

Vulnerability, hazards and multiple risk assessment for Georgia

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Abstract The paper presents a framework for the nation-wide assessment of natural hazards, vulnerability and risk for the Republic of Georgia. Firstly, a relational database was created in order to collect all necessary information available. Secondly, hazard maps were drawn based on an innovative approach of assessing the magnitude and frequency of meteorological hazard types, where the corresponding formalization was not yet satisfying. Thirdly, the associated economic losses were evaluated and presented in monetary terms for some hazard types (droughts, hurricanes, hail, frost, flash floods and earthquakes), while for other types of hazards, the information remained descriptive. Fourthly, based on the hazard inventory, an approach was developed that allowed for the calculation of an overall vulnerability value for each individual hazard type, using the Gross Domestic Product per unit area (applied to population) as the indicator for elements at risk exposed. The correlation between estimated economic losses, physical exposure and the magnitude for each of the six types of hazards has been investigated in detail by using multiple linear regression analysis. Economic losses for all past events were estimated, and historical vulnerability was estimated. Finally, the spatial distribution of general vulnerability was assessed, and the expected maximum economic loss was calculated as well as a multi-risk map was set-up. The presented method will contribute to a reduction of disaster losses in Georgia and will foster future efforts of harmonization of risk management strategies in the country.

Keywords Vulnerability · Historical catalogue · Hazard · Economic loss · Risk

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1 Introduction

Risks resulting from natural hazards are closely related to sustainable development of the society concerned. Global trends show an increasing damage from natural hazards and thus increasing losses from disasters (Munich Re 2011). Such upward trends in intensity and frequency of natural disasters are observed worldwide (e.g. Swiss Re 2012) and are also discussed on the national level (e.g. Downton et al. 2005; Barredo 2007). One possible reason—apart from the ongoing debates on climate change (e.g. Solomon et al. 2007), which will not be discussed in depth here—may be related to urbanization and the associated increase in population density (e.g. Fuchs et al. 2005; Fuchs and Keiler 2006; Keiler et al. 2006). As a result, the areas of overlap between those areas prone to hazardous processes and elements at risk increase persistently, and additional phenomena such as economic and environmental factors contribute accordingly to the turn from hazards to disasters. As disasters are defined as ‘a serious disruption of the functioning of a community or a society involving widespread human, material, economic or environmental losses and impacts, which exceeds the ability of the affected community or society to cope using its own resources’, they develop when the ‘system or asset is susceptible to the damaging effects of hazard’ (UN/ISDR 2009).

The Republic of Georgia, located on the East coast of the Black Sea, is prone to multiple natural hazards, and an increasing economy turned them into disasters. The risk resulting from natural hazards such as earthquakes, landslides and hydrological hazards such as flash floods is considerably high, as recent events during the last three decades have shown. Risk from meteorological hazards also is significantly high. Strong earthquakes in Racha (1991), snow avalanches in the mountain regions of Achara (1971) and along the whole South Caucasus in Georgia (1976, 1987), landslides in the mountain regions of Achara (1989, 2004) and Racha (1992), flash floods (2002, 2012), hurricanes (1998) and droughts (2000) in Western and Easter Georgia, frost hazards in the region of Kakheti (1972) had shown the inherent susceptibility of the country to natural hazards. During these events, more than 700 people died and the economic losses amounted to approximately 6.6×10^9 USD. As such, the entire country is within the category of medium and high risk (EM-DAT 2006). As a result, the natural disasters in Georgia have to be considered as a standing negative factor for the development process of the country; however, this risk level has not been quantified so far in terms of different hazard sources and with respect to vulnerability.

The importance of the issues discussed above stimulates an active investigation of vulnerability and natural hazards that induce natural disasters. It was revealed that various effects caused by different natural disasters, their complex interaction with the environment, and geophysical, geological and other processes, cause some deficits in the current knowledge. In Georgia, there are no generally accepted concepts that response to the specific needs of dealing with natural disasters. A serious problem is revealed in the assessment of vulnerability. The assessment of vulnerability of the element at risk to hazards is very important for an effective and proper assessment of risk. In order to assess vulnerability information about hazard parameters, such as magnitude and intensity of an event, the size of the exposed area and information of damages to elements at risk caused by these hazards are necessary. The assessment of vulnerability still is a considerable challenge, and during the work presented within this paper, it was found that except earthquakes neither electronic databases nor printed catalogues of natural disasters exist for the territory of Georgia. It was still unclear what should be considered as the magnitude or intensity of an event, and how these parameters could be estimated. The only already existing scales on the national level were the seismic intensity scale Seismic intensity scale

version (1964) for earthquakes and the Saffir–Simpson scale (NHC 2010) for hurricanes. Hence, it was impossible to gather information about related damages for various elements of risk. However, the assessment and evaluation of information about the cumulative total damage resulting from multiple hazards was still challenging as there were no official data available on the national scale. The Statistical Department of Georgia was not supplied with any relevant data in the former Soviet Union as these data were considered as confidential. There was no standardized accounting system of hazard events and associated losses developed for the national level. Disaster data have been collected only by some institutions, agencies, NGOs and experts at various local levels. In spite of attempts of many international organizations to collect systematic information on disasters in Georgia (e.g. Emergency Events Database—EM-DAT, www.emdat.be; Munich Re Data Base—NATHAN, www.MunichRe.com), disaster data bases cover only short observation periods and are generally incomplete for developing countries; moreover, sometimes these data are simply not correct. For example, local experts assessed direct losses for residential houses and infrastructure damages resulting from the Racha earthquake (29 April 1991) in Georgia in the order of 10 billion rubles (as of 1991, approximately 5.5 billion USD by commercial course and 16 billion USD by official course) (Gugeshashvili and Kordzadze 1996), while much less economic losses are indicated for this event in the various international databases (e.g. Munich Re reports only 1.7 billion USD for the same event).

The importance of the described issues requires experience in sharing ideas and developing approaches to most precisely assess natural hazards, vulnerability and risk in Georgia. The attempt has been approached within the framework of the project ‘Reducing natural disasters multiple risk: a positive factor for Georgia development (RNDMR)’; after reviewing existing methods of vulnerability and risk assessment methods of vulnerability, hazard assessment have been refined and methods were developed for multiple risk assessment for the territory of Georgia.

2 Natural hazards in Georgia

The Republic of Georgia is situated between the Russian Federation in the North and the Republic of Turkey as well as the Republic of Armenia in the South. The main morphological units of Georgia are the mountain ranges of the Greater and Lesser Caucasus separated by the Black Sea-Rioni and Kura (Mtkvari)-South Caspian intermountain troughs. Recent geodynamics of Georgia and adjacent territories of the Black Sea-Caspian Sea region, as a whole, are determined by the still-converging Eurasian and Africa-Arabian plates. Related tectonic activities caused moderate seismicity in the region. According to geodetic data, the rate of convergence is $\sim 20\text{--}30$ mm/y, of which some 2/3 are likely to be taken up south of the Lesser Caucasian (Sevan-Akera) ophiolitic suture, mainly in south Armenia, Nakhchivan, northwest Iran and Eastern Turkey. The rest of the S/N directed relative plate motion has been accommodated in the South Caucasus chiefly by crustal shortening (DeMets et al. 1990; Jackson and Ambraseys 1997; Allen et al. 2004; Reilinger et al. 2006).

Three principal directions of active faults compatible with the dominant near N–S compressional stress produced by northward displacement of the Arabian plate can be distinguished in the region—one longitudinal (WNW–ESE or W–E) and two transversal (NE–SW and NW–SE). The first group of structures having the so-called Caucasian strike is represented by compressional structures: reverse faults thrusts, nappes and strongly related deformed fault-propagation folds. In contrast to these faults, the transversal faults are also mainly compressional structures having somewhat considerable strike-slip

components. The tensional nature of sub-meridian faults is evidenced by intensive Neogene–Quaternary volcanism related to these faults in some areas of Southern Georgia (Javakheti Highland) and the Greater Caucasian range. NE–SW left-lateral strike-slip faults are the main seismoactive structures in Northeastern Turkey, the Southern parts of Western Georgia and Armenia. Right-lateral strike-slip faults and fault zones are developed in Southeastern Georgia.

The orographic peculiarities of Georgia result in the formation of different atmospheric precipitation modes in western and eastern parts of the country. The main Caucasus dividing mountain range shades the country from the direct spreading of cold arctic winds. The two mountain systems—Greater Caucasus and Lesser Caucasus ranges—are connected with the medium-height Likhi Range that also divides the climate of the Western and Eastern parts of Georgia. The Western part of the country has a humid subtropical climate of the seaside. The sea has less influence on the Eastern part of the country because of its orographic conditions, and this region has a subtropical climate with less humidity.

Current geodynamics and orographic properties of Georgia play an important role for the occurrence of geological (earthquake), geomorphological (landslides, debris flows, snow avalanches), hydrological (flash floods) and meteorological (droughts, hurricanes, lightning, hail, fog, frost, freezing) hazards.

Seismicity—over the historical period, the observed seismicity in Georgia is characterized as moderate. All historical and instrumental earthquakes observed ($4.5 < M_S < 7.0$) were located along the fault systems of the Greater and Lesser Caucasus and the intermountain depressions. The maximum magnitude of observed earthquakes is $M_S = 7.0$. The moderate earthquakes reflect the regional tectonics that are largely determined by the position of the Caucasus range between the still-converging Eurasian and Africa-Arabian lithosphere plates. By this classification, the southern slopes of Greater Caucasus are characterized by thrust and thrust strike slips, while the Javakheti upland is mostly characterized by strike-slip faults. The Kura depression is characterized by thrust and trust-right-lateral strike slips. Earthquakes in Georgia are associated with secondary events such as landslides, debris flows and rock falls, as such, to provide an example, Racha earthquake in 1991 caused about 20,000 landslides (Tatashidze et al. 2000).

Geomorphological (landslide, debris flow, snow avalanche) hazards—Georgia belongs to one of the most complex hazardous mountain regions in terms of heterogeneity of formation of landslides, debris flows and snow avalanches, and damage resulting from these geomorphological hazards to territories is considerably high due to the frequency of occurrence (Gobechia et al. 2009). Hence, the risk to the population and to economic and engineering facilities is remarkable.

Flash floods and flooding cause increased water levels in the rivers of Georgia. Flooding is often characterized by a river water regime phase influenced by melting of snow accumulated in rivers during cold seasons, as well as melting of glaciers in high Caucasus mountains. The increase in river water levels caused by melting of snow only has a short duration but the disposition lasts for about 3 months. In some river basins (such as Kodori, Enguri, Rioni and Tergi), which are additionally fed from glaciers, the spring flooding lasts for up to 6 months. Usually, the flooding is not associated with a disastrous increase in water level and flow velocity is very slow. In contrast, flash floods result in an irregular transitory increase of water levels in rivers. Flash floods are caused by intensive precipitation in the watersheds, and flow velocities are comparatively high (Dolidze et al. 2009).

Western Georgia is characterized by high atmospheric precipitation during almost the entire year. However, less rainy periods are observed in spring time (Elizbarashvili 2007). During this period, the soil and air are relatively warm, but the sea surface and the air

temperature around are still low. This leads to the formation of a stable vertical stratification in the lower atmosphere layers that prevents the upward flow of humid air into the higher atmosphere and hence the formation of rain. Therefore, extensive flooding and disastrous flash floods caused by heavy rain are relatively uncommon in Western Georgian river watersheds during April and May. As a matter of fact, in the section near Chaladidi village (near the Black Sea), the Rioni river—the most water-abounding river of Georgia—has reached its maximum rate of discharge not during a warm season but on 01 February 1987 when the discharge rate was $4,850 \text{ m}^3/\text{s}$. In the Eastern part of the country, rains are most intensive during May and June. However, other summer months and rarely September are also characterized by very heavy local precipitation intensities. Mtkvari (Kura) river and most of its feeders are characterized by dangerous flash floods during April and May. However, sometimes some feeders of the Mtkvari River experience dangerous flash floods in summer, as well as rarely in September.

Drought is a frequent phenomenon in Eastern Georgia. The drought frequency exceeded 40 % in the 1980s in some areas by certain early estimates. As a result of frequent droughts accompanying the global warming in past decades, a transformation of many types of natural landscapes has been observed. The desertification probability of steppes and semidesert landscapes in Eastern Georgia has reached 25–30 % by the end of the twentieth century. According to official figures, an area of approximately 200,000 ha is strongly affected (Elizbarashvili and Elizbarashvili 2012). Property damage caused by drought is significantly high (Elizbarashvili et al. 2009). On the territory of Georgia, the following six main types of atmospheric processes determine weather conditions: Siberian anticyclone, Mediterranean cyclone, Azores anticyclone, polar basin anticyclone, wave disturbance in the south and local anticyclone. Repeatability of each type of processes varies depending on the season. Drought in Georgia occurs in polar, the Azores and mixed types of synoptic processes, frequency of which increases in the warm season. Long dry periods are formed in 70 % polar, 15 and 30 % of Azorean mixed types of synoptic processes (Elizbarashvili 2007). The main meteorological factors for drought formation are dry weather, high temperature and a lack of soil moisture. While the average time of periods with precipitation $<5 \text{ mm}$ is not more than 10–15 days per year, the mean rainfall does not exceed 200–300 mm during the vegetation period in the lowlands, which repeatedly causes severe threats to the agriculture. At the same time, air temperatures sums $\geq 10 \text{ }^\circ\text{C}$ during the vegetation period exceed 4,000 $^\circ\text{C}$, and the mean duration of continuous high temperatures $\geq 30 \text{ }^\circ\text{C}$ is exceeding 4 h per day.

Hurricanes—a wind storm is considered as hurricane if the velocity is exceeding 30 m/s. These winds cause considerable damage to the economy and population: they damage buildings, communication and power lines, cause traffic delay, roughness in the sea and reservoirs, dust storms, displacement of snow, soil erosion and other adverse effects. On the territory of Georgia, hurricanes have mostly westerly or easterly direction. The former occurs during cyclone passages of Mediterranean origin or if a low pressure associated with Atlantic cyclones over the South Caucasus occurs. In this case, the pressure gradient is directed from west to east, which leads to a strengthening of the western and north-western winds. Eastern winds occur when over the central and Eastern regions of the Caucasus, an area of high pressure has been formed, and from the west, a cyclone extends over the Black Sea. In this case, which is mostly observed in Western Georgia, the pressure gradient is directed from east to west and easterly winds grow stronger.

Hail is a frequent phenomenon especially in Eastern Georgia. An economic loss from the hail is very significant every year (Amiranashvili et al. 2002, 2008).

Frost is understood as lowering the minimum air or soil surface temperature below $0 \text{ }^\circ\text{C}$ on the background of positive daily mean temperatures. Frost starts earlier in the ground

than in the air, even if air temperatures are around 1 °C. Therefore, atmospheric frost always includes the freezing of soil. Frost is a dangerous phenomenon for agriculture, and crop damage is observable after plants have been grown accompanied by a rapid decline in their frost resistance. Therefore, frost is particularly dangerous during frost-free periods, that is, during the period between the mean dates of the onset of the last spring frosts and the first autumn frost. This kind of period is mainly characterized by advective–radiative frosts, which are formed as a result of the invasion of cold air and the subsequent cooling by nocturnal radiation. Such frosts occur frequently in late spring and early autumn, and in the mountains—even in summer— although they are rare compared to frost during the entire vegetative season, which have been properly studied both for Georgia and the Caucasus in general (Elizbarashvili et al. 2011). In significant parts of Colchis Lowland, Shida Kartli and the central part of the Great Caucasus frosts of moderate intensity are dominant when the minimum temperature during frosts decreases to -4 °C. In such situation, plants with mean frost resistance will be damaged. On large territories of Eastern Georgia, especially in the region of Shida Kartli and in the inner zones of the Colchis lowlands, frost with strong intensity (minimum temperatures between -4 and -8 °C) is common and severe damages to a significant portion of the cultivated plants are observed. In some mountainous zones of Guria, Adjara and Eastern Georgia, air temperature falls to -8 °C and below. This is a very strong frost intensity at which even frost super-resistant plants and grains, early dandelion, barley and other crops are damaged.

Fog is a frequent phenomenon on the territory of Georgia. Fog days exceed a sum of 150 day per year in some regions, and on the glaxis of the Surami ridge at 1,243 m a.s.l. foggy weather conditions last approximately 260 days (Elizbarashvili 2007). Impairing visibility, fog firstly delays any traffic movement. The most dangerous phenomena are caused by fogs when the visibility is less than 50 m. In this case, a collapse of any kind of transport is possible. Especially in mountainous areas, this results in emergency situations and an increasing number of accidents leading to fatalities. Depending on the basic physical processes of formation, on the territory of Georgia, the following kinds of fogs are observed: radiative, advective (including evaporative fogs), advective–radiative, frontal and orographic. Their distribution over the area is complex, due to a variety of physical and geographical conditions and peculiarities of atmospheric circulation. Nowadays, the geographical allocations of the number of days and the total duration of fog on the territory of Georgia have been studied in detail (Elizbarashvili et al. 2012). The probability of fog formation in a particular location and area, the empirical function of allocation of foggy days and the main areas of their distribution on the territory of Eastern Georgia have been subject to extensive research (Elizbarashvili 2007; Elizbarashvili ESh and Zubitashvili 2007). The share of dangerous mists in the total number of foggy days is more than 70 %. On a significant part of the territory, fogs of long duration exceeding 10 h are common. In addition, there are isolated centres, in particular along the Black Sea coast, in the Kvemo Kartli region and in Southern Georgia, where fogs with moderate (7–9 h) and mean duration (4–6 h) are dominant.

Freezing of wires has a negative effect on the production processes of many industries. Freezing disturbs the normal operation of communication air lines and power lines, causing damage to the transport sector, to agriculture and forestry. Freezing of wires is not uncommon in the mountainous regions of Georgia. Therefore, the study of this phenomenon has a long history (Elizbarashvili and Elizbarashvili 2012). However, the reliability of the previous studies is doubtful, and the resulting maps are considered to be rather schematic than analytic. Therefore, these earlier works on freezing requires editing and revising. Wire freezing takes place in some individual local areas of the country, as well as

over larger regions. The most typical aspect for the formation of glare freezing in the whole Southern Caucasus is a cold front influencing the region mainly from the west, in particular, the Black Sea, and more rarely from the east, the Caspian Sea. This cold front breaks into a territory occupied before by warmer and more humid air masses. As a result, warm air masses rise along the inclined surface of the cold front, and consequently, nimbostratus clouds and precipitation necessary for icing are formed behind the front.

3 Review of existing approaches in hazard, vulnerability and risk assessment with a particular focus on Georgia

Scientists and managers of emergency situations are permanently improving the methodology for vulnerability assessment, natural hazards and risks. Some methodologies focusing on a nation-wide application of the underlying concepts have already been published (Dilley et al. 2005; ProVention Consortium 2006). UNDP, for example, in its global report ‘Reducing Disaster Risk: a Challenge for Development’ emphasized the Disaster Risk Index (DRI) and a relative vulnerability assessment using various indicators (UNDP 2004). An estimation of the risk to an element from a given natural hazard requires the investigation into the vulnerability of the element at risk exposed. There are dozens of different publications released each year by different authors about vulnerability (e.g. Fuchs et al. 2011) focusing either on the socio-scientific or on the natural-scientific aspect. Vulnerability is one of the most challenging components during risk assessment. Consequently, the term vulnerability has wide range of interpretations and conceptualizations (Gabor and Griffith 1980; UNDR0 1991; Blaikie et al. 1994; Cutter 1996; Benson and Clay 2000; Glade 2003; Mechler 2003; Michael-Leiba et al. 2003; Pelling 2003; Barbolini et al. 2004; UNDP 2004; UN/ISDR 2004a, b; Corominas et al. 2005; Douglas 2007; Fuchs et al. 2007; Roca et al. 2006; Villagran De Leon 2006; Cutter and Finch 2008; Papatoma-Köhle et al. 2011) as groups from different disciplines have different views. There are many reports that review the research on vulnerability in hazard research and indicate the paradox of aiming to measure vulnerability if it is not defined precisely (Cutter 1996; ADPC 2000; Birkman 2006; Fuchs 2009; Van Westen 2010). From these definitions and reviews, vulnerability can be defined as multidimensional with a physical, social, economic and environmental component. Moreover, vulnerability is time-dependent, scale-dependent and site-specific.

Natural hazard and risk assessment for Georgia had been a subject for several investigations in various international and national projects that were published in international and local literature. Namely, Probabilistic Seismic Hazard Assessment (PSHA) for the Caucasus had been undertaken in the frame of the Global Seismic Hazard Assessment Program GSHAP (Balassanian et al. 1999). Similar issues were considered by several authors in individual studies (Smit et al. 2000; Slejko et al. 2008; Varazanashvili and Tsereteli 2010; Tsereteli et al. 2011, 2012). However, especially in steps necessary during PSHA for earthquake risk assessment, there are still some gaps, such as in the selection or derivation of ground motion prediction equations models, the determination of active faults or earthquake sources zonation on a large scale, and the estimation of maximum magnitude M_{\max} . These issues are under development in the frame of EMME (Earthquake Model for Middle East Region) project and will not be considered further in this work. Considerable work had been undertaken according to the investigation of individual mountain hazards in Georgia and beyond, such as snow avalanches, landslides, debris flows and flash flood hazards (Abdushelishvili et al. 1984, 1999; Abdushelishvili and Qaldani 1986, 1997; Qaldani et al. 2001; Tsereteli and Tsereteli 1985; Tsereteli and Varazashvili 1986;

Tsereteli 1988; Varazashvili et al. 1998; Tatashidze et al. 2000; Gobechia et al. 2009; Dolidze 2007; Amiranashvili et al. 2009; Chitanava et al. 2009; Dolidze et al. 2009). Furthermore, meteorological hazards were studied by Abdushelishvili et al. (1983) and Elizbarashvili ESh and Zubitashvili (2007). However, no hazard maps resulted from these studies so far. Detailed investigations of frost and fog hazards were provided by Elizbarashvili et al. (2011, 2012) in the frame of the project RNDM.

Recently, there have been some works on the assessment of risk, but there is still a lack in the clear definition of vulnerability (Chachava et al. 2001; Chelidze et al. 2009; Gavardashvili et al. 2009). Very often in seismic risk assessment, structural engineers use the so-called grade of sensitivity of damage (Mukhadze et al. 2008; Tsereteli et al. 2011) or the vulnerability index (Sobolev 1997; Varazanashvili et al. 2008), which is defined as a relationship between the hazard intensity and the degree of loss. However, there was not such clear definition of vulnerability as presented by Lagomarsino and Giovinazzi (2006). In particular, there is neither a vulnerability definition with respect to the individual element at risk, nor for the assessment of multiple hazards and risks for the territory of Georgia. Instead, there were some attempts to calculate the economic loss expressed in deciles using the technique presented in Dilley et al. (2005), Tsereteli (2007a, b), Chelidze et al. (2009), but the obtained maps were very approximative due to the very limited amount of data available.

A review of existing literature in the assessment of vulnerability, natural hazards and the assessment of multiple risk has been undertaken within the RNDMR project. Here, natural hazard is defined as a natural process or phenomenon occurring in the biosphere that may constitute a damaging event and therefore endanger any elements at risk exposed (UN/ISDR 2004a, b). Elements at risk refer to the population, buildings and engineering works, economic activities, public services utilities, other infrastructures and environmental values in the area potentially affected by the natural hazard. Risk is a measure of the probability and severity of a natural hazard to health, property or the environment (e.g. Fell et al. 2008). Risk is generally assessed by a function of probability of a phenomenon of a given magnitude times the consequences (Varnes 1984).

In the following section, the results from this project are presented and additional results from the project ‘Institutional Building for Natural Disaster Risk Reduction (DRR) in Georgia’¹ towards vulnerability, hazard and risk assessment for various types of hazards are taken into account.

4 Method

For the assessment of vulnerability information about hazard parameters such as magnitude or intensity of an event, the exposed area and information on possible damages of elements at risk caused by these hazards are necessary.

In spite of the substantial differences between the different types of natural hazards, they require at least three characteristics for a scientific assessment. First, it has to be principally possible to identify the specific geographical distribution and recurrence period for each type of hazard. Second, the larger an event is (the higher is the event magnitude or intensity), the less probable an event is to occur. Third, the magnitude and intensity of an

¹ This project was implemented by the Caucasus Environmental NGO Network (CENN) and the Faculty of Geo-Information Science and Earth Observation (ITC), University of Twente, The Netherlands. The project was financially supported by the Social Transformation Programme for Central and Eastern Europe (MATRA) of The Netherlands Ministry of Foreign Affairs (ATLAS 2012).

event has to be reliably estimated in terms of effects on the elements at risk exposed in order to quantify the possible damages and losses. All three characteristics have to be evaluated *ex ante* and *ex post* in order to verify the modelling steps undertaken during the risk analyses, in particular with respect to vulnerability.

Thus, in the frame of the Project RNDMR, a first step was to set-up a unified electronic database for natural hazards (DBND) on the territory of Georgia. The main parameters included in the DBND were date (year, month, day), time (hour, minute, second), epicentre coordinates (latitude, longitude), magnitude, intensity, damaged area (km²) and scale of the disaster (number of lives lost, loss in 1000 USD).

Moreover, this database includes specific hazard parameter classes that caused natural disasters (ND). A considerable routine and challenging work has been performed, in particular during reviewing the governmental statements and resolutions on ND loss compensations since 1940. The data containing information about the site, date, amount of damages, height of economic losses caused by different types of natural hazards were collected from the Department of Special Situations of the Georgian Ministry of Internal Affairs, the National Environmental Agencies, the Georgian railway association, the Department of Energy, the Department of Transport and other institutions (e.g. M. Nodia Institute of Geophysics of Tbilisi State University (TSU), V. Bagrationi Institute of Geography of TSU and Hydrometeorological Institute). Furthermore, accessible archives of published literature, bulletins, etc., were reviewed. Private archives of the authors of this paper were also screened in order to achieve necessary information. After the analysis of the data gathered, the main parameters on hazard, vulnerability and elements at risk were estimated. The economic loss was calculated in USD for the point in time the selected ND occurred based on the exchange rate of the same period.

The determination of the magnitude and intensity of a ND event required a revision of the existing magnitudes and scales and the development of new magnitude and intensity scale standards of those phenomena for which the corresponding formalization has not yet been conducted. As a result, new magnitude and intensity scales were suggested for NDs that did not yet have such standards. In the following section, magnitude and intensity scales for all considered NDs except earthquakes are presented (here, we accept M_S as magnitude and MSK-64 as intensity scale), as well as main principles of hazard assessment for these phenomena. Finally, geomorphological and geological hazards maps were calculated on a regional scale (1:500,000), hydrological and meteorological hazard on a 1:000000 scale.

After carrying out the hazard assessment following the procedures outlined below, a ND electronic database was created, which followed an organized structure for saving appropriate information. The catalogue of Georgia's 12 ND types represents the main content of this database, and these 12 types include: drought (for the period 1961–2007), hurricane (for period 1961–2009), lighting (for the period 1940–2006), hail (for the period 1961–2007), frost (for period 1961–2006), fog (for the period 1966–2002), freezing (for the period 1963–2000), landslide (for the period 1900–2007), debris flows (for the period 1776–2007), snow avalanche (for the period 1843–2007), flash flood (for the period 738–2007) and earthquake (for the period 1250 B.C.–2009). The resulting ND_DATABASE.ex program works on the basis of standard database software such as, for example, Microsoft Access™.

4.1 Meteorological hazards

The expression 'Magnitude Scale', developed in 1935 by Richter, refers to a number of ways to assign an individual number to quantify the energy contained in an earthquake (Richter 1935). Following this concept, it is obvious that the magnitude of each event

should characterize these phenomena according to the energy released by them. Compiled data of natural hazards, however, not always allow us to determine the magnitude as an individual number for each natural hazard to quantify these phenomena by their energy. For the magnitude, we have selected parameters that indicate how many particular types of events are larger or smaller than other events of the same type.

Hazard assessment was defined as the analysis of the physical aspects of the phenomena through the collection of historical records and the interpretation of topographical, geological and hydrological information to provide the estimation of the temporal and spatial probability of occurrence and the magnitude of the hazardous event. According to this main concept, spatial-time regularities and magnitude–frequency relationships were investigated for all ND on the basis of the developed ND database catalogues. These regularities were the main keystone that allowed us to constrain hazard (zoning) maps for meteorological hazards such as drought, hurricane, lightning, hail, frost, fog and freezing expressed in terms of magnitude or frequency. In case where good magnitude–special distributions were available, hazard maps were expressed in terms of magnitude that also gives us information about the frequency/recurrence period (year) of this magnitude from magnitude–frequency relationships. Sometimes, however, the spatial distribution by magnitude does not allow us to undertake zonation, even if spatial distribution by frequency/recurrence periods shows quite nice regularities. In such case, meteorological hazards were expressed in terms of frequency/recurrence periods (years).

4.1.1 Drought

The hydrothermal coefficient has been used for the assessment of drought magnitude. It is one of the most popular and informative agro-climatic indicators (Elizbarashvili and Elizbarashvili 2012). Hydrothermal coefficient represents the ratio of monthly precipitation to the sum of active temperatures (daily temperature is above $+10\text{ }^{\circ}\text{C}$) of the same month, decreased by 10 times. The feasibility of using this indicator is justified by its high cross-correlation with other indicators of moisture and crop yield (Gringof et al. 2000). If the hydrothermal coefficient is <1 , then drought occurs. Months with a coefficient <0.3 have been considered as periods of very severe drought. On the basis of the damage area and the value of hydrothermal coefficient, an intensity scale was evaluated for drought (Table 1). Investigation of special distribution of magnitude allows us to express the drought hazard in terms of magnitude.

4.1.2 Hurricane

Hurricane is a wind with velocities exceeding 30 m/s. Available data of hydrometeorological bulletins show that the wind velocities in Georgia vary from 30 to 45 m/s. The wind velocities have been considered as a proxy for the hurricane magnitude according to the so-called Saffir–Simpson scales (NHC 2010). Additionally, local damage characteristics were taken into account, and a local intensity scale was developed on the basis of hurricane magnitude and potential economic loss per unit area (km^2) (Table 2). Hurricane hazard map was presented in terms of magnitude.

4.1.3 Lightning

In order to develop a hazard map for lightning, the annual number of thunderstorm days P was collected from the Hydrometeorological Department of Georgia. The annual number

Table 1 Drought intensity scale

| Intensity | Hydrothermal coefficient | Effect | Description of the probable damage and loss |
|-----------|--------------------------|-------------|--|
| 1 | 1.00–0.70 | Weak | Short-term drought. Delay in growth of grains and herbaceous plants; fire hazard—more than average |
| 2 | 0.69–0.50 | Average | Damage of crops area, herbaceous plants and meadows; great fire hazard; water level in rivers, reservoirs and wells is low; lack of water causes partial limitation on water consumption |
| 3 | 0.49–0.30 | Strong | Loss of harvest and meadows; too great fire hazard; water shortage; limits on water consumption |
| 4 | <0.30 | Very strong | Complete loss of harvest and meadows; extremely great fire hazard; lack of water in rivers, reservoirs and wells that causes critical situation in water supplying |

Table 2 Hurricane intensity scale

| Intensity | Wind velocity m/s | Effect | Economic losses in USD per unit area (Km ²) |
|-----------|-------------------|-------------|---|
| 1 | 30–34 | Weak | <100 |
| 2 | 35–40 | Average | 101–1,000 |
| 3 | 40–45 | Strong | 1,001–5,000 |
| 4 | >45 | Very strong | >5,000 |

of electrical discharges Q per km² was calculated using Eq. (1) according to the international standard IEC 61024-1 (IEC 1990) and the instruction of the Federal Russian Ministry of Energy (MERF 2004) following Eq. (1).

$$Q = 0.04 P^{1.25} \tag{1}$$

For the assessment of lightning magnitude, the number of electrical discharge per km² was used. The corresponding magnitude–frequency relationship (relationship between number of discharge per km² and number of events per year) and the spatial distribution of frequency were investigated. This investigation allows us to express the severity of lightning hazard in terms of frequency. An intensity scale for lightning was developed on the basis of the lightning magnitude and the annual number of thunderstorm days (Table 3).

4.1.4 Hail

The hailstone size (mm) has been used for the assessment of magnitude following the hailstorm intensity scale published by the Tornado and Storm Research Organization (TORRO 2012). Data of the hailstone size and damage area were collected from the Hydrometeorological Department of Georgia; the average size of hailstones in Georgia was calculated with 15 mm. On the basis of these data, a hail intensity scale is developed (Table 4). The link between hail size D_h and the area being 100 % damaged S_{dh} (derived from experimental data for market gardening in Georgia) was expressed by Eq. (2) as

$$S_{dh} = 1.077 D_h - 4.113 \tag{2}$$

with $R^2 = 0.735$ and $\alpha = 0.001$. Thus, for the hail sizes $D_h = 6–10$ mm, 100 % damaged area S_{dh} is $2.4 \pm 3.7–6.7 \pm 4.4$ km², for $D_h = 11–20$ mm, S_{dh} is $7.7 \pm 4.7–17.4 \pm 6.4$ km², for

Table 3 Lightning intensity scale

| Intensity | Yearly number of lightning days | Yearly number of electrical discharges on 1 km ² | Effect | Description of the probable damage and loss |
|-----------|---------------------------------|---|-------------|---|
| 1 | ≤10 | ≤0.7 | Very low | Fires; damage to communication lines, electric substations, overground pipelines, TV and radio communications, airplanes; influence on people and animals; lives loss |
| 2 | 11–20 | 0.8–1.7 | Low | |
| 3 | 21–30 | 1.8–2.8 | Weak | |
| 4 | 31–40 | 2.9–4.0 | Average | |
| 5 | 41–50 | 4.1–5.3 | Strong | |
| 6 | 51–60 | 5.4–6.7 | Very strong | |
| 7 | >60 | >6.7 | Numerous | |

$D_h = 21\text{--}50$ mm, S_{dh} is $18.5 \pm 6.4\text{--}49.8 \pm 12.2$ km². The comparison of these values with our estimates in Table 4 shows the potential for the application of this scale in Georgia. There are no relationships between the annual number of days with hail and the recorded hailstone size. However, quite good relationships were observed for the spatial distribution of the number of days with hail per year. As a result, the hail hazard map was expressed by the frequency/mean recurrence period (years) of the number of days with hail.

4.1.5 Frost

The negative temperature (in °C) during the warm period has been used for the assessment of frost magnitude. The corresponding frost intensity scale is presented in Table 5. Economic losses per unit area have been taken into account during the intensity scale evaluation. The magnitude versus spatial distribution and magnitude–frequency relationship for frost hazards were investigated, and the frost hazard map was expressed in terms of magnitude. The frost intensity scale was developed and is presented in Table 5.

4.1.6 Fog

For the assessment of fog magnitude, the duration of dense fog (visibility <50 m per hour) has been used. The investigation of fog magnitude versus spatial distribution and magnitude–frequency relationship showed good regularities. Therefore, the fog hazard was expressed in terms of the magnitude, and the corresponding fog intensity scale is presented in Table 6.

4.1.7 Freezing

In order to assess the magnitude of freezing, the weight of freezing layer (g) has been used. A quite good relationship between freezing magnitude–frequency and magnitude versus spatial distribution was observed. A hazard map for freezing was expressed in terms of magnitude, and the evaluated freezing intensity scale is presented in Table 7.

4.2 Geomorphological, hydrological and geological hazards

The assessment of geomorphological (landslides, debris flows, snow avalanches), hydrological (flash floods) and geological (earthquakes) hazards has been based on an integrated

Table 4 Hail intensity scale

| Intensity | Size of hailstone (mm) | Damage area (100 % of agriculture, km ²) | Effect | Description of probable damage and loss |
|-----------|------------------------|--|-------------|---|
| 1 | ≤5 | <1 | Low | Vegetable leaves are pierced and split, flower leaves—torn. Sown lands are partially damaged |
| 2 | 6–10 | 1–5 | Weal | Trees are naked; vegetable, fruit and grass are significantly damaged |
| 3 | 11–20 | 6–10 | Average | Hotbeds are damaged, paint scraps are found on ledges of windows and transport. Tents are torn; asbestos–concrete roofs of houses are pierced. Grain stems are cleaved and seeds—overground, fruit—cut and decomposed |
| 4 | 21–50 | 11–50 | Strong | Slated and tiled (except concrete) roofs are slightly damaged or completely destroyed. Thatched and shingled roofs are collapsed; roofs of furrowed iron and some sheet metal are crushed and pierced; some brick and stone walls have holes; wooden frames and many windows are broken; there is risk for car and airplane damage; small livestock are under significant or fatal risk; rind strips are torn off trees; wooden parts of buildings are pecked and cleaved; big tree branches are shortened. There is a full risk for crops annihilation |
| 5 | > 50 | > 50 | Very strong | Most roofs of sheet metal slate and tile are collapsed. Wooden buildings are disassembled, brick buildings—significantly damaged, pavements have holes. Airplanes are damaged. Stems of trees are cleaved. Crops are annihilated. There is risk for human and large cattle damage or death in the open air |

Table 5 Frost intensity scale

| Intensity | Negative temperature during the warm period (–°C) | Effect | Description of probable damage and loss |
|-----------|---|-------------|---|
| 1 | ≥1.1 | Low | Heat-loving plants that are not resistant to frost such as beans, rice, cotton, buckwheat and asparagus are damaged |
| 2 | 1.1–3.0 | Weak | Plants less resistant to frost such as grains, maize, potato and sorghum are damaged. Wheat growing process is delayed |
| 3 | 3.1–4.0 | Average | Plants of mean resistance to frost such as soybean are damaged |
| 4 | 4.1–8.0 | Strong | Plants resistant to frost such as most cultivated plants, oil-bearing crops and hemp are damaged. Vegetational growth of wheat is delayed |
| 5 | <8.0 | Very strong | Plants especially resistant to frost such as early summer wheat, grainy, leguminous and early oil-bearing cultures and barley are damaged |

Table 6 Fog intensity scale

| Intensity | Duration of dense fog (visibility <50 m, hour) | Effect | Description of probable damage and loss |
|-----------|--|-------------|---|
| 1 | ≤2 | Weak | Airplane collapse, hazard for road traffic, destructing of all kinds of transport, human lives loss |
| 2 | 3–6 | Average | |
| 3 | 7–10 | Strong | |
| 4 | >10 | Very strong | |

Table 7 Freezing intensity scale

| Intensity | Weight of ice layer (g) | Effect | Description of probable damage and loss |
|-----------|-------------------------|-------------|--|
| 1 | ≤100 | Low | Negative effect on different industrial processes |
| 2 | 101–300 | Moderate | Negative effect on agriculture and forestry |
| 3 | 301–500 | Average | Exploitation delay of electricity and communication lines |
| 4 | 501–1,000 | Strong | Delay of railway and motor transport |
| 5 | >1,000 | Very strong | Collapse of electricity and communication lines; annihilation of cattle and plants |

analysis of multiple factors. In the following section, a concise description of the main philosophy behind these assessments is presented and the corresponding maps are provided.

4.2.1 Landslides

For the assessment of landslide magnitude, the potential volume of landslides has been used (million m³). The landslide intensity scale is presented in Table 8.

For landslide hazard mapping, the criterion of landslide potential has been applied, which has been expressed by the intensity of process developed in homogeneous geological environments and under similar climate conditions. The intensity of landslide processes has been assessed by three indicators:

- Coefficient of area damage K_p , which is the ratio of area, damaged by landslides F_p to the entire area F of a given homogeneous geological unit: $K_p = F_p/F$.
- The density of landslide events D , namely the number of landslides N normalized to the same area F : $D = N/F$.
- The probability of development of new landslides in the geological environment due to the influence of additional natural-technogeneuous factors such as earthquakes, intensive meteorological impact and human effects, expressed by the ratio of the area of probable formation of new landslides F_p^1 to the total area F of the given territory $K_p^1 = F_p^1/F$.

These coefficients vary in the range from 0 to 1. Their average values give an integrated characteristic of landslide hazard and have been called the average coefficient of landslide hazard. Areas prone to landslides have been delineated according to the average hazard coefficient (Tsereteli 2007a, b).

Table 8 Landslide intensity scale

| Intensity | Damage area (km ²) | Effect | Description of probable damage and loss |
|-----------|--------------------------------|-------------|--|
| 1 | ≤0.00010 | Very low | Population damage and economic loss are unsubstantial, geoeological deterioration—not observed |
| 2 | 0.00011–0.0010 | Weak | Population damage and economic loss are low, just few houses are imposed to damage, geoeological deterioration—not observed |
| 3 | 0.0011–0.0100 | Average | Damage to population and industrial–engineering objects and economic loss are substantial, geoeological deterioration is at conflict level |
| 4 | 0.0110–0.1000 | Strong | Damage to population and industrial–engineering objects and economic loss are great, tens of houses and highways are imposed to damage, cultivated lands are annihilated, geoeological deterioration is at crisis level |
| 5 | >0.1000 | Very strong | Damage to population and industrial–engineering objects and economic loss are extremely great, tens of houses or sometimes whole inhabited areas are damaged and destructed, cultivated lands are annihilated, geoeological deterioration is at catastrophic level |

Table 9 Debris flow intensity scale

| Intensity | Volume of disposables maximal solid discharge (million. m ³) | Effect | Description of probable damage and loss |
|-----------|--|-------------|--|
| 1 | ≤0.0010 | Low | Damage to population and industrial objects is low; economic loss is little |
| 2 | 0.0011–0.0300 | Weak | Damage to population and industrial objects and economic loss are substantial |
| 3 | 0.0301–0.1000 | Average | Population, cultivated areas and motorways are damaged; economic loss is average |
| 4 | 0.1001–3.0000 | Strong | Damage to population, cultivated areas and motorways is significant; economic loss is great |
| 5 | >3.0000 | Very strong | Causes great damage to population and engineering buildings, also motorways and irrigation systems, sands and annihilates cultivated areas, human lives loss is high, economic loss is extremely great |

4.2.2 Debris flows

For the assessment of debris flow magnitude, the volume of maximal available solid discharge (million m³) has been used. The debris flow intensity scale is presented in Table 9.

For the assessment of debris flow hazard (Tsereteli 2007a, b), a combination of several parameters has been applied, namely:

- The ratio of total length of rivers generating debris flows $\sum l$ to the total length of a given river basin L : $K_{S1} = \sum l/L$;

- The ratio of the number of rivers generating debris flows $\sum n$ to the number of rivers of a given basin where debris flow events were not registered n : $K_{S2} = \sum n/n$;
- The ratio of the total area of rivers generating debris flow $\sum f$ to the total area of a given river basin F : $K_{S3} = \sum f/F$; and
- The ratio of total area of active debris flow sources that feed rivers generating debris flows $\sum S$ to the total area of these river basins F : $K_{S4} = \sum S/F$.

Besides the above-mentioned coefficients, the following characteristics have been taken into consideration: 1) the frequency of debris flows in the described geological environment for a unit in time; and 2) the maximum volume (10^3 m^3) of the simultaneous output of the debris flow mass. The resulting debris flow hazard map is expressed by mean recurrence periods of debris flows.

4.2.3 Snow avalanches

For snow avalanches, the impact pressure in the run-out area (t/m^2) has been used as a proxy for the magnitude following international standards (e.g. Bründl et al. 2010). The intensity has been determined by the impact force of the avalanche, and they are affected by the avalanche and are presented in Table 10.

Maps of snow avalanche hazards in Georgia are based on four basic quantitative indicators: the avalanche activity; the density of avalanche sources, namely the number of avalanche sources per 1 km of the length of the valley (n/L); the recurrence ratio of avalanche events, namely the number of avalanches generated by a given source in 10 years; and the maximum duration of the avalanche hazard period (Qaldani and Saluqvadze 2001, Seliverstov et al. 2008). For the calculation of the value, the area of the territory for which the avalanche activity is determined, the percentage of forest land (coniferous, deciduous or mixed forest) have to be taken into account. The density of avalanche sources is formulated on the basis of long-term field investigations and the analysis of maps of different scales. For calculating the recurrence rate of avalanche events, the maximum thickness of snow cover, the amount of new snow during a snowfall period, the steepness of the slopes and the critical height of the snow cover have been considered. In order to calculate the duration of the avalanche active period, the time span when the thickness of the snow cover exceeds a critical value has been taken into account. In the *Atlas of Snow and Freezing Resources of the World*, the zoning of mountain regions of the Caucasus according to avalanche hazards (Abdushelishvili and Qaldani 1997) has been carried out by means of two quantitative indicators—the density of avalanche sources and the recurrence rate of avalanches.

The following gradation of avalanche hazards has been elaborated: *very strong, strong, average, weak and no hazard* Qaldani and Saluqvadze (2007).

Very strong grade corresponds to the following criteria: the number of avalanche sources n per 1 km of the length of the valley exceeds 15 and the recurrence rate of avalanche events n_i exceeds 10 during the avalanche hazard period per winter, which is 100 days ($n > 15$ and $n_i/100 > 0.1$).

Strong hazard grade corresponds to the following criteria: the number of avalanche sources n per 1 km of the length of the valley is between 10 and 15, and the recurrence rate of avalanche events n_i exceeds 10 during the avalanche hazard period per winter, which is 100 days ($10 < n \leq 15$ and $n_i/100 > 0.1$).

Average avalanche hazard is recognized in areas where the number of avalanche sources per 1 km of the length of the valley is between 5 and 10 and/or the recurrence rate

Table 10 Snow avalanche intensity scale

| Intensity | Impact pressure | Avalanche field (km ²) | Effect | Description of probable damage and loss |
|-----------|-----------------|------------------------------------|-------------|--|
| 1 | ≤20 | ≤ 0.004 | Weak | Human lives loss; unsubstantial damage of buildings, (collapse of wooden stairs and railing, glass breaking, etc.); destruction of auxiliary wooden buildings (maize store, drying room, etc.), mills and fences; delay of railway and motor transports, breaking of branches of high trees and plants, damage of young trees; death of small livestock |
| 2 | 21–40 | 0.005–0.008 | Average | Human lives loss; collapse of wooden buildings (residential and other) and auxiliary rooms (kitchen, wattle house, cattle stalls, wood house, etc.); significant damage of buildings of mortared stone and brick (breaking in of doors and windows, collapse of glazed loggia and balcony, roof damage, etc.); delay of railway and motor transports, damage and moving away of carriages and automobiles; damage of electricity and communication lines, overground pipelines; animal death; annihilation of certain trees, years-old plants and small areas of forests |
| 3 | 41–60 | 0.009–0.012 | Strong | Human lives loss; collapse of all kinds of residential and other buildings (wooden, mortared stone, brick); delay of railway and motor transports, damage of roads and bridges, carriages and automobiles; damage of electricity and communication lines and their bases, overground pipelines; animal death; annihilation of years-old plants and forests |
| 4 | >60 | >0.012 | Very strong | Human lives loss; collapse of all kinds of overground buildings (reinforced concrete among them); damage of rail- and motor-ways; destruction of electricity and communication lines and their bases (reinforced concrete among them); destroy of overground pipelines; animal death; annihilation of years-old plants and forests |

of avalanche events n_i is between 5 and 10 during the avalanche hazard period per winter, which is 100 days ($5 < n \leq 10$ and $0.05 < n_i/100 \leq 0.1$).

The avalanche hazard is weak if the number of avalanche sources per 1 km of the length of the valley is less than 5, the recurrence rate of avalanche events n_i is less than 5 and the avalanche hazard period is 50 days ($n \leq 5$ and $n_i/50 < 0.1$).

No hazard has been assigned to those areas that are free of avalanches.

As a result of this procedure, the area prone to avalanche hazards in Georgia equals 51 % of the territory.

4.2.4 Flash floods

For the assessment of flash flood magnitudes, maximum water discharges (m³/s) have been used and the corresponding intensity scales are presented in Table 11.

The orography of the territory is of decisive value in assessing flash flood hazards since flash floods can be generated

Table 11 Flash flood Intensity scale

| Intensity | Recurrence of Maximum water discharges (year) | Effect | Description of probable damage and loss |
|-----------|---|-------------|---|
| 1 | <16 | Weak | Causes little damage. Covers insignificant part of river banks. Floods less than 10 % of cultivated lands |
| 2 | 17–25 | Average | Causes substantial material damage. Covers large areas of river basins. Floods less than 10–15 % of cultivated lands |
| 3 | 26–50 | Strong | Causes great material damage. Covers 50–70 % of cultivated lands. Floods some inhabited areas. Local population evacuation is required |
| 4 | >50 | Very strong | Causes extremely great damage and loss of human lives. Covers large areas of one or several river basins. Floods many of inhabited areas, the more than 70 % of cultivated lands, economical and engineering communication buildings. Local population evacuation becomes necessary |

- By melting of the snow cover, especially when the air temperature is rising fast and intense precipitation occurs;
- By heavy precipitation during the summer and autumn period;
- By incessant autumn rains, covering large part of a river basin; and
- By intensive winter rains of short duration in the seaside areas of the Black Sea.

For the Southern Caucasus, the most typical characteristics of rivers include rivers with springtides, rivers with high waters during the warm period of a year and rivers with flood flows. The maximum water discharge during such anomalous events was found to be almost 30 times higher than the average annual water discharge.

The critical values of precipitation per 12 h causing disastrous water flows, flooding in rivers and in dry ravines is in the seaside regions of Western Georgia 130 mm and more, in the central and Western part of Colchis Lowland and adjoining mountains slopes 100 mm and more, in the remaining part of Western Georgia, on the Southern slopes of Larger Caucasus 80 mm and more, and in the remaining part of Eastern Georgia 60 mm. Using these critical values, the recurrence rates of disastrous heavy rains have been assessed and corresponding flash flood hazard maps have been compiled (Dolidze 2007).

4.2.5 Earthquakes

The probabilistic assessment of seismic hazards involves the calculation of the expected value of ground shaking for a specified probability of exceedence within a specified time period.

Four basic elements are required to apply probabilistic procedures for seismic hazard assessment (PSHA):

- The definition of a reliable seismic earthquake catalogue extended back in time as far as possible;
- A seismotectonic characterization of the area under investigation (based on classical and modern data analysis procedures);
- The characterization of attenuation relationships for the relevant ground shaking parameters; and

- The integration of steps (1) to (3) into probabilistic calculations of seismic hazard curves with uncertainties.

Here, a seismic hazard map expressing in peak ground acceleration (PGA) and intensity (MSK 64) for a 2 % probability of exceedence in 50 years is presented. This map has been calculated using the software SEISRISK III and has been adopted as normative earthquake hazard map in Georgia in 2009.

4.3 Vulnerability assessment

The database of natural disasters in Georgia developed within the framework of this paper not only contains information on the hazard characteristics, but also on the effects of these hazards, that is, information on the scale of the disaster, the affected area and losses. As a result, vulnerability relationships can be established for individual hazard types.

At present, existing data on elements at risk and information on losses allow us to concentrate on the assessment of the vulnerability only generally or stochastically at a country level in Georgia for six natural hazards (namely earthquakes, flash floods, hail, hurricanes, drought and frost) by using the Gross Domestic Product (GDP) per unit area (applied to population) as the indicator of elements at risk. The approach of using the GDP as an indicator of the elements at risk was already earlier presented by Dilley et al. (2005) on the national level. It is noteworthy that the damage data (economic losses) for some types of natural hazards such as landslides, debris flows, snow avalanches, lightning, freezing and fog remained rather descriptive so far. The main challenge for the establishment of vulnerability values has been the determination of loss data for certain elements at risk, apart from the overall problem of converting different monetary units from different time periods into one single value (here: USD). For this reason, some information on economic loss is missing in the database.

For the assessment of vulnerability, we decided to focus on physical vulnerability estimation by empirical methods that based on the information of damaged data and intensities of related hazards for historical and recent events, and to neglect any social aspects of vulnerability (Fuchs 2009; Hufschmidt 2011). This gives us the possibility to constrain vulnerability functions into two different types: Absolute curves that show the relationship between the total amount of damage and the hazard intensity; and relative curves that show the dependence of relative values of damage on the hazard intensity. In our case, the relative value of damage has been estimated as the ratio of observed total economic loss for particular events to the total GDP of the area affected by this event.

To calculate the GDP of the affected area, an approach developed by the Columbia University group during the compilation of the Map of Global Natural Disaster Risk Hotspots (Dilley et al. 2005) was used with a little modification. The investigated territory of Georgia was divided into cells with a spatial resolution of $0.025^\circ \times 0.025^\circ$ latitude–longitude grids with each cell being considered as a unit area. For Georgia, the GDP is available not only for sub-national levels, but for regions. There are some data that show the share in total GDP of regions from the corresponding district centre. The national macro-economic parameters were calculated by the Ministry of Economy Development of Georgia in GEOSTAT (2007). This allowed for the estimation of the GDP per district centre units. To assess the GDP for different cells, the ratio of district GDP to population density values for corresponding cells has been considered as a proxy.

The compilation of a demography inventory for the Republic of Georgia has been realized by integrating the following data in GIS: population data for settlements as a point

layer (on the basis of the 2007 general population census, GEOSTAT 2007) and settlements as a polygon layer in a 1:200,000 scale. To obtain the population distribution for every grid cell, the following steps have been undertaken:

- Settlement polygons have been assigned a code of the closest settlement point;
- The population of each settlement point has been distributed proportionally to the areas of the settlement polygons that belong to that settlement point;
- For each 0.025×0.025 degree grid, the total population of the settlement polygons inside the grid cell has been summed up (if a square boundary intersected with a settlement polygon, only the population of the part of the settlement polygon that was falling inside the cell has been assigned to the cell); and finally,
- Custom Visual Basic scripts were developed to perform these tasks automatically.

The obtained GDP data for the district were applied to population density in the corresponding grid cell.

Obtained data such as intensity of hazards, the total economic loss for particular events and the relative value of economic loss allowed us to investigate the relationship between the hazard intensity and the total economic loss, and also between the intensity and the relative value of economic losses for six natural hazards (Figs. 3, 4). Such relations provide some assumption about the portion of economic losses caused by various hazards to the entire economy of the exposed area.

In order to get information on the spatial distribution of vulnerability, a different approach has been used following the definition in (UNDRO 1979). Here, the susceptibility for losses results from three components—hazard occurrence, elements at risk exposed and vulnerability. The hazard occurrence refers to the frequency of hazard occurrence for a given process magnitude. By combining both occurrence frequency and elements at risk exposed to a given magnitude for a selected type of hazard (Coburn et al. 1991; Dao and Peduzzi 2003, 2004), the physical exposure $PhExp$ has been obtained. So the risk equation can be presented as

$$R = PhExp * Vul \quad (3)$$

If the past risk level is calculated, it is possible to estimate a vulnerability proxy from Eq. (3):

$$Vul = R/PhExp \quad (4)$$

In our case, R can be presented by the ex post assessment of economic losses (total losses for some historical period) from n -th hazard— R_n , and $PhExp$ can be presented by summing up the GDP for areas affected by that n -th hazard— $PhExp(n)$ (for the same period):

$$Vul(n) = R_n/PhExp(n) \quad (5)$$

In the method reported by Dilley et al. (2005), this value is called a historical vulnerability (economic loss rate from the n -th hazard).

As described above, economic losses were only estimated for six types of natural hazards, and in particular only for those events where the data were of sufficient quality: earthquakes (19 out of 147 events with intensities $I > 6$ at the MSK-64 scale); flash floods (43 out of 302 events); drought (42 out of 269 events), hail (for all 217 events from 1973 to 2007), hurricane (for 75 out of 1,760 events); and frost (for 41 out of 1,388 events).

For the estimation of economic losses of these events, we decided to study the correlation between estimated economic losses E , physical exposure $PhExp$ (GDP of people,

which was exposed to the hazard) and magnitude M for each hazard type except hail, as for hail a complete data set was available) using multiple linear regression analysis. Since regression analysis can only be applied to independent variables, and the evaluation of hazard intensity sometimes included information on the damaged area, the intensity value is not independent from the exposure area. Therefore, we used information on the process magnitude instead following Eq. (6).

$$\ln(E_n) = a \ln(M_n) + b \ln(PhExp_{(n)}) + C \tag{6}$$

where n denotes the type of hazard ($n \sim 1-5$). Damaged areas that are known from inventories for all events allow us to calculate the physical exposure (GDP for areas affected by n hazards) using GIS analysis.

The range of variation of magnitude for some NDs (hurricane, frost) is not significant. In such cases, we used the following correlation

$$\ln(E_n) = a M_n + b \ln(PhExp_{(n)}) + C \tag{7}$$

For the other hazard types, the following equations were obtained (Eqs. 8–12):

$$\ln(E_{eq}) = 2.27 M_S + 0.33 \ln(PhExp_{(eq)}) - 2.29 \text{ for earthquake} \tag{8}$$

$$\ln(E_{ff}) = 0.79 \ln(M_{ff}) + 0.20 \ln(PhExp_{(ff)}) + 6.16 \text{ for flash flood} \tag{9}$$

$$\ln(E_{dr}) = 0.61 \ln(M_{dr}) + 0.08 \ln(PhExp_{(dr)}) + 12.3 \text{ for drought} \tag{10}$$

$$\ln(E_{hr}) = 0.08(M_{hr}) - 0.02 \ln(PhExp_{(hr)}) + 9.59 \text{ for hurricane} \tag{11}$$

$$\ln(E_{fr}) = 0.30(M_{fr}) - 0.35 \ln(PhExp_{(fr)}) + 7.57 \text{ for frost} \tag{12}$$

Standard statistic analysis was used to calculate the main statistical parameters such as the multiple linear correlation coefficient R , the level of significance α and the standard error ε . The level of significance depends on the values of multiple linear correlation coefficients, which is related to the quantity of data (Table 12).

The investigation of pair correlation has shown a weak dependence of each variables M_n and $PhExp_{(n)}$, and a significant dependence of each variables M_n and $PhExp_{(n)}$ with variable E_n in the equation. The calculated value of statistical parameters has shown a good confidence of our estimates. This allows us to apply the equations to all data. Economic losses were calculated for all events in the database using the obtained Eqs. (9–13) for the time period 1961–2007.

A correction factor was taken into account in the estimation of $PhExp$ for past events. General population census from 1992 was provided by the Ministry of Economical Development of Georgia. On the basis of these data, population distribution has been

Table 12 Multiple linear correlation coefficient R , level of significance α , and standard error ε for each hazard type

| Hazard | R | α | ε |
|-------------|------|----------|---------------|
| Earthquake | 0.59 | 0.05 | 2.19 |
| Flash flood | 0.54 | 0.01 | 1.08 |
| Drought | 0.47 | 0.01 | 0.87 |
| Hurricane | 0.21 | 0.15 | 1.30 |
| Frost | 0.68 | 0.0001 | 0.83 |

calculated per unit grid area ($0.025^\circ \times 0.025^\circ$) using the same technique as described above.

The equation of current physical exposure (Dao and Peduzzi 2003) was used for every unit area i as

$$PheExp_{1992/i} = Pop_{1992/i} / Pop_{2007/i} \quad (13)$$

where $Pop_{1992/i}$ is the population for each cell i by using the population census in 1992, $Pop_{2007/i}$ is the population for each cell i by using the population census in 2007. $PheExp_{1992/i}$ was used for assessing the historical period 1961–1994. The GDP at national level for 1992 has been taken into account for the estimation of $PhExp$ for the historical period 1961–1994. After 1994 up to now, a rapid increase of town population in Georgia is observable. Therefore, for data after 1994, an estimated population distribution of 2007 was used to calculate physical exposure.

The obtained values of economic losses for the period 1961–2007 allowed us to calculate the historical vulnerability by using Eq. (5).

The human poverty index has been taken into account during the assessment of vulnerability. The method combines household and census data to estimate poverty for disaggregated geographical units and has been applied in Georgia. The results are shown in maps of different welfare indicators (poverty headcount (PH), poverty gap, severity of poverty and income inequality) and were disaggregated at the district level (Labbate et al. 2003). Here, a higher value of PH (that is always less than one $PH < 1$) indicated poorer districts. This value has been applied to all grid cell areas using GIS.

There are various relationships between the level of economic development and absolute and relative economic losses (Van Westen 2010). With the increase in the level of development, the absolute value of economic losses increases for developed countries. However, in relative terms, namely as percentage of GDP, the trend is reverse. For developing countries, the level of absolute economic losses decreases with the decrease in the level of development, but the relative economic losses (as percentage of GDP) increases. So we can conclude that economic losses for a district of Georgia decreases with an increase in the PH value. An artificial parameter was introduced as $H = 1 - PH$, in opposite to PH ; the lower value of H indicates the poorer district.

As vulnerability can be measured by a set or a composite index of indicators, we decided to multiply the evaluated GDP data by the artificial parameter ($1 - PH_i$), where i denotes the i -th cell. Finally, vulnerability for each i -th cell of Georgia for n hazard can be calculated by the equation

$$Vul_i = (1 - PH_i) * GDP_i * R_n / PhExp(n) \quad (14)$$

4.4 Multi-risk assessments

The investigation of spatial-time and magnitude–frequency regularities for natural disasters, the correlation between economic losses, physical exposure and magnitude, and the estimation of general vulnerability for each cell i allowed us to calculate the multi-risk for six natural hazards that occur on the territory of Georgia. For economic loss risk (ELR) calculation, the method presented in Dilley et al. (2005) during the compilation of the Map of Global Natural Disaster Risk Hotspots was used.

We decided to express the degree of hazard for all disasters on the same scale. The degree of hazard is expressed in terms of frequency. The accumulated economic loss in the grid cell j is:

$$E_{ij} = Vul(n) * \omega_{nj} * (1 - PH_j) * GDP_j \tag{15}$$

where $Vul(n)$ is the historical vulnerability for hazard n (in other words, the economic loss rate) calculated from Eq. (5). ω_{nj} is the frequency of each hazard n in the grid cell area j per year, which was taken from the magnitude–frequency relationship and their special distribution, respectively. A distribution of frequencies was applied to each grid cell area j using GIS analysis. GDP_j is the gross domestic products for each grid cell area j , which was calculated by the method outlined in Sect. 4.3. PH_j is the poverty headcount for each grid cell area j .

5 Results

In this section are presented the hazard maps for all investigated natural hazards (Figs. 1, 2) developed on the basis of the methods described above.

The development of a digital inventory of natural hazards allowed us to study the vulnerability for the territory of the Republic of Georgia. In this section, results on the absolute and relative vulnerability are presented. While the first (absolute vulnerability curve) shows the relationship between hazard intensity and total economic losses, the latter (relative vulnerability curve) shows the relationship between hazard intensity and relative value of economic losses (ratio between the observed total economic loss for a particular event and the total GDP of the area affected by this event) for the six natural hazard types drought, hurricane, hail, frost, flash flood and earthquake (Figs. 3, 4).

It is obvious that portions of economic losses caused by various types of hazards to the whole economy of the exposed area are different. Apparently, there is a very significant economic loss from earthquakes. In some cases, economic losses from earthquakes (with an intensity of 9 in 1991 and moderate intensities in 1986 ($I = 8$) and 2002 ($I = 7.5$)) were higher than the GDP of the exposed area. Relative EL from hail is about 0.80 (80 %), for hurricanes, for frost, it is about 0.60 (60 %), for flash flood approximately 0.30 (30 %) and for drought, it is up to 0.30 (30 %).

The estimation of historical economic losses allowed us to calculate the historical vulnerability and then general vulnerability for each grid cell i (Eq. (14)). It allows us to identify vulnerable places to these hazards in Georgia. This gives us assumption which places should be further investigated with first priority at a community level.

The study on spatiotemporal and magnitude–frequency regularities for natural disasters, the correlation between economic losses, physical exposure and process magnitude, as well as the estimation of general vulnerability allowed us to calculate multiple risks for six natural hazards. The obtained results enabled us to compare the political districts of Georgia and their local places by the levels of risk. Below, the economic loss risk is presented for six (selected) natural hazards (expressed in USD, Fig. 5).

The economic loss due to multi-hazard disaster risk RE can be summed up by taking the single-hazard economic losses E (in our case for six hazard $n = 6$) per grid cell using Eq. (16):

$$RE = \sum_n^6 E_{nj} \tag{16}$$

The economic loss risk for these six hazards is expressed in USD. In general, the confidence parameters for economic loss is needed to identify priority areas to be urgently

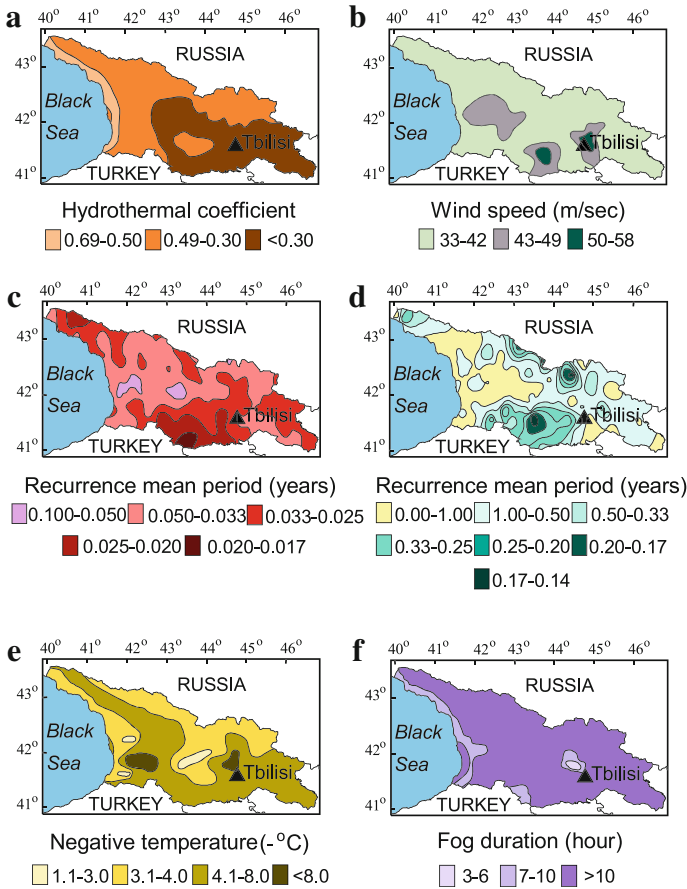


Fig. 1 Maps of natural hazards: drought (a); hurricane (b); lightning (c); hail (d); frost (e); fog (f)

protected (from economical point of view) in Georgia. An average value of GDP per grid was calculated. The values of economic loss of more than 70 per cent of this average GDP value were chosen for the calculation of the summary multi-hazard risk (Fig. 6a).

It is evident that the most economic losses arise from geological hazards, even though the frequency of meteorological and hydrological hazards is higher (Fig. 6b).

The economic loss risk was not estimated for some regions of Georgia such as Abkhazeti and South Ossetia, as we did not have any data of macro-economic parameters and inventories.

6 Discussion

In this paper, an attempt was made to present a method for a nation-wide assessment of hazard, vulnerability and risk for the Republic of Georgia. From the point of view of vulnerability research, the chosen approach can be defined as multidimensional, taking into account the physical, social, economic and environmental perspective (Fuchs 2009). Vulnerability in this sense is time-dependent, scale-dependent and site-specific.

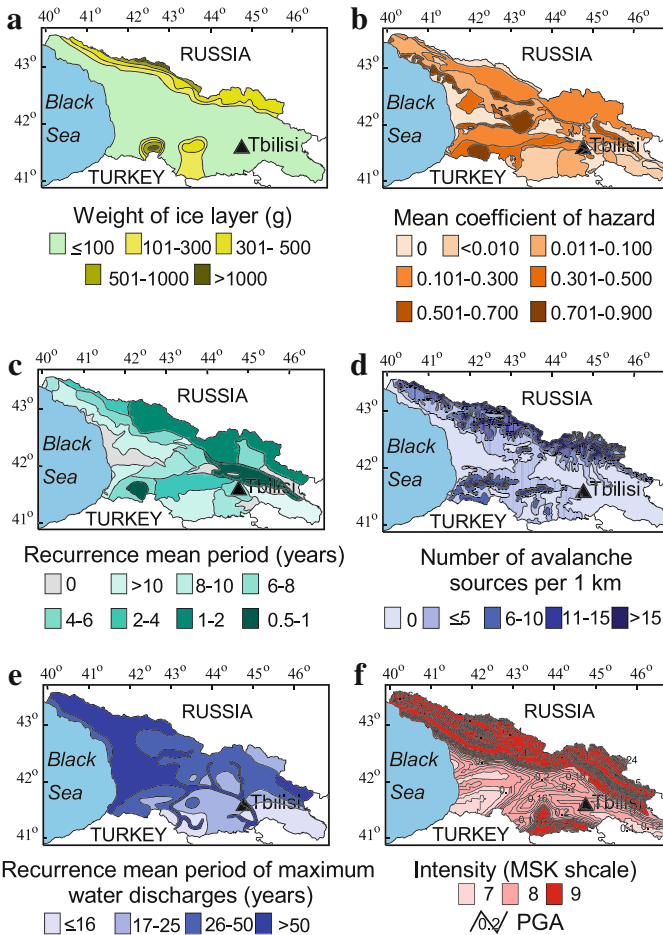


Fig. 2 Maps of natural hazards: freezing (a); landslide (b); debris flow (c); snow avalanche (d); flash flood (e); earthquake (f)

Physical vulnerability is ‘the degree of loss to a given element at risk or set of elements at risk resulting from the occurrence of a natural phenomenon of a given magnitude and expressed on a scale from 0 (no damage) to 1 (total damage)’ (UNDRO 1991). The approach may be used to demonstrate the susceptibility of physical structures such as the built environment or infrastructure lines towards natural hazards and has been applied for hazards relevant for the territory of the country.

Social vulnerability is a measure of both the sensitivity of a population to natural hazards and its ability to respond to and recover from the impacts of hazards. Social vulnerability is complex and dynamical, and was based on the assessment of country-level socio-economic and demographic data (Cutter and Finch 2008).

Economic vulnerability in large degree is determined by the structure of an economy, the prevailing economic conditions and the general stage of technical, scientific, and economic development of the country (Benson and Clay 2000; Mechler 2003). Economic vulnerability can be defined as the potential impacts of natural hazards on economic assets and processes, and was assessed by using the GDP as a proxy.

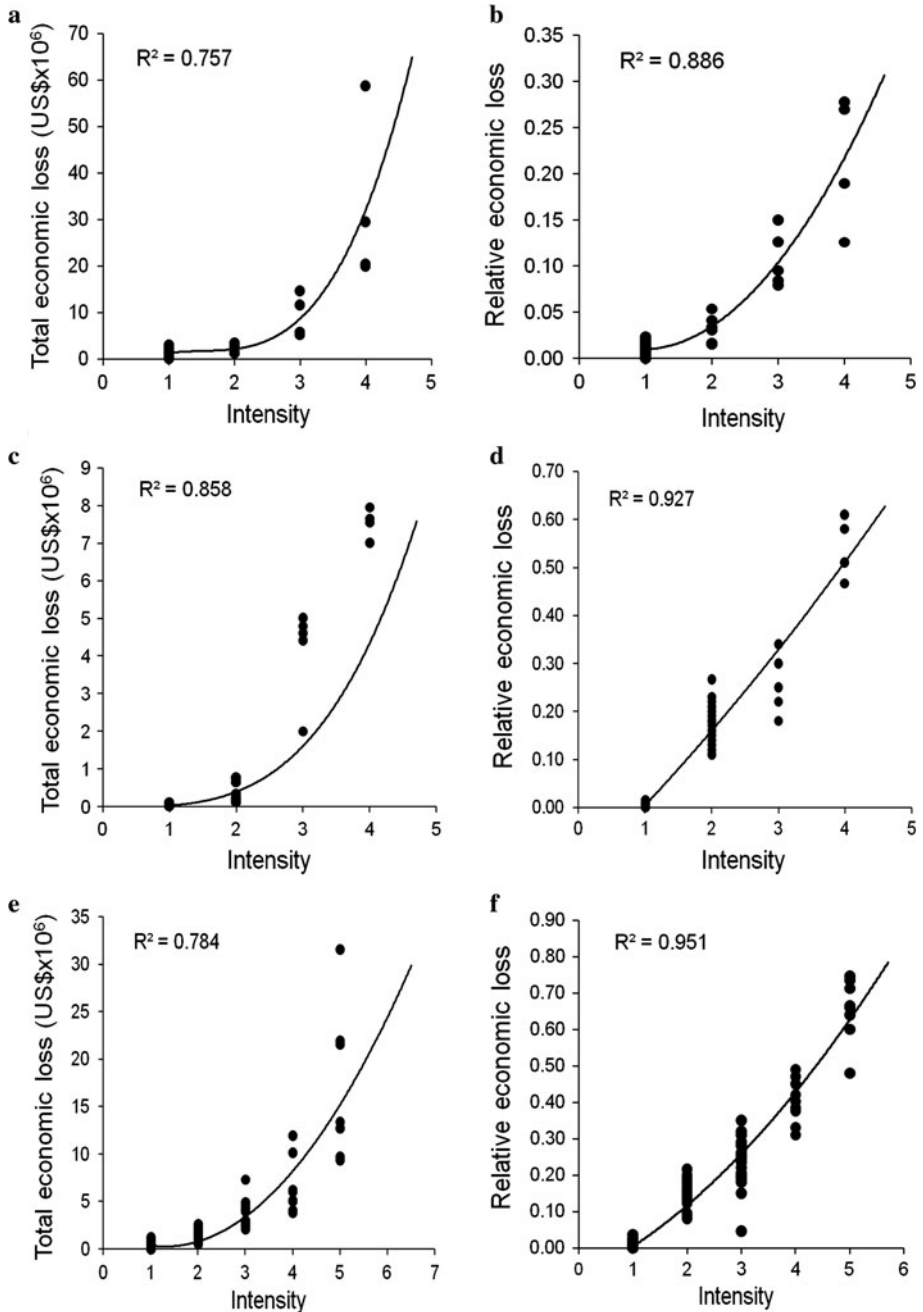


Fig. 3 Vulnerability curves. Relationship between intensity of natural hazard and total economic losses: drought (a); hurricane (c); hail (e); relationship between hazard intensity and relative value of economic losses: drought (b); hurricane (d); hail (f)

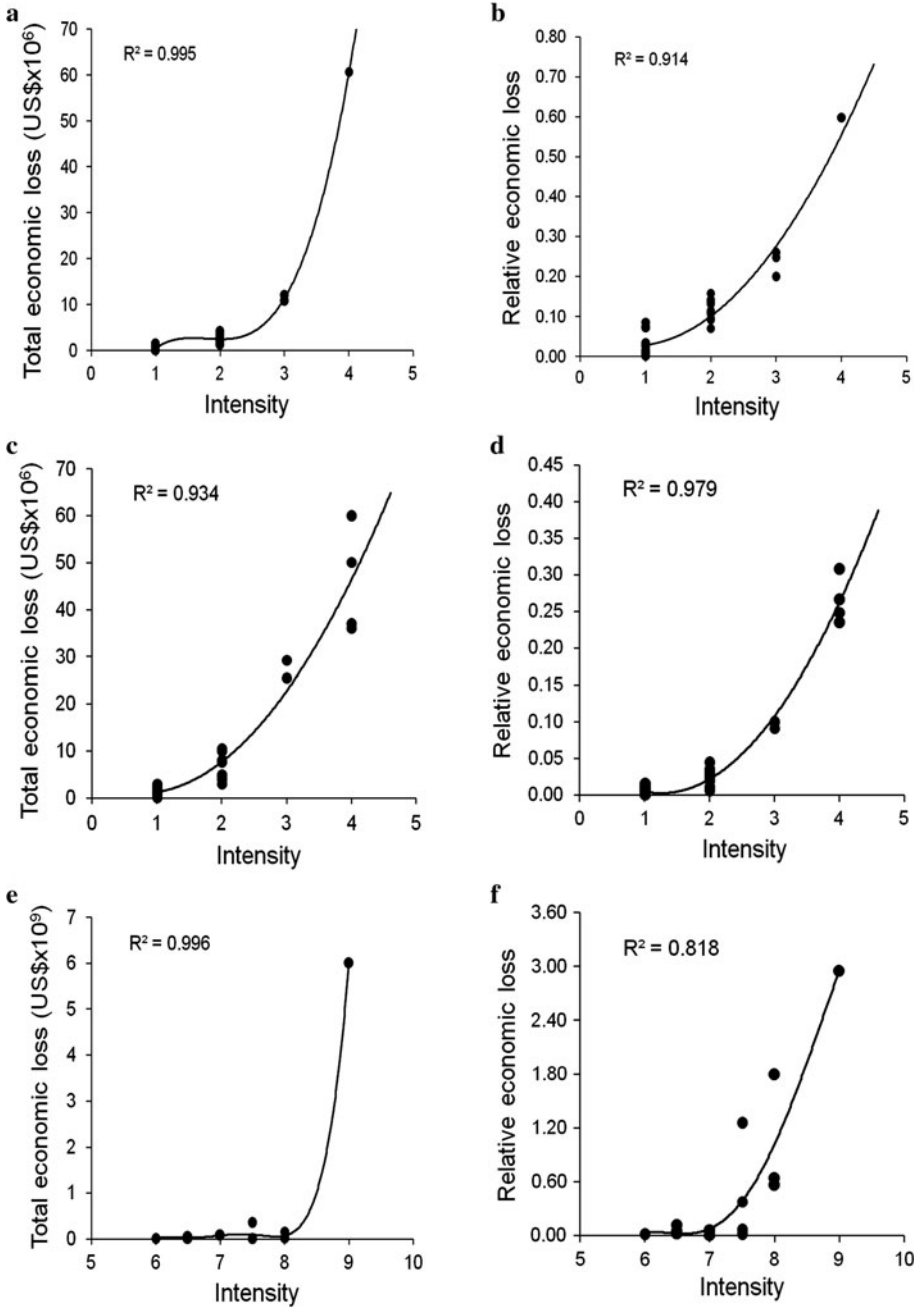


Fig. 4 Vulnerability curves. Relationship between intensity of natural hazard and total economic losses: frost (a); flash flood (c); earthquake (d); relationship between hazard intensity and relative value of economic losses: frost (b); flash flood (d); earthquake (f)

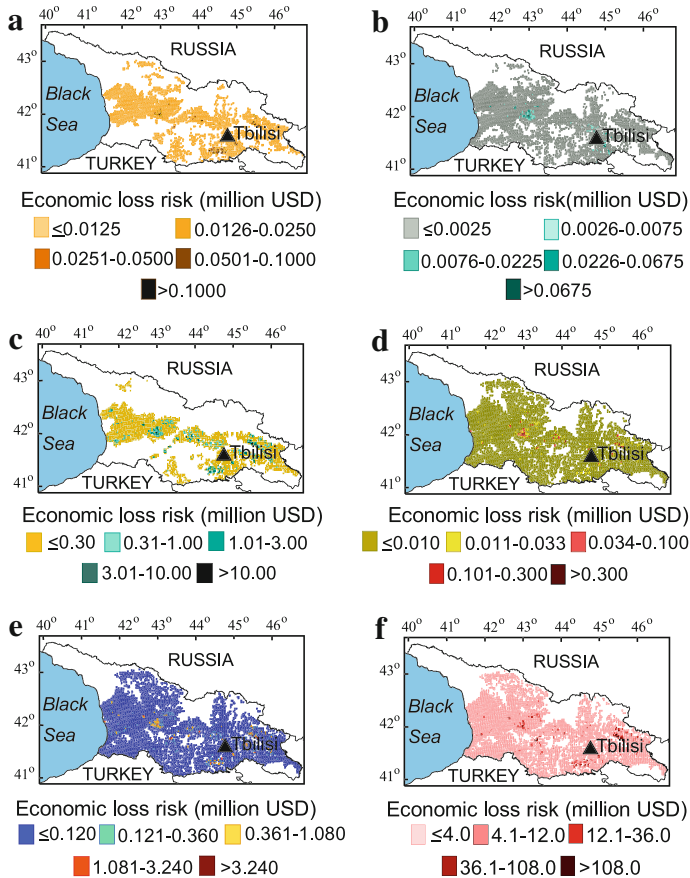


Fig. 5 Economic loss risk for selected natural hazards: drought (a); hurricane (b); hail (c); frost (d); flash flood (e); earthquake (f)

Vulnerability is essential and the most complicated part in the assessment of risk resulting from natural disasters. Often the expert judgments are based on short observation periods and insufficient quality or quantity of data. Finally, this leads to a considerable scatter in risk assessment, as pointed out in Dillely et al. (2005) for the Southern Caucasus: According to this source, the most severe economic losses are caused by hydrometeorological hazards. Taking the information provided by EM-DAT (2006), however, economic losses in Georgia and Armenia are mainly caused by earthquakes, even though the number of floods and droughts exceeds number of earthquakes. This is in line with similar data presented by Pusch (2004); this source also reports the major average annual economic losses in Georgia as a result of earthquakes.

An assessment of vulnerability requires a high-quality inventory of (GIS-based) maps of elements at risk exposed (physical, economic, societal and environmental) and also in-depth information on how these elements are susceptible to the hazards under consideration. Unfortunately, such kind of information is often absent in many countries, as shown in this paper taking the Republic of Georgia as an example. Therefore, in a first step, a disaster inventory was set-up, including information on relevant hazards, incurring losses,

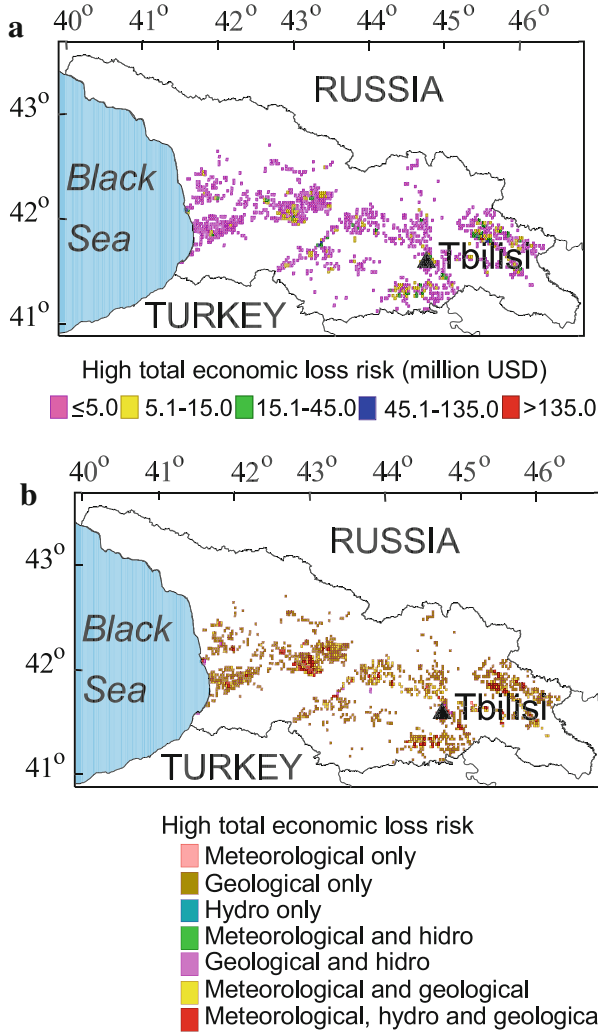


Fig. 6 High total multiple economic loss risk in USD for six natural hazards in Georgia (a); high total multiple economic loss risk for six natural hazards (b)

and information needed for a spatial and temporal localization. On main problem occurring during this step was the determination of hazard magnitude and intensity. In order to overcome this gap, innovative magnitude and intensity scales were used for these phenomena where a proper formalization was not possible. As a result, the specific geographical distribution of hazards was identified and the recurrence period for each disaster was evaluated. Collected data on economic losses allowed us to investigate the so-called general vulnerability using the Gross Domestic Product (GDP) per unit area (applied to population) as an indicator of elements at risk exposed, taking six disasters (earthquake, drought, flash flood, hurricane, frost and hail) as an example. General vulnerability was presented by absolute and relative curves. Vulnerability curves show that portions of economic losses caused by various hazards to the whole economy of the exposed area are

different. A considerable share of the economic losses resulted from earthquakes, even though the frequency of occurrence of other natural hazards was higher. So far, however, the damage data (economic loss) for some types of natural hazards (landslides, debris flows, snow avalanches, lightnings, freezing and fog) remained only fragmentary as description. It appeared a challenging task to determine the economic loss of certain object categories and to sum it up in USD currency. Therefore, it was not fully possible to estimate the nation-wide general vulnerability for these natural hazards

An evaluation of the collective risk to an exposed object as a result of various hazardous events requires a proper assessment of the individual hazards maps for these events (Kappes et al. 2012). Furthermore, a review of various hazard assessment methodologies had shown that there are still some improvements needed with respect to the level of detail, such as for example with respect to earthquake hazards.

By our estimation, we used a normative seismic hazard map expressing the severity of impact by the peak ground acceleration and the intensity (MSK 64) for a 2 % probability of exceedence in 50 years. A generalisation of this map to a small-scale seismic hazard map was calculated in the frame of the GSHAP project (Balassanian et al. 1999) showing considerable differences resulting from generalisation. Taking into account that the GSHAP seismic hazard map for the Caucasus region is calculated for a 10 % probability of exceedence in 50 years, these differences became even larger. The Georgian normative seismic hazard map shows a lower susceptibility than the seismic hazard map that was calculated recently by Slejko et al. (2008). It became evident that normative seismic hazard maps need a careful recalculation, such as currently under preparation within the framework of the EMME project.²

So far, there were no hazard maps available throughout Georgia for meteorological hazards. Hence, the investigation of spatial-time regularities and magnitude–frequency relationships for such hazard was one main goal of our project that allowed us to constrain hazard (zoning) maps for hazards such as drought, hurricanes, lightning, hail, frost, fog and freezing. As our main target in the RNDMR project was the estimation of multiple risks resulting from natural disasters in the territory of Georgia, the investigation of regularities was based on a data set that consisted of parameters such as economic losses. The obtained results from multiple risk assessment enabled us to compare the political districts of Georgia and their local places according to their levels of risk and according to the severity of exposure. It was possible to quantitatively evaluate the type of risk, which is mainly responsible for the majority of losses.

In this sense, the presented work will play an important role in the determination of the main direction of the efforts in the Republic of Georgia to reduce the economic losses and the threats to the population caused by natural disasters.

7 Conclusion

The study of multiple risks and the multi-risk assessment requires an evaluation of well-established vulnerability relationships for elements at risk exposed (Totschnig et al. 2011) and an evaluation of the magnitude and frequency of various natural hazards (Kappes et al. 2012). The review of international and local literature according to risk assessment for Georgia, however, clearly showed some shortcomings, that is, that often vulnerability is not considered at all and solely the hazard level is evaluated.

² <http://www.emme-gem.org/> (23 August 2012).

The most serious deficiency in vulnerability assessment for the territory of Georgia is the lack of high-quality inventories and GIS maps for elements at risk exposed and also a lack of information of how these elements were damaged by hazards due to various types of physical forces. Further gaps were also revealed in natural hazard assessment in spite of the long tradition in this direction.

After reviewing hazard, vulnerability and risk assessment methods for various countries, some attempts were made to fill these gaps towards an enhanced risk management in Georgia:

- A detailed electronic database was created of twelve widespread natural disasters in Georgia. The main parameters included in the database were date (year, month, day), the origin time (hour, minute, second), epicentre coordinates (latitude, longitude), magnitude, intensity, damaged area (km²), scale of the disaster (number of persons killed, loss in 1,000 USD). For six types of hazards, economic losses were collected and assessed in USD; for other types, the loss data remained descriptive only.
- A quantitative investigation of magnitude–frequency and spatiotemporal regularities of twelve types of natural disasters was undertaken.
- The estimation of natural hazard zoning was undertaken.
- The historical and present vulnerabilities were estimated for six types of natural hazards (drought, hurricane, hail, frost, flash floods and earthquakes).
- Finally, an attempt was made to assess multiple risks emerging from natural disasters for the territory of Georgia.

Nevertheless, despite the efforts undertaken so far, the presented work is just a first step in vulnerability and multiple risk assessment, and future efforts include the achievement of a conceptual framework of vulnerability and risk assessment for Georgia. To improve the vulnerability, hazard and risk assessment approach, first of all, the results obtained in the frame of different ongoing or recently finalized projects, such as RNDMR and EMME, should be combined. More specifically,

- Natural disaster databases and inventory catalogues should be completed towards the inclusion of economic losses. Economic losses of natural hazards that are presented as qualitative description so far should be converted into monetary terms;
- Natural disaster databases and inventory catalogues should be completed with parameters of low-magnitude events for all considered types of natural hazards. Even if these low-magnitude events do not necessarily influence the overall height of losses, they influence the shape of the magnitude–frequency relation curve.
- Moreover, high-quality inventory GIS maps should be created for elements at risk exposed.
- Finally, the methodology of probabilistic hazard assessment should be developed on the basis of the obtained inventories for all types of hazards.

In addition, the following work should be undertaken in the near future:

- Information of the impact of past events on the built environment (taking into account a typology of these elements) should be gathered.
- A conversion of vulnerability from existing data should be done for elements at risk with no data entries, in particular with respect to the impact information from hazardous events to these elements at risk.

- Different scientific disciplines should work closer together in order to evaluate a common framework of vulnerability taking into account the specific situation in the Republic of Georgia and the specific needs of the region.
- The methodology of vulnerability, hazard and multiple risk assessment should be applied not only on a regional scale but also at national and local scale.

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