Socio-economic potential of municipalities in the context of natural risk (case study – Southern Siberian regions)

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Abstract. A method for natural risk assessment is proposed. It is based on data of socio-economic potential and natural hazards spatial distribution on the study area. This methodology for assessing the economic component of natural risk consists of two integral indices. The first is the index of social and economic density on the territory. It shows the probable maximum direct and indirect damage from natural hazards per unit area only in the economically exploited part of total municipal territory. Index parameters are: population, fixed assets value and gross production volume, which divided into the built-up area of municipality. The second is the index of socio-economic spatial vulnerability of the territory. It demonstrates the probability of crossing the concentrated social and economic potential areas and disaster zone. Index calculated as multiplication of population, fixed assets value and gross production volume to the spatial vulnerability coefficient. This coefficient is equal to the share of built-up area in the total area of municipal land. We have identified potentially the most vulnerable municipalities in South Siberia with indices values above the macro-regional average. In addition, the maximum debris flow risk zones were singled out.

1. Introduction
In recent years, there has been a steady trend to increase the number of natural disasters and their catastrophic consequences in Russia. The primary reason for this is not only a change in natural conditions, but a factor of the socio-economic development intensification in the most dangerous areas. The lack of land resources in cities, investment projects related to mineral resources extraction, tourism and recreation, new industrial plants and infrastructure building, etc., in places with a high natural danger level is one of the reasons for natural risk increasing. At the beginning of 21 century natural risk is recognized as one of the main strategic risks in Russian Federation [1]. Thus, scientifically based natural risk management is a necessary condition for country sustainable development. Economic approach to natural hazards assessment is currently poorly elaborated and it is basically reduced to make predictions attempt based on damage estimates from already occurred natural disasters, which is methodologically incorrectly [2]. Natural hazards studies are always associated with a high degree of uncertainty. The risk and dangerous natural phenomena stochastic nature determines preferred use a probabilistic (but not a widely used method of direct calculations) methods for assessing the society and economy vulnerability.

Natural risk is a probability function of natural hazard occurrence and its negative consequences for economy and society as a whole in the specific territory. The most general risk indicator is the mathematical expectation (average value) of the damage from a dangerous event for the year, [3].
According to this, we offer a hypothesis: there is close to a direct functional relationship between the economic development level of the territory and the risk level. It allows the expression of natural risks through the socio-economic parameters.

In this study the "socio-economic potential of the territory" was chosen as a complex parameter in order to assess the social component of natural risk. It is defined as the territorial socio-economic system ability to support long-term balanced development through rational use of all resources diversity, which concentrated in it [4]. The socio-economic potential of the territorial system can be destroyed in whole or partly by the natural disaster impact. Thus, based on the adopted approach, it is important to identify the internal regional territorial differentiation according to the degree of catastrophic consequences probability. For these purposes, it is necessary not only to quantify the potential in absolute value, but also to understand features of its spatial distribution in a territory with its unique physiographical characteristics. First of all, we are talking about the finding differences in level of the potential concentration at each point on considered space.

The territory of South Siberian regions, located within two large mountainous countries (Altai-Sayan and Baikal), is characterized by a high natural risk level, taking into account the most destructive natural hazards for Russia: earthquakes, floods, hurricanes, avalanches, landslides and debris flows [5]. In this study, in order to test our approach we chose the debris flows. Southern Siberia characterize as a region with very high level of debris flow activity in Russia [6]. Due to relief specificity debris flows are widespread here, although a most part of the territory is only potentially dangerous (where the debris flows may be activate by vegetation cover destruction). The main factor of dangerous slope processes activation in this territory is not a climatic change, but first of all it is a human activity in areas of industrial, agricultural, and silvicultural development [7].

2. Models and Methods
Based on the conceptual approach described above, a methodology for estimating the maximal likely socio-economic damage from natural hazards was developed. Municipalities’ level was chosen as an optimal territorial level. Socio-economic municipal statistic data do not have a link with relevant economic use areas (especially in eastern Russian regions, where the municipality’s size is extremely large and the territory has only local development). This factor complicates the ability to compare socio-economic data with nature data. According to this, we created a special methodology that eliminated this drawback.

The socio-economic potential density of territory was assessed by the ratio to only most intensive economic development areas (not to the full administrative-territorial unit area, in the borders of which statistical information is provided). Thanks to this it became possible to identify the real concentration of potential and to link population and economy with real areas of their concentration. The spatial vulnerability of socio-economic potential is defined as probability of its crossing with natural hazard zone.

Our methodology for assessing the economic component of natural risk based on two integral indexes: the index of socio-economic density and the index of socio-economic spatial vulnerability of the territory. Indices consist three blocks: population, fixed assets and gross production of the municipality. Parameters choice is conditioned by the fact that the social and economic consequences of catastrophes characterized by the direct and indirect damages. For population and fixed assets the damage from natural disasters is direct in general and manifests itself immediately (people death, production capacities failure, buildings and structures destruction, etc.). Destructive effect of natural hazard to gross product is closely related to the first two parameters, but it can be also manifested directly, independently of them. It means the reduction of goods and services production by reducing the workforce, destruction of infrastructure, plants, industrial chains, agricultural lands etc., additional expenses in the social sphere and some economy sectors, reducing the tax payments in the emergencies territory and so on.

A summary algorithm for calculating the index of socio-economic spatial vulnerability on municipal level:
Assessment of population spatial vulnerability ($I_p$):

$$I_p = kP$$

(1)

where $P$ – population of municipality (people), $k$ – spatial vulnerability coefficient (share of economic developed territory in total municipal lands area ($k = S_{e1} / S_t$, where $S_{e1}$ – built-up area, $S_t$ – total area of municipality)).

Assessment of fixed assets spatial vulnerability ($I_f$):

$$I_f = kF$$

(2)

where $F$ – estimated value of municipal fixed assets (million rubles), $k$ – coefficient of spatial vulnerability.

Assessment of gross production spatial vulnerability ($I_{gp}$):

$$I_{gp} = kGP$$

(3)

where $GP$ – estimated volume of municipal gross production (million rubles), $k$ – coefficient of spatial vulnerability ($k = (S_{e1} + S_{e2}) / S_t$, where $S_{e1}$ – built-up area, $S_{e2}$ – area of agricultural land (used if the share of agricultural sector in regional economy structure and potential damage to agriculture are high (for example, the share is higher than Russian average), $S_t$ – total area of municipality).

Then all of indicators are normalized. The sum of three resulting normalized indicators (population $- NI_p$, fixed assets $- NI_f$, gross production $- NI_{gp}$) gives the required integrated index of socio-economic spatial vulnerability value ($SEP_v$):

$$SEP_v = NI_p + NI_f + NI_{gp}$$

(4)

Further, based on the index values a rating of municipalities is compiled (distribution from maximum to minimum values); boundaries of the index intervals (which demarcate municipality’s types) are delineated by graphoanalytical method.

The socio-economic density index is calculated by a similar algorithm.

Assessment of population density ($P_d$):

$$P_d = P / S_{e1}$$

(5)

Assessment of gross production density ($GP_d$):

$$GP_d = GP / (S_{e1} + S_{e2})$$

(6)

Assessment of fixed assets density ($F_d$):

$$F_d = F / S_{e1}$$

(7)

The socio-economic density index of municipalities ($SEP_d$) is calculated by aggregating of three normalized indicators (population density $- NP_d$, fixed assets density $- NF_d$, gross production density $- NGP_d$):

$$SEP_d = NP_d + NF_d + NGP_d$$

(8)

Comparison of indices calculation results with natural hazards data at the consider territory makes it possible to identify municipalities with the maximum risk level.

3. Results and Discussion

The socio-economic space of South Siberia is characterized by its compressed. According to our calculations, the first 10 municipalities (Krasnoyarsk, Novokuznetsk, Irkutsk, Kemerovo, Barnaul, etc.) concentrate 38% of macroregion population, 49% of gross production and 46% of fixed assets (figure 1, figure 2, figure 3). Besides the study area is characterized by a pronounced internal contrast of three socio-economic potential elements density values. So, in terms of gross production density the value in the first and last municipality in the ranking has a 14.5 thousand times difference (by
population density – 3.3 thousand times, by fixed assets density – 53 thousand times). For comparison, in another Russian more evenly developed mountain macroregion – in the North Caucasus – the differences in gross production density and population density are only 2.6 and 1 thousand times, respectively. Strong internal differences in density characteristics show the heterogeneity of South Siberian spatial development, and, therefore, the heterogeneity of its spatial vulnerability. So, lands of poorly developed peripheral districts are poorly involved to the economic turnover. The most developed zones are characterized by this feature: high vulnerability with rather low density (agrarian and densely populated Altai Krai, plain part of Kemerovo Oblast, etc.). For least developed zones: low vulnerability with high density (peripheral mountainous areas of Irkutsk Oblast, Buryatia Republic, Zabaykalsky Krai with its local resource type of development).

The map (figure 4) illustrates the results of two indices comparison, it shows an integrated spatial vulnerability and most vulnerable to natural hazards municipalities in South Siberia. Among

**Figure 1.** Population structure of South Siberian municipalities.

**Figure 2.** Gross production structure of South Siberian municipalities.

**Figure 3.** Fixed assets structure of South Siberian municipalities.
potentially the most vulnerable municipalities with values of density and spatial vulnerability socio-economic potential indexes the higher than the average macro-region one we can single out those: all regional capitals (Krasnoyarsk, Kemerovo, Irkutsk, Abakan, Barnaul, Chita, Gorno-Altai, Kyzyl, Ulan-Ude) and other large in population and in scale of economy cities (Novokuznetsk, Bratsk, Achinsk, Sayanogorsk, etc.).

Figure 4. Integrated spatial vulnerability of socio-economic potential in South Siberian municipalities, 2017.

Figure 5. South Siberian municipalities groups by the ratio of socio-economic potential density and spatial vulnerability indices with debris flows hazard.
In the municipalities group with high values of potential density with its low vulnerability disposed primarily mountain territories (Sorsk, Sayansk, Severobaikalsk, Bodaibo District, etc.). These are mainly peripheral areas with local development, where the presence of mineral resources historically determines the economic activity areas. In the first approximation, the level of vulnerability to natural hazards looks low there due to small developed lands share in total municipal area or due to low absolute values of the potential parameters. But the calculations shows that it is namely high potential concentration, if other things being equal, makes the territory more vulnerable.

Analysis of the South Siberian municipalities’ combinations results by the ratio of socio-economic potential density and spatial vulnerability indices with debris flows hazard (figure 5), helps to identify municipalities with the highest risk level. These are: Irkutsk, Novokuznetsk, Abakan, Ulan-Ude, Tunkinsky and North Baikal districts of Buryatia Republic.

4. Conclusion
Created integral indices of socio-economic potential density and its spatial vulnerability help to identify the probability of maximal potential concentration and hypothetical natural hazards areas crossing at each point of the space under consideration. In general, the method approbation on the South Siberian territory allowed to detect an important pattern: high absolute values of socio-economic potential components with its high spatial concentration and, finally, a high spatial vulnerability degree determine the maximum integral potential vulnerability in space and, accordingly, the maximum risks in case of hypothetical disaster realization (under other equal conditions). It is very important to note, that municipalities with very different socio-economic and spatial development levels may have the same vulnerability level. In all South Siberian regions there is a debris flows hazard. But the risk level is lower here than, for example, in the North Caucasus, because there is no lack of land resources that’s why the most dangerous areas are rather poorly developed.

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