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Methodological Aspects of Building Information System for Monitoring of Landslide Hazards

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Abstract. The aim of the current paper is to present some methodological aspects of building monitoring information system for landslides. Having regard the importance of data in functioning of the monitoring system a special attention is given to the landslide factors, determining the weights of different factors and methods for making a landslide susceptibility map which is a base for selecting monitoring points and assessment of landslide hazard. The paper is not about the monitoring equipment and technical issues of building monitoring system. It concern landslide factor analysis and characteristics of spatial data in geographic information system (GIS) environment used for assessment of landslide susceptibility as a part of monitoring system. Based on ArcGIS Spatial analyst tools (ESRI Inc.) two overlay techniques – fuzzy logic and weighted sum are suggested for making a landslide susceptibility map. Application of GIS allows processing of a large amount of data and easily updating of information. It helps to better communicating the information about landslide hazards to the public by the relevant visualisation of the spatial data and also facilitate decision makers in case of natural hazard.

1. Introduction

Landslides are a movement of earth masses or unconsolidated deposits on a slope surface. These are one of the most often natural hazards. In many cases they have high intensity and sudden occurrence, in others they develop slowly. However in the both cases these natural phenomena can be assessed as hazard and risk regarding the probability of affecting human life. The landslide hazard is usually defined as the probability of occurrence of a potentially damaging phenomenon within a certain area and in a given period of time [1]. The risk is considered as a combination of the probability of a hazard event and of the potential adverse consequences for human health, the environment,, economy and social sphere.

Landslides triggered by earthquakes, intensive rainfall or intensive snowmelt has rapid development and can destroy transport infrastructure and buildings, and also they can decrease the quality of life and even to take lives. The slow movement of surface land masses, activated by changes in groundwater level or rainfall, causes damage gradually and if the appropriate measures to stop the process are not taken into account it can cause irreversibly negative environmental and social impact.

Landslides are wide spread natural hazard and limiting factor for anthropogenic activity and life, and they are studied for a long time. As a result of these researches we can say that landslides are well known and people are informed about the behaviour of landslides. The knowledge of landslides is important in the construction of roads, hydro-technical facilities and the construction of buildings. In this relation the geomorphological researches are related to the geotechnical and hydrogeological ones.

Factors influencing on landslide occurrence and development as lithology, tectonic features, slope angle, road network, drainage network, land use and rainfall are considered in many publications [2]-[5]. A special attention is given to the degree of slope as a main factor of slope surface stability [6]-[8]. Though the wide investigation of landslide factors, the complex character of the landslides and interaction between these factors, and variation of their occurrence and influence, depending of the particular situation, future researches in this field, collecting and analysing new data, as well as applying new approaches of researches are needed. The publications in the last several years, concerning landslides show rapid development of GIS and remote sensing analyses in determining the landslide areas, analysing landslide activating factors, elaborating landslide inventory, susceptibility and hazard maps and landslide monitoring [1], [9]-[14]. Literature review shows application of different approaches in landslide susceptibility map as a first step in assessing landslide hazard and a base for monitoring Using wide scope of spatial information in digital format and computer technology allow processing of big volume of data and applying variety of methods (fuzzy logic, logistic regressions, analytical hierarchy process, weighted overlay) for analyzing landslide factors and making a susceptibility map [5], [10], [15]-[17]. Determining of landslide susceptibility is essential for organising landslide monitoring and particularly for selecting the locations of monitoring points.

In order to mitigate the negative impact of landslide hazards monitoring of the hazardous events should be organized and regularly held. This is essential for predicting the behaviour of landslides and forecasting which storms can trigger large numbers of landslides [18]. A good landslide monitoring system should have the following features: quick communication in case of emergency, reduced burden of observation and monitoring, affordably a low-cost system, and real time acquisition and transfer of the data [19].

The aim of the current paper is to present some methodological aspects of building monitoring information system for landslides. The paper is not about the monitoring equipment and technical issues of building monitoring system. Having regard the importance of data in functioning of the monitoring system a special attention is given to the landslide factors, determining the weights of different factors and methods for making a landslide susceptibility map which is a base for selecting monitoring points and assessment of landslide hazard.

2. Determining Landslide Triggering Factors

The first step in building monitoring system for geomorphological hazards is clarifying the identity of the natural phenomena, subject of the monitoring, and identifying the factors determining the occurrence of natural hazards. When we talk about geomorphological hazards the most important factors are geological – geomorphological and hydroclimatological conditions. The role of other natural components as soils and vegetation is also important. Anthropogenic activity could influence the mentioned factors in different rate and contribute to the development of the natural hazard. The analysis and assessment of factors should be done taking into account the identity and peculiarities of the particular geomorphological hazard which is subject of the monitoring. For the aim of building monitoring system for landslide hazard we consider the following factors: lithology (rock composition), fault tectonics, slope of the topographic surface, rainfall, distance from streams, soils and vegetation.

The type of rocks and the rate of consolidation of rocks fragments determine the water permeability of the rocks and susceptibility of sliding. The area is more susceptible to sliding when it is built by unconsolidated rock materials or earth masses, located on solid or non-permeable rock and slope surface. In the event of heavy rainfall or rapid snow melting, surface water penetrates into the unconsolidated deposits, saturates the surface horizon, and makes the underlying solid rock substrate slippery. In such a situation, even on small slopes, the earth masses slides down the slope of the topographic surface. The sliding speed depends on the slope of the surface and the resistance on the sliding surface. In this relation physical-mechanical properties of soils and particularly soil permeability have strong impact on the landslide occurrence and development. Intensive stream erosion and high groundwater level also contribute to the landslide activation. Land cover / land use influence on the infiltration of surface water in soil, possibility for development of erosion and could cause changes in the groundwater level. Because of this land cover / land use types are considered as landslide triggering factors.

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In order to assess landslide susceptibility landslide factors have to be evaluated according to their importance for landslide occurrence. Having regards the characteristics of each one of the landslide triggering factors we suggest the following rates: 1 - very low; 2- low; 3 – moderate; 4 – high; 5 – very high. The rates of susceptibility of each one of the landslide factors should be considered in relation to the other factors. For example unconsolidated deposits have very high sliding susceptibility but if they are located on flat areas the total landslide susceptibility will be lower. Slopes greater than 45° are more prone to slide than 10° slopes, but if the steeper slopes are built by solid rocks and less steep areas are covered by unconsolidated rocks materials, the less steep slopes will have higher landslide susceptibility. If we have two areas with a slope of 15° and they are covered by one and the same moderately solid rock or unconsolidated rock but the first one have high humidity, intensive rainfall or rapid snowmelt and the second is dry, the first area will be more prone to landsides.
Having regard the landslides factor analysis the landslide susceptibility should be assessed taking into account the interaction between the factors and their cumulative impacts. For this purpose Analytic Hierarchy Process [20] can be applied (Table 1). The values in rows of the matrix show the importance of the given factor to that written in the relevant column. For example the type of rocks is evaluated as 5 times more important in comparison to the distance from faults, and we consider the distance from fault (row 2) against the rock type as the reciprocal value (1/5). The rates of different factors are determined by expert's view and assessment but summarizing the rates and using the relatively share for the weights minimise the subjectivity of the evaluation. The analysis of the landslide triggering factors and the weights given in the matrix show that slopes, rainfall, rocks type and soils permeability are the most important factors for landslide occurrence which confirm the above considered example.

Table 1. Matrix of landslides triggering factors and factor weights

Factors	Rocks type	Distance from faults	Slope	Rain-fall	Distance from streams	Stream network density	Ground-water level	Soils permeability	Land cover	Total	Weights (%)
Rocks type	1	5	1	2	4	4	2	1/2	3	22.50	16.15
Distance from faults	1/5	1	1/4	1/4	1/2	1	1/2	1/3	1/2	4.53	3.25
Slope	1	4	1	3	4	3	4	4	4	28.00	20.09
Rainfall	1/2	4	1/3	1	5	5	4	4	4	27.83	19.97
Distance from streams	1/4	2	1/4	1/5	1	1	1/3	1/4	1/3	5.62	4.03
Stream network density	1/4	1	1/3	1/5	1	1	1/3	1/4	1/3	4.70	3.37
Ground-water level	1/2	2	1/4	1/4	3	3	1	1/4	3	13.25	9.51
Soils perme-ability	2	3	1/4	1/4	4	4	4	1	4	22.50	16.15
Land cover	1/3	2	1/4	1/4	3	3	1/3	1/4	1	10.42	7.48
										Total:	100

1 - equal importance; 2 – moderate importance; 3 – strong importance; 4 – very strong importance; 5 – extreme importance

3. Building a GIS Database

3.1. Organising the Data

The GIS database consists graphical and attributive information. All available data for each one of the landslide triggering factors have to be entered as a separate layer in the database. An important condition to do correct spatial analyses is all layers to be in one and the same coordinate system, and particularly the analyses in ArcGIS environment require projected coordinate system. The necessary graphical information with the relevant attribute table is as follow:

- Relief – digital elevation model (DEM) – georeferenced raster file or vector file, presenting isolines of topographic map. It is preferable the map to be enough detailed (for example in a scale 1: 5000; 1:10000; 1:25000).
- Rivers – polyline. Polygon buffer layer is created on the base of rivers lines.
- Meteorological stations – point layers. Discontinuous point data for precipitation should be presented as continuous surface by an appropriate interpolation method. The output file is in raster format. The literature review and authors' tests show that the inverse distance weighted interpolation is more appropriate than the other ones for climate and hydrology data. Regression analysis of precipitation and altitude is also applicable and give good results. However the interpolation method should be chosen taking into account the identity of modelled indicator, number and allocation of the measurement points.
- Groundwater level – polygon layer or interpolated raster surface.
- Soils – polygon layer containing soil types polygons and soil indicators.
- Land cover – polygon layer presenting the land cover (including vegetation types) and land use types.
- Roads, railways – polyline layers.
- Settlements – polygon layer.
- Observed cases of occurrence of landslides – polygon or point layer depending on the map scale. This layer is to be used for the validation of the landslide susceptibility map.

3.2. Assessment of Landslide Susceptibility – Susceptibility Map

The assessment of landslide susceptibility of the observed area can be done on the base of landslide susceptibility map. The susceptibility is considered as a sensitivity degree to sliding. The first step in elaborating a susceptibility map is evaluation of landslide triggered factors (considered above). New layers of evaluated factors are generated in GIS environment. The susceptibility map can be elaborated using an overlay analysis. The vector files should be converted in raster format in order to proceed spatial overlay. We suggest to make the susceptibility map by two overlay techniques – fuzzy logic and weighted sum. The fuzzy logic used as an overlay technique gives good results in modelling natural hazards, particularly when there are short data records or few measuring points [21]. The sequence of making landslide susceptibility map is given on Figure 1.

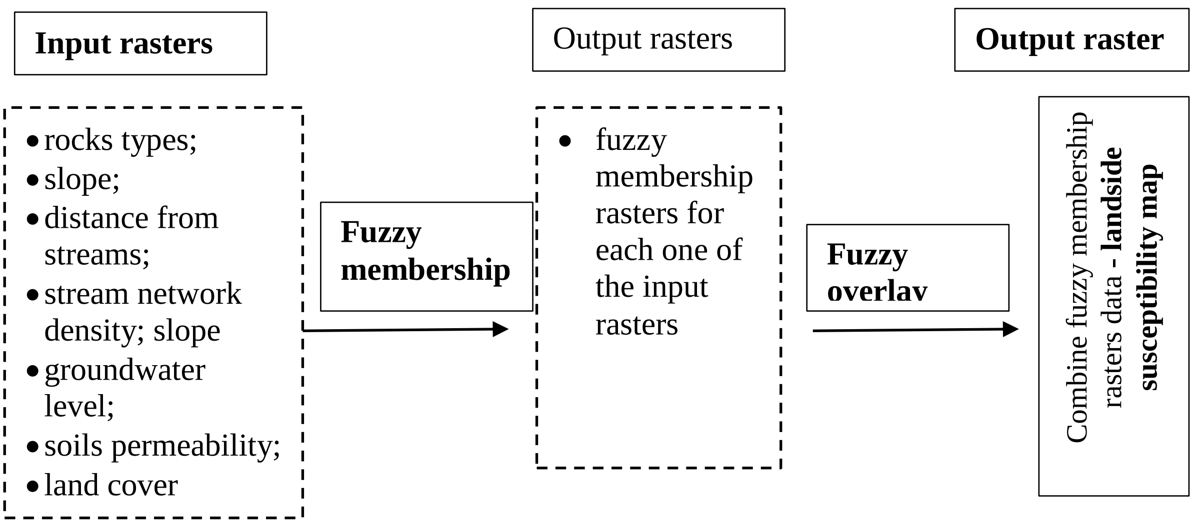

Figure 1. Chart flow of applying fuzzy overlay for making a landslide susceptibility map (based on the ArcGIS Spatial analyst tools)

Weighted sum can be applied using the weights determined in factors analysis. Rasters layers presenting the landslide factors are overlaid, multiplying each ones by the given weight and summing the layers together (Figure 2)

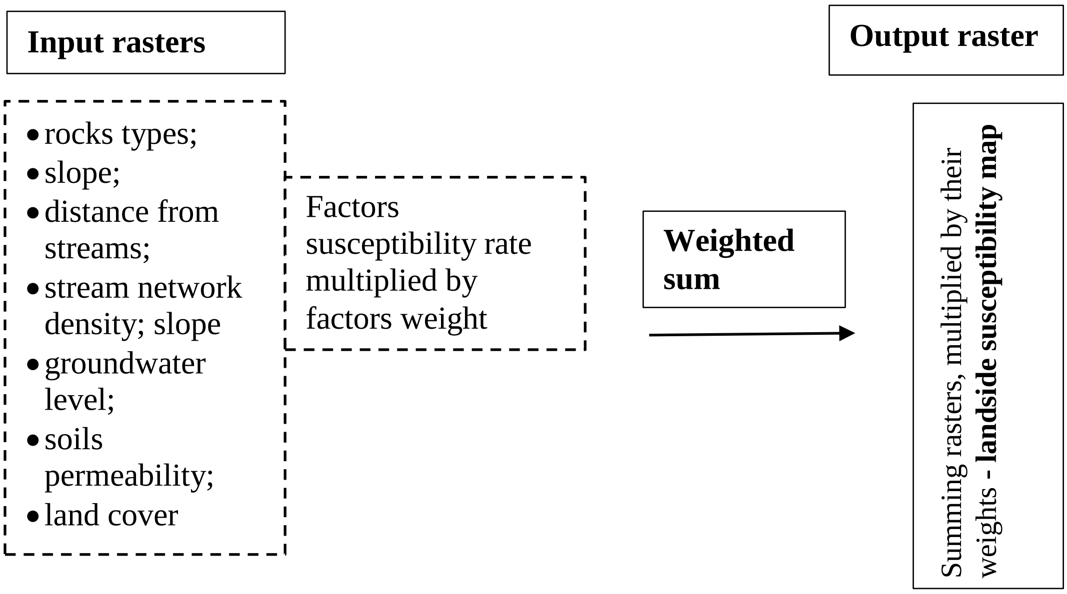

Figure 2. Chart flow of applying weighted sum overlay for making a landslide susceptibility map (based on the ArcGIS Spatial analyst tools)

The next step after making landslide susceptibility maps is to validate the models and to choose the most appropriate method. The validation of the model have to be done on the base of the map of observed cases of landslide in the investigated area.

4. Characteristics of the Monitoring

Landslide monitoring aims to collect information about the landslide occurrence and development, and to warn for possible landslide activation. An important point in organising the natural hazard monitoring is selection of monitoring locations and indicators to be monitored. Landslide monitoring includes observation and measurement of earth mass and deluvial - proluvial materials movement. Rainfall and soil moisture data also have to be monitored. In this regard the monitoring equipment should include landslide speed sensors (landmass moving sensors), rain-gage sensors or stations (automatic weather stations), soil moisture sensors and piezometers in shallow boreholes to observe the changes in water table depth. Ground-based remote monitoring systems consist field sensors but they also employ data acquisition units to record sensor measurements, remote telemetry (such as radio, satellite, or cell phone links), automated data processing, and displays of current conditions (often via the Internet). There is always some delay between sampling remote conditions and displaying these conditions to users, and the term “near-real-time monitoring” is commonly used [22].

About the time and periodicity of monitoring there are continuous monitoring which gives an information about the monitored phenomenon in real time and periodic monitoring which gives information at the particular moment. Continuous monitoring of landslide triggering factors and particularly rainfall is essential for areas estimated as high and very high susceptible to slide, while movement of slope materials could be monitored seasonally.

Selection of the monitoring points location should be done on the base of landslide inventory map (presenting the locations of observed landslides) and landslide susceptibility map (presenting areas prone to slide).

5. Updating of the Susceptibility Map

The landslide susceptibility map should be updated on the base of the monitoring data and other geological-geomorphological researches of the area. The most changeable components of the monitoring system are precipitation, humidity conditions and vegetation. This requires regular updating of the components maps which to be reflected to the susceptibility map. If new areas of high landslide susceptibility are determined after the updating they should be checked and of case of need a new monitoring point to be established.

6. Possibilities of GIS in Building and Operation of the Monitoring System

Building and operation of landslide monitoring system require collecting and organising big volume of various information about landslide activating factors and infrastructure. Geographic information systems give big opportunities in entering and analysing spatial data. Application of GIS allows processing of a large amount of data and easily updating of information. GIS are also an important part of real-time (near-real-time) monitoring. It helps to better communicating the information about landslide hazards to the public by the relevant visualisation of the spatial data. Landslide inventory and landslide susceptibility maps elaborated in GIS environment as well as the all data collected in the monitoring process can be used in territorial planning and could help the decision making.

Though the advantages of GIS technology there are some uncertainties. They are mostly related to the quality of the initial data about the landslide factors. For example the data from different sources and in different scales can present the modelled phenomena in varying degrees of detail or there would be some gaps in the data. Often remote sensing data is used in the spatial analyses and the quality of the images are not always good because of the clouds conditions.

The capacity of the GIS software and hardware facilitate the statistical and spatial analyses but on the other side they could be considered as a limiting factor concerning the selected techniques of the analyses, having regard the comprehensive character of landslides as a natural phenomenon which depends of a complex of interacting factors.

7. Conclusion

Monitoring of landslides is an important part of preventative activity and mitigating the negative effects of sliding. It is a powerful tool for territorial planning authorities in decision making and disaster reduction. For the proper functioning of the monitoring, the information system should contain reliable information about the factors that determine the occurrence of landslides. These factors can be grouped in the following groups: geology-geomorphological; hydro-climatological and land cover and anthropogenic factors. The analysis of the factors considered in the current paper shows the highest importance of slope, rainfall, lithology and soils permeability. The first stage in mitigating and tackling the landslide problem is collecting data, making landslide inventory and landslide susceptibility maps. Application of information technology provide opportunity for using different approaches and techniques for elaborating of landslide susceptibility map. Two overlay techniques (fuzzy overlay and weighted sum) are suggested in this research. However the spatial analyses should be chosen taking into account the availability of the data, number and location of the monitoring points as well as the complex of the landslide factors. In this relation more investigations are needed in removing data imperfections and adding more landslide factors in consideration, in order to have more reliable monitoring system.

8. References

[1] Varnes D J 1984 *Landslide Hazard Zonation: A Review of Principles and Practice* (UNESCO, Paris) pp 1-63.

[2] Bathrellos G D, Kalivas, D P and Skilodimou H D 2009 GIS-based landslide susceptibility mapping models applied to natural and urban planning in Trikala, Central Greece *Estudios Geológicos,* 65(1) pp 49-65, ISSN: 0367-0449, doi:10.3989/egeol.08642.036

[3] Guimarães R F, Machado V P, Abílio de Carvalho J O, Montgomery D R, Trancoso Gomes R A, Greenberg H M, Cataldi M and Mendonça P C 2017 Determination of Areas Susceptible to Landsliding Using Spatial Patterns of Rainfall from Tropical Rainfall Measuring Mission Data, Rio de Janeiro, Brazil *International Journal of Geo-Information,* 6, p 289

[4] Magliulo P, Di-Lisio A, Russo F, et al. 2008 Geomorphology and landslide susceptibility assessment using GIS and bivariate statistics: a case study in southern Italy. *Natural Hazards* 47 pp 411-435. https://doi.org/10.1007/s11069-008-9230-x

[5] Sahana M, Sajjad H 2017 Evaluating effectiveness of frequency ratio, fuzzy logic and logistic regression models in assessing landslide susceptibility: a case from Rudraprayag district, India. *Journal of Mountain Science* 14: 2150 https://doi.org/10.1007/s11629-017-4404-1

[6] Lee S, Min K 2001 Statistical analysis of landslide susceptibility at Yongin, Korea. *Environment Geology* 40 pp 1095-1113 https://doi.org/10.1007/s002540100310

[7] Saha A K, Gupta R P, Sarkar I, et al. 2005 An approach for GISbased statistical landslide susceptibility zonation—with a case study in the Himalayas. *Landslides* 2 pp 61-69.

[8] Sitanyiova D, Vondrackova T, Stopka O, Mysliveckova, M, Muzik, J 2015. GIS Based Methodology for the Geotechnical Evaluation of Landslide Areas. *Procedia Earth and Planetary Science*, 15 pp 389-394.

[9] Gupta R P, Joshi B C 1990 Landslide Hazard Zonation using the GIS Approach – A case Study from the Ramganga Catchment Himalayas *Engineering Geology* 28 pp 119–131

[10] Mancini F, Ceppi C, Ritrovato G 2010 GIS and statistical analysis for landslide susceptibility mapping in the Daunia area, Italy *Natural Hazards Earth System Sciences* 10 pp 1851–1864.

[11] Mahler1 C F, Varanda E, De Oliveira L C D 2012. Analytical Model of Landslide Risk Using GIS. *Open Journal of Geology* 2 pp 182-188, http://dx.doi.org/10.4236/ojg.2012.23018

[12] Ciampalini A, Raspini F, Bianchini S, Frodella W, Bardi F, Lagomarsino D, Di Traglia F, Moretti S, Proietti C, Pagliara P et al. 2015. Remote sensing as tool for development of landslide databases: The case of the Messina Province (Italy) geodatabase *Geomorphology* Vol 249 pp 103–118, http://dx.doi.org/10.1016/j.geomorph.2015.01.029

[13] De la Cerna M A and Maravillas E A 2015 Landslide Hazard GIS-based Mapping Using Mamdani Fuzzy Logic in Small Scale Mining Areas of Surigao del Norte, Philippines, *Proceedings of the World Congress on Engineering and Computer Science* Vol II. pp 901 – 906 (WCECS 2015, October 21-23, 2015, San Francisco, USA)

[14] Casagli N, Cigna F, Bianchini S, Hölbling D, Füreder P, Righini G, DelConte S, Friedl B, Schneiderbauer S, Iasio C et al. 2016 Landslide mapping and monitoring by using radar and optical remote sensing: Examples from the EC-FP7 project SAFER, *Remote Sensing Applications: Society and Environment* 4 pp 92–108

[15] Ayalew L, Yamagishi H 2005 The application of GIS based logistic regression for landslide susceptibility mapping in the Kakuda–Yahiko Mountains Central Japan *Geomorphology* 65 (1/2) pp 15–31

[16] Champatiray P K, Dimri S, Lakhera RC, Sati S 2007 Fuzzy-based method for landslide hazard assessment in active seismic zone of Himalaya *Landslides* 4 pp 101–111

[17] Kayastha P, Dhital M, De Smedt F 2013 Application of the analytical hierarchy process (AHP) for landslide susceptibility mapping: a case study from the Tinau watershed, West Nepal. Computers & Geosciences vol 52 pp 398–408

[18] USGS Landslide monitoring https://landslides.usgs.gov/monitoring/

[19] Tanaka T 2013 *Int. Journal of Landslide and Environment* 1(1) pp 101-102

[20] Saaty R W 1987 The analytic hierarchy process – what it is and it is used Math Modelling vol 9 number 3-5 pp 161 - 176

[21] Nikolova V, Zlateva P 2017 Assessment of Flood Vulnerability Using Fuzzy Logic and Geographical Information Systems. In: Information Technology in Disaster Risk Reduction. 2016. IFIP Advances in Information and Communication Technology, vol 501 (Springer, Cham)

[22] Reid M, LaHusen R G, Baum R L, Kean J W, Schulz W H and Highland L M 2012. Real-time monitoring of landslides. USGS. Factsheet. pubs.usgs.gov/fs/2012/3008/contents/FS12-3008.pdf

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