LANLDSIDE HAZARD, SOCIAL-ECONOMIC VULNERABILITY AND PHYSICAL (BUILDINGS) RISK ASSESMENT

SAGAREJO MUNICIPALITY CASE STUDY

(PROJECT)

1. Introduction

The landscape, geology, geomorphology and climate of the territory of Georgia create favorable condition for development of active geological processes. As a result the landslide processes affecting the social and economic development of the country are widespread on the greater part of the territory of Georgia. Therefore, the study of landslide processes using modern technologies and widely applied new methodologies is important.

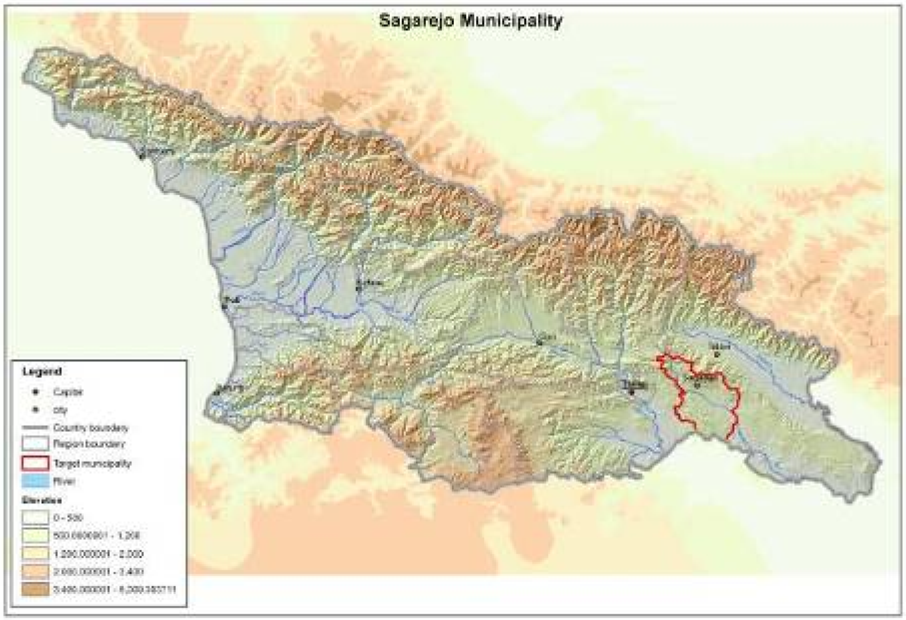
The aim of the mentioned study is to assess landslide hazard, social-economic vulnerability and physical (buildings) risk on the example of the Sagarejo municipality (Georgia) using the quantitative method. The mentioned method is based mainly on landslide field inventory carried out for this specific case. Moreover, the factors influencing on the development of the landslide processes such as slope inclination and exposition obtained from the digital elevation model, land use and stratigraphy will be used. On the basis of the analysis of the mentioned data a landslide susceptibility map at the community level will be developed. During the assessment of social-economic vulnerability of the Sagarejo communities the following information obtained through participatory approach will be used: gender-age structure of the communities of the target municipality, number of people employed in budgetary sector, number of socially vulnerable families, distance from the municipal center, average area of agricultural lands per capita, average density of the population by communities.

Specific objective of the project include:

- To identify spatial criteria for landslide hazard assessment in the Sagarejo municipality;
- To develop a landslide susceptibility map of the target municipality using the Spatial Multi Criteria Evaluation (SMCE) Method and identification of advantages and limitations of this approach;
- To develop a physical (buildings) risk map of the Sagarejo municipality through crossing of the landslide susceptibility map with cadastre data of buildings;
- To develop a social-economic vulnerability map of Sagarejo municipality at the community level using Spatial Multi Criteria Evaluation (SMCE) Method and participatory approach;
- To use ILWIS and ArcGIS software as a tool.

The Sagarejo target municipality is located in the eastern part of Georgia, in Kakheti region. Its area is about 1,520 km^2, population is 65,067 according to the data of 2010. Municipal center is the city of Sagarejo. The target community is bordered by the Akhmeta and Telavi municipalities on north, the Gurjaani and Sighnaghi municipalities on east, the Mtskheta and

Tianeti municipalities on west. Its southern border coincides with the state frontier of Georgia with Azerbaijan. Refer to Map 1.



Map 1. The Sagarejo municipality, Georgia

The mountainous northern part of the Sagarejo municipality is located within the south-western section of the Gombori range. Its southern part covers the territories of the Iori plateau bounded by the Iori river gorge on east and the line passing on the ridge stripe of the Natakhtari (966 m), Demurdagi (990) and Didi Udabno mountains.

The river Iori and its tributaries: Vashliani and Gomboriskhevi are the rivers characterized by permanent liquid runoff within the Sagarejo municipality.

The majority of the Sagarejo municipality in engaged in agriculture. The main sources of income of the local populations are cash resources from selling agricultural products. Winegrowing, vegetable and melon growing are well developed. The local population also cultivates wheat, barley and other crop plants. Cattle breeding and pig breeding are also widespread.

2. Used data

The following data were used for the assessment landslide hazard, resulting physical (building) risk and social-economic vulnerability in the Sagarejo municipality:

1. The map of current landslide prone areas of the Sagarejo municipality developed through the participatory method (for questionnaire see annex 1.)

2. The digital-stratigraphic map of Georgia (scale: 1:500 000)

3. Data of the digital topographic map of Georgia (scale: 1:50 000)

4. The digital land-use map of Georgia (cadastre data)

5. The digital map of buildings of Georgia (cadastre data)

6. Social-economic data of the Sagarejo municipality obtained through the participatory method (for questionnaire see annex 2.):

    - Population density
    - Age structure (number of people under 16 and older 65)
    - Gender structure (number of women)
    - Number of socially vulnerable families
    - Number of local people employed in budgetary sector
    - Area of agricultural lands per capita
    - Distance from the municipal center

7. **"The consequences of development of natural geological processes in 2010 in Georgia and prognosis for 2011" information bulletin** – of The National Environmental Agency (NEA), The Ministry of Environment Protection and Natural Resources of Georgia.

3. Methodology

3.1 Work flow

The study as shown on the Diagram 1 is based on the assessment of the physical vulnerability on the example of the Sagarejo municipality implemented by overlaying of the landslide hazard with the number of buildings. The final result is the identification of physical vulnerability of landslide hazard. Among the used data the landslide inventory (in this case implemented through participatory method) is the most important component in landslide vulnerability assessment. The other components, such as stratigraphy, land-use, digital elevation and topographic data were used too. On the basis of analysis and processing of these data the existing landslide hazards and risks can be assessed and the future landslides can be predicted.

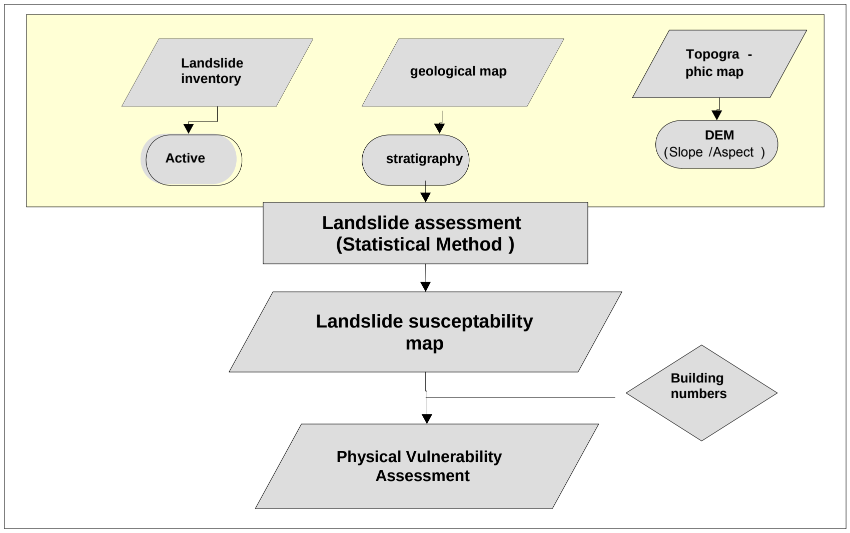


Diagram1. The method of physical vulnerability assessment in the Sagarejo municipality, Georgia

3.2. *Methodology*

To assess the landslide vulnerability the statistical methodology based on “active” landslide type was used. First of all the landslide susceptibility map was created using the statistical methodology called hazard index method and calculated by the following formula:

$$W_i = \ln\left[\frac{Densclas}{Densmap}\right] = \ln\left[\frac{Area(Si)}{Area(Ni)} \Big/ \frac{\sum Area(Si)}{\sum Area(Ni)}\right]$$

where Wi is a weight assigned to the following 4 parameters: aspect, exposition, stratigraphy and land-use. Densclas is a landslide density in each parameter class. Densmap is a landslide density on the whole map. Area (Si) is an area of the landslide in each parameter class, while Area (Ni) is a total area in each parameter class.

The methodology is based on crossing of the active landslide map with the abovementioned 4 parameters maps. The result of map crossing is given the table received as a result of crossing. The table can be used for calculation of landslide density for each parameter class. The density data can by standardized through linking these data with the density of the whole territory. The interrelation shall be established through division or subtraction. In this case the landslide density for each class was divided by the landslide density of the whole map. Natural logarithm was used for assigning negative weights in the cases where the landslide density was below the norm, and positive weights – where the landslide density was above the norm.

Landslide hazard susceptibility map was developed through merging 4 component weight maps. The resulted weight then was grouped into 3 classes: low, medium and high susceptibility classes. Diagram 2 illustrated the mentioned method in more details.

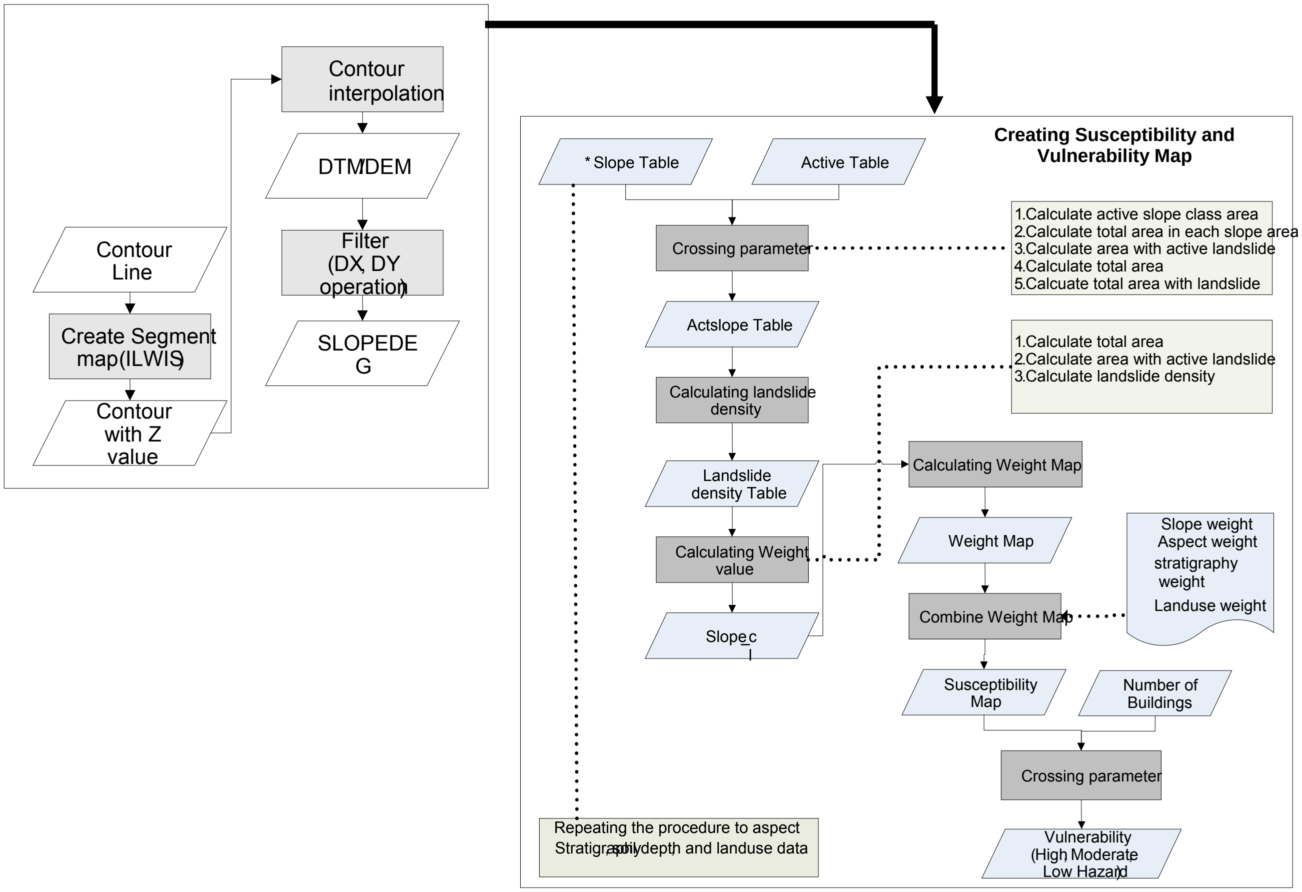


Diagram №2. The methodology of development of landslide susceptibility map of the Sagarejo municipality, Georgia

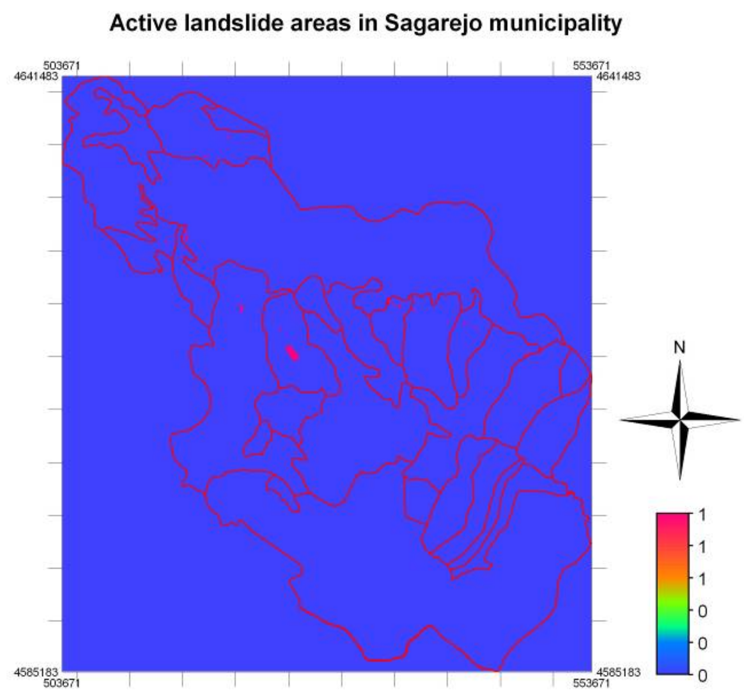
4. Results

4.1. Relief parameters

All relief parameters for the target municipality were generated from DEM, while DEM was derived from the contour map. Slope inclination and exposition are essential components for SMCE based landslide susceptibility assessment. Please refer to Diagram 2.

4.2. Identification of active landslides

Active landslides were identified using the participatory method, implying active involvement of the local population in the process of identification of landslide areas. During the process of identification it was revealed that the landslide processes are developed mainly in the northern part of the target municipality, in foothills areas of the Gombori range. Their triggering factors and characteristics are different. Please refer to Map 2.



Map №2. Map of active landslide areas in the Sagarejo municipality

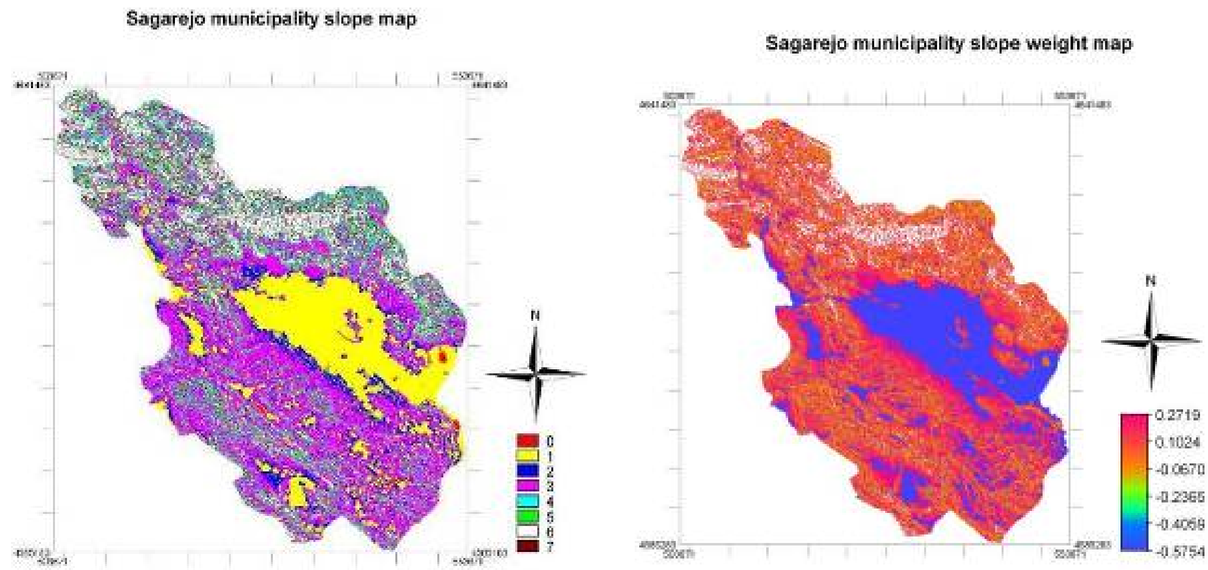
Besides using participatory methodology for identification active landslides within target municipality, also for preliminary landslide identification annual informational bulletin of the National Environmental Agency have been used. In the bulletin each year specialists of NEA identify existing natural hazard in all regions of Georgia and predicting their future evolution. Based on this bulletin we preliminary identified active landslide areas for Sagarejo municipality.

4.3. Weight assignment

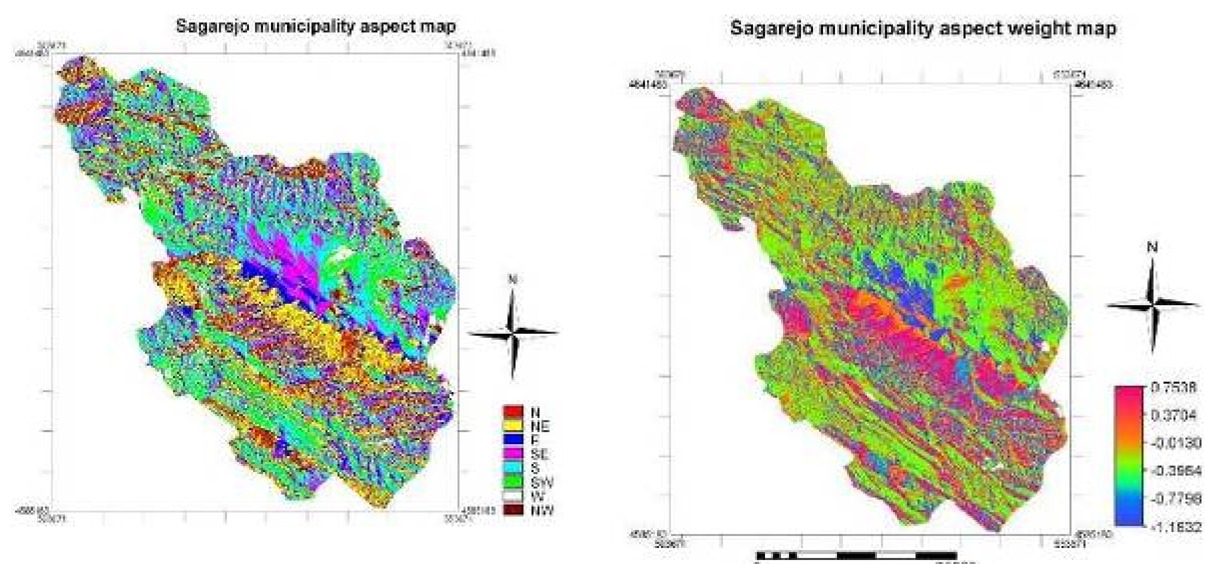
To identify the main reasons of activation of landslide processes the weights of following parameters were calculated: slope aspect, slope exposition, stratigraphy and land-use with the following formula:

$$W_i = \ln\left[\frac{Densclas}{Densmap}\right] = \ln\left[\frac{Area(Si)}{Area(Ni)} \Big/ \frac{\sum Area(Si)}{\sum Area(Ni)}\right]$$

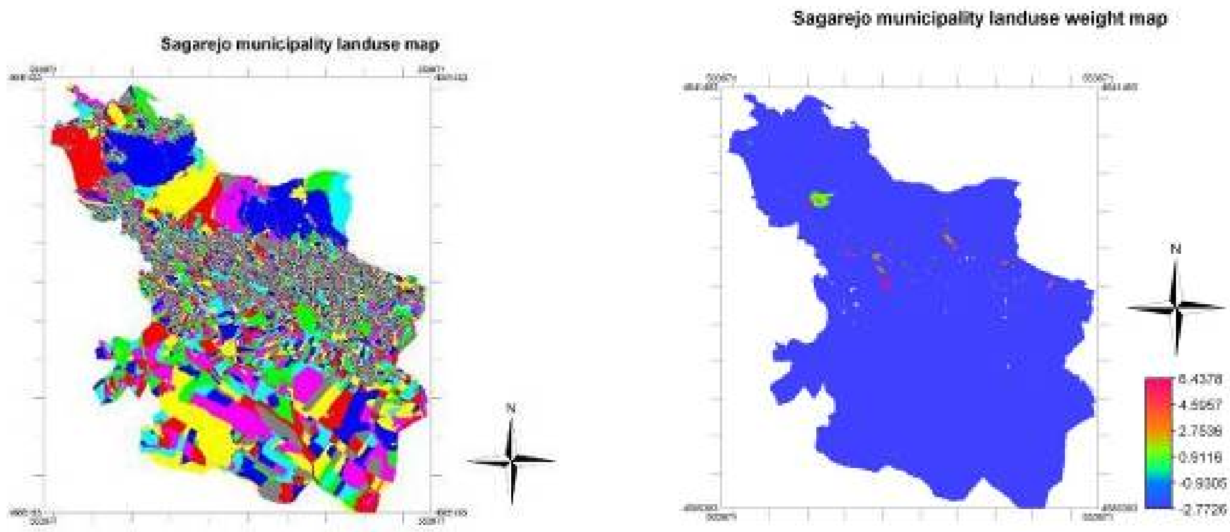
Different landslide triggering factors have different influence on the process of landslide development. In particular, a factor may facilitate the development of the geodynamic process, or hamper its activation. The results of parameter weighting are presented below.



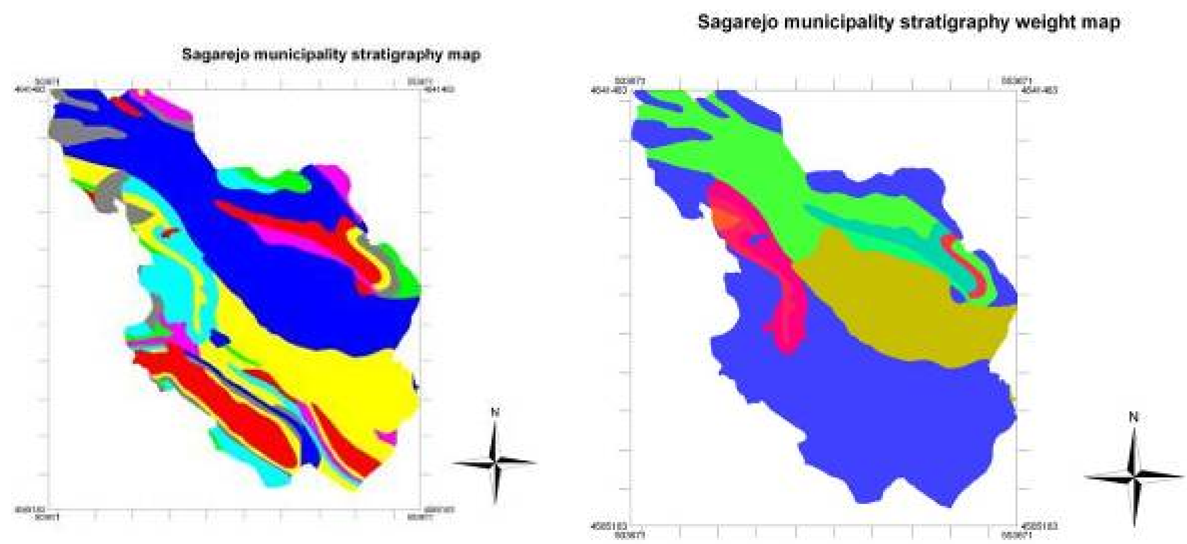
Maps №3,4. Sagarejo municipality slope and slope weight maps



Maps №5,6. Sagarejo municipality aspect and aspect weight maps

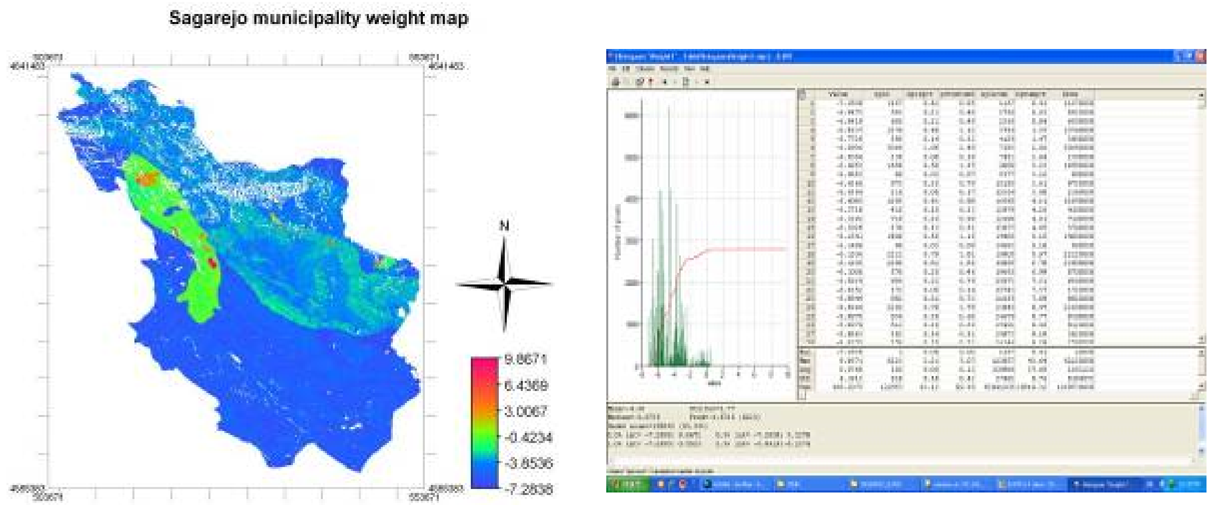


Maps: №7,8. Sagarejo municipality land-use and land-use weight maps



Maps: №9,10. Sagarejo municipality stratigraphy and stratigraphy weight map

The Sagarejo municipality weight map was derived through weighting and crossing of mentioned parameters. See below.



Map: №11. Sagarejo municipality weight map

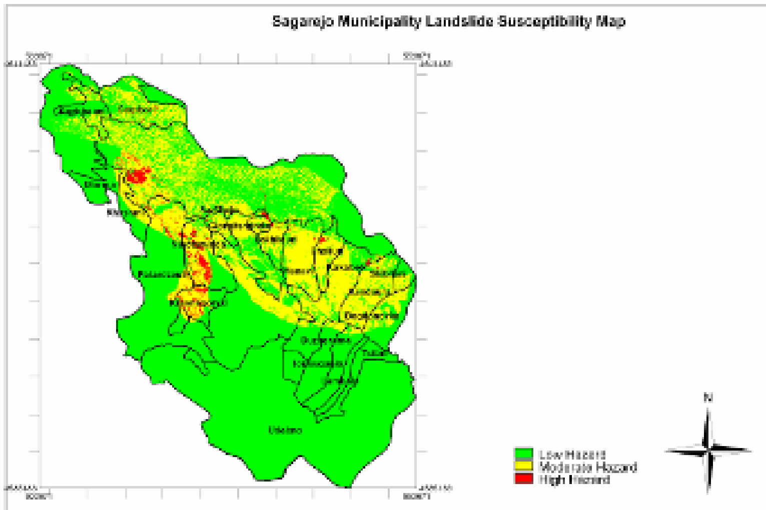
The map shows that the active landslide processes are developed mainly on the slopes of north-eastern exposition with an inclination of 10-15 degrees within the privately owned arable lands and perennial plantations *(note: there was no data base attached to the stratigraphical digital map).*

Table:№1

Map of triggering factors	Slope (degree)	Slope exposition	Land-use	Stratigraphy
The most affected types	10-15	North-east	private – arable lands, perennial plantations	N/A

4.4. Susceptibility assessment

On the basis of the Sagarejo municipality weight map the landslide susceptibility of the Sagarejo municipality was assessed and the relevant map was developed. Please refer to Map 12.



Map: №12. Sagarejo municipality landslide susceptibility map

The weight of the landslide susceptibility map ranges from 7.28 to 9.86. The mentioned map is a good tool for assessment of the landslide hazard in the target municipality. To facilitate the perception of the landslide susceptibility map the three colors - red, yellow and green were used. Red color indicates a zone of high landslide hazard (from 0 to 10), yellow – a zone of medium landslide hazard (from -4 to 0) and green – a zone of low landslide hazard (from -7.28 to -4).

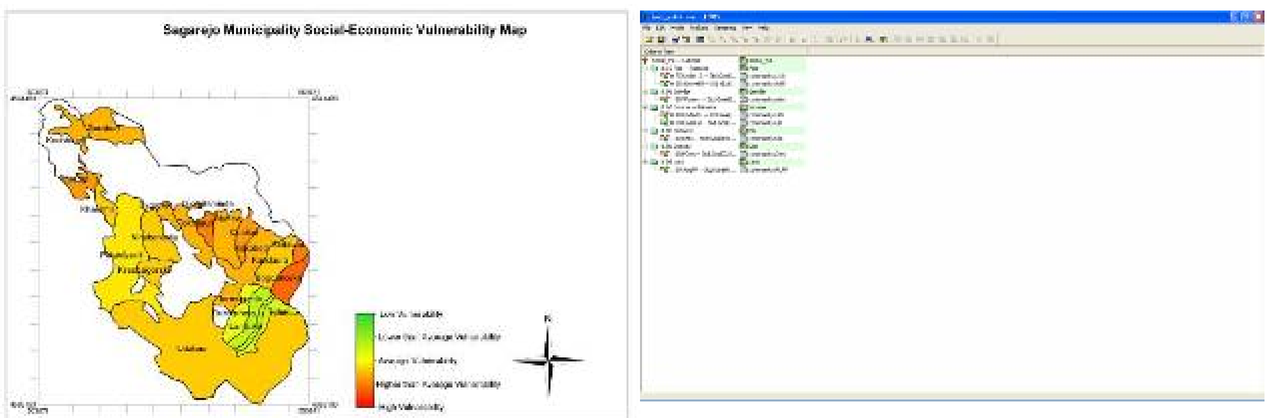
The following data were received as a result of analysis of the mentioned map: 1.082 km^2 (71% of the total area of the Sagarejo municipality) are within a low landslide hazard zone, 418 km^2 (27% of the total area of the Sagarejo municipality) - within a medium landslide hazard zone, and 20 km^2 (2% of the total area of the Sagarejo municipality) - within a high landslide hazard zone.

Table:№2

Landslide hazard	area (km^2)	% of total area
High hazard	20	2%
Medium hazard	418	27%
Low hazard	1,082	71%
Total:	1,520	100%

4.5. Social-economic vulnerability assessment

Besides the landslide hazard map of the Sagarejo municipality the social-economic vulnerability map of community level of the Sagarejo municipality was developed within the framework of this project. The social-economic vulnerability was assessed using the participatory method at the level of 20 communities and 1 city of the municipality. The following indicators were used for the assessment: percentage of women in the community, percentage of people under 16 and above 65 in the community, percentage of people engaged in the budgetary sector, percentage of socially vulnerable families, distance from the municipal center, average density of the population in the community, area (ha) of agricultural lands per capita. Please refer to Map 13.



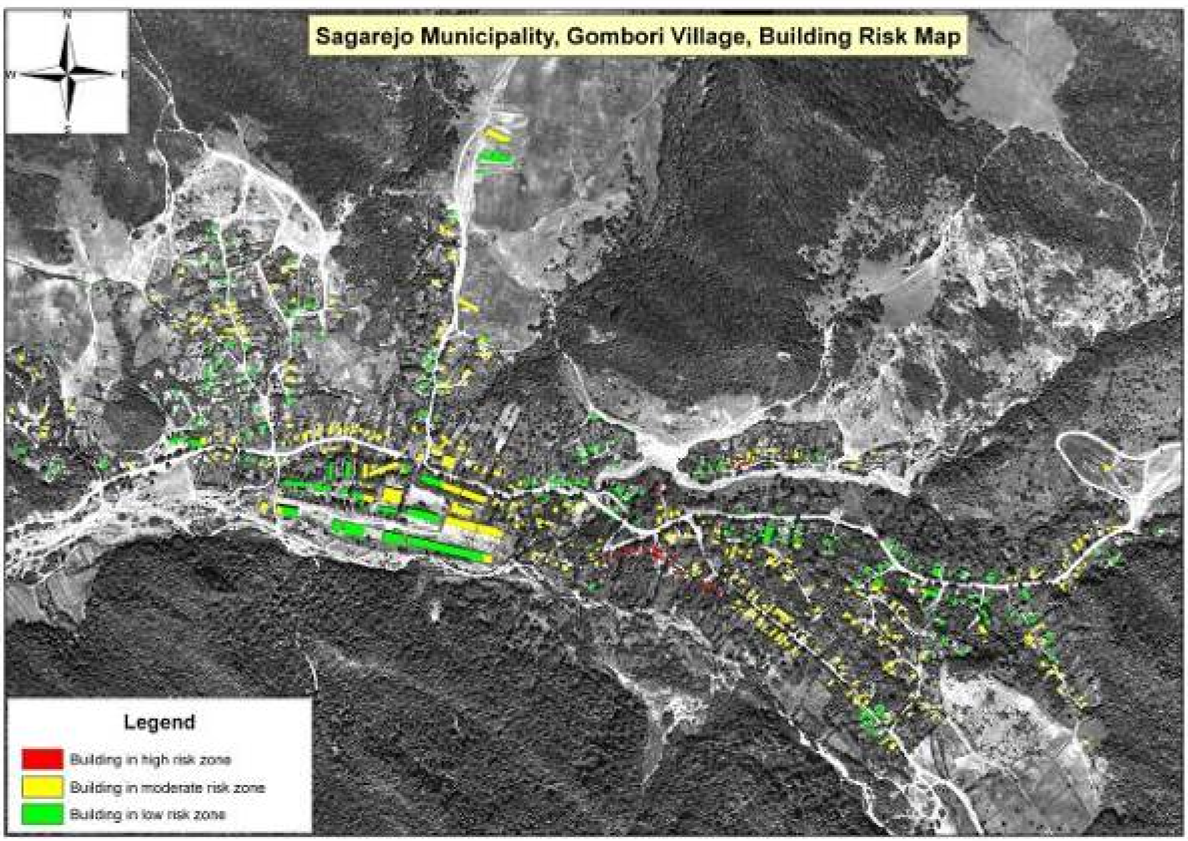
Map №13. Sagarejo municipality social-economic vulnerability map

Colors shading off from green into red indicate the worsening of social-economic conditions for each community of the Sagarejo municipality.

The analysis of the above-mentioned indicators showed that the Bogdanovra, Shibliani, Tokhliauri, Ujarma, Gombori, Kochbaani and Chailuri communities are characterized by relatively hard social-economic conditions among other communities of the Sagarejo municipality. The better social-economic situation is observed in the Iormuganlo, Duzagrama, Lambalo, Tulari and Patardzeuli communities. SMCE was used for development of the mentioned map. A criteria tree incorporating all data obtained as a result of field works carried out in each community of the Sagarejo municipality was created.

4.6. Physical risk assessment

For physical risk assessment the cadastre data of buildings were used. The mentioned data was overlaid on the landslide hazard map through crossing. As a result the buildings located within the high, medium and low risk zones were identified (red – a zone of high risk, yellow - a zone of medium risk, green – a zone of low risk). The risk analysis showed that among 22,382 buildings of the Sagarejo municipality (cadastre information) 240 buildings (1%) are located within the high risk zone, 12,829 (57%) – within medium risk zone and 9,313 buildings (42%) – within the low risk zone. Please refer to Map 14.



Map:№14. Sagarejo municipality, village Gombori, Building risk map

Table: №3

Class	Number of buildings	% of the total number of buildings
High risk	240	1%
Medium risk	12,829	57%
Low risk	9,313	42%
Total	22,382	100%

5. Conclusions

The aim of the mentioned project was to assess landslide hazard, social-economic vulnerability and physical (buildings) risk of the Sagarejo municipality (Georgia) and to develop relevant maps using Spatial Multi Criteria Evaluation (SMCE) and participatory methods. ILWIS and ArcGIS had to be used for the purpose of this project. The project also aimed at identification of shortcomings and advantages of the mentioned methods.

The study revealed that 1% (240 buildings) of the buildings of the Sagarejo municipality is located within the high risk zone, 57% (12,829) - within medium risk zone and 42% (9,313) - within the low risk zone.

The analysis of the 8 social-economic indicators showed that the Bogdanovra, Shibliani, Tokhliauri, Ujarma, Gombori, Kochbaani and Chailuri communities are characterized by relatively worse social-economic conditions among 20 communities and 1 city of the Sagarejo municipality. The better social-economic situation is observed in 5 communities: Iormuganlo, Duzagrama, Lambalo, Tulari and Patardzeuli.

In terms of landslide hazards 2% (20 km^2) of the total area of the Sagarejo municipality (1,520 km^2) are within the high landslide hazard zone, 27% (418 km^2) - within the medium landslide hazard zone and 71% (1,082 km^2) - within the low landslide hazard zone.

The analysis of various parameters showed that the landslide triggering factors are slopes with and inclination of 10-15 degrees, north-eastern exposition and the territories under arable lands and perennial plantations in terms of land-use.

In terms of used methodology, availability of digital data and spatial analysis tool ILWIS it can be stated that digital information required for spatial analysis is limited in Georgia and in case of its availability – rather expensive.

As it has been stated above the participatory methodology was used in study. In case of application of the mentioned approach the local population is a main source of information on various social-economic or natural disasters. The advantage of this methodology is active involvement of the local population in provision of information, identification of local problems, searching of ways for their solving, etc. The negative factor of this approach is the low reliability of data, since the information provided by the local population is non-professional and requires verification of relevant experts. Moreover, in certain cases it is difficult to establish a cause-and–effect relationship of problems.

Also comparative analyses of annual informational bulletin of NEA and our methodology using local knowledge about landslide locations revealed, that practically all locations of active landslides in Sagarejo municipality which were included in NEA`s annual bulletin were identified using participatory methodology. Moreover, our approach revealed several other active landslide places in Sagarejo municipality which were not mentioned in annual informational bulletin of NEA. For example, landslide prone villages in target municipality such as Khashmi, Manavi, Gombori, Patardzeuli, Tokhliauri and Kakabeti were included in both reports (NEA annual bulletin and in the case study), but villages – Kochbaani, Ninotsminda, Giorgitsminda, Chailuri and Kandaura and city Sagarejo were identified only in the case study, based on the information obtained from local population.

The new tool of spatial analysis ILWIS used during the study appeared to be rather effective due to the following reasons. In particular, firstly, the risk and hazard maps allow for maximum visualization of a problem; secondly, the mentioned tool not only allows for identification of the existing problems, but also outlines and visualizes the areas of future potential risks, thus providing an effective mechanism to decision-makers for identification of priority directions and areas and planning relevant preventive measures.

6. References

1. **"Multi-hazard risk assessment"** - *Distance education course, RiskCity Exercise book, Cees van Westen (ed.), United Nations University – ITC School on Disaster Geoinformation Management (UNU-ITC DGIM) Version May 2009.*
2. **"The consequences of development of natural geological processes in 2010 in Georgia and prognosis for 2011" information bulletin** – The Department of Natural Processes, Engineering Geology, Geological Hazards and Management of Geological Environment, The National Environmental Agency, The Ministry of Environment Protection and Natural Resources of Georgia
3. **Social and Economic Information from Sagarejo Municipality Administration** – letter to CENN №2/1-122, 6 May, 2010
4. **National Statistics Office of Georgia** – www.geostat.ge

Annex 1. Questionnaire

INFORMATION ABOUT NATURAL HAZARDS IN SAGAREJO MUNICIPALITY FOR THE YEAR 2010

№	Community	№	Village	Concrete location	Type of hazard	Area of damaged territory	Damage	Elements under the risk	Time of occurrence	GPS

Annex 2. Questionnaire.

SOCIAL AND ECONOMIC DATA OF SAGAREJO MUNICIPALITY FOR THE YEAR 2010

City/Community	Population	Man	Woman	Population under 16 years	Population above 65 years	Number of families	Number of families under the poverty line	Number of people employed in budgetary sector	Total area	Area of agricultural lands