Assessment of Sustainable Development on Territories under the Impact of Different Genesis Disasters

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Abstract. At present, neither international nor Russian literature sources propose any index to assess safety level of disasters that occur everywhere throughout the world. No one doubts the fact that the number of natural, man-made and social disasters, as well as resulting economic losses have increased several times over the past thirty years. In response to this trend, the study aims to develop a disaster safety level index (DSLI). The study presents methodological tools for calculating the Disaster Safety Level Index (DSLI) and calculation of the global DSLI for the 1998–2011 period. The proposed method for calculating the Disaster Safety Level Index has three advantages. Firstly, it is relatively simple. Secondly, everyone can get access to input data for calculations. Thirdly, different indicators used in the index are reduced to units of power, added together and expressed as a single number, which is very important in case of incomparable (heterogeneous) indicators. The proposed Disaster Safety Level Index (DSLI) can be used in practice to prevent disasters of various origins.

1. Introduction

There is hardly a region or place on Earth where no natural, man-made or social disasters have happened. Disasters are complex and interrelated events with a series of associated hazardous phenomena and processes that may occur simultaneously or sequentially [3]. The authors think that the term “disaster” is best defined in [1]. Disasters are discontinuous changes that occur as a spontaneous response of a system to smooth environmental changes [1]. Experts of the Centre for Research on the Epidemiology of Disasters define disasters as “an unforeseen and often sudden event that causes great damage, destruction and human suffering” [5].

Natural, man-made and humanitarian disasters, growing social instability and epidemics that occur simultaneously in a number of countries and are in synergy with each other are called mega-disasters [2]. According to [2], the term “mega-disaster” is taken from UN documents as a comprehensive, concise and convenient term for describing large-scale disasters of any nature with a large number of victims and physical damage. All mega-disasters and disasters are of natural, man-made or social origin.

Mega-disasters and disasters have global consequences and cause damage not only to the country of their origin, but also extend across borders and, in some cases, can become global in scale [3]. Disasters lead to internal migration across the globe: in 2017 alone, over 19 million people had to...
leave their homes due to disasters [7]. In order to analyze consequences and safety level of disasters, we have proposed the Disaster Safety Level Index (DSLI). The index is positioned as a combined indicator designed to assess the safety level of disasters both for individual regions and territories, and for the entire Earth on a global scale.

The purpose of the study is to develop the Disaster Safety Level Index (DSLI) and calculate this index for the entire planet over the 1998–2011 period.

It should also be noted that all natural disasters are the norm for the natural environment. In other words, all these events are considered extreme only from a human point of view. It is social vulnerability that allows us to consider a particular situation as a disaster [5].

2. Mega-Disaster Safety Level Index (DSLI)

All countries studied for the calculation of the Index are assessed by eleven indicators divided into three main groups:

1. The natural disaster safety index includes the following indicators: the national currency power, the natural disaster power, the power load factor of natural disasters, the total power density or anthropogenic load, the biosphere instability, the Fedotov [7] constant, the biosphere instability adjusted for the disaster power.

2. The man-made disaster safety index includes the following indicators: the man-made disaster power and the power load factor of man-made disasters.

3. The safety index of social disasters includes the following indicators: the social disaster power and the power load factor of social disasters.

\[
DSLI = 1 - (N_{bio125} + K_{Tdis125})
\]

where:

\( N_{bio125} \) is the total power density or anthropogenic load;

\( K_{Tdis125} \) is the mega-disaster power density relative to the critical value of the Fedotov constant (125 kW per km\(^2\)).

If the DSLI exceeds 0, the mega-disaster safety level remains below the critical level, i.e., it does not lead to an environmental disaster. If the DSLI tends to zero, the mega-disaster safety level tends to exceed the critical value, i.e., it leads to an environmental disaster. If the DSLI is negative, the mega-disaster safety level exceeds the critical value, i.e., it leads not only to an environmental disaster, but also to aggravating its negative consequences.

Schematically, this can be expressed as:

- DSLI > 0, the mega-disaster safety level does not correspond to values of an environmental disaster;
- DSLI ≤ 0, the mega-disaster safety level leads to an environmental disaster;
- DSLI < 0, the mega-disaster safety level leads to aggravating negative consequences of an environmental disaster.

The Index was developed on the basis of specialized CRED databases and official UN statistics.

2.1. Methodology

All phenomena and processes on our planet, in any region of the world, are a kind of flows in space-time. Hence, all processes and phenomena can be expressed as a flow, e.g., an energy or power flow [4].

A methodology of the Scientific School of Sustainable Development, University of Dubna, is proposed as a basic approach. The approach developed by this School can be used to compare and harmonize heterogeneous indicators. It is based on measurement of material flows, which reflect dynamics of social and natural processes, through physical quantities. This principle obeys the general law of conservation of power [4].

By consuming a flow \( N \) (total power), society will get a flow of resources, which can be measured by \( P \) (useful power).

The \( P/N \) ratio is a measure of how efficiently the insurance market uses resources over a certain period of time. The ratio of the produced power \( P \) to the power \( N \), consumed to produce the power \( P \)
is a measure of the potential society’s ability to expand its capacities. This measure can be denoted as efficiency. The total power $N$, which is available for the insurance market, is a measure of potential capacities; $P$ is a measure of real capacities to influence society; $G$ is a measure of losses (power of losses of the insurance market or benefits paid under insurance contracts).

Most importantly, all resources (flows) are comparable and expressed in units of power (MW), which makes it possible to compare them and carry out all necessary analytical operations to justify proposed solutions.

In the context of the above, the energy-environment approach is to assess all processes in any region of the world in measurable terms, i.e., in units of power.

B. E. Bolshakov [4] proposed a method for converting monetary units into units of power and a formula for converting money supply into power:

\[
P_R = \frac{P_{\text{Watt}}}{P_{\text{Money}}} \tag{2}
\]

$P_R$ is the currency power, W per dollar;

$P_{\text{Watt}}$ is the gross regional product expressed in units of power, watts;

$P_{\text{Money}}$ is the gross regional product expressed in monetary units, dollars.

The author has proposed the following formula for converting damage from disasters of various origins into units of power:

\[
P_{\text{dis}} = \frac{D_{\text{dis}}}{P_R} \tag{3}
\]

$P_{\text{dis}}$ is the disaster power expressed in units of power, kW;

$D_{\text{dis}}$ is the material damage from disasters expressed in dollars;

$P_R$ is the currency power, W per dollars.

Watts can easily be converted into kilowatts and megawatts, respectively. It should be noted that in industry terms, emergencies of various origins are usually defined as combined effects of natural, man-made and social disasters. The power of natural and man-made disasters can easily be calculated, since firstly, this indicator is expressed in monetary units, and secondly, it is readily available on official websites of special services.

Social disasters, however, are difficult to assess, since resulting losses cannot be measured in monetary units. Indeed, how can we compare depopulation of rural areas, abortions, drug and alcohol addiction in terms of money? We proposed our own formulas for calculating social disasters.

Energy losses of a particular region from social disasters can be calculated by the following formula:

\[
L = P \times N \times Y, \text{ kW} \tag{4}
\]

where:

$L$ is the loss of a region from an individual's death caused by social disasters, kW;

$P$ is the region's per capita productivity, kW per person;

$N$ is the number of people who died as a result of social disasters;

$Y$ is the number of years before at time of retiring pension.

Using the above formula, it is possible to calculate energy losses of a region from social disasters in case of death. Such calculations are applicable to all types of social disasters.

Hence, the formula for determining the power of disasters of mixed origin (natural, man-made and social disasters) can be expressed as follows. Let's call it the total power:

\[
N_{\text{dis}} = N_{\text{nat,dis}} + N_{\text{tech,dis}} + N_{\text{soc,dis}} \tag{5}
\]

$N_{\text{dis}}$ is the total power of disasters expressed in units of power, kW;

$N_{\text{nat,dis}}$ is the natural disaster power, kW;

$N_{\text{tech,dis}}$ is the man-made disaster power, kW;
\( N_{\text{soc-dis}} \) is the social disaster power, kW;

By developing the methodological framework for assessing consequences of disasters of various origins in terms of power, the author offers the following options for assessing the disaster power [8]:

\[
K_{\text{dis}} = \frac{N_{\text{dis}}}{S},
\]

where:  
\( K_{\text{dis}} \) is the disaster power load factor or *disaster power density*;  
\( N_{\text{dis}} \) is the disaster power;  
\( S \) is the region’s area.

Disasters of different origins are mostly associated with natural and man-made disasters. Therefore, the total power load factor for disasters of various origins will be as follows:

\[
K_{\text{tot-d}} = K_{\text{d-tech}} + K_{\text{d-nat}} + K_{\text{d-soc}}
\]

where:  
\( K_{\text{tot-d}} \) is the disaster power density;  
\( K_{\text{d-tech}} \) is the man-made disaster power density;  
\( K_{\text{d-nat}} \) is the natural disaster power density;  
\( K_{\text{d-soc}} \) is the social disaster power density.

Energy-environment limits of region’s existence, especially when a region is exposed to emergency situations of different origins, can be determined by a special parameter — *total power density* or anthropogenic load expressed in terms of power. The total power density is determined by ratio of the annual total energy consumption (N) to the region’s area (S) and measured in kilowatts per square kilometer [4]. Another important indicator for the presented methodology is the *biosphere instability*: ratio of the total power density (anthropogenic load) to Fedotov constant [7] with the average value of 70, the minimum value of 15, and the maximum value of 125 kW per km\(^2\).

The biosphere instability can be calculated by the following formula:

\[
N_{\text{bio}} = \frac{P}{K_F}
\]

where:  
\( N_{\text{bio}} \) is the biosphere instability;  
\( P \) is the total power density or anthropogenic load;  
\( K_F \) is Fedotov constant (70 kW per km\(^2\)).

In order to determine the biosphere existence limits of regions in terms of the disaster power, we took the following values of the power load on the region’s biosphere:  
1) up to 15 kW per km\(^2\) as a normal load range; 2) 15 to 70 kW per km\(^2\) as a permissible load range; 3) 70 to 125 kW per km\(^2\) as a significant load range; 4) more than 125 kW per km\(^2\) as an environmental disaster.

Thus, if the biosphere instability is determined relative to the critical (maximum) Fedotov constant of 125 kW per km\(^2\), we obtain upper limits of the biosphere existence in a given territory. If these limits (125 kW per km\(^2\)) are exceeded, this territory is at risk of an environmental disaster.

Similarly, by dividing \( K_{\text{tot-d}} \) by the maximum value of Fedotov constant (125 kW per km\(^2\)), we obtain the disaster power density relative to the critical value of biosphere existence for any territory.

The formula of the disaster power density relative to the critical value of the Fedotov constant can be expressed as follows:

\[
K_{\text{tot-d}, 125} = \frac{K_{\text{tot-d}}}{K_{F, 125}}
\]

where:  
\( K_{\text{tot-d}, 125} \) is the disaster power density relative to the critical value of the Fedotov constant (125 kW per km\(^2\));  
\( K_{\text{tot-d}} \) is the disaster power density;  
\( K_{F, 125} \) is Fedotov constant (125 kW per km\(^2\)).

Thus, using the proposed methodology, we can assess consequences of disasters in measurable terms, i.e. in terms of power.
2.2. *Input Data for Calculations*

The following input data were used for calculating the Disaster Safety Level Index (Table 1).

**Table 1.** Original data for calculation of the Disaster Security Level of Index (DSLI) in the global scale.

| Indicators                                           | 1998   | 1999   | 2000   | 2001   | 2002   | 2003   | 2004 | 2005   | 2006   | 2007   | 2008   | 2009   | 2010   | 2011   |
|-----------------------------------------------------|--------|--------|--------|--------|--------|--------|------|--------|--------|--------|--------|--------|--------|--------|
| P, useful power, GW                                 | 4637.4 | 4733.2 | 4857.4 | 4882.8 | 5006.3 | 5181.6 | 5147.8| 5187.1 | 5417.8 | 5587.1 | 5683.2 | 5881.1 | 5814.6 | 5809.3 |
| N, full power, GW                                    | 15882  | 16191  | 16553  | 16630  | 17006  | 17567  | 17832 | 18347  | 18857  | 19301  | 19468  | 19971  | 20444  | 20558  |
| Standard of living, kW / person                      | 1.01   | 1.02   | 1.03   | 1.04   | 1.06   | 1.08   | 1.11  | 1.13   | 1.11   | 1.01   | 1.02   | 1.03   | 1.05   | 1.03   |
| Damage from manmade emergencies, billion US dollars  | 0.25   | 0.03   | 0.03   | 0.01   | 0.01   | 0.05   | 0.08  | 0.03   | 0.03   | 0.03   | 0.1   | 0.03   | 0.08   | 0.03   |
| Damage from natural disasters, billion US dollars    | 84     | 117    | 46     | 28     | 53     | 70     | 138  | 213    | 36     | 74     | 194    | 48     | 134    | 367    |
| Mortality in the world, millions of people           | 55     | 55     | 55     | 57     | 55     | 55     | 55   | 55     | 55     | 55     | 55     | 55     | 56.8   | 55.9   |
| Average age of working people, years                 | 25.5   | 25.6   | 25.8   | 25.9   | 26.4   | 27     | 27.2 | 27.4   | 27.7   | 27.9   | 28     | 28.2   | 28.3   | 28.4   |
| Average retirement age, years                        | 65     | 65     | 65     | 65     | 65     | 65     | 65   | 65     | 65     | 65     | 65     | 65     | 65     | 65     |
| Number of years before at time of retiring pension,  | 39.5   | 39.4   | 39.2   | 38.6   | 38     | 37.8   | 37.6 | 37.3   | 37.1   | 37     | 36.8   | 36.7   | 36.6   | 36.6   |

We adopted such indicators as useful power, total power and standard of living from the study of B. Ye. Bolshakov [4]. Data on damages from natural and man-made emergencies were taken from websites [9]. Global mortality rates were taken from annual world mortality reports published on the official website of the United States Department of Economic and Social Affairs. Importantly, the final death rate for a particular year includes mortality from various causes: old age, diseases, suicides, and armed conflicts. The average working age population is presented in [12]. According to the Doctor of Economy, Prof. Valentin Roik, the average retirement age in the world for both sexes is 65 years [6]. The global gross domestic product is given in paper [8].

It should be noted that most of the indicators in Table 1 were growing in absolute terms over the 1998–2011 period. The only exception was the damage from natural and man-made disasters, which was growing sporadically. The average retirement age of 65 years remained unchanged.

Thus, based on the data presented above, it is possible to calculate the Disaster Safety Level Index (DSLI) on a global scale, i.e., for the entire world community, over the 1998–2011 period.
2.3. Calculation of the Disaster Safety Level Index (DSLI)

We calculated the Disaster Safety Level Index (DSLI) with the following values of the power load on the Earth’s biosphere:

1) Up to 15 kW per km² as a normal load range;
2) 15 to 70 kW per km² as a permissible load ranges;
3) 70 to 125 kW per km² as a significant load ranges;
4) More than 125 kW per km² as an environmental disaster [8].

It should be understood that the anthropogenic load, measured in kW per km², account for the lion’s share of the power load.

The anthropogenic load on our planet varied in the range of 107 kW per km² in 1998 (i.e. corresponded to the significant load range at the end of the 20th century) to the maximum value, 126.6 kW per km², in 2005. Thus, our planet reached the critical level of 125 kW per km² in 2005, when the world was on the verge of an environmental disaster. The next year, 2006, saw a steep decrease to 109.4 kW per km², which was most likely due to an incipient economic crisis and reduction of resource consumption around the world. At the end of the study period, in 2011, the anthropogenic load reached 121.8 kW per km².

In the future, we will see that the load caused by disasters in addition to the anthropogenic load may be fatal to our planet, since it could reach and exceed critical values of 125 kW per km².

At the next stage of our study, we calculated powers of natural, man-made and social disasters. The results of these calculations are presented in Table 2.

| Disasters power | Year | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 |
|-----------------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|
| Man-made disaster power, GW | 0.0039 | 0.0046 | 0.0042 | 0.0244 | 0.0042 | 0.0042 | 0.0209 | 0.06 | 0.03 | 0.091 | 0.0025 | 0.146 | 18.89 | 0.02 |
| Natural disaster power, GW | 5.61 | 5.81 | 5.78 | 5.98 | 5.83 | 5.94 | 5.94 | 6.11 | 6.21 | 5.55 | 5.65 | 5.67 | 5.91 | 5.83 | 62.7 |
| Social disaster power, GW | 56.1 | 56.1 | 56.1 | 56.1 | 56.1 | 56.1 | 56.1 | 56.1 | 56.1 | 56.1 | 56.1 | 56.1 | 56.1 | 56.1 | 56.1 |

The analysis of Table 2 shows that man-made and natural disasters are spontaneous and vary from insignificant values, e.g. 0.003 GW, up to 180 GW. The power of natural disasters is several orders of magnitude higher than that of man-made disasters. This suggests that the economic consequences of natural disasters are more severe than consequences of industrial disasters on a global scale. During the study period, the power of social disasters was growing steadily, from 56.1 GW in 1998 to 62.7 GW in 2011. This clearly suggests that negative social effects (mortality from all causes) are growing steadily.

At the next stage of our study, we calculated the disaster power load factors. The disaster power load factors vary from 0.0003 to 4.59 kW per km². There are not any regular distribution patterns: values vary in wide ranges from year to year. The maximum values are typical for natural disasters. The power load factor of social disasters varies more evenly in a range of 0.37 to 0.39 kW per km².

Table 3 summarizes the calculations of the Disaster Safety Level Index (DSLI).
Table 3. Results of calculation DSLI.

| Indicators          | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 |
|---------------------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|
| Anthropogenic load, N bios125 | 0.89 | 0.89 | 0.89 | 0.89 | 0.91 | 0.94 | 0.98 | 1.01 | 0.87 | 0.89 | 0.91 | 0.91 | 0.94 | 0.97 |
| $K_{gen125}$        | 0.03 | 0.03 | 0.03 | 0.03 | 0.04 | 0.04 | 0.04 | 0.04 | 0.01 | 0.01 | 0.01 | 0.03 | 0.04 | 0.017|
| Sum of N bios + $K_{gen125}$ | 0.92 | 0.94 | 0.893| 0.93 | 0.944| 0.984| 1.014| 0.88 | 0.893| 0.92 | 0.93 | 0.944| 0.987|     |
| The Disaster Safety Level Index (DSLI) | 0.08 | 0.08 | 0.107| 0.107| 0.12  | 0.08 | 0.05 | 0.013|

The findings clearly indicate several important points: 1) over the study period, the values of anthropogenic load were close to the limit beyond which there was a probability of environmental disasters; 2) in 2005, the anthropogenic load slightly exceeded the normal range, suggesting that the world was on the verge of an environmental disaster; 3) in some cases, disasters can act as catalysts and aggravate consequences of disasters; 4) in a number of cases, the Disaster Safety Level Index (DSLI) was less than 0.1, indicating the probability of a global environmental disaster; 5) The Disaster Safety Level Index (DSLI) shows the safety level, rather than the hazard level of disasters, i.e. it indicates how close the planet is to the point at which this safety level, in combination with human activity (anthropogenic load), can lead to environmental disasters.

3. Conclusion
The findings of the study are summarized below:

1) The methodological framework for calculating the Disaster Safety Level Index (DSLI) has been presented.

2) If the DSLI exceeds 0, the mega-disaster safety level remains below the critical level, i.e., it does not lead to an environmental disaster. If the DSLI tends to zero, the disaster safety level tends to exceed the critical value, i.e., it leads to an environmental disaster. If the DSLI is negative, the mega-disaster safety level exceeds a critical value, i.e., it leads not only to an environmental disaster, but also to aggravating its negative consequences.

3) The Disaster Safety Level Index (DSLI) shows the safety level, rather than the hazard level of disasters, i.e. it indicates how close the planet is to the point at which this safety level, in combination with human activity (anthropogenic load), can lead to environmental disasters.

4) Over the 1998–2011 period, the Disaster Safety Level Index (DSLI) in 2005 exceeded the level at which an environmental disaster was likely to occur. Initially, these high values were associated with a high anthropogenic load and, in combination with the mega-disaster load power, increased the impact on the world biosphere.

5) The proposed Disaster Safety Level Index (DSLI) can be used in practice to prevent disasters of various origins.

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