Seismic risk assessment at urban level: example for the Black Sea region

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SUMMARY:
The paper presents the results of the recent study on risk assessment for the Big Sochi City, venue of the future Olympic Games in 2014, undertaken within the within the Russian Federal Program "Development of the Sochi City as a mountain resort in 2006 – 2014" and the project 7.7 of the Russian Academy Sciences' Program of Fundamental Investigations "Environment in changing climate, extreme natural events and disasters".

Keywords: seismic risk, scenario events consequences, GIS project, Big Sochi City

1. INTRODUCTION

Seismic safety of population and urban territories is one of the most complicated problems of seismology and earthquake engineering worldwide. It is especially vital for the earthquake prone regions with high level of seismicity and high density of population when the negative strong events consequences may be aggravated by secondary technological accidents and high potential of other geological hazardous processes.
According to recent seismic risk assessment at regional level for more that 60% of the Krasnodar area territory, the values of individual seismic risk (probability of death and/or injuries due to potential hazard within one year at a given place) computed taking into account the secondary technological accidents exceed the value of $1.0 \cdot 10^{-5}$ 1/year. Regional estimation of risk obtained for the Sochi City is equal to $35.0 \cdot 10^{-5}$; contribution of technological risk to seismic one is about $5.0 \cdot 10^{-5}$.
The paper contains the results of the recent study that was done by Seismological Center of IGE, Russian Academy of Sciences, Extreme Situations Research Center, Moscow State Technical University named after N. Bauman and "Rosstrojizyskaniya" Ltd aimed at verification of engineering geological conditions, updating of previous map of seismic microzonation and seismic risk assessment for the Sochi City territory, resort located in the Black Sea shore in the Krasnodar area. The paper also gives examples of loss computations due to scenario earthquakes taking into account accidents trigged by strong events at critical facilities: fire and chemical hazardous facilities, including oil pipe lines routes located in the earthquake prone areas.

2. CHARACTERISTICS OF NATURAL HAZARDOUS PROCESSES FOR THE BIG SOCHI TERRITORY

The Big Sochi City is located in the Krasnodar area, which is characterized by a high density of population and a rather high level of seismic hazard. According to maps of review seismic zoning of the Russian Federation territory, earthquakes with intensities $I = 6-10$ according to the MMSK-86 scale may occur here. The City territory is located along the Black Sea shore and characterized by different level potential of landslides, mudflow, erosion and other geological hazardous processes. The Imeretinskaya valley, where future Olympic Games' facilities are under construction, are located

within the marine terrace composed predominantly by gravel-pebble deposits with sand and clay with thickness more than 30 m; the bedrock at the depth of about 70 -90 m, the groundwater level encountered at depths of 0.2-4 m from the surface.
Taking into account the importance of engineering geological and hydro geological conditions for the construction of Olympic Games facilities the special study has been undertaken to compile the map of hazardous geological processes' potential for the Big Sochi territory. Fig.2.1 shows the fragment of this map for the Adler district.

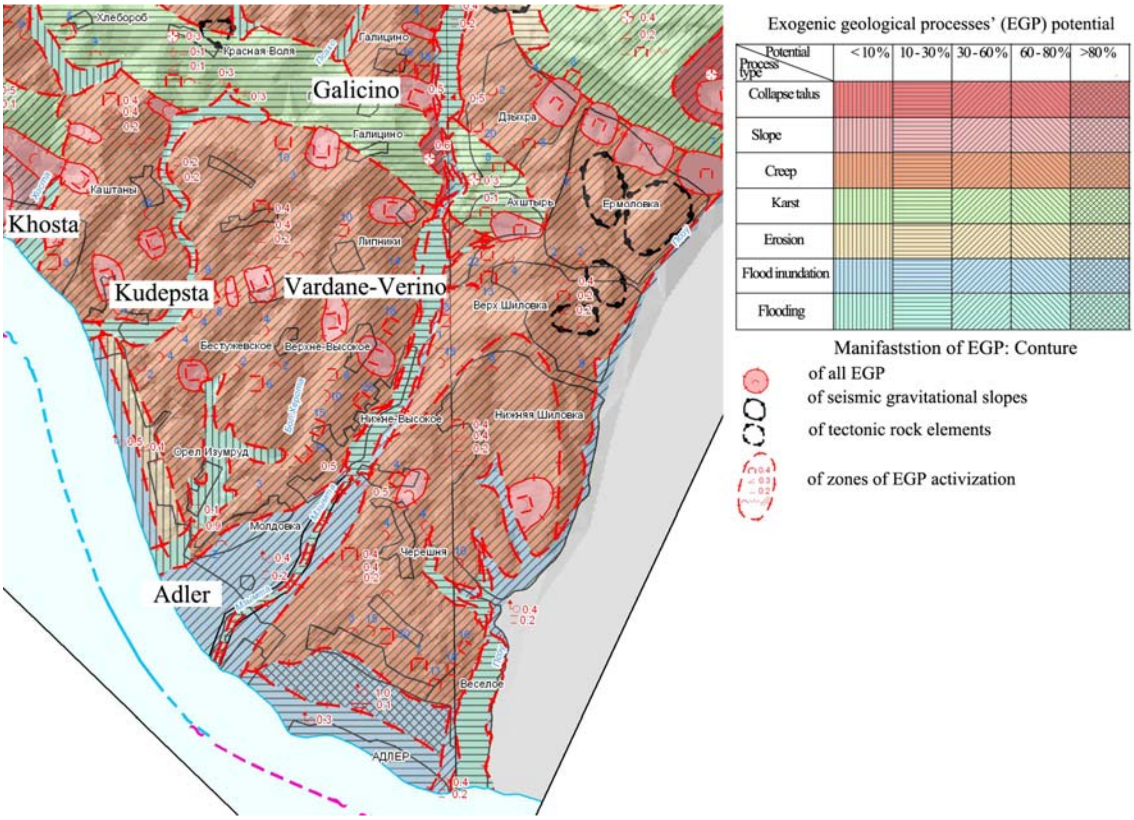

Figure 2.1. Map of hazardous geological processes' potential for the Big Sochi territory (fragment)

The prevailing for Big Sochi territory geological processes with indication the area covered by them as a percentage of the total land area (3,500 km^2) and the nature of the areal distribution are given below:
• nival-glacial complex processes - 2.3% (located in the alpine nival zone);
• collapse-talus phenomena - 5.6% (in the highlands and at the intersection of the limestone ridges, for the rest territory fragmentary);
• avalanches - 2% (intensive in high land and weaker in the midlands);
• mud flow - 1.5% (intensive in high land and weaker in the medium and low lands);
• landslide processes - 6% (along the sea slopes and erosion slopes of river valleys, for the rest territory fragmentary);
• creep - 12.6% (intense for the Paleogene-Neogene molasse deposits);
• slopes denudation (deluvial washout) and accumulation of - 3.5% (spread locally);
• erosion of temporary streams - 52.8% (areal extent);
• erosion-accumulative processes of permanent streams - 5% (linear distribution);
• karst - 3% (by karst rock areas);
• flood inundation - 2.5% (floodplain of the river valleys);
• flooding - 3.0% (the Imeretinskaya valley and bottoms of river valleys and ravines);
• abrasion-accumulative processes - 0.2% (in the sea coastal zone).
During the past 80-100 years for the whole Caucasus activation of mud flow and landslides processes has been observed. This fact is stipulated by deforestation and increased erosion of the slopes associated with their artificial cutting in the construction of roads, pipelines, power lines, etc. Urban

development also influence greatly on intensive geological environment changes. As a result the area of landslides and their activity within the Big Sochi territory is much higher in comparison with underdeveloped areas in the Sochi vicinity. In particular, the central part of Sochi the territory is partially prone to the landslides.

Analyze of spatial distribution of hazardous geological processes allowed to identify the generalized boundaries zones characterized by level of their manifestation. The map (Fig.2.1) identifies four situations which correspond to different levels of hazard and different measures aimed at risk reduction.

Detailed engineering geological study allowed the map of seismic microzonation of the Big Sochi territory to be updated. The verified map (Fig.2.2) was compiled taking into account two of background seismicity levels corresponding to different return periods of earthquakes: T= 500 years (OSR-1997A) and T=1000 years (OSR-1997B). Seismic loads in peak ground accelerations a_{max} were estimated for different zones of the city.

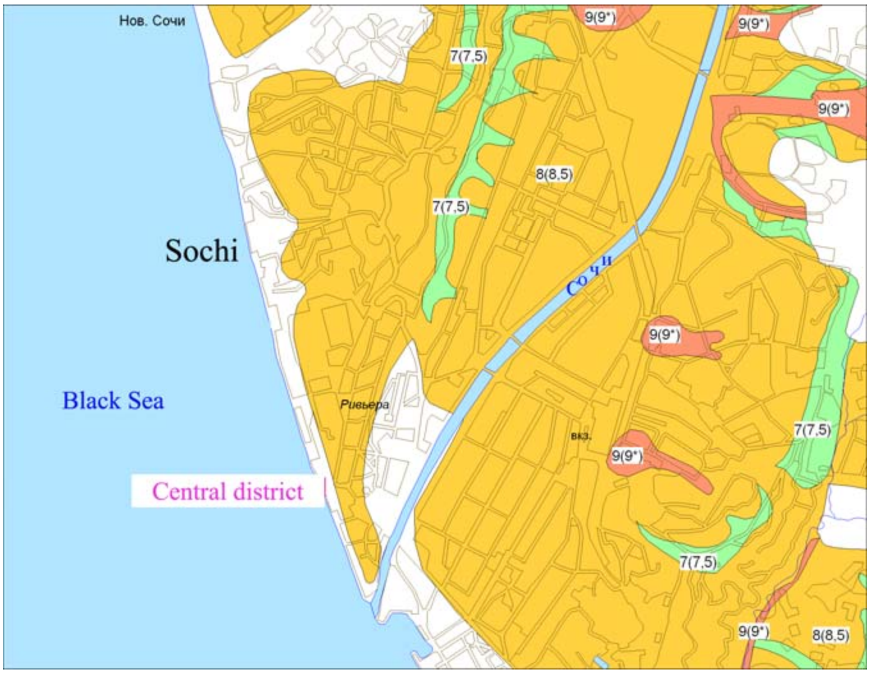

Figure 2.2. Fragment of the seismic microzonation map for the Big Sochi territory: figures on map correspond to different level of background seismicity for T=500 years and in brackets for T=1000 years

For the site of Olympic Games facilities in the Imeretinskaya valley a_{max} varies from 0.32 g to 0.34 g. The computations were made for various predominant periods of oscillations: 0.30 -0.32s and 0.80 - 1.17s. Presence of clay and peat layers results in shift of the spectral characteristics into the low-frequency range.

3. CHARACTERISTICS OF THE BUILT ENVIRONMENT FOR THE CITY TERRITORY

The territory of Big Sochi City is divided into several administrative districts: Lazarevskij, Central, Hosta, and Adler. The City consists of 47 settlements and includes few separate resort areas: Magri, Asha, Goa, Golovinka, Dagomys, Sochi, Adler. Within the city the extensive coastal area along the wide beach extends up to 25 km to north-west, up to 40 km in the central part and along the river Mzymta to 75 km. Separate settlements are mainly located along the Black Sea coast or along rivers' valleys. The whole length of the Big Sochi territory is about 105 km. The City building stock is not uniformed.

The staff of the Emergency Situations Research Center developed the database on existing building stock taking into account the previous work on inventory of residential buildings within the Federal State Program "Development of the Federal System of Seismological Observations and Earthquake Prediction" (Sobolev et al, 1998) and space images of high resolution. The database includes information on the distribution of building types, classified according to MMSK-86 scale (Shebalin *et al*., 1986): buildings' type B (brick, hewn stone or concrete blocks); buildings' type C (reinforced concrete, frame, large panels and wood); buildings' types E7, E8, E9 (earthquake resistant which are designed and constructed to withstand earthquakes with intensity 7, 8, 9) and the average height of buildings. Within the project 7.7 of the Russian Academy Sciences' Program of Fundamental Investigations "Environment in changing climate, extreme natural events and disasters" additional verification of the building stock was undertaken in order take into account Olympic Games facilities and new residential buildings under construction. Fig. 3.1 shows the fragment of the map for the Adlerskij city district and the Olympic Games' village. The map shows the distribution of existing building stock and structures under construction: high rise residential buildings and hotelsNumber the Table headings and please be consistent throughout your manuscript. Leave one blank line before the table heading and one blank line after the table, as shown below.

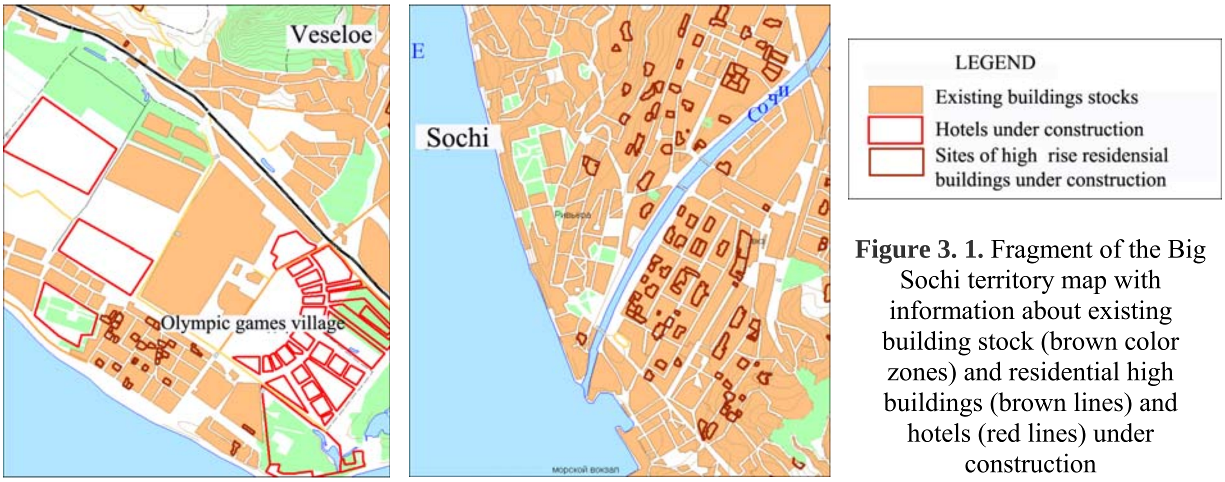

Figure 3. 1. Fragment of the Big Sochi territory map with information about existing building stock (brown color zones) and residential high buildings (brown lines) and hotels (red lines) under construction

On the whole 72 districts with similar building stock were identified for the Big Sochi territory (Fig. 3.2).

The information about existing fire, explosion and chemical hazardous facilities and their characteristics in the Big Sochi territory was analyzed. Chemically hazardous materials are mainly stored at food industry facilities, as well as at refrigerating plants and other utilities. There are 17 chemical hazardous facilities are in operation now in the area. On the whole, there are about 70 registered industrial, scientific and transport facilities with storage of fire and explosion hazardous material in the considered area. During the last 5 years no accidents and fires were registered at these facilities.

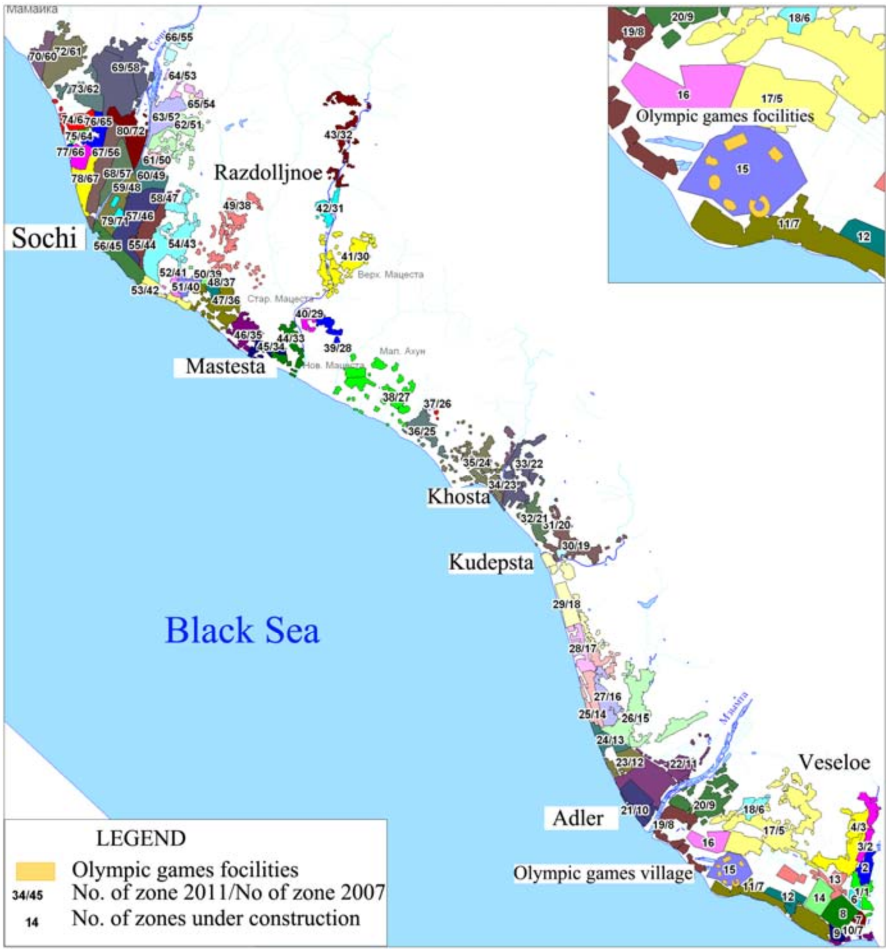

Figure 3.2. Building stock distribution for the Big Sochi territory; figures are number of models: variant of 2011/ variant of 2007

4. GIS PROJECT FOR RISK ASSESSMENT

Within the project 7.7 of the Russian Academy Sciences' Program of Fundamental Investigations "Environment in changing climate, extreme natural events and disasters" the special GIS project was developed for risk and scenario earthquakes' loss computations at urban level for the Big Sochi city territory. The project is ready to use product with all the elements inherent to the automated information system for special purposes. It includes a database with information describing the properties of the territory of Big Sochi city including the territory of location of the Olympic Games facilities; software assigned for risk and damage computation; interface which allows to generate thematic maps and text reports according to prescribed forms.
Databases contain information describing the geographical position of the territory, its structure, main landmarks and boundaries' shape. Thematic content of the database is represented by the spatial information describing the boundaries of zones with various intensities according to the map of seismic microzonation of the city territory; boundaries of the possible earthquakes source zones; the districts of the city with the similar of buildings' types. All mentioned elements of databases are geo-referenced or have coordinate description of the boundaries.
The software of the special project for the Big Sochi City includes three blocks used for data management, computation of risk indexes and visualization of space information on the screen as thematic maps of fixed scale. Fig. 4.1 shows the screenshot of the special GIS project for the Big Sochi City territory.

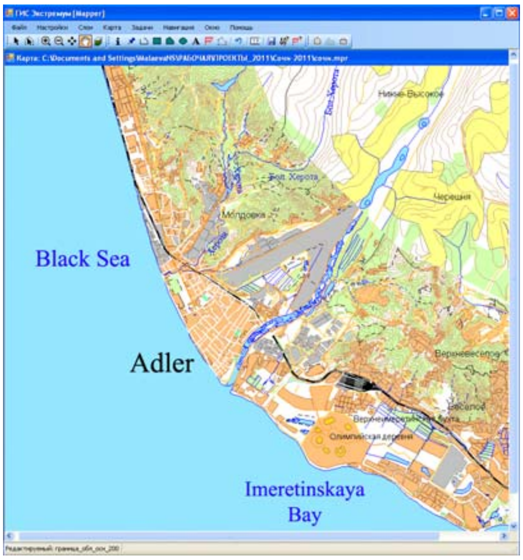

Figure 4.1. Screenshot of the special GIS project for the Big Sochi City territory

5. SCENARIO EVENT CONSEQUENCES FOR THE BIG SOCHI TERRITORY TAKING INTO POSSIBLE ACCOUNT TECHNOLOGICAL ACCIDENTS

In order to identify the parameters of scenario events the two maps of possible earthquake source zones were use. Fig.5.1 shows the map (Nesmeyanov, 2007) constructed using the method of identifying the seismogenic structures, which is based on analysis of geological and geophysical data, taking into account the geological criteria of seismicity, which include a discontinuous nature, age of structures, depth of penetration, the nature of recent and modern activization and others. Fig. 5.2 the verified variant of possible earthquake source zones constructed using the earlier obtained computed estimations and results of paleoseismogeological studies (Rogozhin, 2011).

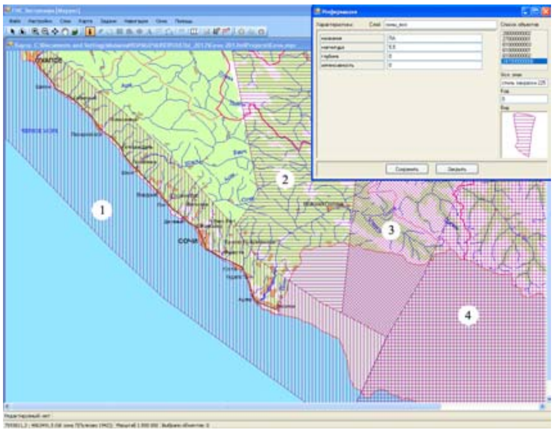

Figure 5.1. Possible earthquakes source zones (Nesmeyanov, 2007)

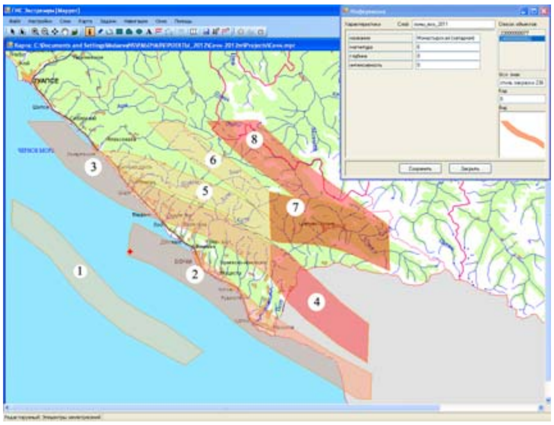

Figure 5.2. Possible earthquakes source zones (Rogozhin, 2011)

Table 5.1 lists the characteristics of possible earthquake source zones shown on Fig.5.1.

Table 5.1. Parameters of possible earthquake source zones (Fig.5.1)

Number of zones	Name of zone	M_{max}	h, km	I_{max}
1	Sochinskaya	6.0	>10	8-9
2	Pshekhsko-Adlerskaya	5.5	5	6-7
3	Verkhnemzymtinskaya	6.5	>10	7-8
4	Mzymtinsko-Tyrnayzskaya	7	>15	7-8

Table 5.2 lists the characteristics of possible earthquake source zones shown on Fig.5.2.

Table 5.2. Parameters of possible earthquake source zones (Fig.5.2)

Number of zones	Name of zone	M_{max}	h, km	Type of displacement
1	Chernomorskaya (west)	5.5	10	thrust
2	Sochinskaya	6.0	15	thrust
3	Monostyrskaya (east)	6.5	15	thrust
4	Monostyrskaya (west)	6.0	15	thrust
5	Krasnopolyanskaya (west)	5.5	10	thrust
6	Bekishejskaya	5.5	10	thrust
7	Krasnopolyanskaya (east)	7.3	20	slip
8	Glavnogo khrebta	6.5	15	thrust

Expected damage to build environment and human casualties were estimated for the worst scenarios under the condition that 95 % of population is inside buildings. Computations were carried out with special GIS code, which was developed for the City and described in section 4. As input parameters the coordinates, magnitude and depth were chosen for two nearest source zones: Sochinskaya (M_{max}=6; h=15 km) and Monostyrskaya, west ((M_{max}=6; h=15 km). Coordinates of the first scenario event in the Sochinskaya zone is φ=43.62°N; λ= 39.46°E and the second event in the Monostyrskaya one is φ=43.40°N; λ= 40.33°E. For the computation of shaking intensity distribution the macroseismic field formula proposed by Shebalin (Shebalin, 1968) was used

$$I = bM - \nu \lg \sqrt{\Delta^2 + h^2} + c\,, \qquad (5.1)$$

where Δ - epicentral distance (km); h - source depth (km); M – magnitude. Regional coefficients were taken as b = 1.48; ν = 3; c = 4; k=2.73 according to (Lutikov, 1985).
Scenario earthquake consequences were estimated according to (Methods…, 2000) for three variants: variant 1- level of seismic hazard is taken according to the map of review seismic zonation; variant 2 - level of seismic hazard is taken according to the map seismic microzonation of the Big Sochi territory for return periods of earthquakes: T= 500 years (OSR-1997A); variant 3 - level of seismic hazard is taken according to the map seismic microzonation of the Big Sochi territory for return periods of earthquakes: T= 1000 years (OSR-1997B).
Table 5.3 and Fig. 5.3-5.4 show the results of scenario earthquake loss computations from Sochinskaya zone.

Table 5.3. Extent of areas with different damage state due to scenario event in Sochinskaya zone

No. of variant	City districts with no damage км^2/ %	City districts with damage км^2/ %	Extent of different damage rate for damaged districts				
			d=1 км^2/ %	d =2 км^2/ %	d =3 км^2/ %	d =4 км^2/ %	d =5 км^2/ %
Variant 1	21/62	13/38	11/85	2/15	-	-	-
Variant 2	20/59	14/41	9/65	4/28	0.9/6	0,1/1	-
Variant 3	13/38	21/62	11/52.5	6/29	3/14	0,9/4	0,1/0.5

Table 5.4. Extent of areas with different damage state due to scenario event in Monastyrskaya zone

No. of variant	City districts with no damage км^2/ %	City districts with damage км^2/ %	Extent of different damage rate for damaged districts				
			d=1 км^2/ %	d =2 км^2/ %	d =3 км^2/ %	d =4 км^2/ %	d =5 км^2/ %
Variant 1	26/74	8/26	4/50	4/50	-	-	-
Variant 2	23/67	11/33	5,9/54	4/36	1/9	0,1/1	-
Variant 3	17.7/52	16.3/48	8,6/53	4/24,5	2,7/16,5	1/6	-

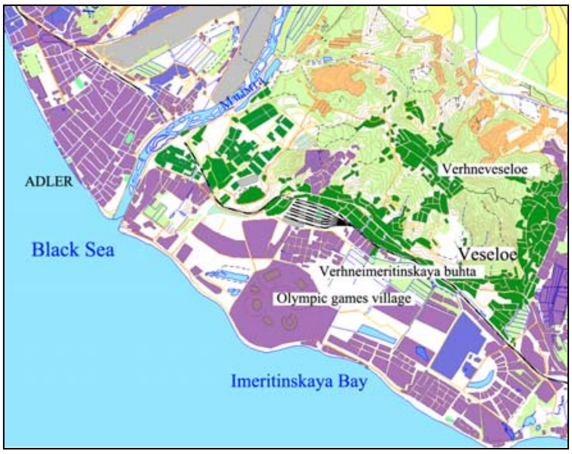

Figure 5.3. Scenario event consequences: variant 1 (Table 5.3)

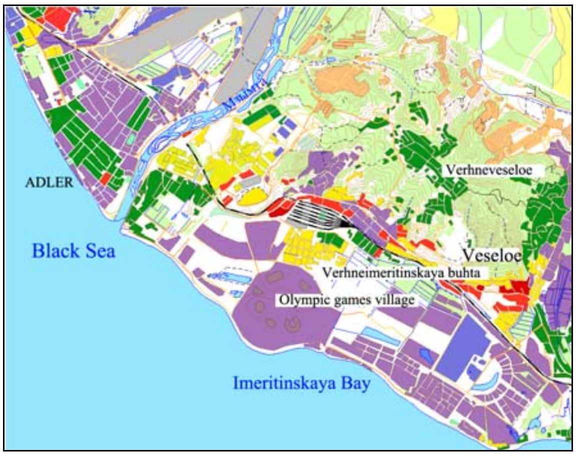

Figure 5.4. Scenario event consequences: variant 3 (Table 5.3)

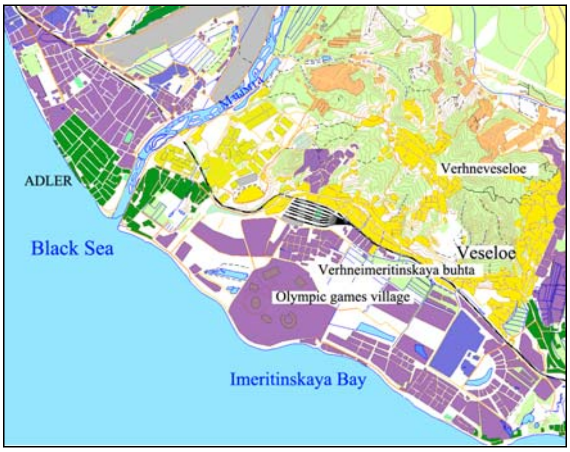

Figure 5.5. Scenario event consequences: variant 1 (Table 5.4)

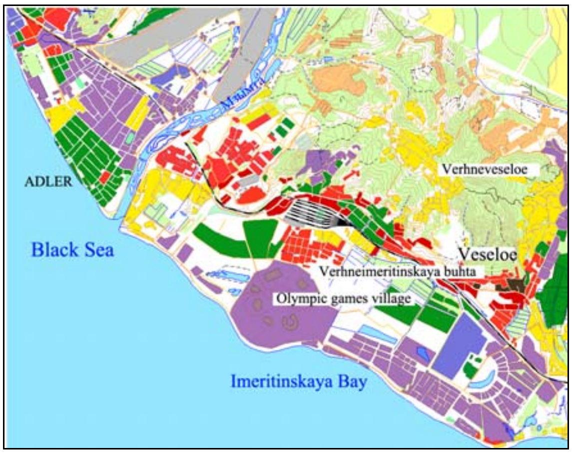

Figure 5.6. Scenario event consequences: variant 3 (Table 5.4)

When estimating scenario event consequences at urban and facility levels, the damage and loss resulting from secondary accidents triggered by earthquakes (Methods…, 2002) is also taken into account. Fig. 5.7 shows the results of possible consequences simulation of chemical hazmat release at industrial facility. By different colors the contaminated zones' boundaries are shown for different time intervals from 1 hr up to 4 hrs. Table5.5 shows the results of possible consequences simulation of chemical hazmat release for two most dangerous and probable events in the case of strong earthquake in Sochi City.

Table 5.5. Possible consequences of chemical hazmat release for two scenario accidents: most dangerous and probable events

Facility	Sochi Fishery Plant	Adler Water Supply System
Type and amount of chemical hazmat	Ammonia, 2 tons	Chlorine, 0.3 tons
Estimated frequency of accidents, /year	$1 \cdot 10^{-5}$	$1 \cdot 10^{-4}$
Size of the contaminated area, km^2	0.82	0.3
Expected fatalities, persons	28	2
Expected casualties, persons	224	16
Expected damage, thousands rubles	120,000	321

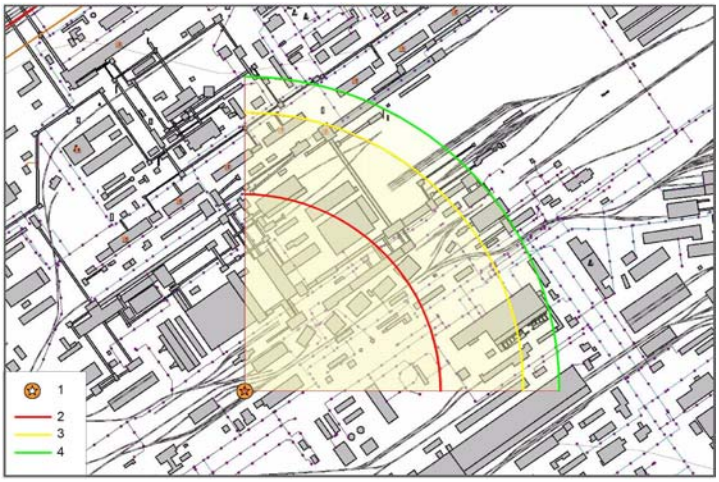

Figure 5.7. Simulation of possible contaminated zones in the case of an accident with chemical material release: 1 –source of release of 0.3 tons liquid chlorine; 2 – after 1 hrs; 3 – after 3 hrs and 4 – after 4 hrs.

In the case of critical facilities like oil or gas pipeline systems in the vicinity of the urban territories possible ecological risk is also estimated. Possible water and air pollution, as well as land contamination are taken into account. The oil pipeline route “Tikhoretsk-Tuapse” belonging to “Chernomorsktransneft” has the length of about 250 km (Fig. 5.8).

Figure 5.8. Oil pipe line system “Tikhoretsk – Tuapse”

The most hazardous for Sochi City segment of the oil pipe line route is between 227 and 248 km. In the case of the pipe failure in this segment the oil may propagate to the rivers Chilipsi or Tuapse and through rivers to the Black Sea. In the case of pipe failure at the point 236 km the maximum volume of oil which may reach the Sea taking into account the operation of emergency shutdown systems was estimated to be equal to 615 tons. Taking into account prevailing wind and water streams’ direction the north - western part of the Big Sochi City may be contaminated along the beach and the estimated extension may reach 15-20 km.

CONCLUSIONS

The present paper describes the results of seismic risk assessment at urban level taking into account secondary technological accidents. The Big Sochi City territory, resort located in the Black Sea shore in the Krasnodar area and the venue of the future Olympic Games in 2014, is considered as a case study. Examples of scenario earthquake computations for few possible source zones are given.
The estimations of seismic risk and scenario events consequences are used for planning and implementing preventive measures, aimed at saving lives and protecting property against future disastrous events as well as for monitoring critical facilities including oil pipe line routes located in the earthquake prone areas. The results also allow effective emergency response plans to be developed taking into account possible scenario events.

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