The feasibility of landslide Susceptibility Map with Using GIS at Golmakan Watershed

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Abstract

Landslide hazard is one of the major environmental hazards in geomorphic studies at mountainous areas. In order to help the planners in the selection of suitable locations to implement development projects, a landslide susceptibility map has been produced for the Golmakan-watershed as part of Binaloud northern hillsides (Northeast of Iran) using the Weighted Linear Combination (WLC) equation. For this purpose, after preparation of a landslide inventory of the study area some 15 major parameters were examined for integrated analyze of landslide hazard in the region. The analyses of parameters were done by Geo-reference and lateral model making and spatial analyses by using geographical information system (GIS). The produced factor maps weighted with analytic hierarchy process (AHP) method and then classified. The final produced map for susceptibility of landslide hazard in Golmakan-watershed revealed that: 1) the parameters of land slope and geologic formation have strong correlation (R^2=0.79) and (R^2=0.83) with dependent variable of landslide susceptibility respectively, ($p<0.05$). 2) About 18.8% of the study area has a minor and negligible susceptibility to future landslides, while 81.2% of the land area of Golmakan-watershed falls into the severe and moderate categories.

Key words: *Landslide Susceptibility Map, GIS, Analytic Hierarchy Process (AHP), Weighted Linear Combination (WLC), Golmakan-watershed*

Introduction

GIS analysis provides a powerful tool to model the landslide hazards for their spatial analysis and prediction. This is because the collection, manipulation and analysis of the environmental data on landslide hazard can be accomplished much more efficiently and cost effectively. Many GIS-based analysis models and quantitative prediction models of landslide hazard have been proposed since the beginning of GIS application in geo-hazards research in the late 1980s;and. The most essential step in this study is to establish spatial databases for landslides in ArcGIS, including landslides inventory data and the effecting factors and. The spatial database preparation is the first fundamental and essential step for landslide susceptibility analysis which mainly comprises of two parts: landslide inventory and landslide affecting factors. One of the most important parameters that should be taken into account is the risk of

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natural hazards. The selection of weighing factors is made by evaluating the related data selected from qualitative or quantitative parameters such as elevation, slope, aspect, drainage coefficient streams, lithology, faults, soil units, land use and land cover, isohypse, isotherm, springs, potential of flood, potential of erosion and anthropogenic factors; and Analytic Hierarchy Process (AHP), a theory for dealing with complex, technological, economical, and socio-political problems and is an appropriate method for deriving the weight assigned to each factor. Basically, AHP is a multi-objective, multi-criteria decision-making approach to arrive at a scale of preference among a set of alternatives. AHP gained wide application in site selection, suitability analysis, regional planning, and landslide susceptibility analysis. The result maps can help to explain the known landslides, making emergency decisions, avoiding and mitigating of future landslide hazards. The aim of the present study was to produce a landslide susceptibility map of a landslide-prone area of 50 km^2 in the Golmakan-watershed, Khorasan-e-Razavi Province, Northeast of Iran, based on analytic hierarchy process (AHP) method. For this purpose, the study includes three main stages: (1) the assessment of event-controlling parameters at the study area (2) application of analytic hierarchy process (AHP) method to determine weights of the parameters affecting landslide hazard; (3) use of geographical information system (GIS) to represent factor maps and produce susceptibility map by Weighted Linear Combination (WLC) equation.

Material and methods

General characteristics of the study area

The Golmakan watershed is located about 30 Km westward Mashhad, Khorasan-e-Razavi province, Iran. The study site lies between latitude 36° 18' N to 36° 28' N and longitude 59° 1' E to 59° 08' E covers an area of about 50 Km^2 from the northern sector of the Binaloud Mountains. The study area (Fig.1) is covered mainly by Phylite and shale formations (>90%), aged to Jurassic period. The topographical elevation values of the study area vary between 1460 m a.s.l at the northward and 3180 m a.s.l at the southward, while the dominant topographical elevation range over 2000 m a.s.l. The study area has a semi-arid climate with mean annual precipitation of 300 mm and mean annual temperature of 11°C. The largest settlement in the close vicinity of the area is Golmakan city with population of 6413 people, located at the south border of the study area. The main land use practice in the study area is grazing land which mostly developed around the streams. More than 65% of the basin is dominated by slopes over 15°, while mild slopes of <15° occupy small portion of the area. One of the most important characteristics of the basin is Cheshmeh-Sabz lake with 38.4 ha area, which is at the origin of the main river at the study area. The dominant slopes of the basin (>75%) are back to sun radiation with high potential of moisture.

Event-controlling parameters

Topography (elevation, slope, aspect), geology (lithology units and faults), land factors (land use and -cover, soil units), climatology (isohypse and isotherm), water condition (springs and streams, potential of flood, potential of erosion and drainage coefficient) and anthropogenic factors were taken into consideration as conditioning parameters for the landslides at the study area (Fig.2). These parameters are commonly referred to as event-controlling parameters. The accuracy of geographical information system (GIS) based susceptibility mapping is believed to increase with the availability of data about such event-controlling parameters.

Results and analysis

At the present study we used the AHP method because of its precision, ease of use, and because of its ready availability as a built-in tool within ArcGIS software. AHP considers only a one-level weighting system developed by collecting expert opinions, in this case our experience obtained during the field work in autumn 2009. The method employs an underlying 9-point recording scale to rate the relative preference on a one-to-one basis of each criteria. For better map presentation purposes the scale assigns a linguistic expression to each corresponding numerical value. The numerical values are quantified translations useful for calculating factor weights and the validity of the numerical values may best be judged by the factor weights and the consistency of the calculation process [22]. The results of the pair-wise comparison matrix and the factor weights are shown in Table 1. In analytic hierarchy process (AHP) method, an index of consistency, known as the Consistency Ratio (CR), which is a ratio between the matrix's consistency index and random index. CR ranges from 0 to 1. A CR of the order of 0.10 or less is a reasonable level of consistency [17]. In this case the CR of the matrix of paired comparisons between the fifteen influential factors in our landslide susceptibility assessment is 0.04, and is thus acceptable. The weights should add up to a sum of 1.0, as the linear weighted combination calculation requires. The aim of these analyses is to determine that the property of each pixel is the same in every level, its mathematical value, and its effect on producing landslide susceptibility map.

Discussion

At the present study, GIS software was used to produce the layer maps that assist in the production of 1:25000 based landslide susceptibility map. The created final susceptibility map was exported into ArcGIS (Fig.3). The landslide susceptibility map is the result of the analysis carried out in the raster data model using the weight values of the obtained layers. The layers in the vector data structure are converted to the raster data model and the dimension of the pixel is determined to be 10 m in consideration of the aim and the scale of the database of the study. The pixel values obtained were classified into four groups having, negligible, minor, moderate and severe susceptibility to determine the class intervals in the landslide susceptibility map. According to the result of the analysis, the susceptibility of the study area by verbal expressions and colors is as follows; 2.43% is negligible (green), 16.38% is minor (yellow), 60.69% is moderate (orange), 20.50% is severe (red). About 81.2% of the land area of Golmakan-watershed falls into the severe and moderate categories (Table 2). The severe susceptibility to future failures occurs in regions that are underlain by the middle to south of the study area. According to our map, future landslides are also predicted for all areas that are in some proximity to slopes over 15° and micro-faults. Moderate landslide susceptibility is identified for areas comprising the Phylite formation covered most of the hillsides. An increased threat also exists in close proximity to rivers and roads. The area towards the northeast of the study area in close proximity to Golmakan city comprises the quaternary alluvial terraces has a minor to negligible landslide susceptibility. In general, safer areas are to be found in northern parts of the watershed where the topography of the region becomes flat. Analyzing by Pearson test ($p<0.05$) also revealed that slope and geologic formations (Mashhad Phylite) have the most strong correlations with the dependant variable landslide susceptibility ($R^2=0.79$) and ($R^2=0.83$) at each land unit of the Golmakan-watershed.

Conclusion

At the present study we utilized the method of analytic hierarchy process (AHP) and GIS analysis to produce a landslide susceptibility map for the Golmakan-watershed at northeast of Iran. The data layers used in the production of landslide susceptibility map were selected very carefully by analyzing the parameters affect the formation of landslides in the region. Our results revealed that landslide events in the Golmakan watershed are strongly correlated to land slope and Geologic formation of the study area. The regions most susceptible to landslide hazard are located in the middle and south parts of the watershed.

Acknowledgement

We thank Islamic Azad University-Mashhad branch for their support of the project.

Table 1: Pair-wise comparison matrix for calculating factor weights

Parameters	Elevation	Slope	Aspect	Drainage Coefficient	Streams	Lithology	Faults	Soil Units	Land use & land cover	Isohypse	Isotherm	Springs	Potential of flood	Potential of Erosion	Anthropogenic Factors	Factor weights
Elevation	1,00															0.0228
Slope	7,00	1,00														0.1845
Aspect	4,00	0,20	1,00													0.0574
Drainage Coefficient	0,50	0,11	0,25	1,00												0.0124
Streams	1,00	0,14	0,20	3,00	1,00											0.0264
Lithology	8,00	1,00	5,00	9,00	7,00	1,00										0.1681
Faults	6,00	1,00	5,00	7,00	5,00	1,00	1,00									0.1496
Soil Units	3,00	0,25	5,00	4,00	2,00	0,25	0,25	1,00								0.0575
Land use & land cover	5,00	0,33	1,00	6,00	3,00	0,50	0,50	1,00	1,00							0.0931
Isohypse	1,00	0,20	0,50	4,00	0,33	0,17	0,20	0,50	0,33	1,00						0.0321
Isotherm	0,25	0,14	0,50	2,00	0,17	0,17	0,14	0,25	0,13	0,50	1,00					0.0144
Springs	0,50	0,13	0,33	1,00	1,00	0,14	0,17	0,20	0,17	0,50	2,00	1,00				0.0172
Potential of flood	3,00	0,20	0,50	6,00	3,00	0,33	0,50	2,00	0,33	1,00	3,00	3,00	1,00			0.0596
Potential of Erosion	3,00	0,20	0,33	5,00	5,00	0,25	0,33	0,50	0,25	0,33	3,00	3,00	0,33	1,00		0.0361
Anthropogenic Factors	5,00	0,25	0,50	7,00	3,00	0,33	0,33	4,00	0,50	3,00	3,00	7,00	0,50	3,00	1,00	0.0688

Table 2: Susceptibility to landsliding for the study area

Factors Overlay Grading	Cumulative Landslide Occurrence (%)	Susceptibility class	Area (ha)	Area (%)
1.19-3.74	33	Negligible	122.4	2.43
3.74-5.02	50	Minor	823.9	16.38
5.02-6.29	66	Moderate	3052.3	60.69
6.29-8.84	100	Severe	1030.5	20.50

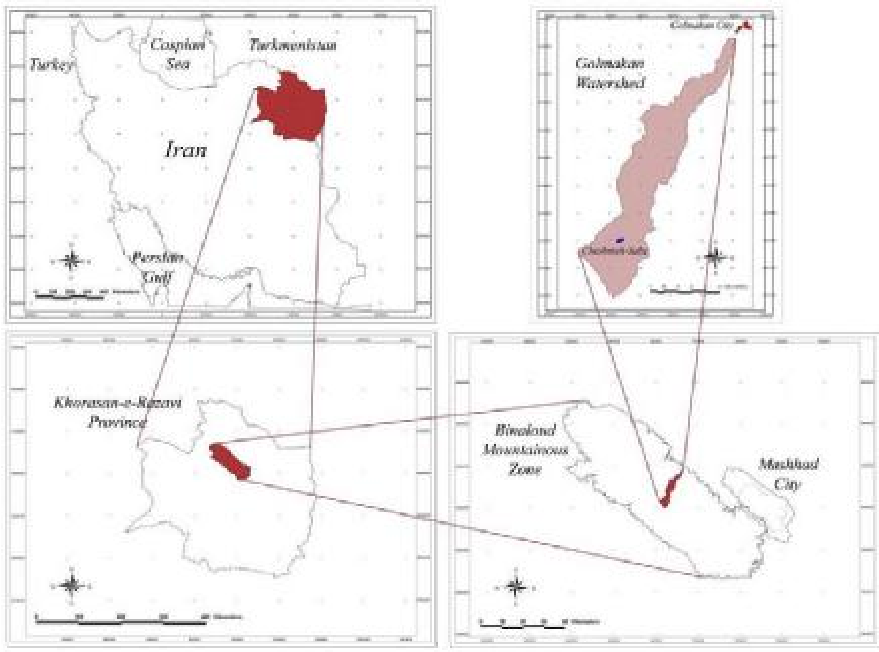

Figure 1: Location and geographical position of the study area

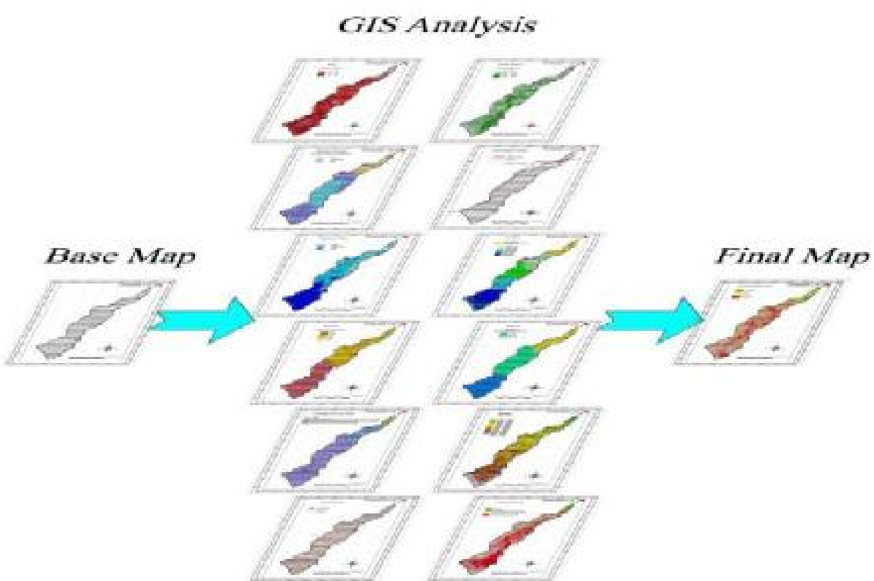

Figure 2: Parameters analysis with GIS at the study area

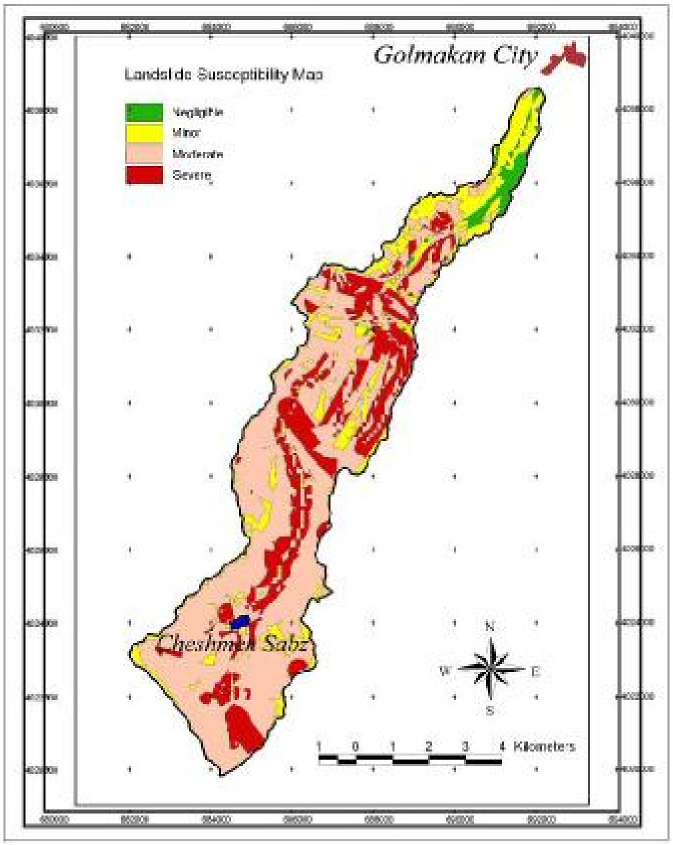

Figure 3: Landslide susceptibility map of the study area

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