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Geological hazard assessment in Georgia

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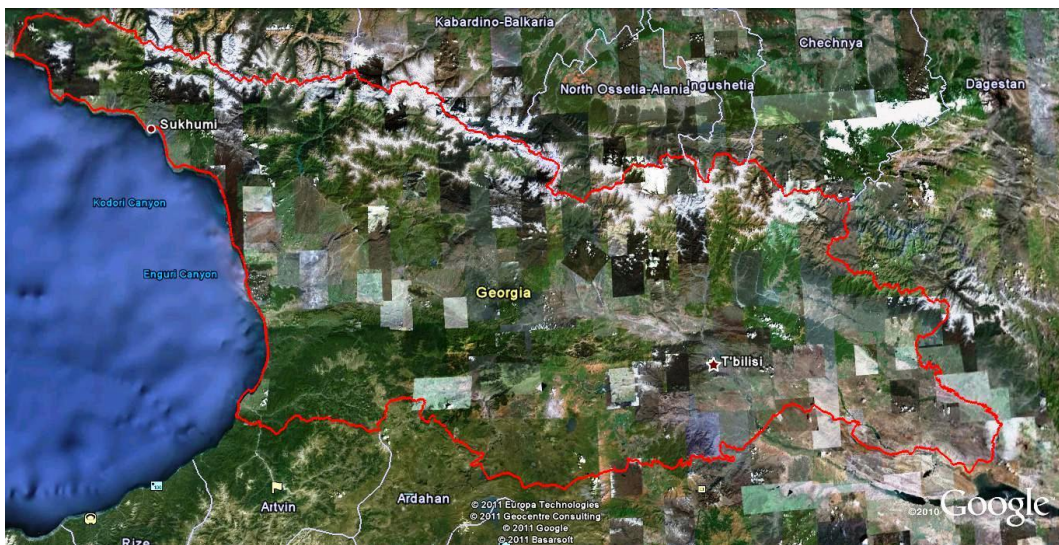
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1. The Study area

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.



The Study area – Georgia (Source: Google Earth)



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 Geological 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.

2. Data Description

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

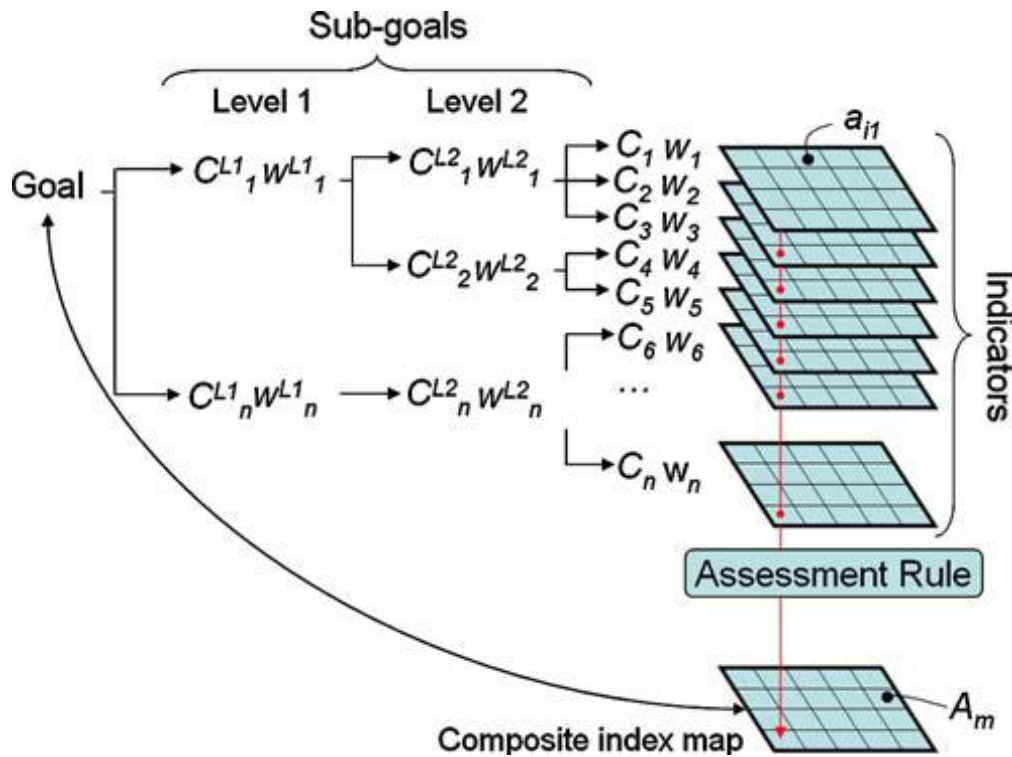
- Topographic map data at 1:50,000 scale
- Geology map of Georgia (scale 1:500 000)
- Faults (from Geology map scale 1:500 000)
- Roads (from topographic map scale 1:200 000)
- Landcover Data (scale: 1:500 000)
- Geomorphology map (scale 1:500 000)
- Physical-Geographical Zoning map (scale 1:500 000)
- Hydrography (from topographic map scale 1:25 000)
- PGA map – national building codes of Georgia (2009)
- Landslide inventory map
- Mudflow inventory map
- Rockfall inventory map

3. 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).



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

3.1 Standardization, 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.

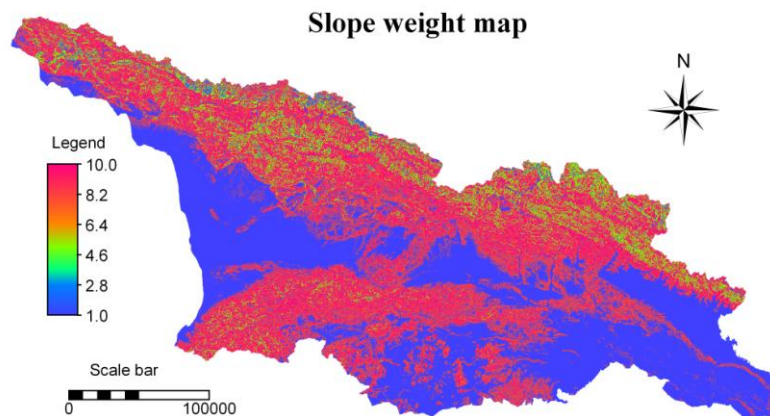
The most important constraint indicator used for the national landslide risk assessment is the slope angle. In areas that have very gentle or flat slopes, landslides are not expected or occur only under very specific conditions. After selecting the appropriate indicators, defining their standardisation 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.

4. Parameter maps

4.1 Slope gradient

Topography is one of the most important factors in landslide, mudflow and rockfall susceptibility assessment. The slope angle is directly related to the geological hazards, it is frequently used in preparing geological 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.



Slope weight map

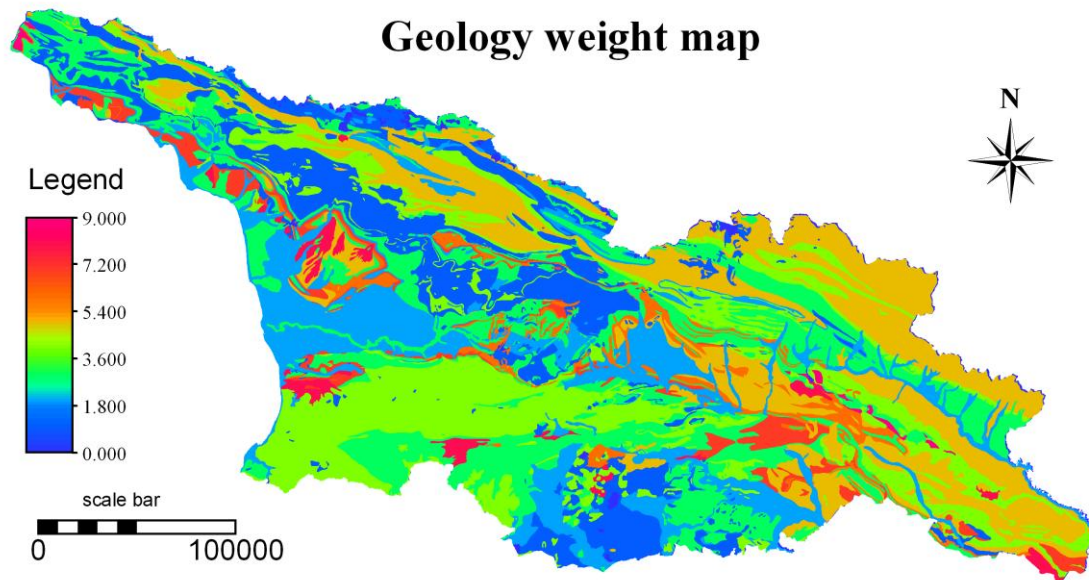
4.2 Geology

The landslide, mudflow, rockfall phenomenon, a part of the geomorphologic studies and research, is related to the lithology and weathering properties of the material of the land. There are many previous studies showing the correlation of geological hazards frequency with lithology.

Within each stratigraphical unit, there are 145 lithological units. These units were given a value for the likelihood of hazards, with values ranging from 0 to 10, in which 10 means very prone to hazards, and 0 means not prone to hazards. Which later were 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)

<i>ID</i>	<i>index</i>	<i>Lithology</i>	<i>Value</i>
63	K2t-m	Turoian, Coniacian, Santonian, Campanian and Maastrichtian stages. Adjara-Trialetian zone: thinbedded red-coloured and pink limestones and marls, bedded lithographic limestones with intercalations 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 Ckhaltalaila zones: clay and sandy shales, argillites, sandstones and siltstones, lavas and tuffs of tholeiitic basalts	4



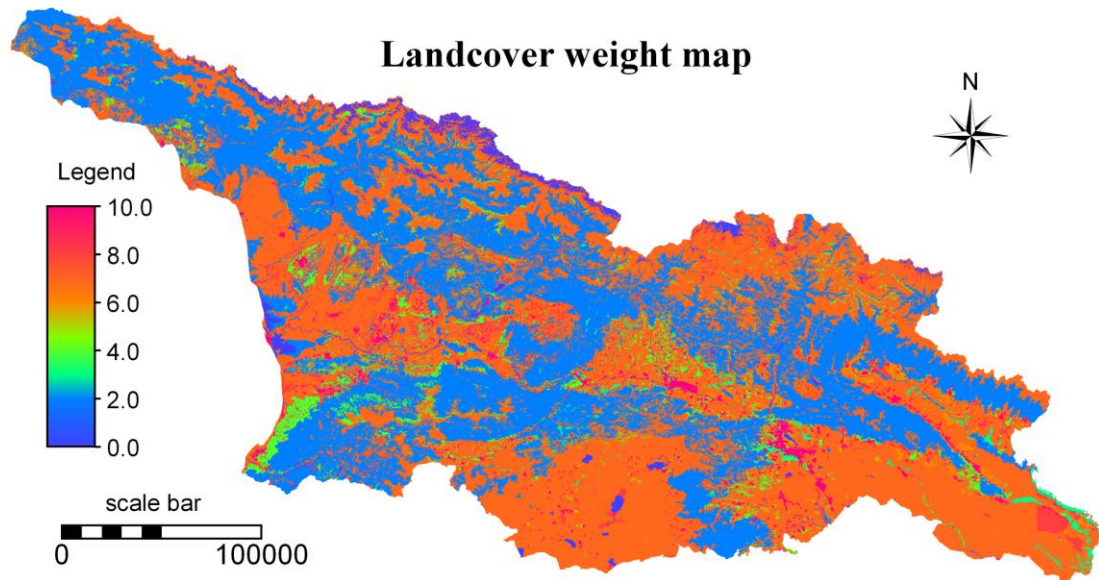
Geology Weight map.

4.3 Landcover

Landcover was chosen as another criterion. According to other studies (Dilley, Chen et al., 2005; Hong, Adler, et al., 2007), the geological hazards susceptibility for global land cover are assigned with numerical values. In our study area Georgia, there are 31 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

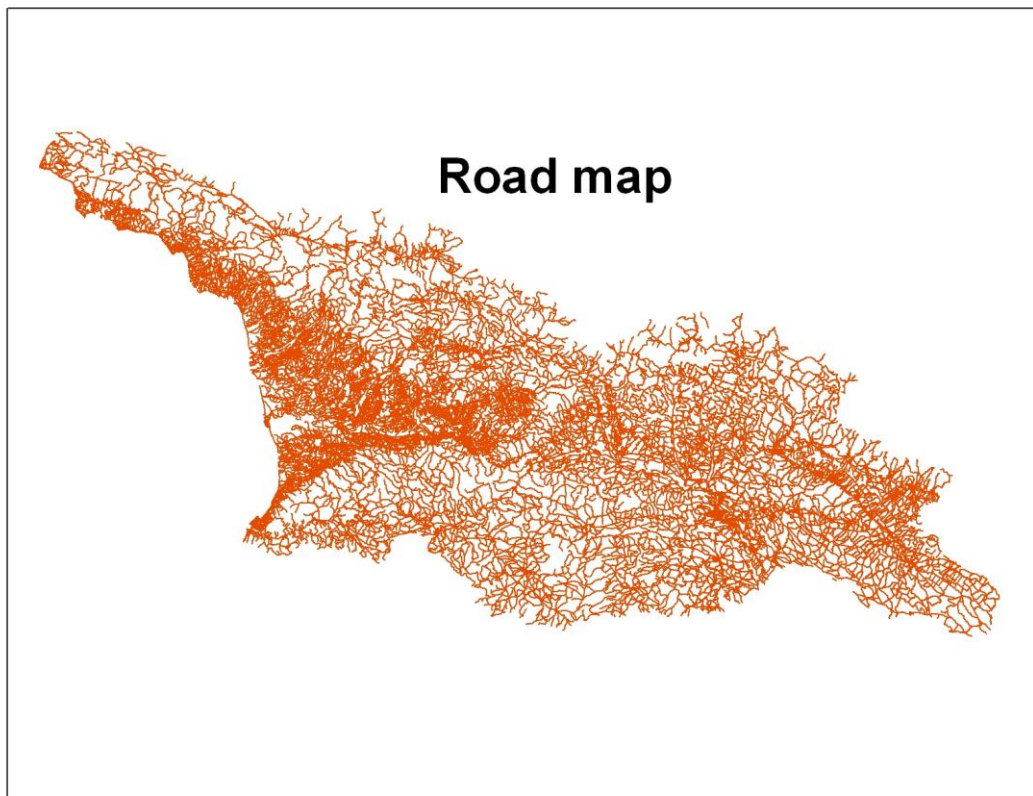
Standardized value	Landcover type
0	Lake, glacier, water reservoir, large river, wetland
1	Bare glacial moraine, badland, rocky
2	Dense forest
3	Open forest, park
4	Orchard, Scrub
5	Urban park
6	Vineyard
7	Grass land, Island
8	Agriculture land
9	Bare river sand
10	Settlement area, urban area, cemetery,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



Landcover weight map

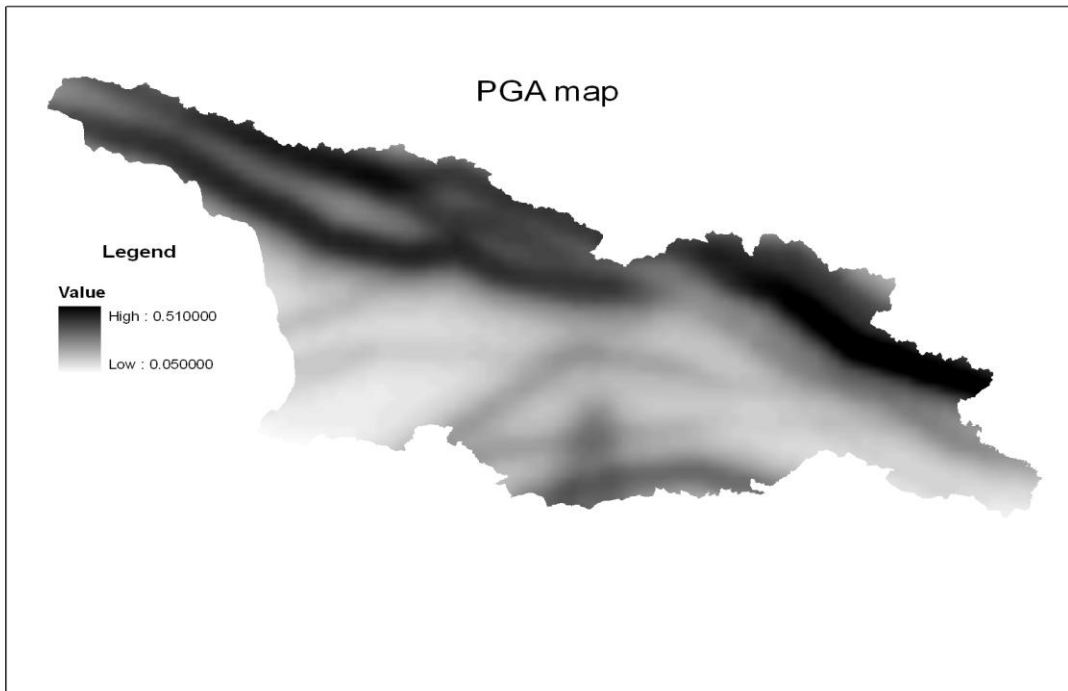
4.4 Distance to the road network

Construction of roads also influences the density of geological hazards, 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.



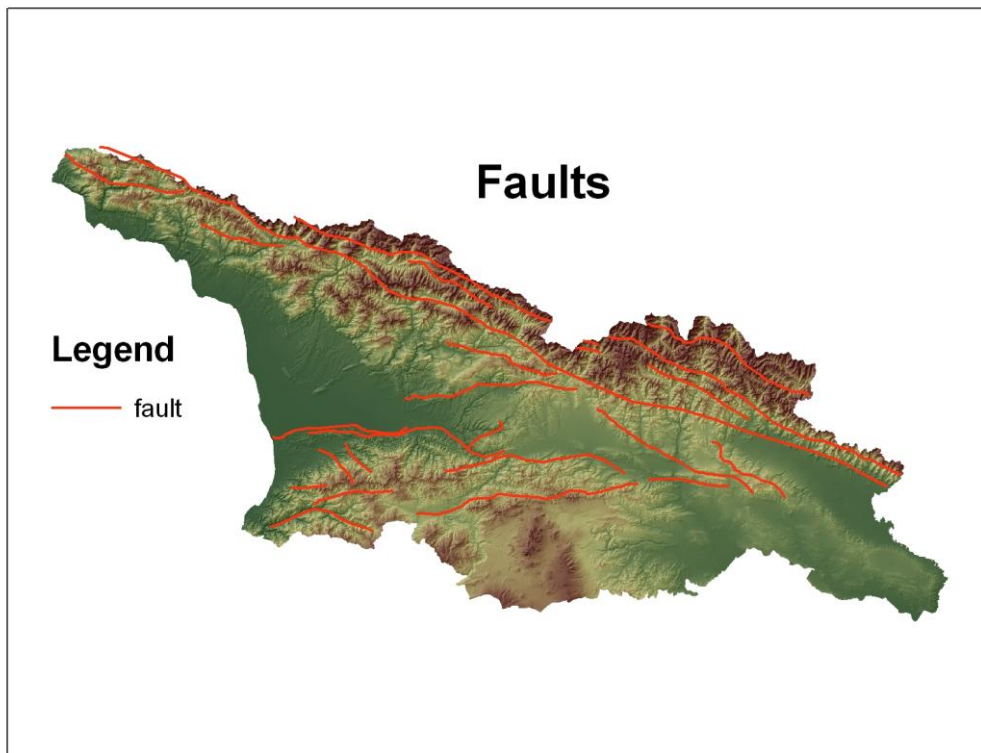
4.5 PGA

The maximum peak ground acceleration (PGA) with a 50 year return period was used as an indicator map in a study. The PGA values obtained for Georgia ranges between 0.05 and 0.51g, with a mean of 0.25 (0.11SD).

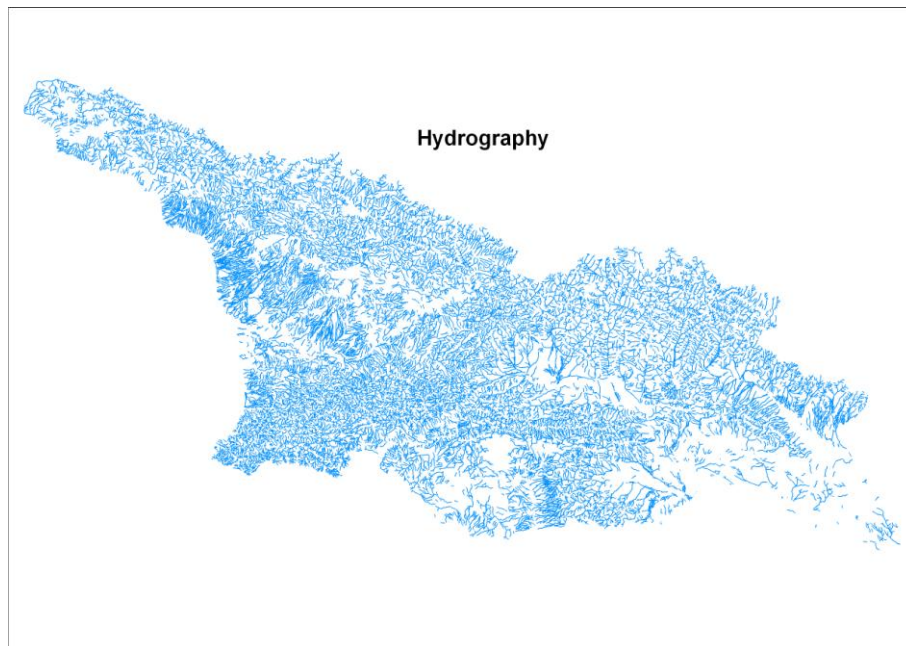


4.5 Distance from Faults

Distance from major Faults was chosen as another criterion. There are several major Faults in our study area, but only major active Faults cause hazards 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.



4.5 Distances from Hydrography – river were grouped by classes.



4.6 Geomorphology map – map was digitized from national atlas of Georgia (1964) scale was 1:500 000.

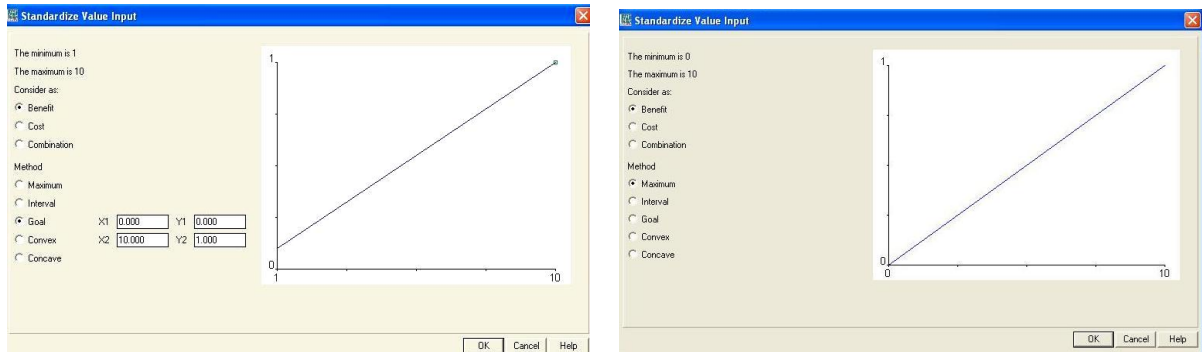
4.7 Physical-Geographical Zoning map – map was digitized from national atlas of Georgia (1964) scale 1:500 000.

4.8 Hazard inventory maps – created from NEA formational bulletins since 2004.

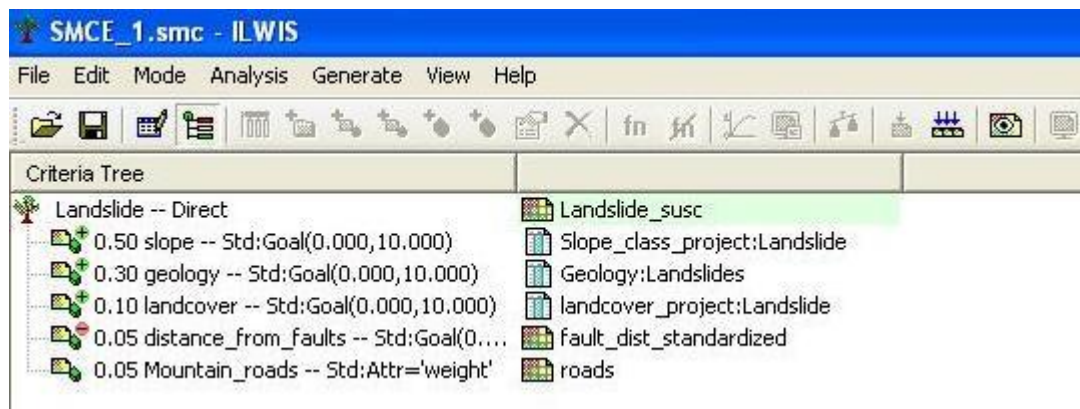
5.6 Weight assignment

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.



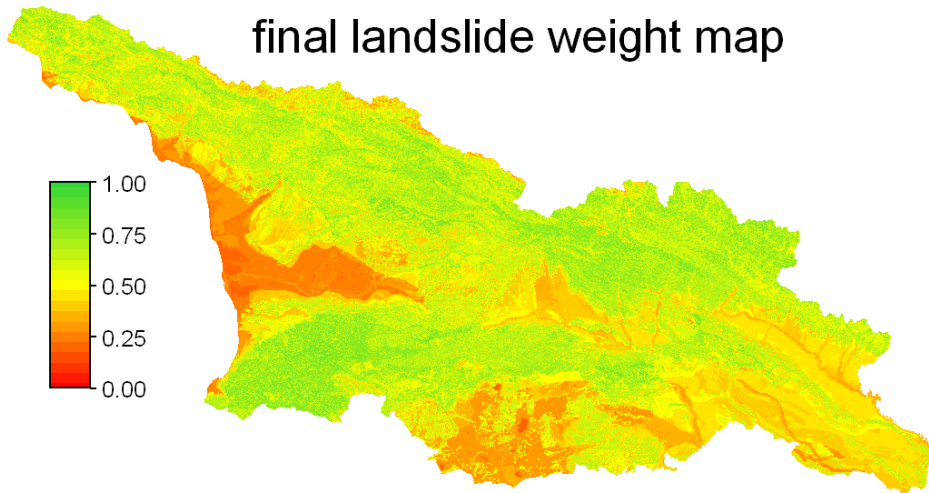
Standardization of factor maps



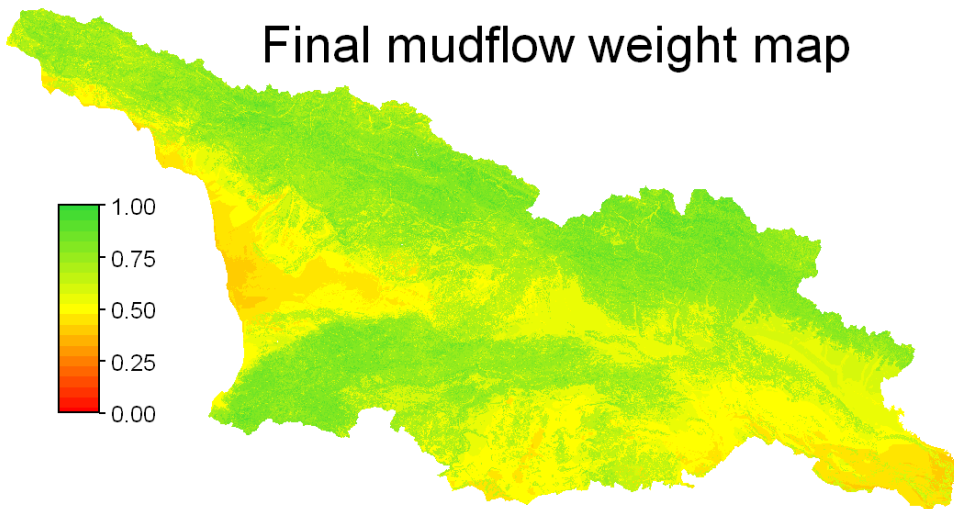
weighting of factor maps

The parameters were combined in SMCE to produce landslide, mudflow, rockfall susceptibility maps. 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.

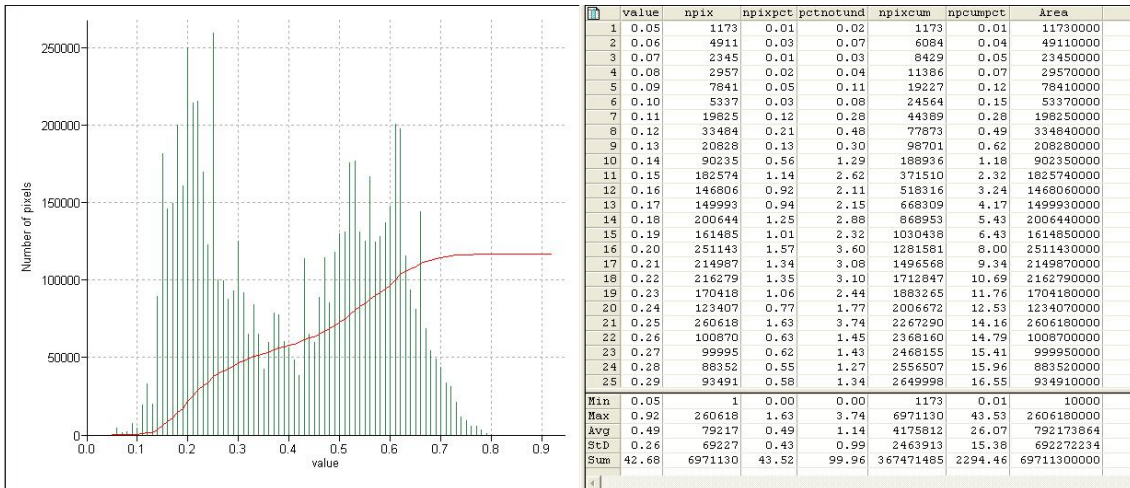
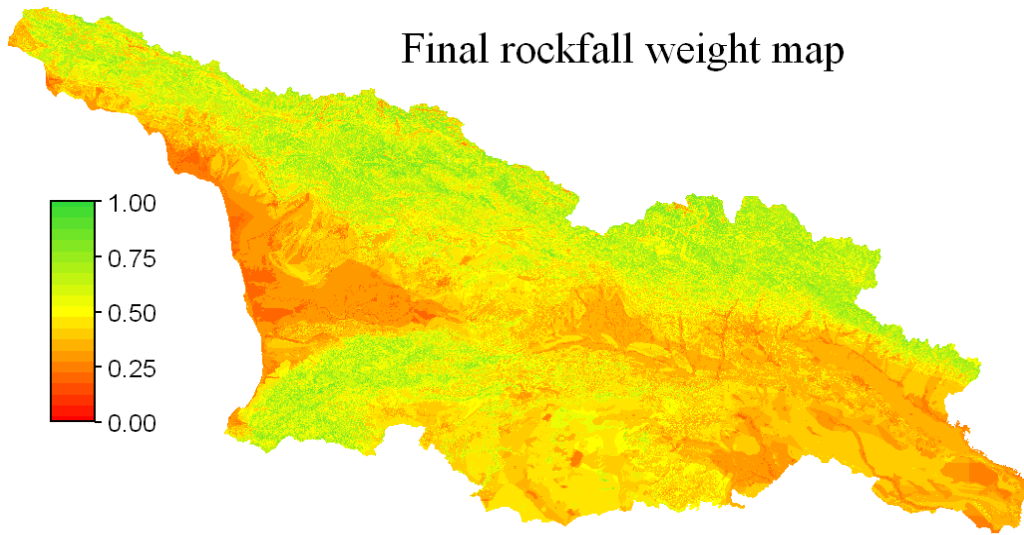
final landslide weight map



Final mudflow weight map

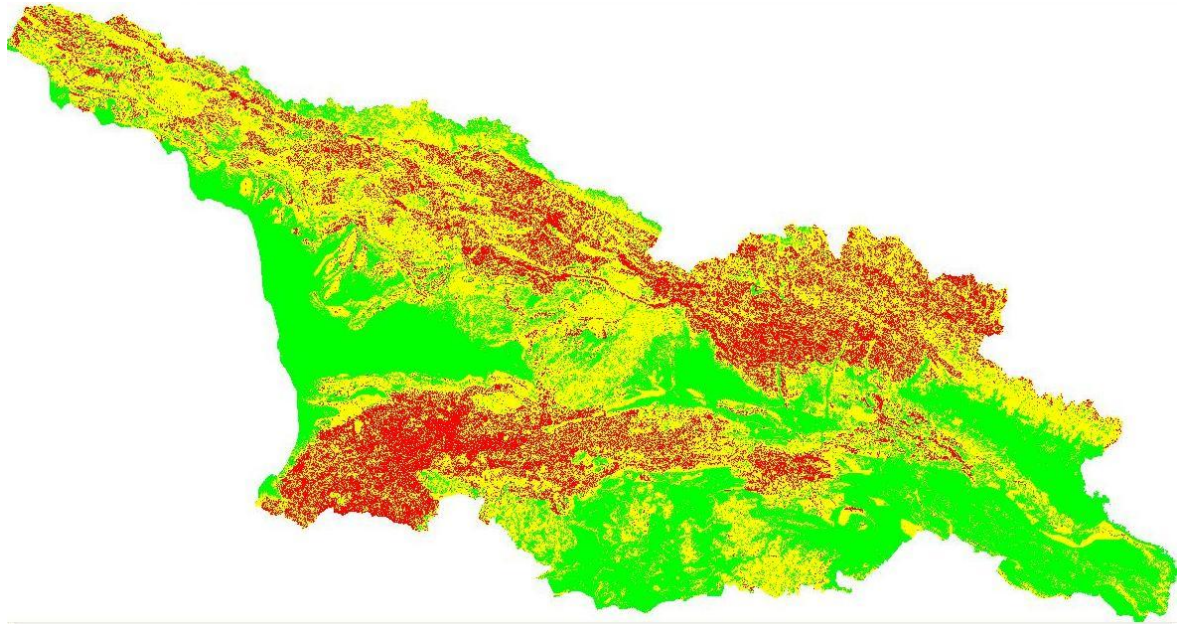


Final rockfall weight map

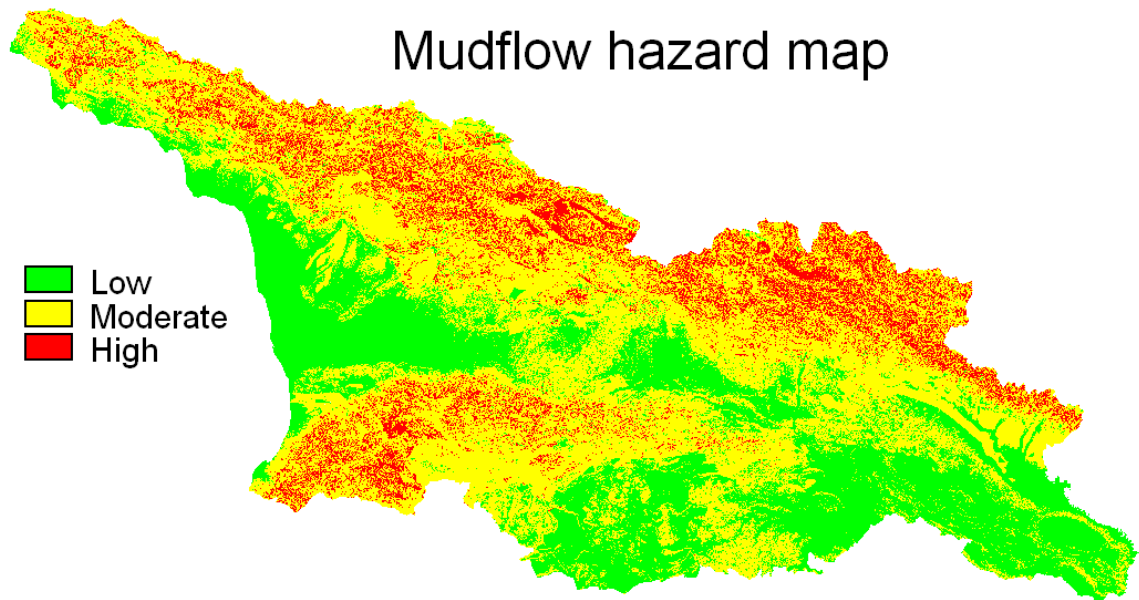


5.7 Susceptibility assessment

Based on the weights assignment, we carried out the susceptibility assessment. The final weights of the resulting map ranged from 0.06-0.93 (landslide), 0.0-0.96 (mudflow), 0.0-0.9 (rockfall).

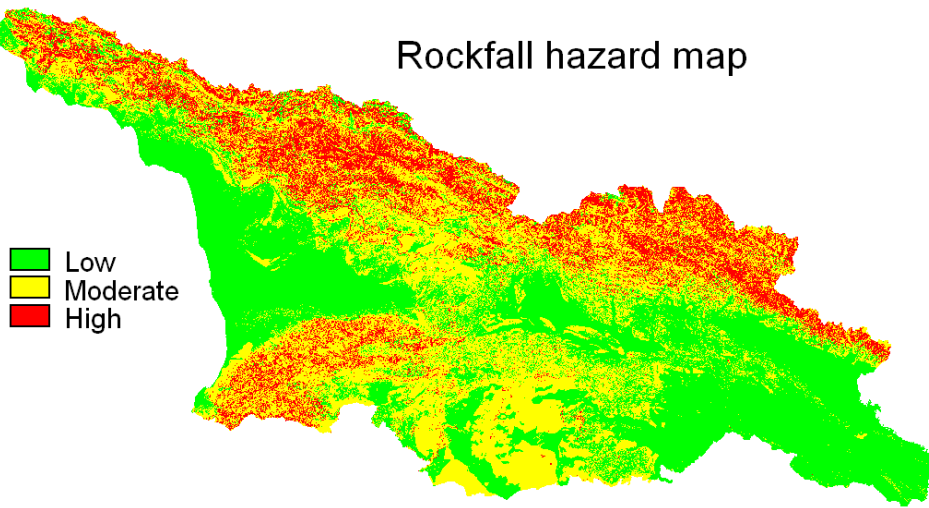


Landslide susceptibility map of Georgia



Mudflow hazard map of Georgia

Rockfall hazard map



rockfall hazard map of Georgia