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DEVELOPMENT OF A VISUAL TOOL FOR NATURAL DISASTER RISK ASSESSMENT FOR THE COMMUNITIES OF THE REPUBLIC OF GEORGIA

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Abstract. The National Risk Index, developed by us, provides a relative measurement of national-level natural hazard risk across communities. The risk is defined as the potential for adverse impact from a natural hazard. Local and national authorities require information on the frequency and impact of hazardous events that have occurred or may occur in the future as a basis for risk-informed planning. Generally, most local authorities do not have the technical expertise to develop tools for this, and therefore, it is important to provide national-scale platforms for disaster risk assessment. This paper presents a national multi-hazard risk profiling platform for administrative units within Georgia, located in the Caucasus. The risk calculation is based on a method that uses historical disasters and their frequencies of hazardous phenomena such as landslides, floods, and earthquakes. We calculate the risk for the communities of Georgia. Most methods require detailed data from different sources to calculate risk, and data availability and quality are one of the main challenges in this type of work. This problem is particularly evident in developing countries, where there are limited resources to collect and analyze data quality. Our method is original because it allows for risk calculation, risk assessment, and online visualization of data based only on disasters, recorded in the country's territory. The interactive map can be used as a visual tool for disaster risk assessment by the parties concerned as well as decision-makers.

Keywords: Disaster Annual Frequency, communities, Natural Disaster Risk, online visualization, risk assessment.

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1. Introduction

Earth science data and knowledge can help society at all levels make informed decisions. Shared reliable information enables choices and determines the right decisions, guiding actions to reduce risk. Analysis of hazardous natural phenomena, such as hurricanes, earthquakes, wildfires, tsunamis, and droughts, is an interdisciplinary subject that requires knowledge of geophysics, physical geography, and climatology. Whether a natural phenomenon turns into a disaster ultimately depends on its location and its impact on people. As the intensity and frequency of natural hazards increase, so do vulnerability and impact, putting society and the economy at risk.

Risk can be expressed in qualitative, semi-quantitative, and quantitative terms, depending on the purpose of the risk assessment, the availability of hazard, exposure and vulnerability data, the types of hazards, and the complexity of the study area give a good overview of approaches that are based on indicators, such as the Urban Disaster Risk Index (UDRi) (Carreño Tibaduiza, 2006) and the Global Urban Risk Index (Brecht et al., 2013).

Based on the above, risk assessment is an important challenge, especially because, except for earthquakes, there are no electronic databases and printed catalogues of natural disasters for the territory of Georgia (Varazanashvili et al., 2012).

The relevance of the research is also determined by the location of Georgia in the Caucasus Mountain range between Turkey, Armenia, Azerbaijan, Russia, and the Black Sea. The South Caucasus is particularly vulnerable to natural disasters due to its complex geological structure and diverse geomorphological, hydro-climatic, and ecological conditions. In all three countries of the South Caucasus (Azerbaijan, Armenia, and Georgia), earthquakes, landslides, avalanches, floods, and other natural disasters are frequent, causing human and economic losses (Damen & van Westen, 2013). According to various data, the economic losses caused by natural processes in the above countries have exceeded 16 billion dollars in the last 2 decades (The World Bank, 2009).

Earlier works were done on hazard and risk assessment in Georgia. The development of the Atlas of Natural Hazards and Risks of Georgia is a particular example of it. This atlas was produced in the project "Institutional building for natural disaster risk reduction (DRR) in Georgia", implemented by the Caucasus Environmental NGO Network (CENN) and Faculty of Geo-Information Science and Earth Observation, University of Twente (ITC), the Netherlands. The project was financially supported by the Social Transformation Programme (Matra) of the Netherlands Ministry of Foreign Affairs. This Risk Atlas contains many maps and explanatory text related to natural hazards, exposure, vulnerability, and risk in Georgia. The atlas also shows the baseline maps, related to natural conditions and human conditions in the country (van Westen et al., 2018).

Historical data on natural hazard disasters are used in our research to develop a risk measurement method for each community in Georgia. This data is available on the Geoportal of Hazards and Risks in Georgia (CENN, 2018), which is the web version of the Atlas of Natural Hazards and Risks of Georgia. Hazard-specific models were applied to generate hazard maps for different return periods, which were combined with exposure data, such as building density, population density, transportation infrastructure, agriculture, and forests, to analyse the vulnerability, exposure, and losses.

Almost all communities in Georgia are affected by natural hazards, and there is a wide range of environmental and socioeconomic factors that affect each community's risk to natural hazards. A community is an administrative unit of the country. Communities are united in municipalities, and municipalities are united in regions (Parliament of Georgia Republic, 2014). The likelihood that a community will be subject to the influence of a natural hazard can vary dramatically, as can the associated consequences. In addition, societal risk is influenced by many social, economic, and environmental factors (Zuzak et al., 2022).

2. Research methodology

The National Risk Index for Georgia is a dataset and online tool that helps us visualize the communities of Georgia at risk from six natural hazards. Only six natural hazards, earthquake, flood, landslide, flash flood, mudflow, and rockfall, were selected for risk calculation from the historical disasters database, a PostGIS spatial table.

2.1. Risk analysis

Natural hazard risk's most general definition is the probability of a natural hazard multiplied by the expected outcome, Equation (1) (Federal Emergency Management Agency [FEMA], 2023):

$$Risk = Likelihood \times Consequence. \quad (1)$$

For our study, we used a simplified method for the national scale analysis of risk, based on historical disaster records (CENN, 2018). A visual risk tool developed in our research helps users better understand their communities' natural disaster risks. The stakeholders are the government represented by local bodies, the Emergency Management Service, scientific research institutions, the National Environment Agency, and interested members of society.

In the National Risk Index (FEMA, 2023), risk is defined as the potential for negative impact of a natural hazard, and the risk is calculated using the Equation (2):

$$Risk = Expected\ Annual\ Loss \times Community\ Risk\ Factor. \quad (2)$$

According to Varnes (1984), risk can be defined as "the expected degree of loss due to particular natural phenomena". We do not dispose of *Community Risk Factor* data, and for the risk calculation, we are using simplified Equation (3):

$$Risk = Expected\ Annual\ Loss, \quad (3)$$

where $Expected\ Annual\ Loss = Exposure_{hazard} \times Freq_{hazard}$ (FEMA, 2023).

The annual frequency of the disaster can be related to the annual frequency of the phenomenon:

$$Freq_{disaster} = Exposure_{hazard} \times Freq_{hazard}.$$

Risk can be defined as the disaster's annual frequency (DAF), Equation (4).

$$Risk = Disaster\ Annual\ Frequency. \quad (4)$$

The frequency of expected disasters determines the Risk. The higher the frequency for a particular area, the higher the risk of expected disasters. Therefore, we can estimate the risk by the annual frequency of disaster occurrence.

The annual frequency of natural disasters is defined as the frequency or probability of expected disaster occurrences per year (Zuzak et al., 2022). Historical data on natural hazard disasters allow us to calculate the annual frequency of disaster occurrence. Disaster Annual Frequency is the ratio of the recorded number of disasters in each community (Disaster Count) to the registration period (Record Period).

$$Disaster\ Annual\ Frequency = {Disaster\ Count}/{Record\ Period}. \quad (5)$$

The natural hazards that affect the population and buildings were selected from the historical database: earthquake, flood, flash flood, mudflow, landslide, and rockfall.

Annual disaster rates for each natural hazard should be determined for each community. Thus, the annual frequency of the selected disasters in the community is determined by the Equation (6):

$$Disaster\ Annual\ Frequency = \sum_{i=1}^{6} DAF_{Hazard\ Tipe(i)}. \quad (6)$$

Using PostGIS analysis, we calculate the number of disasters for each community based on 6 types of hazards and the annual frequencies based on historical disaster data and spatial tables of communities. Examples of PostGIS are presented below, in the calculations section. Annual frequencies are summed as shown in Equation (6). All data are collected in a spatial table of "communities" (Table 1). For summarizing, we are using an SQL statement:

UPDATE communities
SET risk_index = "flashflood_fr" + "rockfall_fr" + "landslide_fr" + "flood_fr" + "mudflow_fr" + "earthquake_fr",

where flashflood_fr, rockfall_fr, landslide_fr, flood_fr, mudflow_fr, and earthquake_fr are annual frequencies for selected disasters. Calculations are available below, in the calculations section.

In our case, the risk is assessed by the annual frequency of disasters caused by six different natural hazards. According to these data, it is possible to determine the value of the annual frequency of the disaster and assess the risk of the disaster. The disaster's Annual frequency for each community was determined according to historical disaster data, using the Equation (6).

It should be noted that the Disaster Annual Frequency data are expressed in percentiles. It should be emphasized that scores are relative, representing the relative ranking of a community among all other communities for a given component. Scores are expected to change over time to reflect new data within communities.

We express the risk as the annual frequency of disasters in relative units – percentiles. Percentiles are used in statistics to give you a number that describes the value that a given percent of the values are lower than. The Python program (Appendix 1), compiled by us, was used to display the data in percentiles. We are calculating the Disaster's Annual Frequency (DAF) for each community and then giving a value between 0 and 100, based on the percentile score of all the scores of all the communities. It is possible to visualize the data, which gives a good idea of the potential for negative impacts of natural hazards in communities (Figure 1).

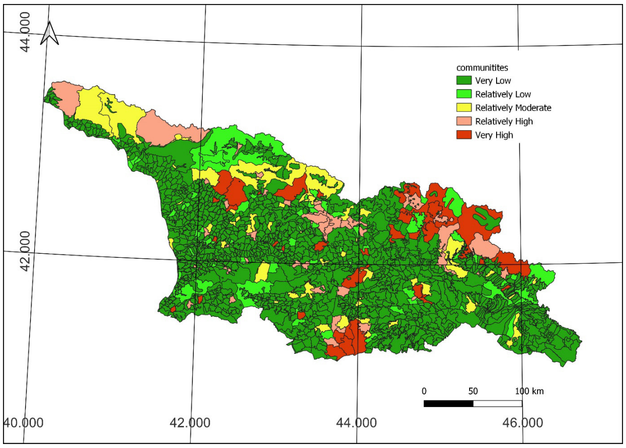

Figure 1. Communities by risk

Risk numerical values are expressed in percentiles. The ratings are divided into quintiles as described below:

- Very High: 80 to 100 percentiles.
- Relatively High: 60 to 80 percentiles.
- Relatively Moderate: 40 to 60 percentiles.
- Relatively Low: 20 to 40 percentiles.
- Very Low: 0 to 20 percentiles.

Table 1. Natural disaster risk assessment visual tool, spatial data table

comm_eng	earthquake_ number	flashflood_ number	flood_number	mudflow_ number	rockfall_ number	landslide_ number	risk_percentile
Arboshiki	3	0	4	2	0	0	51
Tambovka	10	0	0	1	0	0	52
Bakurtsikhe	1	2	0	0	0	2	52
Tsinandali	2	0	2	5	0	0	53
Atskuri	1	0	6	0	0	1	53
Gldani-Nadzalade	1	2	3	1	0	0	54
Ptsa	1	0	8	0	0	0	55
Mtskheta	0	1	5	0	0	1	56
Akhalsopeli	0	2	4	1	0	0	57
Akhaltsikhe	0	1	7	0	0	0	58
Chiatura	0	0	9	0	0	0	58
Achara	0	0	4	0	0	3	59
Surami	0	2	3	1	0	1	59
Akaurta	0	0	9	1	0	0	60
Samtredia	0	1	8	0	0	0	60

2.2. Calculations

2.2.1. Landslides

A landslide is the movement of a mass of rock, debris, or earth down a slope (FEMA, 2023). Georgia belongs to one of the most difficult mountainous regions in the world in terms of the scale, frequency and damage caused by the processes of natural hazards. Landslides occur in almost all geomorphological zones. Landslides destroy buildings, agricultural land plots, roads, and other infrastructure. Landslides also have a significant impact on the population and cause casualties (Gaprindashvili & van Westen, 2016).

Spatial source data include landslide event coordinates, date of observation, links to event source documentation, and impact elements (van Westen et al., 2018). The record period for landslides covers the years 1887–2016. All landslide records are taken into consideration in the annual frequency calculation, so the record period for which the landslide data are used comprises 129 years.

The number of historical landslide occurrences is calculated as the number of distinct landslide disaster points that cross the polygons of the communities of Georgia (Figure 2) and can be calculated by using an SQL statement:

```
create table landslide_number_communities as
SELECT communities.gid, sum(ST_NumGeometries(main_2012.geom)) as landslide_number, communities.the_geom
from main_2012, communities where st_intersects(main_2012.geom, communities.the_geom) and code = 'LAS'
GROUP BY communities.gid.
```

This statement would be a general SQL without PostGIS spatial functions ST_NumGeometries, and ST_Intersects. In this statement, we are using two spatial PostGIS tables – "communities" and "main_2012", and calculating the number of landslide disasters by communities. Such a type of SQL statement is also used to calculate the number of earthquakes, flash floods, floods, mudflows, and rockfalls by communities.

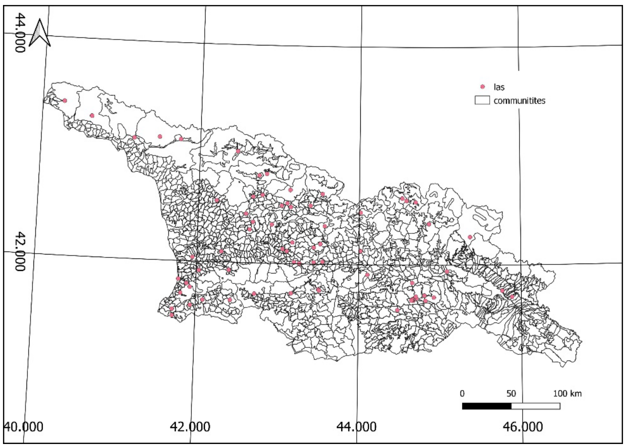

Figure 2. Landslide incidents from 1887–2016

The number of historical disasters is also calculated at the country level as the number of distinct landslide disaster points that cross the country.

The annual frequency value represents the annual number of recorded landslide disasters for a specific area. The annual frequency is calculated at the community level (see Equation 7) and the community is assigned this value (Figure 3). For assignments of values, we are using the SQL statement:

```
UPDATE communities
SET landslide_number = landslide_number_communities.landslide_number from landslide_number_communities,
where communities.gid = landslide_number_communities.gid.
```

Therefore, the annual disaster frequency of an event is equal to the ratio of the number of disaster cases recorded for the community to the period of recording of this event. This community value corresponds to the landslide risk value.

Equation (7): Annual frequency of community landslide disasters (LAS)

$$Freq_{LAScommunitie} = Event\,Count_{LAScommunitie} / Record\,Period_{LAS}. \quad (7)$$

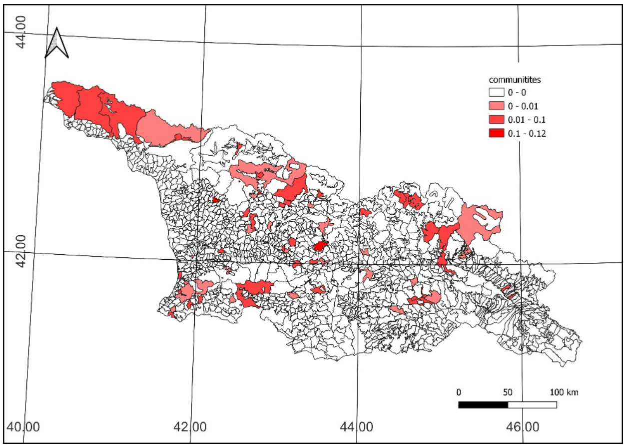

Figure 3. Annual frequency of landslide disaster by community

2.2.2. Earthquakes

An earthquake is the shaking of the Earth's surface by energy waves generated by the friction of slowly moving tectonic plates beneath the Earth's surface (FEMA, 2023). Spatial source data include earthquake event coordinates, date of observation, links to event source documentation, and impact elements (van Westen et al., 2018). The earthquake record period covers the years 1682–2009. All earthquake records are taken into consideration in calculating the annual frequency, so the period of record for which earthquake data is used is 327 years.

The number of historical earthquake occurrences is calculated as the number of distinct points of the earthquake disaster that intersect the polygons of the Georgian community (Figure 4). The number of historical disasters is also calculated at the country level as the number of distinct earthquake disaster points that cross the country.

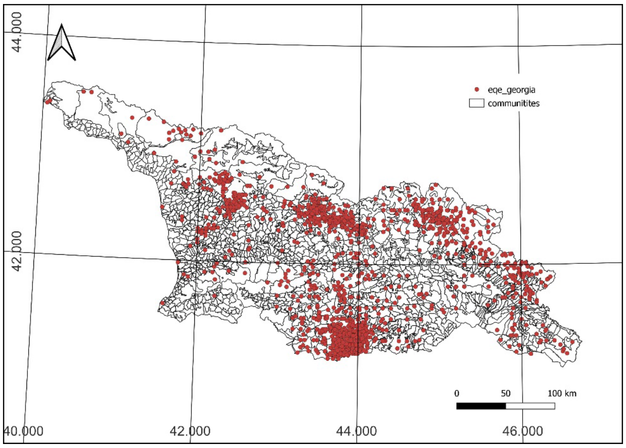

Figure 4. Earthquake incidences from 1682–2009

The annual frequency value represents the annual number of recorded earthquake disasters for a particular area. The annual frequency is calculated at the community level (see Equation 8) and the community is assigned this value (Figure 5). This community value corresponds to the earthquake risk value.

Equation (8): Annual frequency of community earthquake disasters (EQE)

$$Freq_{EQEcommunities} = Event\,Count_{EQEcommunitie} \,/\, Record\,Period_{EQE}. \quad (8)$$

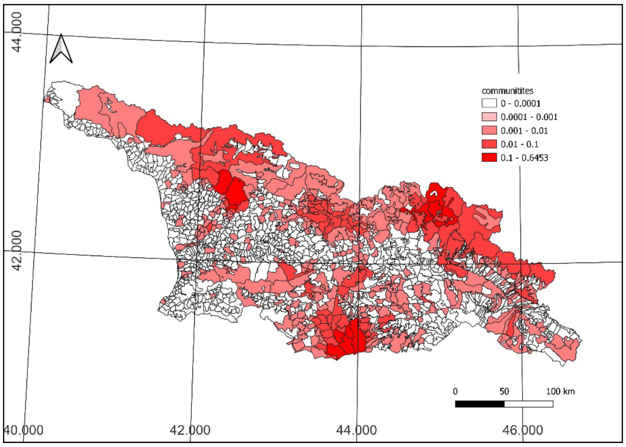

Figure 5. Annual Frequency of Earthquake Disasters by community

2.2.3. Floods

Floods occur when the amount of water in streams and rivers exceeds the capacity of their natural or constructed beds to contain the flow of water, and the water overflows its banks and spills over the surrounding low-lying, dry land (FEMA, 2023).

Due to the complex topography, different climate conditions and hydrographic conditions (a dense network of rivers), natural disasters such as landslides, mudflows, floods and avalanches are common in Georgia. Flood is one of the most important natural disaster phenomena, which is distinguished by the scale of the disaster and poses a threat to people (Straatsma & Megrelidze, 2018).

Spatial source data include flood event coordinates, date of observation, links to the source documentation of the event, and impact elements (van Westen et al., 2018). The flood record period covers the years 1776–2015. All flood records are considered in calculating the annual frequency, so the period of record for which the flood data is used is 239 years.

The number of historical flood events is calculated as the number of distinct flood disaster points that cross the Georgian community polygon (Figure 6). The number of historical disasters is also calculated at the country level as the number of distinct flood disaster points that cross the country.

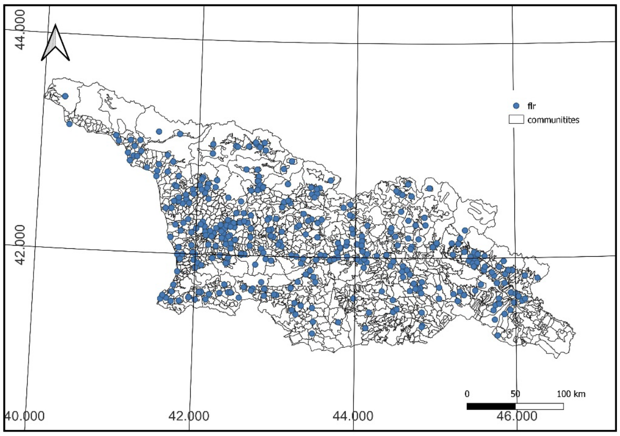

Figure 6. Flood incidences from 1776–2015

The annual frequency value represents the annual number of recorded flood disasters for a particular area. The annual frequency is calculated at the community level (see Equation 9) and the community is assigned this value (Figure 7). This community value corresponds to the flood risk value.

Equation (9): Annual frequency of community flood disasters (FLR)

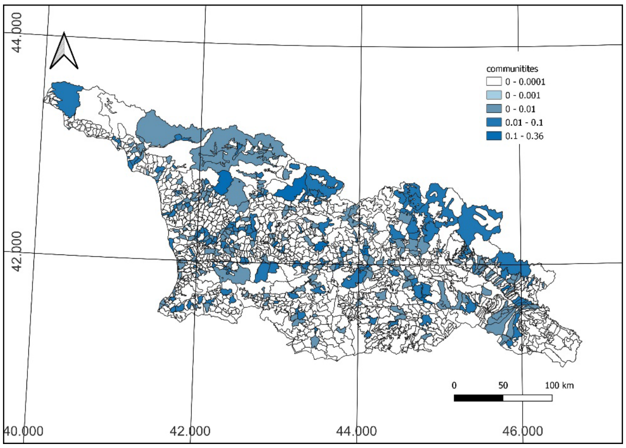

Figure 7. Annual flood disaster frequency by community

$$Freq_{ELR\ communities} = Event\ Count_{ELR\ communities} / Record\ Period_{FLR}. \quad (9)$$

Calculations are performed using PostGIS spatial directives.

2.2.4. Flash flood, mudflow, rockfall

The registration periods of flash floods (FLF), mudflows (LAM), and rockfalls (LAR) in the database include: 1886–2008, 1776–2017, and 1889–2017, respectively. Annual frequencies of disasters are calculated by Equations (10), (11), and (12):

$$Freq_{FLF\ communities} = Event\ Count_{FLF\ communities} / Record\ Period_{FLF}; \quad (10)$$

$$Freq_{LAM\ communities} = Event\ Count_{LAM\ communities} / Record\ Period_{LAM}; \quad (11)$$

$$Freq_{LAR\ communities} = Event\ Count_{LAR\ communities} / Record\ Period_{LAR}. \quad (12)$$

3. Research results and discussion

A visual risk tool developed in our research helps users better understand their communities' natural disaster risks. The parties concerned are the state government, represented by local bodies, the Emergency Management Service, scientific research institutions, the National Environment Agency, and interested members of the general public. Knowledge of the risk will help:

1. Updating emergency operations plans.
2. Clarifying hazard reduction plans.
3. Determining priorities and distribution of resources.
4. Identifying the need for a more sophisticated risk assessment.
5. Encouraging risk communication and engagement at the community level.
6. Informing house owners and tenants.
7. Improving the system of codes and standards.
8. Informing the public during long-term recovery.

The paper reviews in detail the visual risk tool, data sources, and their processing methods. The concepts used to develop the National Risk Index (FEMA, 2023) and calculate its components is also clarified.

Risk arises from a combination of hazards, conditions of vulnerability, and insufficient means or measures to reduce the negative consequences of risk (van Westen, 2013). When the hazard becomes real and materializes, the risk can turn into a disaster. For example, an area around a defined river may be subject to flooding. A risk only exists if there is a vulnerable community or property within that potential flood zone. If the hazard materializes, i.e., if the flood occurs, it will lead to the loss of the vulnerable community or property, and thus a disaster.

Historical data confirms the losses caused by this or that natural phenomenon, however, it does not allow for estimation of the losses. We can have a certain idea about the losses caused by natural hazards on the territory of Georgia in accordance with the frequency of disasters. The greater the frequency of natural disasters, the greater the tangible losses caused by these events. Expected annual losses (EAL) are proportional to the annual frequency of the natural phenomenon (FEMA, 2023). Considering this opinion, the ratio between losses caused by natural hazards can be determined. For example, in the case of Georgia, the ratio between the losses of earthquake and rockfall can be determined, which can be taken into consideration when assigning scores. Considering the annual frequencies of disasters, the ratio between earthquake and landslide can be determined as 30, and between earthquake and flood as 1. See Table 2 for annual disaster rates by natural hazards:

Table 2. Annual frequencies of disasters, according to natural phenomena, at the country level

Earthquake (EQE)	Flash flood (FLF)	Flood (FLR)	Mudflow (LAM)	Rockfall (LAR)	Landslide (LAS)
6.1	1.6	6	2.4	0.2	1.6

The database of disasters allows for conducting an in-depth analysis, according to which it is possible to determine the dynamics of risk over the years. For example, according to FAO data, the number of disasters in recent years is three times more than in the 1970s–1980s (Food and Agriculture Organization, 2021). This is a new research topic based on which proper calculations and results will allow us to draw interesting conclusions in the context of climate change.

Within the framework of the present study, a risk assessment tool was created, which provides a graphical representation of risk for the communities of Georgia.

The quality of the obtained results depends entirely on the quality of the database. We calculate the annual frequency of disasters caused by various natural phenomena according to the cases registered in the database. It is not feasible to assess the quality of the database. It is known that the database was created within the framework of the MATRA project, with the participation of the University of Twente. Although the partners in this project have tried to collect as much historical data as possible on natural hazard events in the past, the historical database is still largely incomplete. It has proven very difficult to effectively persuade the various national organizations to digitize their historical archives, a large part of which are poorly maintained and still recorded in log books, in Russian. Given the relative scarcity of this historical data, it has been very difficult to analyse the magnitude-frequency relationships for most of the hazard types (except for earthquakes). Therefore, we have had to make many assumptions in estimating the temporal probability of occurrences for the hazard and risk assessment. We have therefore decided to continue to present these estimations, even though they need to be improved, as they still give a good, relative indication of the order of magnitude for the various types of hazards and risks existing in Georgia (van Westen et al., 2018).

Based on the research, the risk index tool developed by us can be successfully used by decision-makers and parties concerned.

4. Conclusions

Risk values for the communities of Georgia were calculated. A community is an administrative unit of the country and it might comprise several settlements or be a part of a settlement. The calculated data were reflected in the PostgreSQL spatial table "communities" (Table 1).

The limited number of fields and rows of the table are selected using the SQL statement:

```
select comm_eng, earthquake_number flash-
flood_number,flood_number,mudflow_number,rockfall_
number,landslide_number risk_percentile, the_geom from
communities,

where risk_percentile > 50 and comm_eng is not NULL
order by risk_percentile limit 15.
```

An original risk calculation method based on the use of historical disaster data was developed. The data were visualized in the form of an interactive map: Risk index, which is a graphical tool for risk assessment. For visualization, the MapServer (MapServer Team, 2023) and OpenLayers were used.

Overall, the Graphical Tool for Risk Assessment provides opportunities to expand our understanding of risk distribution at the regional and national level and can help communities prioritize risk assessments, including collecting data to fill information gaps or for more detailed analysis. It is a data repository for 6 hazard types, and historical disaster data, including Disaster's Annual Frequency (DAF) values that are useful for local hazard mitigation planning efforts. The Graphical Tool for Risk Assessment serves as a risk communication resource and decision support tool, allowing users to determine a community's risk of disaster. It may also be possible to explore ways to complement national results with local data sets to better inform stakeholders. Finally, the risk assessment tool also aims to inspire risk assessors to develop new and innovative products that will complement risk estimation and further reduce risk.

References

Brecht, H., Deichmann, U., & Wang, H. G. (2013). *A global urban risk index* (Policy research working paper No. 6506). World Bank. https://doi.org/10.1596/1813-9450-6506

Carreño Tibaduiza, M. L. (2006). Técnicas innovadoras para la evaluación del riesgo sísmico y su gestión en centros urbanos: Acciones *ex ante* y *ex post* [Innovative techniques for seismic risk assessment and management in urban centers] [Ph.D. thesis, Universitat Politècnica de Catalunya]. https://www.tdx.cat/TDX-1102106-110455

Caucasus Environmental NGO Network. (2018). *Geoportal of natural hazards and risks in Georgia*. http://drm.cenn.org/index.php/en/hazards-and-risks/hazard

Damen, M., & van Westen, C. (2013). *National scale multi-hazard risk assessment, with an example of Georgia*. ITC.

Food and Agriculture Organization. (2021, March 18). *Natural disasters occurring three times more often than 50 years ago*: *New FAO report*. https://news.un.org/en/story/2021/03/1087702#:~:text=According%20to%20FAO%2C%20disasters%20happen%20three%20times%20more,other%20sectors%2C%20such%20as%20tourism%2C%20commerce%20and%20industry

Federal Emergency Management Agency. (2023, March 12). *National Risk Index*. https://www.fema.gov/sites/default/files/documents/fema_national-risk-index_technical-documentation.pdf

Gaprindashvili, G., & van Westen, C. (2016). Generation of a national landslide hazard and risk map for the country of Georgia. *Natural Hazards 80*, 69–101. https://doi.org/10.1007/s11069-015-1958-5

MapServer Team. (2023, April 21). *MapServer documentation*. https://www.mapserver.org/pdf/MapServer.pdf

Parliament of Georgia Republic. (2014, February 5). *საქართველოს ორგანული კანონი* [Organic law of Georgia]. https://matsne.gov.ge/ka/document/download/2244429/16/ge/pdf

Straatsma, M., & Megrelidze, I. (2018). *National flood susceptibility map of Georgia*. http://drm.cenn.org/Local_Case_studies/National%20Flood%20Susceptibility%20Map%20of%20Georgia1.pdf

The World Bank. (2009). *Central Asia and Caucasus Disaster Risk Management Initiative* (*CAC DRIM*). http://www.unisdr.org/files/11641_CentralAsiaCaucasusDRManagementInit.pdf

van Westen, C. J. (2013). Remote sensing and GIS for natural hazards assessment and disaster risk management. *Treatise on Geomorphology*, *3*, 259–298. https://doi.org/10.1016/B978-0-12-374739-6.00051-8

van Westen, C. J., Straatsma, M., Turdukulov, U., Feringa, W. F., Sijmons, K., Bakhtadze, K., Janelidze, T., & Kheladze, N. (2018). *Atlas of natural hazards and risks of Georgia*. Caucasus Environmental NGO Network.

Varazanashvili, O., Tsereteli, N., & Amiranashvili, A. (2012). Vulnerability, hazards and multiple risk assessment for Georgia. *Natural Hazards*, *64*, 2021–2056. https://doi.org/10.1007/s11069-012-0374-3

Varnes, D. J. (1984). *Landslide hazard zonation*: *A review of principles and practice*. Unesco. https://worldcat.org/title/12196314

Zuzak, C., Mowrer, M., Goodenough, E., Burns, J., Ranalli, N., & Rozelle, J. (2022). The national risk index: Establishing a nationwide baseline for natural hazard risk in the US. *Natural Hazards*, *114*, 2331–2355. https://doi.org/10.1007/s11069-022-05474-w