Seismic and Integrated Risk Assessment and Management with Information Technology Application

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SUMMARY:
Assessment of expected loss and damage caused by natural hazards and secondary technological accidents are of primary importance for development and implementation of preventive measures plans, as well as for emergency management just after the disaster. The paper addresses the procedures for estimations of loss caused by natural and secondary hazards with information technology application. Examples of integrated natural and seismic risk zoning at Russian federal and regional levels are given, as well as that of scenario earthquakes consequences estimation taking into account secondary technological hazards.

Keywords: natural and seismic risk assessment, secondary technological accidents, information technology

1. INTRODUCTION

Natural hazards, including earthquakes are becoming more devastating, especially, when they occur in industrialized regions. Social and economic losses due to those events and secondary processes triggered by them, increase annually, which is definitely in relation with the evolution of society. Hazards identification and analysis, as well as risk assessment and mapping, are the first steps in prevention strategy aimed at saving lives and protecting property against future events. The paper addresses methodological issues of natural and seismic risk assessment and mapping taking into account technological accidents at fire, explosion and chemical hazardous facilities triggered by strong seismic events. Special GIS environments are usually developed for risk assessment and mapping at different levels. Examples of risk zoning taking into account secondary technological hazards for the population of the Russian Federation and for the Krasnodar and Stavropol regions are given, as well as consequences estimation for recent M= 6.1 earthquake in the South Eastern Siberia.

2. THE METHODOLOGICAL ISSUES OF RISK ASSESSMENT

The section describes the procedures for risk assessment created by earthquakes and other natural hazards, as well as integrated natural and seismic risk assessment taking into account secondary technological accidents. For estimation of risk indexes and risk mapping, the probabilistic approach is used.

For seismic risk assessment the authors follow the concepts proposed and agreed upon by UN and other experts in the field (Karnik V. *et al*., 1978; Fournier d'Albe, 1982, 1986; Karnik Vit, 1984; Boissonnade A. and Shah H., 1984; Mitigating ..., 1991; Dolce M. *et al*., 1995; UNISDR...., 2009; Risk..., 2010).

Individual risk R_e due to any hazard is determined as the probability of death and/or injuries and/or economic loss for persons due to potential hazard within one year at a given place. Individual seismic risk R_s is the product of hazard H and vulnerability V_s. Vulnerability of population to seismic action of a given intensity is understood here as the ratio between the number of persons expected to be affected by fatalities, injuries, losses of property and the total number of persons living in a certain type of buildings (Larionov and Frolova, 2003a). Individual seismic risk R_s (Bonnin *et al*., 2002; Bonnin and Frolova, 2004; Frolova *et al*., 2003, 2011; Larionov *et al*., 2003b; Methods.., 2000) may be determined through mathematical expectation of social losses, which include fatalities, injuries and persons who lost their property, $M(N)$, taking into account the number of inhabitants N in the considered settlement and probability of seismic event H

$$R_s = H \cdot V_s\ (I) = H \cdot M(N\ )\ /\ N \tag{2.1}$$

where - $V_s(I)$ is the vulnerability of population in the considered settlement; - H is the probability of seismic event occurrence *per* one year; - N is the number of inhabitants in the considered settlement.
The mathematical expectation of social losses $M(N_j)$ in certain j type of buildings for the considered settlement taking into account inhabitant migration in the buildings of j type during day and night is determined by Eqn.2.2

$$M(N_j) = g(t) \iint\limits_{S_c} \int\limits_{I_{min}}^{I_{max}} P_{C_j}(I\ ) \cdot f(x, y, I) \cdot \Psi_j(x, y) \cdot dIdxdy \tag{2.2}$$

where - $I_{\min}$ and $I_{\max}$ are the maximum and minimum possible seismic intensities; S_c is the settlement area; $P_{Cj}(I)$ is the probability of fatalities, injuries and persons having lost their property, under the condition of damage to buildings of j type due to earthquake with intensity I; $\psi_j(x,y)$ is the density of population distribution within the considered area in buildings of j-type; $f(x,y,I)$ is the density function of earthquakes' intensity probabilities within the unit area with coordinates x, y; $g(t)$ is the function obtained on the basis of statistical analysis of data on population migration over 24 hours. Computations of $P_{Cj}(I)$ are carried out using Eqn. 2.3

$$P_{Cj}(I) = \sum_{i=1}^{5} P_{Bi}(I) \cdot P\ (C_j | B_i) \tag{2.3}$$

where - $P_{Cj}(I)$ is the probability of people to be impacted during the earthquake of intensity I; - $P_{Bi}(I)$ is the probability of definite damage state i of buildings submitted to earthquake intensity I; - $P(C_j|B_i)$ is the probability of people to survive j level of impact under the condition that the building survived the damage state i (five damage states are considered here, from i=1 [slight damage] to i=5 [total collapse]).
The computations of $P_{Cj}(I)$ are usually done for buildings and structures types classified according to MMSK-86 scale (Shebalin *et al*., 1986): buildings' type A (local materials); 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). MMSK-86 and EMS-98 are originated from MSK-64 and the expert estimation of different building types according to MMSK-86 and EMS-98 was undertaken in order to have possibility of comparison of different vulnerability functions.
The mathematical expectation of social losses $M(N)$ due to earthquakes in damaged and collapsed buildings for the considered settlement, taking into account inhabitant migration in the buildings of all types during day and night, is determined by equation

$$M(N) = \sum_{j=1}^{n} M(N_j) \tag{2.4}$$

where - n is the number of considered building types according to MMSK-86 scale.
Individual risk due to landslides, mud flows, floods, storms, avalanches may be determined using statistical data on consequences due to these processes for the area under study, using Eqn. 2.5

$$R_{ei} = H \cdot P, \tag{2.5}$$

where - $\boldsymbol{R_{ei}}$ is the individual risk due to i-th emergency situation caused by natural hazard;
- H is the probability of natural hazards *per* one year;
- P is the probability of unfavorable event under the condition that natural hazard occurred. Dimension of individual risk is 1/year.
Integrated natural individual risk (R_e) may be determined (Methods…, 2002; Frolova et al., 2007) taking into account the probability of death and/or injuries and/or economic loss for population, due to all possible natural hazards within one year in the area under consideration applying Eqn. 2.6

$$R_e = 1 - \prod_{i=1}^{n} (1 - R_{ei}), \tag{2.6}$$

where - n is the number of considered natural hazards;
- R_{ei} is the individual risk due to i-th natural hazard.
In the present study, for estimating integrated natural risks from earthquakes, landslides, mud flows, floods, storms, avalanches, assumption is made that all these events are independent.
Collective risk due to natural hazards R_{ec} is determined as the expected number of casualties, both fatalities and injuries, as well as the number of people who lost their property as a result of natural hazards' occurrence *per* year.

$$R_{ec} = R_e \cdot N, \qquad (2.7)$$

where - R_e is the integrated individual risk due to natural hazards under consideration, N is the number of inhabitants in the area under study.

At regional and urban levels secondary consequences resulting from technological accidents (fires, explosions, release of chemical materials) triggered by earthquakes, are estimated in few steps: 1. Critical facilities with storage of different hazardous materials (fire, explosion and chemical hazardous substances) are identified; 2. Distribution of shaking intensity is simulated for given parameters of scenario earthquake; 3. Field of impact factors, such as excessive pressure, combustion temperature, concentration of chemical hazardous materials, are constructed taking into account wind direction, air temperature and pressure, wind velocity and others factors; 4. Probability is estimated that the critical facility will survive damage state above threshold value; 5. Social loss and individual risk are estimated in the case of technological accidents triggered by earthquake, according to Eqn. 2.8 and 2.9.

Individual risk R_{ei} in the case of an accident at fire and explosion hazardous facilities (Methods…, 2002) is determined by

$$R_{ei} = \frac{1}{N}\sum_k H_k \sum_j \iint_S E_{kj}(x,y)\cdot P_j(x,y)\cdot \psi(x,y)\cdot dx\cdot dy\,. \qquad (2.8)$$

where - H_k is the probability of accident *per* year according to scenario k (fires, fire balls, explosions and other phenomena may be considered as scenario events); $E_{kj}(x,y)$ is the probability of impact mechanism j in the point (x,y) for the accident scenario k (as impact mechanism the following factors could be considered: heat effect on population, shock wave, debris of buildings and constructions, and others); $P_j(x,y)$ is the probability of fatality in the point with coordinates (x,y) under the condition that impact mechanism j is realized; $\psi(x,y)$ is the density of population distribution in the vicinity of the point with coordinates (x, y); N is the number of people within the zone of risk; S is the area within which people may be impacted in the case of the accident (*i.e.* the zone of risk).

Individual risk R_{ei} in the case of an accident at chemical hazardous facility (Methods…, 2002) is determined by

$$R_{ei} = \frac{H}{N}\iint_S \int_0^{2\pi} \int_{V_{\min}}^{V_{\max}} f(a,V)\cdot P[Д(x,y)]\cdot \psi(x,y)\cdot dV\cdot da\cdot dx\cdot dy, \qquad (2.9)$$

where - H is the probability of accident *per* year; N is the number of inhabitants; S is the area within which the people may be impacted in the case of an accident at a given facility; $\pi = 3{,}14$; V_{min} and V_{max} are minimum and maximum possible values of wind velocity; $f(a,V)$ is the density function of probability of wind direction a and wind velocity V; $\psi(x,y)$ is the density of population distribution in the vicinity of the point with coordinates (x, y); $P[Д(x,y)]$ is the probability of the population to be impacted by toxic dose in the point with coordinates (x, y); $Д(x,y)$ is the toxic dose, which is determined under time-dependent concentration of chemical hazardous material at a point with coordinates (x, y) by Eqn. 2.10

$$Д(x,y) = \int_{t_n}^{t_k} \Omega(x,y,t)\cdot dt, \qquad (2.10)$$

where - $t_n \ldots t_k$ is the time interval within which the concentration of chemical substance is dangerous; $\Omega(x,y,t)$ is the concentration of the chemical hazardous substance in atmosphere for the point with coordinates (x,y).

Integrated individual risk $R_e(x,y)$ due to earthquakes and secondary technological accidents (Methods…, 2000, 2002; Frolova *et al.*, 2007) is determined by Eqn. 2.11

$$R_e(x,y) = 1 - \prod_{i=1}^{n}\left[1 - R_{ei}(x,y)\right] \qquad (2.11)$$

where - n is the number of considered emergencies; $R_{ei}(x,y)$ is the individual risk due to i-th emergency situation.

3. SPECIAL GIS PROJECT FOR RISK ASSESSMENT AND MAPPING AT COUNTRY LEVEL

In order to estimate risks and construct maps for the Russian Federation territory, special GIS environment was developed (Frolova et al., 2010). It includes data bases with information describing

the Russian Federation territory, software assigned for hazard and risk indexes' assessment, interface which allows to create thematic maps and text report according to specified forms.
The databases contain information describing the geographical situation of the territory, its structure, main landmarks and boundaries' shape. The main sources of information are digital and paper maps of average scales, thematic maps with description of zones characterized by different levels of natural hazards, statistical data about natural hazards' impact.
Thematic information about landslides, mud flows, floods, storms, avalanches is presented as vector digital maps, with detailed description of zones characterized by different hazard levels and recurrence period. Information is developed by the laboratories of geological risk and geoinformatics and computer mapping of IGE RAS. Maps of review seismic zoning of Russian Federation RSZ-97, scale 1:8000000, developed by Institute of Physics of the Earth RAS (http://seismos-u.ifz.ru/zoning.htm) were used as source of information about seismic hazard levels. Fig.3.1 shows the special GIS screen used to visualize different natural hazards; Fig.3.2 shows integrated indexes of natural hazards for the Russian Federation territory.

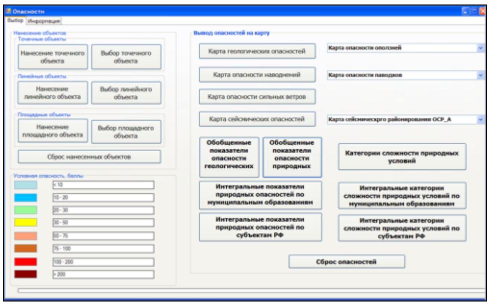

Figure 3.1. Screenshot of the special GIS for natural hazards visualization

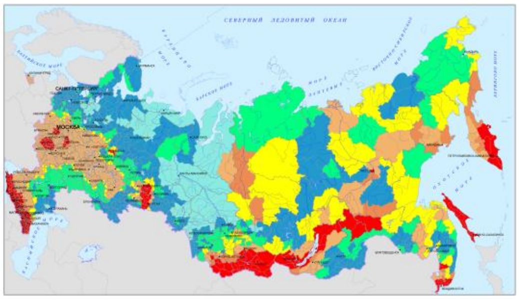

Figure 3.2. Map of integrated natural hazard for the territory of the Russian Federation

The GIS project includes also an impact database which was developed by the laboratory of seismic risk of IGE RAS. It contains brief descriptions of consequences of emergencies caused by natural and technological hazards during the last 20 years, from 1991 up to 2010, in the Russian Federation.
The software of GIS project for the Russian Federation includes three blocks used for data management, computation of risk indexes and visualization of space information, on the screen, as thematic maps fixed scales. For computations at regional and urban levels the corresponding GIS environment is further developed. Examples of risk estimations and mapping at different scales are given below.

4. RISK ASSESSMENT AT DIFFERENT LEVELS

Earthquakes, floods, storms, landslides, mud flows and avalanches are the most hazardous natural processes in the Russian Federation, which may results in casualties and economic loss. The estimations of seismic and integrated natural risks were made for the administrative areas of the Russian Federation.
The results of integrated natural and seismic risk assessment taking into account secondary hazards are essential (practical) input for planning and implementing preventive measures at national and local authority levels, as well as actions to be taken by the Ministry of the Russian Federation for Civil Defense, Emergencies and Elimination of Consequences of Natural Disasters (EMERCOM of Russia) just after the occurrence of a strong earthquake and other organizations, like TRANSNEFT JSC taking into account the fact that at present, in Russia, existing and under-construction oil pipe routes cross the earthquake prone areas with high level of seismicity.

4.1. Seismic Risk Assessment and Mapping at Federal Level

The procedure described above was used for computation of individual risk for the territory of the Russian Federation with application of special GIS environment. Values of seismic risk obtained for separate cities and settlements were averaged within the administrative divisions of the country. Three maps of individual seismic risk were constructed: R_s1 – probability of fatalities; R_s2 – probability of fatalities and injuries; R_s3 - probability of fatalities, injuries and economic loss for population due to occurrence of earthquakes within one year. Fig. 4.1 shows the map of individual seismic risk zoning R_s1 (probability of fatalities). Values obtained for individual seismic risk vary from negligible, close to zero, up to rather high values: more than $30 \cdot 10^{-5}$ for the probability of fatalities (map R_s1); more than $100 \cdot 10^{-5}$ for the probability of fatalities and injuries (map R_s2); more than $150 \cdot 10^{-5}$ for the probability of fatalities, injuries and economic loss to population caused by earthquakes *per* year (map R_s3). Table 2 shows extent of zones with different levels of individual seismic risk according to maps R_s1, R_s2 and R_s3.

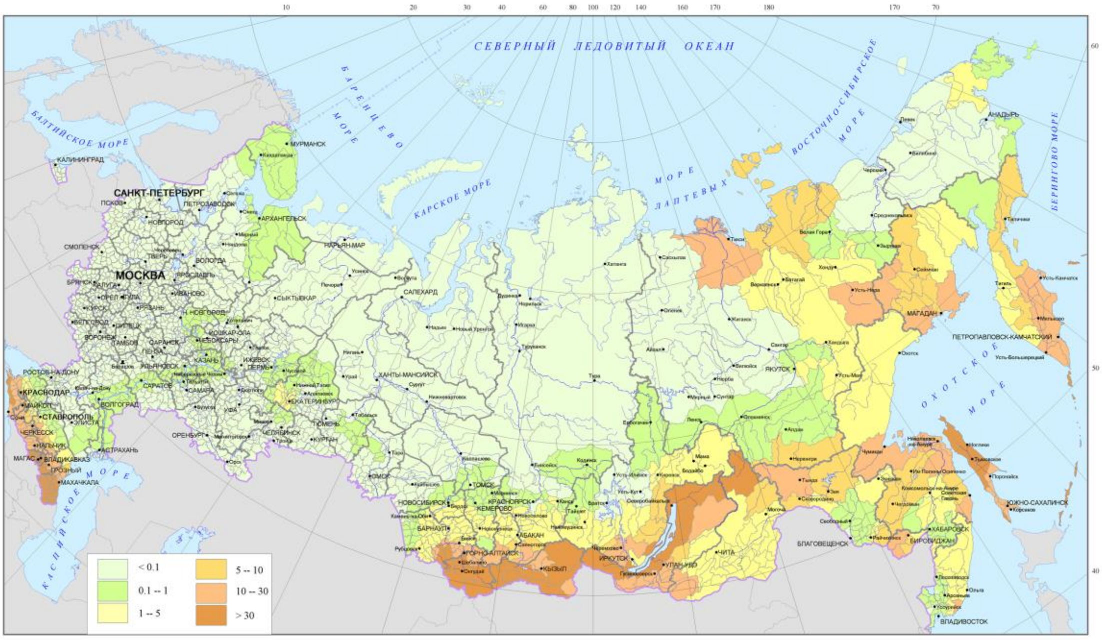

Figure 4.1. Map of individual seismic risk R_s1, 10^{-5} /year, for the territory of Russian Federation

The computed values of individual seismic risk R_s1 are more than $30 \cdot 10^{-5}$/year for all administrative divisions within Sakhalin area, Republic of Altay, Tuva, Dagestan and Northern Osetia. The highest values of individual seismic risk R_s3 are obtained for Kamchatka, near lake Baikal, Republic of Buryatia, Irkutsk region, Altay kray, as well as for Krasnodar region and Chechen Republic.

Table 4.1. Values of individual seismic risk and extent of zones with different risk levels

Risk ranges, 10^{-5}/year	Qualitative risk characteristics	Extent of zones, map R_s1		Extent of zones, map R_s2		Extent of zones, map R_s3	
		10^6 km^2	%	10^6 km^2	%	10^6 km^2	%
< 0.1	small	8.8	53	8.1	49	7.6	46
0.1 – 1.0	moderate	2.5	15	2.9	17	2.2	13
1.0 – 5.0	average	2.4	14	1.5	9	1.9	11
5.0 – 10.0	high	1.2	7	1.4	8	0.9	5
10.0 – 30.0	rather high	1.2	7	1.5	9	1.8	11
30.0 – 100.0		0.5	3	1.1	7	1.6	10
100.0 – 150.0	extremely high	-	-	0.1	1	0.2	1
> 150.0		-	-	-	-	0.4	2

4.2. Integrated Risk Assessment and Mapping at Federal Level

Individual risks from separate natural hazards (landslides, mud flows, floods, storms, avalanches) were computed according to Eqn. 2.5 using regional empirical data about each hazard consequences over the last 20 years. Integrated individual risk from all considered six hazards (earthquakes, landslides, mud flows, floods, storms, avalanches) was computed according to Eqn.2.6. Three maps of integrated individual natural risk were constructed: R_e1 – probability of fatalities; R_e2 – probability of fatalities and injuries; R_e3 - probability of fatalities and injuries, economic loss for population due to six hazards within one year. Three maps of integrated collective natural risk were constructed as well: $R_{ec}1$ – expected number of fatalities due to six hazards *per* year; $R_{ec}2$ – expected number of fatalities and injuries due to six hazards *per* year; $R_{ec}3$ – expected number of fatalities and injuries, as well as those who lost their property due to six hazards *per* year. Fig. 4.2 shows the map of integrated individual natural risk zoning R_e3: probability of fatalities, injuries and economic loss to population due to six hazards within one year.

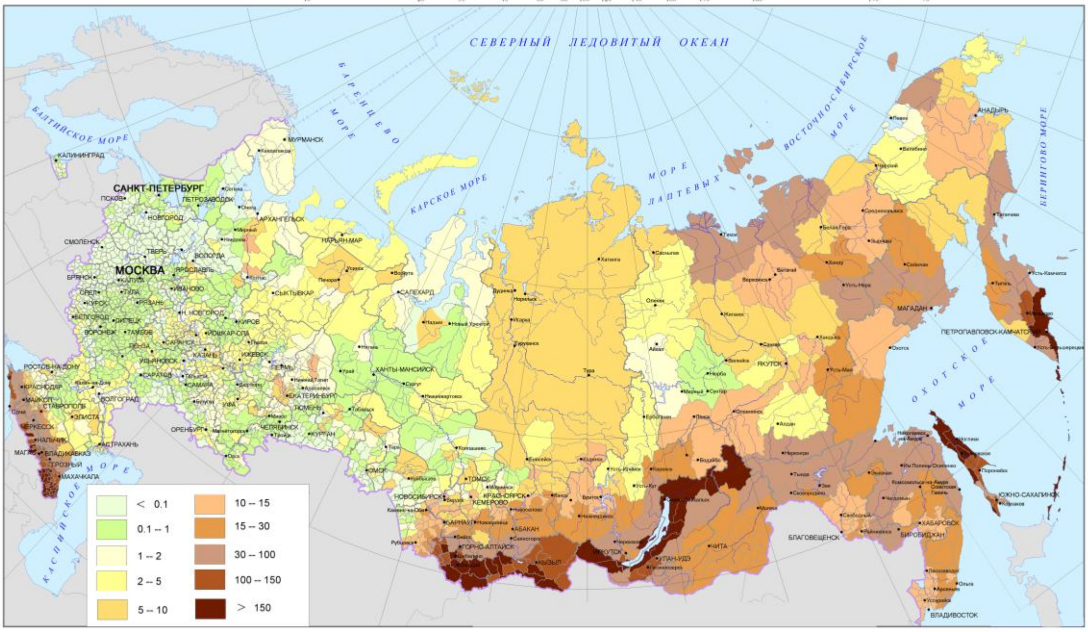

Figure 4.2. Map of integrated individual natural risk $R_{e}3$ for the territory of Russian Federation

Obtained values of integrated individual natural risk vary from negligible, close to zero, up to rather high values – more than $30 \cdot 10^{-5}$ for the probability of fatalities (map $R_{e}1$); more than $100 \cdot 10^{-5}$ for the probability of fatalities and injuries (map $R_{e}2$); more than $150 \cdot 10^{-5}$ for the probability of fatalities, injuries and economic loss for population caused by six hazards *per* year (map $R_{e}3$). Table 4.2 shows extent of zones with different levels of integrated individual natural risk according to maps $R_{e}1$, $R_{e}2$ and $R_{e}3$.

Table 4.2. Values of integrated natural risk and extent of zones with different risk levels

Risk ranges, 10^{-5}/year	Qualitative risk characteristics	Extent of zones, map $R_{e}1$		Extent of zones, map $R_{e}2$		Extent of zones, map $R_{e}3$	
		10^6 km^2	%	10^6 km^2	%	10^6 km^2	%
> 0,1	small	7.9	48	5.7	34	1	6
0,1 – 1	moderate	3.3	20	5	30	1.9	11
1 – 2	average	0.9	5	0.5	3	1.6	10
2 – 5		1.6	10	1.2	7	2.6	16
5 – 10	high	1.1	7	1.4	8	3.5	21
10 – 15	rather high	0.5	3	0.4	2	1.6	10
15 – 30		0.7	4	1.1	7	1.6	10
30 – 100	extremely high	0.6	4	1.2	7	2.1	13
100 – 150		-	-	0.1	1	0.2	1
< 150		-	-	-	-	0.5	3

The highest values of integrated individual natural risk $R_{e}1$ are obtained for the same areas as for individual seismic risk: Kamchatka, near lake Baikal, Republic of Buryatia, Irkutsk region, Altay kray, as well as for Krasnodar region and Chechen Republic. It could be explained by the fact that among the six natural hazards considered, earthquakes more often result in fatalities in comparison with landslides, mud flows, floods, storms, avalanches. In other words, seismic risk is dominant. In Sakhalin, Republic of Altay, Tuva, Dagestan, Northern Ossetia computed values of $R_{e}1$ exceed 30-$40 \cdot 10^{-5}$/year for 70% of the territory of their administrative divisions.

The highest values of integrated individual natural risk $R_{e}3$ are obtained for Kamchatka, Republic of Altay, Krasnodar area, Baikal area, Republics of Buryatia and Tuva, Sakhalin and Northern Ossetia.

Fig. 4.3 illustrates the contribution of earthquakes to the integrated individual natural risk $R_{e}1$ in Siberia region. Contribution of hazards to integrated risk $R_{e}1$ is shown at the centres of administrative divisions by circles: red color – contribution of earthquakes; blue color – contribution of landslides, mud flows, floods, storms, avalanches. Fig. 4.4 shows the distribution of $R_{e}3$ values for administrative regions of the Trans-Baikal area.

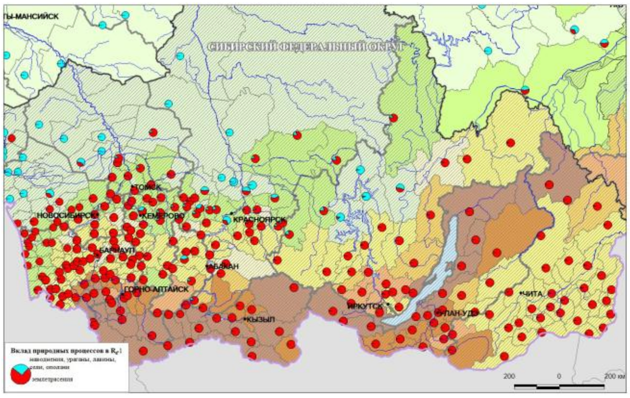

Figure 4.3. Contribution of earthquakes and other hazards to R_e1 for the Siberian federal area

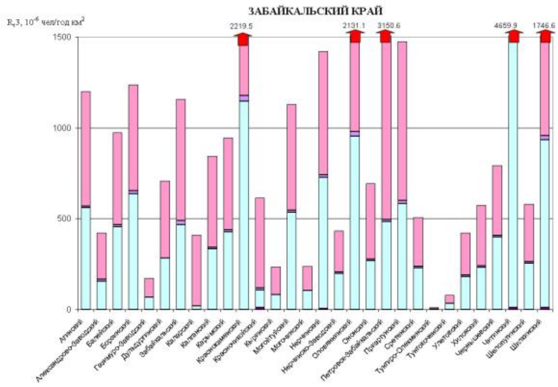

Figure 4.4. Distribution of R_e3 for the Trans-Baikal administrative divisions

4.3. Seismic Risk Assessment and Mapping at Regional Level

For the Krasnodar and Stavropol regions, which are characterized by rather high level of seismic hazard (tables 2 and 3) and high density of population, the loss computations were done at regional level. For individual seismic risk assessment and mapping at regional scale the information about population and building stock distribution in these regions were updated. The maps of population density distribution were complied. The detailed inventory data obtained during last years by the Extreme Situations Research Center and data on built environment provided by the Regional Department of Emercom of Russian Federation was used to develop the building stock models for about thousand settlements in threes regions. The averaged models, characterized by percent of buildings of different types and their height, were used for other settlements. The parameters of regional vulnerability functions, as well as laws of earthquake impact on population were verified for the Krasnodar and Stavropol regions. The table 4.3 shows size of zones subjected to different seismic hazard levels according to the maps OSR-97.

Table 4.3. Size of zones with different level of seismic hazard in the Krasnodar and the Stavropol regions according to the maps OSP-97

OSR-97	Sizes of zones in km^2 with different level of seismicity and % to the whole area								
	Krasnodar region					Stavropol region			
	I=6	*I*=7	*I*=8	*I*=9	*I*=10	*I*=6	*I*=7	*I*=8	*I*=9
OSR-97-A	26,570 31.93%	28,270 33.97%	28,370 34.09 %	-	-	31,930 48%	21,160 32%	9,650 15 %	-
OSR-97-B	19,150 23,01 %	25,170 30,245 %	25,590 30,75 %	13,310 15,99 %	-	25,680 39 %	23,310 35 %	16,170 24 %	-
OSR-97-C	806.2 0,96 %	26 ,50 31,9 %	23,320 28,02 %	27,400 32,92 %	5,135 6,17 %	5,100 8 %	30,370 46 %	20,400 31 %	10,26 15 %

Estimation of individual seismic risk for the population of the Krasnodar and Stavropol regions was carried out according to the procedure described above for worst scenarios when earthquakes occurred during night time. In order to estimate expected social losses within cities and towns, they were divided into unit sites. Then indexes obtained for each unit site were summed up. The regional maps of seismic risk zoning (Fig. 4.5 and 4.6) include two elements: risk for settlements with number of inhabitants less than 1,000 and risk for settlements with number of inhabitants more than 1,000. The hypsometric scale is used to represent both elements on the map. When constructing isolines, the value of risk was computed in the points which are the geometric centers of settlements and then the risk values were averaged within the unit sites. The method of bilinear interpolation was used to construct the isolines and identify the color of corresponding zones. The results of seismic risk computations for these regions (Fig. 4.5 and 4.6) are presented by signs (circles of different size and color) for big cities and towns and by hypsometric layers for small settlements with number of inhabitants less that 1,000 people.
The computations of seismic risk for the Krasnodar and Stavropol regions were made taking into account possible accidents at fire, explosion and chemical hazardous facilities.

Figure 4.5. Map of seismic risk $R_{st}1$, 10^{-5} /year zoning for the territory of the Krasnodar region, taking into account technological accidents triggered by earthquakes

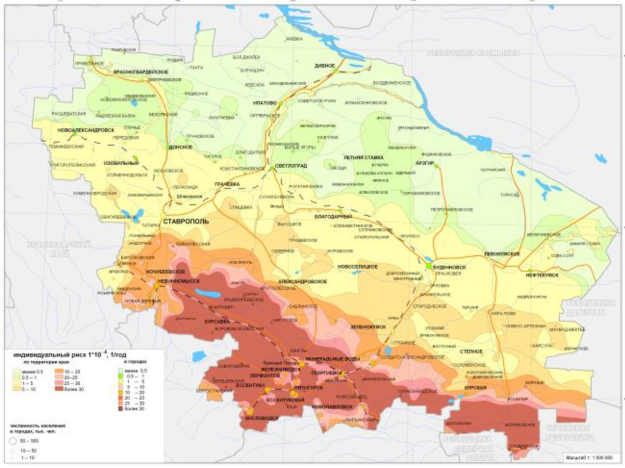

Figure 4.6. Map of seismic risk $R_{st}1$, 10^{-5} /year zoning for the territory of the Stavropol region, taking into account secondary technological accidents

Obtained values of seismic risk for the Krasnodar and Stavropol regions (Fig. 4.5 and 4.6) vary from negligible values up to rather high ones equal to $40.2\cdot10^{-5}$. On the whole for more that 40 % of the Krasnodar region territory and about 30% of the Stavropol region territory the values of seismic risk computed taking into account the secondary technological accidents exceed the value equal to $1.0\cdot10^{-5}$. High level of individual seismic risk for these regions results from relatively high seismic activity of the area under consideration and lack of earthquake resistant measures of the existing building stock.

4.4. Earthquake Consequences' Estimation

The reliability of loss estimation strongly depends on regional parameters of simulation models used in the GIS- based systems at all stages from modeling shaking intensity to assessing the damage to different elements at risk, as well as on data bases used in such systems. The influence of regional peculiarities of shaking intensity attenuation is shown on the example of the October 14, 2011 earthquake in the South Eastern Siberia. The event with M_s=6.1 occurred at 16:10 of local time and was widely felt in Amur area, Russia, as well as in separate parts of China and Mongolia. In the settlement Bam closest to the epicenter the buildings of the type *B* according to MMSK-86 scale in general survive the damage state *d*= 2 and 3, the observed shaking intensity was equal to *I*= 7-8, the partial collapse was observed for electric power substation facilities which resulted in serious accident with a short circuit and fire. The damage states *d*=2-3 for building types *A* and *B* , as well total collapse of chimneys were prevailing in the settlement Solnechnyj (*I*=7). In Takhtymygda the macroseismic effect reached *I*= 6-7, damage state *d*=2 of the building type *B* was prevailing. In the largest town Skovorodino about 20 km from epicenter, damage states *d*=1 and 2 in building type B and *d*=1 in building type C were prevailing. The electric equipment of the Eastern Siberia – Pacific Ocean oil pipe line route was damaged. TRANSNEFT JSC has suspended oil exports to China via a branch, which is near Skovorodino.

For the computation of the October 14, 2011 event consequences the macroseismic field formula proposed by Shebalin (Shebalin, 1968) was used

$$I = bM - \nu \lg \sqrt{\Delta^2 + h^2} + c, \qquad (4.1)$$

where Δ - epicentral distance (km); *h* - source depth (km); *M* – magnitude. As input data were taken the source parameters determined by GS RAS: M_s=6.1; h=15 km; epicenter coordinates φ= 54.04°N; λ= 123.77°E (http://www.ceme.gsras.ru), as well as two sets of regional coefficients in Eqn.4.1 and different ratios of ellipse major and minor semi-axis. Different orientation of elliptical macroseismic field was taken into account: along existing faults and at angles corresponding to the source mechanism solution.

Fig. 4.7 shows the comparison of simulated shaking intensities with different input data and the observed values. For the first three variants (b = 1.4; ν = 4; c = 4; k=1.5 and angles equal to 109° and 281°) $\Delta I_{average}$=0.6 -0.8 grade and σ=0.7-0.8; for the rest four variants (b = 1.6; ν = 4.5; c = 3.3; k=2-3 and orientation along faults) $\Delta I_{average}$=0.2 -0.4 grade and σ=0.4-0.6.

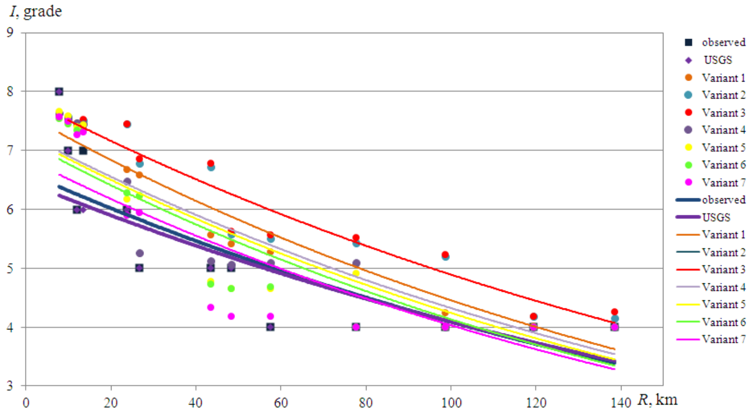

Figure 4.7. Comparison of simulated and observed shaking intensities

Fig. 4.8 shows the results of simulation of the October 14, 2011 earthquake: variant 7. Dots are settlements in the stricken area; colour of dots stands for the average damage state of building stock: black -total collapse, brown - partial collapse, red - heavy, yellow -moderate, green - slight damage, blue - no damage.

Figure 4.7. Results of possible losses assessment due to October 14, 2011 earthquake in Russia

The results of the damage states and shaking intensity distribution simulation proved to be in a good agreement with observed data after the earthquake on October 14, 2011. It should be separately mentioned that the previous study of stability against seismic loads for the linear and areal structures along the oil pipe line route in the Eastern Siberia made by Moscow State Technical University named after N. Bauman within the contract with TRANSNEFT JSC have been confirmed by practice.

5. CONCLUSIONS

The present paper describes the methodological procedures used for the assessment of natural and seismic risk taking into account secondary technological accidents.
Examples of risk assessment at different levels using special GIS environments are given. Influence of regional peculiarities of shaking intensity attenuation on reliability of loss estimations is shown on the example of the October 14, 2011 M=6.1 event in the South Eastern Siberia, Russia.
The estimations of natural and seismic risk obtained are used by EMERCOM of the Russian Federation, as well as by other federal and local authorities, for planning and implementing preventive measures, aimed at saving lives and protecting property against future disastrous events. The results also allow effective emergency response plans to be developed taking into account possible scenario events.

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