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Catastrophic Flood in the Russian Town Krymsk (North Caucasus, 6-7 July, 2012) — Analysis of Natural and Anthropogenic Causes

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Abstract: On 6-7 July 2012, huge water flow had rushed downstream river Adagum and flooded the town Krymsk located in the Western end of the Caucasus. The flood caused many (human) victims and destructions. This paper presents results of both geographical and hydrological analysis of natural and anthropogenic factor which could lead to this catastrophe. Though the main cause was the extreme amount of precipitation, a significant negative role was played also by anthropogenic factors, among which the development of the floodplain of the river Adagum, insufficient capacity of the bridge spans, low efficiency of the engineering flood protection, gaps in the monitoring system of hydro-meteorological phenomena, delayed warnings of population. Extent of the flooding had been determined by means of the GIS-models from high-water marks. Preventive control measures aimed at minimization of a possible damage from future extremely high floods are proposed.

Keywords: Flood in Krymsk, North Caucasus, Natural and anthropogenic factors, GIS-modeling
JEL Classifications: R14, H84, I39, Q54

1. Introduction

Floods in the North Caucasus, having become more frequent and intensive in recent decades, often result in human casualties and tremendous economic damage (Kotlyakov et al., 2012; Alekseevsky et al., 2012; Bazelyuk, 2012; Taratunin, 2008; Matishov et al., 2012; Prevention..., 2013, and others). Floods happened in the Krasnodar Territory in the winter and in the summer of 2002 caused numerous casualties and large material losses. After a lapse of 10 years, still stronger catastrophic flood had happened again and spread over the cities of Novorossiysk, Gelendzhik and the town Krymsk. It was accompanied by massive destructions (Fig. 1). More than 170 people were killed, mostly in Krymsk with the population of 57,000 people located on the Adagum river (the Kuban river basin). Institute of Geography, RAS (IGRAS) took an active part in consideration of various aspects of this flooding; results of analysis of the space monitoring of the river Adagum basin performed on 9-11 July 2012 from the Russian segment of the International Cosmic Station (ICS) were also used during this research.

Figure 1. A house in the town Krymsk destroyed by the flood. One can see the mark of the maximum flood levels above the window in the undestroyed wall.

Cosmonaut Gennady Padalko had manually made and transmitted to the Earth more 200 panoramic and detailed satellite images of the disaster area, most of which was promptly interpreted at the IGRAS. In parallel with this, a complex of field works had been carried out. It included collection of hydro-meteorological and socio-economic information, the state estimation of the floodplain and the riverbed, and searching tracks of high flood – marks left on the trees, buildings, and the valley slopes by silt deposits and debris. Plane and vertical geodetic conjunction of the high water tracks (marks) and points of routes had been made using the GPS receivers.

Modeling of the flood area had been made using the geo-information system (ArcGis 9.3 GIS) and digital relief model (DRM), additional modules Spatial Analyst and 3D Analyst were also used. Before a number of vector maps had been constructed by means of numbering of topographic and thematic (subject) maps. Created vector maps contained the following thematic layers: hydrography; boundaries of the city, its blocks, individual buildings, industrial and agricultural objects, etc.; the road network, and vegetation. As a digital model of the relief, the global model ASTER GDEM [http://reverb.echo.nasa.gov/reverb/] was used, developed jointly by METI and NASA. A part of area under investigation had been cut from global data on the relief, and then initial data were converted into the relief surface - TIN (the triangulated irregular network) built from non-intersecting triangles of different sizes. A surface of each triangle, vertices of which are points with known coordinates x, y, z, is a plane.

In order to simulate a flood and to estimate a flooded area, a plane imitating the water surface of a river should be built. To do this, a new linear system of cross sections of the riverbed was created. The cross-sections were drawn in every 150 m. Position of the water surface for the pre-flood period was pre-assigned from the water line marks in each cross-section of the river.

In a case if information about the water line in a cross-section was absent, values of the water lines were given equal to the height values in cells of the relief grid, at points of intersections with the coastline. Further the TIN surface was created from lines of the cross-sections. The surface imitating the water level became the base for further calculations of the flooded area of the city of Krymsk. For the computations of the flooded area of each every type of the land use the option "The TIN Difference" of the 3D Analyst module was used.

2. Natural Conditions of the Flood Formations in the River Adagum Basin

The river Adagum is formed by the confluence of rivers Bakanka and Neberdjay at 10 km above the town of Krymsk (Fig. 2). The catchment area of the river Adagum is 336 km^2, and the length is about 100 km. Its rather steep slope, especially in the mountainous upper reaches, determines a short time of the flood wave run down to the outlet section. The gradient changes from 30-50 ºin the mountainous upper reaches down to 5-10 ºin the lower plain part of the basin.

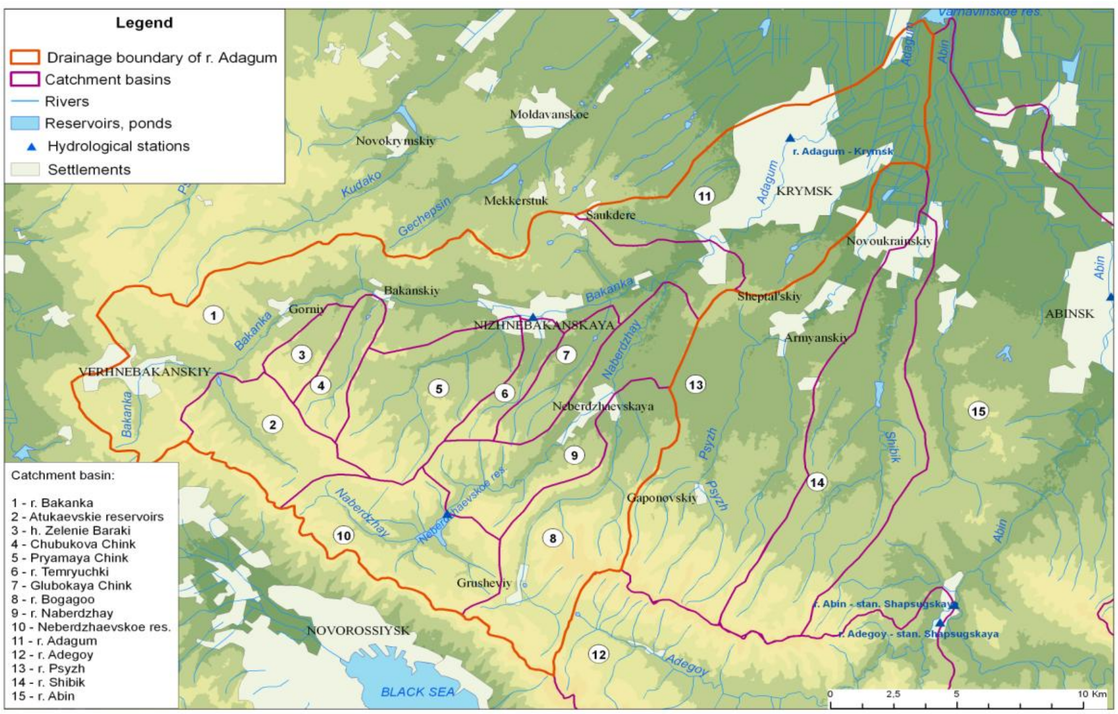

Figure 2. The catchment of the river Adagum

A form of the river valley near the town of Krymsk is the box-like since there is the smooth bottom and slopes with heights of approximately 40 m. Width of the river channel within the city amounts to 25-35 m, the usual depth of the river is 0.3–1.0 m, and the flow speed is 0.3–0.5 m/s. The average annual water discharge of the river Adagum in the Krymsk section is small (~ 4 m^3/s) and very variable. In some years the river dries in the low water time. During periods of floods, the water discharge can exceed several hundred m^3/s (Fig. 3). In 1964, the Varnavinsky water reservoir had been constructed in 10 km below the city (the absolute heights slightly higher 10 m); it was mostly used for irrigation.

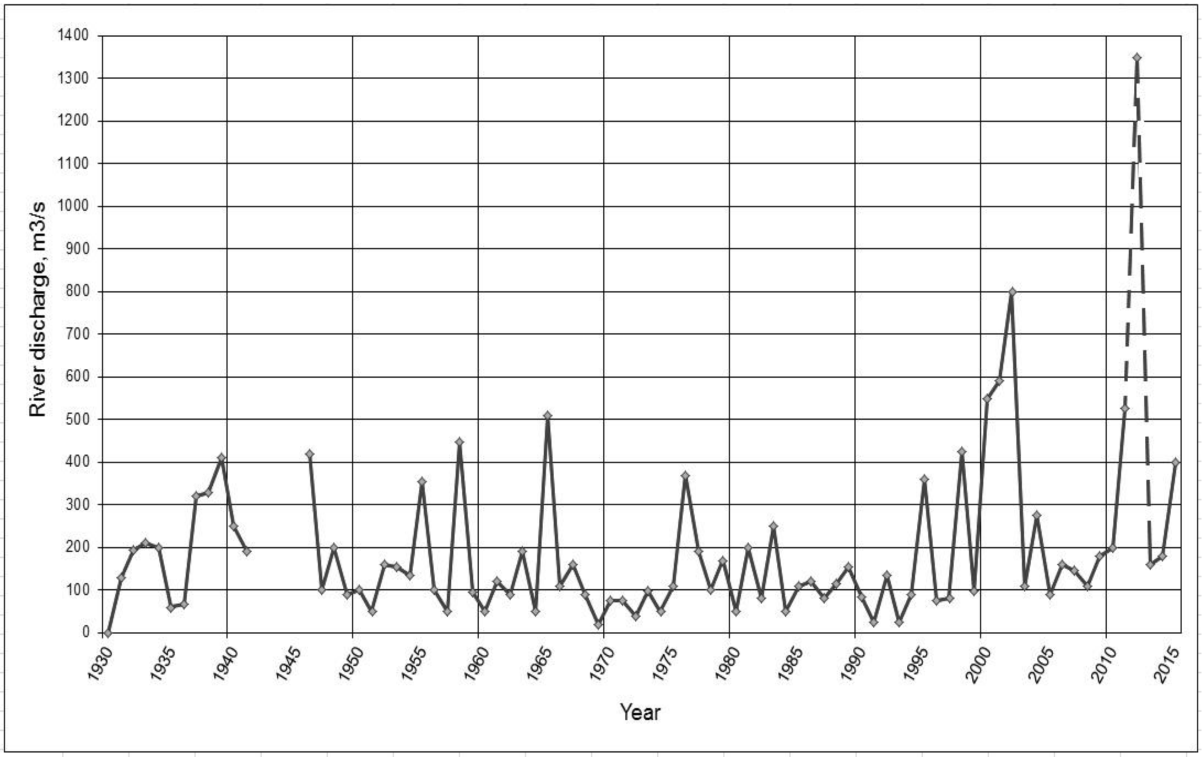

Figure 3. Graph of maximal discharges of the river Adagum in Krymsk

A characteristic feature of climatic fluctuations of the maximum and minimum water levels of the river Adagum is the existence of the certain tendencies (Figures 3, 4), and this is probably related to the climate changes and may be also caused by deepening of the channel due to intensification of the river flow cutting into the underlying rocks. The anthropogenic influence may also play a certain role. A tendency for growth of maximal water levels of the river within the city is simultaneously observed with a certain fall of the minimal levels. Similar character of changes allows definite assertion about increasing of the risk of damage from flooding for living buildings and commercial facilities at the same hypsometric level.

The sources of the rivers Bakanka and Neberdzhay are located at the absolute altitudes of 300-320 m in the Main Caucasus area, on the slopes of the Markhotsky mountain range. Strongly dissected low mountain ranges run in the North-West direction. Maximal absolute altitude of the ridge separating the Adagum basin from the Black Sea is 543.1 m. The catchment area of the river Bakanka is 179 km^2, and of the Neberdjay is 111 km^2. Their sources are located at the absolute altitudes of 300-320 m. These are typical mountain rivers with numerous narrowings of winding valleys, gorges with steep and precipitous slopes. In the foothills, the absolute altitudes of bottoms of the river valleys go down to 30-50 m or still smaller. Both rivers take many short tributaries which often dry up in summer. These are small shallow rivers, but after heavy rains their water levels rise quickly, and they turn into turbulent streams of muddy water. In the upper part of the Neberdjay river, the Neberjaevskoye water reservoir has been constructed. It is used for water supply of the city of Novorossiysk. The hydrostatic head of the reservoir is the earth-fill dam 250 m long.

The river Adagum basin is rather irregular in the geomorphological conditions for formation of its runoff. The lower part of the basin, which is located around the town Krymsk, belongs to the

Azov-Kuban plain. But the main volume of the runoff is formed in the mountain upper zone that is on the catchment areas of the rivers Bakanka and Neberdjay. Significant relief gradients in this area promote the fast runoff of rainwaters and formation of high floods in the area under consideration.

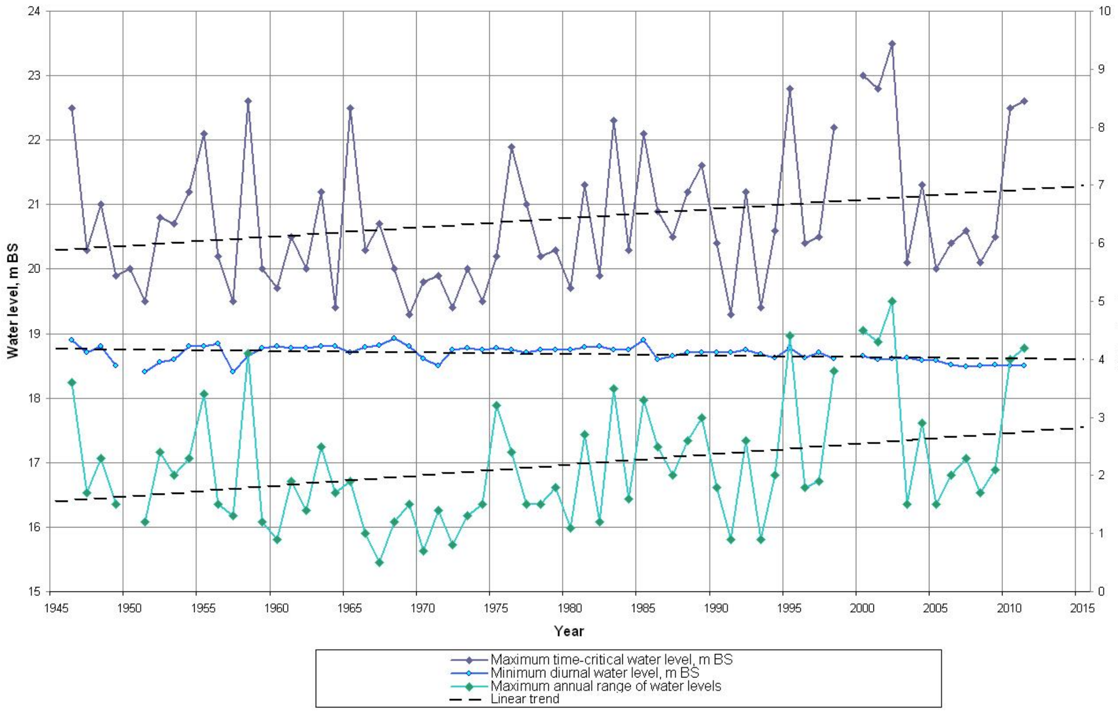

Figure 4. Climatic fluctuations of maximal and minimal levels of water in the river Adagum

Combination of mountain and plain relief predetermines pronounced differences in the precipitation amounts which generally grow with elevation. Another feature is a significant lowering of gradient of the catchment slope at the transition of the Adagum valley to the foothill plain above the town of Krymsk that promotes decreasing of the flow velocity and thus lifting of the water level during floods. It is significant also that the spill capacity of the river valley seriously deteriorates due to obstructions formed by the washed away and fallen trees and fragments of them (both of local origin, and brought from the upper part of the catchment).

Low thicknesses of mountain-forest and mountain-meadow soils in the mountainous parts of the territory under consideration in combination with significant gradients of the relief, especially on the treeless areas, is one of the reasons for formation of quick runoff of rain and melt waters into the river-bed network. It should be noted also that the runoff is increased by presence of leached and drained black earths (chernozems) soils which are characterized by low permeability, and they are almost everywhere cultivated and devoid of a wood vegetation.

The mountainous part of the territory is mainly covered with oak and oak-beech forests; pine-oak forests are on washed-out brown forest, mountain-forest, and rendzina soils which are skeletal and thin; large areas are occupied by shrubs (Safronov, 1987). There is also a secondary meadow vegetation, that is spread on axial parts of the ridges and on the steep slopes as well as on forest clearings and pastures, but often this vegetation is highly transformed, or even absent on sites of bedrock outcrops.

The foothills are characterized by landscapes of low mountains and hills with beech-hornbeam and oak-hornbeam forests (often completely destroyed), growing on gray forest soils, and plowed the foothill meadows. Plowed meadow steppes on typical and leached chernozems are widespread.

Mean annual amount of precipitation is equal to almost 700 mm. Distribution over the territory is irregular. Amount of precipitation and, respectively, the runoff increase with elevation in mountains [Resources of..., 1973]. Important factor in the mountains is not only the height but also the exposition of slopes. So, moistening of the landscapes is usually larger on the windward slopes.

Distribution of the precipitation in time is also highly variable [Resources of..., 1973]. In wet years the precipitation amount is 1.5–2.5 times larger than that in dry years. Distribution of monthly precipitation amounts during a year are also irregular. During the summer period the rainfall amount exceeds the mean annual value by more than 60%. In the mountains, number of days with showers increases up to 60-70, especially in June and July. The second maximum of precipitation falls usually on September – October.

The atmospheric circulation in this area is another important factor determining a possibility of extremely high wetting of the Black Sea coasts. The mountain ranges exert significant local influence on the atmospheric circulation. They intercept air masses carrying the moisture, retard movements of atmospheric fronts, and increase amounts of precipitation in mountains and foothills. But processes of the atmosphere circulation in this region are governed by not only the relief characteristics. They also reflect the global changes in the land-ocean interaction and change with time. When doing analysis of the atmospheric circulation for 1899-2012, (N.K. Kononova, 2012) made a conclusion that the present-day character of the circulation promotes increasing of a probability and intensity of floods in the Northern Caucasus. Starting in 1998, the processes under which the Mediterranean cyclones moving to the North Caucasus become longer, and the cyclones linger in this territory meeting across their trajectories a barrier in the form of a stationary anticyclone in the South of the East European Plain. This results in intensification of the atmospheric fronts and thus continuous abundant precipitations, reaching several monthly norms for a few days. This synoptic situation took place in July 2012 and promoted formation of the flood.

3. Anthropogenic Factors of the Flood Formation

Over the long history of economic development of this region the landscape structure of the river Adagum basin has undergone significant changes. Extension of lands occupied by the human settlements, development of dacha and recreation building, construction of roads and bridges, deforestation, plowing-up and replacement of natural vegetation with agricultural crops disturbed the water-regulating functions of the landscapes, thus promoting increasing of the surface runoff and intensity of floods. And it should be noted that, in the 1990s (Russian “perestroika” when many industrial enterprises stopped), unlike many other regions of the country the anthropogenic pressure in the Krasnodar Territory did not sharply decrease. On the contrary, in some aspects it did even grow, including the degree of use of recreational potential, expansion of settlements, construction of roads, gas- and oil-pipelines, etc. Exactly such forms of the anthropogenic pressure increased that could promote formation of floods.

An important point is that in the process of development of the territory the riverside areas of the floodplain, flooded in the wettest years, were often populated. But the negative consequences of floods become especially severe and hard if authorities and population are not prepared for extraordinary situations or emergencies. This is precisely the situation happened in 2012 in Krymsk. The large number of victims was the result of not only houses in the riverside and on the floodplain, but the lack of timely notification of the population, night time, and presence of lonely and helpless people in their apartments played the negative roles in this case too.

As it is noted in the book "Catastrophic floods early XXI century: lessons and conclusions" (2003), "preventive measures against floods, timely forecasts, people relocation, and repair of dams and providing of anti- flood measures, including emergencies, make possible to prevent about 70% of normal floods. And therewith, costs of prevention and eliminations of consequences are related as one to thirty". However, anti-flood protection in the city of Krymsk was not adequate with respect to increased risks of occurrence of the extreme floods and could not provide guaranteed protection against floods. It included mainly the banked up dams. They needed to be reconstructed in consideration of the recently increased maximal discharges of water. The deficiency of the local anti-flood protection was that it did not provide the ability to reduce the water discharges during floods by means of construction of adequate regulatory capacities.

Hydro-meteorological characteristics of the flood progress. The main cause of the catastrophic flood, happened at the night of 6 to 7 July, 2012, is the abundant rainfalls precipitated almost simultaneously over the whole catchment area of the river Adagum. The maximum amount of them had fallen in the mountainous upper reaches of the rivers.

Since no instrumental observations were carried out in the mountainous parts of the basin, the precipitation amount and the maximal water discharge in the city of Krymsk were estimated rather approximately. Existing observational post had been flooded and damaged.

We present the chronicle of this catastrophic event below.

On July 5-6, a deep cyclone with a significant moisture content of the air had moved to South-West of the Krasnodar territory. On July 6, a low local cyclone with a front surface and thick convective clouds had been formed. In the evening of 6 July, it was very slow-moving and super-saturated with moisture that caused the shower-type long-lasting precipitation (Fig. 5). The rains fallen during July 6-7 were extremely heavy and large by their amount. Nothing similar was recorded for the whole period of the instrumental observations. Daily precipitation sum measured at the meteorological station Krymsk never exceeded 80 mm, while at night from 6 to 7 July it reached 156 mm. Much larger amount of precipitation had fallen in mountain reaches of the river Adagum, almost twice larger as one can judge from data of meteorological station Novorossiysk. Short, but quite intensive rainfall started by mid-afternoon on 6 July. By 20.00 of the same day (here and below we indicate the local time), the precipitation have reached 88 mm in the city of Novorossiysk, and 24 mm in the town Krymsk. The flood wave from upstream had already reached the town. We consider this wave as the first one.

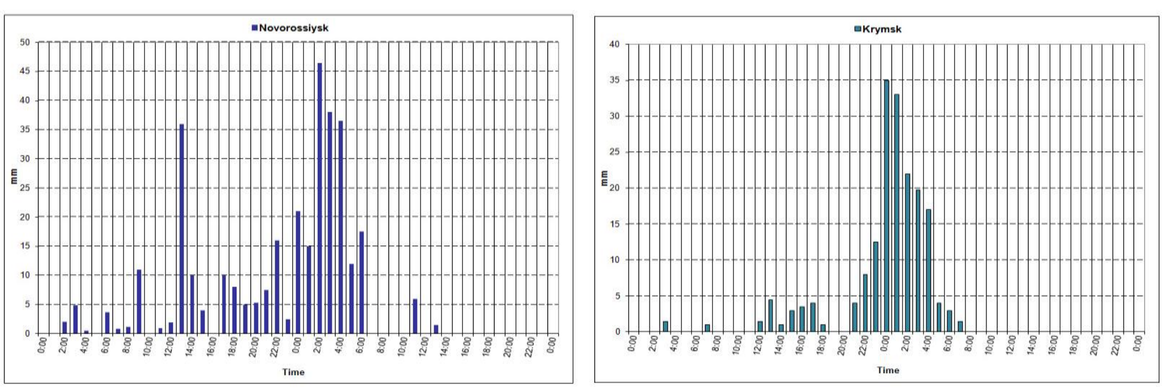

Figure 5. Dynamics of the hourly layer of the water precipitated on 6-7 July 2012

From 20.00 to 22.00 of July 6, the precipitation became more intensive, and at 21.40, the water level on the river Bakanka had grown up to 2.00 m, and - up to 2.34 m on the river Neberdzhay. The great part of the Adagum floodplain was flooded. A movement of weak material (small landslides and mud-flows) started down from the mountain slopes. All usually dry valleys of temporary water streams and still smaller gullies and ravines became rivers of rapid streams. From 22.00 to 24.00 of 6 July, 23 mm had fallen in Novorossiysk and 47 mm - in Krymsk. In the stanitsa (large Cossack village) Neberjaevskoye located on the river Bakanka, the maximal water level reached 4.16 m. At the same time, the water level in the tributaries rose by 2-3 m, and the catastrophic flood started in Krymsk. This stage of the disaster development may be considered as the second wave.

From 00.00 to 02.00 of July 7, the maximal amount of showers that reached 62 mm had fallen on the near-watershed slopes. At the same time (for 2 hours), 54 mm of rain had fallen in Krymsk. Neberjaevskoye water reservoir was filled with rain waters that caused the emergency discharge through the shaft spillway. A trace of the flood rushed down the river Neberdjay can be clearly seen in pictures made onboard of the International Space Station. The Neberjaevskoye water reservoir was filled with water up to the upper edge of its dam however the dam itself was not damaged. Impeding some portion of the rain water, the reservoir promoted a certain decrease in the maximum discharge of the river Adagum (by 130 m^3/s approximately).

Below the reservoir, the waves being formed due to breaks of temporary dams in valleys of rivers and their tributaries, rushed downstream, making many destructions. At 2.2 km to the city of Krymsk in the way of flood water, there was the obstacle – the railway embankment and bridge on it. The flood waters had overcome this obstacle, and did not destroy the bridge supports. The space of a width 30 m across the way had been quickly filled by woody debris and other solid material, including a heavy truck. It seemed that the wave had not caused any serious damage, but it became an obvious sign of soon trouble.

Peak of this flood in Krymsk occurred from 02 to 03 hours on 7 July 2012. It was mostly caused by the heavy rainfall in the upper reaches, which did drastically increase the normal local rainwater runoff of the river Adagum. Maximum water discharge in the river at the entrance to Krymsk had reached 1350 m^3/s [Prevention of..., 2013] that was significantly higher the historical maximum of 2002 (for the period of observations since 1929) – 800 m^3/s. It happened to be close to the discharge amounting to 0.1–0.2% of the probability (repeats once in 1000-500 years).

The main obstacle on the flood way was located immediately at the southern edge of the town. Here, the local motorway was built across the river Adagum, and the height of its surface was by 6.45 m higher the thalweg of the valley (built with consideration for floods of 1% probability). Actually, this road formed a dam of 800 m long which efficient cross-section for the pass was almost 10 times smaller, and moreover, it was divided into parts by wide reinforced concrete supports. By the beginning of the disaster, a huge space under the bridge was filled with debris that was everything that the river carried down.

Embankment of the road turned out to be the main temporary dam that impeded the flood waters and promoted the river level rising by more than 7 m that exceeded the calculated maximum level of 1% probability (repeatability of 1 time for 100 years). The breastwall water reservoir had been formed in front of the dam with an area of about 5.5 km^2. The wave of 7 m height have broken this dam and then poured through the efficient cross-section of the bridge wave down to the city.

There were two other permanent bridges and several pedestrian crossings built over the river Adagum in Krymsk. These objects were also filled with different wooden material and household waste, which promoted formation of new flood waves. As a result, more than a half the territory of the town had been flooded. The flood was accompanied by destructions of buildings and losses of life. More than 60% of the victims were found near this bridge on the left river bank. Part of the wave turned to the right side of the floodplain. Here and below dead bodies of people were also found.

At the same time, it should be noted that the main bridges in both inside the town and outside were not damaged by this the most rare and powerful flood of July 6-7, however they were designed with due regard for passing of possible flood of only 1% of the probability. The main transport infrastructure was preserved.

Modeling with use of GIS (Geographic Information System), performed on evidence of the high-water marks identified by the field survey, made possible to reconstruct this catastrophic flooding (Fig. 6, Table 1).

Table 1. Area flooded in the Krymsk town at high water floods on 6-7 July 2012

Objects	**Areas** (km^2)
Settlements	10.089
Blocks	7.239
Objects of industry and infrastructure	1.520
Individual buildings	0.071
Arable land	2.216
Fruit gardens	0.261

***Note:** Area of the Krymsk town is 47.5 km^2; On average, the water level in the river Adagum exceeded the normal one by 8 m.

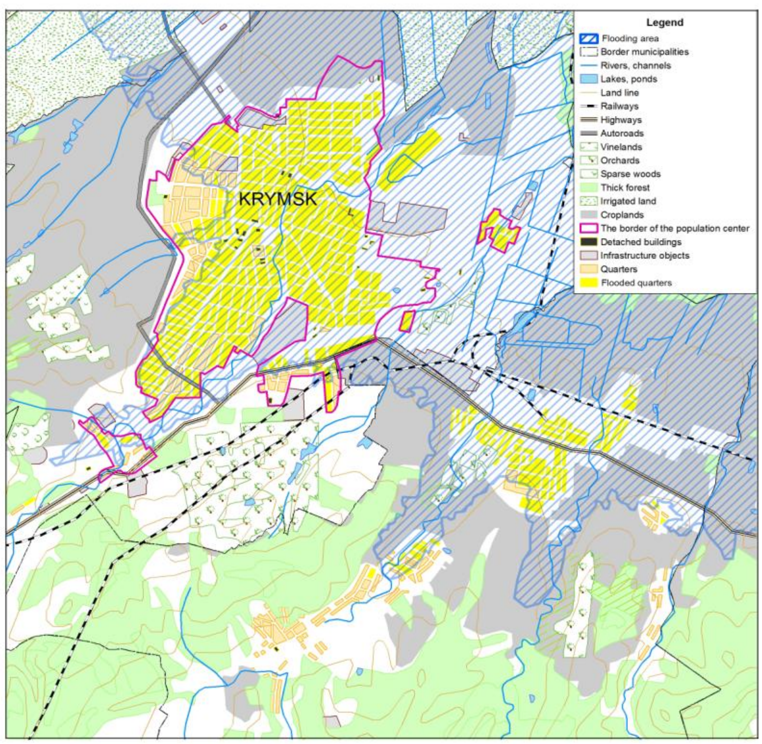

Figure 6. Flooding of the Krymsk region territory up to the high water level

4. Conclusions

Formation of catastrophic flood on the river Adagum in the town Krymsk at the night of 6-7 July of 2012 was mainly caused extremely heavy rainfalls which were never observed earlier for the period of instrumental observations. The natural conditions of the river Adagum basin promoted this extreme flood. The man-made impacts (buildings on the floodplain, including the water-protecting zone, great littering and cluttering of floodplains, low bandwidth spans of bridges and water ways through the road embankments, the lack of efficient drainage system, etc.) together with insufficient efficiency of engineering flood control protection and monitoring system and late notification of the population significantly intensified the negative consequences of this event. So, when developing measures to reduce possible flood damage it is very important to take into consideration both the natural and the anthropogenic factors.

Due to the high variability of climatic factors it is not possible now to eliminate completely the threat of floods. However, basing on available Russian and foreign experiences it becomes possible to minimize potential losses by means of preventive protective measures.

Recommendations

To prevent similar disasters in the future, we would recommend implementation of the following measures:

(1) Development of a network of automated weather and gauging stations, covering evenly dangerous in the hydrological meaning areas, especially in the mountainous part of a river basin;

(2) Organization of the observational network of surface slope runoff, groundwater levels and moisture content of soils in the watershed, as well as observations of debris flows and landslides;

(3) Development of operational method to predict the maximum water discharges and levels;

(4) Improvement of a life insurance system for people living in the flood hazardous areas;

(5) Moving of residents from the most flood-dangerous places;

(6) Implementation of measures aimed at improving water retention (water-absorbing) functions of the landscape (afforestation, conservation of old-growth forests with deep root system and a strong litter-humus horizon) on the river catchments to reduce the destructive power of floods;

(7) Building of small water reservoirs in the system of anti-flood protection for accumulation of the flood runoff in the upper river reaches and the channels to turn the flow out of the settlement boundaries;

(8) Deepening and clearing the channel and floodplain from debris, deepening the river bottom for pipelines or lifting their height with account of possible flood levels;

(9) Reconstruction of bridges taking allowing a passing of floods higher than the previous ones;

(10) Improving the system of early warning of the population about the imminent threat of flooding.

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References

[1] Alexeevsky N.I., Magritsky D.V., Krylenko I.Kh., Yumina N.M., Ajbulatov D.N., Efremova N.A. (2012). "Structure and dangerous hydrological phenomena in the Black Sea coastal zone". In: *Natural and social risks in the coastal zones of the Black and Azov seas*. Moscow, Triumph, 2012, 4-16 pp.

[2] Bazelyuk A.A.(2012). "Dangerous hydro-meteorological phenomena in the South of the European Territory of Russia". In: *Natural and social risks in the coastal zones of the Black and Azov seas*. Moscow, Triumph, 2012, 33-41 pp.

[3] Kononova N.K. (2012). "The atmosphere circulation as a factor of natural disasters in the Northern Caucasus in the 21st century". // Geo-policy and eco-geodynamics of regions. *Scientific Journal of the Tavria Vernadsky National University*, 8(1-2): 72-103.

[4] Kotlyakov V.M., Desinov L.V., Dolgov S.V., Koronkevich N.I., Likhacheva E.A., Makkaveev A.N., Medvedev A.A., Rudakov V.A. (2012). "Flood of 6-7 July 2012 in the town Krymsk". *Proceedings (Izvestia) of the Russian Academy of Sciences*, (Series Geography), 2012 (6): 80-88.

[5] Matishov G.G., Kleschenkov A.V. (2012). "Kuban flood crisis". *Climate, geomorphology, forecast*. Krymsk, July 2012. Rostov-on-Don, p.128.

[6] Prevention of catastrophic floods and the security of the Crimean district of the Krasnodar Territory / Under editing of V.I. Danilov-Daniljan and M.V. Bolgov. Institute of Water Problems of RAS. M. Publisher "Altair", 2013. 36 p.

[7] Resources of the land waters of the USSR (1973). The Northern Caucasus. L., Gidrometeoizdat, 1973. Vol. 8. 447 p.

[8] Safronov I.N. (1987). *Geomorphology of the Northern Caucasus and the Low Don*. Publisher of the Rostov State University, 1987. 275 p.

[9] Taratunin A.A. (2008). *Floods on the Russian Federation Territory*. N.I. Koronkevich (Ed.). Ekaterinburg, Publisher FSSE RosNIIVH, 432 p.

[10] Vorobjev Yu. L., Akimov V.A., Sokolov Yu.I. (2003). *Catastrophic floods in the beginning of the 21st century: lessons and conclusions*. Moscow, "DEKS-Press", 352 p.