ercanoğlu, 2001). This study was carried out by accepting the statement more landslides occur on concave slopes.

d) Aspect: The slope direction (aspect) indicates the direction of the land surface and is expressed by the direction of the tangent plane at any point on the surface. Slope direction is an important parameter that is frequently used in studies related to the preparation of landslide susceptibility maps (Dağ, 2007).

The map of these four criteria was obtained using Digital Elevation Model (DEM) data in the '3D ANALYST TOOLS' analysis. (Figure 2 -5).

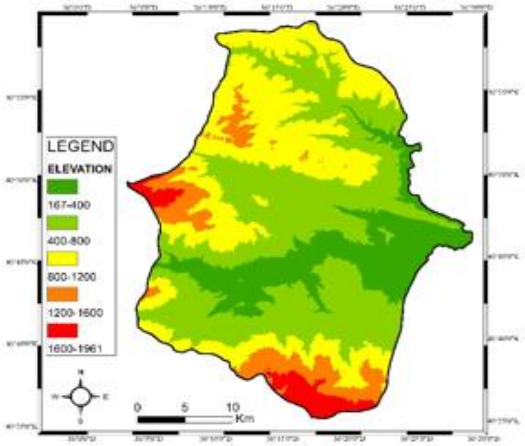

Figure 2. Elevation map

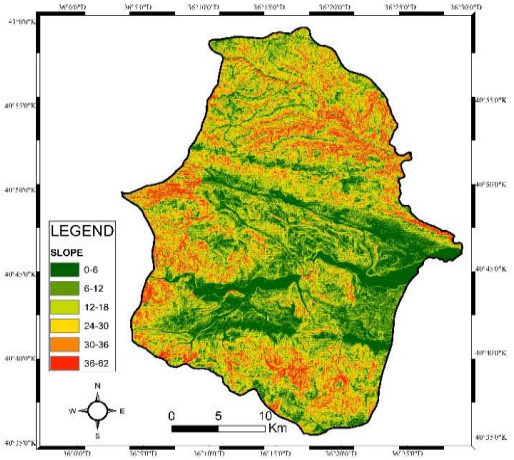

Figure 3. Slope map

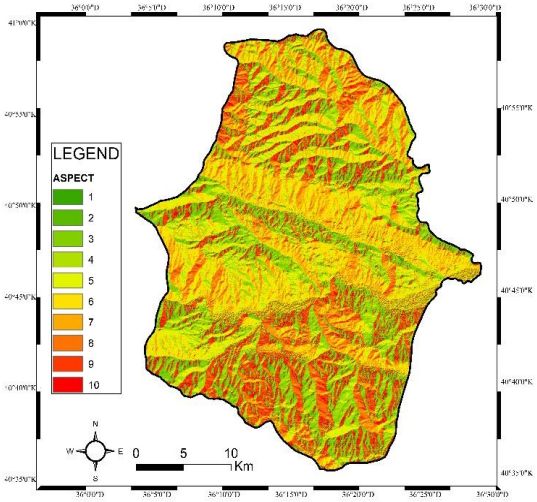

Figure 4. Aspect map

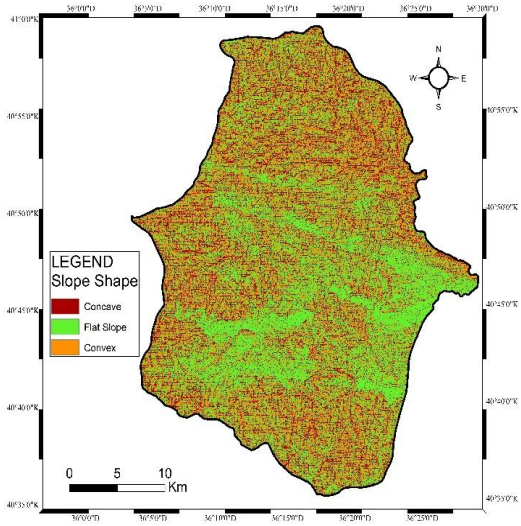

Figure 5. Slope shape map

e) Proximity to the fault line: Proximity to the fault line increases the risk of landslides. The landslide analysis was carried out by considering the faults remaining in the study area in the fault line map published by MTA.

f) Proximity to the stream: Since being close to the stream will increase the water saturation of the soil, the risk of landslide increases as you get closer to the stream.

g) Proximity to the road: The roads opened on the slopes cause a load reduction in both the topography and the slope toe. The change in topography and the decrease in load cause stress increases behind the slope and this causes the development of stress cracks (Yalçın, 2007).

The maps of these three criteria were obtained by using the multiple ring buffer analysis of the proximity tool (Figure 6-8).

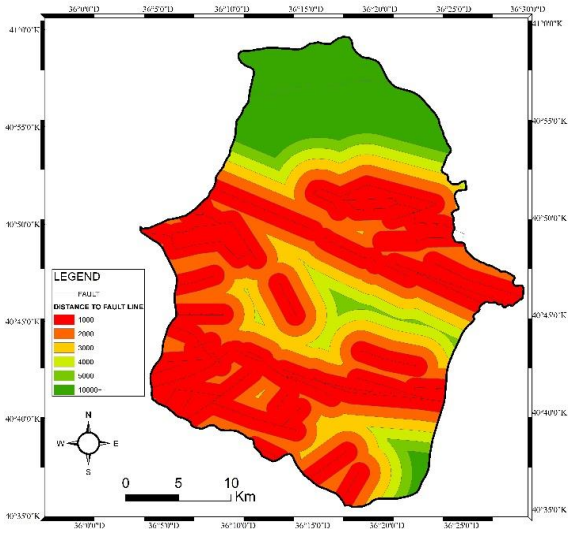

Figure 6. Distance to fault line

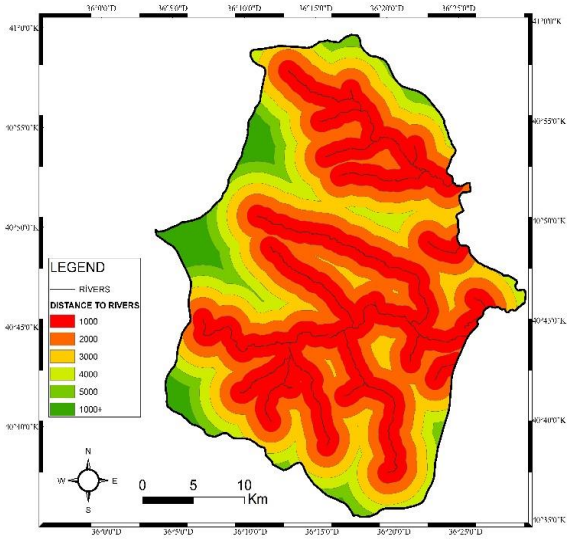

Figure 7. Distance to rivers

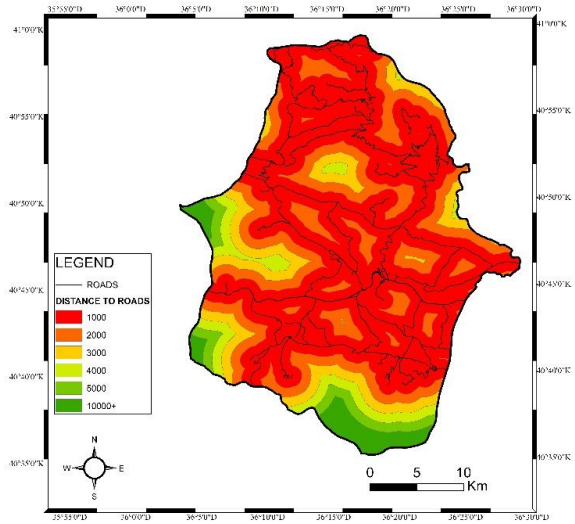

Figure 8. Distance to roads

h) Lithology: Lithology is one of the important parameters affecting landslide formation and plays an important role in landslide susceptibility studies. Using the earth sciences website published by MTA, it was determined that there are five different lithologies in the region.

i) Land use: Although the land use situation includes a part of the NDVI analysis such as forest, meadow, swamp, residential area, agricultural area, pasture, etc. It was used as a separate criterion as it would affect the landslide in certain situations.

j) Soil type: The type of soil the ground has is also very important for landslides. The soil mass covering the ground of the topography also causes the formation of landslides. In fact, soils affect landslide formation according to grain size, arrangement and types (Özşahin, 2015).

The lithology map was taken from the earth sciences site of MTA and the soil types map was taken from the agriculture portal site, coordinated and digitized. The land use map was obtained from the Copernicus page by classifying the CORINE 2018 vector data. (Figure 9-11)

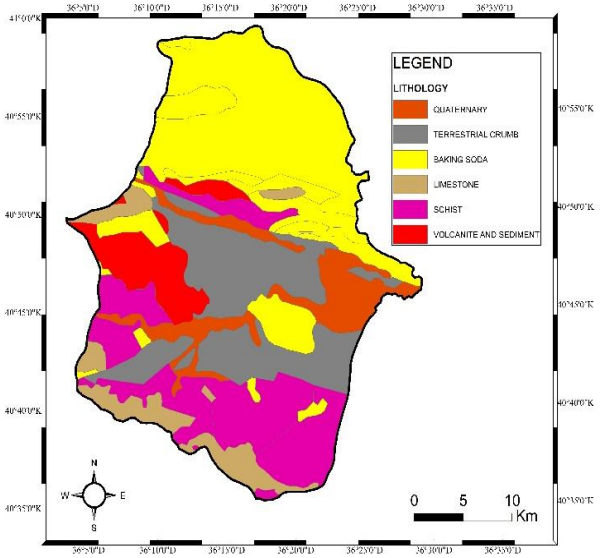

Figure 9. Lithology map

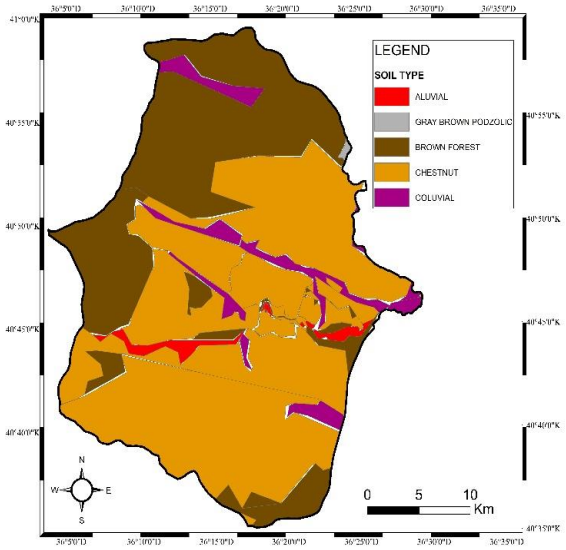

Figure 10. Soil type map

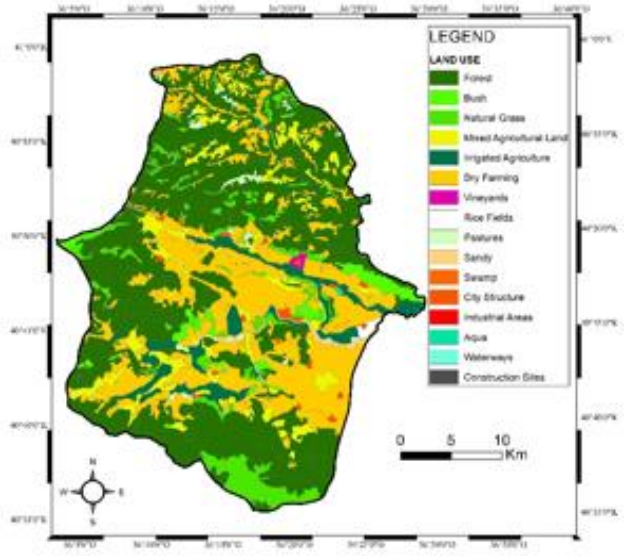

Figure 11. Land use map

k) NDVI: Landslide risk increases in areas with low vegetation density. Therefore, the NDVI map was produced and the places with low vegetation were determined.

l) Precipitation: Annual average precipitation is considered as an important factor for landslide susceptibility analysis. Because, as a result of precipitation, the ground becomes saturated with water, the groundwater level rises and the leakage forces reach their maximum value (Özşahin, 2015). The annual precipitation of Taşova district is 967mm.

The last two criteria maps were made as follows: NDVI data was calculated with the help of band4 and band5 in the Landsat satellite image (Equation 11).

$$Band5 - Band4 \,/\, Band5 + Band4 \qquad (11)$$

The precipitation map is produced at the end of the calculations made with the help of climate data. (Figure 12, 13).

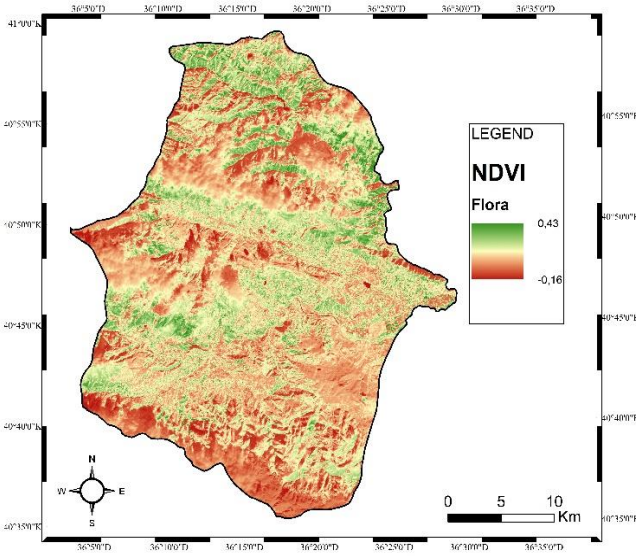

Figure 12. NDVI map

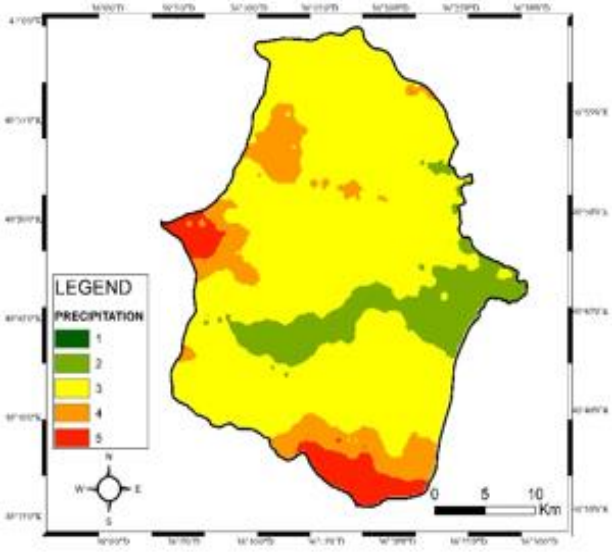

Figure 13. Precipitation map

3. Results and Discussion

The criteria weighting steps above were carried out sequentially and the criteria weights were calculated for both methods. The criteria weights calculated using AHP method and FUCOM method are shown in table 4.

According to the results, the most important weight calculated using AHP was lithology, and the least important criterion was NDVI. The consistency calculated in the AHP was found 0.02 and since it was less than 0.1, the measurements were considered consistent.

The most important criterion calculated using FUCOM was lithology, and the least important criterion was NDVI. Since the FUCOM method is based on full consistency, the consistency deviation (DFC(X)) was found to be 0 as a result of the calculations and full consistency was obtained in the measurements.

The closer the consistency rate is to zero in the AHP method, the more consistent the measures are, while in FUCOM, full consistency is essential. This shows that the measures of FUCOM are more consistent.

In the current study, a total of 144 comparisons were made with AHP, and 11 comparisons were made with FUCOM. It was observed that the FUCOM method differs from the AHP method with less pairwise comparison. With fewer comparisons, the effect of expert opinion is reduced.

Table 4. Criterion weights with AHP and FUCOM

Criteria	AHP	FUCOM
Lithology	0.204	0.2473
Slope	0.162	0.1236
Slope Shape	0.150	0.1236
Precipitation	0.125	0.0824
Aspect	0.093	0.0618
Prox. to Fault Line	0.072	0.0618
Prox. to the Stream	0.061	0.0618
Distance to Road	0.043	0.0618
Land Use	0.032	0.0495
Soil Type	0.025	0.0495
Elevation	0.019	0.0495
NDVI	0.013	0.0275

The raster data produced for each criterion separately were overlapped using 'Weighed Sum' analysis based on the weights calculated from two different methods and two landslide susceptibility maps were obtained

Figure 14 shows the map produced using the AHP method and Figure 15 shows the map produced using the FUCOM method. The Landslide Susceptibility maps are divided into five classes; Risk-free areas are dark green, low-risk areas are light green, medium-risk areas are white, risky areas are pink, high-risk areas are red.

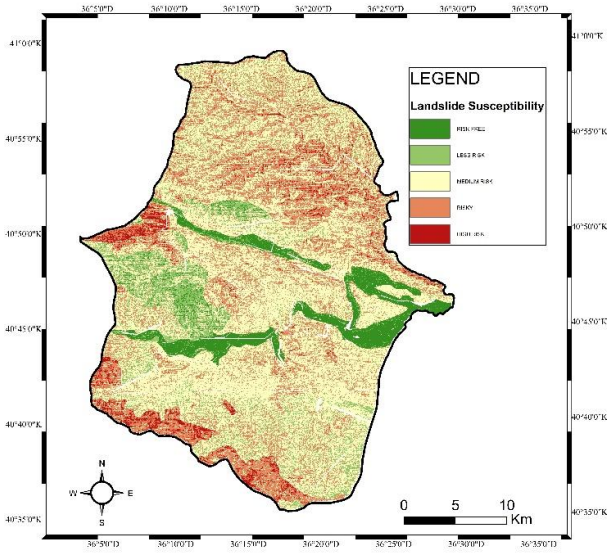

Figure 14. Landslide susceptibility map with AHP

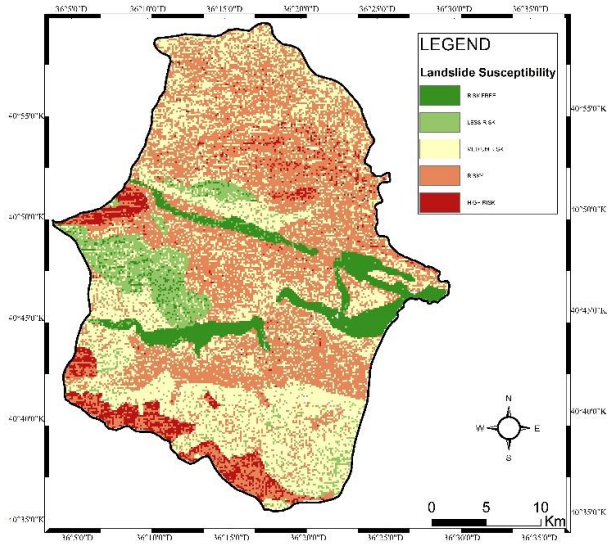

Figure 15. Landslide susceptibility map with FUCOM

When we interpret by looking at the two maps in Figure 14 and Figure 15, it is seen that the red colored areas are more in FUCOM.

The area of Landslide Susceptibility classes were calculated with the help of the pixels of the classes from the maps obtained. By making area calculations from pixels according to colors, ratio calculations were made over the total area.

Table 5 shows that; risk-free, low-risk and high-risk areas results were almost similar, but medium-risk areas and risky areas were different results in the two methods.

Table 5. Map Classes Rates calculated with AHP and FUCOM

Classes	AHP (%)	FUCOM (%)
Risk-Free Area	7.25	7.89
Low Risk Area	10.75	8.08
Medium Risk Area	50.60	35.97
Risk Area	27.95	42.98
High Risk Area	3.45	5.08

As a result of the calculations, according to AHP the risky area was determined as 27.95%, and the high-risk area was 3.45%. According to the FUCOM method, the risky area was determined as 42.98% and the high-risk area was 5.08%. The percentage of risky areas in the map produced based on FUCOM method was higher than the AHP method.

In general, it is seen that high-risk areas are in the same places in both maps. These high-risk areas are seen as areas where the slope is high and the vegetation is low.

4. Conclusion

In the current study, two different landslide susceptibility maps were produced using AHP and FUCOM criterion weighting for Taşova district.

Twelve criteria were used for both landslide susceptibility maps. These criteria are slope shape, slope, elevation, aspect, lithology, precipitation, proximity to stream, proximity to road, NDVI, land use, soil type, fault line. While the most important criterion among the AHP criteria weights was lithology with 0.204, the least important criterion was NDVI with 0.013. The most important criterion among the FUCOM criterion weights was lithology with 0.247, while the least important criterion was NDVI with 0.027. The consistency of the criteria weights was calculated for both methods. The consistency ratio with AHP was found to be 0.02, and it was seen that the measurements were consistent.

Maps of each criterion were obtained according to the studied area. Criterion maps were converted to raster data according to weights calculated by AHP and FUCOM methods. Landslide susceptibility maps were obtained by combining the weighted criterion maps in both methods.

The landslide susceptibility maps were divided into five classes and risk classes were determined. The risk of landslide increases from green to red. The ratios of the classes were calculated by pixel measurements from the maps. It was observed that risky areas in FUCOM were 15.03% higher than in AHP. It was observed that the medium-risk areas in FUCOM were 14.63% less than in the AHP. Other classes gave similar results in both methods.

Both methods are made by taking expert opinion, but FUCOM minimizes expert opinion with less pairwise comparison and provides full consistency. As a result, the FUCOM method, which is the version developed in 2018 of the AHP method, which is frequently used in the literature, can also be preferred and used in map production studies.

Finally, landslide susceptibility maps can be prepared with various methods and criteria data. The aim of this study is to compare the results which obtained AHP and FUCOM methods.

Author Contributions

The contributions of the authors of this article is equal.

Statement of Conflicts of Interest

There is no conflict of interest between the authors.

Statement of Research and Publication Ethics

This study was improved from the paper presented in the 5th Intercontinental Geoinformation Days (IGD). Research and publication ethics were complied with in the study.

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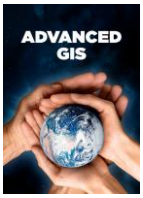

Evolution and future trends in global research on geographic information system (GIS): a bibliometric analysis

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ABSTRACT

In this article, the global research status and future trends of GIS are examined using bibliometric analysis. This study is based on an analysis of the most cited articles on GIS research topics, scientific production, collaboration between countries and authors, and GIS research from the Scopus database from 1969 to 2023. A total of 6398 articles were published in 3983 different journals, most of them original articles (4040, 63.1%) and conference proceedings (1701, 26.6%). The United States is the most productive country with 1847 articles and 29% of the total literature, followed by China with 596 articles and 9.3% of the total literature. Chinese Academy of Sciences was found to publish the highest number of documents with 72 articles and to cover 1.1% of the total literature followed by United States Geological Survey with 42 articles and to cover 0.6% of the total literature. Most used six keywords were "Remote sensing", "Spatial analysis", "Mapping", "Groundwater", "AHP" and "Big data" (n = 255, 164, 130, 121, 98, and 97 times, respectively. The top two authors who contributed most were Goodchild, M.F. (22 articles), Ehlers, M. (14 articles). The top-cited publication was "Extracting topographic structure from digital elevation data for geographic information system analysis" with 1964 citations.

1. Introduction

Emerging Information and Communication Technology (ICT) offers academics significant opportunities in many ways, from data collection and analysis, to finalization of results, to the publication of scientific papers to the academic community. In addition to all these advantages, these advantages help scientists improve the standard, quality and reduce the time it takes to complete a study. The incorporation of ICT into the publishing industry changed academia and scholarly communication in general (Mohamad et al., 2013). One of the information systems used extensively by academics in many different disciplines is the Geographic Information System (GIS). Looking at the development process, GIS first emerged in the 1960s, began to be used largely in the public sector, and then began to be used in many fields in the 1970s and 1980s. In general terms, GIS is a computer system that captures, stores, processes, analyzes and displays geo-based referenced data (Fahui, 2006; Önder et al., 2022). To date, GIS has been applied in many disciplines (e.g. environmental science, computer science, ecology, geography, library and information science) (Yalçın et al., 2022; Yıldız & Şişman, 2022). Many scientific studies have been conducted on the use of GIS in these disciplines. Every year, hundreds of thousands of scientific-based articles are published in journals at an international level. Scientific journals are considered as the most important communication tool in which the latest findings and developments related to the discipline they belong to are conveyed (Kantek et al., 2019). Articles published in these journals are more attractive to researchers because of the subject they contain, the introduction of the latest scientific research, their criticism, and their contributions to the evolution of knowledge (Erfanmanesh & Nojavan, 2016).

Today, the most important communication tool in which scientific information is produced and shared is peer-reviewed journals (Matcharashvili et al., 2014). Presenting the data obtained about the leading journals of each science field with objective scientific methods, comparing and evaluating the results, provides an understanding of the development and change stages of the discipline. For this reason, it is recommended to examine the performances and trends in the field of individuals, institutions and publications that ensure the transfer and dissemination of information produced in any field through journals. The most commonly used method for this purpose is bibliometric analysis (BA). The BA is a useful tool for providing quantitative analysis of scientific-based research productivity in any field based on the number of articles and citations in international peer-reviewed journals (Matcharashvili et al., 2014; Nascimento et al., 2019). Bibliometric analysis

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studies are the method of mathematically examining scientific publications made in a specific field, using specific keywords, authors, countries, institutions, years of publication, number of citations, journals in which they are published, number of authors, language of publication and sources used in publications. It is a type of study that has been done widely in recent years. While it was used mostly in social sciences at the beginning, it has been used frequently in the fields such as health and engineering in recent years (Rosas et al., 2011; Küçük et al., 2021).

Despite the growing interest, there has been little scientific work that can guide society about the scientific activities being done at the global level in the field of GIS. Tian et al. (2008) analyzed publications in all subject categories of the Science Citation Index compiled by the institute for Scientific Information (ISI) between 1997 and 2006 to evaluate the global scientific production of GIS articles. Mohamad et al. (2013) aimed to help researchers better understand the publication status of GIS-based studies between 2002 and 2011 and improve the applicability of GIS in many fields by analyzing the studies conducted between 2002 and 2011 and indexed in the Web of Science database. Bielecka (2020) made a bibliometric analysis of studies on the use of GIS-based spatial analysis model in land use change. The Web of Science was chosen as the data source for the studies analyzed in this study. Garramone et al. (2021) conducted a bibliometric analysis of studies focusing on GIS BIM integration for the management of infrastructure assets. Shkundalov & Vilutienė (2021) conducted a bibliometric analysis of studies covering building ınformation modeling, geographic ınformation systems and web environment integration.

Although there are a limited number of studies in the literature, researching and examining the studies produced in the field of GIS is important in terms of seeing at what level the concept of GIS is perceived and where it will reach in the future. In this study, the scientific literature on GIS presented in the SCOPUS database was reviewed using the bibliometric analysis (BA) method. In this way, it is aimed to guide the scientists who want to work in this field by analyzing the publications in terms of the number of citations, publication type, publication status, publication date, publication year, author productivity, keywords used, country or institution in which they are published.

2. Method

2.1. Bibliometry

A bibliometric analysis is a very useful tool to obtain valuable information and knowledge about the evolution of scientific research studies in specific disciplines (Ye, 2014; Niu et al., 2016; Li et al., 2018), which helps researchers to recognize novel trends and interests within investigation frameworks (Abejón et al., 2017; Zyoud et al., 2017). The value of BA increases depending on the number of publications in literature because BA sometimes allow us to analyze lots of publications about a specific topic or research interest and reveal the most productive publications, countries, authors, collaborations between the institutions, and active journals. There are many studies in the literature that contain BA of many journals operating in different disciplines (Such as medicine, information science, finance, marketing, engineering).

Bibliometric studies that have increased in number and quality recently, analyzing scientific studies on a subject in some aspects, number, journal in which they are published, citation status, the author who has published the most in that field, which subjects are studied, which subjects should be studied, research and analysis method. When bibliometrics is examined as a concept, it means the examination of scientific articles, books, journals with mathematical and statistical techniques and the determination of relationships. It is known that the first bibliometric study was done by Cole & Eales in 1917. In our country, the first known bibliometric analysis study was conducted by Ozınonu in 1970 (Al, 2008). Bibliometric studies mostly seek answers to the following questions:

- In which years were the studies carried out?
- Which database was used?
- What are the keywords used?
- What is the number of citations to the studies?
- Which universities or institutions produce the most publications?
- Who are the authors who produce the most publications?
- In which countries have the most publications been made?

2.2. Data Sources and Methodology

2.2.1. Data Sources

The bibliometric data source used in this article was obtained from the online platform of Scopus database. Scopus is a comprehensive database of abstracts and citations that provides access to rich data and academic literature in different disciplines. Launched in November 2004 (Zhang et al., 2017), Scopus is a source-independent database of abstracts and citations compiled by independent and unbiased subject matter experts (Scopus, 2023).

In general, the Scopus database is considered one of the most popular databases covering scientific journals, books, conference proceedings. (Singh et al., 2021). Scopus was searched online using the keyword “Geographical Information System (GIS)” to find a complete bibliography of all relevant articles directly related to GIS. The search made in the database on January 2023 covers the period from 1969 to 2023. Since the oldest study scanned in the database belongs to 1969, the search period covers the years 1969 to 2023.

2.2.2. Methodology

The term "bibliometrics" was first defined by Pritchard (1969) as "the application of mathematical and statistical methods to scientifically based communication tools (eg books, articles)". Bibliometrics are closely related new scientific fields that measure and analyze scientific publications in a particular field (Pritchard,

1969; Hood & Wilson, 2001; Ho, 2007; Abejón et al., 2017; Senel & Demiri, 2018). Bibliometric methods come to the fore to predict the scientific output or research trends of authors, journals, institutions and countries, and even to determine and measure international cooperation (Niu et al., 2016). This study includes the use of quantitative BA methods and social network analysis (SNA). SNA has been widely used to visualize and analyze relationships between various nodes in bibliometric studies, such as keyword collaborative use, academic collaborations between authors, institutions, and countries (Li et al. 2018). In order to evaluate and determine the trends in the scientific field related to the GIS subject, the subject indexes in which the database is classified, the most frequently used author keywords in each subject category, the articles with the highest number of citations were taken into consideration. In this context, 6398 articles published in the period from 1969 to January 2023 and indexed in the scopus database were analyzed. This study also uses the VOSviewer software to graphically map the co-occurrences of authors, key words and countries in the articles by published by Scopus.

3. Results

3.1.1. General trends

A set of 6398 published papers were obtained from Scopus database. The distribution of the number of publications by years is given in Figure 1. According to these data, there has been a significant increase in the number of publications, especially since the 90s. The reason for this increase is that the problems encountered during data collection, analysis and publication are largely solved with the developing technology and access to resources is facilitated.

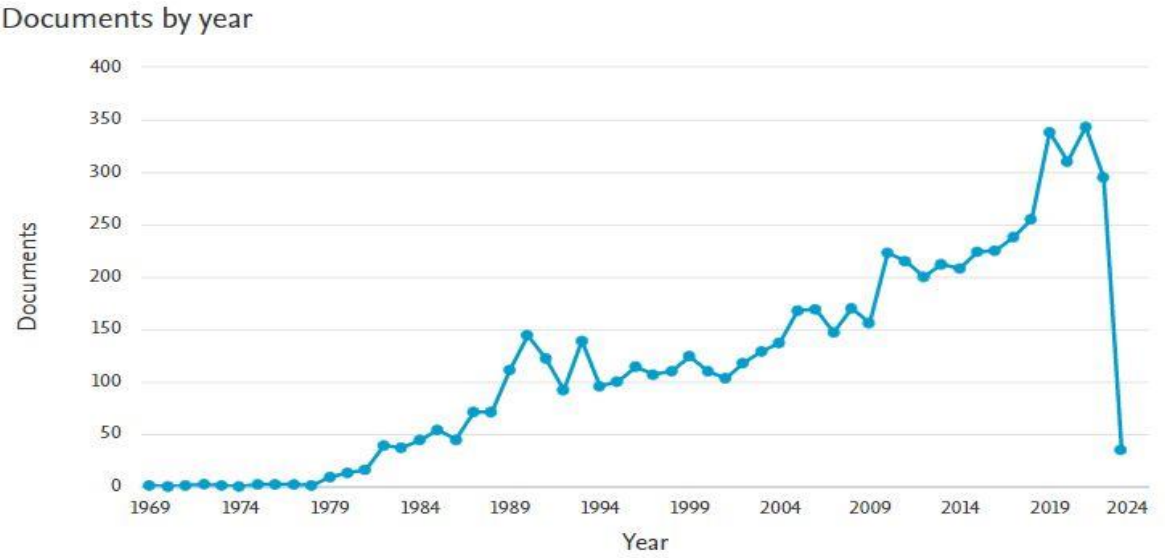

Figure 1. Evolution of published papers between 1969 and 2023

The distribution of document types of 6398 publications indexed by Scopus was analyzed. According to the results of this analysis, the published studies were prepared in 11 different document types (Table 1). The article (n: 4040) was the most frequently used document type comprising 63.1% of the total production, followed by Conference paper (1701, 26.6%). Book chapters (231, 3.6%), reviews (201, 3.1%), conference review 71, 1.1%), editorial (46, 0.7%), erratum (30, 0.5%), letter (21, 0.3%), book (20, 0.3%), and others (22, 0.3%) showed lesser significance than articles and conference papers.

Table 1. Document types of the publications

Document type	Number of publications	Percentage (%)
Article	4040	63.1
Conference paper	1701	26.6
Book chapter	231	3.6
Review	201	3.1
Conference review	71	1.1
Editorial	46	0.7
Erratum	30	0.5
Letter	21	0.3
Book	20	0.3
Note	15	0.2
Other	22	0.3

3.1.2. Distribution of journals

4040 of 6398 publications were published as articles. These articles have been published in 3983 different journals. Table 2 shows the 10 journals with more than 20 published articles with the total number articles, impact factor, Scopus subject categories.

There was a high contribution related to GIS research from these journals. According to Table 2, "Transportation Research Record" published the most articles on GIS (150; 3.7%), followed by "Photogrammetric Engineering Remote Sensing" (33; 0.8%), "Geocarto International" (31; 0.7%), and "Computers Environment and Urban Systems" (31; 0.7%).

Table 2. Most productive journals in GIS research

Journal	Number of article	Percentage of the articles in total number (%)	Impact factor
Transportation Research Record	150	3.7	2.019
Photogrammetric Engineering Remote Sensing	33	0.8	-
Computers Environment And Urban Systems	31	0.72	6.454
Geocarto International	31	0.72	3.450
Sustainability Switzerland	29	0.71	-
Environmental Monitoring And Assessment	27	0.66	3.307
Arabian Journal Of Geosciences	26	0.64	1.827 (2020)
Environmental Earth Sciences	21	0.51	3.119 (2021)
Environmental Management	21	0.51	3.644 (2021)
ISPRS International Journal Of Geo Information	21	0.51	3.099 (2021)

3.1.3. Country productivity and global network of collaboration

146 different countries around the world contributed to 6398 publications. Among these countries, the countries that contributed the most and the number of publications are given in Table 3. It was obvious that the most productive countries are United States (1847 articles, 29%), China (596 articles, 9.3%), Indonesia (291 articles, 4.5%), India (240 articles, 3.7%), and Canada (238 articles, 3.7%) respectively.

Table 3. The 10 most productive countries in GIS research during 1969–2023

Rank	Name of country	Number and percentage of countries' articles
1	United States	1847 (29%)
2	China	596 (9.3%)
3	Indonesia	291 (4.5%)
4	India	240 (3.7%)
5	Canada	238 (3.7%)
6	United Kingdom	222 (3.5%)
7	Iran	179 (2.8%)
8	Australia	156 (2.4%)
9	Brazil	155 (2.4%)
10	Turkey	154 (2.4%)
11	Other country	3246(50.7%)

The distribution and number of contributing countries shows that the development of GIS has been contributed from all over the world. The relations of the most productive countries with each other are given in Figure 2. The size of each bubble in Figure 2 represents each country's contribution to publication. The link between the two balloons shows the relationship between the countries in the publications. Data on publications are graphed using VOSviewer. Figure 2 shows that interoperability between these countries is quite strong, intense and sustainable.

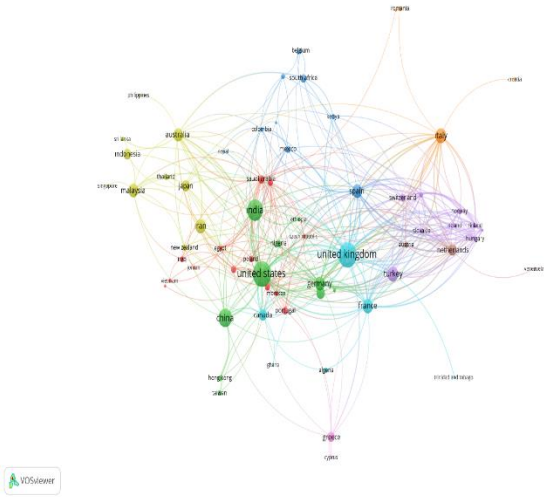

Figure 2. Co-occurrence network of countries/territories (more than 3 publications) in GIS research during 1969–2023

3.1.4. Publication distribution of institutions

162 different institutions contributed to 6398 publications. The 10 most productive institutions contributing 25 or more publications are listed in Table 4. The most productive institutions are Chinese Academy of Sciences (72 articles; 1.1%), United States Geological Survey (42 articles; 0.6%), University of California, Santa Barbara (41 papers; 0.6%), Louisiana State University (36 articles, 0.5%), and University of Minnesota Twin Cities (34 articles, 0.5%) respectively. According to the data in Table 4, the majority of the institutions in the top ten are institutions in the United States and China.

Table 4. The most productive institutions

Rank	Name of institution	Country	Number and percentage of institution's articles
1	Chinese Academy of Sciences	China	72 (1.1%)
2	United States Geological Survey	United States	42 (0.6%)
3	University of California, Santa Barbara	United States	41 (0.6%)
4	Louisiana State University	United States	36 (0.5%)
5	University of Minnesota Twin Cities	United States	34 (0.5%)
6	Pennsylvania State University	United States	31 (0.4%)
7	Texas A&M University	United States	29 (0.4%)
8	Wuhan University	China	29 (0.4%)
9	Ministry of Education China	China	28 0.4%)
10	University at Buffalo, The State University of New York	United States	27(0.4%)
11	Other institution (152)	Other countries	1935(30%)

3.1.5. Author productivity and global network of collaboration

According to the results of the analysis, 6387 authors contributed to at least 1 article on GIS. 731 of these authors contributed to 3 or more articles. The 10 most prolific authors who contributed 8 or more articles are listed in Table 5. This is an indication that top productivity writers have made major contributions to GIS research. The most productive authors are Goodchild, M.F. (22 articles, 1.01%), Ehlers, M. (15 articles, 0.83%), Malone, J.B (14 articles, 0.82%), Marble, D.F (14 articles, 0.82%) and Dangermond, J. (12 articles, 0.66%), respectively.

Table 5. The most productive authors working on GIS research

Rank	Name of author	Number and percentage of author's articles
1	Goodchild	22 (1.01%)
2	Ehlers	13 (0.83%)
3	Malone	14 (0.82%)
4	Marble	14 (0.81%)
5	Dangermond	12 (0.66%)
6	Gahegan	10 (0.62%)
7	Qin	10 (0.62%)
8	Estes	9 (0.58%)
9	Robinson	9 (0.54%)
10	Clarke	8 (0.54%)
11	Other authors (3 or more articles)	721(11.2%)

The frequent use of co-authoring networks in determining collaboration trends and highlighting scientists and organizations that shape science shows that they are a very important tool (Fonseca et al. 2016). Collaborations among 731 authors, who published more than three articles, were shown in Figure 3. The size of each bubble in Figure 3 indicates the density of the author's publications on GIS research. The bubbles are colored based on the total publication of the author in this research area. A link between two bubbles indicates a co-authorship relationship for tree or more publications on GIS research. The graphs showing the relationships of the co-authors were drawn using VOSviewer.

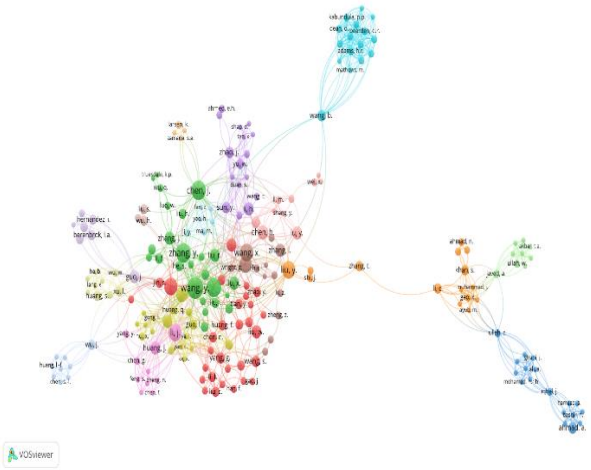

Figure 3. Co-authorship network of authors with three or more publications on research

3.1.6. Subject categories

GIS-themed studies published in the period 1969-2023 were classified in 27 subject categories determined by Scopus. These categories are closely related so that a single article can be assigned to more than one subject category. The existence of so many subject categories is an indication that GIS is used in all areas. Topic categories that overlap most with the articles are listed in Table 6. The five most common categories were Environmental Science, Earth and Planetary Sciences, Engineering, Computer Science, Social Sciences.

Table 6. Top 10 subject categories

Rank	Subject categories	Number and percentage of articles in Subject categories
1	Environmental Science	1911 (29.8%)
2	Earth and Planetary Sciences	1768 (27.6%)
3	Engineering	1555 (24.3%)
4	Computer Science	1304 (20.3%)
5	Social Sciences	1232 (19.2%)
6	Medicine	658 (10.2%)
7	Agricultural and Biological Sciences	637 (9.9%)
8	Mathematics	331 (5.1%)
9	Energy	279 (4.3%)
10	Physics and Astronomy	235 (3.6%)
11	Other categories (17)	1272(19.8%)

3.1.7. Key word analysis and hot issues

Searching for frequently mentioned terms (Goyal 2017) or author keywords (Abejón et al. 2017) in article titles and abstracts can gather relevant information to identify research trends, hot topics, methods and policies in a particular field. Keywords provide very important information about the content of the article (Singh et al., 2019). A common network analysis between keywords can be used to track research topics and emerging trends (Kevork & Vrechopoulos, 2009). 5008 different keywords were used 7232 times in 6398 articles. Social network analysis with 5008 keywords is given in Figure 4.

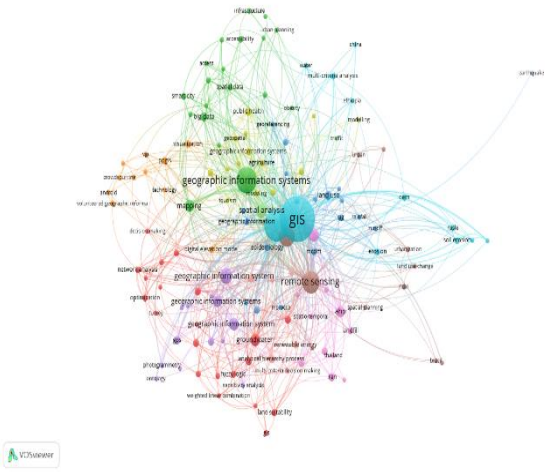

Figure 4. Social network analysis with 5008 keywords

The 15 most used keywords (more than 60) in the articles are listed in the Table 7. Most used six keywords were "Remote sensing", "Spatial analysis", ''Mapping'', ''Groundwater'', ''AHP'' and ''Big data'' (n = 255, 164, 130, 121, 98 and 97 times, respectively.

Table 7. Most used keywords

Rank	Keywords	Frequency of use of the keyword in the article	Number of keywords used together
1	Remote Sensing	255	118
2	Spatial analysis	164	76
3	Mapping	130	72
4	Groundwater	121	65
5	AHP	98	23
6	Big data	97	70
7	Site Selection	95	106
8	Agriculture	88	100
9	Land use	87	105
10	Flood	79	34

3.1.8. Highly cited papers

The number of citations a publication receives is an important indicator for measuring its impact in the research field. 10 articles receiving more than 340 citations are listed in Table 8. The most cited paper was published in 1988 by Jenson, S.K and et al. (n=1964). The title of the article is "Extracting topographic structure from digital elevation data for geographic information system analysis". The second most cited article (n=786), was published in 2006 by Sieber R. This article focuses on public participation in GIS. The third most cited article (n=592) was in 1995 by Pickles, J. This article focuses on the social effects of geographic information systems.

Table 8. The top 10 highly cited publications during 1969-2023

Rank	Title	Author(s)	Year	Source	Number of Citations
1	Extracting topographic structure from digital elevation data for geographic information system analysis	Jenson & Domingue	1988	Photogrammetric Engineering and Remote Sensing, 54(11), pp. 1593–1600	1964
2	Public participation geographic information systems: A literature review and framework	Sieber	2006	Annals of the Association of American Geographers, 96(3), pp. 491–507	786
3	Ground truth: the social implications of geographic information systems	Pickles	1995	Ground truth: the social implications of geographic information systems,	592
4	It's About Time: A Conceptual Framework for the Representation of Temporal Dynamics in Geographic Information Systems	Peuque	1994	Annals of the Association of American Geographers, 84(3), pp. 441–461	449
5	Walkability of local communities: Using geographic information systems to objectively assess relevant environmental attributes	Leslie et al.	2007	Health and Place, 13(1), pp. 111–122	447

Table 8. (Continued)

Rank	Title	Author(s)	Year	Source	Number of Citations
6	Time in geographic information systems	Langran	1992	Time in geographic information systems,	424
7	Estimating lonq-term average particulate air pollution concentrations: Application of traffic indicators and geographic information systems	Brauer et al.	2003	Epidemiology, 14(2), pp. 228–239	415
8	Associations of the local food environment with diet quality - A comparison of assessments based on surveys and geographic information systems	Moore et al. Jacobs	2008	American Journal of Epidemiology, 167(8), pp. 917–924	413
9	Geographic information systems: a management perspective	Aronoff	1989	Geographic information systems: a management perspective,	378
10	Development of a framework for fire risk assessment using remote sensing and geographic information system technologies	Chuvieco et al.	2010	Ecological Modelling, 221(1), pp. 46–58	348

4. Discussion

Since the first article published in 1969, thousands of scientific studies on GIS have been published until 2023. These scientific studies show that GIS plays a very important role in collecting, analyzing, visualizing and sharing scientific information in many fields such as Engineering, earth and space science, environment, health, computer science, energy, agriculture and biology, social sciences. In this study, all GIS articles indexed in the Scopus database from 1969 to 2023 were analyzed using BA methods and knowledge mapping tools, and the development process and domain of GIS were revealed. Most used keywords with GIS are "Remote sensing", "Spatial analysis", "Mapping", ''Groundwater'', ''AHP'', ''Big data'', ''Site selection'', ''Agriculture'', ''Land use'' and ''Flood''. These keywords, which were popular in different periods of GIS, revealed that GIS formed the basis of many scientific fields between 1969-2023 and played an important role in data architecture. Both the significant majority in the number of authors and the distribution of countries show that GIS is followed by many scientists in many countries around the world. Especially the authors of highly cited studies have an important role in the recognition of GIS. According to the results of the analysis, many public institutions and universities have played a key role in the development of GIS. The majority of these institutions and universities operate in the USA and China. This is an indication that GIS contributes to the development of countries with large economies. Also, the results from this analysis can be used for the future research direction of GIS. For example, the frequency of publications on GIS-based remote sensing systems, measurement techniques, spatial data modeling, AHP, suitability analysis, and land uses indicates that these topics will become popular in the future.

5. Conclusion

The purpose of this study was to trace the development of his 'GIS'. This study provides an overview of the articles indexed in the Scopus database and published from 1969 to 2023. The data used in this study were obtained using the Scopus online database. A total of 6398 publications of different types (e.g. articles, proceedings, reports) published since 1969 were examined. The results of the analysis show that the high increase in the number of articles and citations took place especially after the 90s. The 6398 publications contributed by 6387 authors from 146 different countries show how widespread the impact of GIS is. The need for geographic data is increasing day by day, and the importance of geographic information systems is increasing. The findings obtained as a result of this analysis show that GIS is used in many countries in an integrated manner with many fields. In addition, studies conducted regularly for many years show that GIS will continue to be an important topic in the future. Repeating a similar study in later periods may allow periodic comparison of the findings with the findings obtained from this study.

Author Contributions

The contributions of the authors of this article is equal.

Statement of Conflicts of Interest

There is no conflict of interest between the authors.

Statement of Research and Publication Ethics

Research and publication ethics were complied with in the study.

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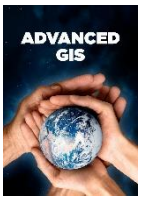

Applying an integrated approach to evaluating ecotourism capabilities in Margavar district, northwest Iran

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ABSTRACT

Ecotourism considered as purposeful travel to the natural and cultural history of nature to understand the environment by avoiding change Ecosystems, environmental degradation, and creating economic opportunities. Moreover, this is one of the new sources of social activities in the field of sustainable development. Our study aims to assess and mapping the ecotourism capabilities of the Margavar rural district, in northwest Iran. In this regard, a set of associated factors were considered. Hence, we want to evaluate the ecotourism capabilities through an integrated approach using the Analytic Network Process (ANP) method, VIKOR technique, Geographic Information System (GIS), and considering the environmental and tourism criteria. A Fuzzy gamma operator was used to overlay the weighted maps and the ecotourism map was obtained. The overall results indicated that 14.50% of the study area is located in a very high potential class, 26.32% in a high potential class, 32% in a moderate potential class, 18% in a low potential class, and 9.18% in a Very low potential class. Due to the pristine nature of the study area and the need to create new investment opportunities, our findings can be useful in identifying the ecotourism potentials of the region and achieving a higher level of local development.

1. Introduction

Tourism as one of the largest and most diverse economic sectors with its rapid growth in recent decades has made a significant contribution to the national interests of countries and is known as a substantial phenomenon in international developments (dos Anjos & Kennel, 2019) and offers real prospects for sustainable development on a global and local level (León-Gómez et al., 2021). Despite some global challenges such as COVID-19, the tourism industry has been able to continue to grow gradually and according to the World Tourism Organization (WTO), the number of international tourists will reach 1.8 billion in 2030 (Uppink & Soshkin, 2022).

Among the various types of tourism, nature-based activities considered as one of the main resources of worldwide tourism industry (Metin, 2019). Ecotourism is one of the main types of nature-based tourism that has become more widespread over the last 20 years with the increasing growth of travel and tourism and highly regarded by tourists and researchers in recent years (Safarabadi, 2016). Ecotourism has a deep connection with sustainable tourism, which stems from the interactions between tourists and the environment (Bunruamkaew & Murayama, 2011). The concept of Ecotourism emphasized the responsible journey to pristine landscapes with the aim of environmental protection and ensuring sustainable development (Seifi & Ghobadi, 2017), which came into reality in order to react to traditional mass tourism and its negative impact on local culture and environment (Sahani, 2019). Ecotourism has emerged as a component of alternative tourism that can improve positive environmental, economic, and socio-cultural outcomes from tourism (Wondirad et al., 2020). Therefore, it can be said that ecotourism is regarded as an efficient strategy for facilitating sustainability that aims to reduce damaging environmental influences on potential sites in developing countries (Kiper, 2013). Accordingly, identifying areas prone to ecotourism, And Proper planning in order to develop ecotourism is critical to maintaining the environmental richness and economic development of the local community.

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Identifying Ecotourism potentials must be performed by using an integrated approach where Geographical Information Systems (GIS) and spatial decision-making tools can act as decision support systems (Jokar et al., 2021). GIS with its great capabilities is a powerful tool, which has been commonly used in ecotourism assessment. GIS can be used to determine the best sites for a new tourist destination while trying to preserve a sustainable natural area (Hai-ling et al, 2011). The use of GIS allows the combination of a large number of spatial criteria in the context of tourism studies, which greatly increases the accuracy and comprehensiveness of the assessment (Šiljeg et al., 2019). Moreover, GIS-based Multi-Criteria decision analysis (GIS-MCDA) has been considered as an effective approach for resolving spatial decision problems (Feizizadeh et al., 2021), and provides a powerful tool to identify the ecotourism potential of different regions (Kumari et al., 2010). In this regard, Fuzzy logic and the Analytic Network Process (ANP), as GIS-MCDA approaches provide the ability to ecotourism capability assessment (Yamani et al., 2017). Fuzzy Analytic Network Process (FANP) is a widely used multi-criteria method for handling interactions between criteria and linguistic variables. (Senturk et al., 2016).

The GIS-MCDA approach has been used in numerous research for assessment ecotourism capabilities in recent years. Ullah & Hafiz (2014) determined suitable areas for ecotourism development by using 5 criteria such as landscape, wildlife, topography, cultural heritage, and social parameters. Aminu et al. (2014) in their research, studied sustainable tourism using the GIS and ANP, and with their conclusions, they have presented a tourism development model to ensure that future generations will also benefit from the natural mountains of Cameroon. Aliani et al. (2017) in their research in order to allocate land for the development of ecotourism have used a multi-criteria evaluation method based on ANP and Fuzzy logic. They concluded that ecological criteria accounted for 64% of the relative weight of the parameters, indicating a greater impact of ecological criteria on the potential for ecotourism. Shaterian et al. (2017) investigated the affecting factors of rural ecotourism development and for this purpose; they used an integrated approach by combining DEMATEL and ANP methods. Fathi & Khorshiddoust (2018) by combining various spatial data in the GIS and evaluating the tourism attractions of Margavar rural district have drawn a map of geotourism and geohiking and mentioned that the use of this map can be a suitable action in the field of achieving sustainable local development goals. Omarzadeh et al. (2021) performed a GIS-based multiple assessment for investigating the ecotourism sustainability of West Azerbaijan province in northwest Iran and mapped the potential for sustainable ecotourism development, using 28 spatial indicators.

Iran is one of the countries that has great tourism potential in terms of unique conditions such as natural attractions, unspoiled landscapes, and a favorable climate in different parts of the country (Makian & Hanifezadeh, 2021). However, The Iranian ecotourism industry is relatively new and studies show that Iran's natural tourism assets are a vast array of scattered, unstabilized, and in some cases endangered resources (Ronizi & Rezvani, 2015). It seems that one of the main reasons for this situation is the existence of traditional tourism management and the lack of assessment of potential studies of different areas. The main goal of this study was to run an integrated GIS-MCDA approach for ecotourism potential assessment in Margavar rural district in northwest Iran. For achieving this goal, an ecotourism potential map, which shows the capability of different parts of the study area in terms of ecotourism, was developed.

2. Method

2.1. Study area

The study area of the current research is the Margavar rural district, which is located in Urmia County in Northwest Iran (Figure 1). Margavar has a natural border with Republic of Turkey and Islamic Republic of Iraq from the west part and covers an area of 450 km^2. The average elevation of this district is about 1952 meters, lowest elevation is 1400 meters in the northern parts, and highest elevation is 3429 meters in southwest. In terms of climate, Margavar has mild and relatively hot summers and very cold winters, and its average annual temperature is 8°. According to the latest population census, Margavar has 40174 inhabitants, who live in 57 villages (Statistical Centre of Iran, 2016). Margavar district with its beautiful nature and unique mountains attracts thousands of tourists from different parts of the country in different seasons of the year, especially spring and summer. Moreover, this area has a very rich cultural landscape and its historical, traditional, and ethnic heritage is of particular interest and has always been a tourist destination. Margavar has not been well evaluated and planned, despite its great potential. The ecotourism attractions of this area have been identified only on a local scale and no effective action has been taken to present its potential on a national or global scale. Therefore, the current study aims to evaluate the capabilities of Margavar rural district in order to take effective action to identify its ecotourism potential and provide suitable places to create facilities with minimal environmental impacts.

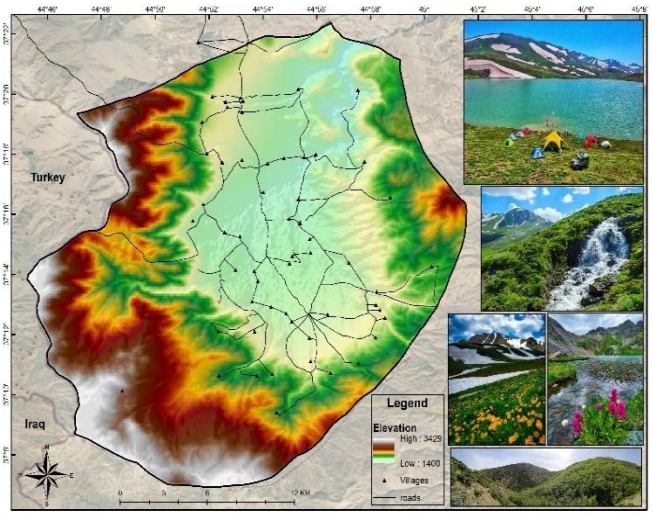

Figure 1. Study area

2.2. Dataset and criteria selection

The current research is an applied research in which various data have been used to evaluate the potential of ecotourism in the study area. In order to carry out a comprehensive assessment of the ecotourism potential of the study area, we selected two major groups of indictors, including tourism attractions with 6 indicators, and environmental indicators with 8 indicators, based on the literature review and interviews with tourism experts and most data gathered using field operations and Google Earth maps. Table 1 shows the dataset and criteria used in the research. As mentioned, GIS-based data is divided into two main groups: tourism and environmental. Within the tourism attractions group, there are indicators such as waterfalls, lakes, valleys, forests, vegetation and touristic villages, and other indicators such as precipitation, temperature, soil, rivers, land use, landforms, roads and service centers are included in the group of environmental criteria. Our data collected in vector format were linear, point, and polygon, and then, layers were converted into raster layers in ArcGIS in order to performing overlay operations. For this purpose, for some polygon layers, such as land use or landforms, the polygon to raster tool is used based on coding and for other layers, the Euclidean distance tool has been used. Figure 2 represent the spatial distribution of tourism indicators, and Figure 3 represent the spatial distribution of environmental indicators.

Table 1. Research criteria

Cluster	Criteria
Tourism attractions	Distance to Waterfalls
	Distance to Lakes
	Distance to Valleys
	Distance to Forests
	Vegetation
	Distance to Touristic villages
Environmental indicators	Precipitation
	Temperature
	Soil type
	Distance to Rivers
	Land use
	Landforms
	Distance to Roads
	Distance to Service centers

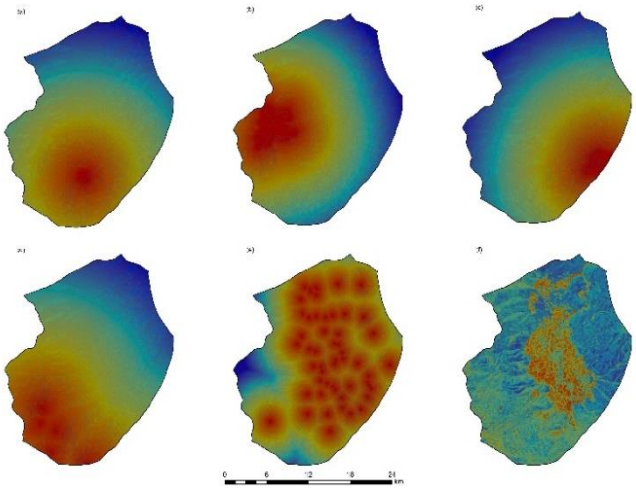

Figure 2. Tourism attractions; (a) Waterfalls, (b) Valley (c) Forest, (d) Lakes, (e) Touristic villages, (f) Vegetation.

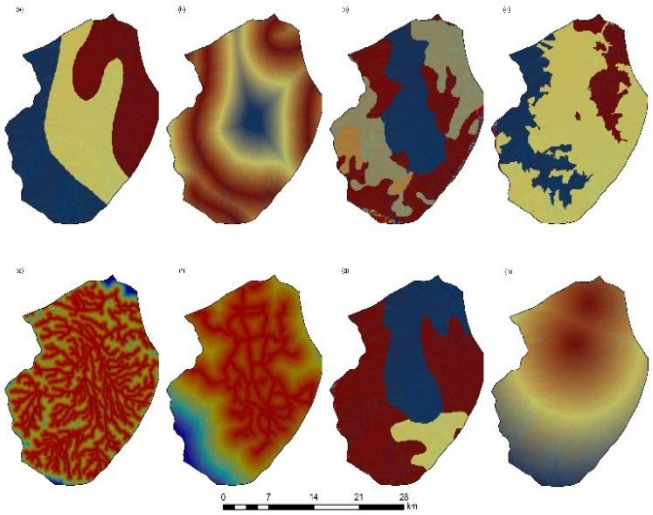

Figure 3. Environmental indicators; (a) Precipitation, (b) Temperature. (c) Landform, (d) Land use, (e) Rivers, (f) Roads, (g) Soils, (h) Service centers

Given the complex nature of ecotourism and the influence of various factors, we must employ an effective method to identify areas suitable for ecotourism development. Accordingly, an integrated approach of GIS-MCDA and the fuzzy technique was applied to extract the significance of each criterion. It is obvious that in the GIS-MCDA approach each criterion has its own significance in terms of ecotourism potential; thus, we employed the analytical network process (ANP) method and VIKOR technique to extract and rank the criteria weights. In this regard, 30 questionnaires were distributed among geography and tourism experts for comparison and rank the fourteen criteria, and by calculating the average of the results for the questionnaires, the ANP super matrix and relative significance of the criteria in the pairwise systems have been determined. Finally, the GIS-MCDA-based fuzzy (Gama Function) method was applied to overlay criteria maps and generate an ecotourism potential map. The general steps of the research are shown in figure 4.

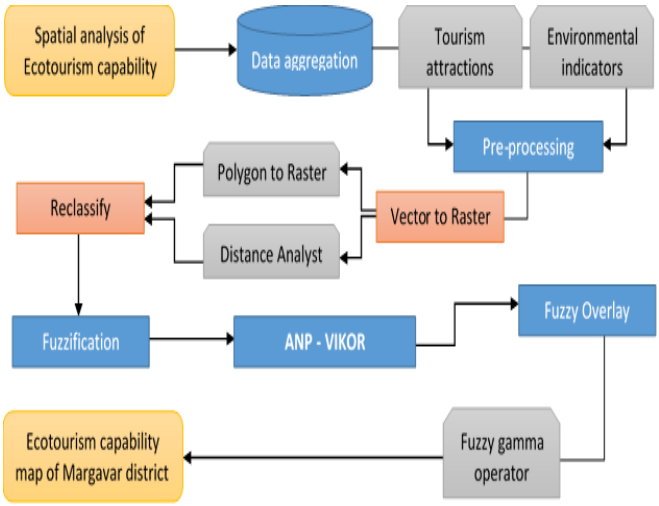

Figure 4. General process of the research

2.3. Analytic network process

Analytic Network Process (ANP) is a MCDA-based technique that can represent the significance of various parties by considering the interconnection between existing criteria and sub-criteria (Feizizadeh et al., 2014). The network structure contained in the ANP reduces the multidimensional problem to clusters and elements, i.e. nodes within clusters. This non-linear "feedback" structure permits interaction and dependence between elements of one cluster (inner dependence), and dependence between elements of another cluster (outer dependence) (Ghorbanzadeh et al., 2019). There are basic steps for implementing the ANP technique and pairwise comparison is one of the most important steps in this process, which is run using the pairwise comparison matrix. The preference relations in the pairwise comparison matrix are filled in by the experts' judgments and presented using different measurement scales. The ratio scale proposed by Saaty (1980), is considered the most common scale in the field of pairwise comparisons between criteria. The structure of a forenamed Scale used for the judgments is given in table 2. Furthermore, the judgments may have a certain level of inconsistency because of the limits of decision makers' expertise and capabilities or the complexity of the decision problems; therefore, various indices have been proposed to measure the consistency of the pairwise comparison matrix. In this regard, the consistency ratio (CR) index has been used to calculate the inconsistency of judgments. The consistency of a matrix is given by CI = (λmax – n)/(n-1), and the consistency ratio (CR) is obtained by forming the ratio of CI and a set of random numbers (Kou et al., 2016). Here, if the CR < 0.1, the consistency value is acceptable, otherwise, some pairwise values need to be checked.

Within this research, pairwise comparisons were carried out using the relative importance scale, and values from 1 to 9 were considered to compare criteria. On the other hand, the overall consistency ratio (CR) was computed to be 0.067, which indicates an acceptable level for the matrix. In the next step, we derived a weight vector for each criterion and for this purpose; the priorities obtained from the pairwise comparison matrix have been entered as parts of the columns of a super matrix, by considering inner and outer dependency between criteria or clusters. Finally, a limited matrix was calculated. To obtain the limit we must raise the matrix to powers. Each power of the matrix captures transitivity of an order that is equal to that power. The limit of these powers is equal to the limit of the sum of all the powers of the matrix (Saaty & Vargas, 2006). The result of limited matrix is shown in table.3. The numbers in the rows of the limited matrix demonstrate the relative importance of the criteria.

2.4. VIKOR technique

VIKOR method is an optimized MCDM technique developed by Opicovic (1990) which emphasized on selection and ranking of alternative sets of conflicting criteria, based on a compromise solution that is the closest to the "ideal" (Mardani et al., 2016). The compromise ranking of VIKOR has four steps, that n and m are the numbers of criteria and alternatives, respectively (Yazdani & Graeml, 2014). Hence, the VIKOR technique was used in order to determine optimized weights for criteria. In this regard, steps 1 and 2 included finding utility measures and regret measures for alternatives regarding each criterion. Then, in step 3 the minimum and maximum amounts of the step 2 results have been computed. In the last step, Qj was calculated as the majority agreement prioritizes the alternatives. Finally, the VIKOR's weights are combined with the weights obtained from ANP and the standard weights of the criteria have been obtained.

Table 2. Saaty's scale of relative importance

Description	Numerical rating	Reciprocal
Equally Preferred	1	1
Equally to Moderately Preferred	2	1/2
Moderately Preferred	3	1/3
Moderately to Strongly Preferred	4	1/4
Strongly Preferred	5	1/5
Strong to Very Strongly Preferred	6	1/6
Very Strongly Preferred	7	1/7
Very Strong to Extremely Preferred	8	1/8
Extremely Preferred	9	1/9

Table 3. Limited matrix

Criteria	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
Waterfalls (1)	0.189	0.189	0.189	0.189	0.189	0.189	0.189	0.189	0.189	0.189	0.189	0.189	0.189	0.189
Lakes (2)	0.234	0.234	0.234	0.234	0.234	0.234	0.234	0.234	0.234	0.234	0.234	0.234	0.234	0.234
Valleys (3)	0.063	0.063	0.063	0.063	0.063	0.063	0.063	0.063	0.063	0.063	0.063	0.063	0.063	0.063
Forests (4)	0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.125	0.125
Vegetation (5)	0.218	0.218	0.218	0.218	0.218	0.218	0.218	0.218	0.218	0.218	0.218	0.218	0.218	0.218
Touristic villages (6)	0.171	0.171	0.171	0.171	0.171	0.171	0.171	0.171	0.171	0.171	0.171	0.171	0.171	0.171
Precipitation (7)	0.134	0.134	0.134	0.134	0.134	0.134	0.134	0.134	0.134	0.134	0.134	0.134	0.134	0.134
Temperature (8)	0.198	0.198	0.198	0.198	0.198	0.198	0.198	0.198	0.198	0.198	0.198	0.198	0.198	0.198
Soil type (9)	0.081	0.081	0.081	0.081	0.081	0.081	0.081	0.081	0.081	0.081	0.081	0.081	0.081	0.081
Rivers (10)	0.153	0.153	0.153	0.153	0.153	0.153	0.153	0.153	0.153	0.153	0.153	0.153	0.153	0.153
Land use (11)	0.099	0.099	0.099	0.099	0.099	0.099	0.099	0.099	0.099	0.099	0.099	0.099	0.099	0.099
Landforms (12)	0.077	0.077	0.077	0.077	0.077	0.077	0.077	0.077	0.077	0.077	0.077	0.077	0.077	0.077
Roads (13)	0.145	0.145	0.145	0.145	0.145	0.145	0.145	0.145	0.145	0.145	0.145	0.145	0.145	0.145
Service centers (14)	0.113	0.113	0.113	0.113	0.113	0.113	0.113	0.113	0.113	0.113	0.113	0.113	0.113	0.113

2.5. Fuzzification

Decision making in complex and uncertain environments generally requires dealing with problems in which descriptions of the environment and decision elements as well as judgments are highly subjective, vague or imprecise. Especially, the use of qualitative analytical models such as analytical network process (ANP) may produce unrealistic results with remarkable uncertainty (Asan et al., 2012). Fuzzy logic provides more realistic results which has proven advantages for dealing with uncertain and imprecise decision problems, and implements grouping of data with boundaries that are not distinctly defined (Li & Wang, 2019). Accordingly, fuzzy logic has been applied with ANP to address uncertainties, and in order to improving result's precision. Hence, fuzzy membership defined to all layers in the Arc GIS, and weighted criteria maps converted to values between 0 and 1 by linear Fuzzification function. Then, the overall ranking of the factors was obtained and standardized weights allocated to criteria maps (Table 4). Finally, the overlay of maps was performed using fuzzy gamma 0.9 operator.

Table 4. Weights and values for criteria

Criteria	Layer values	Fuzzy values	ANP weight	VIKOR weight
Distance to Waterfalls	0 – 2295.5	0 - 1	0.189	0.421
Distance to Lakes	0 – 23691.5		0.234	0.529
Distance to Valleys	0 – 16716.1		0.063	0.054
Distance to Forests	0 – 21058.4		0.125	0.262
Vegetation	0 – 255		0.218	0.488
Distance to Touristic villages	0 – 9027.88		0.171	0.363
Precipitation	1 -3		0.134	0.289
Temperature	0 – 0.09258		0.198	0.441
Soil type	1 – 3		0.081	0.118
Distance to Rivers	0 – 2223.02		0.153	0.312
Land use	1 – 3		0.099	0.174
Landforms	1 – 4		0.077	0.097
Distance to Roads	0 – 8824.31		0.145	0.298
Distance to Service centers	0 – 19698.6		0.113	0.241

3. Results and Discussion

The current study set out to evaluate the ecotourism capabilities of the Margavar district of Urmia county in northwest Iran. For this purpose, as mentioned above, different geographic criteria were combined using an integrated approach. Analysis of the relative importance of the criteria used in the study has shown that some criteria are more important in terms of the ecotourism potential of the study area. It has been determined that the lakes (0.234), vegetation (0.218), and waterfalls (0.189) were the most important criteria in the cluster of

natural attractions. Furthermore, among the environmental criteria, temperature (0.198), rivers (0.153), and roads (0.145) were the most important criteria. In general, the evaluation of the criteria has shown that according to the current situation of the region, lakes (0.151), vegetation (0.131), and waterfalls (0.12) obtained the greatest weight and have been recognized as the most important criteria (Figure 5).

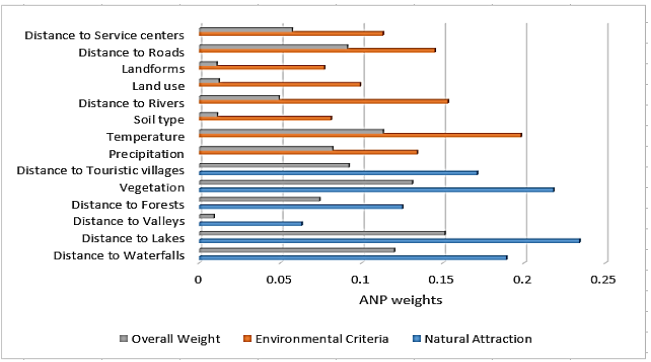

Figure 5. Criteria weights

Figure 6 demonstrates the ecotourism capability map of the studied area. based on the relative weights obtained from the ANP method for the layers and through overlaying the maps using the fuzzy gamma 0.9 operator, the ecotourism potential of the Margavar district has been produced in five classes. Hence, we can classify the ecotourism capability of the Margavar district from very low to very high. The green areas in the map indicate a high potential for ecotourism and the red areas indicate lower levels of potential for ecotourism. According to the evaluations, 14.50% of the study area has very high potential and 26.32% has high potential in terms of ecotourism activities. In general, the analysis of the ecotourism capability of the region shows that 72.82% of its total area, which covers an area of 327.69 km, has moderate to very high potential for sustainable ecotourism development. Moreover, the spatial analysis of the ecotourism potential of the region indicates that the central and south-western parts of the region, which mostly consist of relatively flat lands with low slopes and include natural landscapes such as springs and waterfalls, with infrastructure facilities, and dense pastures and forest lands, are placed as the classes with very suitable areas for ecotourism development. On the other hand, in some parts of the region, the slope of the land is gradually increased and the dense vegetation cover is replaced by semi-arid and partially barren lands, but there are still favorable conditions such as tourist villages or facilities, which have moderate to high ecotourism capabilities. In addition, highly mountainous areas with complex topographical conditions and difficult access were identified as the most unsuitable areas for ecotourism development. However, this situation can provide special tourist attractions and sports activities such as climbing, Skiing, group and adventure tours, etc. can be considered for sustainable ecotourism development.

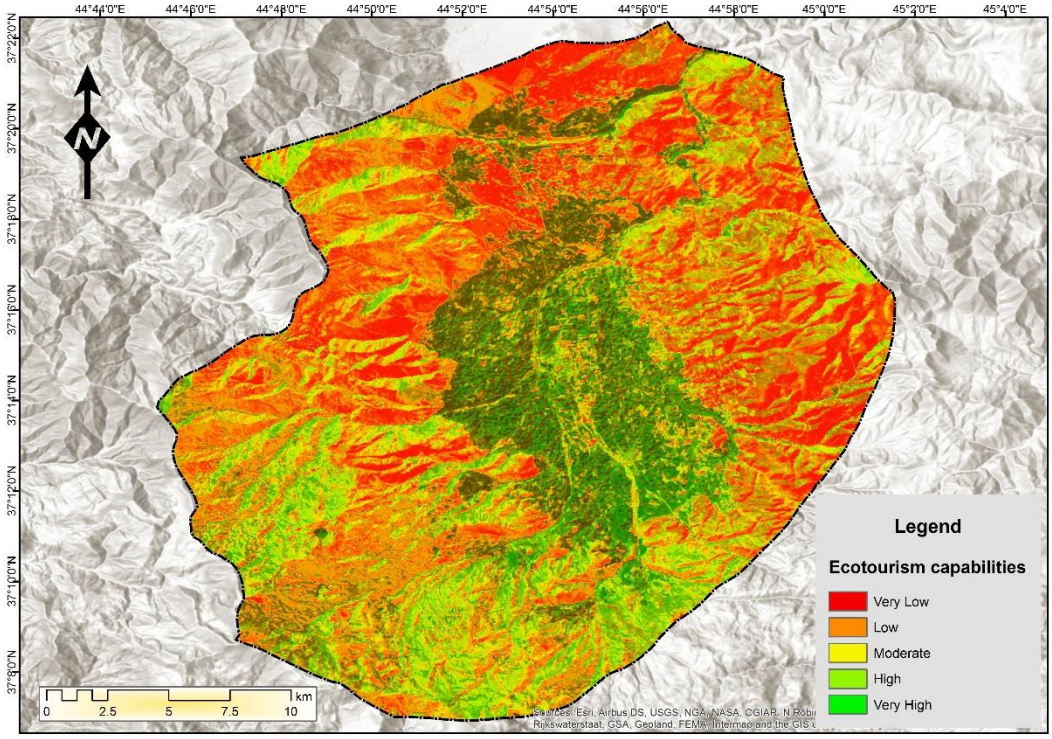

Figure 6. Ecotourism capability map

4. Conclusion

The main objective of the current research was to apply a GIS-based MCDA approach to identify the potential of Margavar rural district for ecotourism development. For this purpose, in the present study, we proposed an efficient integrated approach for ecotourism capability mapping and identifying the potential areas for ecotourism. The results of the research show that the Margavar rural district has great potential in the field of ecotourism development, both in terms of its ability to develop future ecotourism and in terms of its current situation in terms of accepting a large number of tourists. In this regard, it is quite obvious that the adoption of comprehensive planning

and compilation of effective solutions in this field can be a breakthrough and an important step to achieving

sustainable regional development at the local level. The use of a multi-criteria integrated approach and the results of the ANP model and the fuzzy logic in this research indicated the great flexibility of these methods and the possibility of defining different scenarios and combining multiple spatial criteria using the analytical functions of the GIS, which considered as a suitable platform for conducting research in the field of qualification, assessment and identification of the natural environment. Therefore, it can be said that considering the potential of the Margavar district, it is essential to review measures and pay more attention to ecotourism development plans and studies in this region. On the other hand, the virginity of this area and the urgent need to provide new opportunities for investment and employment can be considered one of the important findings of this research. In general, the examination of the obtained results shows the high capability of the analytical approach used in the research and its effective application according to the environmental conditions of the region can lead to objective results in the evaluation of the tourism capabilities of the region and lay the groundwork for effective local management and planning for Provide sustainable development.

Author Contributions

The contributions of the authors of this article is equal.

Statement of Conflicts of Interest*)*

There is no conflict of interest between the authors.

Statement of Research and Publication Ethics

Research and publication ethics were complied with in the study.

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