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Impact of Natural Disasters on Water Resources in Georgia Caused by Global Warming

Nodar Kandelaki[1], Irina Iordanishvili[2], Adam Ujma[3], Inga Iremashvili[2], Konstantin Iordanishvili[2], Shorena Kupreishvili[2], Vladimer Shurghaia[2], Giorgi Natroshvili[2]

[1] Georgian Technical University, 68, Kostava Str., 0160, Tbilisi, Georgia; [2] Tsotne Mirtskhulava Water Management Institute of Georgian Technical University, 60-b, I. Chavchavadze Ave., 0179, Tbilisi, Georgia, Corresponding author, e-mail: ingairema@yahoo.com, irinaiord48@mail.ru; [3] Częstochowa University of Technology (CUT), ul. Akademicka 3, 42-200 Częstochowa, Poland, aujma@bud.pcz.pl

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Abstract

Ecological and hydrological problems of water reservoirs on rivers of the Black Sea coast in the context of the increasing air temperature and emissions of greenhouse gases, the melting of glaciers, and the occurrence of floods and forest fires have been analysed in the given article. The article presents the results of field and theoretical studies of sedimentation processes in the large water reservoirs of Georgia focusing on their morphometric conditions during the warming period.

Key words: Global warming, water resources, elemental phenomena, ecological condition, Black Sea, reservoirs

1. Introduction

Since the second half of the 19th century a number of natural anomalies have been observed in hydrometeorological conditions around the world, including tornados, temperature peaks, etc. How can these natural events be explained? And what other changes are to be expected in the world as a whole as well as in Georgia?

Over the last 2.5 million years, several cycles of glaciation and warming have taken place on Earth. During the Eo-pleistocene period (250 000–2 500 000 years ago), up to 4 glacial and 3 interglacial periods were observed, continuing for up to 280 000 years each; during the Mesopleistocene period (75 000–250 000 years ago), there were 2 glacial and 2 interglacial periods of up to 45 000 years; and during the Neo-Pleistocene

Table 1. Global climate changes on Earth

<table>
<tr><td>Thousand year</td><td colspan="2">2500</td><td colspan="2">1000</td><td colspan="2">600</td><td colspan="4">250</td><td colspan="4">75</td><td>10</td><td>6</td></tr>
<tr><td>Period</td><td colspan="14">Quaternary (Pleistocene)</td><td colspan="2">Holocene</td></tr>
<tr><td>Epoch</td><td colspan="6">Eo-pleistocene (Early pleistocene)</td><td colspan="4">Mezzo-pleistocene (Middle pleistocene)</td><td colspan="4">Neo-pleistocene (Late pleistocene)</td><td colspan="2">Modern</td></tr>
<tr><td>Ice (+) and warming (–) processes</td><td>–</td><td>+</td><td>–</td><td>+</td><td>–</td><td>+</td><td>–</td><td>+</td><td>–</td><td>+</td><td>–</td><td>+</td><td>–</td><td>+</td><td>–</td><td>+</td></tr>
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period (10 000–75 000 years ago), 2 glacial and 2 interglacial periods of up to 16 000 years each occurred (Table 1) (Kobak and Kondrashova 1992, Iordanishvili et al 2009).

2. Formulation of the Problem

Despite numerous scientific studies and new developments in production, the social and economic crisis in Ukraine over the last 10 to 15 years has been a significant obstacle to hydrotechnical amelioration (Herasymov 2007). The pipeline fittings used in the existing CIS and drainage facilities are not designed to prevent the occurrence of water hammer in CIS pipelines, but rather to eliminate the already existing waves of elevated pressure in the pipeline network (Herasymov 2007, Design of Closed Irrigation Systems 1986). Such pipeline fittings do not ensure a high reliability and efficient operation of CIS pipelines. Moreover, sterile spills that occur through various bursting discs, discharging valves and water hammer blocking devices have a negative impact on energy conservation. Under such conditions, accidents in pipeline networks result in frequent downtimes of CIS, which in turn disrupt crop irrigation and negatively affect agricultural yields.

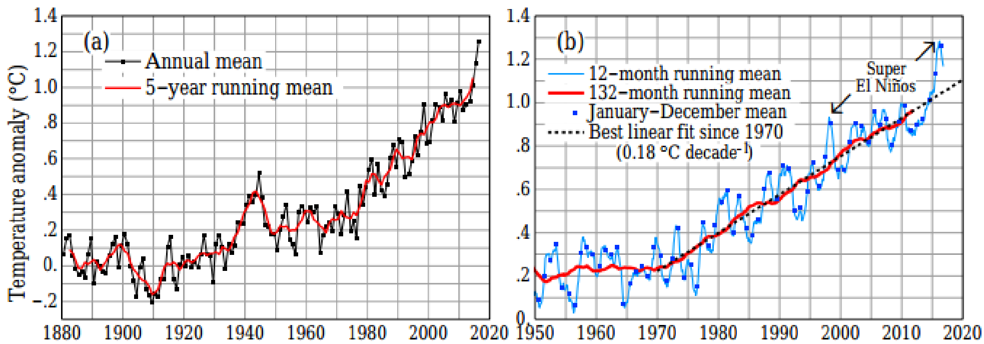


Fig. 1. Global surface temperature in 1880–1920 based on GISTEMP data (Appendix A3). (a) Annual and 5-year means since 1880, (b) 12- and 132-month running means since 1970. Blue squares in (b) are calendar year (January–December) means used to construct (a). Panel (b) uses data through April 2017 (Hansen et al 2017)

The duration of each subsequent cycle of glaciation decreased (28 0000 years, 45 000 years, 16 000 years, 6 000 years). The last cycle of climatic cooling started 6 000 years ago, although a warming has recently been observed, popularly known as "global warming" (IPCC 1996, UNFCCC 2013).

Since the second half of the 19th century, the average temperature on Earth has increased by more than 1.0°C (Fig. 1a). The present global warming rate, based on a linear fit for 1970 is +0.18°C per decade (Fig. 1b). If this process continues, at the rate of +0.18°C per decade following a linear trend line, the global temperature rise will reach 1.5°C around 2040 and 2.0°C around 2060 (Hansen et al 2017).

3. Problem Formulation

Global warming effects are observed in Georgia as well. The main types of water resources are seas, glaciers, rivers, lakes and water reservoirs, atmospheric precipitations, water-saturated mudflows and landslides, underground waters, etc. (Tab. 2) (Iordanishvili et al 2018).

Table 2. Water reserves of Georgia

Water reserves	Volume of water, km^3		
	East Georgia	West Georgia	Total
Rivers	14.7	51.13	65.83
Lakes	0.422	0.30	0.72
Reservoirs	1.9929	1.4891	3.482
Glaciers	5.08	18.74	23.82
Ground waters	6.4	4.2	10.6
Swamps	–	1.86	1.86
Thermal waters	0.04	0.02	0.06
Mineral waters	0.001	0.1	0.101
Total	28.64	77.84	106.48

It should also be noted that the water supply index is increased by the total volume of the Black Sea (555 000 km^3), whose coastline in Georgia totals 310 km.

The Caucasus Mountains tend to mitigate abnormal meteorological elements in Georgia, as the mountains prevent them from penetrating from the north. However, climatic change in Georgia results in the melting of glaciers and rising of the Black Sea level, as well as in storms, floods and freshets, landslides and mudflows, strong winds, hails, avalanches, biological threats, fires, etc.

Black Sea water level and storms. Length of wind run on the surface of the Black Sea, which stretches over a distance of 1 200 km, as a result of which high and steep waves are formed. Air masses coming from the sea contain a large amount of water vapour, resulting in heavy precipitation in west Georgia.

Global warming and anthropogenic activities (construction of dams on the rivers of the Black Sea basin, improper removal of construction material (up to 40 mln m^3 in total), inefficient coastal protection works, etc.) lead to the Kolkheti coast segment being eroded because of the rising water level of the Black Sea (Fig. 2). For instance, during a storm in the autumn of 2017, a large segment was broken away from the Batumi city boulevard – out of the 7 meters wide boulevard only 3 meters was left, and the storm surge barriers were destroyed as well.

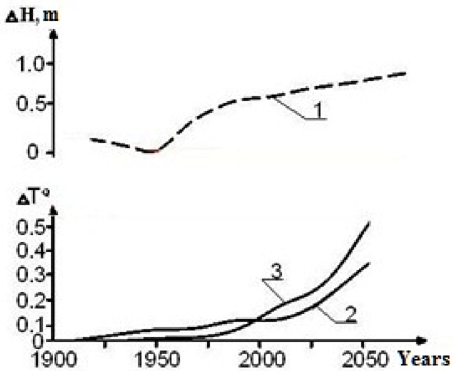


Fig. 2. Trends of the Black Sea water level (1), water temperature (2) and air temperature (3) in the Kolkheti coastal zone

Before 1980, on the 100 km stretch of the Black Sea coast from Gagra to Makhinjauri artificial beaches were created and 150 ha of land was claimed from the sea. Currently, the total sediment influx into this area has decreased to just one third of the former volume, and during storms the sea started to erode the coast again (Tab. 3) (Iordanishvili et al 2018).

Table 3. Volume of fluvial sediments on the Kolkheti coast of the Black sea

Rivers	Volume of sediment, m^3/per year	
	the 1980s	from 2010 to 2015
Enguri	370 000	29 000
Rioni	2 066 000	1 350 000
Chorokhi	5 330 000	1 060 000
Total	7 760 000	2 439 000

Melting of glaciers. According to research by Georgian glaciologists, in the Kodori Gorge there were 145 glaciers in the second half of the 19^{th} century and only 118 in 2014; in the Enguri River basin there were 299 glaciers in the second half of the 19th century and 269 in 2014; whereas in the Tergi River basin, out of 99 glaciers present in 1960 only 58 remained in 2014. While melting, some glaciers not only reduce in size, but also divide. For instance, in 1960 Ushba was a typical valley glacier but in 2012–2013 it was already divided in two.

Floods and freshets are typical of almost all rivers in Georgia. The rivers of the Imereti, Samegrelo, Guria and Mtskheta-Mtianeti regions, as well as the Mtkvari and Alazani rivers, pose an especially high risk. Before 1995, intensive freshets recurred every 5–6 years, while in 1995–2013 these events occurred almost twice as frequently (every 2–3 years). The flooding that occurred on June 13, 2015, in the Vere river basin, when water flow amounted to 500 m^3/sec, is a clear example of the dangers of this natural disaster.

Maximum flow rates for floods occurring as a result of global warming on the rivers of Georgia are provided in Table 4 (Grigolia et al 2013). Instant peak flows of floods on the rivers of west Georgia increased, while instant peak flows of floods on the rivers of east Georgia show an insignificant but positive trend. This situation results from the rapid consumption of water accumulated in the water reservoirs of east Georgia during hot summers because of the high demand for irrigation water.

Table 4. Immediate maximum flow rates for the main rivers of Georgia

River	Catchment area, km^{2*}	Observation period	Maximum flow rate, m^3/s	Year
Enguri (Jvari village)	3 170.0	1928–1965 1966–1970	1000.0 154.0	1941 1970
Khobi (Legarkhe village)	310.0	1937–1965 1966–1982	41.0 850.0	1962 1982
Rioni (Sakochakidze village)	13 300.0	1928–1965 1966–1977	3000.0 3520.0	1963 1977
Kvirila (Zestafoni)	2 490.0	1930–1965 1966–1982	883.0 1030.0	1933 1982
Chorokhi*) (Erge village)	22 000.0	1930–1968 2002–2012	3840.0 500.0	1942 2012
Mtkvari (near Likani)	21 000.0	1968–1977 1978–1986	800.0 1500.0	1977 1984
Vere (Tbilisi)	152.7	1963–1992 1993–2015	140.0 468.0	1963 2015

*) Two reservoirs (Muratlo and Borchkha) have already been built on the Chorokhi river on Turkish territory, and the construction of 10 reservoirs is planned, which will significantly reduce the risks of floods and high waters.

Over the recent years, the volume of water discharged into the Zhinvali water reservoir (V_{full} = 510.0 mln m^3) has been much greater than it was in previous years because of more frequent and abundant rainfall (Fig. 3, 4). As a result, the amount of sediment brought down has increased (Fig. 4) (Iordanishvili et al 2018).

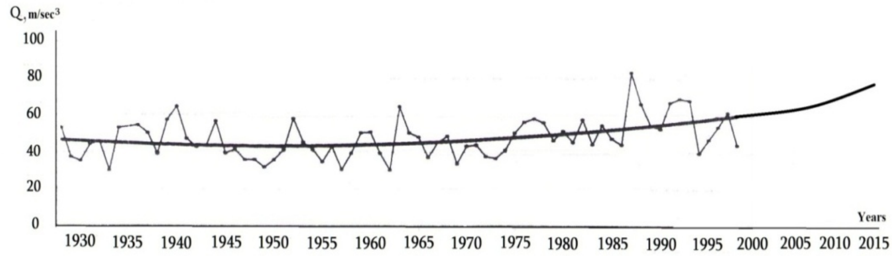


Fig. 3. Fluctuations in annual average water *f* volume rates for the river Aragvi at the head of the Zhinvali reservoir?

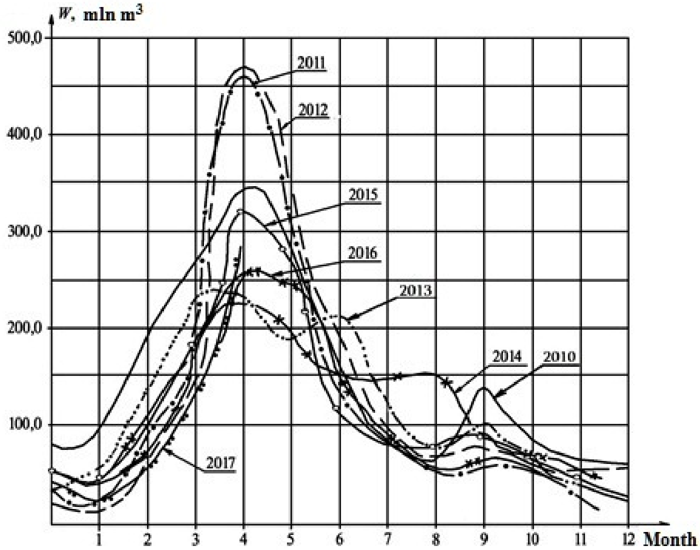
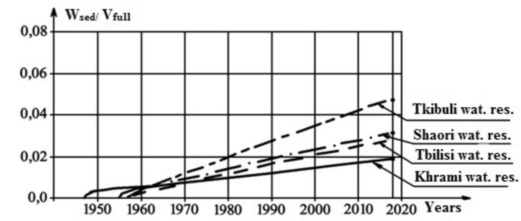


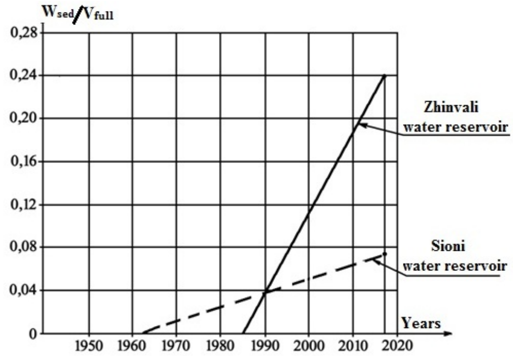
Fig. 4. Water volume inflows into the Zhinvali reservoir

As it is known, the Zhinvali reservoir is seasonally regulated. The seasonal runoff regulated by the reservoir is almost completely consumed every year because of the chronic shortage of electricity. The intra-annual fluctuation of the water level in the reservoir is determined by the annual runoff of the Aragvi River and demand for electric energy (Iordanishvili et al 2016).

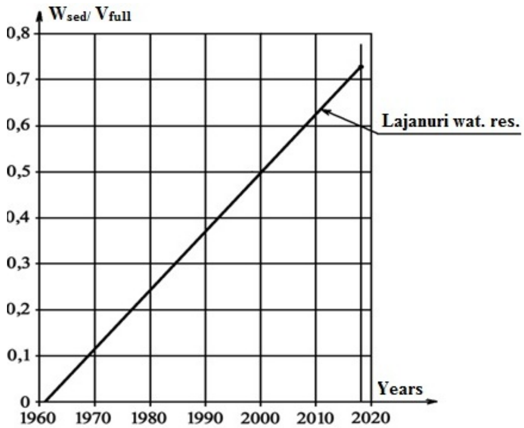
Due to the global warming of climate and a natural periodic increase in the Aragvi river runoff, the inflowing part of the water balance of the Zhinvali water reservoir in 1990-1998 increased by 30% compared with the average value for 1950–1960. Actually, during the flood period, this increase amounts to 33%, but is very insignificant during the period of shallow waters in October, when the runoff slightly decreases.



a) reservoirs with low sedimentation



b) reservoirs with average sedimentation



c) reservoirs with intense sedimentation

Fig. 5. Silting and sedimentation dynamics on the bottom of selected reservoirs in Georgia since the beginning of their operation (1960–2018)

By 2017, 121.54 mln m^3 of sediment accumulated on the bottom of the Zhinvali water reservoir. Before 2010, the sedimentation process was less intensive (2.6–2.9 mln m^3/year), but abundant floods and the higher volume of water in the reservoir after 2010 increased the rate of sediment accumulation to $W_{sed}/t = 8.08$ mln m^3/year.

If sediment accumulation continues at this rate, the volume of solid sediment in the Zhinvali water reservoir will equal the dead volume of the reservoir ($W_{sed.} = V_{dead} \approx$ 150.0 mln m^3) by 2020.

As a result of the water reservoir sanding up, or becoming gradually filled with sediment, its available storage (regulating prism) and consequently the accuracy of the designed value of the curve $W = f(H)$ decreases. It will therefore become necessary to correct this curve in the nearest future (by 2030). It will be reasonable to create a sand/gravel pit.

The situation is the same in the Sioni water reservoir (V_{full} = 325.0 mln m^3), where 24.30 mln m^3 of sediment accumulated by 2017.

Mudflows/debris flows occur in all climatic zones of Georgia, starting from the seacoast to the high-altitude alpine zone. Mudflows (debris flows) are triggered, among others, by heavy atmospheric precipitation, freshets, snow and ice melting, barrier breakdowns, glacier collapses and landslides, timber cutting, mining inert materials, excessive cattle grazing, and (chaotic, non-regulated) urbanization (construction in high risk areas). Such cities and regions of Georgia as: Tbilisi, Kvareli, Telavi, Sagarejo, Lagodekhi, Oni, Borjomi, Mestia, Lentekhi, Adigeni, Mtskheta and Tsageri are at high risk. There are 532 rivers in Georgia that are capable of transporting mudflows (Tab. 6). In May 2014, mudflow caused by the melting Devdoraki glacier resulted in a serious natural disaster in the gorge (Iordanishvili et al 2018).

Research has shown that mudflows caused by rain are the most common in Georgia.

According to data from the National Environment Agency, in 1995–2012 mudflows alone caused the deaths of 35 people and economic losses amounting to GEL 358 mln. Tbilisi is located in an area at a high risk of mudflow disasters. In May 2012, mudflows caused by heavy precipitation killed five people and destroyed several houses in Tbilisi. The damage inflicted by that disaster was evaluated at over USD 20 mln. On June 13, 2015, after a 4–5 hour heavy downpour, the Vere River flooded rapidly, causing a mudflow to form in its riverbed. It should be noted that, in association with global warming, strong winds, hails, avalanches, storms and forest fires have became increasingly common in Georgia in recent years.

It is necessary to take appropriate measures. One of the ways to slow down processes caused by global warming to achieve what is to use alternative energy sources, namely, wind, solar and hydroelectric energy, instead of conventional and nuclear power plants, which pollute the atmosphere with harmful substances. In 2014, the National Statistics Office of Georgia prepared a document titled *Climate Change Impact on Water Resources*, which states that Georgia will have to take steps to reduce emissions of heat, steam and harmful substances into the atmosphere. It is necessary to [“increase the use of”] electric cars (for information, electric cars manufacturing started in the city Kutaisi) and to close down coal power plants. Various measures against landslides and erosive mudflows should also be taken to prevent natural disasters in natural forests on mountain slopes. In 2010, the United States Center for

Table 5. Key indicators of bottom sediments for mountain water reservoirs in Georgia (2019)

No.	1	2	3	4	5	6	7
Name of the reservoir	Khrami	Tbilisi	Shaori	Zhinvali	Sioni	Lajanuri	Tkibuli
Year of putting the reservoir into operation	1947	1956	1955	1985	1963	1961	1956
Full volume of the reservoir (V_{full}), mln m^3	312.0	215.0	9.0	520.0	325.0	24.6	84.0
Dead volume of the reservoir (V_{dead}), mln m^3	20.0	60.0	3.0	150.0	25.0	7.0	22.0
Useful volume of the reservoir (V_{useful}), mln m^3	292.0	155.0	87.0	370.0	300.0	17.6	61.0
V_{full}/F, km	9.17	26.10	5.17	45.20	28.50	17.1	7.3
Normal pounding level of the reservoir	1512.0	54.0	113.0	810.0	1068.0	494.0	522.5
Length (L) and width (B) of the reservoir, km	14.0/3.5	9.0/2.0	7.5/3.0	12.0/1.0	11.5/2.0	3.2/0.45	6.0/3.7
Full depth of thereservoir, H, m	25.0	45.0	12.3	98.0	68.0	67.8	32.0
Mirror area of the reservoir on a normal pounding level, km^2	34.00	11.80	13.20	11.52	11.40	1.40	11.50
Average sediment accumulation per year, W_{sed}/t, mln m^3/year	0.092	0.080	0.050	3.790	0.450	0.32	0.063
Sedimentation volume for 2019 W_{sed} mln m^3	6,5	6.5	3.0	125.0	25.0	18.0	3.91
W_{sed}/V_{full}	0.021	0.030	0.033	0.210	0.008	0.730	0.047
Sedimentation height near the dam, m	7.0	4.3	2.5	23.0	20.0	45.0	14.0
Reservoir type according to siltation	I	I	I	II	II	III	I
Prognostic equations for sediment accumulation volume for a fiscal year (t)	$0.092(t-1947)$	$3.23 + 0.08(t-1970)$	$0.05(t-1955)$	$65 + 3.79(t-2010)$	$0.45(t-1963)$	$0.32(t-1961)$	$0.063(t-1956)$
Sedimentation stage	First, $W_{sed}/V_{full} < 0.12$	First, $W_{sed}/V_{full} < 0.12$	First, $W_{sed}/V_{full} < 0.12$	Second, $W_{sed}/V_{full} > 0.12$	Second, $W_{sed}/V_{full} > 0.12$	Third, $W_{sed}/V_{full} > 0.12$	First, $W_{sed}/V_{full} < 0.12$

Table 6. Mudslide regions in Georgia

No.	Area	number of mudslide basins
1	Kodori–Bzipi	109
2	Enguri–Khobi	56
3	Rioni	122
4	Kvirila–Dzirula	29
5	Adjara–Guria (Chorokhi–Supsa)	40
6	Tergi–Arghuni	99
7	Liakhvi and Aragvi	106
8	Tsivgombori (Iori)	44
9	Alazani	80
10	Javakheti and Meskheti (Mtkvari – up to the upper Borjomi)	160
11	Shida (inner) Kartli (from the right embankment of the river Mtkvari to Tbilisi)	53
12	Loki (Algeti–Khrami)	29
Total		920

International Development developed the programme "Integrated Natural Resources Management in Georgian Water Catchment Basins (INRMW)" as part of the "Global Water Resources" (GLOWS) programme. The programme is aimed at introducing innovative approaches and practical models of Integrated Natural Resources Management in the Alazani, Iori and Rioni basins. The programme made it possible to assess the vulnerability of the Alazani and Rioni water catchment basins to climate change and natural disasters, as well as to design mitigation and adaptation measures. As a result, water infrastructure rehabilitation projects have been implemented in 20 communities (in the region), involving the improvement of drinking water supply, irrigation systems, drainage systems and flood prevention measures.

4. Conclusions

In Georgia, the frequency of strong winds has doubled over the last 20 years, and now they recur every 4–5 years. Strong winds of 25–30 m/sec blow 5–7 times a year.

Strong winds damage communication and power transmission lines, trigger sea storms, dusty hurricanes and severe snowstorms, as well as cause an uneven distribution of snow, resulting in snowdrifts, depletion of soil moisture and activation of abrasive processes of water reservoirs and sea coasts.

Hails have become increasingly common. The intensity and frequency of hails are especially high in east Georgia, where five to fifteen hail storms occur annually.

Hail can completely destroy crops, ruin harvest, kill cattle and poultry. A single hailstone weighing 100–200 g or more can even kill a human. The damage caused by hail in Georgia over the last thirteen years exceeds GEL 140 million.

Avalanches have also become increasingly common in Georgia. Snow avalanches occur in strongly dissected and steep terrain as a result of intensive snowing, rapid melting of the snow cover, snowstorms, rapid temperature increase and rain.

Avalanches are most frequent in the cold period of the year. The frequency and intensity of this natural disaster have increased since 1970. Avalanches were most common in 1970–1971, 1975–1976, 1986–1987, 1991–1992, 1996–1997 and 2004–2005.

Snow avalanches cause casualties and losses to agriculture, damage human settlements and power transmission poles, block roads and disrupt traffic. Under unfavourable climatic conditions (drought, warm winter or hot summer), veterinary and phytosanitary risks increase. At least 2500 species of mushrooms and 1500 species of pests causing various diseases are registered in Georgia. Massive migration of grasshoppers caused severe damage to the agriculture of Georgia, resulting in deterioration of at least 200 ha of land used for agricultural purposes (the area most afflicted by grasshoppers was east Georgia).

Prolonged periods of drought and high temperature raise the risk of forest fire. In Georgia, the most extensive fire broke out in 2017 in the regions of Borjomi and Dusheti around Tbilisi. It has been describled as a national disaster because, in addition to soil destruction, a unique forest and an important source of oxygen was destroyed and will probably need several decades to recover. This fire destroyed more than 100 ha of unique forest. Given that 1 ha of forest absorbs 10.0 t of carbon dioxide and releases 20.0 t of oxygen per year, the affected region suffered an annual loss of 2000 t of oxygen and had to deal with additional 1000 t of carbon dioxide a year, which obviously took its toll on the local population.

The issues related to the global warming discussed above represent a grave problem that requires urgent analysis and evaluation.

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