Damage from natural disasters: Fast growth of losses or stable ratio?

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[1] The analysis of an average amount of damage from natural disasters as in the death toll and in money equivalent allows to conclude a fast nonlinear growth of damage amount with time. The result was used to be ascribed to growth of population, development of potentially hazardous industries, and general deterioration of environment. Extrapolation of the tendency for an increase of average damage amount suggests that all the economic gain will be taken up by greater losses from natural disasters by the mid-XXI century. Empirically, the distribution of damage amount from disasters, as a rule, is governed by laws of the heavy tail of the distribution. However, an ordinary approach based on average values will be incorrect for such distributions, because in this case formally evaluated average values prove to be infinite. The application of statistically more correct approaches for description of disaster pattern results in qualitative change in prediction character. It becomes possible to establish limits of nonlinear growth of damage amount; while the comparison of the latter with data on social-economic development makes it possible to interpret damage pattern as an example of realization of principles in terms of the sustainable development concept. It turns out, that by increase of damage in cost, normalized values of losses tend to decrease with the social-economic development. The above analysis was based mainly on statistical data for seismic disasters, however, the authors believe that the results obtained, can be applied to other types of natural disasters as well. *INDEX TERMS:* 1240 Geodesy and Gravity: Satellite geodesy: results; 1242 Geodesy and Gravity: Seismic cycle related deformations; 8488 Volcanology: Volcanic hazards and risks; *KEYWORDS:* natural disasters, hazards, risk, assessment.

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Tu ne cede malis
Sed contra audentior ito!
Virgil

Introduction

[2] Mass media is abound in information about natural disasters: hurricanes, earthquakes, floods, droughts occur in one or another place of the globe. Consequences of such disasters sometimes are horrific. So, the death toll of the 2004 Sumatra earthquake amounted to 320 thousand people, in the Tien Shan 1976 earthquake in China according to different sources there were as many as 240 to 650 thousand. During floods in China and Bangladesh in 1931 and 1970, casualties numbered 1300 and 500 thousand, respectively. For the development of the mankind it is important to understand a recurrence pattern of natural disasters and to predict a possible damage.

[3] Many authors have studied changes in tendencies of damage amount from natural disasters. Based on the data reported at the World Conference on Natural Disasters held in Yokohama (1994), the number of disasters over a period of 1962–1992 increased by a factor 4.1 as this takes place, the damage amount increases on the average to 6% a year and a number of casualties rises to 4.3% [*Vorobiev et al.,* 2000]. Based on such statements, there comes unfavorable forecast, that by the end of the XXI century all the economic gain will be taken up by growing losses from natural disasters [*Osipov,* 2001, 2002; etc.]. Figure 1 provides an example of such a regularity (after data-base EM-DAT: International Disaster Data-base, www.em-dat.net) inferred from global data on the number of major disasters and resulted damage amount. A tendency to disaster growth in number and dam-

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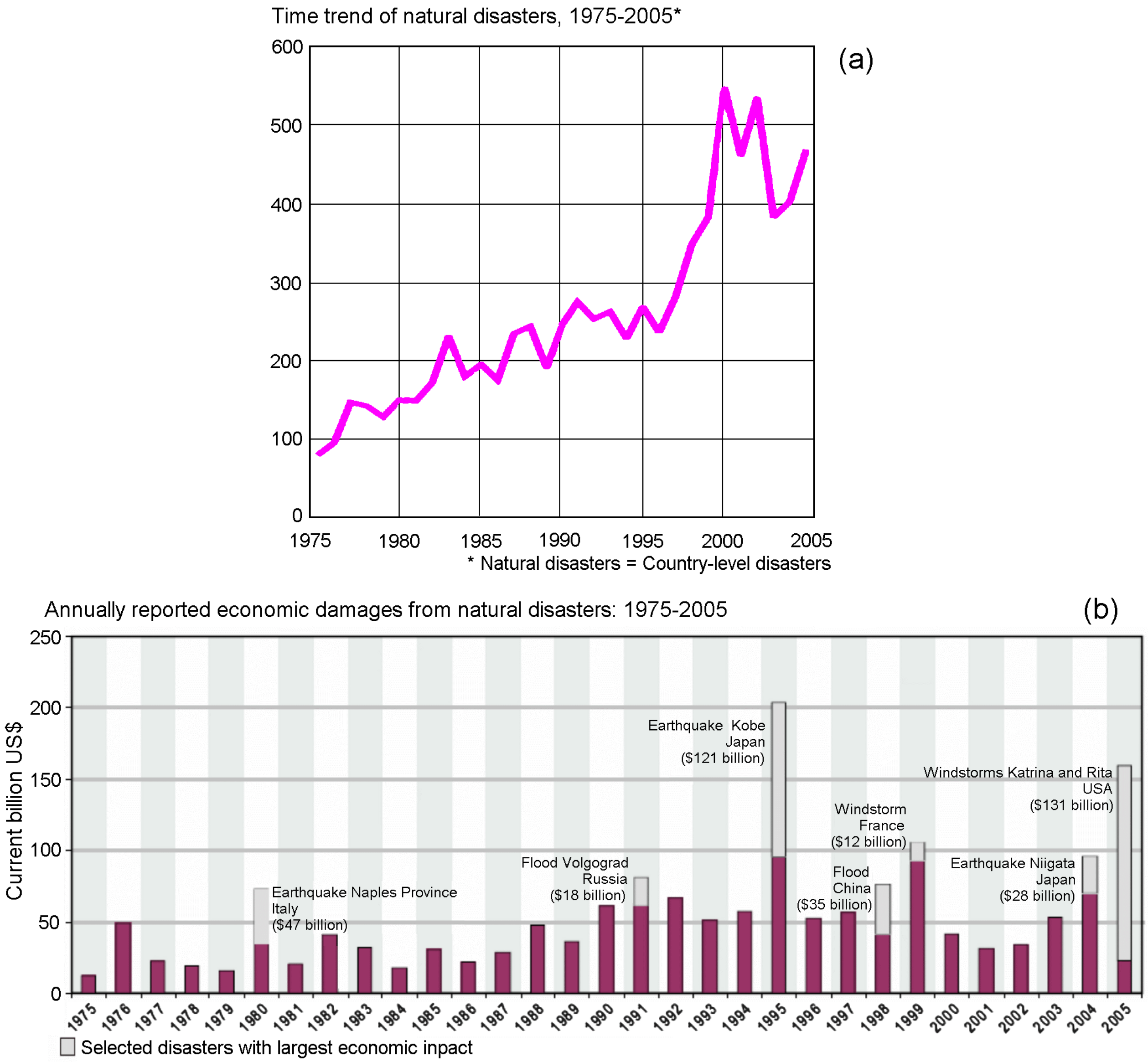

Figure 1. Change in number of natural disasters in the world (a) and damage from disasters (including separate most strong events) over a period of 1975–2005, based on EM–DAT: The National Disaster Database (http://www.em-dat.net).

age amount from disasters is used to assign to increases in population, development of potentially hazardous industries, general worsening of geoenvironment, and involving into operating economy of less environmentally friendly territories.

[4] However, the statistical approach used in the analysis of disaster pattern and hence the prediction results are not quite correct. The problem is the presence of occasional anomalously great damage amount comparable with net damage estimates. So, the death toll from the two above mentioned – Tien Shan and Sumatra earthquakes – amounts to about one-third of casualties from earthquakes for the entire XX century. Such a comparison makes one think that the conventional approach based on calculation of average values cannot give reliable estimates, hence other statistical approaches are required to study the damage pattern from disasters. The correct analysis of the damage pattern is given below, so the character of the resultant prediction will undergo a qualitative change. Thus, the prediction of not disastrous growth, but a model of quasi-stationary relative damage values tending to decrease with fast social-economic development seems a more justified.

Stationary Model of Nonlinear Growth of Damage From Seismic Disasters

[5] The study of natural disaster pattern was based on the authors' compiled database of damage from earthquakes

[*Rodkin and Pisarenko,* 2000]. Such a choice was caused by the fact, that data allowing to reliably track the character in change of the death toll from natural disasters over the last century are available only for earthquakes, moreover starting from the 1950–1960s the data on the economic damage are fairly comprehensive. As to the other natural disasters, the information is not abundant. However, the data available convincingly imply a qualitative uniformity of damage patterns from different types of natural and natural-technogenic disasters and make one assume, that the obtained conclusions may be used not only in case of earthquakes but may be applied to other types of natural disasters. The presented results of the damage pattern from earthquakes were obtained by *Pisarenko and Rodkin* [2003a, 2003b], *Rodkin and Pisarenko* [2000, 2004, 2006], etc.

[6] The above mentioned general tendency of nonlinear growth of cumulative damage is well exemplified by earthquakes. A number of the 1900–1999 earthquakes resulted in casualties growth with time as $t^{1.4}$ and the total death toll as $t^{1.6}$. This might result in the conclusion about nonstationary growth of damage from earthquakes. However, such a conclusion is not correct.

[7] To analyze seismic disaster pattern in more detail all the events will be divided into three scale-ranges with the death toll from 1 to 10 persons, 11 to 100 and above 100 persons, respectively. A number of events within the three scale-ranges (due to difference in completeness of information about powerful and weak disasters) is almost the same. More than 99% of the general death toll fall into scale-range III with events, whose casualties numbered more than a hundred. Hence, important changes in the cumulative death toll may be associated only with events of this scale-range. However, there is no considerable growth in a number of disasters of scale-range III. A fast growth of a general number of seismic events is associated with increase in number of earthquakes of scale-range I resulted in death of 1 to 10 persons (Figure 2). Disasters of this scale-range resulted in casualties numbered less then 0.1% of the total death toll,

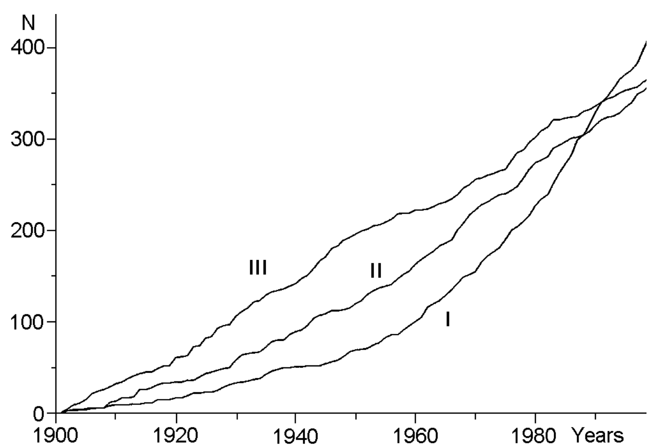

Figure 2. Time-dependent cumulative number of earthquakes N with a different number of losses (scale-range I–III). It shows a flow stationary of extreme disasters of scale-range III, casualties numbered no less than 100 persons.

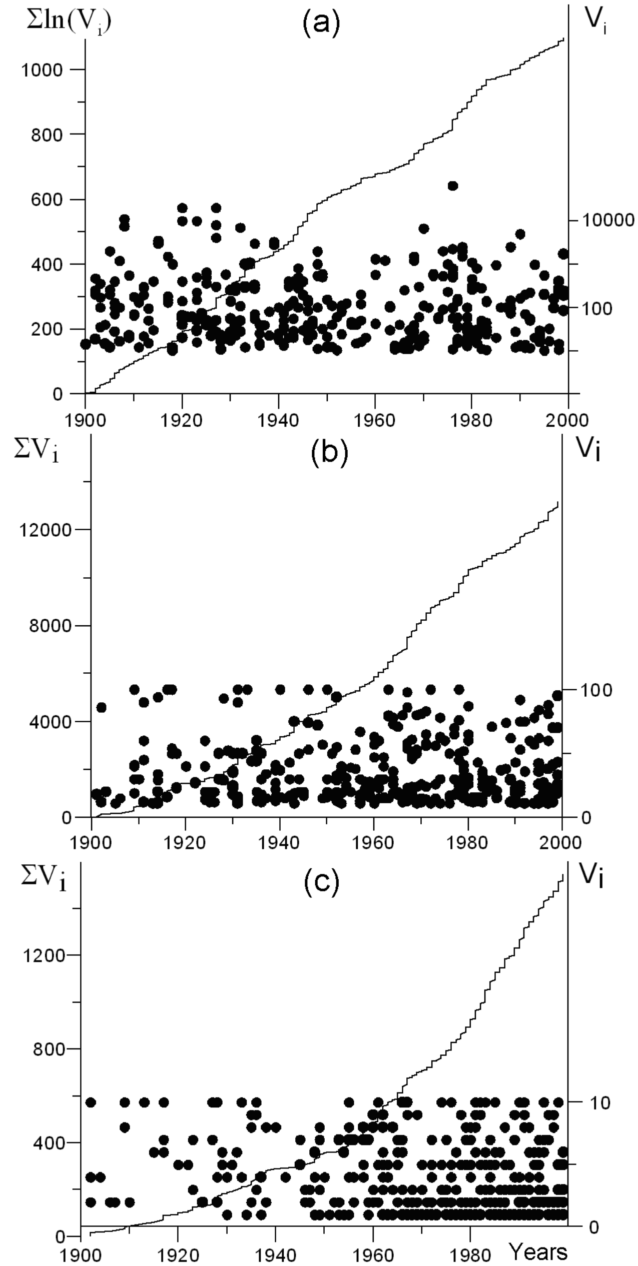

Figure 3. The sequence of the death toll (V) by successive events (dots) and total death toll (line) at different scale-ranges. (a) – events of scale-range III, (b) – II, and (c) – scale-range I. Logarithm of the death toll was used for scale-range III. Stationary in the death toll distribution is marked in case of very strong disasters.

hence the increase in number of such events should not affect the cumulative death toll.

[8] To find out, whether the distribution of a number of casualties changes with time within different scale-ranges, we plotted the death toll by successive events of all the three scale-ranges versus cumulative death toll (Figure 3). For events of scale-range III the death toll was replaced by loga-

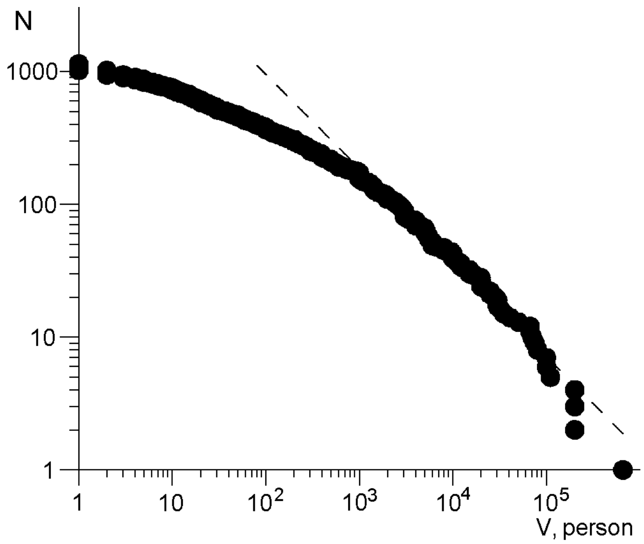

Figure 4. Distribution of the death toll V from separate earthquakes. Dotted line is an approximating straight line corresponding to the Pareto power-distribution. Distribution of 150 strongest disasters is seemed to follow the power-distribution with exponent of power $\beta < 1$.

rithms, because of inadequate presentation of values differing in 1000 times at a linear scale. In case of steady-state process distribution of the death toll in some events should not undergo considerable changes, and the curve slope showing cumulative death toll by the events of this scale-range (or sum of logarithms of the death toll) should not be subjected to important systematic changes.

[9] Figure 3a shows that sequence of values for the death toll in events of scale-range III does not change systematically. The curve of cumulative sum of logarithms in fact does not differ from straight line suggesting stability of the death toll logarithm mean. Hence a conclusion about stationary of a number of strongest seismic events and distribution of the death toll from such earthquakes. A sequence of values of cumulative death toll in events of scale-range II (Figure 3b) also does not show important changes, whereas growth of cumulative sum shifts slightly from a straight line. Only the event pattern of scale-range I reveals a strong non-stationarity. A number of such events grows fast (Figure 2), while an average death toll in case of unit event tends to decrease (Figure 3c). However, such changes is naturally to attribute to a better record system and not to a change in recurrence pattern of seismic events.

[10] Thus, a strong non-stationarity of seismic event pattern is reported only for weak events totaling less then 1% of the total death toll. Such a non-stationarity cannot explain an observed tendency of a strong growth of the death toll with time.

[11] There appears an apparent controversy attributed to the fact, that nonlinear growth of cumulative death toll may take place in a stationary case as well. Here, it is to be accounted for specific distribution of casualties from earthquakes, namely drastically high (as compared to normal distribution) probability of a disaster that caused an extremely great number of casualties. A distribution of casualties from earthquakes over a period of 1900–1999 is shown in Figure 4. The figure shows that distribution of 150 major seismic events (responsible for 96% of the total death toll) is described by the Pareto power-series distribution with an exponent of power of distribution of $\beta = 0.71 \pm 0.06$. A density of power distribution $f(x)$ is given by the relation

$$f(x) = \begin{cases} \dfrac{\beta a^{\beta}}{(x^{1+\beta})}, & x \geq a \\ 0, & x < a \end{cases} \tag{1}$$

[12] Another condition (typical of damage cases) that the power distribution starts to be fulfilled with some minimal damage quantity a is entered into equation (1). The condition is caused by a fairly incomplete statistic on minor disasters. Noteworthy, that an actual law of distribution for a number of weak disasters is not of real interest, because they contribute slightly to the total damage amount.

[13] This also holds true to the power pattern with cut off in case of weak disasters showing distribution of a number of casualties from hurricanes, floods [*Pisarenko,* 1998] and other types of natural disasters and the same distribution pattern of economic damage values. As an example, Figure 5 shows data on economic losses from natural disasters in the USA (the data seem to be the most reliable, because the insurance premium has been paid).

[14] Atypical (imitating the presence of non-stationarity) behavior of cumulative damage values is due to the fact, that mean value and dispersion are infinite for power distribution of eq, (1) type with an exponent of power of distribution $\beta \leq 1$ (such distribution are called the heavy tale distribution). A unit maximal event and the total effect for such distributions turn to be of the same order. Probability of realization of an extremely strong disaster increases with time of observations, and, correspondingly, accumulative damage value increases nonlinearly. As a result, a tendency of non-linear growth cumulative damage with time is observed in the context of a well-defined stationary model.

[15] In case of heavy tail power-law distributions, medians, i.e. values accounting for not more than 50% of elements of a sample and no less than other 50% of elements, are used instead of mean values that are formally infinite. In our case of special interest is an estimate of median of expected total damage in time t, $\sum_t$, or resulted from n events, $\sum_n$. Analytically, this problem can be solved using the relation between the total damage median $\sum_n$ and that of distribution of M_{max} of sample μ_n

$$\sum_n \cong \frac{\mu_n}{(1-\beta)} , \tag{2}$$

where maximum μ_n can be found using a known distribution function. For distribution (1), in case of not a few number of events, a relation to determine the quantity μ_n takes a form

$$\mu_n = a \left(\frac{n}{\ln(2)} \right)^{\dfrac{1}{\beta}} . \tag{3}$$

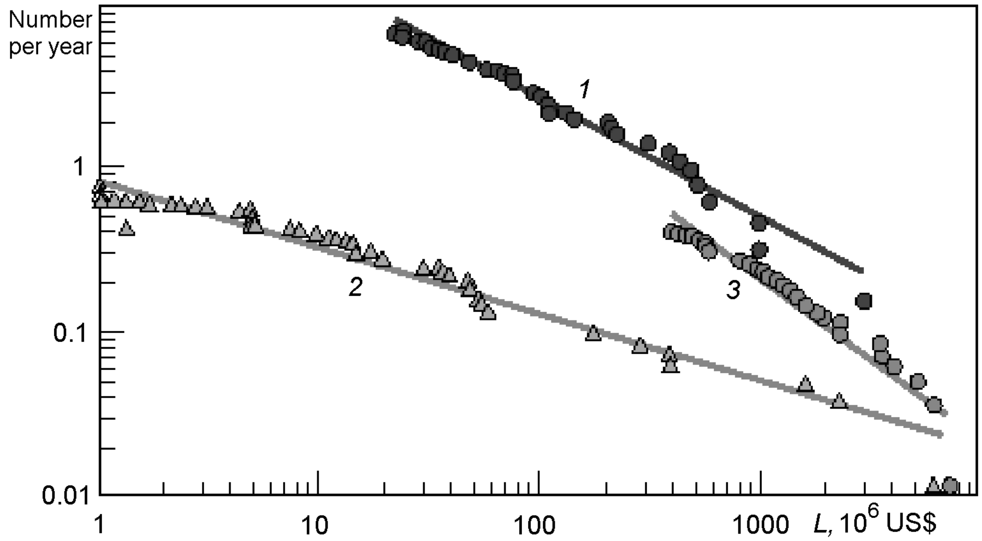

Figure 5. Distribution of economic losses from occasional events (mil. US dollars) per annum for: floods (F), earthquakes (E), and hurricanes (H). Data on the USA for 1900–1989 (earthquakes and hurricanes) and for 1986–1992 (floods). Lines are plots for the approximating power-distribution with exponent of power $\beta = 0.74$ (floods), $\beta = 0.98$ (hurricanes), and $\beta = 0.41$ (earthquakes).

[16] Equations (2) and (3) show that the quantities μ_n and $\sum_n$ increase with number of events or with time nonlinearly as $n^{1/\beta}$ or $t^{1/\beta}$, respectively. Relations (2) and (3) are convenient to use for evaluation of specific total damage in these cases, when the empirical distribution of damage is described by the Pareto law at $\beta < 1$. Quantitatively close estimates of damage can be obtained by means of numerical simulation.

[17] Let us sum up. The analysis of the power pattern of the damage value distribution (1) implies, that nonlinear growth of cumulative damage can occur within the framework of the stationary model, i.e. empirically observed nonlinear growth of damage is not necessarily assumes the non-stationary disaster pattern. In case of earthquakes, it turns out that the observed tendency of damage growth with time might be easily attributed to the presence of the heavy tail of the damage distribution (a number of casualties and economic losses) caused by occasional earthquakes. Actually, according to relations (2) and (3) an expected nonlinear growth of the death toll is given by exponent $\dfrac{1}{\beta} = \dfrac{1}{0.7} = 1.4$; whereas an empirically revealed law of average growth amounted to 1.6. It is obvious that an observed growth of casualties caused by earthquakes accounted for an important scatter in behavior of different statistical achievements is not in conflict with the stationary model (1). Actual non-stationarity (discussed below) is of secondary importance.

[18] Naturally, in case of other types of natural disasters, for example, hurricanes, whose recurrence pattern depends on climate changes, a real non-stationarity may be of great importance. However, at least partly the observed effect of nonlinear growth of damage amounts with time, will be due to the power distribution law of damage, caused by individual hurricanes. Noteworthy, for the case of the number of people, who became homeless during floods the readers are referred to the paper by *Pisarenko* [1998] showing a key role of this factor.

[19] The presented schematic diagram shows the growth of damage with time for the case of the heavy tale distribution. However, two important questions remain unsolved. First, within which range simulation of damage distribution can be described by the power law, and hence when is nonlinear growth of total damage with time to be expected. Second, what is the relation between damage amount and such important social-economic processes as the growth the population and the development of technosphere. Let us discuss these issues.

The Relation Between Damage Pattern Caused by Earthquakes and Social-Economic Development of the Society

[20] It is obvious, that the death toll from any disaster cannot exceed population of the Earth, while material damage cannot be higher than the total cost of technosphere. It means, that the power law of damage distribution cannot be realized in case of very great damage. A real pattern of damage distribution will not satisfy the power-law distribution at $\beta < 1$ for events $x > A$, where A is necessarily not above an event of the "doomsday" type. An event with an extent of $x \cong A$ will be named characteristic maximally possible disaster. For interval larger than that of recurrence of such an event, the growth damage pattern changes qualitatively. The total damage amounts will be linearly time dependent, and the use of mean values becomes justified.

Table 1. Relation between characteristic amounts of damage from earthquakes and social-economic conditions in different countries

Region	Number of events and data on casualties	Mean amount of damage, $\$10^6$	Mean damage/casualties ratio, $\$10^6$ per capita	Annual value product, $\$10^3$ per capita (for 1970)	(4)/(5) ratio $\times 10^3$	(3)/(5) ratio $\times 10^3$ per head per annum
(1)	(2)	(3)	(4)	(5)	(6)	(7)
North America	36	800	32	4.5	7.1	180
South Europe	167	340	8	1.5	5.3	230
Japan	74	430	5.5	1.6	3.4	270
Latin America	236	130	1.3	0.5	2.6	260
Asia	415	50	1	0.2	5	250
Indochina	133	30	1.2	0.2	6	150
max/min		45	32	30	3	2.2

It means, that it is important to determine a quantity of characteristic maximal event A, and what is the time interval when such a change in the damage distribution pattern takes place.

[21] A number of approaches to characterization of maximal possible event A and the recurrence period of such event T_a have proposed and verified, using the data of the Harvard Catalogue of Seismic moments, in the works [*Pisarenko and Rodkin,* 2003b; *Rodkin,* 2007; *Rodkin and Pisarenko,* 2006]. To more correctly determine these parameters it is better to divide the available data aggregate into the uniform groups. Further we will discuss a relation between statistical characteristics of natural disaster pattern and social-economic parameters, therefore we will deal with damage amounts, so breaking is to be accounted for social-economic development. Namely, let us compare a pattern of losses from seismic disasters in different regions: in North America, Europe, Japan, Latin America, Asia, Indochina (Table 1). To determine a value of a characteristic maximally possible disaster A and time of its recurrence T_a will combine the selected regions into two groups with respect to higher (North America, Europe, Japan) and lower (Latin America, Asia, Indochina) level of economic development. Such a distribution complies with the commonly accepted subdivision into developed and developing countries.

[22] To find changes in the disaster pattern due to rapid growth of the social-economic development in the XX century, we will discuss separately data for 1900–1959 and 1960–1999; because of differences in catalogue accumulation, a number of events within these two time intervals are almost the same. Assuming the distribution stationarity of the death toll during these periods of time, we estimate spe-

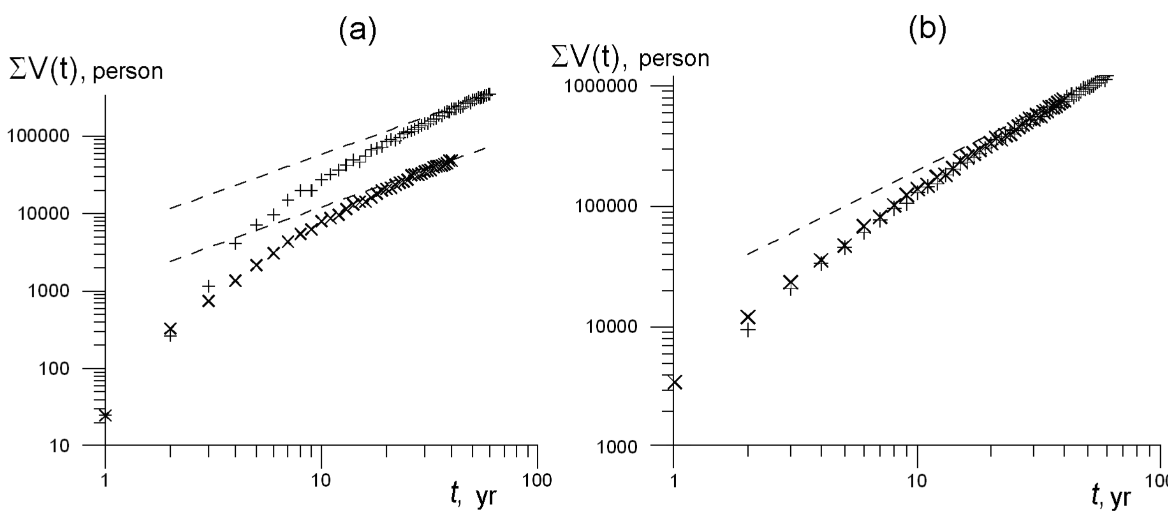

Figure 6. Models of the growth of the characteristic death toll for developed (a) and developing (b) countries. Estimates are given for the periods of 1900–1959 (+) and 1960–1999 (×). Dotted lines are straight lines corresponding to a linear growth pattern of the death toll with time. The change in growth pattern of the total death toll $\sum V$ shows a transition from nonlinear to linear growth pattern. There is also a tendency to decrease in the death toll in the developed countries.

Table 2. The Death toll from natural disasters for different regions (in growth pattern parameters)

Region	T_a, years	A, death toll	Max disaster, death toll
earthquakes			
developed countries, 1900–1959	33	95000	110000
developed countries, 1960–1999	30	24000	17000
developing countries, 1900–1959	40	270000	200000
developing countries, 1960–1999	65	260000	240000 (650000)*
floods			
North America and European Union, 1950–1979**	15	1500	650
North America and European Union, 1980–2005**	10	500	200

Note: * – expert (probably overestimated) assessment of the Death toll from Tien Shan earthquake, China, 27.07.1976. ** – after the database EM-DAT: the International Disaster Database (http://www.em-dat.net).

cific quantities of cumulative death toll $\sum V(t)$ over a time period from 1 to 60 and from 1 to 40 years, respectively. In this case, it is possible to use the analytical approach based on relations (2) and (3) along with numerical simulation (to do this we randomly accumulate sums of the death toll for 1 to t years from the observed aggregate of an annual number of casualties, so we take the median of these random realizations).

[23] Figure 6 shows simulation results strongly implying the change in growth pattern of the total death toll caused by earthquakes with time: i.e. from nonlinear growth law corresponding to the power distribution at $\beta < 1$ to linear growth law adequate to some (unknown) distribution at final value of mathematical expectation. Based on the distribution with finite mean value obtained $\sum V(t)$ we find the length of the time interval T_a of the change from nonlinear to linear growth pattern $\sum V(t)$. A maximally characteristic disaster A is defined as an event with specific times of recurrence in T_a years. Table 2 presents the obtained parameters T_a and A along with the data on the maximal death toll Max from one earthquake. Figure 6 and Table 2 show that characteristic cumulative death toll and extent (size) of maximal seismic disaster A decreased essentially during the second half of the XX century in the developed countries.

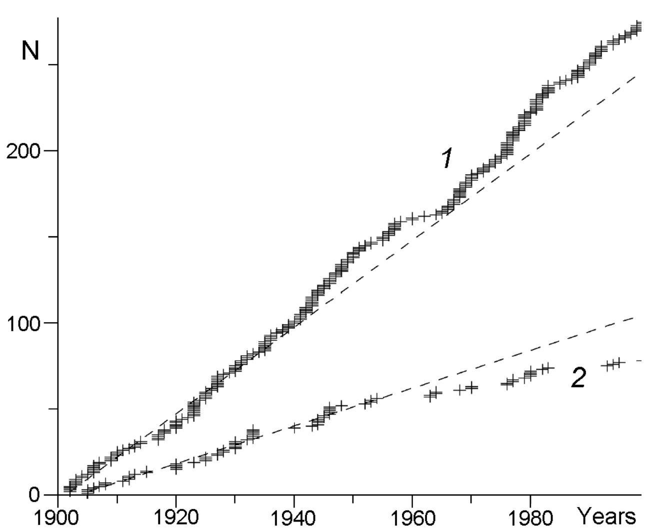

Figure 7. Deviation of a number of disasters N with casualties above 100 persons from linear prediction (dotted line). (1) – developing countries, (2) – developed countries. Disaster flow becomes less intense in the developed countries and more intense in the developing countries.

[24] A similar estimate was based on a less representative data on flood losses from the database EM-DAT: The International Disaster Database www.em-dat.net. Table 2 presents also the estimate suggesting the decrease in the death toll in the developed countries from the floods.

[25] The described approach gives an answer to the first of the above stated question, i.e. to evaluate the limits of application of the power-law distribution with exponent of power $\beta < 1$. As a result, the length of time when such an approach was used is given by time interval T_a, and maximal disaster described by this relation is defined by characteristic maximal disaster A. At the same time it implies a probable characteristic relation between a disaster pattern and social-economic development.

[26] Now let us consider the relation between damage from seismic disasters and social-economic parameters. The population of the world is known to have increased four-fold during the XX century. However, the growth of disasters with casualties numbered more than a 100 persons has not been reported (Figure 2). This makes it possible to assume the presence of a factor compensating for potential growth of vulnerability of society with increase of population. It would appear natural to attribute such a compensation to the advancement of technosphere. If it is really associated with the above factor, then with due account for difference in the technical development in the developed and developing countries, one should assume overcompensation and under-compensation in the first and second case, respectively.

[27] Let us verify this assumption. Figure 7 shows a number of disasters with casualties more than 100 persons, that took place in developed and developing countries. It presents also a linear extrapolation to intensity of flow of a number of major disasters inferred from the data over the period of

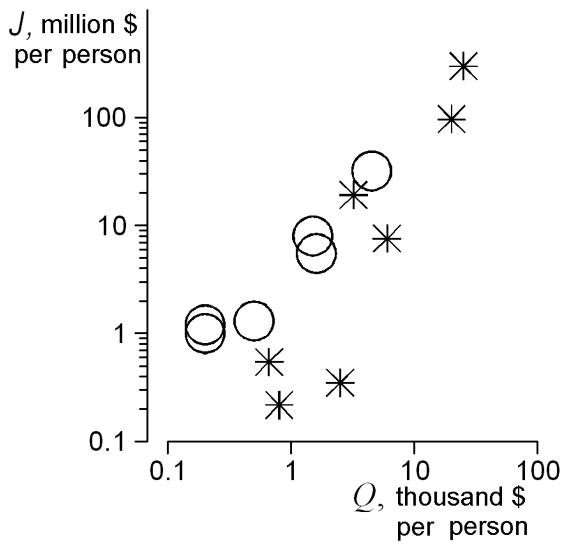

Figure 8. Growth of "damage/casualties" ratio J increases with an annual per capita national product Q, based on Table 1 data (circle) and for earthquakes in megapolises (asterisk).

1900-1939. We notice that the major seismic disasters of the second half of the century differs greatly from results of extrapolation. An actual number of major seismic disasters turned to be less than that to be expected in developed countries and slightly higher than that of developing countries.

[28] Now let us compare data from different regions (Table 1). The relation between the damage characteristics and social-economic parameters follows from the comparison of data on damages and those of per capita national product (information from database http://unescostat.unesco.org/database). There is correlation between an average ratio of material damage per dead ("damage/casualties") and a national product per head ("per capita product"). This ratio shows a relatively constant value of 5.2±2. Minimal and maximal ratios differ only by factor 3, whereas the scatter of "damage/casualties" and "per capita product" parameters by in order of magnitude higher when taken separately. It means that a characteristic material damage to the death toll ratio shows a regular change in the course of economic development, remaining roughly proportional to the annual per capita product.

[29] Now material damage from earthquake is to be discussed. Material earthquake losses are known to increase with time. However, to understand the impact of natural disasters on the development of the society one should envisage not this particular effect (fairly expected), but changes of relative losses normalized to current level of national wealth. An annual per capita product – comparison of man-years required to compensate for damage – is taken as the unit of measurement. Damage from major earthquakes in different regions measured in this units turned to be almost the same, namely (200±50) thousand man-years (column 7, Table 1). Such a result might be interpreted in terms of quasi-stationarity of an amount of a relative material damage from earthquakes in the history of mankind.

[30] Damage from seismic disasters increases greatly (and often more accurately estimated) if it occurs in a megapolis area. In this case, important changes in the damage pattern may be caused by the difference in the economic development in different countries. For comparison we shall use a set of data on destructive earthquakes in the largest cities of the world over a period of 1971–1995 [*Kronrod and Nekrasova,* 1996] along with the above mentioned UN database (http://unescostat.unesco.org/database). We were able to get a required minimal set of data (magnitude, population number of casualties, material damage, per capita national product) only for several events. Figure 8 shows a dependence between material damage per capita and a level of per capita national product as inferred from these data. There is a close correlation between the parameter J – "damage/casualties" – and an annual per capita national product Q. The coefficient of correlation is $r = 0.94$ (at a double logarithmic scale of 0.83) at the significance of relation of more than 99%.

[31] Considering the relation between natural disaster pattern and social-economic development it is pertinent to ask how short a time interval should be for such a relation to be realized. The fastest and more important changes in social-economic situation take place during the periods of social-economic cataclysms. Hence, the question, whether such cataclysms can give rise to changes in vulnerability of the society resulted from natural disasters. To preliminary discuss this issue we made an attempt to compare changes in disaster pattern in such large countries as Russia and China who have undergone staggering social-economic shock.

[32] As to China (area of fairly height seismic activity), it is possible to compare changes in vulnerability to seismic impact and main milestones in the social-economic history of the stormy XX century. The first-third of the XX century is known to be marked in China by the development followed by a period of intervention and civil war. The time of a relatively successful development after the Second World War gave place to the years of the Cultural Revolution. Since the early 1980s China witnessed a stable and fast economic growth. Such a history of development was reflected in the seismic disaster pattern. Plots in Figure 9 show the death toll during strong earthquakes normalized to earthquake energy and to a current number of people in China. As a whole, there is a tendency to decrease in relative losses from seismic disasters, but it was complicated by a relative increase in vulnerability during the 1970s and early 1980s. Since the mid-1980s there was observed some growth in a number of events but consequences were not that grave. The growth in number of events can be explained by a more complete record, whereas a decrease in normalized number of the death toll would be reasonably to attribute to a fast economic growth of China.

[33] There is just a few earthquakes in Russia, therefore the database created in the Laboratory of the geological risk analyzes of IGE RAS was used to analyze the disaster pattern; this database includes data on natural and natural-technogenic disasters that have taken place in the present territory of Russia since the X century till resent [*Ragozin*

et al., 2003]. The database contains more than 1300 extreme events differing in genesis, negative consequences and in other characteristics. 193 cases of most hazardous events: earthquakes, landslides, mudflows, floods, avalanches, hurricanes, tsunami, and other abiotic disasters have been chosen. All the above cases according to the rules of the EMRCOM (Provisions on classification of emergency situations of natural and technogenic character. Adopted by the Decree of the Government of RF no. 1094 of 13.09.1996) meet the provisions on emergency situations of the federal level. According to the database compilers such a selection provides acceptable completeness and uniformity of data on a number of disasters [*Ragozin et al.,* 2004].

[34] Figure 10 shows an annual number of strong disasters (dots) and moving modified for five years average dependence of a number of disasters. Apparently, during this period of time the society became anomalously vulnerable to potentially hazardous natural and natural technogenic impact due to the change for the worse of social-economic situation. The inobservance of production discipline and incompliance with work performance can strongly affect a probability of occurrence and strength of natural and technogenic disasters, and might well play an important role. Long delay in wages and salaries could not strengthen the labor discipline and work performance rules. In the time of crisis there were also no means for preventive maintenance and safety measures.

[35] Figure 10 also shows (may be accidental) decrease in average number of disasters in the mid-1990s and a new much weaker peak during 1998–1999. Hypothetically, it is possible to associate these peculiar features with economic revival in the mid-1990s and with the crisis of the 1998, that also resulted in delay of wages and salaries, and freezing of many projects.

[36] A hypothesis about the relation between changes in number of disasters and short-term changes in a social-economic situation seems quite realistic, and the data of analysis for Russia and China strongly support the hypothesis. If we assume, that even extensive preventive engineering measures cannot be accomplished during a short time interval, still infrastructure, management, and communication systems might be markedly improved; as a result all the above can lessen the burden from disasters. One has to remember, that the Emergency Committee (EMRCOM), powerful in resources available, was set up in Russia during the time interval in question.

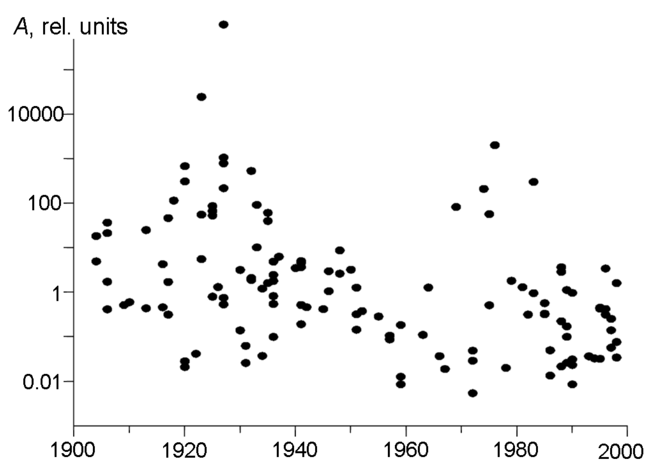

Figure 9. The death toll (in arbitrary units) normalized on population of China and earthquake energy. A relative growth of vulnerability of the society during the Civil War and intervention, and in time of the Cultural Revolution along with an marked decrease in normalized death toll in the end of the XX century.

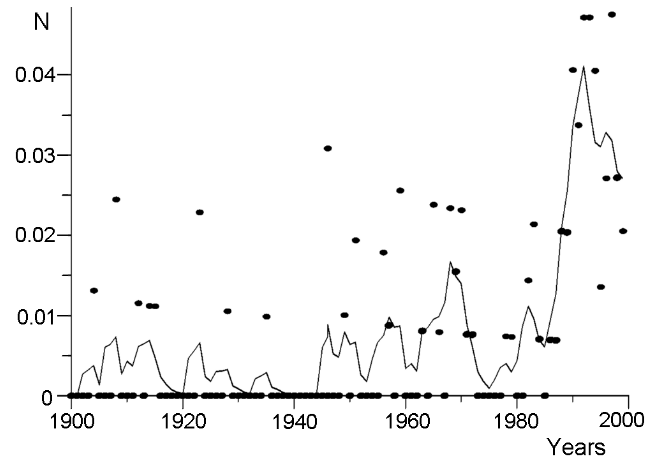

Figure 10. Annual values of a number of strong disasters in Russia [*Ragozin et al.,* 2003] per million of population (dots) and averaged values on overlapping 5-year time intervals (lines).

[37] The above presented conclusions about the relation between seismic losses and social-economic conditions are in good agreement with results obtained by other authors. A statement that regions with a fairly low level of economic development are less resistant to earthquake impact was published in [*Sobolev,* 1997]. Similar conclusions about the relation between characteristics damage amount from natural disasters and a level of social-economic development are presented in the work by *Kahn* [2003]. The study provides an analysis of data on 225 strong (major) natural disasters over a period of 1990–2001. The author presents relation between a characteristic death toll from natural disasters and social-economic situation in different countries. As a result, the analysis revealed a number of empirical relations. For example, the growth of gross national product (GNP) from 2000 to 15000 dollars per capita per year will correspond meanly to decrease in a number of casualties by 500 people in year for a 100 million of population. Another important factor affecting an average death toll from disasters is a management structure; countries with more developed democratic institutions turned to be relatively less vulnerable (in terms of normalized casualties from natural disasters).

Damage Pattern From Natural Disasters as an Example of Realization of the Sustainable Development Concept in Practice

[38] The above mentioned empirical relationship (and some other references omitted for reasons of space) makes us doubt the validity of a pessimistic prediction of a catastrophic growth of damage caused by natural disasters, that was mentioned in the beginning of the paper. In fact, the growth in number of disasters is mainly caused by the better record system of weak disasters. As to nonlinear growth of total damage with time, this effect (at least partly) arises from the power-series distribution of damage amount and not by its non-stationary growth.

[39] Proceeded from the relation between the seismic disaster pattern and social-economic parameters there are all grounds to assume a decrease in intensity of the disaster flow with a large number of casualties in the developed countries, and then a further extension of this tendency to the developing countries (as their economic and social situation develops and as the rate of population growth slows down). If the tendency to growth of absolute values of material losses is preserved, than a relative stability, and possibly, a decrease of normalized values (in units of private income) seems to be quite feasible.

[40] An attention is called to a marked uniformity of normalized values of damage from earthquakes in different countries. There is an impression, that some social communities and mankind as a whole has adapted in the course of its historical development a certain permissible (depending on concrete social-economic conditions) to a level of damages from natural disasters. It is possible to assume that if such a relation remains persistent, it will result in an optimal link between the profit from the use of some or other natural resources and losses caused by their use in the course of natural disasters (for example, the use of fertile soils in the river valleys presupposes flood damage). Thus, in case of damages from natural disasters, the principles of the sustainable development turn to be implemented. An example of the realization of the sustainable development concept in practice promises that this optimistic concept can be realized also under more complicated conditions, when people and environment will be more closely interrelated. An example of a possible practical realization of the sustainable development concept becomes even more important, because the discussion on this issue is dominated by a pessimistic viewpoint, namely, that "despite unprecedented large scale discussion of sustainable development, the world keeps developing along the trajectory of non-sustainable development" [*Kondratiev and Losev,* 2002, p. 598].

Inferences and Conclusion

[41] It is common to consider that the noted growth of damage from natural disasters depends on the increase in number of population, the development of potentially hazardous industries, and general deterioration of geological environment. A standard extrapolation of growth of an average amount of damage makes it possible to predict, that the entire economic gain can be taken up by still increasing losses from natural disasters by the mid-XXI century. However, the statistical approach based on mean values used in calculation is not quite correct in this particular case. The empirical distribution of amounts of damage from natural disasters, as a rule, corresponds to the power-law heavy tail distribution, and and formally estimated means turn to be infinite for such distributions.

[42] The application of more correct statistical approaches to describe a disaster pattern results in a qualitative change of the prediction pattern, when nonlinear growth (at least partly) does not depend on an actual nonlinear growth of damage amount, but is governed by the power distribution law of damage amount. The obtained comparison gives grounds to interpret damage caused by disasters as an example of the implementation of the sustainable development concept. The rise of cost due to damage will show a tendency to decrease of normalized values of losses as the social-economic situation develops. The presented analysis was based mainly on statistical data on seismic disasters, however, the authors believe that the obtained results can be, to a greater extent, used by the study of other types of natural disasters.

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References

Kahn, E. M. (2003), *The Death Toll From Natural Disasters: The Role of Income, Geography and Institutions,* http://ssrn.com/abstract=391741 or doi: 10.2139/ssm.391741 pp., University of California, Los Angeles.

Kondratiev, K. Ya., and K. S. Losev (2002), Illusions and reality of the sustainable development strategy, *Vestnik RAN* (in Russian), *72*(7), 592.

Kronrod, T. L., and A. K. Nekrasova (1996), Seismic risk in largest cities of the world: Assessment verification, *Computational Seismology* (in Russian), *28,* 225.

Osipov, V. I. (2001), Natural disasters at the turn of the XXI century, *Vestnik RAN* (in Russian), *71*(4), 291.

Osipov, V. I. (2002), Natural risk management, *Vestnik RAN* (in Russian), *72*(8), 678.

Pisarenko, V. F. (1998), Nonlinear growth of cumulative flood losses with time, *Hydrological Processes, 12,* 461, doi:10.1002/(SICI)1099-1085(19980315)12:3<461::AID-HYP584>3.0.CO;2-L.

Pisarenko, V. F., and M. V. Rodkin (2003a), Damage from earthquakes, *Computational Seismology* (in Russian), *34,* 205.

Pisarenko, V. F., and M. V. Rodkin (2003b), Problems in assessment of the long-term seismic hazard, *Nauka i Technologia v Rossii* (in Russian), No. 4–5*,* 8.

Ragozin, A. L., A. V. Uvarova, and S. A. Chumachenko (2003), Supplement catalogue of major nonantropogenic disasters in the territory of Russia over 1000 years, in *Prirodnye Opasnosti Rossii,* vol. 6, *Otsenka i Upravlenie Prirodnymi Riskami* (in Russian), p. 12, KRUK, Moscow.

Ragozin, A. L., A. V. Uvarova, and S. A. Chumachenko (2004), First results of the dynamics analysis of major disasters in the territory of Russia, in *Sergeevskie Chtenia,* Issue 6*, Inzhenernaya Geologia i Okhrana Geologicheskoi Sredy* (in Russian), p. 185, GEOS, Moscow.

Rodkin, M. V., and V. F. Pisarenko (2000), Economic damage and casualties from earthquakes: Statistical analysis, *Computational Seismology* (in Russian), *31,* 42.

Rodkin, M. V., and V. F. Pisarenko (2004), Earthquakes losses and casualties, A statistical analysis, in *Computational Seismology and Geodynamics,* edited by D. K. Chowdhury, vol. 6*,* p. 85, Am. Geophys. Un., Washington D.C..

Rodkin, M. V., and V. F. Pisarenko (2006), Extreme earthquake disasters – verification of the method of parametrization of the character of distribution of the rare major events, *Advanced in Geosciences, 1,* 75.

Rodkin, M. V. (2007), Heavy-tailed distributions: application to disaster analysis, *Computational seismology,* No. 38*,* 240.

Sobolev, G. A., Ed. (1997), *Assessment of Seismic Hazard and Seismic Risk* (in Russian), 52 pp., FTzNTP RP “Bezopasnost”, Moscow.

Vorobiev, Yu. L., G. G. Malinetsky, and V. I. Osipov (2000), *Disasters and Society* (in Russian), 332 pp., Kontakt-Kultura, Moscow.

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