



Vulnerability analyses in forests using AHP in a GIS environment

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Abstract

Vulnerability, which is one of the criteria used in the preparation of the World Risk Index, is the measure of the damage and loss that a community or structure can suffer when a hazard occurs. In this research, a region with a high fire hazard was selected, and a model was created to determine the extent to which spatial objects (assets) could be damaged when the expected danger occurs in the selected region, using Analytic Hierarchy Process (AHP) in a Geographic Information System (GIS) environment. Since GIS-based AHP analysis is based on the comparison of different layers with each other and determining the weight values of the layers, the Terrestrial Measurement, Photogrammetry and Remote Sensing techniques, which are used as data sources in the evaluation of spatial data, are also discussed in the study.

Keywords: GIS, QGIS, AHP, photogrammetry, forestry, remote sensing.

Introduction

When Hazard and Risk are considered separately, they can be defined as following:

Hazard: Hazard can be defined as damage and potential for damage.

Risk: Risk can be defined as loss, injury or other consequences from the hazard. To define the overlap and separation between them, it can be evaluated that if an earthquake is the danger, it is the risk to buy a house from an earthquake zone. Again, one of the generally accepted definitions of risk is that 'risk is the combination of the probability of occurrence of an identified dangerous event and its consequences'. On the other hand, according to AS/NZS 4360:1999 Risk Management by Standards Australia (1999), risk can be defined as the likelihood of the occurrence of an event that has the potential to cause hazards, which can be measured in terms of outcomes and probability.

As can be understood from the definitions, risk is manageable and analyzable. Risk management regulates readiness before a risk takes place and enables efficient, fast, and accurate decision making in difficult situations. The determination of risk probability and risk effect is only performed by risk analysis.

The criteria used for ranking in the preparation of the World Risk Index are based on the most basic concepts such as Risk, Exposure, Vulnerability, Fragility, Coping, and Adaptation as mentioned in the Index for Risk Management or INFORM (Marin-Ferrer et al., 2017).

Vulnerability, which is one of the criteria mentioned above, is defined as the measure of the damage and damage that people, structures, or services may suffer when a hazard occurs. Hazard sources are divided into two main groups according to their reasons.

- a) Natural Hazards (earthquakes, floods, landslides, avalanches, etc.)
- b) Human Hazards (technological accidents, traffic accidents, fire, etc.)

According to the World Risk Report 2016, when evaluated in terms of Hazard (Human and Natural) and Exposure dimensions, Turkey ranks 12th in the world among the 12 highest scoring countries (Ersoy et al., 2017).

The presentation or preparation of the region where the risk analysis will be carried out in numerical data in a measurable, evaluable manner with all the details of the place directly affects the results of all evaluations to be made. Therefore, different methods can be followed in providing the data required for the type of hazard and the size of the impact area. However, in the case of regional or local hazards, the location and quality accuracy of all spatial details is very important for vulnerability analysis. In order to achieve this, it is useful to know different engineering measurements and data supply techniques.

Spatial data may require different engineering measurements depending on the hazard type. However, it should be noted that the first and most important data source is historical written data, records, and images related to the hazard of the place in question. In such analysis studies, the data in question is defined as existing data.

If measurement points related to hazard limits and hazard probability of the area defined as risk area are needed, a terrestrial measurement network is created from measurement points (control points) in the area. Nowadays, terrestrial measurements are carried out with highly sensitive measurement systems such as, total stations, global navigation satellite system receivers and terrestrial laser scanners (Ghilani & Wolf, 2011).

In the vulnerability assessment of an area, photogrammetry is a very important data source that provides all the natural or artificial details of the area, gathered in a three-dimensional, traceable, observable, and measurable manner. All spatial information of the region can be accessed by evaluating the overlapping and transverse overlapping (sidelap) aerial photographs taken with aircraft cameras (Lillesand et al., 2015). With the new generation of systems and sensors, such measurements can be made more accurately. Recordings and photos acquired with sensors placed in drones are examples of these (Yurtseven et al., 2019).

Obtaining reliable and measurable information about objects and/or areas without direct contact is called remote sensing. The demands of humanity to comprehend the environment, the earth and the universe brought up space studies and the perception of the earth from space, and thus temporal changes began to be monitored by periodic sensing of the ground surface. At the core of this technology are sensing systems and satellites to carry these systems into space, that is, carrier platforms. Today, satellite images (recordings) entered into our daily lives with the data presented to humanity and scientific studies (Campbell & Wynne, 2012). With the help of satellite data, the unknowns of the earth and the universe (with sensor systems directed to other planets) are being analyzed. Consequently, if spatial data is desired to be obtained in any region of the globe, it should be known that such data is readily available. However, understanding the remote sensing technology as a whole increases the sensitivity of the evaluations to be made.

The use of satellite data in temporal controls will help to control the dangers that await our world. The role of hardware and software required for the evaluation of satellite data will be recalled under the heading Geographic Information System (GIS).

Therefore, spatial data is the source of data for us, regardless of the method or system it is collected with, and each is defined as geographic information. The evaluation of the collected geographical information and the deduction of the results from the evaluations are realized with Geographic Information Systems (Showalter & Lu, 2009; van Oosterom et al., 2005).

Geographic Information System (GIS) is a combination of hardware, software, people, geographical data, and processes, which performs the functions of collecting, storing, processing, managing, spatial analysis, querying and presenting large volumes of data to assist users in location-based decision-making processes to solve complex social, economic, environmental, etc. problems around the world. Perhaps the data is the most important component of a GIS. Geographical data and related tabular data can be collected internally or purchased from a provider of commercial data. Most GIS use a Database Management System to create and maintain a database to assist in the organization and management of data.

The data model is a mathematical construct in GIS which represents geographic objects or surfaces as data. A GIS data model makes it possible for a computer to represent real geographical elements as graphical elements. There are 2 data models: Vector Data Model and Raster Data Model. Vector data is the positioning of spatial objects consisting of points, lines, and areas in a coordinate system. Raster data are formed by the combination of neighboring unit areas defined as pixels, which is the smallest unit that sensor systems can detect (Kennedy et al., 2013; Nghiem, Q. H., 2015; Kang et al., 2016).

Spatial data obtained by using the above mentioned techniques can be used in vulnerability studies. The use of GIS software in the management and analysis of spatial data can be considered as a necessity. In this study, spatial data obtained by using combination of such techniques were evaluated by using GIS and (Analytic Hierarchy Process) AHP techniques and the vulnerability of forest areas from wildfires was evaluated over a study area.

Material and Methods

Study Area

In this study, Bucak Forest Management Directorate which is a part of Isparta Forest Regional Directorate is selected as study area. As shown in Figure 1, an area of 100400 hectares (approximately 1004 square kilometers) covered with coniferous forests, which is 80% sensitive to fire, was selected as the research area. In this context, stand types data prepared for forest management by using photogrammetric, remote sensing and terrestrial techniques in GIS environment were used in the study.

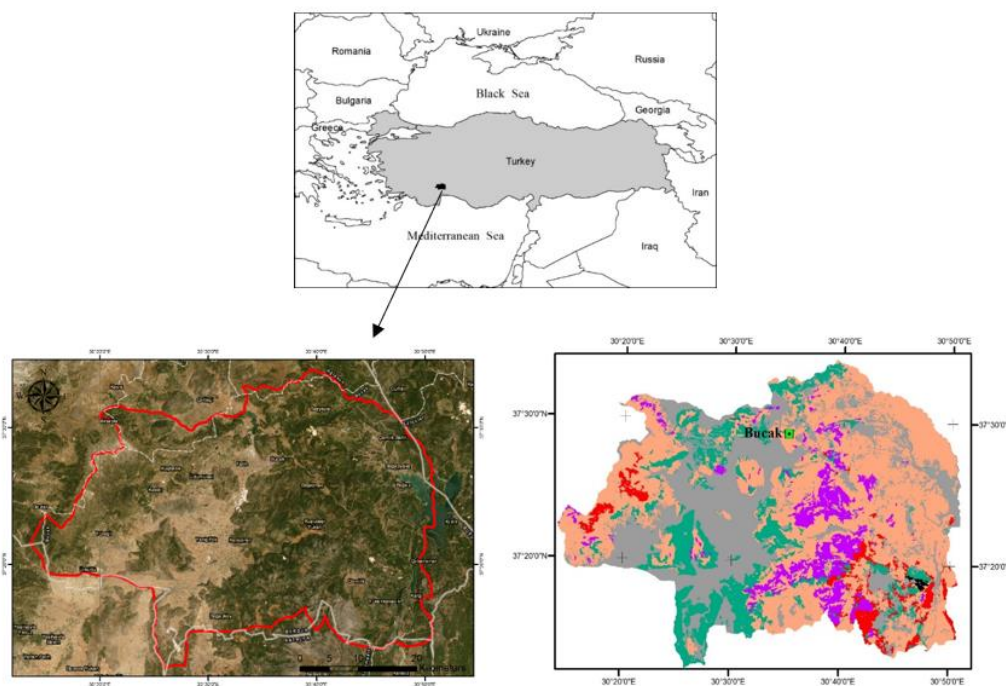


Figure 1. Research Area

GIS and AHP Analysis

As mentioned earlier components of GISs are listed as Hardware, Software, Data, Analysis, and Users. Hardware is the computer Geographic Information Systems operates in. In this context entire process and the analysis were conducted on a desktop computer with 2.6 Ghz processor, 16 GB of RAM and 64 bit Windows 10 Enterprise operating system.

GIS software provides the necessary functions and tools for processing, analyzing and displaying geographic data. Key software components of GISs are, Database Management System (DBMS), Tools (for the geographic information input and manipulation), and Graphical User Interface (GUI). There are several open source and commercial GIS software are presented to the users in the field of Geographic Information Systems. In this study, commercial ArcGIS (<https://www.arcgis.com/>) and open source QGIS (<https://www.qgis.org/>) software were used for data evaluations.

ArcGIS is a spatial data production, management, sharing and research tool for organizations. This software can be implemented on-location or in the cloud (e.g. Amazon, Azure, etc.) with ArcGIS Enterprise, or can be used as ArcGIS Online which is hosted and operated by Esri. Spatial analysis and spatial statistics it performs include one of the techniques that examine assets using topological, geometric or geographic features. ArcGIS v. 9.1 desktop (ArcReader, ArcView, ArcEditor, and ArcInfo), and extensions are used as GIS software in its structure.

Compared to other GIS software systems, QGIS allows similar users to create multi-layered maps using different map projections. Maps can be combined in different formats and for different uses. QGIS maps allow the creation of raster or vector layers. QGIS have many advantages such as flexibility, quality, security, performance, independence from a certain company, and compliance with open standards.

During the evaluations, firstly, data sources (e.g. remote sensing data [satellite data]) are evaluated with the ArcGIS software and appropriate hardware, and all details are classified. If there are specialized knowledge and symbols about spatial objects in the research area, they should be reached and descriptions should be international. Thus, the database of the research area is created in the GIS environment.

GIS software is generally commercial, and when it is cannot be obtained for economic reasons, the ease and free use of QGIS Open Source Software attracts researchers' attention. In order to perform QGIS-based AHP vulnerability analysis, a plug-in named Easy AHP is used in this study. The analysis is then performed by integrating it with the Weighted Linear Coupling. Further information can be found at <https://github.com/MSBilgin/EasyAHP> on how to perform this analysis.

Results and Discussion

Determination of Input Layers (Parameters)

Because GIS-based AHP analysis is based on determining the weight significance values of different layers, layer weights should be determined for AHP in the research area. This way, decision-makers define a hierarchy in the solution of complex problems and select the result that provides the suitability value.

Our research area includes forest areas, agricultural areas, settlements, and facilities that are sensitive to fire hazards. The parameters (input layers) that will be affected in case of an occurring fire hazard are as follows:

K1-Forest Areas, K2-Agricultural Areas, K3-Settlements, K4-Facilities

The comparison matrix of parameters (input layers) was created as shown in Table 1, in accordance with the recommendations of forest fire experts (Saaty, 1990).

Table 1. Comparison matrix of input layers (parameters)

	K1	K2	K3	K4
K1	1	5	8	8
K2	0.2	1	4	3
K3	0.125	0.25	1	2
K4	0.125	0.25	0.5	1
	1.45000	6.50000	13.50000	14.00000

According to this matrix, the importance weights of the criteria were calculated as shown in Table 2 and the consistency ratio (CR) was found to be less than 0.1.

Table 2. Calculation of importance weights of input layers (parameters)

K1	K2	K3	K4	Total	W	v	v/w
0.689655	0.769231	0.5925926	0.571429	2.6229071	0.655727	2.808143	4.28249
0.137931	0.153846	0.2962963	0.214286	0.8023592	0.20059	0.848185	4.228457
0.086207	0.038462	0.0740741	0.142857	0.3415997	0.0854	0.33408	3.91195
0.086207	0.038462	0.037037	0.071429	0.233134	0.058284	0.233097	3.99936
					1		16.42226
							4.105564
Random Index (n= 4)					0.9		
Consistency Index	CI	0.035188					
Consistency Ratio	CR	0.039098			<0.1		

After determining the importance weights of the input layers (parameters), the forest cover which has the highest significance weight (0,66) was represented by two sub-criteria (Vegetation type, Stand development stages) instead of the single weight value for all forest areas in line with the recommendation of forest fire experts, and again, they were evaluated with local weights (0.44 + 0.22) determined according to the evaluations of the experts (Table 3).

Table 3. Importance weights of input layers (parameters)

Criteria	Weight	Sub-Criteria	Local
Forest	0.66	Vegetation type	0.44
		Stand development stages	0.22
Agricultural Areas	0.20		0.20
Facilities	0.08		0.08
Settlements	0.06		0.06
	1.00		1.00

The stand data (Table 4 and Table 5) indicated by special symbols and definitions in the database created following the GIS basic principles for forest cover in the research area, for example, the meaning of the symbols used for stand development stages in Table 4, are defined as given in Table 6. The Values column shows the class values.

Table 4. Stand development stages

Stand development stages	Value
a, ab	10
b, bc	7
c, cd	5
d	3
e	1
Forest land (O, BP (black pine), S (spruce), etc.)	3
Other land (Bld., G, L, F, GP, etc.)	0

Table 5. Vegetation type classes

Vegetation type classes	Value
Pure / disordered coniferous	10
Pure / disordered – mixed coniferous	7
Pure / disordered – mixed coniferous – deciduous	5
Pure / disordered deciduous	3
Pure / disordered – mixed deciduous	3
Other lands (Bld., G, L, F, GP, etc.)	0

Table 6. 1.30 m diameters in terms of stand development stages

Diameter of Breast Height (d 1.30)	Stand Development	Stand Development Stage
0–7,9 cm	Youth	a
8–19,9 cm	Pole and Mast	b
20–35,9 cm	Thin Wood	c
36–51,9 cm	Middle Woodland	d
52 cm and over	Thick Wood	e

Proximity classes of agricultural areas to forest areas (m), Proximity classes of settlement areas to forest areas (m) and Proximity classes of facilities to forest areas (m) are given Table 7, Table 8 and Table 9.

Evaluation of Criterion Weights with Research Area Database

The criterion weights were recorded in the database of the forest units (stand) in the research area and using the ArcGIS Spatial Analyst module, the weight coefficients for each class were calculated by considering the class values determined for each type of vegetation and development age type, and the result values for the forest cover were obtained. Similar calculations were performed for the agricultural area, settlements, and facility areas, and a vulnerability map was obtained for the whole area (Figure 2).

Table 7. Proximity classes of agricultural areas to forest areas (m)

Proximity of Agricultural Areas to Forest Areas (m)	Value
0-100	10
100-200	7
200-300	5
300-400	3
400-500	1

Table 8. Proximity classes of settlement areas to forest areas (m)

Proximity Classes of Settlement Areas to Forest Areas (m)	Value
0-100	10
100-200	7
200-300	5
300-400	3
400-500	1

Table 9. Proximity classes of facilities to forest areas (m)

Proximity Classes of Facilities to Forest Areas (m)	Value
0-100	10
100-200	7
200-300	5
300-400	3
400-500	1

Conclusion

The research shows that in the face of any hazard, multidimensional and multi-staged studies should be conducted based on scientific approaches. Based on the fact that hazard and risk pair will always be together, it should be remembered that risk management before the hazard occurs and that risk analysis after the hazard occurs will be complementary. The studies that will be carried out before the damage occurs will allow researchers to determine the status of the available resources, risk factors, the measures that can be taken, and the duties of the society. The damage and losses that may occur in spite of all these measures can be calculated with the data obtained as a result of these previous studies, the things to be done to recover the losses can be determined, and the preventative measures can be renewed in order not to face similar situations again.

To be able to calculate the extent of damage and loss caused by every hazard, there is a need for very healthy, measurable, and computational spatial information about the hazard area (environment). Although open source GIS software has existed for a long time and is getting increasingly popular and progressing towards becoming mainstream, there may still be some concern about the quality of open-source software. Likewise, in the collection of the above-mentioned and indispensable data, it is likely that there are some hesitations in the minds of researchers about data quality.

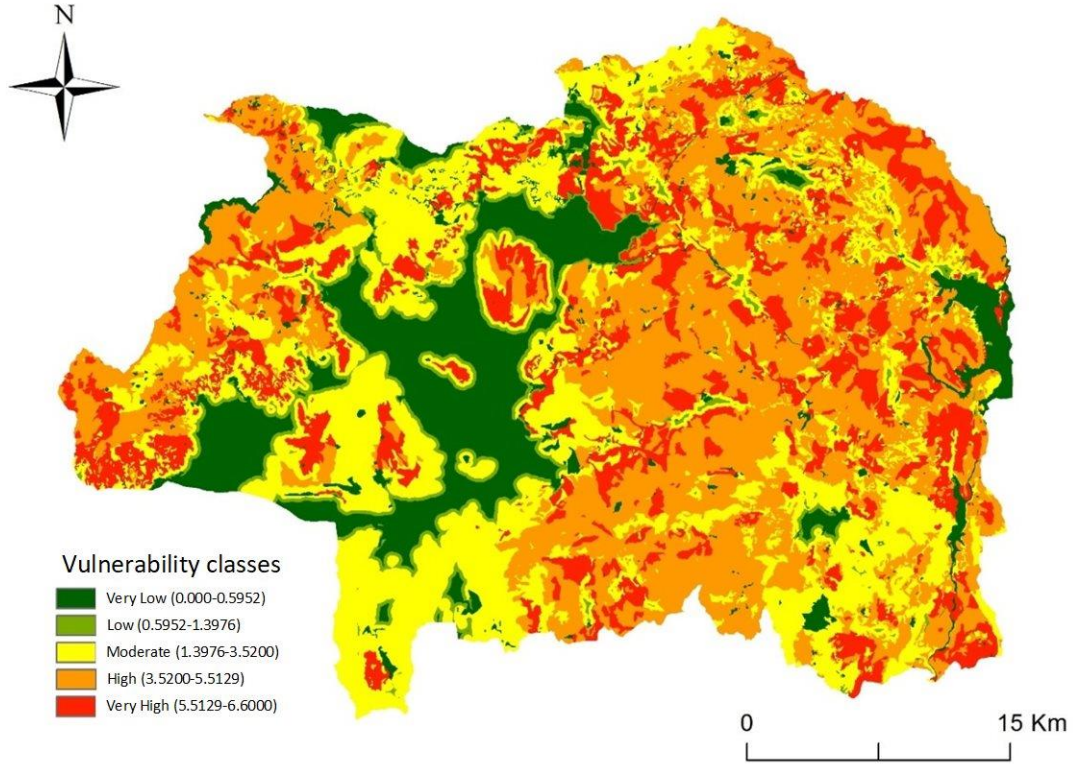


Figure 2. Vulnerability map of the research area.

The aim by demonstrating that QGIS, which is an open-source GIS software, can be used instead of commercial GIS to do the analysis of damage levels of spatial assets for the forest areas, agricultural areas, settlements, and facilities (which are intertwined in Turkey) with a GIS-based AHP analysis approach in the nature part selected as the model, is to pave the way for interested researchers.

The results of the vulnerability analysis invite people to take individual measures and to request measures to be taken by the administrations, taking into consideration the vulnerabilities before the hazard occurs, and invite the management to support the evaluation and research projects to be carried out in the hazard areas, and to produce public solutions according to the results. Thus, it will be possible to take the necessary precautions before the damages that may occur naturally. Researchers should do their part in this matter and publish their findings in publicly accessible environments. While doing this research, healthy data can be obtained not only with commercial software but also with open-source software. This way, researchers can use open-source software for determining risk indices, instead of waiting for resources to obtain commercial software.

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