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Developing the methods and principles to ensure safety of the population living in the high-risk zone flooded as a result of possible accident of Zhinvali earth dam

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A B S T R A C T

The work describes the state of Zhinvali Earth Dam and development of the Dam control risk frame by using the critical state and risk portfolio analysis (GAPRA). By using the theoretical and experimental global positioning device (GPS) and geographical information system (GIS) software, a digital map of the flooded area was compiled. The article describes the modern methods and principles to ensure safety of the population living in the high-risk zone flooded as a result of possible accident of Zhinvali Earth Dam.

Keywords: Reservoir, Flooded area, Population safety, Risk, Digital map, Portfolio analysis.

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1. Introduction

Examples from recent history of operation of hydraulic structures of reservoirs evidence that all over the world, including Georgia, the protection of the population, significant infrastructure, surrounding areas and agricultural lands against floods and mudflows in case of possible accidents resulting in unfavorable environmental problems and consequently, social and economic problems for humanity is an urgent problem. By considering that it is almost impossible to accurately predict the expected accidents of hydraulic structures (dams, coast protection walls, reservoirs, etc.) due to a great variety of their causes and their formation at different times, there is currently no universal method to assess the said process. Modern methods are necessary to develop based on the scientific studies by using novel tools and technologies.

One of the most urgent issues, which is of a state importance in our country, is the development and introduction of the national safety strategy and risk management action plan, and the assessment of the risks for vulnerable infrastructure by considering the threats caused by natural and anthropogenic (including terrorist acts) catastrophes.

The project envisages active cooperation between the governmental and non-governmental organizations in contemporary management and realization of risks what will allow developing an efficient, integrated and consistent national platform for risk management to prevent and neutralize natural and anthropogenic catastrophes.

Besides, in line with the memorandum concluded between Tsotne Mirtskhulava Water Management Institute of Georgia of Georgian Technical University and the University of Maryland (USA) (2011), a Critical Asset and Portfolio Risk Analysis (CAPRA) model is planned to use. The model envisages the quantitative assessment, and testing and introduction of all expected risks.

The author of CAPRA theory is Bilal M. Ayyub, the editor in chief of journal “Risk and Uncertainty in Engineering Systems” with ASCE (American Society of Civil Engineering) classification and the consultant scientist of the present project. The journal is published in almost all leading countries of the world. Based on the above-mentioned, it is planned to publish the scientific results gained within the scope of the grant study in the above-said journal [1,2].

The object of the study is to develop the methods and principles to ensure the safety of people living in the risk zone flooded as a result of a possible accident of Zhinvali Earth Dam. The article accents the development and assessment of methods and principles to evaluate the impact of the expected catastrophe on the people living in the risk zone; increasing the awareness of the local people and designing, developing and introducing preliminary preventive measures.

2. Thorough assessment of Zhinvali Earth Dam

Zhinvali Reservoir is a reservoir with a complex designation in East Georgia, Dusheti Municipality, north of Zhinvali settlement, 70 km from Tbilisi. It is located in the middle course of Aragvi, between Alevi, Gudamakari and Kartli Ridges. Its area is 11,5 km^2; the water volume is 520 mln. m^3; the useful capacity is 370 mln. m^3, and the maximum depth is 75 m. Zhinvali Reservoir was built in 1985 within the scope of Zhinvali HPP construction project in the Aragvi River gorge [3]. Its generated electricity capacity is 130,000 kW. The section of the Aragvi River where Zhinvali Reservoir was built is abolished and no river ecosystem exists along this former section of the river [3]. Zhinvali Reservoir plays an important role in the water supply of Tbilisi. It is noteworthy that Zhinvali Reservoir supplies about half of the population of Tbilisi with drinking water. Due to the construction of Zhinvali hydraulic complex, the XII century Jvarpatiosani Church was flooded. The Church is under the water for 6 months a year and can be seen above the water for the rest 6 months [4,5].

The complex of Zhinvali structures contains an earth dam and clay core, with deep water intake and deep idle open outlets.

Normal flooding level of the Reservoir is 810,0 m, maximum flooding level is 812 m and the minimum flooding level is 770 m. Generally, the Reservoir is prohibited to operate below 766 m level.

Particularly important is the increased frequency of recurrence of natural anomalies, landslides and mudflows in particular, denivellation events in the Reservoir coastal line and surrounding area affecting the environmental balance, the possibility of transporting the drift with the rivers forming the coastal line, dynamics and intensity of the underground water levels and potential impacts of various nature and strength on the artificial structures.

Figure 2 shows Zhinvali Reservoir plan in isogyphs by using GIS technologies.

Following the above-mentioned, the intensity of silting the Reservoir, as compared to the design data, is increased by 2,5 times. Mean annual silting value is 4,5 mln. cub.m. At present, the total volume of the deposited mass is 126,0 mln. cub.m.

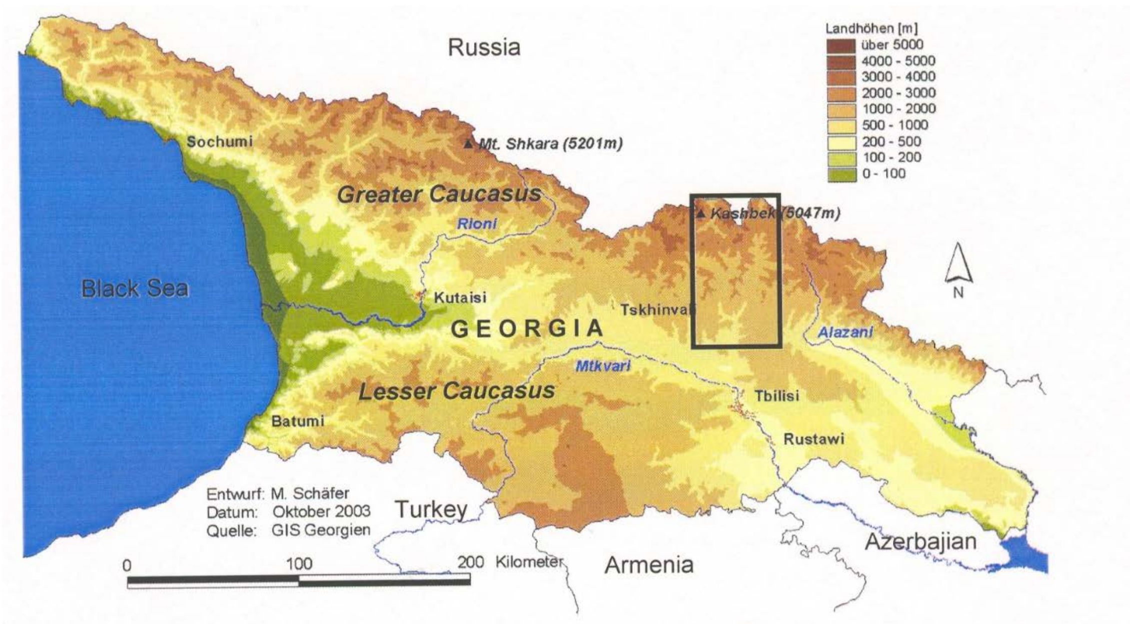


Fig. 1. *Study object*

The process of sedimentation of the Reservoir with solid drift takes place in the upper reaches where the drift surface level is at the height of 20 m from the water intake sill. As for the control of the water reservoir level, it is done continuously, with a 1 cm accuracy by means of automatic self-recording and as the calculation results suggest, the evaporation loss is 6,5 mln. cub.m. a year [6-9].

In order to predict the volumes of Zhinvali Reservoir, 3 field expeditions were organized: in April and May and September to December of 2018 and in April and May of 2019, in the periods of maximum and minimum flooding of water levels in the Reservoir and Figure 4 shows the views of Zhinvali Reservoir in a 3D format [10,11].

By considering the field-expedition and GIS technologies and by using the digital maps, the volumes of Zhinvali Reservoir are established by considering the area of the water level.

The field studies evidence that in terms of fluctuations of Zhinvali water horizon in the Reservoir water area, frequent changes of erosive processes observed, in particular, where the mudflow mass is transported by the Aragvi River and is then accumulated in the Reservoir water area, at places where no accumulation takes place, but bed erosion. Such locations are considered sensitive sites.

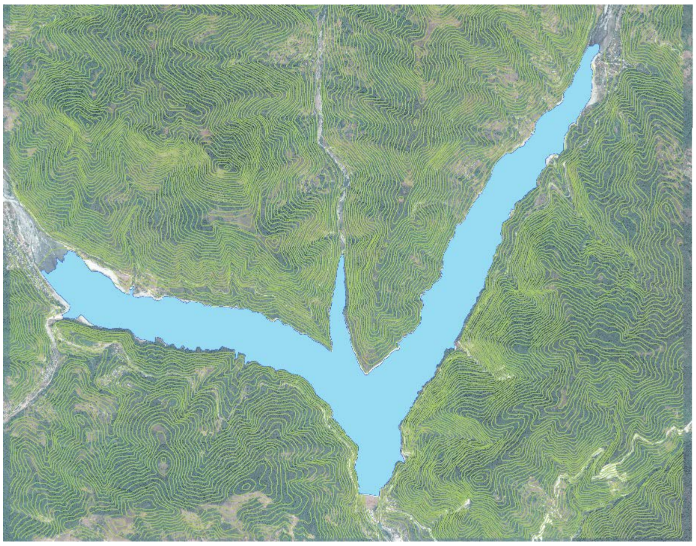


Fig. 2. *Plan of Zhinvali Reservoir*

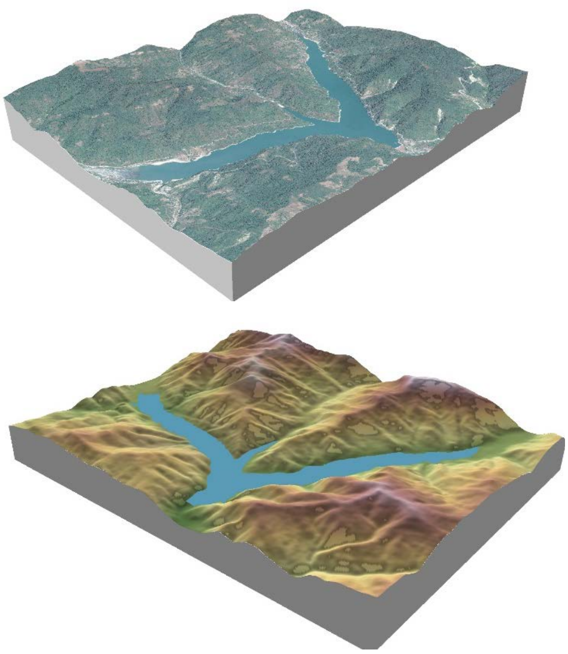


Fig. 3. *Views of Zhinvali Reservoir in 3D format*

3. Establishing the flood risk zone in case of possible accident of Zhinvali Earth Dam

A Critical Asset and Portfolio Risk Analysis (CAPRA) model, whose author is Bilal M. Ayyub, professor of the University of Maryland (USA), considers the quantitative assessment, testing and introduction of all expected risks [12].

A risk is the probability of the outcome, which is a deviation from the planned/expected result and has a negative impact on the achievement of the set goals on the study object.

The risk is defined with the combination of the following properties:

a) Probability;

- The probability is the possibility of a concrete outcome to occur, by considering the frequency of the outcome.

b) Impact (if any).

An impact is an effect in case of a concrete outcome and considers four elements: 1) time, 2) quality, 3) benefit, 4) human resource and other resources.

The combination of the probability and the impact determines the level of a concrete risk value and following the set goals, allows classifying the risks depending on their priorities.

In the first instance, the risks with the highest probability and impact must be considered and managed. In the row, every next risk must have less probability and impact than the previous risk. In practice, this process is much more complex, as there are risks with high probability, but low impact and/or vice versa. In such cases, in order to avoid mistakes, the risks must be classified by priority following the goals and objectives of an organization (Table 2).

As for the risk management, it must be permanent and be done by the study object manager in line with the risk management strategy proved annually.

Risk management helps and promotes the study object, as it allows efficient realization of its objectives, including:

- The formulation of the general direction of the study object that allows running the business in a trouble-free and controlled manner;
- The improvement of processes – making, planning and prioritizing the decisions;
- The protection and improvement of the reputation of the study object;
- The development and strengthening a human resources and institutional knowledge base.
- Operation optimization, etc.

Table 1. *Volumes of Zhinvali Reservoir 20-meter levels Maximum flooding (level) – 840, minimum flooding (level) (thalweg) – 712*

Water horizon absolute level (m)	Water level surface area (m^2)	Water volume in the Reservoir, (m^3)
840	10939612	884724026
832	10879099	799599514
812	10847811	586982276
792	10509107	376098980

Table 2. *Risk Assessment Scale*

Probability	High	A priority
Impact	High	
Probability	High	Ranking must be based on the goals and strategies of the organization
Impact	Low	
Probability	Low	Ranking must be based on the goals and strategies of the organization
Impact	High	
Probability	Low	Less priority
Impact	Low	

The process of risk management is a set of coordinated and consistent continuous actions [1,2].

A common practice of risk analysis is to develop a risk matrix what allows risk ranking and identification. The matrix is compiled by associating the risk probability and the impact that is used as a reference point to rate and categorize the risk.

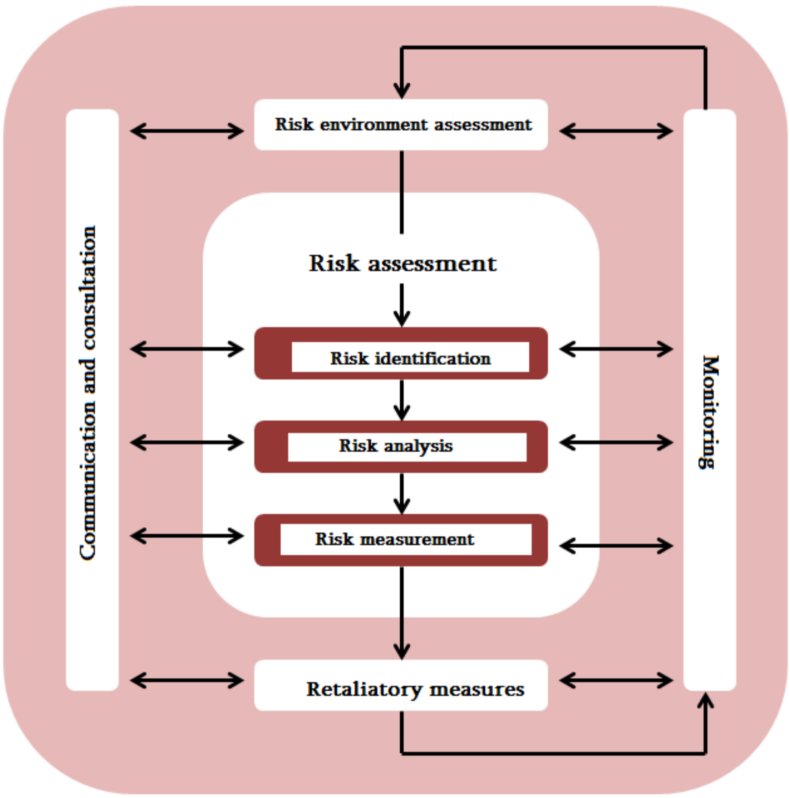
The volume of water in the Reservoir (W_0) was calculated with the following dependence [12]:

$$W = \frac{H_B S_B}{3} \qquad (\text{mln. m}^3) \qquad (1)$$

Where: H_B is the water depth at a normal dam flooding level (m); S_B is the area of the Reservoir water surface (mln. m^3);

The length of the river is taken from topographic maps. As for the number of points, it must not exceed 3 points on each side from the river axis, mak-

Table 3. *Risk management process (under ISO 31000)*



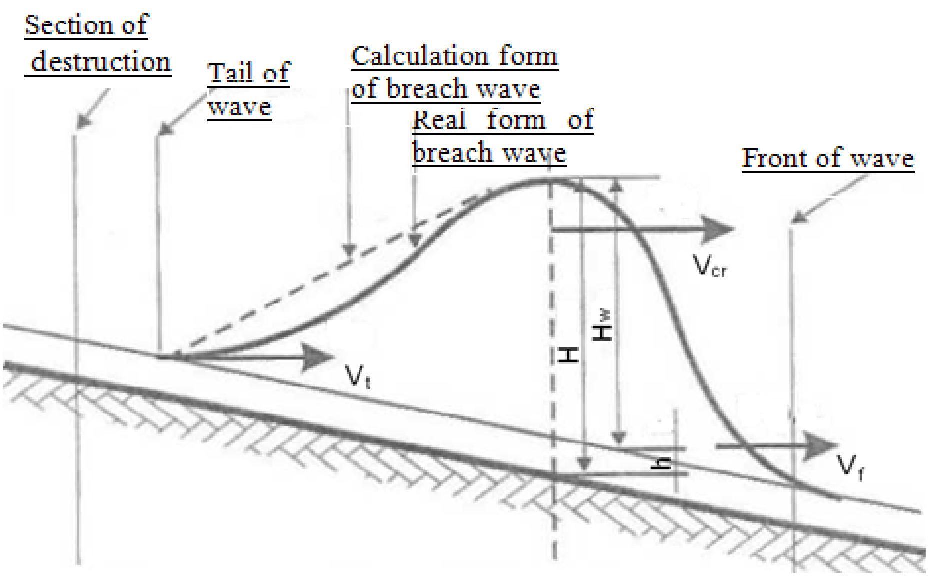


Fig. 4. *A longitudinal profile of a tsunami wave*

ing total 6 points, and must cover the whole water catch area. The number of sections from the dam needed to determine the area of the flooded territory must not exceed 8 sections, and the distance between them must be plotted on a topographic map in advance.

During the flood, a wave velocity (V) in the tailrace of the structure is calculated by formula [13, 14]:

$$V = V_0 (H_1 / H_0)^{2/3}, \text{ (m/sec)} \tag{2}$$

Degree of the dam failure (E_p) was calculated with the following dependence [13]:

$$E_p = \frac{F_B}{F_0}, \tag{3}$$

Where: F_B is the area of the bank ruptured area (m^2); F_0 is the surface area (m^2).

In addition to the above-mentioned, the algorithm considers: the height of the river bank sill (m), number of the sections along the length of the river, distance between the sections (km), width of the riverbed (m), water velocity in the riverbed (m/sec), width of the River Nogha bed (m), values of riverbed levels (m), etc.

In case of a possible rupture of Zhinvali earth dam in the bed of the Aragvi River when tsunami waves are formed, the only means to protect the people is an organized evacuation. However, Zhinvali Dam rupture will not occur abruptly, but will be preceded by the accumulation of defects in the structure what is a prognostic sign. Besides, the technical parameters and hydrological values of the Dam and the topographic indices of the Aragvi River must be taken into account, as they allow predicting the area of the territory flooded following Zhinvali Dam accident.

By means of field studies, GPS, GIS and relevant software, the maximum widths of the Aragvi River bed where areas may be flooded as a result of a flood formed in case of possible Zhinvali Dam accident what will bring a great damage to our country, including great human and animal losses, were identified.

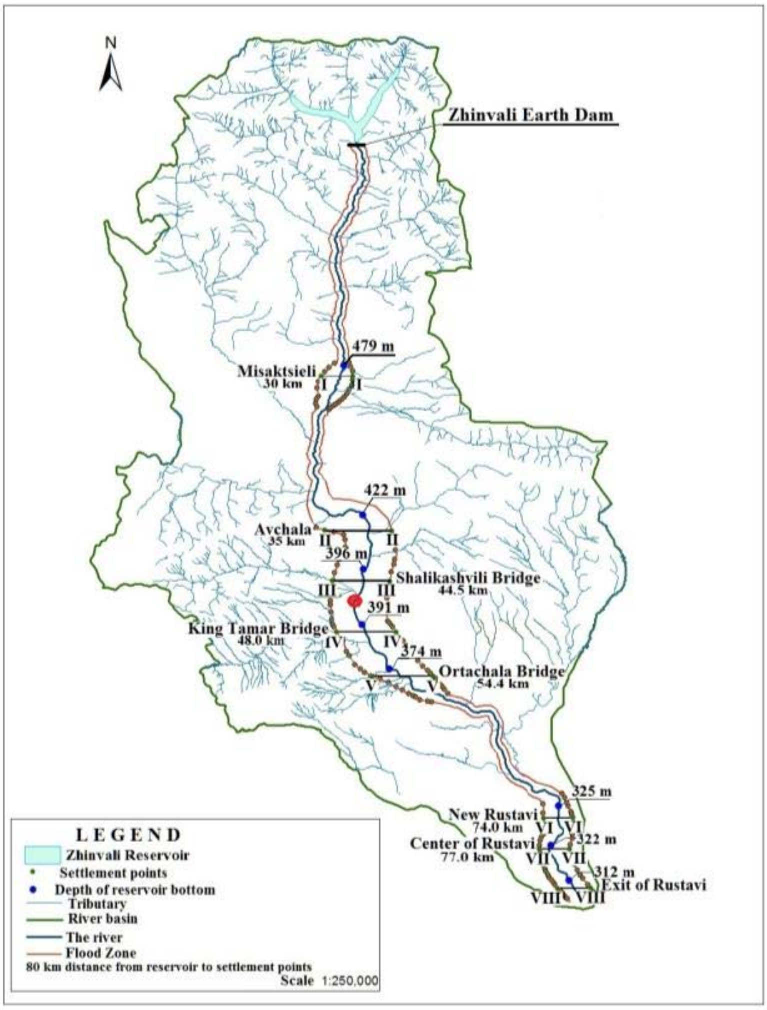


Fig. 5. *A digital, map of the flooded areas, GIS system*

As a result of the analysis of the accomplished studies, it was established that in case of a possible Zhinvali Earth Dam accident, a number of villages in Dusheti and Mtskheta Municipalities up to Tbilisi, the capital of Georgia, with their population of 14 823, will be in a high risk zone of flooding. This is similarly true for the population of Tbilisi and Rustavi living in high flooding risk zone.

Thus, the areas of villages of Dusheti and Mtskheta Municipalities in a high risk zone flooded as a result of possible Zhinvali Earth Dam accident and their population facing a great danger is identified based on the initial prediction data.

5. Increasing ecological awareness of the population living in flood risk zones

In case of emergency, including floods (Fig. 7), the awareness of each resident of the rules of behavior and action living in the high-risk zone of natural calamity, in addition to determining the degree of awareness of specific methods and rational actions, leads to the psychological stability and better self-confidence of people in extreme conditions [15-18].

If the people live in the Dam tailrace, then they live in a high-risk zone and must be aware of the following things [19-21]:

- Possible boundaries of flooding, as well as elevated locations in immediate vicinity of their houses, which rarely get flooded, and the shortest ways to them. The practice has evidenced that in case of rupture of big reservoirs, tsunami waves are formed, and the best protective means from them is the organized evacuation of people.
- All members of the families must be aware of the evacuation plan and rules of conduct in case of abrupt and rapidly progressing floods. They must remember where the boats, rafts and building materials to make them are stored.
- They must have a list of documents, things and medications to take with them in case of evacuation. They must put all necessary warm clothes, products, water and medications in their bags or rucksacks.
- They must urgently leave a possible zone with the danger of catastrophic flooding with the mandated rule immediately after they receive the message about flooding hazard and evacuation and move to a safe region or elevated area, take with them the documents, jewelry, necessary items and supply of products sufficient for two days.
- As they leave home, they must turn off the electricity and gas, put out the fire in an oven, fix all swimming items outside the building or put them in auxiliary storerooms. If there is a time, they must move the family's valuable things to the upper floors of the house or garret. They must close doors and windows and, if needed and if time allows, they must

Table 4. *Flooded villages at high risk in case of Zhinvali Earth Dam accident*

#	Name of the settlement	Number of the population (People)
1	Chinti	188
2	Zhinvali	121
3	Bichagnauri	424
4	Aragvispiri	907
5	Bodorna	140
6	Tsiteli sopheli	546
7	Navazi	677
8	Misaqtsieli	2100
10	Natakhtari	1234
11	Mtskheta	7 940
12	Zahesi	546
	Total:	14 823

board up the doors and windows of the first floor with planks from the outside.

- In case of a sudden formation of a catastrophic flooding, they must quickly move to an elevated area, climb a large tree or get on upper floors of solid structures to protect themselves from the beat of a breakdown wave. If they are in water, they must not be confused and scared at an approaching wave, they must deeply dive near the bottom of the wave, and swim up onto the water surface after some delay in water (by swimming underwater). In case they are in water, they must try to reach a dry place (preferably, an embankment or dam) by swimming or by using swimming items what will allow them to easily reach non-flooded area.
- Self-evacuation of people on foot or by using swimming items is permitted in the following cases: if the non-flooded area can be seen straightforward; if the foodstuff is over; if it is hopeless to wait for the external help or if the people are in need of urgent first aid.
- During the flood, they must take self-control and not panic. They must put the shipping equipment in order, but in case there is none, they must do it by using locally available materials. If they find themselves in water, they must try to take off heavy clothes and footwear and swim to non-flooded sites. They must try to avoid contact with the items swimming on the water surface to avoid possible trauma.
- If no organized evacuation is organized, they must go to the upper floors of a building, roofs, trees or other elevated places before the lifeguards arrive or before the water level lowers. At the same time, they must give out the signal of disaster continuously: by waving a stick with a well visible cloth on it during the day and by using a light signal and calling out periodically as it is gets dark. When the lifeguards are near, they must get on the swimming vessels calmly and carefully and without a panic. At the same time, they must fulfill the lifeguards' requirements and must not overload the swimming vessels. They must stay in place on their swimming vessel during the transportation, must not sit on outer borders and must carefully fulfill the instructions of the swimming crew.
- During the flood, apart from disruption of the existing medical service system in the area of disaster, a number of other serious problems occur as well. As the buildings ruin, such vitally important objects, as power supply and drinking water supply structures, get out of order. Insanitation may be the case what is followed by the hazard of spreading infectious diseases. Therefore, the given issues must be permanently supervised by health service provides of the relevant regions.

6. Conclusion

Based on the field-scientific and theoretical studies, the article establishes the number of people living in the risk zone of flood caused by possible accident of Zhinvali Earth Dam and measures to improve their ecological awareness and preliminary preventive measures, in particular:

- By using the theoretical and experimental studies, Global Positioning System (GPS) and Geographical Information Systems (GIS) software, the territories occupied by settled areas and infrastructure damaged (flooded) as a result of floods and mudflows in case of water current flow over Zhinvali Earth Dam were studied and their contours were plotted on the digital maps.
- In case of a possible accident of Zhinvali Earth Dam, the area of the flooded territory and the number of the local population in the zone of natural calamity were specified.
- The rules of behavior of the population living in the risk zone during the flood before, during and after the calamity were developed and the necessary rules of behavior of people during emergencies were specified.

Acknowledgement

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