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Landslide Risk Assessment Based on GIS Multi-Criteria Evaluation: A Case Study in Bostan-Abad County, Iran

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Abstract: Although typically small in terms of their spatial footprint, landslide hazards are relatively frequent in Northern Iran. In this study, we combine Geographic Information System (GIS), remote sensing and derive a landscape susceptibility map for Bostan Abad County, Iran. The main objective is an inventory evaluation and zonation of natural landslides. This 2685 square kilometer sized county is one of the most important settlement areas in the East Azerbaijan province (North-Western Iran) also containing industrial regions next to the originally predominant agricultural land use. The basic landslides affecting factors are established in form of GIS dataset layers including topography, geology, climatology and land use which is derived from remote sensing imagery. After necessary pre-processing the original data sets a topology is created and active fault lines are buffered and overlaid. Vector layers are transformed into raster format and standardized based on a fuzzy logic model. An Analytical Hierarchical Process (AHP) is applied in order to derive the weights associated with suitability (attribute) map layers. And based on these weights, GIS datasets are combined by weighted overly techniques and the landslide susceptibility map of the study area created. The resulting information is useful for (a) a better understanding of existing landslides and their origins; (b) supporting emergency decisions and (c) prioritization of efforts for the reduction and mitigation of future landslide hazards.

Key words: Landslide, zoning, spatial analysis, GIS, AHP, susceptibility map, Bostan Abad, Iran.

1. Introduction

Disasters are natural hazard events in which a natural phenomenon or a combination of natural phenomena such as earthquakes, mass movements, floods, volcanic eruptions, tsunamis etc., can cause many loss of lives and damage to the property. Almost no part of the earth's surface is free from the impact of natural hazards. Though, it may not be feasible to control nature and to stop the progress of natural phenomena but the efforts could be made to avoid disasters and alleviate their effects on human lives, infrastructure and property. It is almost impossible to prevent the occurrence of natural disasters and their damages. However, it is possible to reduce the impact of disasters by adopting suitable disaster mitigation strategies. Among natural disasters landslides are recognized as the third type of natural disaster in terms of world importance [1]. Due to natural conditions or man-made actions, landslides have produced multiple human and economic losses [2, 3]. Individual slope failures are generally not so spectacular or as costly as earthquakes, major floods, hurricane or some other may cause more damage to properties than any other geological hazards [4]. Most damages and a considerable proportion of the human losses associated with earthquakes and meteorological events are caused by landslides, although these damages are attributed to major events which lead to a substantial underestimation in the available statistical data on landslide impact [5]. The term "landslide" describes a wide variety of processes that result in the downward and outward movement of slope-forming materials including rock, soil, artificial hill, or a

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combination of these. The materials may move by falling, toppling, sliding, spreading, or flowing [4]. Landslide can be produced by tectonic factors such as earthquake or fault, but to do so, there should be a common climate factor such as precipitation on unstable slopes. Climate factors play an important role in making landslide. They can increase or decrease landslides on unstable slopes [6]. The main objective of this research is to evaluate natural landslide hazards in Bostan Abad County of Iran. This county with 28,500 hectares area is located in the northwest part of Iran and includes two cities and 188 villages with altogether 96,555 inhabitants [7]. It stretches from about 1,559 to 3,680 meter above sea level. It is an important area of human habitation, industrial regions and agricultural activities within the East Azerbaijan province. The geophysical location of this region makes it potentially face with some naturally hazardous phenomenon such as landslide, earthquake and volcano activities.

Enormous progress has been made in the development of landslide inventories, landscape susceptibility mapping and hazard zoning, whereby much of this progress is based on the extensive use of GIS, GPS and remote sensing techniques [8, 9]. While for many years aerial photography was dominantly used satellite remote sensing is more and more regarded as a cost-effective tool for the monitoring of landslides [10]. Our research is based on GIS techniques that are increasingly viewed as a key tool for managing spatial and temporal data for natural hazards [11-17]. GIS technology provides effective tools for the handling, integrating and visualizing diverse spatial data sets [3-17]. Especially GIS Multi Criteria Decision Making (MCDM) is one of important methods of spatial analysis in GIS that allows knowledge derived from different sources to be combined in order to support landslide analysis. One multi-attribute technique that has been incorporated into the GIS-based landslide analysis procedures is the Analytical Hierarchy Process that presented by Saaty [18]. In this study, AHP is employed to derive the weights to weighted overly layers. The weights are then combined with the attribute map layers in a manner similar to that used in the linear additive combination methods [19]. In this study, the GIS-MCDA was applied to develop landslide risk map for the Bostan-Abad County which is located in northern west of Iran. To achieve this objective, eight landslide causal factors were taken into consideration. These parameters were extracted and calculated from their associated database. These factors were evaluated, and then factor weight and class weight were assigned to each of the associated factors.

2. Methods and Data

Landslide susceptibility is predominantly a function of slope and combinations of slope, concavity/convexity and aspect. Next to these topography factors, geology, geotechnical properties, climate, vegetation and anthropogenic factors such as development and clearing of vegetation [20] are other important factors. In this study landslide susceptibility was evaluated by applying different analytical GIS techniques including, overlaying, buffering, and network analyzing based on multi criteria analysis and Analytical Hierarchical Process (AHP). For this to happen, the following factors affecting landslides were established, for hazards assessment:

- Lithology map derived from geological maps 1:100,000;
- Fault distance map from both geology map and SPOT 5 satellite images;
- Transportation network extracted from topography maps 1:25,000 and updated with the help of satellite images;
- Hydrological networks map extracted from topography maps 1:25,000;
- Digital topographic maps 1:25,000 and hypsometric map as well as a Digital Elevation Model (DEM) with slope, aspect and other slope derivates;
- Land use and land cover maps derived from

SPOT 5 satellite images;

• Meteorological data including rainfall for a 30 year period and precipitation maps created from the rainfall data.

These data were pre-processed and added to a Geo-database. The spatial data layers listed above were prepared. In the next step, active fault lines were buffered and vector layers were transformed into raster format through overlay techniques while being standardized based on fuzzy logic models. Then, a Analytical Hierarchical Process was applied to extract standardized weights for the different layers. Finally, the landslide susceptibility maps of the study area were created by weighted overlaying techniques as described in the next sub-section.

2.1 Selection of Evaluation Criteria and Standardization

The set of criteria selected should adequately represent the decision-making environment and contribute towards the final goal [21]. The evaluation criteria listed in Table 1 were selected in order to consider to address the objective of mapping landslide susceptibility. Various pre-processing steps were carried out for the spatial data layers listed in Table 1 and a topological geo-spatial database constructed. Vector layers were converted into raster format with 20 m resolution and the spatial datasets were processed in Arc GIS. Slope and aspect were generated from a 20 m resolution DEM which was derived from the 1:25,000 topographical maps. Our methodology is based on a pairwise comparison technique based on AHP.

2.2 Land Use and Land Cover Classification

Satellite imagery has been effectively utilized in classification process, especially, in generating land use/cover (LULC) maps and detecting land cover conditions. In this study, we produced a LULC classification of the study area as input to the landslide analysis. For this purpose we used two scenes of SPOT 5 images of 15 May 2010 for a supervised classification. After Geo-referencing and atmospheric correction, the images were classified using a maximum likelihood classification (MLC) algorithm in a per-pixel classification approach. Five land use/cover types were identified, including (1) settlement area, (2) agricultural area, (3) pasture lands, (4) water bodies and (5) rock and bare soils. To evaluate the accuracy of the classified image, the "Accuracy Assessment" tool in Envi was used based on random sampling method whereby 120 points were selected from high resolution aerial photos and Google Earth maps. The overall accuracy and the Kappa Coefficient were calculated and result in an overall accuracy of 90.2% and a Kappa Index of 0.88. In a consecutive stage the classification was exported to the GIS as one dataset layer for the landslide analysis.

Table 1 Evaluation criteria.

General criteria	Criteria/factors
Topography	Slope aspect
Human factors	Landuse roads
Geology	Lithology faults
Climate	Rivers precipitation

2.3 Assessing the Weights and Overlaying Map Layers

Deriving weights for the selected map criteria is a fundamental requirement for applying the AHP method [17]. Determination of the particular criterion weight is therefore a crucial step in MCDM. The AHP is considered to be an adequate mathematical method for this step when analyzing complex decision problems [22]. GIS-based AHP has gained popularity because of its capacity to integrate a large quantity of heterogeneous data, and because obtaining the required weights can be relatively straightforward, even for a large number of criteria. It has been applied to a variety of decision making problems [22]. In this research we used standard weights obtained from the AHP. One of the strengths of AHP is that it allows for inconsistent relationships while, at the same time, providing a consistency ratio (CR) as an indicator of the degree of consistency or inconsistency [23]. The AHP implementation in this study therefore incorporated an option to let the user define an acceptable CR threshold value. If the CR is greater than 0.10, it is important to be careful to accept the resulting weights without changing the inputs to the pairwise comparison matrix, and also to feel confident that the matrix really reflects the user's beliefs and does not contain any errors [23, 24]. The resulting pairwise comparison matrix for landslide analysis in Boston Abad County is shown in Table 2. The resulting CR for the pairwise comparison matrix was equal 0.064. In the next step, the map layers used in the landslide analysis were weighted using the weights derived from through the AHP process and the final result is shown in Fig. 1.

3. Results

In this study, the analytical hierarchy process (AHP) was applied to develop landslide susceptibility map for the Bostan Abad County. To achieve this objective, eight landslide inducing factors were calculated, namely aspect, slope, distance from streams, lithology, distance from roads, distance to fault, precipitation and land use/land cover (LULC). These factors were evaluated, and then factor weight and class weight were assigned to each of the associated factors. The obtained susceptibility map indicates that the high

Table 2 Pairwise comparison matrix.

Factors	1	2	3	4	5	6	7	8	Eigen values
(1) Distance to stream	1								0.045
(2) Distance to road	1	1							0.036
(3) Aspect	1/3	1/3	1						0.020
(4) Slope	6	5	7	1					0.122
(5) Lithology	8	7	9	4	1				0.300
(6) Distance to fault	1/2	3	5	1/3	1/4	1			0.063
(7) Precipitation	7	6	8	3	1/2	4	4		0.207
(8) Land use	7	6	8	3	1/2	4	4	1	0.207
Consistency ratio: 0.064									

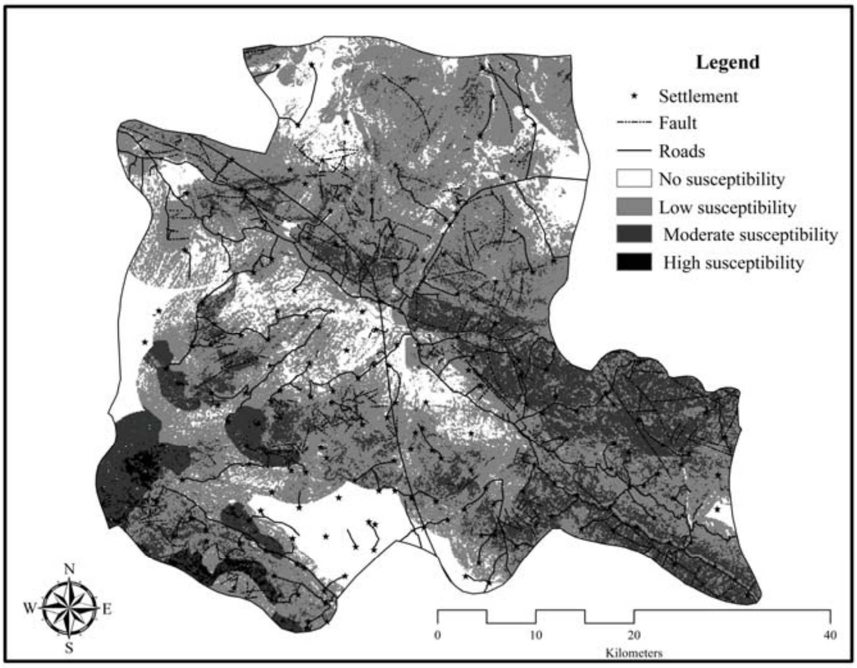

Fig. 1 Landslide susceptibility map of Bostan Abad County.

susceptible zones cover about 20.4% (53,703.9 hectare) of the total area while about 67.20% (180,447.16 hectare) were classified as being the moderately susceptible and 12.39% of the case study area (33,272 hectare) are classified as low susceptible. The map was verified using existing landslide location data for the area, particularly agriculture activities and critical human settlements such as Bostan Abad city. It turned out that highly susceptible zones cover most of the known landslides that occurred in the unstable slopes over the last several years and which were predominantly induced by high precipitation. It is known that the role of precipitation as triggering mechanisms of landslides is strongly influenced by the landscape dynamic and geology. In Bostan Abad County landscapes are common, and rainfall and snowmelt (especially snow melting of the Sahand glacier) often bear the potential for initiating slope Instabilstes. Susceptible stratigraphy and weathering too, contribute much for the occurrence of landslides in this area. With conditions conducive to the development of slope instability being in place in several areas, there was a demand to conduct landslide susceptibility mapping. Results of this research could be useful for explaining the known existing landslide, making emergency decisions and supporting the efforts of reduction and mitigation of future landslide hazards.

4. Conclusions

Landslides are natural phenomena which often have detrimental consequences. Landslide hazards can be systematically assessed by using different factors and methods. Movements and landslide predisposing factors will be similar to those verified in the past, we are able to predict that future slides occurring in a non-specified time span. The hazard and risk maps have usually incorporated the estimated frequency of landsliding in a qualitative sense rather than quantitatively. Landslide hazard zoning has already been used to manage landslide hazard risk in urban areas by excluding development in highly susceptible areas, whereas geotechnical engineering assessment of slope stability necessitates more detailed on-site exploration, before development is approved in other areas. GIS-MCDA can be thought of as a process that combines and transforms geographical data regarding accessibility to facilities and value judgments of decision maker(s) to analysis and model of geographical phenomena such as landslide susceptibility mapping [25, 26]. Fine-scale GIS-based susceptibility maps derived in this study can bridge the gap between overview plans and regional zoning on the one side and the cost-intensive on-site investigations for engineering tasks on the other side.

The results of the entire analyses and evaluation allowed us to divide the study area into four zones of hazard susceptibility, which is that believed to be useful for identifying slope sectors liable to landsliding on relative basis. Prepared landslide prediction map could be the basis for decisions making. The information provided by this map could help citizens, planners and engineers to reduce losses caused by existing and future landslides by means of prevention, mitigation and avoidance. More over result is useful to planners and engineers in identifying and delineating favorable locations for siting development schemes, such as building and road constructions.

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