Assessing Losses of Human Capital Due to Man-Made Pollution Caused by Emergencies

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Abstract. World-renowned approaches to assessing losses of the human capital due to man-made pollution caused by emergencies have been studied and compared. The concept of the approach to assessing losses of the human capital due to man-made pollution was built on the theory of fuzzy sets. The proposed concept of the approach assessing losses of the human capital due to man-made pollution is based on the theory of fuzzy sets. A qualitatively new approach to the economic assessment of possible (predicted) losses of human capital caused by pollution from emergencies is proposed. Pollution is considered as a set of emissions into the atmosphere, discharges into water, pollution of land with liquid and solid industrial waste, etc. This was taken into account when choosing a data set to test the concept of the proposed approach. It takes into account the risks of possible losses from mortality using fuzzy logic. The expediency of applying the theory of fuzzy sets to calculate the mortality rate due to pollution from emergencies is substantiated.

Keywords: Risk, Assessing Losses, Risks of Possible Losses, Human Capital, Fuzzy Sets Theory, Man-Made Pollution, Emergencies.

1 Introduction

The problem of risk management is directly related to the problem of the calculations of man-made damage. The largest share of economic losses falls on the damage to the population caused by associated with its morbidity, premature ageing, and mortality, and as a result - losses from underutilization of labor resources. Mortality in working-age leads to great losses for society. A person begins to create public goods only after the age of 28 until the end of his period of economically active age because otherwise a person only pays for the money spent on it. The death of a person under the age of 28 is considered a direct economic loss, and after that age - indirect. Investigation of the structure of economic losses inflicted on the population caused by man-made pollution and assessment of the size of these losses become acute relevance in terms of the spread of the disease in CoVid 2019. Increased mortality due to emergencies caused by pandemic CoVid 2019, forced to create new approaches to evaluating economic losses of human capital.

The unpredictability of emergencies and the lack of the necessary information to assess possible losses (expected losses) lead to the existence of uncertainty, the negative manifestations of which are commonly described as risks. The study of the application of fuzzy set theory to predict the risks of possible losses of human capital due to an emergency is fragmentary. For this reason, the main purpose of the work is to use fuzzy logic to develop a concept of methodology for assessing the loss of human capital due to man-made pollution caused by emergencies. Achieving the goal involves testing the proposed approach to assessing the loss of human capital due to man-made pollution caused by emergencies, using the available data set in open sources of the State Statistics Service of Ukraine.

2 Related Works

Problems of assessment of human capital and its changes caused by emergencies, in scientific research [1, 2] are considered by scientists from different points of view and are interdisciplinary. Today, information technology and systems play a crucial role in ensuring administrative and economic management [3, 4], so researchers pay special attention to the problems of analysis of causes [5] and assessment of the consequences of emergencies (EM) [6]. To do this, they are grouped and systematized in the form of interactive databases [7-11].

The most well-known international databases and computer systems for calculating losses from man-made and natural disasters are the following Emergency Management Australia Disaster Database [7], Canadian Disaster Database [8], Em-Dat [9], NatCat [10], and Sigma [11]. The first two NA databases are maintained by government organizations, including the governments of Australia and Canada. They are available online and contain information on all emergencies in Australia since 1622 (Emergency Management Australia Disaster Database) [7], and on all emergencies in Canada since 1900 (Canadian Disaster Database) [8].

Among the private international databases of the National Assembly, the most famous are NatCat (Munich Reinsurance Company) [10], and Sigma (Swiss Reinsurance company) [11]. NatCat is run by one of the German insurance companies Munich Reinsurance Company. The information in this database applies only to natural disasters. There is information on more than 25,000 natural disasters, including the largest international disasters and accidents. Here, approximately 1000 NA is added annually [10]. Sigma is run by the Swiss insurance company Swiss Reinsurance company. This database contains information on natural and man-made emergencies that have caused significant damage. The database includes only those emergencies that caused damage according to strict criteria. The criteria are 20 deaths and / or 50 injuries, 2,000 homeless and / or insured losses of at least $ 14 million. US (in the event of a water disaster), $ 28 million. US (in the event of an air disaster) and $ 35 million. USA (for other NC). This database contains information on about 10,000 cases. Almost 300 NA is added every year [11].

Such databases are common in many countries, as they allow the insurance company to predict and characterize the insured event for which the payment will be made. According to the insurance policy of each of the companies, the criteria for assessing an emergency also differ. Private databases are not available to the average user. Insurance companies-owners annually publish bulletins with statistics and updates of records in it.

EM-DAT is the largest international database of emergencies, which contains data on almost 22,000 emergencies [9]. It provides complete information on losses and damages caused by both natural and man-made disasters. The sources of information for this database are various governmental and non-governmental organizations, including the UN, insurance agencies that practice insurance of relevant risks, research institutes, and the media [9]. EM-DAT is the largest database of emergencies, but it does not provide enough information on man-made disaster losses.

The loss of human resources due to emergencies is a key factor in determining the scale (size) of emergencies and their classification in these international databases of disasters and accidents. This indicator is a traditional economic indicator that reflects the negative impact of emergencies on the economy of states.

Losses of human capital have a negative impact on the national economies of states in the short term (immediately after the onset of emergencies) through the payment of compensation for losses and losses. The loss of human capital has a destructive effect on the resulting characteristics of national economies and in the long run due to the shortfall in the formation of GNP regions and states.

Losses among the population cause losses in future periods due to losses of intellectual capital. Such losses go beyond the local boundaries of regions and states and are global in nature. Many authors [1, 12, 13] have devoted their research to the development of security at potentially dangerous sites. Other authors [14, 15, 16, 17] focus on the study of human capital losses in critical facilities, where man-made emergencies are predicted with high probability.

For potentially dangerous objects, various complex security systems have been developed according to a wide set of criteria "cost - security - benefit" [1, 12, 15, 18], "threat - loss - damage" [6, 14, 19], systems for taking into account the impact of natural hazards on them [6], systems for taking into account the impact of man-made emergencies on these potentially dangerous objects, the environment, population, economy [1, 18] and many other types of systems or techniques [17, 19, 20].

Most of these information systems and known methods determine the impact of emergencies in the short term [1, 3, 5, 21]. The authors [5, 14, 22] assess the direct loss of human capital due to an emergency. These losses of human capital are called direct losses caused by emergencies.

Man-made emergencies are accompanied by environmental pollution in most cases. Damage to the environment, in most scientific sources [12, 19, 23] is called environmental and economic damage and is also classified as direct damage. Emissions of harmful substances into the atmosphere, discharges of polluted waters into rivers and reservoirs, pollution of land and forest areas with hazardous substances degrade the quality of the environment. Such damage to the environment leads to a deterioration in the quality of life in the long run. This is manifested in an increase in the incidence of the population and an increase in mortality from these diseases. All these losses from emergencies are classified as indirect losses [1, 17, 22]. The problem of estimating the loss of human capital due to man-made pollution caused by emergencies remains unresolved.

3 Materials/Methods/Methodology

The orthodox methodology to assessing losses of the population due to emergencies is determined by the official recommendations of the "Methodology for assessing losses from the consequences of man-made and natural emergencies" in Ukraine [21]. According to these recommendations [21], the formula for the total man-made losses from the consequences of emergencies (TML) is:

$$TML = \text{social losses} + \text{environmental losses} + \text{economic losses}$$

The social losses (SL) are defined as the damage from the loss of human life and health from the consequences of emergencies. It is accounted as the sum of losses from the disposal of labor resources from production; funeral expenses and payment costs and pensions in case of loss of a breadwinner. The social losses due to the emergencies consequences are defined as follows:

$$SL = Ldlr + \sum Cpfa + \sum Cppb$$

where Ldlr is losses from the disposal of labor resources from production; Cpfa is the cost of paying funeral assistance; Cppb is the cost of paying pensions in the event of loss of a breadwinner.

The losses from the disposal of labor resources from production are defined as follows:

$$Ldlr = Ml \times Nl + Mt \times Nt + Mi \times Ni + Mz \times Nd$$

where Ml is losses from a minor accident; Mt are severe case losses; Mi is losses from a person's disability; Mz is losses from death.

Necessary data for calculation are the number of employees within the territory affected by the emergency situation who lost their ability to work for up to 9 days (Nl), more than 9 days (Nt), became disabled (Ni), died (Nd).

The costs for the payment of funeral assistance are defined as follows:

$$Cpfa = 12 \times Mfa \times Nd$$

where Mfa is funeral allowance (according to social security authorities); Nd is the number of deaths due to the emergency.

The cost of paying pensions in the event of loss of a breadwinner due to the emergencies consequences are defined as follows:

$$Cppb = 12 \times Mmp \times (18 - Ac)$$

where Mmp is the amount of the monthly pension for a child under the age of majority 18 years (according to the social security authorities); Ac is age of the child.

Necessary data for calculation are the number and age of disabled family members who died as a result of the emergency.

The basis for the systematization of man-made losses should be the calculation of losses amount based on the definition of factor-by-factor and to-recipient losses [1, 21]. Factor-by-factor losses reflect a comprehensive economic assessment of the damage caused by the main factors of influence [19-24]. These include damage to the population from air pollution, surface and groundwater, land, and soil [5, 14, 21]. To-recipient losses reflect an economic assessment of the actual damage caused to the main recipients of the impact [21]. Due to the peculiarities of the dynamics and impact of emergencies on the human capital [1, 17, 19, 21, 22], the formula for calculating the total amount of losses, determined by this method, is imperfect and needs to be supplemented.

In the event of an emergency, there is an environmental risk, due to which it is accepted to calculate the environmental damage. To determine the risk index R, the authors of [19] propose to use the sum of the products of the probability of loss of the i-th species pi and the magnitude of possible losses of the same i-th species Q_i for the whole set of m species losses:

$$R = \sum_{i=1}^{m} p_i Q_i \, .$$

The authors of [19] substantiate that the theory of probability is a partial case of the theory of fuzzy sets, because here they operate with the functions of fuzzy affiliations to the distribution of possibilities in fuzzy sets. This proves the greater possibilities of fuzzy set theory compared to the classical probabilistic approaches for assessing losses of the human capital due to emergencies. The authors of [19] used the possibilities of fuzzy logic to build a heterodox approach to assess possible losses in production by assessing the risks of possible losses.

4 Experiment/Results/Discussions

To construct a new approach for assessing losses of the human capital due to man-made pollution, we use the basic principles and laws of fuzzy sets theory. The proposed approach uses of fuzzy-logical result at the following its stages (Fig. 1).

Fuzzy subset F of the set of P factors of the losses is determined by the membership function $\mu^F(p)$, where p - an element of the universal set, that is $p \in P$. The function of reflecting elements of the set P on the set of numbers in the range [0, 1], which characterize the degree of membership of each element $p \in P$ to a fuzzy set F, whereby $F \subset P$. If the full set P covers finite number of sets of elements $p_1, p_2, \ldots, p_n$, then the fuzzy subset F can be represented as $F = \sum \mu F(p_i)/p_i$ according to the [19, 25].

In our case, we research pollutions influences on the human capital, which are described at the input n variables $x_1, x_2, \ldots x_n$, and variable y is an output (the level of technogenic losses, or technogenic loss ratio) by $y=f_y(x_1, x_2, \ldots x_n)$.

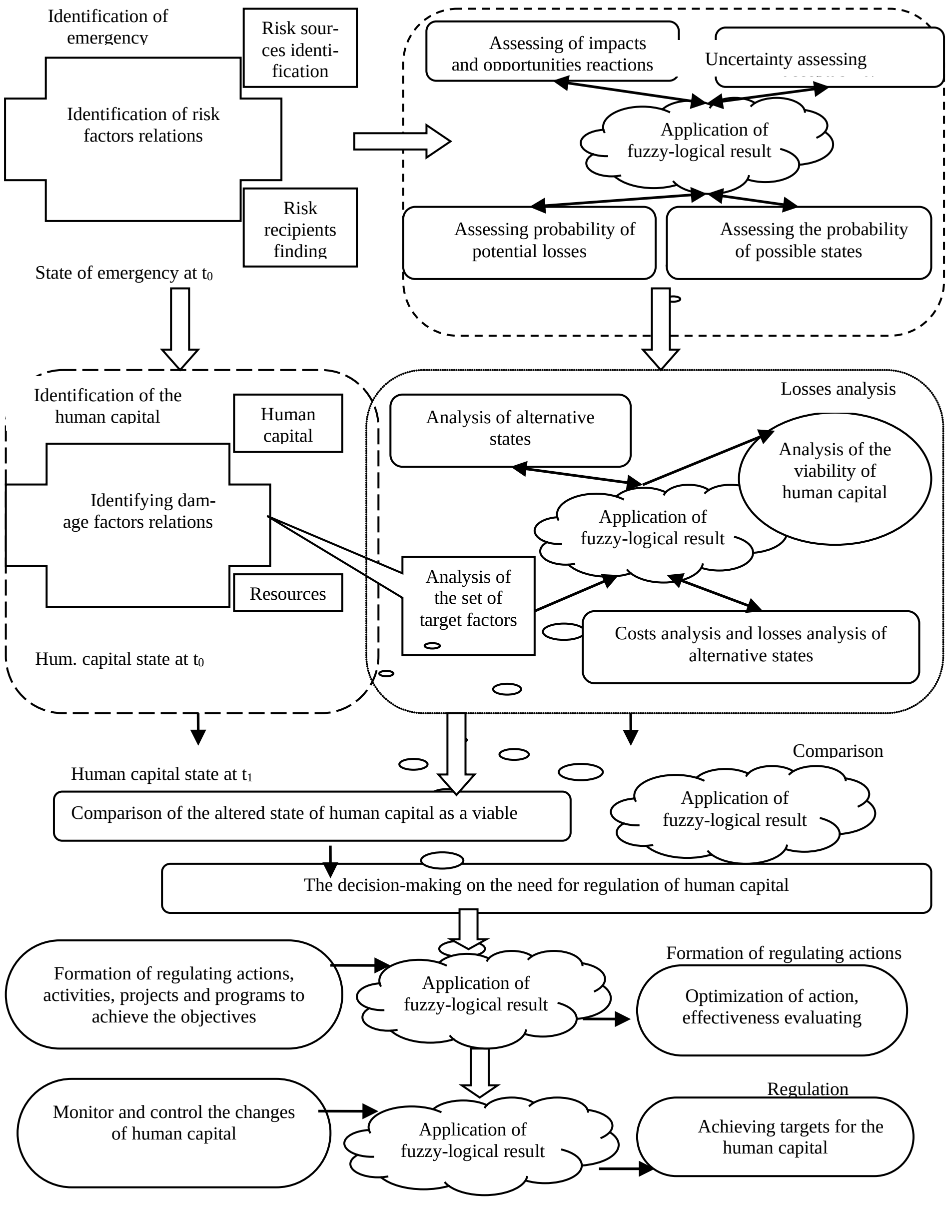

Fig. 1. Conceptual model of the application of fuzzy-logical result in new approach for assessing losses of the human capital due to man-made pollution

To solve the problem assessing losses of the human capital due to man-made pollution it is necessary to develop a method of fuzzy decision making as a result of all the stages of fuzzy-logical conclusion (see Figure 1). The expert analyst creates a separate set of parameters $X = \{x_i\}$, where $i = 1, \ldots, N$, which is the indicator for assessing losses of the human capital due to man-made pollution (otherwise the index of risk of emergency pollution). In formalized language, that means to a fixed vector of input variables $\vec{X} = \langle \vec{x_1}, \vec{x_2}, \ldots, \vec{x_n} \rangle$, $\vec{x_i} \in P_i$ it should be definitely put in correspondence a solution $\vec{y} \in Y$ (for an object with a discrete output) according to the [19]. The expert analyst must choose values according to their significance for assessing losses of the human capital due to man-made pollution; take into account various sources of losses and others. Thus, the set of all indices to assess complex measure of losses may include both qualitative and quantitative criteria and $x_1, x_2, \ldots x_n$ [19].

Fuzzy descriptions of the structure of the new method assessing losses of the human capital due to emergency pollution occur in connection with the expert's uncertainty arising during the various classifications. The expert creates a linguistic variable with its term-set values.

The losses level of human capital due to man-made pollution can be described as term-set of values *{Very Low, Low, Medium, High, Very High}* [19]. Then the expert chooses the corresponding quantitative trait for a linguistic variable y, which is losses of the human capital due to man-made pollution. In our case we used trapezoidal membership functions. The next stage is to construct the fuzzy knowledge base by the principle of "if-then". In our case, it is the level of losses of the human capital due to man-made pollution.

The stage of fuzzy decision-making, in our case, is done with the help of a table of decision rules for the system of fuzzy knowledge from the knowledge base [19]. The stage of transformation of fuzzy data from the output stage of fuzzy decision into precise quantities (quantitative or qualitative) used in the economic environment, is done in the opposite direction to the stage fuzzyfication for linguistic variable of the damage level Y.

To test the new method of assessing losses of human capital due to emergency pollution, a data set of 6 independent variables was formed, which included 5 indicators of anthropogenic impact and radiation background for 24 administrative units of Ukraine and Kyiv City (Fig. 2). Input variables were specific emissions (of pollutants and carbon dioxide), specific discharges of reverse contaminated water, specific waste and radiation background (Fig.3). The population mortality rate was selected as level losses of the human capital due to emergency pollution (the output variable Y).

The active rules and membership functions operating concerning the output variable population mortality rate based on compliance with fuzzy-logical rules in Dnipropetrovsk region is presented in Fig.4.

It is important, that the active rules and membership functions operating concerning the output variable population mortality rate of Dnipropetrovsk region based on compliance with fuzzy-logical rules. The mathematical framework, which lays in the mechanism of the conclusion [19], identifies features of all the other stages of expert system.

Vinnytsia region; [112.29; 4.06; 0.61; 1925.38; 11.99; 12]
Volyn region; [48.46; 1.35; 0.96; 705.58; 23.46; 11]
Dnipropetrovsk region; [354.65; 11.40; 115.79; 88030.90; 24.76; 12.5]
Donetsk region; [391.90; 14.44; 127.53; 12947.55; 51.04; 13.5]
Zhytomyr region; [67.54; 1.26; 2.36; 683.11; 58.24; 14.5]
Transcarpathian region; [57.48; 0.88; 1.59; 447.94; 6.62; 12]
Zaporizhzhia region; [177.01; 7.84; 39.77; 3428.69; 162.78; 11]
Ivano-Frankivsk region; [180.27; 8.68; 0.72; 1290.20; 5.43; 12]
Kyiv region; [178.91; 5.92; 2.32; 1751.29; 24.04; 13]
Kirovograd region; [74.16; 1.71; 5.02; 40284.57; 10.95; 12]
Luhansk region; [234.66; 9.48; 44.76; 7403.59; 470.42; 12]
Lviv region; [99.93; 2.16; 17.32; 1318.69; 6.77; 11]
Mykolaiv region; [74.22; 2.56; 22.16; 2109.16; 29.83; 13]
Odesa region; [70.56; 2.09; 43.00; 558.28; 11.77; 11]
Poltava; [121.88; 2.79; 2.73; 4292.27; 233.75; 11.5]
Rivne region; [52.21; 1.82; 6.92; 1107.62; 89.38; 12.5]
Sumy region; [70.07; 1.92; 19.24; 1064.29; 119.23; 12]
Ternopil region; [60.34; 1.21; 2.78; 929.45; 5.66; 11.5]
Kharkiv region; [116.38; 4.85; 4.74; 880.88; 112.56; 12]
Kherson region; [68.26; 1.21; 1.85; 450.38; 68.63; 10]
Khmelnytskyi region; [60.65; 2.13; 0.00; 1119.56; 11.42; 11.5]
Cherkasy region; [115.38; 3.47; 3.15; 1493.73; 83.54; 12.5]
Chernivtsi region; [45.30; 0.77; 2.20; 606.92; 6.39; 12]
Chernihiv region; [86.84; 2.32; 17.63; 687.14; 90.09; 13]
Kyiv; [91.11; 3.44; 7.38; 471.85; 27.70; 12]

Fig. 2. Data set for assessing losses of the human capital due to man-made pollution based on fuzzy-logical result in proposed new approach

X1	X2	X3	X4	X5	X6
anthropogenic impact					Radiation background μR / hr
Specific emissions		Specific discharges of reverse contaminated water., m^3 per person	Specific waste		
of pollutants, kg per person	of carbon dioxide, t per person		of I - IV classes, kg per person	of I class, kg per person	

Fig. 3. The input variables of man-made pollution used on fuzzy-logical result

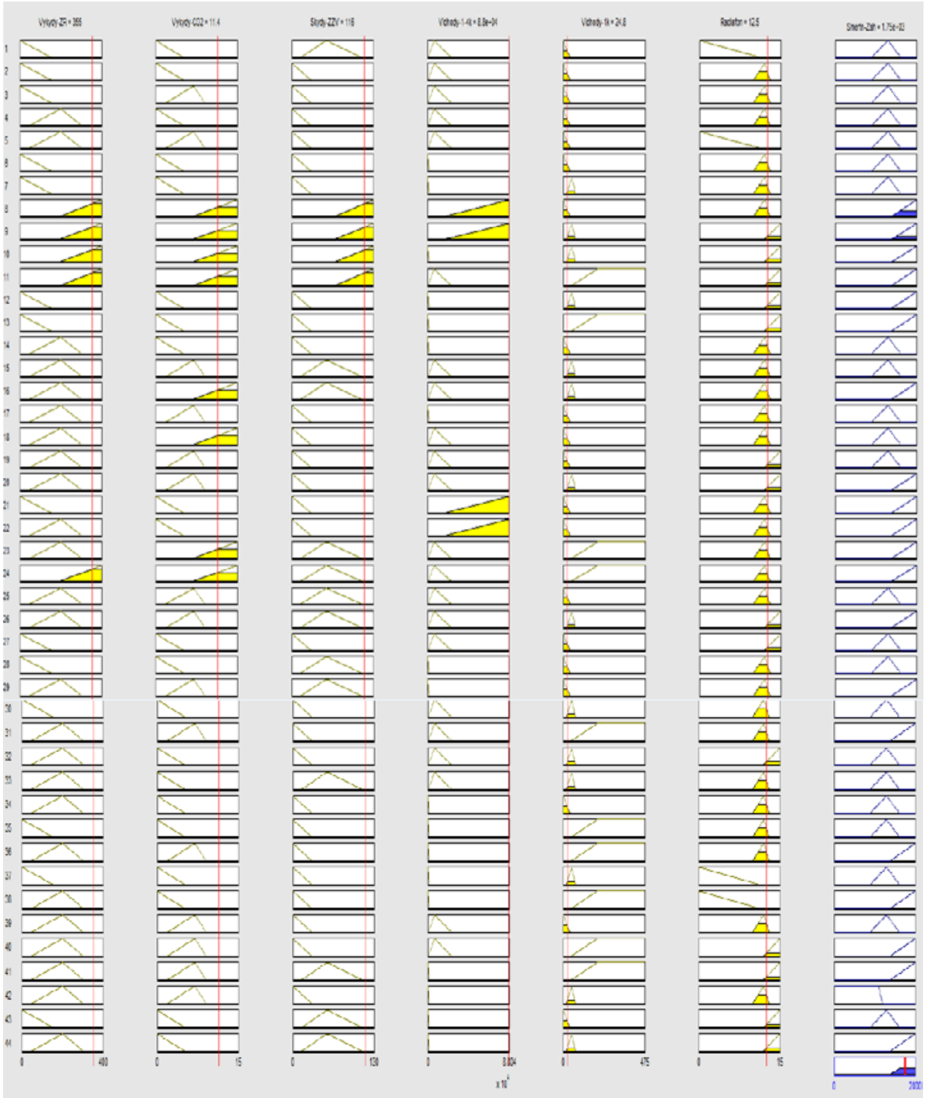

Fig. 4. The active rules and membership functions operating concerning the output variable "mortality" based on compliance with fuzzy-logical rules in Dnipropetrovsk region

The developed rules and functions of membership also gave the appropriate result for the initial variable mortality of the population of the remaining 23 regions and Kyiv. The error of the obtained results does not exceed 0.05. This indicates the possibility of using a new approach to estimating the mortality rate of the population of Ukraine caused by pollution from the future in the future.

Simulated results of the population mortality rate as the level losses of the human capital due to emergency pollution for all Ukrainian regions are presented in Table 1.

Table 1. The results of the population mortality rate simulated by the new proposed approach used on fuzzy-logical result

Administrative units	*Anthropogenic impact*					*Radiation background*	*Simulated*
	Specific emissions		Specific discharges of reverse contaminated water., m^3 per person	Specific waste			Population mortality rate, case per 100 thousand cash. settlement
	of pollutants, kg per person	of carbon dioxide, ton per person		of pollutants, kg per person	of carbon dioxide, ton per person		
Vinnytsia region	112,29	4,06	0,61	1925,38	11,99	12	188
Volyn region	48,46	1,35	0,96	705,58	23,46	11	165
Dnipropetrovsk region	354,65	11,40	115,79	88030,90	24,76	12,5	204
Donetsk region	391,90	14,44	127,53	12947,55	51,04	13,5	241
Zhytomyr region	67,54	1,26	2,36	683,11	58,24	14,5	189
Transcarpathian region	57,48	0,88	1,59	447,94	6,62	12	148
Zaporizhzhia region	177,01	7,84	39,77	3428,69	162,78	11	189
Ivano-Frankivsk region	180,27	8,68	0,72	1290,20	5,43	12	188
Kyiv region	178,91	5,92	2,32	1751,29	24,04	13	216
Kirovograd region	74,16	1,71	5,02	40284,57	10,95	12	245
Luhansk region	234,66	9,48	44,76	7403,59	470,42	12	209
Lviv region	99,93	2,16	17,32	1318,69	6,77	11	194
Mykolaiv region	74,22	2,56	22,16	2109,16	29,83	13	206
Odesa region	70,56	2,09	43,00	558,28	11,77	11	189
Poltava region	121,88	2,79	2,73	4292,27	233,75	11,5	244
Rivne region	52,21	1,82	6,92	1107,62	89,38	12,5	209
Sumy region	70,07	1,92	19,24	1064,29	119,23	12	187
Ternopil region	60,34	1,21	2,78	929,45	5,66	11,5	159
Kharkiv region	116,38	4,85	4,74	880,88	112,56	12	245
Kherson region	68,26	1,21	1,85	450,38	68,63	10	221
Khmelnytskyi region	60,65	2,13	0,00	1119,56	11,42	11,5	166
Cherkasy region	115,38	3,47	3,15	1493,73	83,54	12,5	240
Chernivtsi region	45,30	0,77	2,20	606,92	6,39	12	132
Chernihiv region	86,84	2,32	17,63	687,14	90,09	13	247
Kyiv	91,11	3,44	7,38	471,85	27,70	12	200

5 Conclusions

The problem of estimating the loss of human capital due to man-made pollution caused by man-made and natural disasters is considered in the article.

To develop a methodological approach for estimating the loss of human capital due to man-made pollution caused by emergencies, the risks of possible losses from mortality caused by environmental pollution due to emergencies were taken into account.

The world-famous interactive databases of emergencies have been studied and compared, where not only the amount of damage caused by emergencies is collected, but also the amount of losses from losses of human capital caused by emergencies.

The classical approaches used in the world to assess man-made losses from environmental pollution (emissions, discharges, waste) do not cover the full range of direct and indirect losses caused to human capital. The approach recommended by the United Nations Environment Program (UNEP) is intended only to assess solid waste flows, and in no way takes into account the potential damage from these contaminants.

The proposed concept of the approach assessing losses of the human capital due to man-made pollution is based on the theory of fuzzy sets. A qualitatively new approach to the economic assessment of possible (predicted) losses of human capital caused by pollution from emergencies is proposed. Pollution is considered as a set of emissions into the atmosphere, discharges into water, pollution of land with liquid and solid industrial waste, etc. This was taken into account when choosing a data set to test the concept of the proposed approach. It takes into account the risks of possible losses from mortality using fuzzy logic. The expediency of applying the theory of fuzzy sets to calculate the mortality rate due to pollution from emergencies is substantiated.

The suggested approach to assessing the loss of human capital can be used for various emergencies of man-made and natural nature, among the consequences of which is environmental pollution in future periods.

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