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## Socio-economic risk assessment of flooding for Russian coastal regions

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# SOCIO-ECONOMIC RISK ASSESSMENT OF FLOODING FOR RUSSIAN COASTAL REGIONS<sup>1</sup>

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**Abstract.** An increasing number of hazardous natural phenomena is one of the results of climate change for Russia. Risks increase in coastal areas with high concentration of hazards and high density of population and economic activity. In 2012, an integrated damage from floods was about 1 billion euros; floods had caused death of over 200 people. Particularly destructive consequences were for Krymsk in Krasnodar region. The purpose of the work is to estimate the influence of hazardous hydrological phenomena (e.g. floods, groundwater level rise and surges) on sustainable development of coastal regions.

The first stage was to estimate potential damage for population and economy of Kaliningrad and Leningrad regions (the Baltic Sea coastal zone). The authors used methodology of EMERCOM based on the model of direct (loss of life, destruction of buildings, etc.) and indirect effects (loss of profits, loss of the budget, etc.). A database of chosen indicators based on satellite images, maps, statistical yearbooks and reports of entities, was prepared. Maximum direct potential damage for both regions in 2012 was about 15.7 billion euros, but indirect damage was more than 25.5 billion euros. The damage increased with growth of economic activities without proper strengthening of protective infrastructure.

Vulnerability assessment for municipal societies of Krasnodar Region (the Azov and the Black Sea coastal zone) was the second stage. A database, as a matrix of 250 parameters from 2005 to 2010 for 14 municipalities, was developed. The parameters were divided into several blocks according to UNU-EHS methodology: 'exposure' and 'vulnerability', consisting of 'susceptibility', 'coping capacity' and 'adaptive capacity'. Relevant indicators were selected, verified by statistical methods, and sub-indices were calculated. Areas with the highest risks are Slavyansk, Krymsk, Krasnoarmeysk and Temryuk municipal districts. Olympic Sochi has one of the lowest risks, but it is increasing.

Both approaches were integrated using 'field' data (opinion polls, interviews, municipal statistics, etc.). The study was conducted in Slavyansk district, in the Kuban river delta (1-5 m. above sea level). Environmental, economic and social risks with a set of damages were identified. Integrated risk was calculated using GIS and developed formulas:  $R = \sum p_j * D_j$ , where  $R$  – risk,  $p$  – probability,  $D$  – expected damage,  $j$  – flood zone, and  $D_j = \sum d_{li} * V_{ij} * S_j - C$ , where  $d_{li}$  – potential damages per unit of area,  $V$  – vulnerability,  $S$  - area,  $I$  - type of risk,  $i$  - type of damage,  $C$  - costs of preventive measures. The risk is growing and covers new areas.

In Russia, probability growth of hazardous natural events (caused by climate change) coincides with increasing risk of technogenic catastrophes because of errors in planning and underinvestment in protection systems. Sustainable development is limited by these factors.

**Keyword:** social vulnerability, damage and risk assessment, coastal areas, aqua-territorial systems

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## INTRODUCTION

Climate change has a varying intensity in different parts of the Earth. Today the debate is only about the genesis of these changes: natural or anthropogenic. Climate change is already having a direct impact on characteristics of the environment, and therefore affects sustainable development of regions. The greatest impact of climate change in Russia is on aqua-territorial systems.

Coastal zone, which is a type of aqua-territorial systems (ATS), is a natural 'ecotone', or an area of various natural environments interaction. Concentration and diversity of biological communities and speed of natural processes are much higher in natural ecotones. To some extent, due to high rates of the processes, it is also an indicator of the whole biosphere. Geomorphological, hydrological and ecological features of ATS are the factors, which determine concentration of different types of natural hazards (floods, underflooding<sup>5</sup>, surges, landslides, debris flows, etc.) in it.

Due to unique geographical position, coastal areas can perform a variety of functions from 'resource' (mining of raw materials, fishing, etc.) to 'contact' (lower costs of water transport), so they have a higher concentration of population and economic activity. Analysis of Russian large investment projects, announced for the next 5-7 years (Zemtsov, 2011), indicates that most of them are focused on development of marine transportation, communication infrastructure and, at the same time, resort and recreation complexes. This creates a classic situation of increased competition between different functions of one place. Complex interactions require specific forms of resource use, management and control. That is why risk assessment is extremely important for these areas.

An increasing number of dangerous natural phenomena (Atlas, 2010) are one of the effects of climate change for Russia. Although Russia has one of the lowest socio-economic risks, estimated in the report of 'World risk index' (World Risk Report, 2012), the risk among regions is very unevenly distributed. And the risk for coastal areas is much higher because of higher concentration of hazards and higher density of population and national wealth. Climate change affects Caspian Sea level (Baburin, 1998), ice conditions in the Arctic (Baburin, 2009), etc.

Hazardous hydrological phenomena are one of the main natural dangers in Russia (Atlas, 2010). In 2012, an integrated damage from floods was about 1 billion euros; floods have caused death for over 200 people. Particularly destructive consequences were for Krymsk citizens in Krasnodar region in August 2012.

The main object of the work is aqua-territorial systems of Russian coastal regions<sup>6</sup>. The subject is socio-economic risk assessment of flooding in these territories.

Sustainable development is not only related to rational use of resources, but to equal development of all subsystems. The main purpose of the work is to estimate the influence of hydrological phenomena on sustainable development of coastal regions in condition of climate change. The research was divided into several stages:

- examination of Russian and foreign methods of risk assessment;
- identification of areas with the highest risk of natural phenomena;
- assessment of potential economic damage for coastal regions of the Baltic Sea;
- assessment of social risk and vulnerability of municipal communities in Krasnodar region on the coast of the Azov and the Black Seas;
- development of a method for integrated (damage and vulnerability) assessment of socio-economic risk (on an example of Slavyansk municipal district in Krasnodar region).

Scientific novelty of the work is in the application of social science methods to assess potential impact of natural processes on the functioning of society at the level of regions, municipalities and settlements<sup>7</sup>. As the final result, integration of two approaches: foreign (vulnerability assessment) and domestic Russian (economic damage evaluation) was performed.

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<sup>5</sup> 'Underflooding' is a ground water level rise

<sup>6</sup> Only sea coastal regions are considered in the work

<sup>7</sup> Official administrative-territorial division (regions, municipal districts, urban districts, urban and rural settlements) was used in analysis, because the governments use it for planning of flood protection measures and their financing, and for collection and processing of statistical information.

This work is a preliminary assessment of the potential risks and damages to identify regional priorities, but it cannot be used to assess the real damage. The paper has some features of methodological work; the approaches can be later used for Russian and foreign researches.

**METHODOLOGY AND METHODS**

Several Russian and foreign papers, devoted to potential impacts of dangerous hydrological phenomena on different territorial systems, was investigated during preparation of the work.

In Russia, most of the papers are devoted to the probability evaluation of dangerous phenomena. Maps of flooding danger for coastal areas (Atlas, 2010) and intensity of the flood (Extreme hydrological situation, 2010) were developed. There is a classification according to the danger of floods (Taratunin, 2008). Assessment of flooding impact on socio-economic development is rarely considered in publications (Baburin, 1998; Gladkevich, 2011; Shahin, 2009).

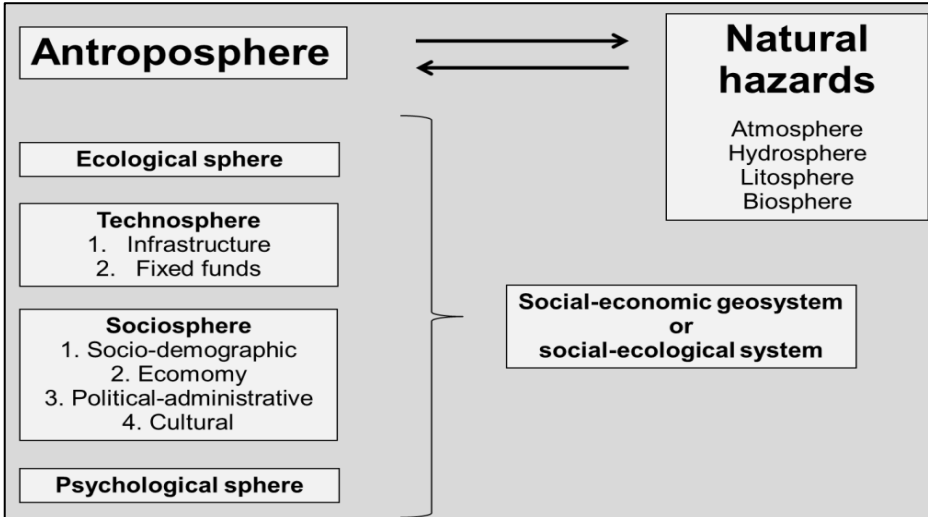
Most scientists agree with the opinion that risk is the product of the flooding probability and potential damage from it (Mikhailov, 2010).

$$R = p \times D \tag{1}$$

where *R* – an integrated socio-economic risk, or risk of potential annual loss; *p* – the probability of a natural hazard (in shares); *D* - integral potential damage (can be expressed in rubles, persons, etc.).

In Russia, the focus is on potential damage assessment (Alekseevskiy, 2011; Baburin, 2009; Gladkevich, 2011), while in foreign papers vulnerability of communities (Damm M., 2010; Fekete A., 2010; Hossini V., 2008) or risk management (Hossini V., 2008) are main scientific objects. In the work both approaches were used, an attempt to combine them were made on the last stage.

The study of potential effects of natural hazards is an assessment of influences of natural geospheres on the parameters of different anthroposphere components. Fig. 1 shows a conceptual framework, showing possible areas of influence. This structure will be used to define types of socio-economic risks and corresponding sets of damages.



**Figure 1. Interaction between subspheres of antroposphere and natural geospheres (developed by the authors).**

In the paper ‘Complex multifactorial risk assessment of flooding in Russia’ (Gladkevich, 2011) all Russian regions were divided in groups by natural and social risks, an integrated index is represented on Fig. 2. The selection of regions and methods in our study was based partly on results of this work. The Baltic regions have an average index of natural risks and an average index of socio-economic vulnerability, but they concentrate a significant socio-economic potential. Krasnodar region has very high integrated risk and one of the highest indices of natural hazards.

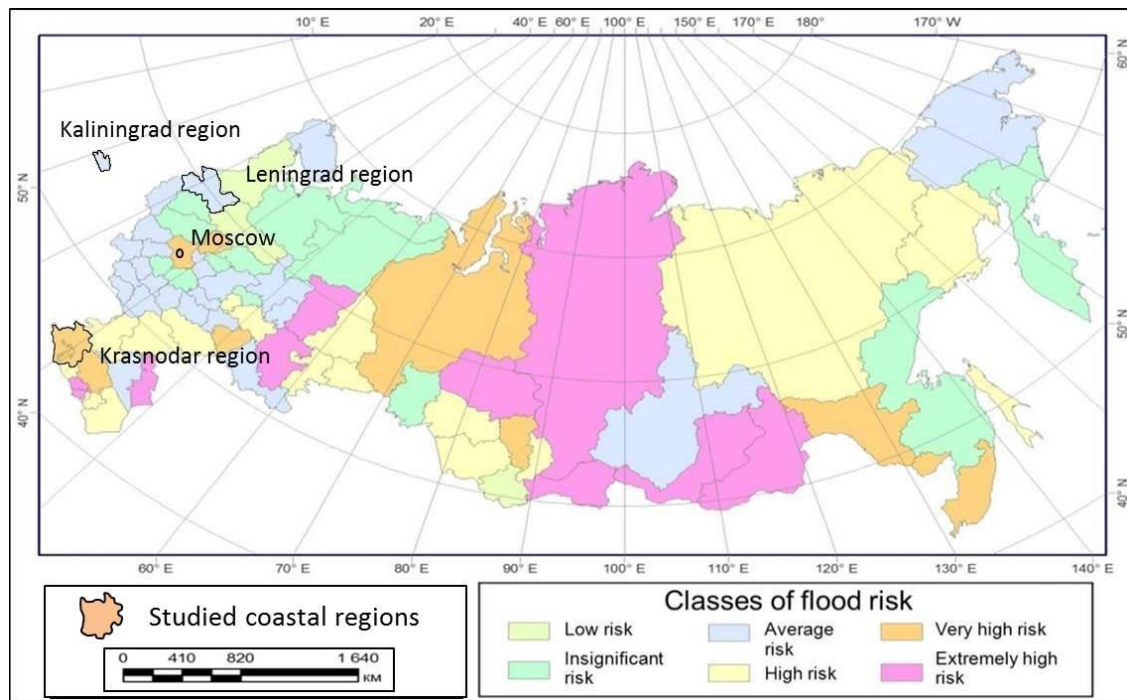


Figure 2. Classes of socio-economic risk for Russian regions (created by Gladkevich, 2011).

Three different methods on three levels (interregional, regional and municipal) were used for each stage of the research. The first stage was dedicated to economic damage assessment of coastal regions by traditional Russian methodology, on the second stage social risk and vulnerability were assessed for municipalities by foreign methodology of United Nations University Institute for Environment and Human Security (UNU-EHS), and on the last stage both methods were integrated on micro-geographical level using field data.

**The first part of the research** was devoted to economic risk assessment, or potential damage evaluation, for population and economy on an example of Kaliningrad and Leningrad regions in the Baltic Sea coastal zone.

In the study the main potential risks were the processes of:

- sea and ground water level rise, flooding and wind-surges;
- wave action on buildings and constructions;
- storm affecting shipping, port operations and coastal recreation;

The model takes into account direct (loss of life, destruction of buildings, etc.) as well as indirect effects (loss of profits, loss of the budget, etc.)<sup>8</sup>. The technique had been tested in previous works for calculation of the effects of the Caspian Sea level fluctuations for Russian regions (Dagestan, Kalmykia, Astrakhan region) by direct calculation. Later its individual blocks were used to evaluate the effects of global climate change on the river valley complexes (Syr-Darya basin, Kuban and small rivers near Moscow) (Baburin, 1998, 2009).

The method of direct calculation involves database compilation of the largest objects on the coast (ports, industrial facilities, residential buildings, etc.). Assessment of the objects value was based on official company reports, market value of real estate, costs of federal infrastructure programs, etc. In some cases it was possible to evaluate some indirect potential losses, such as profit of companies. But in most cases direct and indirect costs were calculated by the methodology of EMERCOM<sup>9</sup> (The method for determining of the damage..., 2007). The methodology is related to parameters of relationship between density of population, infrastructure and national wealth (2).

<sup>8</sup> Direct damage, associated with direct physical contact of water, determines the value of damage restoration costs for or the current market value of damaged objects. Indirect damage has an impact on virtually all other sectors of the economy, representing a loss due to violations of economic relations, the decline in production, trade, etc.

<sup>9</sup> The Ministry of the Russian Federation for Affairs for Civil Defense, Emergencies and Elimination of Consequences of Natural Disaster

$$I_1 = I_{1(\text{background})} \times \sum S_i \times K_i \times P_i = I_{1(\text{background})} \times (S_1 \times K_1 \times P_1 + S_2 \times K_2 \times S_2 + S_3 \times K_3 \times P_3) \quad (2),$$

where  $I_1$  - damage to the main production assets;  $I_{1(\text{background})}$  - the total book value of fixed assets of the region per unit of area, which is equal to:

$$I_{1(\text{background})} = C / S_i \quad (3),$$

where  $C$  is a total book value of fixed assets of the region without transportation facilities and communications;  $S$  – exposed area of the region;  $i$  – hazard level ( $1 \leq i \leq 3$ ) of strong, medium and weak destructions.

$$P_i = \rho_i / \rho_{\text{reg}} = m_i \times S_i / S_i \times M \quad (4),$$

where  $P_i$  - concentration ratios of fixed assets in the area;  $\rho_i$  - density of population in each hazardous zone;  $\rho_{\text{reg}}$  – density of population in the region;  $M$  – population of the region;  $m_i$  – population in zones of hazard level;  $K_i$  – levels of demolition.

The similar normative approach was used in most of calculations. Iterative process of summing socio-economic effects of the natural dynamics includes:

1. Calculation of the density of population for rural and urban territories.
2. Calculation of the density of wealth.
3. The calculation of loss (as a result of downtime of vessels, limitations of handling, etc.).
4. The calculation of loss / acquisition of own investment capacity of business entities, municipalities, and region.
5. The calculation of loss / income revenue budget.
6. Calculates the increase / decrease of the budget expenditures.

**The second part of the research** was devoted to social risk, or vulnerability, assessment of coastal municipalities of Krasnodar Region (the Azov and the Black Sea coastal zone).

General procedure was approved by the Institute of Environment and Human Security, United Nations University (UNU-EHS), on an example of German regions (Damm, 2010; Fekete, 2010), Southeast Asia (World Risk Report, 2011), etc.

The concept of ‘**risk**’ was divided into two components. The first component is ‘exposure’, or the amount of potential losses, it involves an assessment of exposed area and affected population. The second component is ‘vulnerability’. It is used to assess the system's ability to withstand flooding, including ‘susceptibility’ (evaluation of the system sensitivity to natural environment changes), ‘coping capacity’ (recovery abilities) and ‘adaptive capacity’ (ability to adapt to changes).

Complex index, which evaluates each of the parameters (and sub-parameters) in several indicators, were used. The study is the result of adaptation of foreign models for the Russian statistics, which is more focused on account of material assets, so ‘abilities’ of the community can be assessed only through indirect indicators.

A database in MS Excel was created. It is a matrix of 252 indicators from 2005 to 2010 for 14 most prone to flooding municipalities: Anapa, Gelendzhik, Novorossiysk, Sochi, Kalinin, Kanevsk, Krasnoarmeysk, Krymsk, Primorsko-Akhtarsk, Shcherbinovsk, Slavyansk, Temryuk, Tuapse and Yeisk municipal areas. The parameters were divided into several blocks: population, economic sectors (retail trade, agriculture, utilities, investment, the public sector, health and education, social services), as well as employment, payroll and fixed assets. The database is based on information resources of Russian Statistical Service ([www.gks.ru](http://www.gks.ru)), ministries and agencies of Russia, Krasnodar region, and municipalities. The database was used to calculate a vulnerability index for municipalities. Relevant indicators were selected by component analysis<sup>10</sup>, expert interviews and reviewed scientific works.

The proportion of people affected by flooding was an ‘exposure’ element. A geographic information system (GIS) in ArcGis 9.1 was created for the municipalities. Area of previous floods was recorded, as well as map of maximum potential flooding (evaluation was based on the height of

<sup>10</sup> Component analysis can be used with certain limitations due to the small number of cases (14).

the relief), and population density. ‘Exposure index’ was assigned to proportion of people living in flood-prone areas (Table 2, Fig. 2).

A set of parameters and sub-parameters corresponded to the method of the ‘World risk index’ (World Risk Report, 2012) was used to assess vulnerability of socio-economic system. An algorithm for constructing the integral index included several iterations: database compilation, its transformation to matrix of normalized indicators, assessment of weights for each indicator; application of the final formula or each district, and its verification by sensitivity analysis.

Equations of linear scaling between the variable  $X$  and the index  $I$  were used to normalize the indicators, which could be associated with an integral index as monotonically increasing or decreasing sequences.

$$I = (X - X_o) / (X^* - X_o) \quad (5);$$

$$I = 1 - (X_o - X) / (X^* - X_o) \quad (6),$$

where  $X_o$  – the minimum value of the variable  $X$  to all 14 municipalities,  $X^*$  – the maximum value.

Integral index of socio-economic risk was calculated using the following equation

$$Integral\ I = I_e \times I_v \quad (7),$$

$$I_v = 0.33 \times (I_s + I_{cc} + I_{ac}) \quad (8).$$

Each parameter consists of sub-parameters (Table 1) with a specific weight in the final index. Weights were given by experts and based on studies (Gladkevich, 2011, Damm, 2010).

**Table 1. Indicators of vulnerability (developed by the authors)**

<b>Susceptibility (<math>I_s</math>)</b>							
Public infrastructure		Housing conditions	Poverty and dependencies			Economic capacity	Index
Length of improved water source / people	Length of improved sanitation / people	Percentage of inhabitants in fragile dwellings	Percentage of population with incomes below the subsistence minimum	Percentage of population benefiting from social assistance to pay for housing services	Percentage of population served by the departments of social services at home for senior citizens and disabled	Sales of own-produced goods, works and services / people	
<b>0.075</b>	<b>0.075</b>	<b>0.15</b>	<b>0.15</b>	<b>0.15</b>	<b>0.15</b>	<b>0.25</b>	<b>0.33</b>
<b>Lack of coping capacity (<math>I_{cc}</math>)</b>							
Government and authorities		Medical services		Social networks	Material coverage	Index	
Unemployment rate	Percentage of own revenues of local budgets	Number of hospital beds per 10000 inhabitants	Number of physicians per 10000 inhabitants	Percentage of participants in voluntary groups for the protection of public order	Average monthly wages per capita		
<b>0.1</b>	<b>0.10</b>	<b>0.22</b>	<b>0.22</b>	<b>0.26</b>	<b>0.1</b>	<b>0.33</b>	
<b>Lack of adaptive capacity (<math>I_{ac}</math>)</b>							
Education		Environmental management	Adaptation strategies		Investment	Index	
Share of employed people with good education		Observed /Maximum flood area	Diversification of the labor market (Herfindahl–Hirschman Index)		Private investment / people		
<b>0.25</b>		<b>0.25</b>	<b>0.25</b>		<b>0.25</b>	<b>0.33</b>	

Susceptibility of the system depends on the state of infrastructure, housing and social protection of population, the overall economic potential of the region. Water networks provide access to drinking water; sewage networks regulate the outflow of heavy rainfall, and reduce potential damage. Fragile homes are more prone to destruction. Socially vulnerable groups, which

include the elderly and families with children, are more affected during the floods. High economic potential of the region contributes to the accelerated recovery of the families.

An ability to recover (coping capacity) is linked to the efficiency of the local authorities, the development of health services, social relationships and material prosperity of the community. The authors chose unemployment and the percentage of its own revenues in the local budget to evaluate the effectiveness of the authorities. To assess the development of social ties selected index of participants in volunteer groups for the protection of public order.

Adaptive capacity was estimated by the level of education and diversification rate of the labor market, which was calculated by simplified Herfindahl – Hirschman index ( $I_{HH}$ )

$$I_{HH} = S_1^2 + S_2^2 + \dots + S_n^2 \quad (9),$$

where  $S_1$  – proportion of the most common sphere of activity (job);  $S_2$  – proportion of the next common job;  $S_n$  – proportion of the last common job.

The ability of technical systems was estimated as a proportion between observed and maximum potential flooding areas. Private investment is an indicator of the attractiveness of the area and the potential diversification.

**The purpose on the third stage of the research** was to integrate both ('economic' and 'social') approaches on micro-geographical level, using 'field' data (opinion polls, special interviews, municipal statistics and data from companies, etc.) of Slavyansk municipal district.

Floods have been classified into three groups according to degree of danger<sup>11</sup>: widespread process of ground water level rise (average probability for most of the settlements is 0.99), floods because of embankment dams breaks with medium level of danger (0.1) and catastrophic flooding after the breakout of Krasnodar reservoir and destruction of earthen dam (0.01).

Several types of socio-economic risks, according Fig. 1, can be studied (Table 2). But only four key risks were identified and calculated for Slavyansk municipal district and for its settlements: environmental, technological, economic and social.

**Table 2. Types of socio-economic risks and set of damages (developed by the authors).**

Types of socio-economic risks ( $I$ )	Set of damages ( $i$ )			
	Environmental	Soil erosion and salinization.	Water pollution and fish death.	Contamination of drinking water.
Technological	Destruction of infrastructure (roads, bridges, pipelines, power lines, sewer).	Destruction of assets of industrial enterprises.	Destruction of housing.	
Economical	Loss of profits.	Reduction of budget revenues.	Reduction of investment attractiveness.	
Social	Death / Loss of health.	Destruction of social ties.	Impoverishment	
Political	Incompetence of the authorities.	Social "explosion".	Looting.	
Psychological	Loss of mental health.			
Informational	Negative press coverage.		Loss of territorial brand name.	

Authors calculated the potential damages and vulnerability for each spatial object, according to the type of risk. All indicators were submitted as separate layers in GIS. Then the authors perform an integral calculation by the synthesized formulas:

$$D_j = \sum dI_i * V_{ij} * S_j \quad (10),$$

where  $dI$  - maximum potential damages per unit area, according to the type of risk,  $V$  - indicator of vulnerability, depending on properties of the object,  $S$  - area of the different flood zones,  $I$  - type of risk,  $i$  - type of damage (depending on the type of risk),  $j$  - the intensity of the flood zone: 1 – ground water level rise, 2 – flooding with dam outbreak, 3 – catastrophic flooding;

<sup>11</sup> Probability of natural and technogenic disasters were estimated according to processes of climate change, aging and underinvestment of infrastructure



$$V_{ij} = f(Sus_{ij} - C_{ij}) \quad (11),$$

where  $f$  is a function,  $Sus$  – object’s susceptibility to natural hazards,  $C$  – object’s ability to resist.

Vulnerability assessment was performed using standard coefficients from methodological recommendations of Ministry of Natural Resources (e.g. coefficients of ecological sustainability), EMERCOM (e.g. stability of buildings and infrastructure) (The method for determining of the damage..., 2007), and were calculated independently for every type of the risk. For example percentage of average yield losses from annual yields was used as coefficient of vulnerability for agriculture. It depends on the type of flooding for different cultures. Vulnerability coefficient of rice for underflooding is nearly zero (a small percentage can still be spoiled with a long standing ground water) due to moisture resistance ( $C$ ). Even in catastrophic scenario coefficient for rice is less than 0.05, but it is totally different for wheat (0.9).

Investment risk assessment was based on different method and included two parts: losses for existing projects and for planned facilities. The authors used a coefficient of variation ( $C_v$ ) for calculation. Risk index is  $C_v$ , or average expected losses from natural events per year as a share of cash flow in the year. If index is greater than one, the project will not be implemented. Investment losses on existing businesses was calculated as a proportion between percentage of investment in fixed assets in the year for the Russian Federation and percentage of investment in the value of fixed assets in Slavyansk district in the year.

Component analysis (by SPSS) of the data, collected in poll, was conducted to identify the vulnerability indices of different groups of population. Poll was representative by age and gender, 485 respondents participated in the survey. Based on selected questions the authors formed three groups (Table 3): the most vulnerable, less vulnerable, and weakly vulnerable.

**Table 3. Combination of answers for groups of people with different value of vulnerability**

	The most vulnerable	Less vulnerable	Weakly vulnerable
Can you provide the safety of your life?	No	In part. Do not know	Yes
What is your age?	0-16, >66	56-65	> 16, < 56
How many years do you live in the area?	Less than 1, 1-5	5-20	> 20
Did you experience flood?	No	Once	More than once

These percentages may be used as coefficients of vulnerability (0.2, 0.15, and 0.62) (Table 4) for different types of danger.

**Table 4. The distribution of the groups for Slavyansk municipal district (calculated by the authors).**

Index of vulnerability					
		Frequency, persons	Percent	Valid Percent	Cumulative Percent
Valid	The most vulnerable	96	<b>20.3</b>	21.0	21.0
	Less vulnerable	69	<b>14.6</b>	15.1	36.0
	Weakly vulnerable	293	<b>61.8</b>	64.0	100
	Total	458	96.6	100	
Missing	System	16	3.4		
Total		474	100		

After estimation of social risks in persons financial estimation was given according treatment value for health losses and estimations of man’s possible contribution to the economy plus previous expanses of government (education, medical system, etc.). Based on this method an average value of Russian citizen is about 0.8 million euros and less for agricultural region. Damage for health can be estimated in 5000 euro as an average free medical insurance premium.

The authors calculated an integrated risk for settlements in three scenarios, according to danger and its probability. When all the calculations of damage was finished, some simulations for settlement were conducted, their aim was to show the difference of risk in day / night dimension (less prepared people), seasonal changes (tourists), construction works, etc. These simulation added

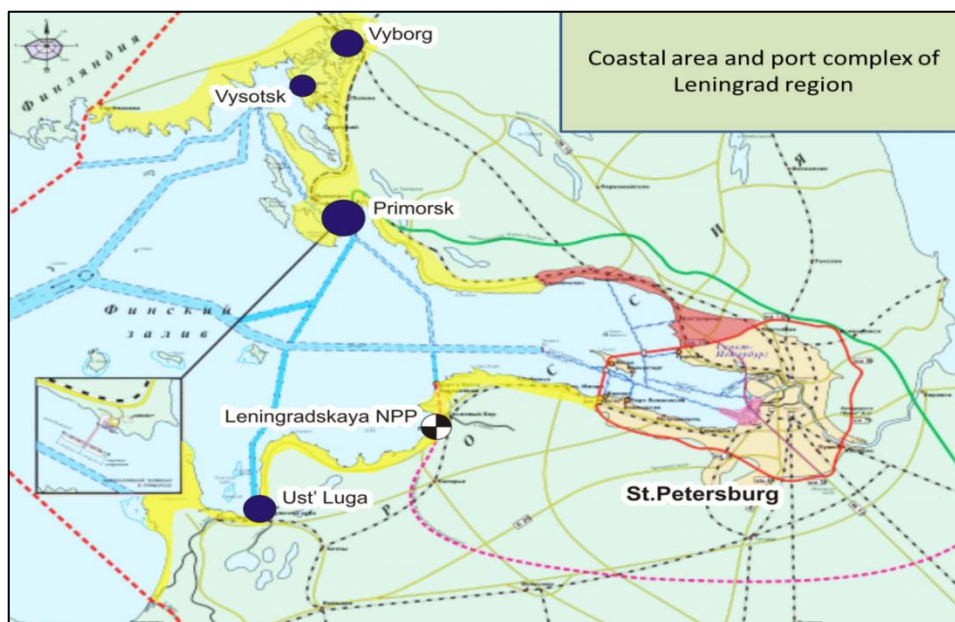
dynamic component in the model. System of connections between different risks and damages was developed and added to model on the last stage. For example, impoverishment is connected with destruction of assets of industrial enterprises and loss of work as a consequence, budget losses depends on damage of industries, etc.

## RESULTS AND DISCUSSION

### 1. DAMAGE ASSESSMENT FOR THE BALTIC REGIONS

Coastal zone of Leningrad and Kaliningrad regions is one of the closest to Northern Europe with the largest concentration of port infrastructure, which is rapidly developing. Saint Petersburg is one of the largest economic centres in Russia. Automobile industry is rapidly growing in St. Petersburg and its suburbs. One of the Russia's largest oil terminals was constructed in Primorsk and greatly increased ecological risks of hazardous hydrological phenomena. Ust'Luga is one of the youngest and largest Russian ports.

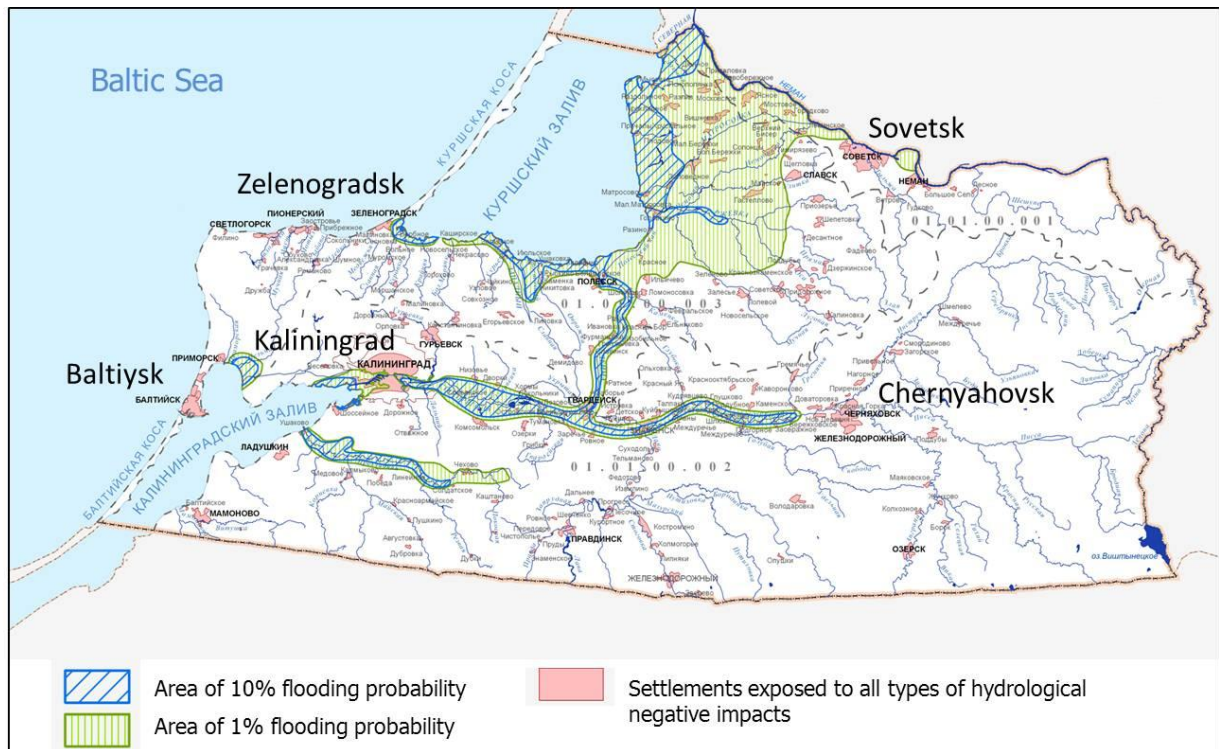
It is known that some of the most hazardous phenomena in the history of St. Petersburg are surges. This problem is urgent for Kaliningrad region because of development of polders, which are lower than sea level, and the drainage system require urgent repair. Sustainable regional development is not possible without additional control of protective structures.



**Figure 3.** Coastal area of Leningrad region (developed by V. Baburin). Yellow color represents an area of catastrophic surges. Black dots are the main ports.

The authors identified zones with different probability of flooding for Kaliningrad region, using satellite images and data from Russian Hydrometeorological Service, Kaliningrad basin administration (Fig. 4). Almost 96.4 thousands of people (10% of total region population) are exposed to hazardous hydrological processes. The most dangerous floods and surges usually occur at Deima, Matrosovka, Nemonin, Neman and Pregolya river deltas, flooding such big cities as Kaliningrad and Polessk.

Analysis of the map shows, that only approximately ¼ of all exposed settlements are located in high probability flooded zones, others have another cause of negative hydrological impact – underflooding. There are two main factors of groundwater level rise in Kaliningrad region: relief (a large part of the region is below sea level) and irregularly work and deterioration of the drainage melioration system. About 80% of the region area is covered with the drainage system, which guarantees normal functioning of regions economics. The drainage system was constructed in the beginning of XX-th century and it is almost depreciated. In 29 of total 45 melioration systems more than half of the channels have 80% of technical depreciation. More than 4 thousand km of channels have to be reconstructed, it is almost 80% of all channels.



**Figure 4. Map of flooding probability and exposed cities in Kaliningrad region (developed by Shikunova E. and Kidyaeva V.)**

The authors used methodology of EMERCOM. A database, based on satellite images, maps, yearbooks of Russian Statistical Service and reports of entities, had been prepared. The database is a matrix, in which the rows are parts of coastal zone, and the columns are given indicators: number of people in port areas, cost of fixed assets (million rubles), investment (million rubles), revenue / profit (million rubles), etc. The database was used for damage calculation.

According to the calculations by the authors and V. Baburin the total damage because of a gradual rise in sea level to 1 m, as a result of global climate change, is just over 2 billion euro for Leningrad region. Combined damage of cyclones (and surges), depending on their strength can be more than 200 million euro every year, which is 0.5% of the GRP of St. Petersburg.

With a total turnover of 200 million tons, the potential damage (loss of profit) of downtime due to weather conditions will amount to 0.12 million euro per day. During 2000<sup>th</sup>, port infrastructure on the Baltic Sea is actively developed for handling an increasing amount of cargo.

Cost protection is quite different by costs (Baburin, 2009):

- Cost of gabions (not ferro-concrete) are about 1.7 million euro per km.
- Cost of protection wall (earth embankment) fluctuates from 0.6 to 1 million euro per km.
- Cost of a ferro-concrete protection wall is more than 37 million euro per km.
- Cost of drainage channels is less than 1.2 million euro per km.
- Cost of pumping plant is nearly 1 million euro per one cubic meter per second.

There is a significant underinvestment in protection structures according to ecological reports and federal programs for construction of dams and shore protection. In Kaliningrad region all natural factors are expanded by depreciation of drainage system.

Maximum direct potential damage for both regions for catastrophic flooding is about 15.7 billion euro, but indirect damage is more than 25.5 billion euro. The damage increased with growth of economic activities without proper strengthening of protective infrastructure. The authors evaluate cost of protection measures in 7.2 billion euro, which is about 17% of maximum potential damage.

## **2. SOCIAL VULNERABILITY ASSESSMENT FOR MUNICIPALITIES ON THE BLACK AND THE AZOV SEA.**



The second part was devoted to vulnerability assessment for municipal societies of Krasnodar Region. Region (Krasnodarsky kray in transliteration) is 41<sup>st</sup> region of Russia by area, the 3<sup>rd</sup> region by population, the 7<sup>th</sup> by Gross Regional Product, and the largest agricultural region. The highest diversity of natural landscapes (from the steppes and wetlands in the north to the Alpine mountain meadows and subtropical forests in the south) determines the diversification of economic activities.

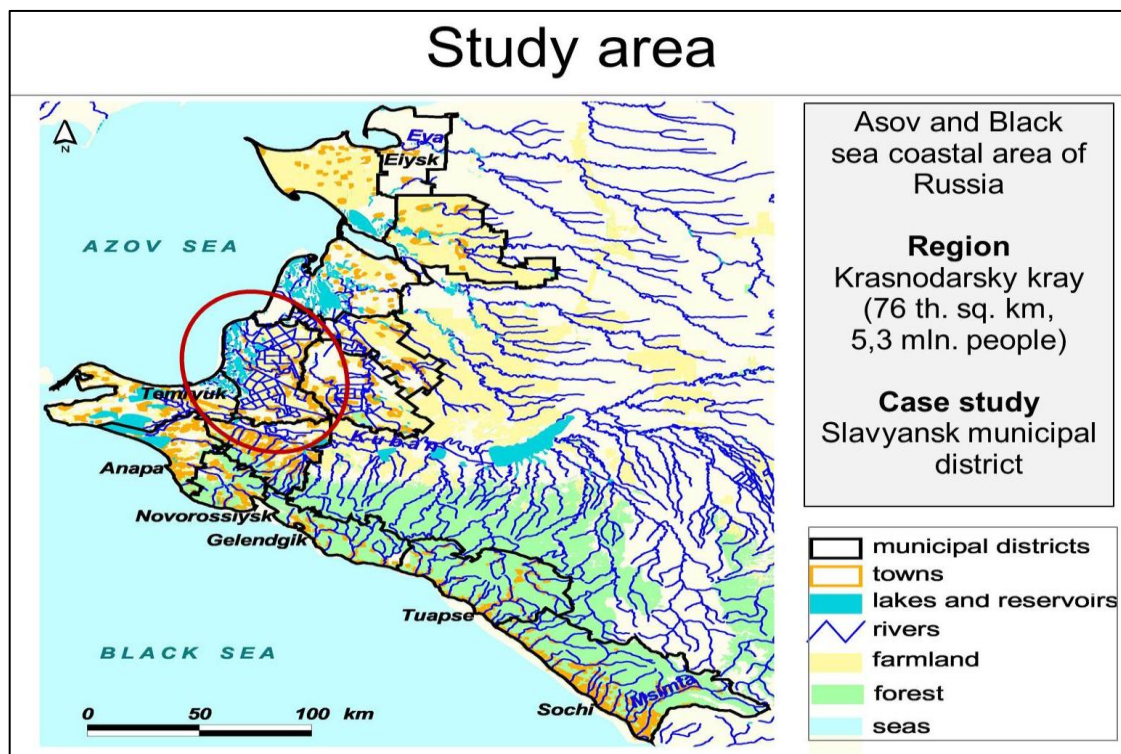


Figure 5. Krasnodar region (developed by the authors and I. Krylenko).

The region, especially its coastal zone, is one of the most exposed to hazardous natural phenomena (Shahin, 2010) in Russia. Four most catastrophic extreme flood events in previous 15 years are shown in the table 5.

Table 5. Extreme events in previous 15 years in Krasnodar region (compiled by the authors, based on data from 'Flooding in the delta of the Kuban' (Magritsky, 2011)).

Date	Flood reason	Damage
1998, march	Heavy rains and groundwater level rise	Around 500 000 ha, 132 settlements, more than 22 500 houses were flooded, 113 economic objects were damaged in Krasnodar region. Huge flood activated landslide processes in Temryuk city. Around 107 private houses were damaged and 300 people were injured in Temryuk district.
2001, December – 2002, January	Ice jams, heavy rains and reservoir releases	Huge area along the river and part of Temryuk city were flooded (around 74 ha). 3283 people were injured
2002, July	Snow melting and heavy rains	One of the river dams was broken. 1,5 km <sup>2</sup> of rice fields and pump station were flooded
2011, February	Surge	Water level reached 1,5 m

Exposure area is shown on Fig. 6. The authors calculated population in flood prone areas and efficiency of the protection system, as relation between potential and maximum observed flooding areas.

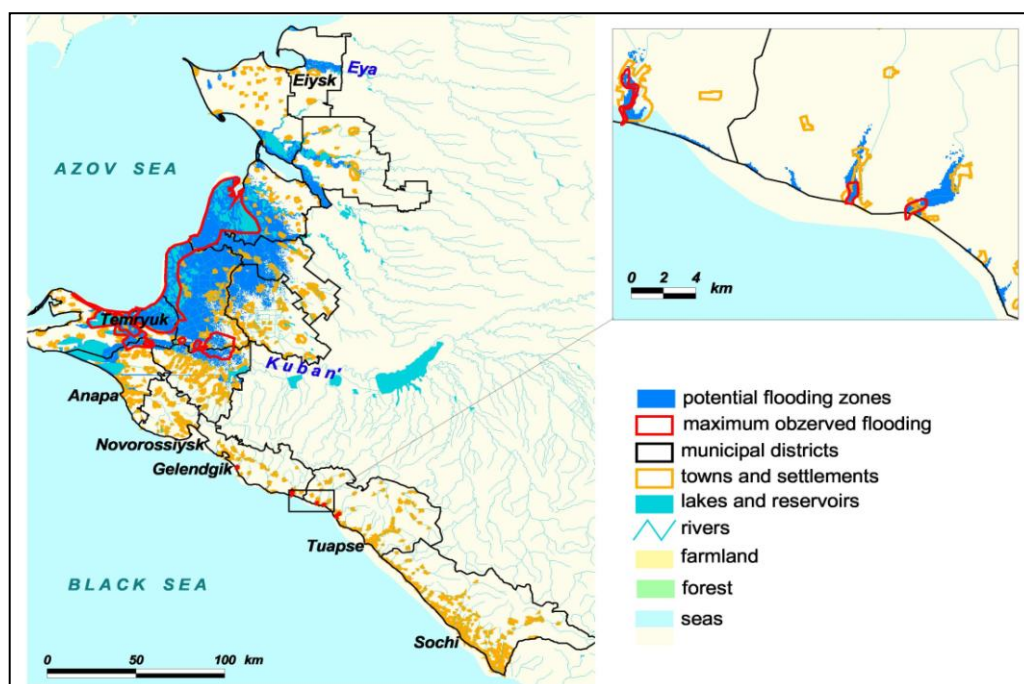


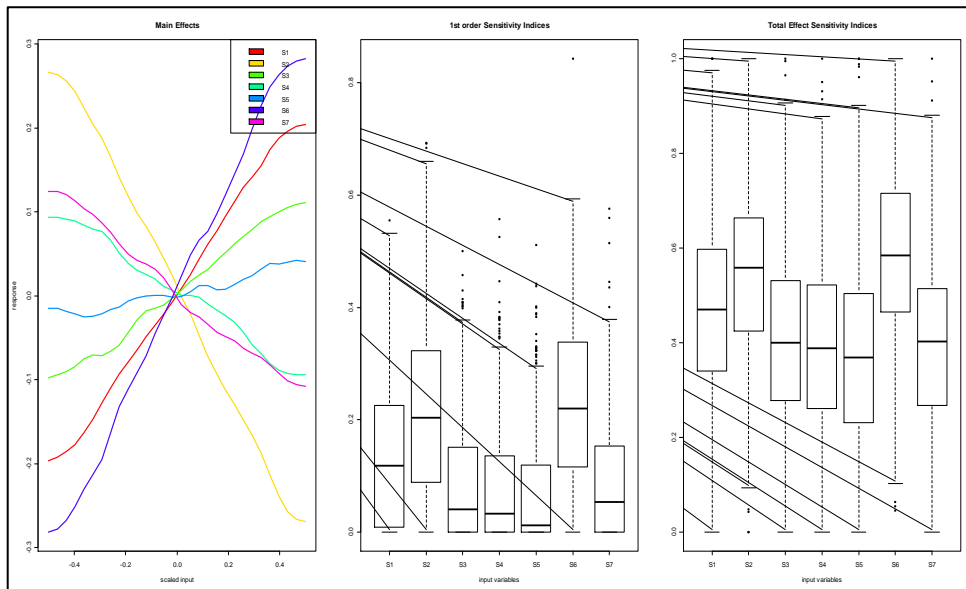
Figure 6. Potential flooding zone and settlements (developed by the authors and I. Krylenko).

Sub-indices were calculated for 14 coastal municipal districts (Table 6).

Table 6. Indices of vulnerability and exposure for municipalities of Krasnodar region (calculated by the authors).

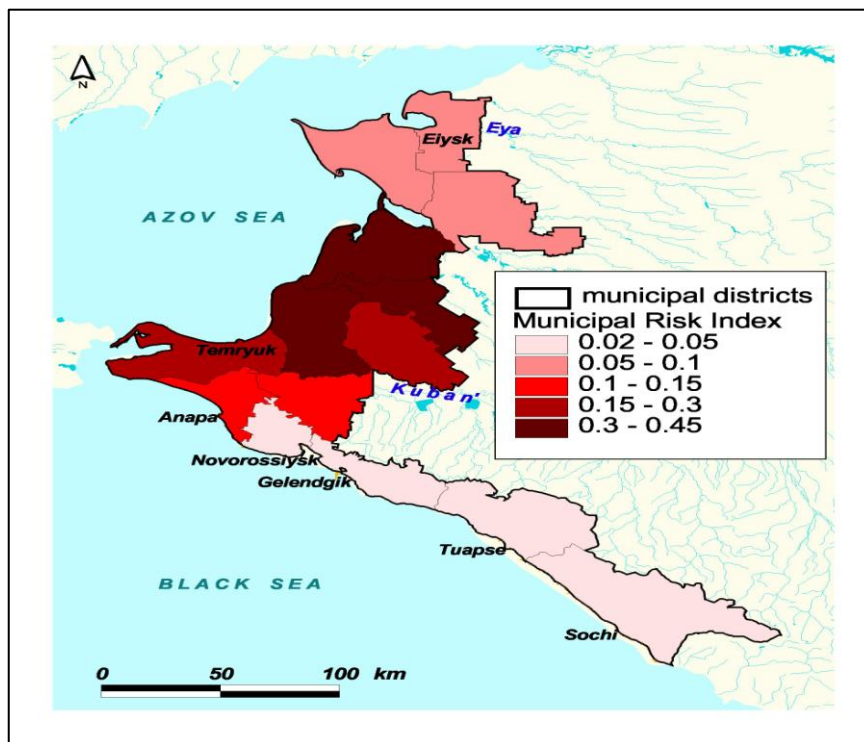
	Municipal Risk Index	Exposure	Vulnerability	Susceptibility	Lack of coping capacity	Lack of adaptive capacity
Novorossiysk	0,02	0,05	0,40	0,26	0,37	0,58
Gelendzhik	0,03	0,07	0,42	0,47	0,25	0,55
Sochi	0,03	0,06	0,51	0,66	0,39	0,47
Tuapsinsky	0,04	0,09	0,50	0,45	0,56	0,49
Sherbinovsky	0,08	0,11	0,70	0,65	0,68	0,79
Kanevsky	0,09	0,14	0,62	0,40	0,70	0,77
Eysky	0,10	0,16	0,65	0,67	0,66	0,63
Anapa	0,13	0,28	0,47	0,49	0,36	0,56
Krymsky	0,14	0,24	0,58	0,67	0,59	0,49
Krasnoarmeysky	0,23	0,32	0,70	0,56	0,83	0,72
Temryuksky	0,26	0,53	0,49	0,45	0,74	0,27
Kalininsky	0,35	0,47	0,74	0,63	0,86	0,75
Primorsko-Akhtarsky	0,39	0,7	0,56	0,63	0,65	0,40
Slavyansky	0,45	0,75	0,59	0,43	0,71	0,65

Calculated indices were verified by statistical methods. Subsequently, sensitivity analysis of used figures was conducted with the help of Jan Wolfertz, UNU EHS (Bonn, Germany). It helped to select the most representative indicators. The analysis generally confirmed the legitimacy to use most of indicators, but also noted the impossibility of precise mathematical verification for only 14 municipalities because of lack of samples. Overall, the work has been deemed as successful. An example of graphical method of analysis (in R<sub>+</sub> package) is represented on Fig. 7.



**Figure 7. Sensitivity analysis of sub-indices in ‘Susceptibility’ category (conducted with the help of Jan Wolfertz, UNU EHS). On the first chart main effects are shown, on the second – the first order sensitivity indices, on the third – total effect sensitivity indices.**

After release of a number of values final indices were obtained (Fig. 8).



**Figure 8. Municipal Risk Index (developed by the authors).**

The group with the lowest index (0.02 to 0.05) is on highly developed areas and urban districts of the southern coast of the Krasnodar region. The potential damage of hydrological events in the region is related with high intensity and high velocity of water flow (Zemtsov, 2012). It is foothills and mountainous area that have low proportion of population and the area prone to flooding, but also rather low values of vulnerability, which are associated with well-developed coping capacities. Large cities (Sochi, Novorossiysk, Gelendzhik, Tuapse) located in this area have the necessary infrastructure (e.g. health services), economic potential (e.g. high budget revenues and wages) and social ties for the prevention and consequences elimination of natural disasters. Olympic Sochi has one of the lowest risks, but it is increasing with the infrastructure development.

"Middle" index municipalities are located in areas that have larger flood areas than previous group and also high level of vulnerability. This area is located between the delta of the Kuban River on the North (part of the Kuban-Azov Lowlands) and the south part of the Caucasus.

Areas with the highest integral index are both the most exposed and the most vulnerable to flooding. There was the largest number of destructive floods in the region (Tabl. 4; Magritsky, 2011). Floods can cover large areas and have a long duration. These flat areas located in the delta of the Kuban. The main specialization of this area is agriculture. For rural plains one-storeyed buildings near the river are typical, that complicates the ability to adapt ATS to the consequences of floods. Socio-economic system of Temryuk district due to high volume of private investment in port infrastructure intended to increase the degree of economy diversification. The coping capacity of regions is generally low due to the low economic potential.

Natural risk also increases (Fig. 9) for the Black Sea rivers, increasing social-economic integral risks.

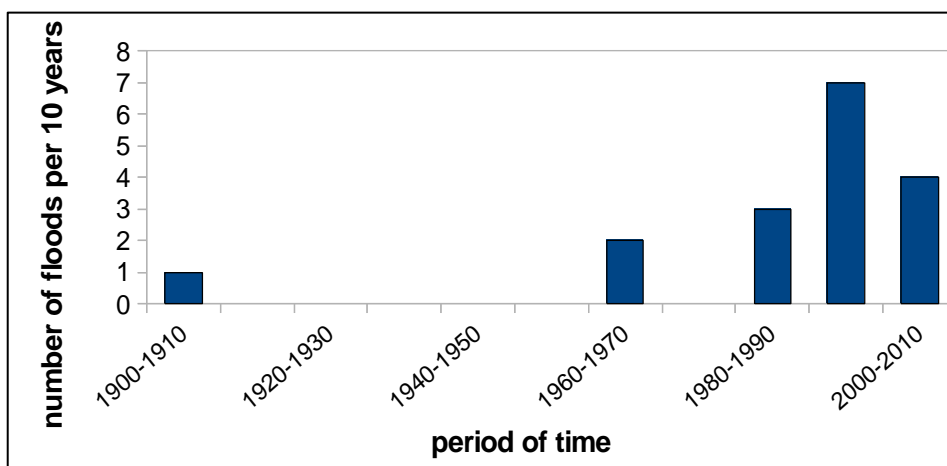


Figure 9. Number of floods per 10 years of Black sea rivers in Krasnodar region (compiled by the authors, based on data from 'Flooding in the delta of the Kuban' (Magritsky, 2011)).

Krymsk district is one of the most vulnerable. The area has one of the highest indices of sensitivity, which is associated with a high proportion of socially disadvantaged groups, as well as low economic potential.

### 3. INTEGRATED SOCIO-ECONOMIC RISK ASSESSMENT OF SLAVYANSK MUNICIPAL DISTRICT.

Field study was conducted in Slavyansk municipal district of Krasnodar region. The area is located in the delta of the Kuban River at a height of 1-2 meters above sea level. The district has the highest risk index (Fig. 7). Hazardous hydrological phenomena are regular, affect the economy and threaten the health and lives of people. This situation requires the development of an adapted methodology for assessing of socio-economic risks. Key studies were conducted in: Achuevo, Anastasievskoe, Prikubanskiy, Zaboyskiy, Urma and Derevyankovka.

The main object of expedition was evaluation of integral social and economic risk. To achieve this purpose, synthetic methodology based on Russian and foreign approaches was developed. Both approaches were integrated using 'field' data (opinion polls, special interviews, municipal statistics, and etc.) and integrated formulas (9), (10).

Only a few of the calculated indicators and developed maps will be presented in the article because of known restrictions on volume of the work.

The first iteration was estimation of population percentage, exposed to hazardous hydrological phenomena. Fig. 10 shows the population density in settlements towards type of flood zone. Blue color shows the catastrophic flooding area after the breakout of Krasnodar reservoir and destruction of poorer sections of earthen dam. Black grilles show flood are with 'middle' level of danger, coupled with breaks of embankment dams. Diagonal stripes indicate widespread process of flooding.

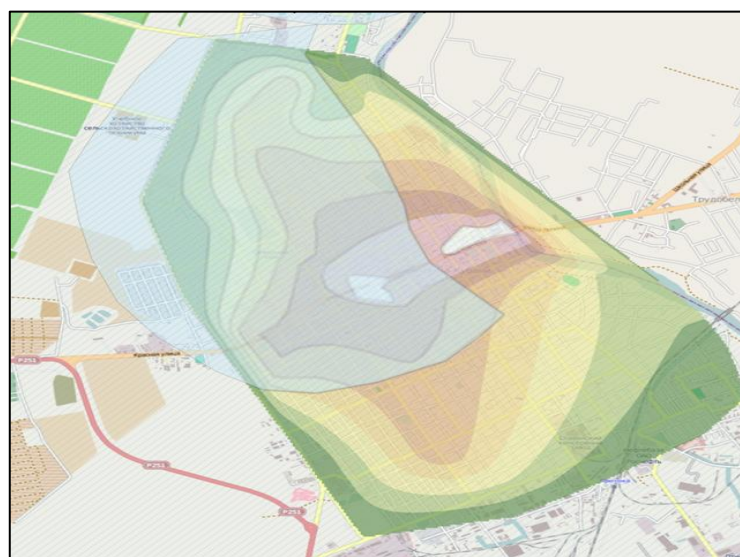




**Figure 10. Population density of Slavyansk district settlements towards hazardous zones (worked out by the authors).**

Loses of infrastructure for the whole area after catastrophic flood event can reach 12 million euro, but it is 6 million euro every year for underflooding damages of infrastructure. Budget profit of Slavyansk municipal district is over 40 million euro per year for comparison.

Map of residential property price was based on data of free media and local real estate agencies (Fig. 11).

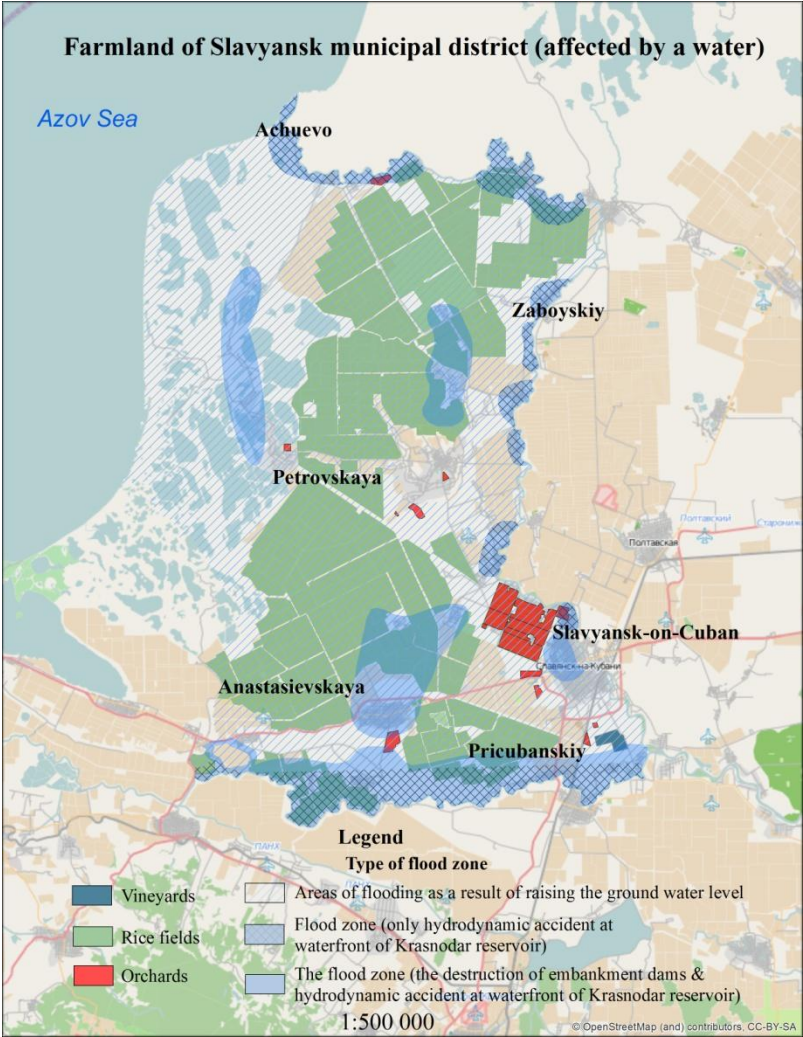


**Figure 11. Map of residential property price in Slavyansk-on-Cuban (worked out by the authors). Blue zone represents the catastrophic flooding area. The price is falling from centre to periphery from brown to green colour.**



The calculation was based on this map and map of different strength of buildings, which were revealed by visual observations. Damage to residential property after a catastrophic flood could reach 150 million euro. But every year buildings are affected by underflooding, to estimate this impact, the authors worked out a map of drainage sewage system of the town, which can indicate that only constructions in the centre are well protected. But the system of drainage cannot help during the storm or flooding because of low difference of heights and weakness of suction-pumps.

Agricultural damage (Fig. 12) for ‘middle’ event is 1 million euro, but for catastrophic events it’s almost 32 million euro.



**Figure 12. Agricultural risks (worked out by the authors).**

Investment losses on the planned investment project are about 42 million euro for projects with vulnerability index equal or more than 1. Investment losses on existing businesses are 38 million euro per year, comparing to average annual Russian investment rate in fixed assets (Fig. 13)).

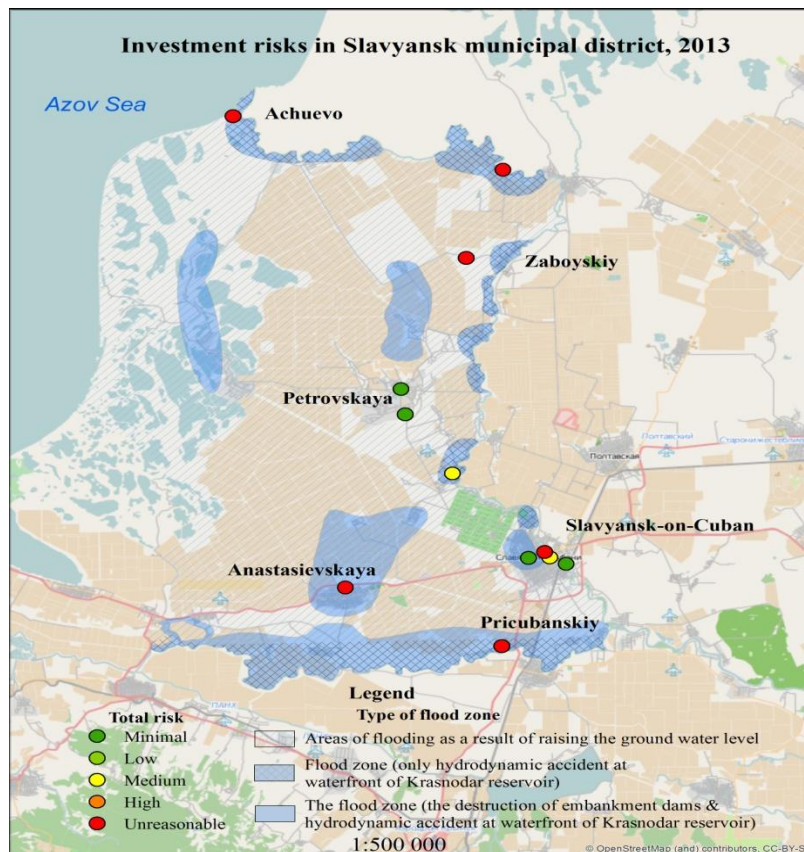


Figure 13. Map of investment risks in Slavyansk municipal district (developed by the authors). Dots are representing investment projects.

Total annual losses from underflooding are approximately 8 million euro every year, which is just under 20% of the total income of the municipality, total potential ‘middle’ damage is about 62 million euro and losses from catastrophic event can exceed 314 million euro. But we should apply probability coefficients, which reduce damage value to 6.5 and 3.1 million euro per year respectively.

Social risks were assessed by indices, which were extracted from component analysis of social poll data. A distribution between settlements of the most important, in terms of protection, responses of citizens, is presented in the table 6.

Table 7. The respondents' answers to questions about preparedness and responses to flooding (%)

	Slavyansk district	Anastasievskaya	Achuevo	Zaboyskiy	Prikubanskiy	Slavyansk-on-Cuban
Training activities were not carried out by EMERCOM	55	56	32	42	68	57
Do not know evacuation routes	69	79	21	43	61	77
Do not know safe place	58	66	14	35	41	69
Will ignore an alarm system	14	6	14	16	18	15
Do not participate in voluntary groups for protection	93	95	86	90	86	95
Do not have any transport vehicles	44	35	57	62	63	50
Count only on themselves in case of flooding	45	54	43	47	45	43
In event of flooding do not take any action	9	9	18	12	6	7

Source: own data

Calculation of social risk for the settlements is shown in the table 8. The authors estimate the amount of victims on the basis of the share of elderly, children and people with high vulnerability index. In fact, this figure is a number of losses in the absence of reaction of the authorities, EMERCOM, without mutual assistance and complete ignorance of citizens. ‘Day / night’ and seasonal simulations of the model can change indicators in more than 40%.

**Table 8. Social risks of settlements in Slavyansk municipal district (calculated by the authors).**

	Weakly flooding		‘Middle’ danger			Catastrophic flooding				
	Loss of health, persons	Death, persons	Loss of health, persons	Value mln euro	Death, persons	Value mln euro	Loss of health, persons	Value mln euro	Death, persons	Value mln euro
Total	118000	0	9600	48	192	153.6	73200	366	2050	1640
Anastasievskaya	10923	0	0	0	0	0	10923	54.615	328	262.4
Achuevo	402	0	80	0.4	2	1.6	402	2.01	4	3.2
Zaboyskiy	2427	0	876	4.38	17	13.6	2306	11.53	44	35.2
Prikubanskiy	297	0	151	0.755	1	0.8	297	1.485	8	6.4
Slavyansk-on-Cuban	63842	0	0	0	0	0	38305	191.525	1149	919.2

*Source:* own data

Financial estimation of social risk can be shocking for local authorities or seems invalid, but it’s an estimation of social damage, of social losses from death and health problems. Total social damage for ‘middle’ scenario is about 201.6 million euro, or 20.1 million euro per year; for catastrophic scenario – 2006 million euro or 20 million euro per year. In Russia, the system of protection is directed to buildings and infrastructure, but social risk is much higher. Actually social risk is much more important for society. It’s the main reason to develop the system of protection, warning and evacuation more accurately for people’s requirements.

Recommendations (based on calculations and special maps) for improvement of protection and evacuation system were prepared.

## CONCLUSION

The result of the first stage of work is very important for economic politics of coastal regions. Geopolitical factors determine an increase of Baltic ports turnover, but socio-economic risks of hazardous hydrological phenomena is not favourable. A trade-off between the high concentration of population and the possible cost of defence equipment must be found, but now the risk is increasing rapidly. In the long-term perspective sea level rise threatens virtually all Russian port infrastructure on The Baltic Sea.

The result of the second stage was zoning of coastal areas in Krasnodar region. In fact, the policy priorities of EMERCOM for improving protection of citizens and their property from natural disasters have been identified. The approach cannot be applied to calculate real damages, and overestimation of the index approach is dangerous. Indices can smooth out many disparities and hide real problems. The disadvantage of the approach is the dependence on existing statistics.

Conducted field research allowed us to identify the weaknesses in the infrastructure sphere of preparedness (improper state of embankment dams and storm sewer, lack of dredging in rivers), economic vulnerability (planning and implementation of investment projects without risk analysis). Indicators of extreme vulnerability and absolute unwillingness of the population to hazardous hydrological phenomena were the results of an opinion poll. Approximately 15% of the population, (19,600 people) are classified as vulnerable, and 20% or about (26,000 people) are the most vulnerable for health losses. By the results of the research areas with different degrees of risk were identified. The potential damage for a number of settlements (Achuevo, Derevyankovka) exceeded the cost of protection measures, which raises a question of appropriateness of the settlements.

One of the most important results of the work is estimation of economic and social risks in equivalent measures. In Russia, the system of protection is directed to buildings and infrastructure

as the most expansive components of socio-economic system, but our calculations show that social risk is much higher even in financial values.

One of the problems of damage compensation for victims is imperfection of the Russian law system. There is no current efficient law for insurance procedure. Local authorities cannot prevent local people and investors from constructing in the most vulnerable zones using insurance charges. And in case of hazardous events only the government determines amounts of payments, usually they are equal for all victims and not fair. This problem should be solved on the level of Federal Government, the solution should be based on detailed hydrological, social, economic local investigations at the most vulnerable regions of Russia.

Generalized groups of recommendations are:

**1. For local authorities:**

- to accomplish a complex inventory of flood protection dams, with detection of the most vulnerable to floods constrictions;
- to restore the eroded dams that were allocated during the 'field' observations;
- to reveal and control the owners of the dams and to take under consideration numerous ownerless dams;
- to monitor places with high possibility of riverbed clogging and conduct regular riverbed clearing;
- to clean river banks from obstructions, that can cause river blockage during spring floods;
- to construct coastal fortifications in the river banks exposed to erosion;
- to transmigrate the settlements and private houses that are located in the most dangerous zones and which transmigration will cost less than future recovery of damages;
- to introduce a special technical local notification system, which should connect a decision-making centre with all settlements. the aim of this measure is to shorten the time of interaction to several minutes;
- to perform explanatory activities about flooding and necessity of evacuation for local people;
- to print and make public maps of flooding possibility, risk maps and etc., so that they could be available to all levels of the population, investors, social organizations and other interested parties;

**2. For investors:**

- to use risk map for planning investment projects.

**3. For EMERCOM:**

- to increase the efficiency of public warning;
- to reveal deficiencies in the public awareness of hazards;
- to develop programs, plans and rules in case of extreme events and make them available to all interested parties;
- to specify areas of population evacuations and routes to them, to assess necessary infrastructure of aid posts and provisional allocation of victims.

High risk on the coastal zones is caused by combination of hazardous phenomena and high density of population and economic activity. In Russia, probability growth of hazardous natural events (caused by climate change) has coincided with increasing risk and recurrence of technogenic catastrophes because of errors in territorial planning, organization of warning and prevention systems and underinvestment of protection systems. Sustainable development of the regions is limited by these factors; moreover it affects investment and residential attractiveness of Russian cities.

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