Challenges of Geologic Catastrophes in Georgia and Ways of Their Reduction

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Abstract

Protection of the population of Georgia against the geological hazards, land preservation and safe operation of engineering objects has become a most important social-economic, demographic, political and ecological problem quite a long time ago. This problem has become particularly acute recently, on the background of global climate change and activated and intensified earthquakes, as well as extremely intense human pressing on the geological environment. It should be noted that since the beginning of the 21 century (in 1995–2012 in particular), the trends of activation of the geological calamities in Georgia above the acceptable point is registered almost every year. Recent large-scale development-reactivation of exo-geologic processes against the general background of sensitive geologic environment was stipulated by negative meteorological elements and frequent earthquakes preconditioned by global climate conditions and geologic processes proceeding in transient conditions as well as high pressing of human influence. For mitigation or prevention of negative results, caused by geologic nature the government of Georgia took for indication of basic challenges the plan concerning sustainable development elaborated during the world summit held in Johannesburg in 2002 and resolution, adopted at the world conference held in Hyogo (Japan) in the year of 2005 which was devoted to reduction of catastrophes. The Ministry of Environment Protection and Natural Resources of Georgia was distinguished as institute, responsible for settlement of problems, stipulated in the above-mentioned documents.

Keywords

Geological hazard • Tectonic movement • Landslide • Mudflow • Hazard risk

313.1 Introduction

In the last decades of the 20th century, protection of the population against geological calamities in most mountainous countries of the world, safe operation of engineering objects and survival of the lands from destruction has become one of the most significant social-economic, demographic and ecological problems. This was why at the World Conference on Disaster Reduction held in 2005 on the aegis of UNO (Hyogo, Japan), the identification, assessment and monitoring disaster risks and development of early warning mechanisms, drafting risks maps and development the indicators to reduce disaster risks, insecurity and adaptation were named as the major trend of 2005–2015.

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G. Lollino et al. (eds.), *Engineering Geology for Society and Territory – Volume 2*,
DOI: 10.1007/978-3-319-09057-3_313,

The normative base adopted in Georgia, which is a mountainous country, fully responds to the Framework for Action adopted at the Conference in Hyogo and is realized by considering the financial and technical resources of the country.

The problem of geological hazard is particularly severe in young Caucasus-Pontides folded mountain system, which covers the key segment of the mobile belt of the Mediterranean (Apline-Himalayas) (Gamkrelidze 2010) with the quantitative and qualitative characteristics of modern alternating-sign tectonic movements and associated seismic risks playing a decisive role in forming its modern geodynamic condition as the main factors provoking the erosive-gravitational processes. A particular stage of a "geological life" of a modern neo-tectonic stage in the region started in the Upper Sarmatic Age, when in parallel to the new tectonic regime, a significant pre-Apline relief transformation and formation of hypsometric and bathymetric zoning started and modern morpho-structural configuration developed. In the same period, deep faults formed in pre-Apline orogene started revitalization and new ones, mostly lateral surface disturbances, faults, extreme overthrusts and seismic dislocations were originated, mostly as lateral surface disturbances, faults, edge overthrusts and seismic disolocations. All this was followed by "mosaic" dissectoning of large geostructural units into individual arch-lumpy and horst bodies, sharp increase in the relief power potential, increase of geophysical fields and activation of seismic processes and subaerial volcanism. This set has cause high effect of development of erosive-gravitational and other exo-geologic processes.

313.2 Study Area

The geomorphological studies (Tsereteli et al. 2008) have revealed that if the range of tectonic movement in the Caucasus generally, at the stage of neotectonics was ±17 km, the speeds of vertical movement in the anthropogene must have been 4 or 5 times more than their average maximum speeds through the neotectonic stage (Tsereteli et al. 2008; Milanovsky 1968). In the Pliocene-Quaternary Period, the range of elevation within the limits of the Caucasus mountain system varied between 2.5 and 5 km. Such a high speed of elevation was followed by intense activation of the erosive and denudation processes. This is proved by rough molasse sediments of the Upper Pliocene Age with the strength of 1000–2000 m and more deposited in the depressions of the Caucasioni mountain system with the total estimated volume of 2,99,450 m^3 (Milanovsky 1968). Despite the fact that the structural stages of all stratigraphic levels is open due to erosive processes, the ascending movements of morphological structures much exceed the downcutting of abyssal erosion, and quite often, the unequal alternating-sign movement of adjacent individual blocks along the live faults were followed by graben-like subsidences of a compensatory nature, which were further filled in with 400–500-m-thick Quaternary alluvial-lacustrine and glacial deposits. There are many such geomorphological phenomena in the gorges of the major rivers in the mountainous region of the Caucasus (the rivers Tergi, Baksani, Teberda, Bzipi, Rioni, Ajaristskali, Chorokhi, etc.) (Tsereteli et al. 2008).

Besides, the unconformable shifts of adjacent block-disjunctive morphological structures morphologically are well seen through the abyssal downcutting of the gorges of the principal rivers of the southern slope of the Caucasioni ridge (the rivers Bzipi, Gumista, Kelasuri, Kodori, Enguri, Rioni) and longitudinal profiles of the riverbeds. At some points, the depth of the gorge downcutting in the same river crossing the morphological structures and riverbed inclination in the rocks resistant to erosion are higher than in the area of the adjacent gorge built with milder rocks clearly indicating the existence of live faults between the adjacent areas built with the rocks of different stability in the given morphological structure, even if this cannot be mapped geologically.

The period of elevation in the Caucasian-Pontides mountain system was ever-increasing through the Quaternary Period reaching its peak in the Holocene Age. In this period, the annual indicators of alternating-sign elevation within the mountain system varied between +3 mm (piedmont)—+5 mm (Dzirula crystal massif) and +10–15 mm (fold-faulty structures of the high mountainous area), and the maximum subsidence (−6 mm) was fixed within the limits of Kolkheti intermontane trough of eastern depression of the Black Sea trench (Tsereteli et al. 2012; Tchelidze et al. 2008). The particular activation of the geodynamic regime of the Caucasus in the Holocene Age is proved by a 500-m-deep borehole cut through the Quaternary alluvial-prolluvial deposits of a mudflow nature in the contact zone between Alazani tectonic depression and the southern slope of Caucasus ridge, with the first 250-m-thick sediments belonging to the Holocene Age (Tsereteli et al. 2004).

Thus, the Caucasus-Pontides region and Georgia in particular, is a wonderful natural polygon to design and realize a wide spectrum of studies of modern active tectonics and associated earthquakes and multi-exogeologic elemental processes, and to design and develop scientific-research projects in geo-hazard analysis and management.

Much diversified natural and landscape conditions of the South Caucasian region historically offered unique conditions to settle and develop mixed farming in it. The present geo-political location with the activation of the "Eurasian corridor" and "Great Silk Road" projects becoming real, has made the regions of Caucasus and Turkey even more attractive. However, high pressing of farming and engineering in the extremely sensitive geological environment of the given areas has led to the severe disturbance of homeostatic balance in the nature followed by large-scale development and activation of geological elemental phenomena and disasters and most severe complications in the geo-ecological situation. Recently, the situation has been further aggravated by frequent and intensified negative meteorological phenomena provoking geological processes and activation of high-intensity earthquakes and increased gravitational stress over the slopes on the background of the global climatic changes.

313.3 Methodology

In terms of dominant geological environment extremely sensitive to the geological calamities, the human pressing is particularly impressive for Georgia with only 15.3 % of the whole area of the country, with its scarce land resources, occupied by cultivation lands (Tsereteli et al. 2010) making it impossible to extend the areas of arable and sowing lands without large capital investments. In many regions of modern Georgia (particularly, in the Black Sea coastal region and mountainous Achara), a man's farming and engineering activity has reached its critical point (with the impact coefficient of 0.8–0.9), which, if exceeded, will be followed by irreversible ecological catastrophes. It is notable that in the last 50 years the major reason for the reduction of the agricultural plots of field to 13 % is the activation of exogenous geological processes.

The natural-anthropogenic conditions of Georgia create standard conditions for developing and stimulating the heterogeneous exo-geodynamic elemental processes, and with the negative outcomes resulted from such processes, Georgia is one of the most complex mountainous regions. Up to 70 % of the territory and over 60 % of the settled areas of the country, plots of field, roads, oil and gas routes, high-pressure power transmission lines, hydraulic structures and reclamation constructions and mountain tourist complexes are under the periodic impact of geological calamities (often with catastrophic outcomes). All climatic-morphological zones, starting from the Black Sea coastal region through the Alpine-Nival zone in the country are within the area of hazard of calamities. Out of multi-spectrum geological calamities, floods and water erosive processes, landslide and gravitational phenomena, mudflows and snow and glacier avalanches, with their degree of hazard, rank first in Georgia, often followed by large material losses and human victims in case of their extreme development (Fig. 313.1).

For the country with such a small area, as Georgia is (69,700 km^2) with more than 32,000 rivers with the total length of over 75,500 km registered and 6,445 m^3 water resources (Khmaladze 2009) with most of them being the high-energy mountain rivers transformed in complex relief and climatic-meteorological conditions, the risk of hazard of flash floods and erosive processes for Georgia becomes clear. In addition, if the main problem in the lowland is floods or flooding and associated erosive washout of productive soils and origination of coastal landslides, the risk of particular hazard for most mountainous rivers, in addition to floods with erosive complications, is frequent and often unpredictable transformation of mudflow processes.

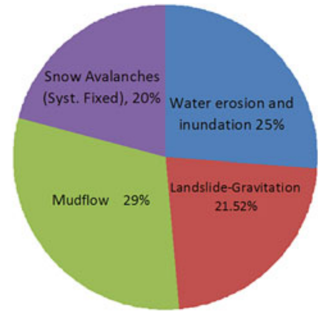

Fig. 313.1 Multi spectrum geological calamities

The mode of floods and flash floods is conditioned by four major factors: (1) intense melting of snow and glaciers, (2) melting of snow and rains, (3) long and short intense rains, (4) temporal damming of mountain rivers due to landslides or rockfalls, mudflows or snow or glacier avalanches, with their disturbance making the flood hydrograph of a clearly peak appearance and making them particularly hazardous. Notwithstanding the fact that there are water reservoirs constructed across the large river of Georgia regulating the river flow, the risk of the said type of floods is still alarming. For the last 108 years, catastrophic floods took place for 16 times with 0.15 reoccurrence coefficient. The most destructive of them was the flood of 1987 having flooded 3,50,000 ha area and damaged and destructed up to 5,000 residential houses thus resulting in the total loss of over 500 mln. USD. At present, up to 970 accidental areas of active erosive river washout are registered in Georgia needing cardinal measures, if not talking about the areal washout with 30.5 % of the total arable lands of 674 ha eroded, and average 100–150 tons of soil per ha washed down annually. The banks along 220 km out of the total length of the Georgian segment in the 320-km-long Black Sea coastal zone is subject to catastrophic destruction.

Up to 70 % of the gross economic loss resulted from the geological calamities in Georgia is caused by landslide-gravitational phenomena developed in all landscape-morphological zone. Up to 22 % of the territory of the country is subject to the risk of hazard of such phenomena. By 2013, 53,000 sites with up to 2,000 settled areas (including over 60 landslide bodies in Tbilisi), up to 30 % of the motorways, up to 20 % of the oil and gas pipelines and up to 25 % of the banks of the water reservoirs have been registered as the areas damaged by the said phenomena and as high-risk areas. Up to 80 % of eco-migrants subject to resettlement and up to 60 % of the economic loss are for landslide-gravitation processes. The zoning map of Georgia showing the degrees of damage and risks of hazard clearly shows the risk of hazard of landslide-gravitation phenomena. If the landslide-gravitational phenomena rank first among the geological calamities causing damage to Georgian economy, the mudflow processes with their human victim are dominant. By approximate statistical data, at least 1,300 people were perished due to the mudflow processes in the last two centuries (including 64 human victims in 1995–2012). Georgia, with the diversified conditions and heterogeneous properties of mudflow formation, frequency of phenomena and negative outcomes, is one of the most complex mountainous regions. Consequently, the history of studying the regularities of formation of these disastrous natural phenomena is over 200 years old.

By the beginning of the 21 century, the first three orders of rivers in Georgia (Khortini classification) included up to 3,000 mudflow-transformable watercourses with their total risk area of 29 %. In the relevant geological environment, up to 65 % of mudflows are transformed through downpours of over 40–65 mm a day; 30 % of mudflows are formed as a result of damming and break of landslide-gravitational processes, while 10–12 % of them are of a "glacial mudflow" type. It is worthwhile that almost always, a mudflow is followed by large-scale flash flood. Mezozoic shales and flysch deposits and Pliocene mollases are distinguished for the highest reoccurrence intervals of mudflows (0.5–3 years). Following the environmental conditions, the volumes of single currents transformed due to mudflows vary within a large range, from several thousand through tens of millions of cubic metres.

The "glacial mudflows" developed in the alpine-nival geomorphological zone in the central segment of the Caucasus are distinguished for particular properties of formation and destructive force. Their number exceeds 200. However, the mechanism of their transformation and problem of their prediction is less studied and is an unsolved problem to present. In this respect, the basins of the rivers Tergi and Baksani are of a particular attention. For example, it is sufficient to recall the "glacial mudflow" with the volume of 200-mln. m^3 transformed from the glacier Kolka avalanche on September 20 of 2002 in the basin of the river Genaldon in the glacier unit of Mkinvarstveri-Jamaraikhokhi in the river Tergi basin resulting in up to 130 people human victims. By incomplete statistical data, the catastrophic mudflows in the same river basin have occurred 32 times for the last two centuries with the human victims of over 200 and with the reoccurrence interval of once every 7, 3 years (Gobechia and Tsereteli 2009).

Following the sensitivity of the geological environment of mudflow-forming hearths in Georgia, the lower limit of transformation of mudflows dominating by downpours is fixed the point over 40–50 mm/day precipitations. The more the intensity of the precipitations, the more the geographical area of mudflows and risk of hazard. The monitoring studies have been used to fix that in case of downpours of 50–80 mm a day or more, mudflows are formed in all geologically "sensitive" mountain mudflow-forming rivers. It should be noted that if until the 1970s, the reoccurrence of mudflow-forming precipitations of a catastrophic nature (80–100 and more) for the Caucasus mountainous region was fixed once every 20 years on average, the recent period was marked by much more frequent reoccurrences. For example, in the segment of eastern Georgia of the Caucasus by the data of Lagodekhi weather station, over 150 mm of precipitations was fixed for 3 times in 1983, twice in 1986 and once in 1988, all of them having caused catastrophic mudflows. The territory of Georgia, by the degree of damage caused by mudflows, mudflow frequency and risk of hazard, was conventionally divided by 8 zones by us (Fig. 313.2).

The safety of the mountain population and economy of Georgia (linear objects in particular) have to face a serious hazard of snow avalanches. By the beginning of the 21st century, approximately 10,000 systematic (annual) hearths of avalanche formation were registered, with 3,000 of them being hazardous for the settled areas and linear-engineering objects. A particularly hazardous area is high-mountainous Alpine zone, with 56 % of it being avalanche-hazardous. Systematic fall of avalanches accounts for 20 %.

Despite the fact that the population in the mountainous regions of Georgia is well aware of the disastrous nature of snow avalanches since the ancient times and always avoided to live in the area of these hazardous phenomena, the caused damage and human victims is nevertheless enormous. By the incomplete data, there were up to 300 destructed residential houses and 655 human victims registered in 15 municipalities in the last 150 years. There are even villages where the number of people perished by single avalanches was 22–56 and 68–112. In the same years, the damage caused by avalanches amounted to several hundreds of millions of dollars (Basilashvili et al. 2012).

By considering such tragedies caused by such disastrous natural phenomena, the monitoring observations in the highly hazardous area are organized permanently with the aim of early warning.

It is notable that since the last decade of the 20 century, the trends of activation of the geological calamities in Georgia exceeding the permissible level have always been marked by frequent explorations and the intervals of their extreme activation have been drastically reduced. This is proved by the analysis of the incomplete results of the

Fig. 313.2 Zoning map of Georgia on the degree of exposure and the risk of mudflow activity processes

regional monitoring in 1995–2012, where 6,377 landslides in dynamics and 2,155 mudflows transformed in the erosive watercourse. 6,113 settlement and 20,776 families were in the risk zone of such hazard, area of damaged agricultural lands 4,278 ha, while the economic loss amounted to 1,651 billion USD and number of human victims was 107 (Table 313.1).

313.4 Results and Discussion

Such large-scale development and reactivation of exo-geological natural calamities in recent years on the general background of the sensitive geological environment was the result of intensified and frequent negative meteorological phenomena and earthquakes provoking the geological processes taking place intermittently caused by global climatic changes as well as extremely high pressing of human impact on the geological environment to the extent making it impossible to differentiate between the natural calamities provoked by the natural and technogenic factors.

It is impossible to develop a package of sustainable social-economic development of the country, ensure the safety of the population, prevent lands against degradation or desertification, ensure safe operation of the engineering units and maintain the vital environment generally, unless we are always ready to defend ourselves from the natural-technogenic calamities. The major challenges in mitigating or preventing the negative results caused by geological calamities must be based on the long-term projects to develop the plans of adaptation and technologies. For this purpose it is necessary:

- to have a real basic picture of the geological environment determining and provoking the hazard of risks of disasters and developed with the relevant maps with the area ranging, determining the sensitivity of the elements of the system of a geological environment to some or other geological phenomenon and resistance against the technogenic pressure by considering the geo-ecological complications.
- to identify the kinds and scales of the geological processes, which are anticipated to originate or be intensified in some or other geological environment and kind of expected hazard to the population or engineering-economic objects.
- to perfect and modernize (operative, short- and long-term) early warning system for the anticipated natural calamities and early information delivery to the central

Table 313.1 Landslide, mudflow statistics, number of event, direct loss (mln GEL), human loss (1995–2012)

Year	Landslide			Mudflow			Total loss (mln GEL)—1 GEL—0.41 EURO	Objects under hazard risk zone	
	Number of event	Direct loss (mln GEL)—1 GEL—0.41 EURO	Human loss	Number of event	Direct loss (mln GEL)—1 GEL—0.41 EURO	Human loss		Agricultural lands (ha)	Buildings
1	2	3	4	5	6	7	8	9	11
1995	670	132	6	250	96	12	228	179	195
1996	610	80.3	3	165	27	5	107.3	232.3	626
1997	871	102	2	335	44	7	146	336.5	227
1998	543	67	5	173	20	6	87	229.6	159
1999	56	12	1	27	4.5		16.5	137.8	314
2000	65	13	1	23	3		16	162.2	207
2001	75	15		26	4		19	127.5	127
2002	69	13.8	1	23	2.5	2	16.3	147.9	193
2003	71	14.5	3	28	4		18.5	106.5	207
2004	949	147	4	258	28	2	175	16289.2	6042
2005	603	96		155	9	4	105	7589.6	3682
2006	356	70.5	1	63	9		79.5	3172.5	2066
2007	136	20.5		104	11.5		32	1389.1	707
2008	311	48	8	126	15	8	63	1387.7	1198
2009	323	63.5	1	193	16.5	3	80	8232.3	2696
2010	250	20	3	81	5	2	25	1155	822
2011	94	Unknown	3	37	9	8	20	652	463
2012	325	Unknown	1	88	50	5	50	1255	845
Total	6377	915.1	43	2155	358	64	1284.1	42781.7	20776

and local authorities, media and population. The crises can be overcome provided we have a continuous cycle of methodologically and technologically well-organized geo-monitoring studies of various levels, starting from the observation and control parameters to management. The basis of this is processing of geological hazard and risks special zoning maps, where will be defined criteria of hazard and developed technological adaptation measures.

- It is true that the questions of natural calamities in Georgia are regulated by the constitution of the country, but the existing legislative base is not sufficient to introduce and operate an efficient system to manage the disasters. Particularly important is the regulation of the issues, which will reduce the negative outcomes of the anthropogenic impact on the geological environment and will form the grounds to reduce the risks of natural calamities and efficiently liquidate the negative outcomes caused by them.

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