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## DEVELOPMENT OF A POSTGIS-BASED METHOD FOR CREATING RISK MAPS OF NATURAL DISASTERS USING THE EXAMPLE OF GEORGIA

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**Abstract.** This article discusses a method for creating a risk map of natural disasters for a specific area using PostGIS analysis. This method, which is described in detail, is based entirely on the use of open-source programs and spatial SQL directives. It is designed to use widely available GIS programs to create a flexible method that performs operations on OGC geometry. The area to be analyzed is covered with a polygonal grid. The size of the polygon is determined by the size of the study area. For each element of the grid (polygon), attribute values are determined for the traits characteristic of the area: seismic, landslide, mudflow, rockfall, population density, and number of buildings. The attribution values for geometry are assigned based on PostGIS analysis. The process of creating a risk map involves the summation of different hazard maps. Our method's originality lies in the fact that the initial data is transformed so that it is possible to carry out map algebra operations with vector data. The method is designed to create risk maps based on OGC vector data analysis, which will help experts and stakeholders working on risk assessment and decision-making to develop a risk management strategy.

**Keywords:** risk map, natural hazard, vulnerability, PostGIS analysis, spatial SQL.

### Introduction

#### About the method

The PostGIS method for creating risk maps of natural disasters is based on an article “Hazard, vulnerability and risk analysis” (van Westen, 2018a). The article discusses the use of raster data for creating a risk map with the Integrated Land and Water Information System (ILWIS) (ITC, 2018).

The analysis presented in the current paper is carried out with vector data using PostGIS, being the main difference between the two methods.

The data used in current paper was prepared for “Atlas of natural hazards and risks of Georgia”. The Atlas was elaborated by CENN and University of Twente’s (ITC) Geo-Information Science and Earth Observation Faculty (van Westen & Damen, 2013), with financial support provided by the Social Transformation Programme (MATRA) of the Ministry of Foreign Affairs of Netherlands.

#### Republic of Georgia

Georgia’s territory extends to an altitude of around 5,201 m above sea level. Georgia’s geographic coordinates are: in the North – latitude 43° 35′ 25″ N and longitude:

40° 23′ 31″ E. In the South – latitude 41° 02′ 58″ N and longitude: 46° 30′ E. In the West - latitude 43° 23′ 31″ N and longitude: 40° 00′ 30″ E. In the East – latitude: 41° 17′ N and longitude 46° 44′ 31″ E (Figure 1).

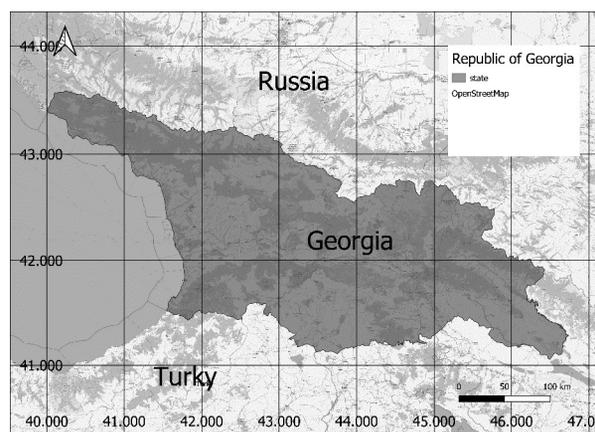


Figure 1. Republic of Georgia

The surface of Georgia’s territory characterized by complex hypsometry and is subdivided into several major altitudinal zones. At the highest part of Georgia (the

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Svaneti section of the Caucasus Range), the change in elevation within 4–20 km, ranges between 2,700–3,550 m.

Georgia is characterized by a highly diverse climate, which is further conditioned by the complexity of its landscape (topography), i.e. the spread of its territory at a high elevation and periodic penetration of air masses (characterized for tropical and polar zones) that are frequently noted in its regions.

Due to the complexity of the geological structure and the diversity of geomorphologic, hydro-climatic and geobotanical conditions, Georgia is considered to be prone to natural disasters. Earthquakes, landslides, mudflows, floods and other natural events, which cause human deaths and economic losses, are frequent. According to various sources, the economic losses caused by natural disasters during the last period has exceeded 3.5 bln GEL (van Westen, 2018a).

### Natural Hazards, vulnerability and disasters

It is important to distinguish between the terms disaster, hazard and risk. Risk results from the combination of hazards, conditions of vulnerability and insufficient capacity or measures to reduce the potential negative consequences of risk. When the hazard or threat becomes a reality, when it materializes, the risk becomes a disaster. For example, a certain river valley may be prone to flooding. There is risk if and only if a vulnerable society or property is located within this flood prone area. If the hazard materializes, that is, if the flood actually occurs, it will cause losses to the vulnerable society or property, thus creating a disaster (van Westen, 2013).

There are three important components in risk analysis: hazards, vulnerability and elements-at-risk (van Westen et al., 2008). They are characterized by both spatial and non-spatial attributes. Hazards are characterized by their temporal probability and intensity derived from frequency magnitude analysis. Intensity expresses the severity of the hazard, for example flood depth, flow velocity, and duration in the case of flooding. The hazard component in the equation actually refers to the probability of occurrence of a hazardous phenomenon with a given intensity within a specified period of time (e.g. annual probability). Hazards also have an important spatial component, both related to the initiation of the hazard (e.g. a volcano) and the spreading of the hazardous phenomena (e.g. the areas affected by volcanic products such as lava flows) (van Westen, 2013).

A hazard is defined as a potentially damaging physical event, phenomenon or human activity that may cause the loss of life or injury, property damage, social and economic disruption or environmental degradation. This event has a probability of occurrence within a specified period of time and within a given area, and has a given intensity (United Nations International Strategy for Disaster Reduction [UN-ISDR], 2004). Many of the hazards have a relation to Geomorphology. Geomorphology is the science of landforms and of the processes that have formed or reshaped them. These processes that have shaped the

Earth's surface can be potentially dangerous if they occur in populated regions and may cause impact to the vulnerable societies if they exceed a certain threshold, e.g. they may result in instability and erosion on slopes, flooding in river- or coastal areas or earthquakes and volcanic eruptions.

Vulnerability refers to the conditions determined by physical, social, economic and environmental factors or processes, which increase the susceptibility of a community to the impact of hazards (UN-ISDR, 2004). Vulnerability can be subdivided in physical, social, economical, and environmental vulnerability. The vulnerability of communities and households can be based on a number of criteria, such as age, gender, source of income etc. Physical vulnerability is evaluated as the interaction between the intensity of the hazard and the type of element-at-risk, making use of so-called vulnerability curves.

Elements-at-risk are the population, properties, economic activities, including public services, or any other defined values exposed to hazards in a given area. They are also referred to as “assets”. Elements-at-risk also have spatial and non-spatial characteristics. There are many different types of elements-at-risk and they can be classified in various ways. The way in which the amount of elements-at-risk is characterized (e.g. as number of buildings, number of people, economic value or the area of qualitative classes of importance) also defines the way in which the risk is presented. The interaction of elements-at-risk and hazard defines the exposure and the vulnerability of the elements-at-risk. Exposure indicates the degree to which the elements-at-risk are actually located in an area affected by a particular hazard. The spatial interaction between the elements-at-risk and the hazard footprints are depicted in a GIS by map overlaying of the hazard map with the elements-at-risk map (van Westen, 2013).

Hazard assessment using GIS can be carried out at different mapping scales. Although it is possible to visualize and analyze GIS data in many scales, in practice the scale of the input data determines the scale of analysis. There are a number of factors that play a role in deciding the scale of hazard and risk assessment (Fell et al., 2008), such as the aim of the hazard assessment, the type of hazard, the size and characteristics of the study area, the available data and resources, and the required accuracy.

### 1. Data

Before we can start with the actual analysis, it is important to have an idea of the input data.

The analysis was carried out on a national scale, using data and methods that are only applicable for smaller scales. The resulting hazard, vulnerability and risk maps are meant to give a general overview at the level of administrative units (regions, districts municipalities and communities). The results cannot therefore be used to make decisions on the part of communities or for specific sites. For these areas a more detailed scale, greater accuracy of data and a higher resolution of data should be used,

alongside a more advanced method for the assessment of hazards and risks.

### 1.1. Seismic hazard

The first probabilistic seismic hazard map of Georgia was created in 1999–2000 by the Regional Seismology Department of the former Institute of Geophysics (Authors: T. Chelidze, Z. Javakh-ishvili, O. Varazanashvili, M. Elashvili, I. Kolesnikov, T. Godoladze, N. Butikashvili and E. Glonti). Later, in 2009, the probabilistic seismic hazard map was officially approved and became a part of the acting Building Codes of Georgia. The map is based on the following principle: “From the earthquake source zones to the seismic effects on the Earth surface” (van Westen, 2018a), i.e. initially, potential sources of earthquakes and their parameters have been studied and identified before the total probability of the cumulative effects of the stated earthquakes were calculated at various points of the Earth surface.

To carry out a probabilistic seismic hazard assessment of Georgia, the software SEISRISK III was used. See Figure 2.

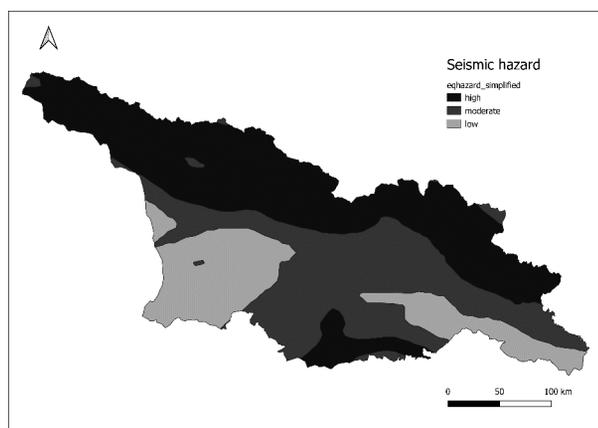


Figure 2. Seismic hazard map (CENN, 2018)

### 1.2. Landslide, mudflow and rockfall hazards

For the purpose of a qualitative assessment of the landslide, mudflow and rockfall hazards presented in this Atlas, the decision support tools such Spatial Multi Criteria Evaluation (SMCE) method have been applied (See section 4.1). The main goal was to design a methodology for the assessment of a landslide, mudflow and rockfall hazard index for Georgia that took into account the limitations in data availability and spatial resolution (1 hectare). The hazard assessment was made using Geographic Information System (Integrated Land and Water Information System, ILWIS-GIS).

The hazard maps were grouped into three simplified categories based on the histogram of the final weight maps: high, moderate and low. This was done for the landslide, mudflow, and rockfall hazard maps (van Westen, 2018a). See Figures 3–5.

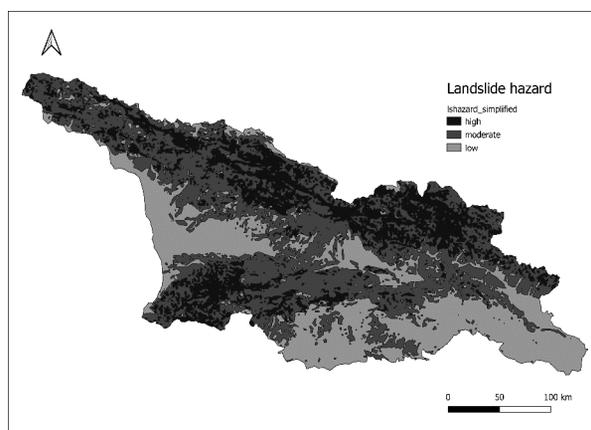


Figure 3. Landslide hazard (CENN, 2018)

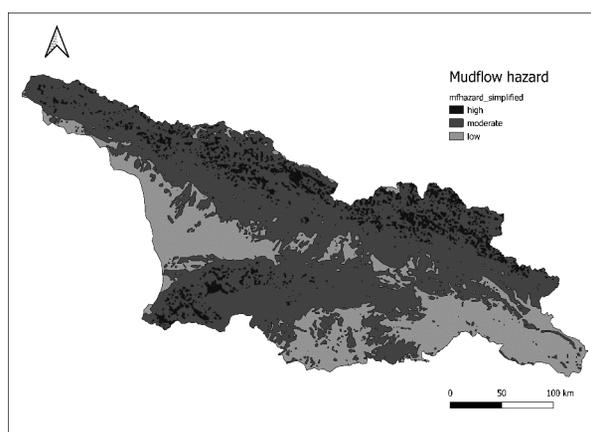


Figure 4. Mudflow hazard

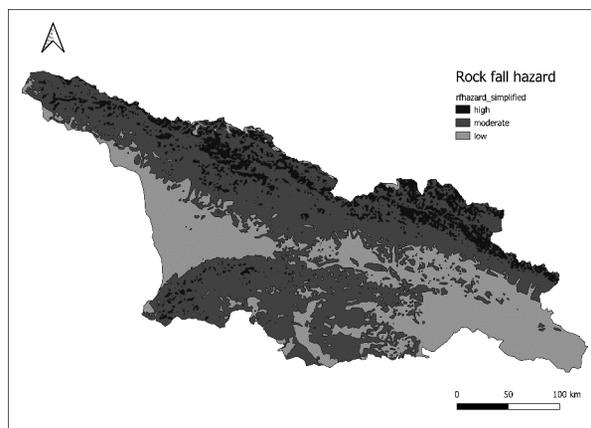


Figure 5. Rock fall hazard

### 1.3. Flood hazard

The flood hazard in Georgia was determined using a GIS-based approach. The assessment was carried out in a freeware GIS, called PCRASTER, which was developed by the University of Utrecht in the Netherlands. A script was used to compute the height above the river based on a Digital Terrain Model (DTM). The DTM was based on the ASTER GDEM v2, a globally available DTM with a 30 m resolution. This DTM was re-sampled to a 100 m

resolution for application in Georgia. The work-flow was based on a method developed by the EU Joint Research Centre for potential flood hazard and risk mapping at a pan-European scale. The script determines the location of the main rivers derived from the stream order of the water courses. Then the height above the river for each location in the study area was computed by forcing the catchments to have their outlet at the location of the river. The height of the outlet was assigned to the whole catchment, and was subsequently subtracted from the DTM. To determine the flood hazard, the height above the river should be assigned a temporal probability, the chance of water actually reaching that height. Return periods of water levels were determined by analyses of the hydrological station, as explained in section 2.5.2. Assuming that the height of the DTM equaled the water level of the 5 year return period, we determined the height above the river for the 10, 50, and 100 year return periods for each of the stations by subtracting the 5 year water height from the 10, 50, and 100 year water heights. These water heights were interpo-lated over Georgia using inverse distance weighting (IDW), with break lines assigned to catchment boundaries. By comparing the height above the river from the DTM with the heights above the river from the different return periods of the stations, we derived a flood extent map for each of the return periods. The flood hazard map is a combination of the flood extent maps for each of the return periods.

A few manual corrections were done for specific areas, based on expert knowledge on the occurrence of floods in the country and information from local people. In some areas the flood extent was reduced, for example in the desert area in the east of Georgia. Other areas were added to the flood hazard map, such as the marshy plains of the Kolkheti lowlands, as this method did not perform well in flat terrain and the DTM showed larger errors here (van Westen, 2018a). See Figure 6.

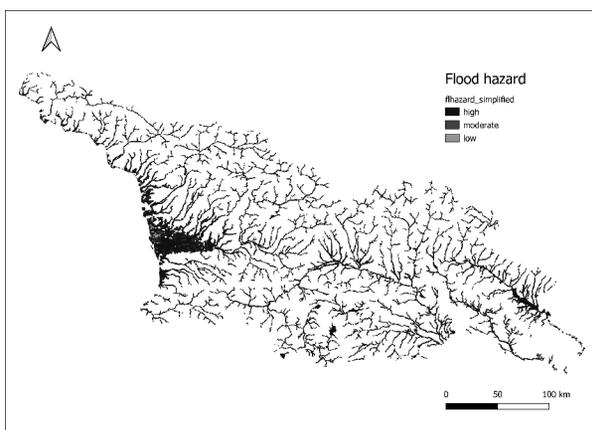


Figure 6. Flood hazard (CENN, 2018)

#### 1.4. Polygonal grid

The territory of the Republic of Georgia was covered with a polygonal grid. The size of the polygon is determined

by the size of the study area and is 300 meters. The grid was developed using the QGIS Create grid Research tool.

#### 1.5. Elements at risk

Buildings and Population are the important elements at risk. The creation of a building map of Georgia is crucial for the exposure, vulnerability and risks analyses. The buildings database has been prepared using QGIS and OpenStreet-Map data (QGIS User Guide, 2017). See Figure 7.

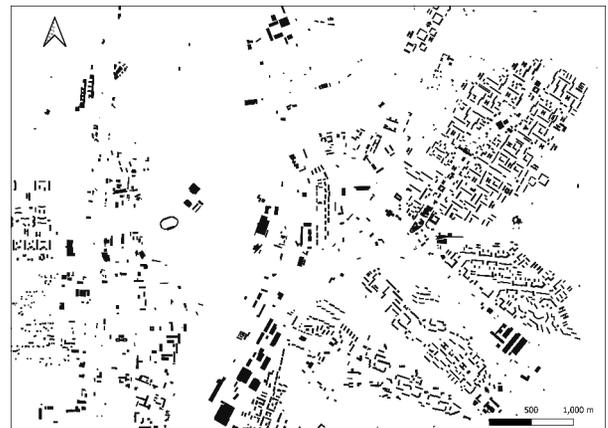


Figure 7. Buildings map

According to 2014 General Population Census, the total population of Georgia is 3,713,804 of which, 2,122,623 live in urban areas and 1,591,181 live in rural areas, (excluding the population residing in the occupied territories, for which no recent population data are available). The average density of the population is around 65 individuals per km<sup>2</sup>.

The population is unequally distributed over the territory of Georgia, this is directly related to the natural-geographic and economic factors in the different regions. For instance, due to unfavorable farming conditions, only 4% of the population lives in the Caucasus mountain regions, 8% live in the southern uplands and 88% live in the intermountain plains. From an agricultural point of view Samegrelo, Imereti, Shida and Kvemo Kartli, Guria and Javakheti represent the most cultivated regions.

The information regarding the number of people living within Georgia and their locations was provided by Geoland and is based on statistical information from 2002 (van Westen, 2018a).

For population density calculations, we can use the PostgreSQL spatial table “communities”, which contains data on community areas and population. Areas are given in square meters. To calculate the population density per square kilometre, use a statement that determines the population density of the community, and this value will be added to the spatial table “community” in the attribute field “density”:

```
UPDATE communities
```

```
SET density = pop_comm_t/(shape_area/1 000 000).
```

See Figure 8.

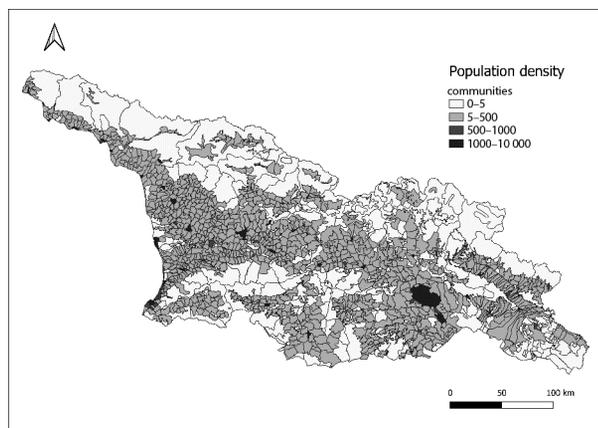


Figure 8. Population density by communities

## 2. Spatial analysis

This manuscript is intended to illustrate the meaning of hazard, vulnerability and risk, using a data set on the national-scale of Republic of Georgia. The occurrence of a disaster depends on two factors:

- Hazard: the probability of occurrence of a potentially damaging phenomenon;
- Vulnerability: the degree of loss resulting from the occurrence of the phenomenon.

We will first generate a qualitative hazard map by combining several factor maps. Then a vulnerability map is made. The hazard and the vulnerability map are combined into a risk map.

### 2.1. Creating the hazard map

First we will look at the aspect: hazard. Later we will evaluate the vulnerability and finally the risk. The degree of hazard of a certain area is determined by a combination of factors. The different factors, which influence the degree of hazard, can be observed separately, although they do influence each other (e.g. in an area with high seismic hazard there will be more landslides). The factors are provided in the form of parameter maps, each of them describing a potentially damaging phenomenon. The following phenomena are taken into account:

- Seismic Hazard;
- Landslide Hazard;
- Mudflow Hazard;
- Rock fall Hazard;
- Flood Hazard.

To create the hazard map it is necessary to combine individual hazard maps. However, this is not possible with the data we have. As such, it is necessary to find an original way to transform the data so that it is possible to combine the maps. To do this, we used a polygonal grid that covered the territory of the Republic of Georgia. Each cell of the polygonal grid takes the values of the seismic, landslide, mudflow, rockfall, flood, population density and building maps with PostGIS statements. For example, to assign values of the seismic map to the cells, Spatial SQL

statement can be used:

```
UPDATE georgia_grid_300;
```

```
SET eq = eqhazard_simplified.gridcode from eqhazard_simplified,
```

```
where st_intersects(georgia_grid_300.geom, eqhazard_simplified.the_geom).
```

As assignment process completed, we are able to create multi factor (seismic, landslide, mudflow, rockfall and flood) hazard map. This can be done with using simple SQL statement:

```
UPDATE georgia_grid_300
```

```
SET hazard = eq + ls + mf + rf + fl.
```

The hazard map which was made has many different values. From the range of values we can see that the best way to classify the map hazard is to divide it into classes:

- hazard\_class = 'very low' WHERE hazard < 3;
- hazard\_class = 'low' WHERE hazard >= 3 and hazard < 5;
- hazard\_class = 'moderate' WHERE hazard >= 5 and hazard < 7;
- hazard\_class = 'high' WHERE hazard >= 7 and hazard < 9;
- hazard\_class = 'very high' WHERE hazard >= 9.

Each polygon of the table "georgia\_grid\_300" represents the value of hazard in the attribute column "hazard\_class".

If we carry out the visualization of the "georgia\_grid\_300" table using the QGIS program, we select the "Categorized" visualization method and classify it according to the data in the "hazard\_class" column, we get a polygonal hazard map for the Georgia. See Figure 9.

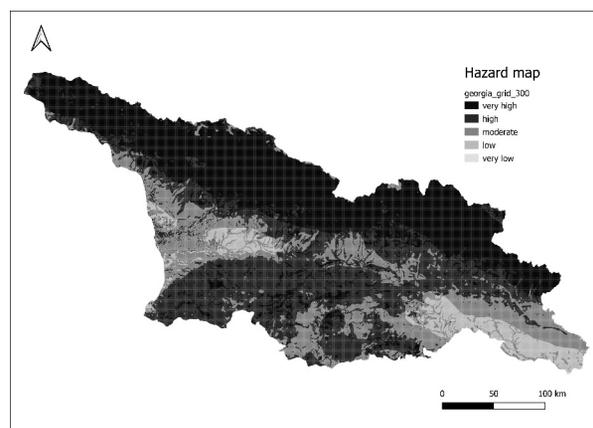


Figure 9. Multi factor (seismic, landslide, mudflow, rockfall) hazard map

### 2.2. Creating the vulnerability map

Now we will look at the input data for a vulnerability analysis. Elements at risk are the population, properties, economic activities, etc. at risk within a given area. The necessary step in the creation of the vulnerability map is

the combination of the individual vulnerability maps. The following maps are used for this:

- Population density;
- Building number.

Each cell of the polygonal grid takes the values of the population density and building number with PostGIS statements (PostGIS Development Team, 2017). In the case to assign values of population density map to the cells, spatial SQL statement can be used:

```
UPDATE georgia_grid_300;
```

```
SET density = communities.density from communities,
```

where st\_intersects(georgia\_grid\_300.geom, communities.the\_geom).

In the case to assign values of building number map to the cells, spatial SQL statements can be used:

```
CREATE TABLE building_n_intersects as
```

```
SELECT georgia_grid_300.gid, sum(ST_NumGeometries(
building_georgia.the_geom)) as building_n, georgia_
grid_300.geom
```

```
FROM building_georgia, georgia_grid_300 where st_intersects(
building_georgia.the_geom, georgia_grid_300.geom)
```

```
GROUP BY georgia_grid_300.gid;
```

```
UPDATE georgia_grid_300
```

```
SET bn = building_n_intersects.building_n FROM
building_n_intersects
```

```
WHERE georgia_grid_300.gid = building_n_intersects.
gid.
```

In the case of a Population density map, weights were assign by density (Table 1). The amount of weight that will be given to a certain element and the way this factor will be classified is highly subjective. This method is also referred to in the literature as blind weighting (van Westen, 2018b).

Table 1. Population density weights

Population density	Weight
density <= 5	0
density > 5 and density <= 500	3
density > 500 and density <= 1000	7
density > 1000	10

The column “wdensity” is added to the spatial table “georgia\_grid\_300” and its data is filled in using the SQL statement according Table 1.

In the case of a Building number map, weights were assign by number. See Table 2.

Now we are able to create multi elements (population, buildings) vulnerability map. This can be done with using simple SQL statement:

```
UPDATE georgia_grid_300
```

```
SET vulnerability = wdensity + wbn.
```

Table 2. Building number weights

Building number	Weight
number <= 1	0
number > 1 and density <= 20	4
number > 20 and density <= 50	8
number > 50	12

The vulnerability map which was made has many different values. From the range of values we can see that the best way to classify the map vulnerability is to divide it into classes:

```
vulnerability_class = 'very low' WHERE vulnerability < 3;
```

```
vulnerability_class = 'low' WHERE hazard >= 3 and vul-
nerability < 5;
```

```
vulnerability_class = 'moderate' WHERE hazard >= 5 and
vulnerability < 12;
```

```
vulnerability_class = 'high' WHERE vulnerability >= 12.
```

Each polygon of the table “georgia\_grid\_300” represents the value of vulnerability in the attribute column “vulnerability\_class”.

If we carry out the visualization of the “georgia\_grid\_300” table using the QGIS program, we select the “Categorized” visualization method and classify it according to the data in the “vulnerability\_class” column, we get a polygonal vulnerability map for the Georgia. See Figure 10.

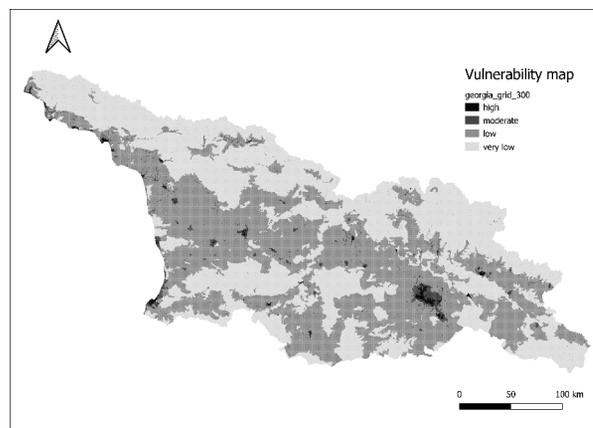


Figure 10. Vulnerability map

### 2.3. Creating the risks map

At this point we have a hazard map and a vulnerability map, and now we can combine them into the final risk map.

The final stage in a risk analysis is the creation of a risk map. According to Varnes (1984), risk can be defined as “the expected degree of loss due to particular natural phenomena”. In a real project this would be the multiplication of costs\* vulnerability\*recurrence interval of natural damaging phenomenon (van Westen, 2018b). We do not dispose of cost data, and neither of recurrence intervals in this example.

Therefore we will simplify the procedure by calculating the risk as the combination of natural hazard and the vulnerability. We will make a qualitative risk map, giving the general relation between hazard and vulnerability. The combination will be done using a two-dimensional table:

- When the hazard is very low, it doesn't matter whether the vulnerability is low or high; the risk will be low in all cases.
- When the vulnerability is very low (meaning that the area doesn't contain any important elements at risk), the risk is always low. See Table 3.

Table 3. Two dimensional table

		Vulnerability			
		Very low	Low	Moderate	High
Ha- zard	Very low	Low	Low	Low	Low
	Low	Low	Low	Low	Moderate
	Moderate	Low	Low	Moderate	Moderate
	High	Low	Moderate	Moderate	High
	Very high	Low	Moderate	High	High

The column "risk" is added to the spatial table "georgia\_grid\_300", which takes the values according to the conditions specified in the two dimensional table. See Table 4 which is the part of the table "georgia\_grid\_300".

If we carry out the visualization of the "georgia\_grid\_300" spatial table using the QGIS program, we select the "Categorized" visualization method and classify it according to the data in the "risk" column, we get a polygonal risk map for the Georgia. See Figure 11.

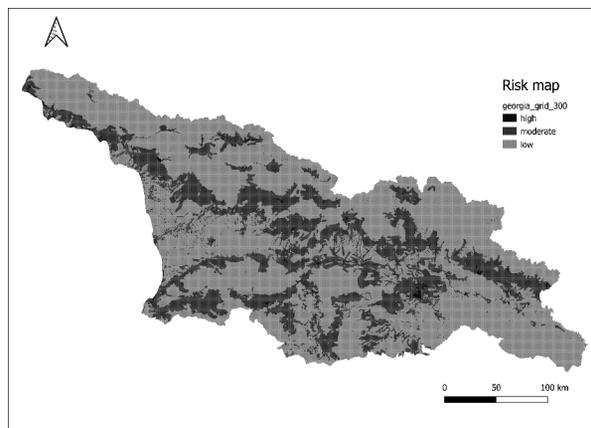


Figure 11. Risk map

### Conclusions

The analysis was carried out on a national scale, using data and methods that are only applicable for smaller scales. The resulting hazard, vulnerability and risk maps are meant to give a general overview at the level of administrative units (regions, districts municipalities and communities). The results cannot therefore be used to make decisions on the part of communities or for specific sites. For these areas a more detailed scale, greater accuracy of data and a higher resolution of data should be used, alongside a more advanced method for the assessment of hazards and risks.

The process of creating a risk map involves the summation of different hazard maps. This topic originates in the realm of map algebra.

Map algebra, essentially, involves doing maths with maps. The key difference is that it only applies to raster data, which is why it is also called raster maths (GIS Geography, 2020). The simplest approach is map algebra on

Table 4. Part of the spatial table "georgia\_grid\_300"

gid	eq	ls	fl	mf	rf	bn	hazard	hazard_class	density	vulnerability	wdensity	wbn	vulnerability_class	risk	geom
1	2	1	0	2	2	0	7	high	9	3	3	0	low	moderate	
2	2	1	0	2	1	0	6	moderate	35	3	3	0	low	low	
3	1	3	0	2	2	0	8	high	114	3	3	0	low	moderate	
4	2	1	0	2	2	0	7	high	35	3	3	0	low	moderate	
5	2	1	0	2	2	0	7	high	35	3	3	0	low	moderate	
6	2	2	0	2	2	0	8	high	35	3	3	0	low	moderate	
7	1	2	0	2	2	0	7	high	127	3	3	0	low	moderate	
8	2	1	0	2	2	0	7	high	35	3	3	0	low	moderate	
9	2	2	0	2	1	0	7	high	35	3	3	0	low	moderate	
10	1	2	0	2	2	0	7	high	127	3	3	0	low	moderate	

Notes: eq – earthquake, ls – landslide, fl – flood, mf – mudflow, rf – rockfall, bn – building number, density – population density, wdensity – density weights, wbn – building number weights, geom – geometry column.

a cell-by-cell basis. For example, we have 2 rasters stacked on top of each other. Then, we add each cell one-by-one.

Such an operation cannot be performed with our initial data, with hazard maps. Our method's originality lies in the fact that the initial data is transformed so that it is possible to carry out map algebra operations with vector data. After transformation, our vector data is composed of cells, like raster data. The difference is that the cells in our vector maps are rectangular polygons, and these polygons repeat the properties of the original maps. This representation is superior, since it is now possible to summarize data, as well as perform PostGIS analysis using spatial functions, such as ST\_Intersection.

The polygon size is selected according to the original data. The smaller the area under study, the smaller the size of the rectangular cell of the grid that covers the area. The choice of cell size depends entirely on the properties of the original data and on the purpose of the planned study.

We discussed the method of creating a multi-factor risk map. Only five factors were considered for the visible presentation of the method – earthquake hazard, landslide hazard, mudflow hazard, rockfall hazard, flood hazard, and two risk elements – the population and buildings. However, the method can be used with more or fewer than five factors. Our goal was to create a method based on PostGIS analysis, transform original data for this purpose and made multi-factor risk map. Based on the processing of the initial data, all the generated data are collected in the PostgreSQL spatial table “georgia\_grid\_300” (Table 4).

As we saw, it is very easy to visualize spreadsheet data and generate thematic maps. See Figures 9–11. It is also not difficult to visualize data by using Web GIS principles in the form of interactive maps, which allows the data to be shared online (see the link: <http://levan.link/firewood/risk.html>). All maps are produced from one spatial table by assigning the desired values to the polygons, which determines the colours of the cells.

A simple and flexible method of data processing was presented in the study, which allows the creation of a multi-factor risk map. GIS program QGIS and PostGIS analysis are used for data processing. MapServer (MapServer Team, 2017) or Geoserver provide convenient spatial visualization of data, which can be used as a component of decision support systems (DSS) (Aye et al., 2012).

Disasters are spatial in nature and occur in a certain geographic location. With the help of advanced web services, standards and geospatial technologies such as remote sensing and photogrammetry, Geographic Information Systems (GIS), Global Positioning Systems (GPS), Spatial Data Infrastructure (SDI) and Open Geospatial Consortium (OGC) web services, nowadays, it is possible to deliver, access, analyze and share rich spatial information over the web (Aye et al., 2015).

Our PostGIS-based method for creating risk map of natural disasters compatible with above mentioned systems as our method applies SDI principles and OGC standards.

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