Faculty of Geo-Information Science and Earth Observation

UNIVERSITY OF TWENTE.

Report on the 1st project of AES Geohazards Stream

Landslide hazard assessment in Georgia

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March 2011

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1. Introduction

Up to now, large amount of research has been carried out on landslide risk assessment in Georgia. But this data are on papers (reports, maps, cadastral and etc), not in the digital format. Most landslide studies in Georgia that have been published thus far concentrate on landslide inventory mapping, created engineering-geological map, landslide descriptions and qualitative hazard assessment cover the entire country, but as we mentioned all these data are on papers.

Unlike landslide hazard, landslide risk assessment has been receiving only full attention by the international scientific community in the past decade (van Westen et al. 2005). One of the most useful definitions of risk is presented by Varnes (1984) as “the expected number of lives lost, persons injured, damage to property and disruption of economic activity due to a particular damaging phenomenon for a given area and reference period.” When dealing with physical losses, (specific) risk can be quantified as the product of vulnerability, cost or amount of the elements at risk and the probability of occurrence of the event with a given magnitude/intensity (van Westen et al. 2005).

For large-scale landslide risk assessment, a range of methodologies have been published (Bonnard et al. 2004; Lee and Jones 2004; Eberhardt et al. 2005; Glade et al. 2005), but only limited research has been done on landslide risk assessment for large areas such as entire countries (Guzzetti 2000; Yoshimatsu and Abe 2006). At such small scales, the aim is to produce a landslide risk index, which makes it possible to zoom in on the high-risk areas for more detailed studies.

As in most developing countries, landslide inventory maps in digital format are still scarce in Georgia, due to the limited resources available for research.

There are four different approaches to the assessment of landslide hazard: landslide inventory-based probabilistic, heuristic, statistical and deterministic (Soeters and Van Westen, 1996; Aleotti and Chowdhury, 1999; 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).

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 collect many data.

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). Decisionsupport tools such as (spatial) multicriteria analysis have not been popular for qualitative assessment of landslide hazard.

The main goal of this project was to design a methodology for the assessment of a nationwide landslide risk index for Georgia taking into account the limitations in data availability and detail. These data do not allow the application of deterministic landslide hazard assessment methods, which are required to derive quantitative landslide risk maps. Given these limitations, it was decided to derive a qualitative landslide risk index using spatial multi-criteria evaluation (SMCE) methods in a Geographic Information System (Integrated Land and Water Information System [ILWIS]-GIS). The landslide risk index should use indicator maps collected from a variety of national information sources.

2. The Study area

Georgia is a sovereign state in the Caucasus region of Eurasia (shown in Fig. 1). Situated at the juncture of Eastern Europe and Western Asia it is bounded to the west by the Black Sea, to the north by Russia, to the southwest by Turkey, to the south by Armenia, and to the southeast by Azerbaijan. Georgia covers a territory of 69,700 km² and its population is almost 4.5 million.

The Greater Caucasus Mountain Range is much higher in elevation than the Lesser Caucasus Mountains, with the highest peaks rising more than 5,000 meters above sea level.

Georgia is divided into two autonomous republics (Adjara and Apkhazeti) and nine regions (shown in Fig. 2). The nine regions are Guria, Imereti, Kakheti, Kvemo Kartli, Mtskheta-Mtianeti, Racha-Lechkhumi and Kvemo Svaneti, Samegrelo-Zemo Svaneti, Samtskhe-Javakheti, and Shida Kartli.

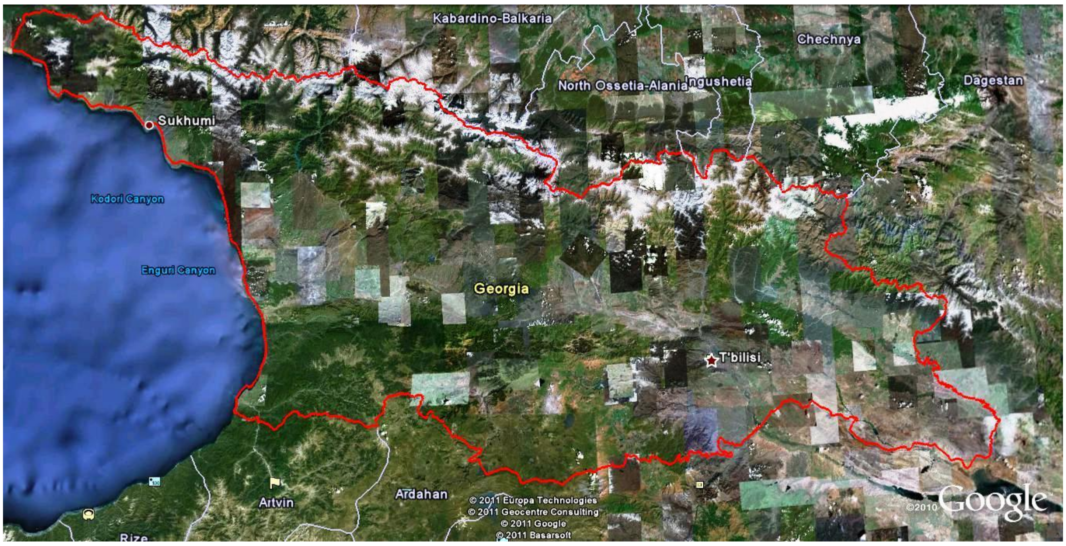


Fig. 1: The Study area – Georgia (Source: Google Earth)

Fig. 2: Administrative map of Georgia

Despite its small area, Georgia has one of the most varied topographies of the Eastern Europe. Georgia lies mostly in the Caucasus Mountains, and its northern boundary is partly defined by the Greater Caucasus range. The Lesser Caucasus range, which runs parallel to the Turkish and Armenian borders, and the Surami and Imereti ranges, which connect the Greater Caucasus and the Lesser Caucasus, create natural barriers that are partly responsible for cultural and linguistic differences among regions. Because of their elevation and a poorly developed transportation infrastructure, many mountain villages are virtually isolated from the outside world during the winter. Earthquakes and landslides in mountainous areas present a significant threat to life and property.

Georgia has about 26,000 rivers. Drainage is into the Black Sea to the west and through Azerbaijan to the Caspian Sea to the east. The largest river is the Mtkvari, which flows 1,364 km from northeast Turkey across the plains of eastern Georgia, through the capital, Tbilisi, and into the Caspian Sea. The Rioni River, the largest river in western Georgia, rises in the Greater Caucasus and empties into the Black Sea at the port of Poti.

The climate of Georgia is extremely diverse, considering the country's small size. There are two main climatic zones, roughly separating Eastern and Western parts of the country. The Greater Caucasus Mountain Range plays an important role in moderating Georgia's climate and protects the country from the penetration of colder air masses from the north. The Lesser Caucasus Mountains partially protect the region from the influence of dry and hot air masses from the south as well.

Much of western Georgia lies within the northern periphery of the humid subtropical zone with annual precipitation ranging from 1000–4000 mm. The climate of the region varies significantly with elevation and while much of the lowland areas of western Georgia are relatively warm throughout the year, the foothills and mountainous areas experience cool, wet summers and snowy winters (snow cover often exceeds 2 meters in many regions).

Adjara is the wettest region of the Caucasus, where the Mt. Mtirala rainforest, east of Kobuleti receives around 4500 mm of precipitation per year. Midwinter average temperature in West Georgia is 5 C and the midsummer average is 22C.

Eastern Georgia has a transitional climate from humid subtropical to continental. The region's weather patterns are influenced both by dry, Central Asian/Caspian air masses from the east and humid, Black Sea air masses from the west. The penetration of humid air masses from the Black Sea is often blocked by several mountain ranges (Likhi and Meskheti). Annual precipitation is considerably less than that of western Georgia and ranges from 400–1600 mm.

The wettest periods generally occur during spring and autumn while winter and the Summer months tend to be the driest. Much of eastern Georgia experiences hot summers (especially in the low-lying areas) and relatively cold winters. As in the western parts of the country, elevation plays an important role in eastern Georgia where climatic conditions above 1500 meters are considerably colder than in the low-lying areas. The regions that lie above 2000 meters frequently experience frost even during the summer months. The average temperature in summer here is 20-24 degrees of Celsius, in winter 2-4 degrees of Celsius. Humidity is lower.

In Georgia a strong influence of natural hazards (earthquake, floods, flashflood landslide, mudflow, rockfall, avalanche and etc) is experienced by thousands of populated areas, plots of field, roads, oil and gas pipes, high-voltage electric power transmission towers, hydraulic structures and reclamation constructions, mountain and tourist complexes, etc.

Many environmental factors, related to the fields of geology, geomorphology, topography and land use, have the potential to affect land sliding (Clerici et al., 2002). 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, however, are not yet available in Georgia.

The objectives of this project are as follows:

- Define and justify a relevant set of spatial criteria for this case of landslide hazard assessment.
- Develop a mass movement initiation model based on Spatial Multi Criteria Evaluation.
- Analyze the relevant factors related to the occurrence of landslides based on expert knowledge from literature and local landslide experts
- Generate landslide susceptibility map for whole country.

3. Data Description

In order to assess the landslide hazard in the Georgia area, the following dataset were utilized:

- Topographic map data at 1:50,000 scale
- Geology map of Georgia (scale 1:500 000)
- Faults (from Geology map scale 1:500 000)
- Roads (from topographic map scale 1:200 000)
- Landcover Data (scale: 1:500 000)
- Limited Landslide inventory map

4. Methodology

The landslide risk index method started with the selection of indicator maps, the way the criteria are going to be structured and the selection of standardisation and weighting methods.

As mentioned above, in Georgia, the landslide inventory maps in digital format are still under development and does not have a full national coverage yet. If a complete landslide database would have been available, it could have served as the main input in the landslide risk index, as landslide density of landslides per municipality could then have been used as the main hazard indicators and the landslide damage per municipality as the main vulnerability indicator.

For implementing the model the SMCE module of ILWIS-GIS was used. SMCE application assists and guides users in doing multi-criteria evaluation in a spatial manner. The input is a set of maps that are the spatial representation of the criteria. They are grouped, standardized and weighted in a 'criteria tree.' The output is one or more 'composite index map, which indicates the realization of the model implemented. The theoretical background for the multi-criteria evaluation is based on the analytical hierarchical process (AHP) developed by Saaty (1980). The AHP has been extensively applied on decision-making problems (Saaty and Vargas 2001), and only recently, some research has been carried out to apply AHP to landslide susceptibility assessment (fig. 3).

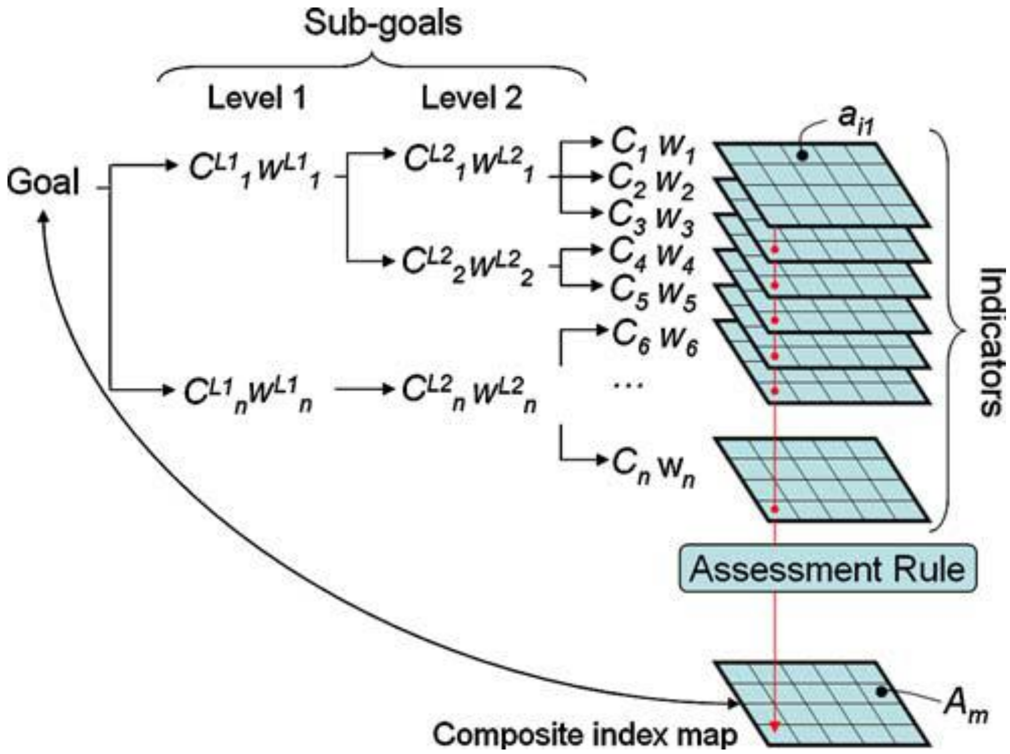


Fig. 3. Schematic procedure for spatial multi-criteria evaluation based on the analytical Hierarchical process

4.1 Standardisation, weighting

To make spatial multi-criteria analysis possible, the input layers need to be standardized from their original values to the value range of 0–1. There was provided different standardization in the SMCE module of ILWIS (ITC 2001). For standardizing value maps, a set of equations can be used to convert the actual map values to a range between 0 and 1. The class maps use an associated table for standardisation where a column must be filled with values between 0 and 1. In Section Indicator Analysis, a detailed description of the indicator maps and their standardization is given. The next step is to decide for each indicator whether it is favourable or unfavourable in relation to the intermediate or overall objective.

The most important constraint indicator used for the national landslide risk assessment is the slope angle. In areas that have very gentle or flat slopes, landslides are not expected or occur only under very specific conditions. After selecting the appropriate indicators, defining their standardisation and the hierarchical structure weights were assigned to each criteria and intermediate result. For weighting, 3 main methods can be used: direct method, pairwise comparison and rank order methods. Finally landslide index map was created by direct method.

5. RESULTS AND DISCUSSION

According to literature, 5 factors are most often selected in landslide susceptibility mapping: slope, lithology, landuse, distance from roads and distance from faults.

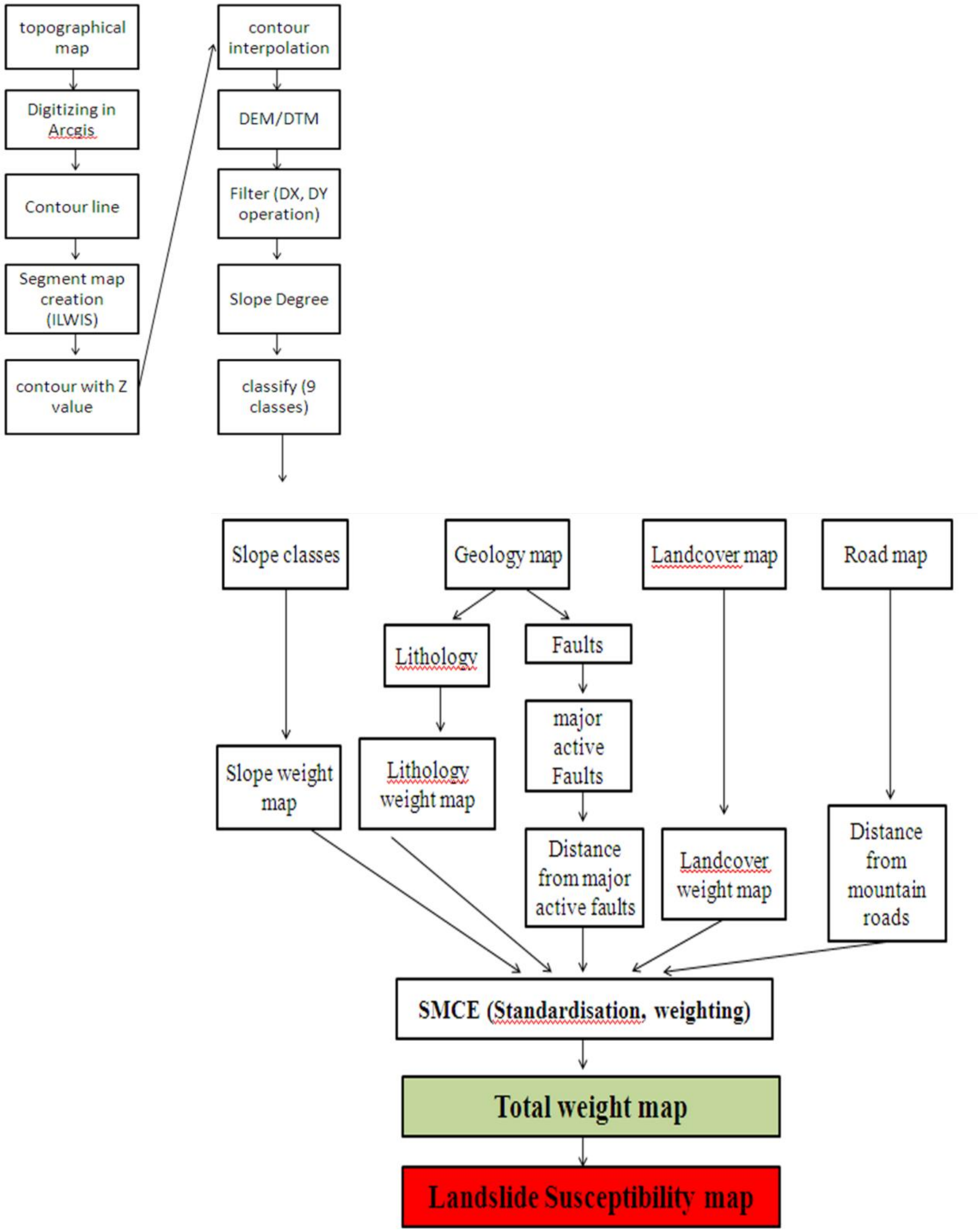


Fig. 4. Methodology employed in this study

5.1 Slope gradient

Topography is one of the most important factors in landslides susceptibility assessment (Castellanos Abella & Van Westen, 2008). In literature, slope length, slope convexity, slope direction (aspect) and slope steepness are all studied, while the latter is mostly used (Dai & Lee, 2002). the slope angle is directly related to the landslides, it is frequently used in preparing landslide susceptibility maps. The slope map of the study area was divided into 9 slope categories.

Based on literature study (Berti, Genevois et al., 2000; Catani, Casagli et al., 2005; Dai & Lee, 2002; Thiery, Malet, et al., 2007) the following standardized values for slope classes were used in this analysis, ranging from 0 to 10, where 10 means high susceptible area for landslide and 0 none susceptible (Tab. 1 and Fig. 2). Later these values were converted to a range 0 to 1.

Table.1 weight assigned of slope gradient

Slope gradient	Standardized value
0 - 10	1
10 – 20	8
20 - 30	10
30 – 40	5
40 - 50	2
50 - 60	1
60 - 70	1
70 - 80	1
80 - 90	1

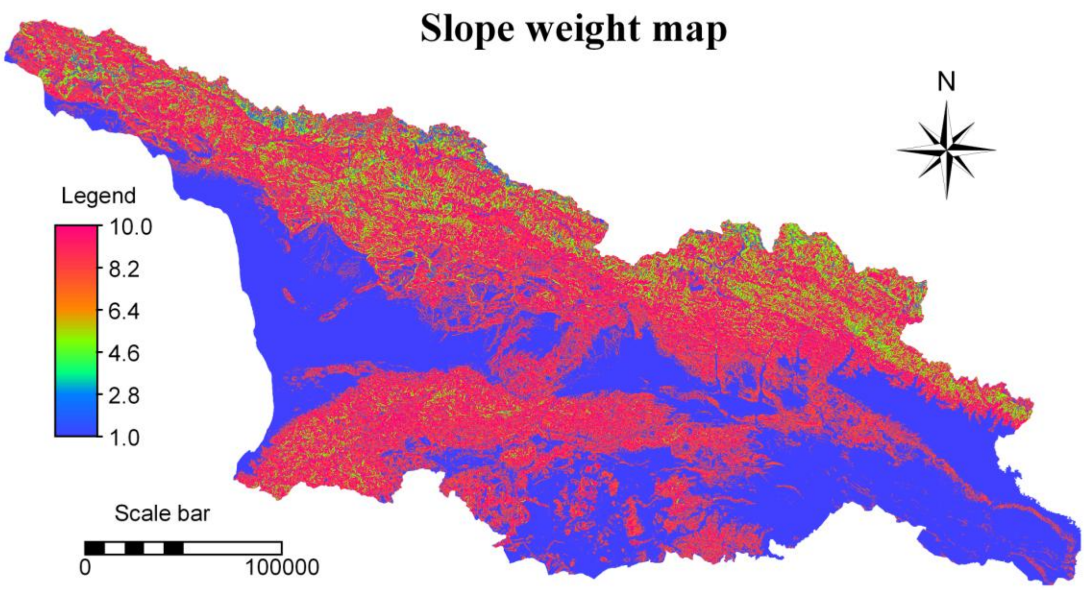


Fig. 5. Slope weight map

5.2 Geology

The landslide phenomenon, a part of then geomorphologic studies and research, is related to the lithology and weathering properties of the material of the land. Lithology may affect the likelihood of landslides to a large extent. There are many previous studies showing the correlation of landslide frequency with lithology.

More weathered rock are more prone to landslides and that fine-grained rocks (shales, marls, claystone) and rocks with intervalations of fine materials are more prone to landslides. The stratigraphy of the Georgia region is of several geologic time scales: Quaternary, Neogene, Paleogene, Cretaceous, Jurassic and etc.

Within each stratigraphical unit, there are 145 lithological units. These units were given a value for the likelihood of landslides, with values ranging from 0 to 10, in which 10 means very prone to landslides, and 0 means not prone to landslides. Which later were on converted to a range between 0 and 1 (Table 2 and fig. 6).

Table 2. Normalized weight assigned of Lithology (not all geological units are displayed)

ID	index	Lithology	Value
63	K2t-m	Turoian, Coniacian, Santonian, Campanian and Maastrichtian stages. Adjara-Trialetian zone: thinbedded red-coloured and pink limestones and marls, bedded lithorgaphic limestones with interscalations of bentonitic clays, sandy and marly limestones, sandstones, rarely lenses of conglomerates	3
75	K1b-h1	Berriasian and Valanginian stages and lower substage of Hauterivian stage. Mestia-Tianeti zone: clastic-limestone and sandstone turbidites, pelagic marls, limestones, argillites and clay shales	5
76	J2	Middle Jurassic (undismembered). Kazbegi-Lagodekhi and Ckhalta-Laila zones: clay and sandy shales, argillites, sandstones and siltstones, lavas and tuffs of tholeiitic basalts	4

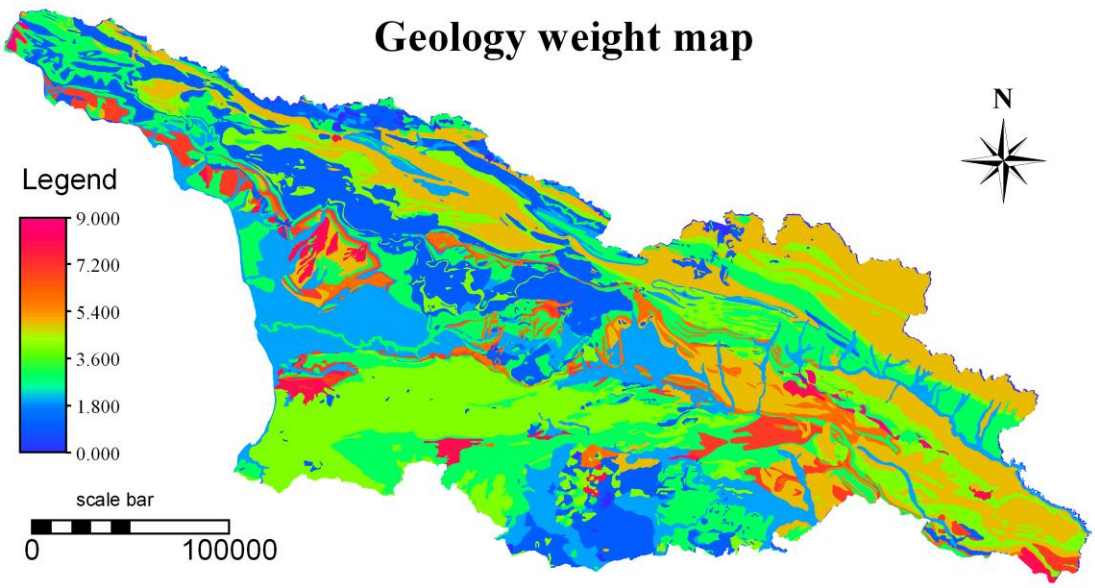


Fig. 6. Geology Weight map.

5.3 Landcover

Landcover was chosen as another criterion. According to other studies (Dilley, Chen et al., 2005; Hong, Adler, et al., 2007), the landslides susceptibility for global land cover are assigned with numerical values In our study area Georgia, there are 24 types of land cover. Table 3 and figure 7 shows the standardized values that were used based on the literature and expert weighting by several experts.

Table 3. Numerical value assigned to each land type

Standardized value	Landcover type
0	Lake, glacier, water reservoir, large river, wetland
1	Bare glacial moraine, badland, rocky
2	Dense forest
3	Open forest, park
4	Orchard , Scrub
5	Urban park
6	Vineyard
7	Grass land, Island
8	Agriculture land
9	Bare river sand
10	Settlement area, urban area, cemetery, railway

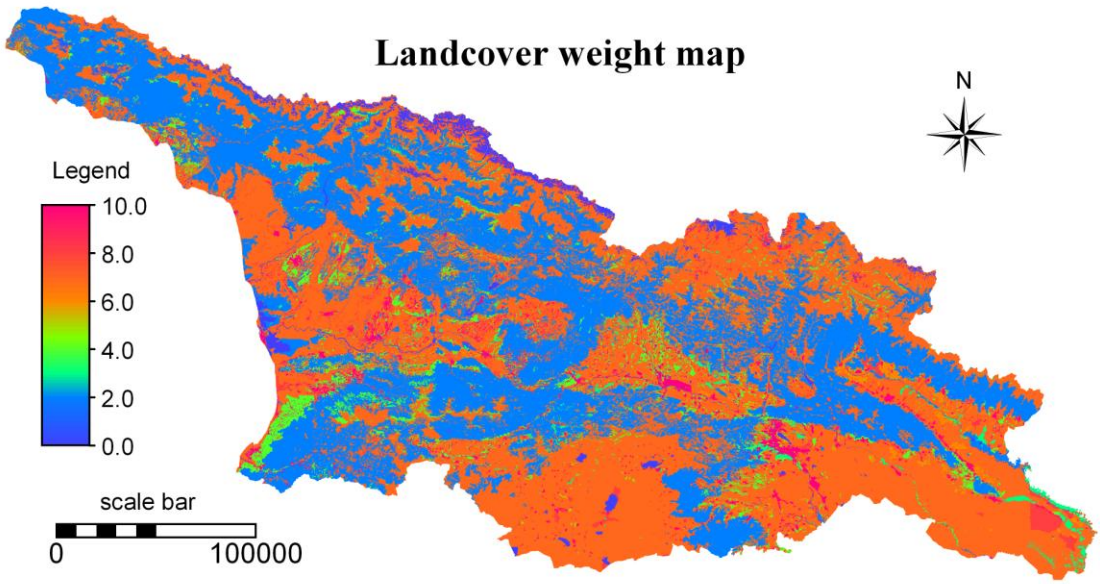


Fig. 7. Landcover weight map

5.4 Distance to the road network

Construction of roads also influences the density of landslides, especially in sloping areas where road cuts are made. In this study, roads that are located on areas with slopes steeper than 20 degree and that are close to a road are taken into account with the value of 1, other areas are assigned value of 0.

5.5 Distance from Faults

Distance from major Faults was chosen as another criterion. There are several major Faults in our study area, but only major active Faults cause Landslides in Georgia. It was created buffer zones. Threshold magnitudes, minimum shaking intensities, and relations between M and distance from epicenter or fault rupture were used to define relative levels of shaking that trigger landslides in susceptible materials.

5.6 Weight assignment

After the selection of the indicators, their standardisation and the definition of indicator weights, the analysis was carried out using an ILWIS GIS script to obtain the composite index maps and the final landslide risk index map.

The processed of combining factors for mass movement initiation assessment was carried out in the SMCE module of ILWIS (Integrated Land and Water Information System). The input is a set of maps that are the spatial representation of the criteria, which are grouped, standardized and weighted in a criteria tree. In our case we admit that Slope>geology>landcover>distance from faults=mountain roads. The theoretical weighting background for the multi-criteria evaluation is based on the AHP (fig.8).

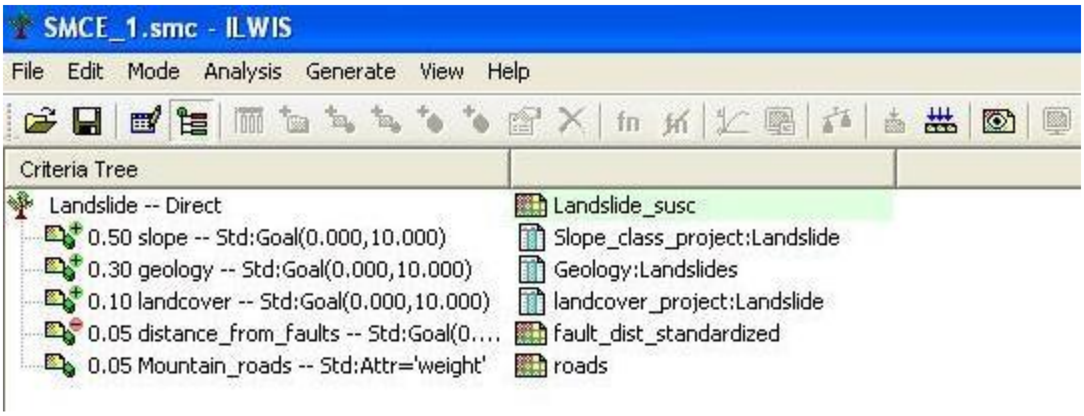
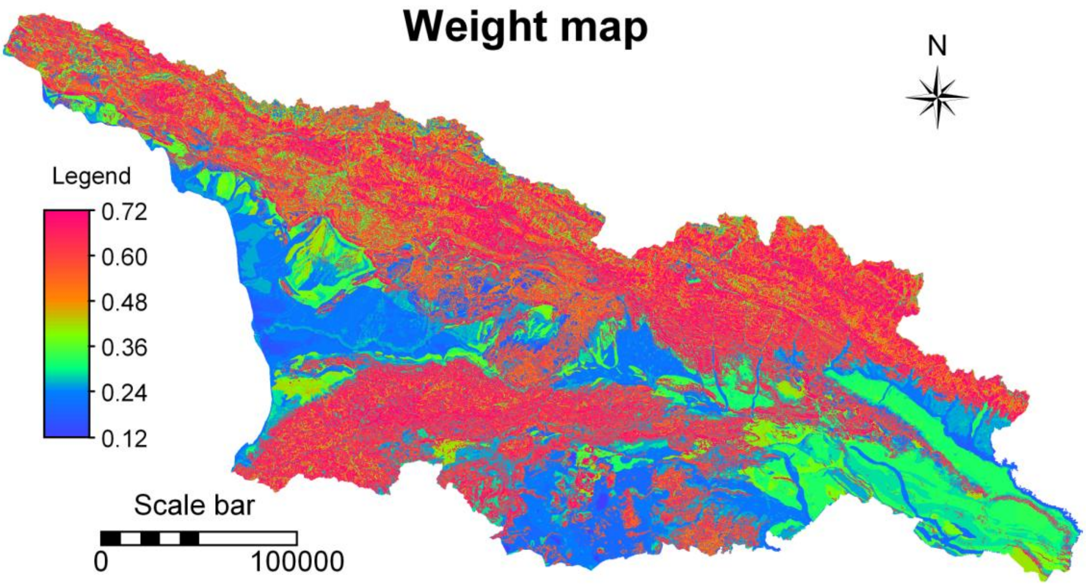
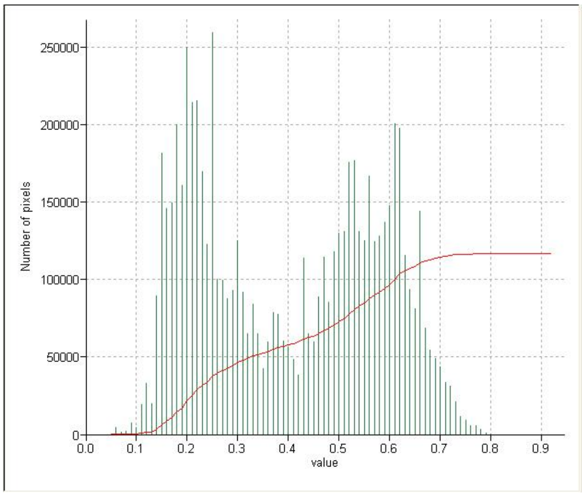
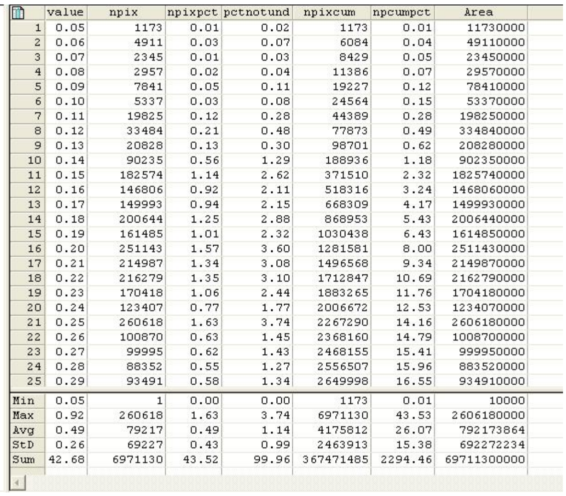


Fig. 8. Standardization of factor maps (slope>geology>landcover>distance from faults=mountain roads)

The parameters were combined in SMCE to produce a landslide susceptibility map. According to the AHP method, importance of every two parameters is set according to their contribution to landslides. For the weighting of the individual factors a comparison was made between the various factors using a direct approach. It is generally confirmed in landslide literature that topography contributes most in mass movements. Therefore, the slope always has the highest weight. Distance from faults and distance from roads are equally important for landslide. The importance of lithology is considered more than land cover (Fig. 9).







	value	npix	npixpct	pctnotund	npixcum	npcumpct	Area
1	0.05	1173	0.01	0.02	1173	0.01	11730000
2	0.06	4911	0.03	0.07	6084	0.04	49110000
3	0.07	2345	0.01	0.03	8429	0.05	23450000
4	0.08	2957	0.02	0.04	11386	0.07	29570000
5	0.09	7841	0.05	0.11	19227	0.12	78410000
6	0.10	5337	0.03	0.08	24564	0.15	53370000
7	0.11	19825	0.12	0.28	44389	0.28	198250000
8	0.12	33484	0.21	0.48	77873	0.49	334840000
9	0.13	20828	0.13	0.30	98701	0.62	208280000
10	0.14	90235	0.56	1.29	188936	1.18	902350000
11	0.15	182574	1.14	2.62	371510	2.32	1825740000
12	0.16	146806	0.92	2.11	518316	3.24	1468060000
13	0.17	149993	0.94	2.15	668309	4.17	1499930000
14	0.18	200644	1.25	2.88	868953	5.43	2006440000
15	0.19	161485	1.01	2.32	1030438	6.43	1614850000
16	0.20	251143	1.57	3.60	1281581	8.00	2511430000
17	0.21	214987	1.34	3.08	1496568	9.34	2149870000
18	0.22	216279	1.35	3.10	1712847	10.69	2162790000
19	0.23	170418	1.06	2.44	1883265	11.76	1704180000
20	0.24	123407	0.77	1.77	2006672	12.53	1234070000
21	0.25	260618	1.63	3.74	2267290	14.16	2606180000
22	0.26	100870	0.63	1.45	2368160	14.79	1008700000
23	0.27	99995	0.62	1.43	2468155	15.41	999950000
24	0.28	88352	0.55	1.27	2556507	15.96	883520000
25	0.29	93491	0.58	1.34	2649998	16.55	934910000
Min	0.05	1	0.00	0.00	1173	0.01	10000
Max	0.92	260618	1.63	3.74	6971130	43.53	2606180000
Avg	0.49	79217	0.49	1.14	4175812	26.07	792173864
StD	0.26	69227	0.43	0.99	2463913	15.38	692272234
Sum	42.68	6971130	43.52	99.96	367471485	2294.46	69711300000

Fig. 9. The overall weight (upper) produced by averaging the 5 factor weight maps and the corresponding histogram (lower) based on overall weight on the landslide

5.7 Susceptibility assessment

Based on the weights assignment, we carried out the susceptibility assessment. The final weights of the resulting map ranged from 0.05 to 0.92. The hazard map was grouped into three simplified categories based on the histogram of the final weight map shown in Fig. 10: high, moderate and low (Fig. 9). Low hazard corresponded to the range of (0.05-0.34), the moderate to (0.34-0.6) and the high one to (0.6-0.92). According to the susceptibility map shown in Fig. 10, we got the statistics of area and percentage of Landslide Susceptibility Classes, which is given in Table 4. We found that the area of 11866.3 sq.km (17.03%) located in the high hazard zone.

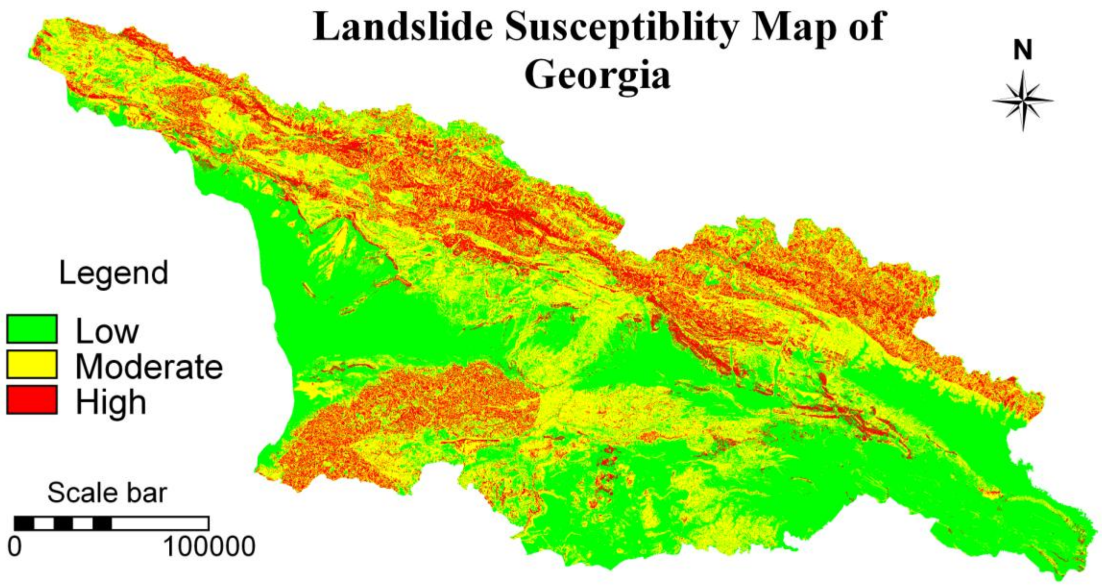


Fig. 10. Landslide susceptibility map of Georgia

Table 4. Area and percentage of landslide susceptibility classes

HAZARD	Area (sq. km)	%
low hazard	30847.3	44.25
moderate hazard	26997.6	38.72
high hazard	11866.3	17.03
Total area	69711.3	100

6. CONCLUSIONS AND RECOMMENDATIONS

In Georgia, unfortunately landslide inventory covering the entire country is not available. Therefore, it is not possible to re-classify the landslide inventory map according to regions, or municipalities to obtain the landslide hazard map, which is one of the two required components of the national landslide risk map.

In landslides, lithology is found to have more influence than land cover for the susceptibility map.

Slopes have more influence than land cover for the susceptibility map.

According to the susceptibility map we got the statistics of area and percentage of Landslide Susceptibility Classes. We found that the area of 11866.3 sq.km (17.03%) located in the high hazard zone. 38.72% in the moderate hazard zone and 44.25 in low hazard zone.

The resulting landslide susceptibility map is not a static one, as a number of indicators have a temporal variability, and the landslide susceptibility map should therefore be updated regularly.

The use of landslide susceptibility map for provinces and municipalities is useful for ranking them in order of importance for landslide risk reduction measures.

This study was one of the first steps in the national landslide risk assessment, and it is necessary to follow it up with studies at a larger scale.

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