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SUSTAINABLE DEVELOPMENT IN QUANTITATIVE INDICATORS OF TECHNOGENIC SAFETY ASSESSMENT

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Abstract. The sustainable development concept presupposes integration of social, economic, and ecological aspects of development in their interrelation as well as a complex of sustainability indicators. In this connection solving industrial ecological safety problems at all stages of the production life cycle is a topical issue.

Keywords: region sustainable development, assessment of technogenic safety, classification of ecologically and technogenically hazardous facilities, atmosphere pollution assessment, assessment of water recourses pollution, soil pollution assessment.

1. Introduction

Society's sustainable development strategy presupposes assessment of industrial plants hazard to prevent possible failures and reduce harm to the environment and people.

Use of indices is one of the promising directions in the industrial facilities hazard assessment. The results of the industrial facilities categorization largely depend on the accepted index assessments system. The developed procedure of the industrial hazard assessment is intended for the plants ranking according to the extent of their hazard to the environment [1-3].

2. Results and Discussion

2.1. Classification of Environmentally and Technogenically Hazardous Facilities

Methodological basis for classification of the potentially environmentally and technogenically hazardous facilities (*i.e.* those using harmful substances) was developed [1-2]. It provides a possibility to make a list of hazardous facilities for the further ecological audit as well as set requirements to these plants. The safety requirements are directed to decrease the risk of ecological incidents.

The use of the Harrington desirability function D is proposed as the generalized criterion of the safety assessment calculation. For defining the generalised desirability function D the transformation of the values of indices received by different procedures into the dimensionless scale of desirability d is done.

The relative hazard index is calculated by:

$$D_{RL}^{m} = 1 - \sqrt[4]{d_{PT} \cdot d_{RS} \cdot d_{EX} \cdot d_{TX}}\ , \qquad (1)$$

where d_{PT} is a particular desirability function for the potential damage index I'_{PT} which depends on the maximum total mass of a certain type of hazardous material, its threshold mass, and number of such materials; d_{RS} denotes particular desirability function for the risk index I'_{RS} which depends both on internal exogenous and endogenous factors as well as on the industrial area and equipment deterioration; d_{EX} is a particular desirability function for the fire and explosive risks index I'_{EX} which considers explosion hazard of substances, their quantity, ignition danger, caloradiance hazard, hazard of technological parameters of the process; d_{TX} is a particular desirability function for the toxic hazard index I'_{TX} which considers toxic hazard, the action time, and the size of the area contaminated.

The resulted empirical dependence can be used for finding the index of relative hazard and evaluation of the danger category for the object under study [2-3]. This dependence can be completed with the new hazard indices according to the offered algorithm. Thus, the value of the relative hazard index will not change. The facilities are ranged from 0 to 1 depending on their hazard ("1" corresponds to the maximum hazard level of the object).

This approach is applied not only to the operating industrial plants but also at their design stage with a purpose of the environmental impacts assessment (AEI) [3].

One of the basic aspects of environmental impact evaluation is the assessment of complex measures aimed to meet the environmental regulations and ensure safety of the environment. Hence, the complex of design solutions in addition to resourcesaving, protective, and compensatory measures should include also the assessment of the ecological risk of the planned activity and impacts on the humans. It should be emphasised that nowadays the risk assessment of the planned activity concerning natural, social, and technogenic environment remains beyond the methodical issues of AEI.

Thus working out the procedures of quantitative definition and then environmental qualitative analysis (of air, water, soil, *etc.*) is a prospective direction of research.

2.2. Quantitative Assessment of Water Pollution Level

Quantitative and qualitative assessment of water pollution represents the system engineering of index assessments. For water pollution assessment we propose to use the water pollution index (*WPI*). *WPI* characterizes the general sanitary state of water and water body as well as the presence of harmful chemical substances. *WPI* index allows to compare water quality of various facilities and to reveal their pollution tendencies in dynamics. *WPI* is a typical additive coefficient and represents an average excess fraction of maximum concentration limit on the strictly limited number of individual ingredients

$$WPI = \frac{1}{n} \cdot \sum_{i=1}^{n} \frac{C_i}{MCL_i} \tag{2}$$

where C_i denotes ingredient concentration (in some cases - value of physical and chemical parameter); n is the number of factors used for the index calculation; MCL_i is the maximum concentration limit for the specific water body type.

Depending on *WPI* value water body sections are divided into five classes of water quality. *WPI* values are brought to the dimensionless scale from 0 to 1 by means of Harrington function using the following formula:

$$I = 1 - d_i = 1 - \exp(-\exp(-0{,}2 \cdot WPI_i + 1)) \tag{3}$$

where d_i is desirability function for *i*-th of water pollution index.

On the basis of the calculated pollution index values, classification of water bodies by the water pollution level and by water body hazard class according to a 7-level scale from 0 to 1 is presented, 1 being the worst case.

2.3. Quantitative Assessment of the Air Pollution Level

To make a quantitative assessment of the air pollution level of the facility under study we applied the comparison of one contaminant pollution index (*PI*) and total pollution index (of contaminants mix) C_{PI} with the maximum pollution index *MP*.

The total pollution index C_{PI} is calculated as follows:

$$C_{PI} = \sum \frac{C_1}{MCL_1 \cdot K_1} + \frac{C_2}{MCL_2 \cdot K_2} + \frac{C_3}{MCL_3 \cdot K_3} + \\ + \ldots + \frac{C_n}{MCL_n \cdot K_n} \cdot 100\% \tag{4}$$

where C_{PI} is a total pollution index, %; K_1, K_2, K_3... K_n are the values of the coefficients, which consider the hazard class of the particular contaminant.

PI is compared with *MP* of atmospheric air, a relative integrated criterion of the urban area air pollution assessment which characterizes intensity and pattern of combined action of all contained detrimental impurities. *MP* is calculated for each case on the basis of experimental and adopted coefficients of combined action C_{CA} as follows:

$$MP = C_{CA} \cdot 100\% \tag{5}$$

The air pollution assessment is made with the account of the ratio of the pollution indices excess to their standard value *MP*. It includes definition of pollution and its hazard levels.

On the basis of desirability function the aggregate pollution excess ratio values are calculated as follows:

$$I = 1 - d_i = 1 - \exp(-\exp(-0{,}25 \cdot FR_i + 1)) \tag{6}$$

where d_i is desirability function for the *i*-th aerosphere pollution index; *FR* is excess rate ratio factor of standard pollution C_{PI} as compared to *MP*.

On the basis of these values the assessment of the object's hazard class according to a 5-level scale from 0 to 1, where 1 corresponds to a maximum hazard level, is made.

2.4. Quantitative Assessment of the Soil Pollution Level

On the basis of the present approaches, we offer a total soil pollution index for each pollutant, which is expressed as:

$$I_{TP_i} = \sum_{i=1}^{n} k_i \cdot \frac{(C_{av_i} - C_{bg_i})}{MCL_i} \tag{7}$$

where k_i is the coefficient defined by the hazard index; C_{av_i} is the average actual content of a pollutant in the soil, mg/kg; C_{bg_i} is the background impurity of a pollutant in the soil, mg/kg (in case of absence of the maximum concentration limit (MCL) value is taken).

For the soil pollution analysis we offer to use Harrington desirability function as the criterion of the soil pollution by hazardous facilities. Desirability function is used to calculate the corresponding relative pollution indices, *i.e.* the aggregates of the total soil pollution index:

$$I_{TP_{rd}} = 1 - d_i = 1 - e^{-(e^{-I_{TP_i}'})} \quad (8)$$

where d_i is desirability function; I_{TP_i}' is some unitless value related to the total pollution index I_{TP_i}. It is defined by the following formula:

$$I_{TP_i}' = \frac{2 \cdot I_{TP_i} - (I_{TP_{\max}} + I_{TP_{\min}})}{(I_{TP_{\max}} - I_{TP_{\min}})} \quad (9)$$

For making decisions as to soil pollution decrease actions a universal scale from 0 to 1, considering all soil pollutants, has been developed.

The conducted analysis of the existing approaches to the soil pollution quantification allows to make the conclusion about their variety as well as the absence of a decision-making stage. Therefore it is necessary to work out a universal approach to the decision-making in the AEI system. The approach presented herein is based on the total soil pollution index, which considers not only admissible standard values of the contaminants, but also their excessive containment in terms of hazard indices. In addition, the decision-making universal scale for the soil pollution with the application of desirability function is developed. Thus, in view the importance of the universal approach as an integral component of the soil pollution analysis procedure and decision-making regarding the design acceptability, we consider it reasonable to introduce this approach into the AEI system.

2.5. Region Technogenic Hazard Indicator

As regions safety is an integral part of sustainable and ecologically safe development, we suggest to use the developed indicator of technogenic hazard as one of sustainable development indicators:

$$I_{TD} = \bar{\rho}_R \cdot J_{TD_\Sigma} \quad (10)$$

where $\bar{\rho}_R$ is a population relative density in the region; J_{TD_Σ} is the generalized index of the region's technogenic hazard.

Relative population density in the region is calculated by:

$$\bar{\rho}_R = \frac{N_R/1000}{S_R/100} \quad (11)$$

where N_R is the number of population of the region; S_R is the area of the region, km^2.

The generalized index of the region's technogenic hazard is presented as follows:

$$J_{TD_\Sigma} = \sum_{i=1}^{n} J_{TD_i} \quad (12)$$

where J_{TD_i} is the technogenic hazard index of a separate industrial facility; n is the number of potentially hazardous facilities in the region.

Index of technogenic hazard of the industrial facility is calculated by:

$$J_{TD} = R_{DG} \cdot D_{RL} \quad (13)$$

where D_{RL} denotes the relative hazard index of a separate hazard source; R_{DG} is the regional hazard index [2].

3. Quantitative Estimation

As an example, we will quantify the level of pollution of the thermal power-station (TPS), located near the water bodies according to paragraph 2.2. Results of *WPI* calculations by the formula (2) for the sewage receiver of the TPS are presented in Table 1.

According to this calculation, the sewage receiver of the TPS belongs to the moderately contaminated ones (*WPI* = 1.713, class of water quality – III).

Based on the formula (3) the *WPI* value for the TPS is calculated:

According to the obtained value, the reservoir can be attributed to the objects with moderate hazard and for

Table 1

Calculation *WPI* receiver for sewage TPS

№	*Datum*	C_i	MCL_i	C_i/MCL_i
1	pH (hydrogen ion exponent)	8.48	8.5	0.998
2	BOC5 (biological oxygen consumption)	5	2	2.500
3	O_2 (concentration of dissolved oxygen)	10.8	4	2.700
4	NH_4^+	0.69	1	0.690
5	Nitrate-anions NO_3^-	18.2	45	0.404
6	Nitrite-anions NO_2^-	0.43	0.1	4.300
7	Synthetic surfactants (SSA)	0.006	0.5	0.012
8	Petroleum	0.63	0.3	2.100
Index of water pollution				**1.713**

acceptable level of hazardous substances content in the water, the definite measures should be carried out for the its reduction.

4. Conclusions

In our opinion, the use of the technogenic hazard indicator will allow to better evaluate sustainability level of the separate regions and the countries as a whole, and will give the chance to see the extent of the technogenic load with the account of the population density.

Methodology of the technogenic safety quantitative assessment presented herein is applied at every stage of the industrial plant life cycle including its designing and exploitation. This enables generating sustainable development indicators of the region taking into account the technogenic load.

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СТІЙКИЙ РОЗВИТОК У КІЛЬКІСНИХ ПОКАЗНИКАХ ОЦІНКИ ТЕХНОГЕННОЇ БЕЗПЕКИ

Анотація. *Концепція стійкого розвитку припускає інтеграцію соціальних, економічних і екологічних аспектів розвитку й, відповідно, сукупність індикаторів стійкості й повинна відображати всі ці області, і співвідношення між ними. У зв'язку із цим все більшу актуальність здобувають питання про визначення екологічної безпеки промислових виробництв на всіх етапах життєвого циклу.*

Ключові слова: *стійкий розвиток регіону, оцінка техногенної безпеки, класифікація екологічно й техногенно небезпечних об'єктів, оцінка забруднення атмосферного повітря, оцінка забруднення вод, оцінка забруднення ґрунту.*