Preparedness Against Landslide Disasters with Mapping of Landslide Potential by GIS- SMCE (Yazd-Iran)

Jamali, A. A.,[1] and Abdolkhani, A.,[2]
[1]Watershed MGT Dept., Islamic Azad University-Maybod Branch, Yazd, Iran, E-mail: jamhek@yahoo.com
[2]Islamic Azad University-Maybod Branch, E-mail: aliabdolkhani@yahoo.com

Abstract
Various controlling factors such as geology, slope angle, slope aspect, landuse, stream proximity etc are generally considered. Spatial multi-criteria evaluation (SMCE) tool in GIS software were used which takes into account such a complex relationship among parameters. The study is based on a terrain mapping units map, generated at 1:25,000 scale by interpretation of thematic maps, satellite images and field data. Five area factors, three linear factors and six constraint factors were entered to model. In this research, a criteria tree model for landslide susceptibility is proposed, priority weights and fuzzy standardization for each parameter controlling the landslide were determined, and a composite index map that was classified to four class as a hazard map was prepared of an area in a fragile mountainous terrain in the centre part of Iran. Watershed area was 5685 ha that 69.5% from that had no risk, 8.3% of area had moderate risk and 1.9% of area had high risk. The presented susceptibility maps was intended to help in the design of hazard and fear mitigation and land development policies at watershed scales.

1. Introduction

1.1 Motivation and Aims

Landslides are among the most widespread geological hazards on earth and threaten lives and property globally, specially in mountain roads in Iran. Despite advances in science and technology, these events continue to result in human suffering, property loss and environmental degradation. As regional populations, urban expansion and storm intensities increase due to changing development and climate patterns, the economic and society costs of landslides will continue to rise, increasing the demand for improved protection against landslides. Landslide susceptibility mapping is a valuable tool for assessing current and potential risks that can be used for developing early warning systems, mitigation plans and land use restrictions. Aim was landslide potential mapping for preparedness against landslide disasters by using GIS and spatial multi-criteria evaluation (SMCE) tools in Manshad watershed in Iran.

1.2 Overview and References

As in most developing countries, landslide inventory maps are still scarce in Iran, due to the limited resources available for research. Most conventional landslide studies in Iran are descriptive, and a few focus on hazard assessment. Moreover, most of the quantitative risk assessment methods that have been developed elsewhere are case-specific and require many types of data, on landslide occurrence and impact, most of which are not yet available in Iran. In the last decade or so, the combination of Geographical Information Systems (GIS) and multicriteria evaluation (MCE) has been routinely adopted as an approach to assess the suitability of an area to a spatial aim, and consequently to select optimal locations for some ideas (Buenrostro Delgado et al., 2008). MCE in a GIS environment (or spatial multicriteria evaluation, SMCE) is a procedure to identify and compare solutions to a spatial problem, based on the combination of multiple factors that can be, at least partially, represented by maps (Malczewski, 2006). SMCE is commonly applied to land suitability analysis (see reviews in Malczewski (2004) and Collins et al., (2001)). There are four different approaches to the assessment of landslide hazard: landslide inventory-based probabilistic, heuristic, statistical (bivariate or multivariate statistics) and deterministic (Soeters and Van Westen, 1996, Aleotti and Chowdhury, 1999, and Guzzetti et al., 1999). Landslide risk assessment methods are classified into three groups, as qualitative (probability and losses in qualitative terms), semi-quantitative (indicative probability, qualitative terms) and quantitative (probability and losses both numerical) (Lee and Jones, 2004). The heuristic approach is considered to be useful for obtaining qualitative landslide hazard maps for large areas in a relatively short time. It does not require the collection of geotechnical data. The heuristic approach may result in more reliable susceptibility maps than using statistical methods, where a considerable amount of generalization always needs to be accepted in the analysis. Qualitative risk assessment procedures in many countries are heuristic, e.g. in Switzerland (Lateltin, 1997). The qualitative approach is based on expert opinion. The increasing popularity of geographic information systems (GIS) has lead to many studies, mainly using indirect susceptibility-mapping approaches (Aleotti and Chowdhury, 1999). Therefore, fewer investigations use GIS in combination with a heuristic approach, or index overlay mapping (e.g. Barredo et al., 2000 and Van Westen et al., 2000, 2003). Nowadays, new decision-support tools are available for GIS-based heuristic analysis. They allow better structuring of various components, including both objective and subjective aspects and compare them in a logical and thorough way (Saaty, 1980). Decision support tools such as (spatial) multicriteria analysis have not been popular for qualitative assessment of landslide hazard (Castellanos Abella and Van Westen, 2007). For a regional scale landslide susceptibility assessment, statistical methods may be the most applicable because they are relatively simple to implement, provide quantitative results and are easily updated. However, traditional statistical methods still lack the ability to quantify the influence of individual factors and their different categories (He and Beighley, 2008). In recent years, geographical information systems (GISs) have proven to be a versatile tool for the display, analysis, management and modeling of spatial data. Through appropriate use of GISs, most approaches to landslide susceptibility mapping enable total automation of assessment and the standardization of data management techniques, from acquisition through final analysis (Soeters and Van Westen, 1996, Stevenson, 1977 and Anbalagan and Singh, 1996). This paper presents a GIS-based multivariate statistical approach for regional landslide susceptibility assessment. The approach is applied to map landslide susceptibility in central Iran using a newly digitized factor maps inventory. Landslide risk mapping is too complicate without GIS because there are multi criteria that must be considered. Environmental concepts are becoming common and ever more important parts of decision support models, which are a vital part of decision support systems (Žnidaršič et al., 2006). In this study all factors and constrains are spatial. The data driven approach, sometimes called data mining, is considered as very promising, because theory in general in many disciplines is poor and spatial data is becoming increasingly available (rapid move from a data poor environment to a data rich environment). Spatial multicriteria decision analysis requires data on the geographical locations of alternatives and/or geographical data on criterion values. To obtain information for the decision making process the data are processed using MCDM as wells as GIS techniques. Spatial multicriteria decision analysis is a process that combines and transforms geographical data (the input) into a decision (the output). This process consists of procedures that involve the utilization of geographical data, the decision maker's preferences, and the manipulation of the data and preferences according to specified decision rules. In this process, multidimensional geographical data and information can be aggregated into one-dimensional values for the alternatives. The difference with conventional multicriteria decision analysis is the large number of factors necessary to identify and consider, and, the extent of the interrelationships among these factors. These factors make spatial multicriteria decision analysis much more complex and difficult (Malczewski, 1999). GIS and MCDM are tools that can support the decision makers in achieving greater effectiveness and efficiency in the spatial decision-making process. The combination of multi-criteria evaluation methods and spatial analysis is referred as Spatial Multiple Criteria Evaluation "SMCE". SMCE is an important way to produce policy relevant information about spatial decision problems to decision makers (Sharifi and Retsios, 2003).

2. Methods

2.1 Study area

Manshad watershed is in centre of Iran. The area is located between latitudes 31° 29' 10" to 31° 35' 57" North and longitudes 54° 10' 00" to 54° 16' 22" East. Average elevation is 2400 m a.s.l and elevation changes from 1800 to 3400 m a.s.l in this watershed. Climate is arid and semi arid with 280 annual precipitation. Stones are limestone partly marmorized, sandstone, conglomerate, gravel fans and granite. There are 3 villages (Figure 1).

2.2 SMCE Programming

Criteria may be of two types: factors and constraints. Factors are generally continuous in nature (such as the slope gradient or roads proximity factors). Proximity maps were made by buffering around line, point or polygon features (Figure 2). They indicate the relative suitability of certain areas. Constraints, on the other hand, are always Boolean in character. They serve to exclude certain areas from consideration. Factors and constraints can be combined in the SMCE programming in ILWIS as GIS software. SMCE is characterized by some level of assumed risk that will strongly influence the final suitability map. Factor maps: area factors (slope, aspect, landuse, geomorphology, geology), linear factors (proximity to roads, to streams, to fault) and constraints: (slope less than 15% and more than 100%, elevation upper than 3000 m a.s.l., land use i.e. unusable stony areas, geomorphology faces rock and stone, road surfaces, stream surfaces).

These spatial data were used to mapping landslide hazard by entering to sub program "SMCE" from ILWIS 3.3 (GIS) software. Factor and constraint maps changed to raster with unique georeference and pixel size. Criteria tree designed and in every bench of tree, a map inserted (Figure 3).

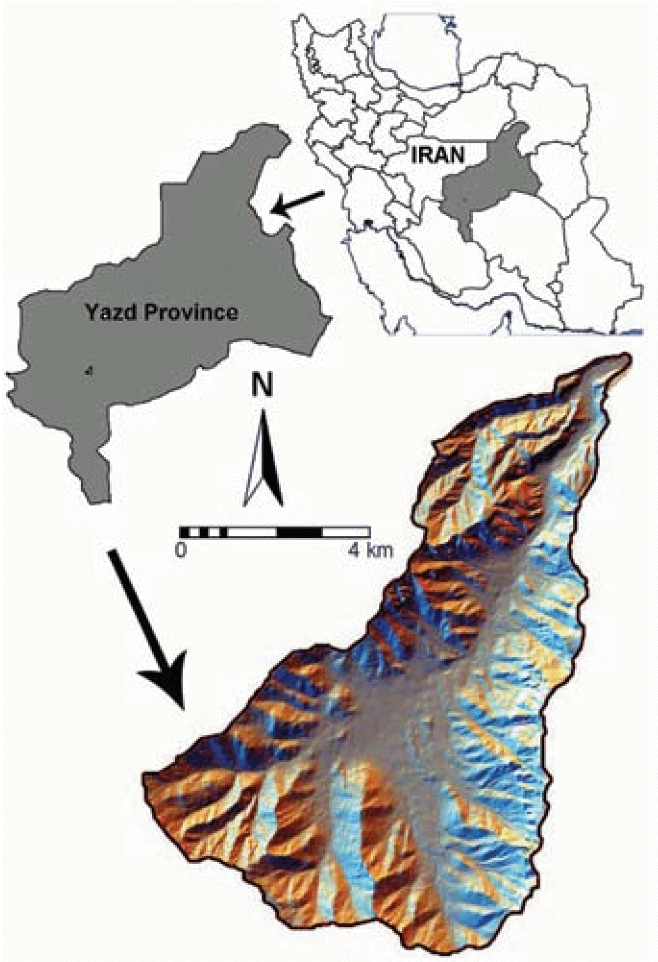

Figure 1: Manshad watershed in Iran Yazd province

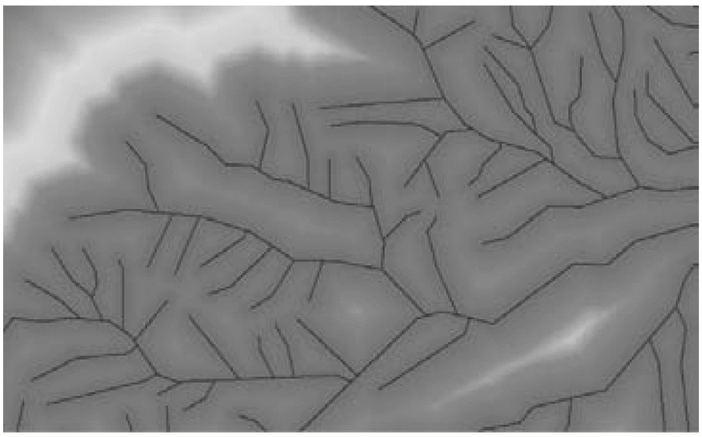

Figure 2: Proximity to stream by buffering

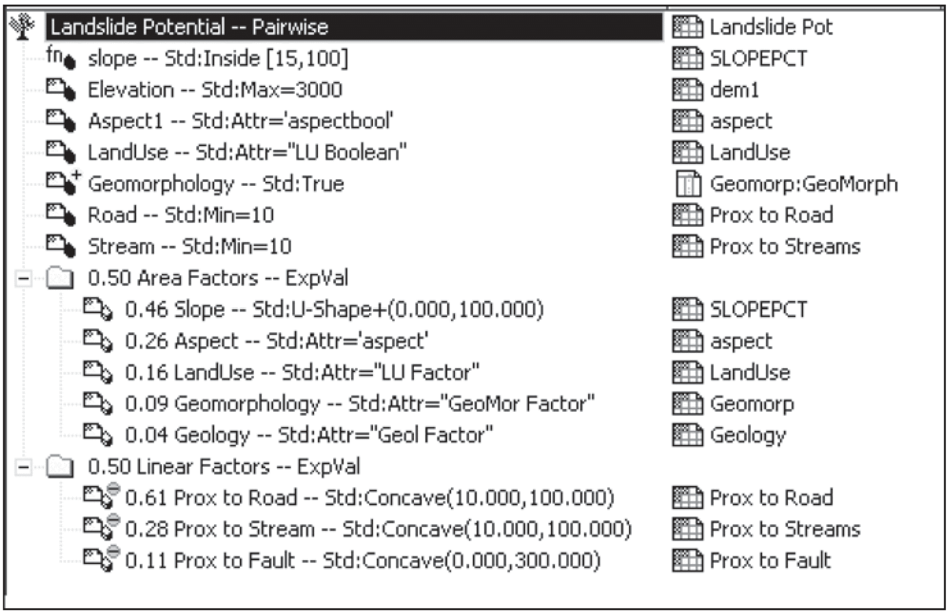

Figure 3: Designed criteria tree model in SMCE

2.3 Standardization

Standardization converts a quantitative image to a new image expressed as standardization scores. Standardization of factors (benefits+ and costs-): output values range between 0 and 1; Standardization of constraints; output values are either 0 or 1. For standardization of factors, must be select one of the following functions: Maximum, interval, goal, convex, concave, and combination (U-shape, Gaussian, Piecewise linear). (Figure 2).

For example in maximum method, the following formula was used:

Benefit factor = value / maximum input value	1
Cost factor = 1 - (value / maximum input value) + (minimum input value / maximum input value)	2

2.4 Standardization of Constraints

Unlike factor standardization, standardized constraints cannot be compensated by good performance of other criteria. Standardized constraints will either obtain value 0 (not performing) or value 1 (performing). Standardization constraints methods are unequal to zero, minimum, maximum, inside, outside. For Boolean landuse map, standardization, "TRUE passes, FALSE will be blocked" was used. This means that all input pixels with value True will be included in the output map; all pixels with value False will be excluded from the output.

2.5 Weights

Weigh multiple factors (benefits and costs) and optional groups under the main goal, and/or weigh multiple factors and optional groups under a sub goal. Assigning weights is needed in order to indicate the relative importance of these factors with respect to the main goal or to optional sub goals. There are some method for weighing: Direct Method, Pairwise Comparison, Rank Ordering. For example in Pairwise Comparison, Decision maker goes through all unique pairs and assigns Saaty weights (in words). From these weights, normalized weights are calculated (Saaty, 1984) (Figure 3). In rank ordering (Expected value, Rank sum): Decision maker assigns a rank-order to the items. From this rank-order, normalized weights are calculated. Weights are always numbers between 0 and 1. Weights cannot be negative in Figure 3 see standardize and weight methods that are selected.

2.6 Results

From Saaty matrix with the best consistency ratio the eigenvector i.e. the relative weights of factors, was calculated. Constraints do not give weight, because they were standardized for being or elimination not a gradient effect. The constraints by Boolean method eliminated from watershed. Slope as an area factor gained the biggest weight (0.46) and proximity to road as a linear factor gained the biggest weight (0.61). Maximum standardization for natural factors was used. From combination of factor and constraint raster maps, composite index map (CIM) in range 0 until 1 was generated by SMCE procedure. Near 0 value in this map had lesser hazard and near 1 vice versa (Figure 4).

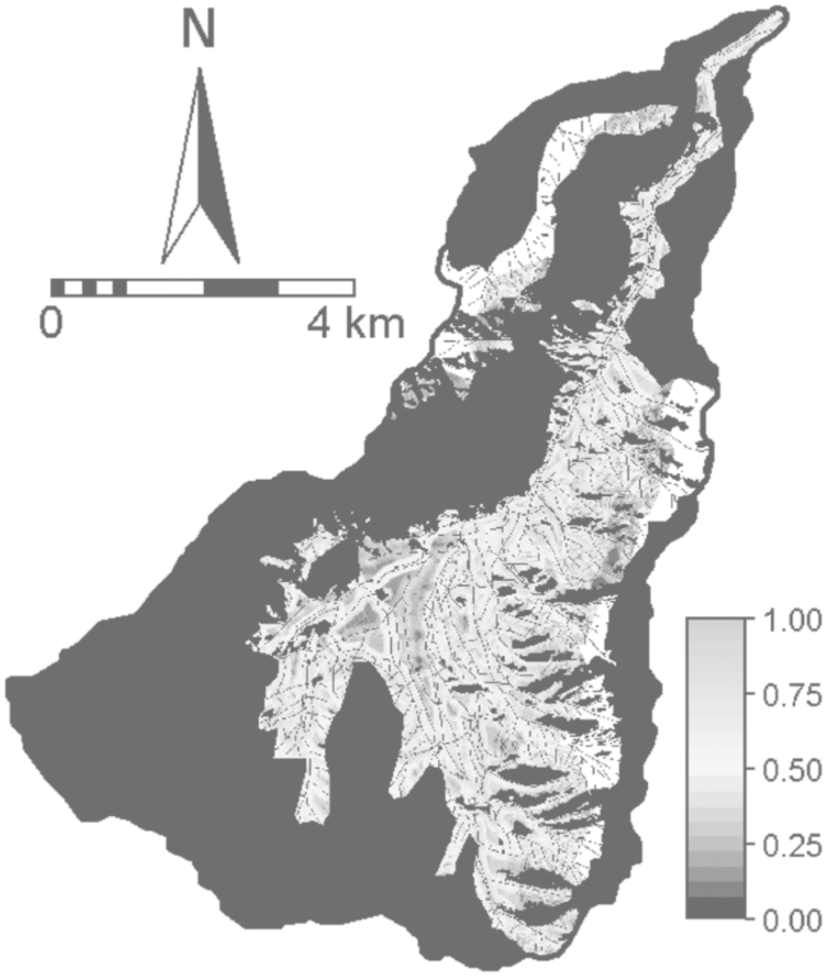

Figure 4: Composite index map (CIM)

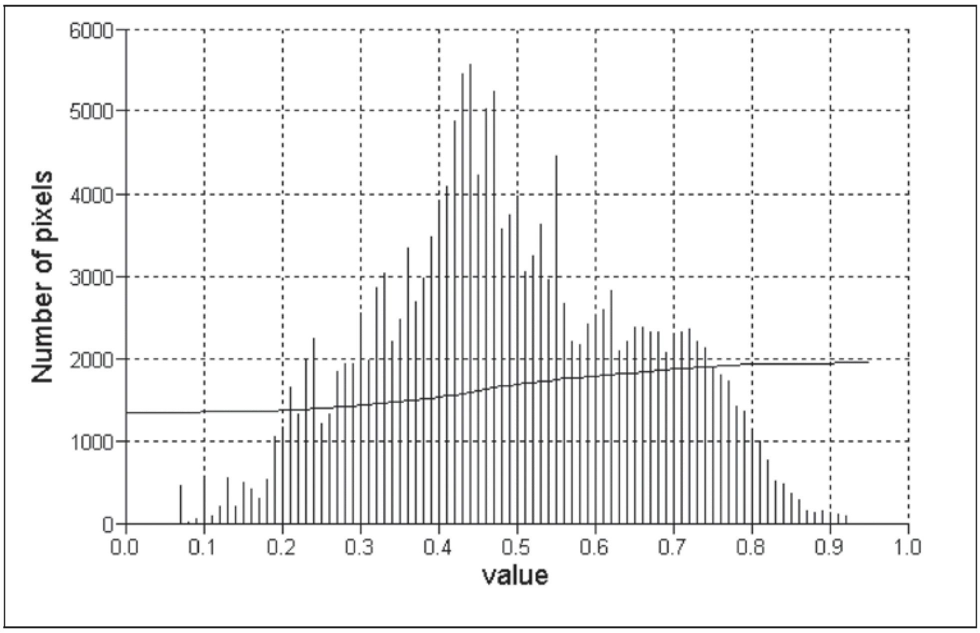

Figure 5: Histogram of CIM

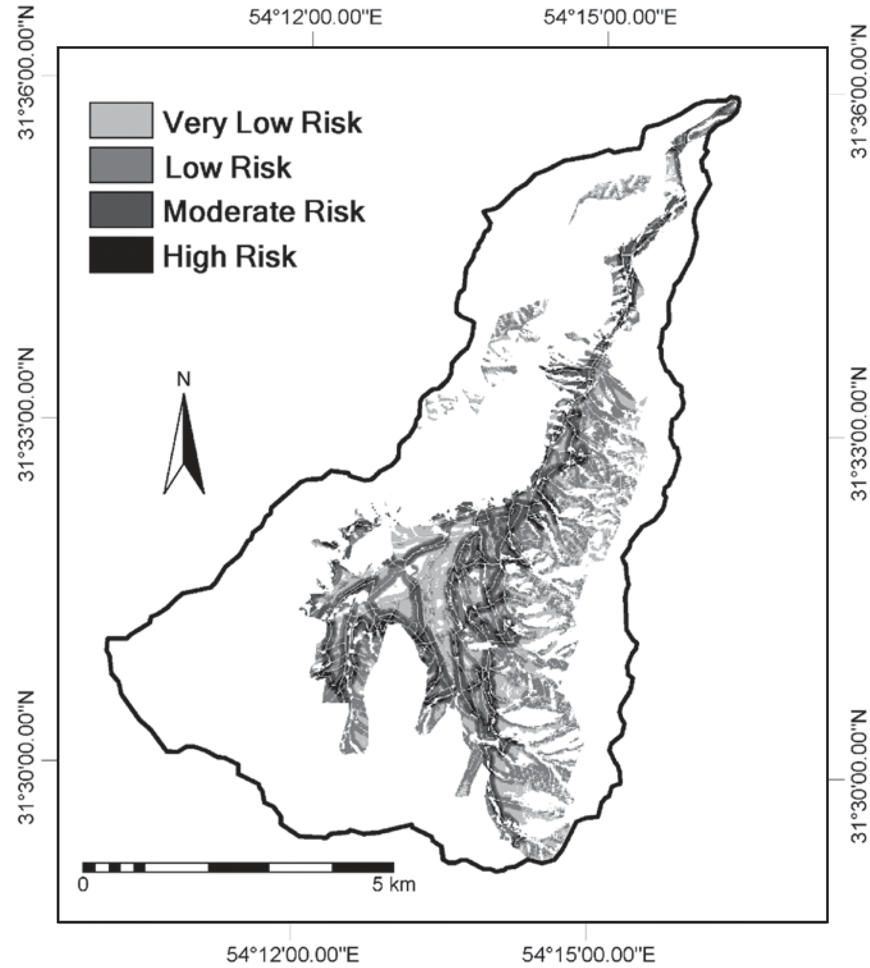

Figure 6: Classified CIM

2.7 Discussion and Conclusion

Majority pixels in the composite index map (CIM) got value between 0.1 and 0.9 in normally shape (Figure 5), thus classifying by considering this range was done. In medium slopes and near linear items and susceptible areas, i.e. value near 1 has most landslide risk (Figure 6). GIS and computer aided to decision makers and stakeholders to composite and analysis multicriteria. Then decision makers by considering some issues can decide to do project. This model can help to decision making and measure ends anticipatory be faster, easier and more exactly. In this paper, landslide disaster mapping were developed to quantify and weight the influence of potential risk factors for predicting the locations of landslides and subsequently preparedness against its disasters. Using GIS, a multivariate statistical approach for landslide susceptibility mapping was developed. Modeling results for central Iran suggest that ground slope and slope aspect are the most important landslide risk factors, followed by landuse, elevation, proximity to road, to stream and to fault. Watershed area was 5685 ha that 69.5% from that had no risk, 8.3% of area had moderate risk and 1.9% of area had high risk. The area with high risk is small but knowing it for human tranquillity is very important. The presented susceptibility maps was intended to help in the design of hazard and fear mitigation and land development policies at watershed scales (Figure 6).

Acknowledgements

We would like to express our profound gratitude to Research Deputy and young researchers club of Islamic Azad University-Maybod Branch.

References

Aleotti, P., Chowdhury, R., 1999, Landslide Hazard Assessment: Summary Review and New

Perspectives. *Bulletin of Engineering Geology and Environment*, 58, 21–44.

Anbalagan, R., and Singh, B., 1996, Landslide Hazard and Risk Assessment Mapping of Mountainous Terrains – a Case Study from Kumaun Hymalaya, India. *Eng Geol* 43, 237–246.

Barredo, J., Benavides, A., Hervas, J., and van Westen, C. J., 2000, Comparing Heuristic Landslide Hazard Assessment Techniques using GIS in the Tirajana Basin, Gran Canaria Island, Spain. *International Journal of Applied Earth Observation and Geoinformation,* 2, 9–23.

Buenrostro Delgado, O., Mendoza, M., Lopez Granados, E., and Geneletti, D., 2008, Analysis of Land Suitability for the Sitting of Inter-Municipal Landfills in the Cuitzeo Lake Basin, Mexico. *Waste Management*, 28, 1137–1146.

Castellanos Abella, E. A., and Van Westen C. J., 2008, Qualitative Landslide Susceptibility Assessment Bymulticriteria Analysis: A case study from San Antonio del Sur, Guantánamo, *Cuba Geomorphology*, 94, 453-466.

Collins, M. G., Steiner, F. R., and Rushman, M. J., 2001, Land-Use Suitability Analysis in the United States: Historical Development and Promising Technological Achievements. *Environmental Management*, 28 (5), 611–621.

Guzzetti, F., Carrara, A., Cardinali, M., and Reichenbach, P., 1999, Landslide Hazard Evaluation: A Review of Current Techniques and their Application in a Multi-Scale Study, Central Italy. *Geomorphology*, 31, 181–216.

He, Y., and Beighley, R. E., 2008, GIS-Based Regional Landslide Susceptibility Mapping: A Case Study in Southern California, *Earth Surf. Process. Landforms,* 33, 380 –393.

Lateltin, O., 1997, Berücksichtigung der Massenbewegungsgefahren bei raumwirksamen Tätigkeiten. Empfehlungen 1997. Swiss Federal Office for the Environment (FOEN). http://www.bwg.admin.ch/themen/natur/e/index.htm.

Lee, E. M., and Jones, D.K.C., 2004, *Landslide Risk Assessment*, Thomas Telford, London. 454.

Malczewski, J., 1999, *GIS and Multicriteria Decision Analysis,* John Wiley & Sons, Inc, New York.

Malczewski, J., 2004. GIS-Based Land-Use Suitability Analysis: A Critical Overview. *Progress in Planning,* 62 (2004), 3–65.

Malczewski, J., 2006, GIS-Based Multicriteria Decision Analysis: A Survey of the Literature. *International Journal of Geographical Information Science*, 20 (7), 703–726.

Saaty, T. L., 1980, *The Analytic Hierarchy Process*. McGraw Hill, New York.

Saaty, T. L., and Vargas, L. G., 1984, Comparison of Eigenvalue And Logarithmic Least Squares and Least Squares Methods in Estimating Ratios. *Mathematical modelling*, 5, 309-324.

Sharifi, M. A., and Retsios, V., 2003, Site Selection for Waste Disposal through Spatial Multiple Criteria Decision Analysis, *III International Conference on Decision Support for Telecommunications and Information, Society,* 4 - 6 September 2003, Warsaw, Poland.

Soeters, R., and Van Westen, C. J., 1996, Slope Stability: Recognition, Analysis and Zonation. In Landslides: Investigation and Mitigation, Transportation Research Board, *National Research Council Special Report* 247, Turner AK, Shuster RL (eds); 129 –177.

Stevenson, P. C., 1977, An Empirical Method for the Evaluation of Relative Landslide Risk. *Bull Int. Ass Eng Geo,l* 16, 69–72.

Van Westen, C. J., Soeters, R., and Sijmons, K., 2000, Digital Geomorphological Landslide Hazard Mapping of the Alpago Area, Italy. *International Journal of Applied Earth Observation and Geoinformation*, 2, 51–59.

Van Westen, C. J., Rengers, N., and Soeters, R., 2003, Use of Geomorphological Information in Indirect Landslide Susceptibility Assessment. *Natural Hazards*, 30, 399–419.

Vente, J. de, and Poesen, J., 2005, Predicting Soil Erosion and Sediment Yield at the Basin Scale: Scale Issues and Semi-Quantitative Models, *Earth-Science Reviews***,** 71, 95-125.

Žnidaršič, M., Bohanec, M., and Zupan, B., 2006, proDEX – A DSS Tool for Environmental Decision-making, *Environmental Modelling & Software,* Volume. 21, 1514-1516.