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ASSESSMENT OF ECOLOGICAL SAFETY LEVEL OF KAMYANETS-PODILSKY CITY BY THE DENSITY OF PETROL STATIONS PLACEMENT

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Abstract. The article is devoted to the assessment of the environmental threats from petrol stations. During operation, petrol stations cause the inflow of pollutant substances into natural environment. Besides this, the emergencies, leaks and spills of petroleum products during repairs and service of technological equipment are probable. The aim of the article is systematization of environmental risks from petrol stations at the urban territories as well as analysis of environmental threats from their manifestation.

Key words: petrol station, environmental risk, integral indicator of environmental safety, density of petrol stations placement, urbanized territory.

Introduction. The provision of environmentally safe conditions of human life and preservation of the environment are among the priority national interests of Ukraine. For provision of environmental safety and for fulfillment of the tasks formulated in The Law of Ukraine "On the Main Principles (Strategy) of the National Environmental Policy of Ukraine for the Period until 2020" [**Помилка! Джерело посилання не знайдено.**], there is a need for a predictive environmental risk assessment as a measure of existing threats for adoption of preventive measures to reduce this level of risk, which is becoming more and more relevant.

At the beginning of 2016, in Ukraine, there were above 10 million vehicles owned by private owners, state and communal enterprises [2]. Besides this, it is necessary to take into account a significant number of agricultural, construction and road vehicles [1]. For service, and provision of all these vehicles with fuel, a wide network of petrol stations (which exceeds 7000) is developed in the country. By the beginning of 2000, the majority of petrol stations had been situated, as a rule, outside the cities, at the entrances to the cities, in industrial zones, on the roads outside urban areas. In recent years, the situation has changed significantly. New petrol stations are placed in the city lane, residential neighborhoods, near large shopping and entertainment complexes [[10]].

The increasing density of petrol stations within urbanized territories causes the increase in pollution of the environment due to the inflow of fuel evaporations into the air. The analysis of petrol station operation shows that pollution of environment by fuel vapors is observed during refueling of petrol stations from refueling tanks; storage of fuel in tanks; direct refueling of cars. The main pollutant substances during petrol station exploitation (during operation with gasoline, diesel fuel and liquefied hydrocarbon gas) are saturated hydrocarbons: propane, butane, ethane and methane. The prevailing emissions sources, directly at petrol stations during technological processes, are: respiratory valve of fuel tank (organized source) – pollutant substances get into environment during tank filling from gasoline tank and during storage of fuel in reservoirs; mouth of fuel tank (non organized source) – pollutant substances get into environment during refueling of motor vehicles tanks. The presented data give an opportunity to affirm, that such activity is potentially dangerous due to the increasing environmental risk. The issues related to environmental risks assessment are studied by domestic and foreign experts, among which special contribution to the study of this issue has been made by: S. P. Ivaniuta [7], K. V. Taraniuk [7], A. B. Kachinskyi [8], V. V. Vitlinskyi , O. O. Veklich, M. V. Golovanenko, S. M. Illiashenko, O. V. Kozmenko, S. K. Harichkov, E. V. Hlobistov, P. A. Vaganov, K. Richter,O. N. Rusak, O. V. Sadchenko and others [4]. Characteristics of soil contamination level by petrochemicals near petrol stations are presented in the work [19]. Authors conducted researches at petrol stations in Kyiv. In general, soil contamination level on the territories of petrol stations varies in wide ranges. In relation to allowable concentration, (4000 mg/kg) soil contamination level varies from 0.6 to 5.3 of particles that certainly confirms the assumption about high pollution level. According to the recommendations of V. I. Soloviov [16] the analyzed samples can be divided into:

Uncontaminated – 12 %;

Slightly contaminated – 21 %;

Moderately contaminated – 47 %;

Highly contaminated – 20 %.

Some results of the selected samples are presented in Table 1.

Table 1

Evaluation of soil contamination by petrochemicals

№	Mass fraction of petroleum products, mg/kg	Contamination level of soils in relation to allowable concentration
1	3765	0.94
2	3149	0.78
3	4223	1.05
4	3017	0.75
5	7490.5	1.87
6	7683	1.92
7	8816	2.20
8	7088	1.77
9	10014,6	2.50
10	11234	2.80
11	11166	2.79
12	11187	2.79
13	10563	2.64

Researches results of soil contamination by petrol stations are presented in the article [1]. Authors submit information on concentration of petrochemicals in the samples taken from different depths. In general, the territories of three petrol stations were researched by the scientists. A borehole for sampling was drilled at each station. The statistical information about soil contamination in the territory of one of the stations is presented in Table 2.

Table 2

Vertical distribution of petrochemical contamination of soil on the territory of petrol station

Borehole	Layer depth, m	Compound	μg/kg of wet soil median (n = 3)	Standard deviation	GROs median, μg/kg of wet soil (n = 3)	Standard deviation
1	2	3	4	5	6	7
T1	0–1	Naphtalene	3.02	0.26	14.00	1.39
	1–2	–	not detected	not detected	6.02	0.60
	2–3	Hexane	18.44	11.56	37.71	24.31
		Octane	8.88	7.26		
		Naphtalene	4.00	2.01		
	3–4	Hexane	3.63	3.00	8.99	7.90
		Naphtalene	1.81	1.59		
	4–5	Hexane	2.43	0.55	5.79	0.96
	5–6	Hexane	21.42	10.82	37.04	26.05
		Octane	5.00	2.34		
		Decane	1.73	2.58		
		Naphtalene	1.86	2.26		
	6–7	Hexane	4.80	0.51	6.33	1.17
	7–8	Hexane	9.53	5.40	13.40	8.25
		Octane	2.42	2.85		
	8–9	Hexane	2.35	0.21	3.40	0.13
	9–10	Hexane	5.91	3.23	8.11	5.64
		Octane	1.28	2.12		
	Blank	Hexane	7.36	0.08	7.71	0.32

Continuation of table 2

1	2	3	4	5	6	7
T2	0–1	Decane	3.92	0.50	20.92	2.03
	1–2	Decane	3.41	0.52	17.40	2.17
	2–3	Decane	3.56	0.39	18.09	0.87
	3–4	Hexane	6.15	2.34	10.11	1.51
	4–5	Hexane	2.11	0.17	5.09	0.34
	5–6	Hexane	2.44	2.78	4.22	2.82
	6–7	Hexane	3.69	1.42	8.25	4.28
		Toluene	3.41	3.09		
	7–8	Hexane	1.72	0.41	2.83	0.62
	8–9	Hexane	2.15	0.71	3.24	0.82
	9–10	Hexane	1,30	0.34	2.18	0.47
	Blank	Hexane	2.57	0.20	3.26	0.19
T3	0–0.3	Hexane	5.54	3.72	3185.74	5414.42
		Ethylbenzene	3.49	2.97		
		o-Xylene	4.71	3.98		
		1,3,5-	6.52	5.53		
		Trimethylbenzene				
		1,2,4-	26.27	22.47		
		Trimethylbenzene				
		Naphtalene	19.68	17.49		
	0.3–0.6	Hexane	3.49	0.62	17.63	21.23
		1,2,4-	4.12	6.56		
		Trimethylbenzene				
		Naphtalene	5.89	9.17		
	0.6–0.95	–	not detected	not detected	6.53	1.76
	0,95–1,20	–	not detected	not detected	6.49	2.56
	Blank	Hexane	2.21	0.10	2.80	0.10

Concentrations of benzene, toluene, ethylbenzene and xylenes (BTEX) in the samples from T1, T2 and T3 boreholes (Table 2) indicate considerable variability among the three replicates of each sample. The fact that VOCs have been detected in the headspace containing only the Modifying Matrix Solution (MMS) suggests the possibility of the sample contamination by the atmosphere, in this case, by the gases from the combustion in the equipment used for drilling boreholes at the petrol station. Similarly, the high octane concentration from the 5 m depth in T1 borehole is not real because during the gas chromatography mass spectrometry (GC-MS), laboratory technicians were working with this compound very close to the GC–MS equipment where BTEX and (Gasoline Range Organic) GROs determination was being carried out. Additionally, it may be due to a laboratory contamination: a residual concentration in the atmosphere by hexane solvent used to perform other chemical determinations by a lab technician.

The highest recorded hexane value in the subsoil samples is 18 μg/kg of wet soil which belongs to T1 borehole at the 2–3 m depth. Individual concentrations of BTEX have been detected and quantified. Toluene has been quantified in the concentration of 3.41 μg/kg of wet soil in T2 borehole at the 6–7 m depth. Concentrations of ethylbenzene and oxylene have been detected in the first 30 cm in T3 with the values of 3.49 and 4.71μg/kg of wet soil respectively. Naphthalene was detected with the highest concentration (19.68 μg/kg of wet soil) in T3 borehole in the surface layer, from 0 to 0.03 m, in T3 at the 0.6 m depth (5.89 μg/kg of wet soil) and in T1 at a depth of the first meter with an average concentration of 3.02 μg/kg of wet soil. A downward trend can be seen in the concentration of GROs with increasing depth, which is obvious as GROs compounds are more volatile than Diesel Range Organic and Waste Oil Organic, and therefore, they migrate to the surface and suffer significant losses due to volatilization. The highest concentrations in these three boreholes are presented at a depth of 3 m.

Despite the deep ecological and economic crisis in Ukraine, the introduction of effective methods for regulation of nature use, namely environmental risk assessment as well as monitoring and assessment of environmental safety level) remains one of the top tasks for further sustainable development of Ukraine. But unfortunately, this problem is not paid enough attention to and it needs further development.

Materials and methods of research. Risk is a quantitative degree of danger. The application of the term "risk" allows transferring danger to the measured categories [[1]]. The main conception of risk assessment is identification of risks quantitatively or at least in a comparative form (qualitatively), relative to any other risks.

Almost all ecological processes are accompanied by uncertainty elements, which lead to ambiguity of the result. The corresponding risk is determined by quantitative and qualitative characteristics of probability for different variants of risks. The definition of risks is connected with compulsory studying of statistics and fulfillment of the following conditions: the availability of full amount of necessary information and factors concerning the uncertainty; the necessity of evaluation of all possible options and their consequences; choosing the best probabilities out of the available ones. The choice is made in the presence of alternative options by objective, subjective or subjective-objective estimates depending on the purpose of choosing a solution and its implementation.

The identification and assessment of risks should be based on the results of control of the technical condition at a petrol station, statistical data about failures, incidents, accidents and emergencies of anthropogenic nature, the data on dangerous geological and hydro-meteorological processes monitoring, the condition of urban ecosystem, statistical data on natural disasters, as well as on the results of modeling and forecasting of relevant hazardous events and situations [[5], 10].

The quantitative assessment of environmental risks creates the basis for classification of all petrol stations, and ranking of urbanized territories in the country by the degree of danger. Such assessment allows applying legal norms and state mechanisms of administrative and economic impact in proportion to the risk of danger in order to ensure an acceptable level of risk to achieve life safety for the society [[5], 10].

For Ukraine, the following basic risk indicators are defined: insignificant risk, acceptable risk, marginally tolerable and unacceptable risk [6]. Herewith, the acceptable risk is "risk, which is ensured in full compliance of the conditions and safety of work with the requirements of normative and legal acts on labor protection, but allows presence of grave and harmful working conditions, work in which is rewarded by benefits and compensations in accordance with current legislation" [[1], 10].

The generalized procedure for the assessment of risk from petrol stations can include such steps [17]:

1. Danger source identification. Given information can be used to receive the answers to the questions:

– What is the genesis of primary and secondary sources of danger of petrol stations for urban ecosystems?

– where, when and under what conditions did the urban ecosystems (or their separate components) suffer from petrol stations, or when will they suffer from them?

2. The assessment of a hazard level of petrol station sources – the analysis of spatial-temporal and volume-powerful parameters of hazard sources, detected in relation to the urban ecosystem.

3. General assessment of ecological vulnerability of the personnel, urbanized territory, and population within the urbanized territory and objects of management adjoined to the territory of the petrol station.

4. Risk assessment of the accident transformation into a complex accident or into a crisis.

5. Justification of measures to minimize risks with consideration of economic, social and environmental requirements and possibilities of the urban ecosystem (in the vicinity of the petrol station placement).

The assessment of risks from petrol station functioning can be based on relationships [6]:

$$R_{ns}\left(W_j\right)=P_s\left(W_j\right)\cdot V_{sf}\left(W_j\right)\cdot V_{nt}\left(W_j\right)\cdot V_{ns}\left(W_j\right)\cdot N_s\,, \quad (1)$$

where R_{ns} (W_j) is collective risk of death or loss of health in an urbanized territory S from j types of impact from petrol stations W_j (pers./year); P_s (W_j) *is the* probability of impacts manifestation from petrol stations (W_j) at the urbanized territory S (cases/year); V_{sf} (W_j) is physical vulnerability of the urbanized territory S from the impacts of petrol stations W_j, that is determined as the ratio of the affected territory S_i to the general area of the territory S; V_{nt} (W_j) is time vulnerability of the population, determined as the probability of presence on the urbanized territory S during the manifestation of the impressive impacts of the petrol station; W_j; V_{ns} (W_j) *is* spatial vulnerability of the population, determined as the probability of getting into the affected part of the urbanized territory S; N_s is total population within the urbanized area S [[2].

Further scientific research is to find out the mechanisms that cause the development of hazardous processes during the petrol station exploitation, identification of the main natural and man-made factors that contribute to their activation, zoning of the urbanized area by intensity, scale and nature of hazardous processes manifestation (at petrol stations), quantitative assessment of risks from the petrol station functioning.

Due to the transformation of methodology for environmental risk assessment, the following algorithm of research is proposed: First of all, the most serious threats are determined and their ranking is conducted. Then risk assessment and assessment of environmental safety level are made. It is important to take into account the components that may cause ecological threats, because they can serve as information and statistical basis in the form of specific indicators, characterizing the quantitative parameters of risk or violation of the ecosystem functioning in the region, settlement, city district, etc. [[10]].

To determine the environmental safety of the territory by the density of petrol station placement, the application of relative indicators is proposed. The proposed indicators can be divided into three levels: the level of petrol station density in the territory, the level of petrol station density per inhabitant, and the level of petrol station density in relation to the area of recreational territory. The chosen indicators reflect the level of man-made load from the number of petrol stations at a specific territory [10].

The assessment of the level of petrol station density in the territory is carried out by the calculation of an individual indicator for a petrol station placement (by density) for the corresponding region (settlement, city district), and is determined as a correlation:

$$S_н = \frac{n}{S_{н.п.}}, \quad (2)$$

where $S_н$ is the maximum value of an individual indicator of the petrol station placement (by density), for the corresponding region (settlement, city district), un./km^2; n is the number of petrol stations placed in the territory of the district (settlements, city districts), un.; $S_{н.п.}$ is the territory of the region (settlement, city district), km^2.

The evaluative individual level of the petrol station density per inhabitant is calculated by the formula:

$$N_н = \frac{n}{N_{н.п.}}, \quad (3)$$

where $N_н$ is the maximum value of an individual indicator of the level of the petrol station density per inhabitant in the corresponding region (settlement, city district), un./per; n is the number of petrol stations placed in the territory of the district (settlement, city districts), un; $N_{н.п.}$ is the number of the population in the region (settlement, city district), persons.

The evaluative individual degree of the petrol station density in relation to the area of the recreational territory of the region (settlement, city district) is calculated by the formula:

$$L_н = \frac{n}{L_{н.п.}}, \quad (4)$$

where $L_н$ is the maximum value of the evaluative individual degree of the petrol station density in relation to the area of the recreational territory of the region (settlement, city district), un./km^2; n is the number of petrol stations placed in the territory of the district (settlement, city district), un.; $L_{н.п.}$ is the area of the territory of the region (settlement, city district), km^2.

A separate indicator can not be the basis for ranking of the region (settlement, city district).

To compare individual time periods with further determination of the integral indicator of the ecological safety of the territory, the values of the level of the petrol station density in the territory, the level of the petrol station density per inhabitant, and the level of the petrol station density in relation to the area of the recreational territory of the corresponding region (settlement, city district) should be used.

The normalized individual indicator of the petrol station placement for the corresponding region (settlement, city district) is calculated by the formula:

$$S = \frac{S_н}{S_н^{\max}}, \quad (5)$$

where $S_н^{\max}$ is an individual indicator for the petrol station placement (by density) among the considered regions (settlement, city district) during the analyzed period.

The normalized individual level of the petrol station density per inhabitant of the corresponding region (settlement, city district) is calculated by the formula:

$$N = \frac{N_н}{N_н^{\max}}, \quad (6)$$

where $N_н^{\max}$ is the maximum value of the individual level of the petrol station density per inhabitant among the considered regions (settlements, city districts) during the analyzed period.

The normalized individual degree of the petrol station density in relation to the area of recreational territory of the region (settlement, city district) is calculated by the formula:

$$L = \frac{L_н}{L_н^{\max}}, \quad (7)$$

where $L_н^{\max}$ is the maximum value of the individual degree of the petrol station density in relation to the area of the recreational territory among the considered regions (settlements, city districts), during the analyzed period.

Integral indicator of ecological safety of the territory by the density of the petrol station placement is:

$$D_{A3C} = g_k \cdot S + g_k \cdot N + g_k \cdot L, \quad (8)$$

where *k* is the number of hazard indicators from petrol stations of the region (settlement, city district), in the given case *k* = 3; γ_k is the weight coefficient, in the first approximation $\gamma_k = 1/k$.

It is proposed to apply the given methodology to determine the acceptable risk in the region (settlement, city district), the degree of which is determined depending on the environmental situation, the level of population morbidity and the number of emergencies at man-made objects [10].

By the results of the assessment of the integral indicator of environmental safety, special ranking of regions (settlements, city districts), aimed at classification of the regions in terms of safety level, is carried out. It should be taken into account that the highest value of this indicator shows the lowest level of environmental safety of the region (settlement, city district).

Having determined the quantitative assessment of environmental risk, it becomes relevant to implement a qualitative interpretation of the calculated values by identifying quantitative values of risk, that is, a degree of risk. For qualitative interpretation of the calculated values, it is proposed to divide the numerical interval of ecological risk level (which has all possible values from zero to one) into five intervals, that is, to define such intervals and their qualitative interpretation [10]:

I [0.00–0.20) – ecological risk of low level;
II [0.20–0.40) – ecological risk of moderate level;
III [0.40–0.60) – ecological risk of average level;
IV [0.60–0.80) – ecological risk of high level;
V [0.80–1.00) – ecological risk of extremely high level.

According to the proposed scale, the received values of risks can be divided into five classes of environmental hazard:

– Extremely hazard level of danger – ecological risk level above 0.80;

– High danger – ecological risk level in the range of [0.60–0.80);

– Increased danger – ecological risk level in the range of [0.40-0.60);

– Moderate danger – ecological risk level in the range of [0.20- 0.40);

– Relative danger – ecological risk level below (0.20).

The results and their discussions. The area of Kamyanets-Podilsky is 27,871 km^2. In January 2016, the population of the city was 101 235 people. The density of petrol stations within the city was 0.72 un./km^2 and $1.98 \cdot 10^{-4}$ un./per. From the end of 2016 to the middle of 2017, 20 petrol stations were placed within the city.

According to the methodology used to determine environmental safety level, placement of petrol stations requires the analysis of the scheme of functional zoning of the settlement territory.

The chosen indicators, presented in the research methodology, reflect the level of man-made load from the number of petrol stations in a specific territory, so within Kamyanets-Podilsky it is necessary to select areas of the city that could be compared (ranked) with each other. By the Department of Housing and Communal Services of Kamyanets-Podilsky City Council, the territory of Kamyanets-Podilsky is divided into four districts, which are serviced by four housing and communal enterprises (Fig. 1). The given scheme was used as a basis for our research. The separate districts of the city are marked by Latin numbers: I – Northeastern district of the city; II – Central district of the city; III – Southwestern district of the city; IV – Southern district of the city.

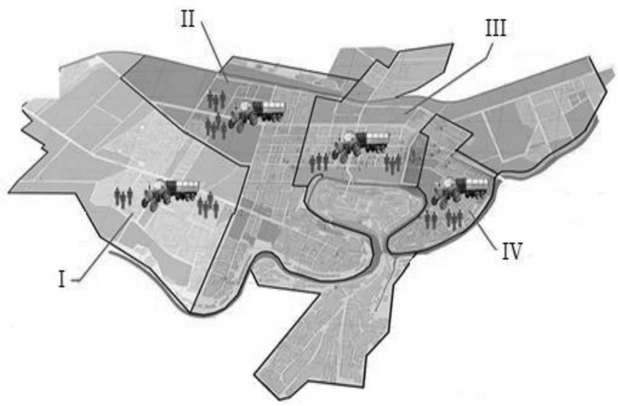

Fig. 1. Map of the territory and experimental districts of Kamyanets-Podilsky city

According to the methodology, the indicators of the city districts area, the number of the city districts, and the area landscape and recreational zone of the city are applied as the initial data to calculate integral estimation of ecological safety level of the territory by the density of petrol stations placement (Table 1).

Table 1

The numerous characteristics of Kamyanets-Podilsky city

District of the city	Area, m^2	Number of petrol stations, units	Population, pers.	The area of the landscape and recreation zone, m^2
I – Northeastern	9931587	12	43986	433100
II – Central	7400006	4	31279	301400
III – Southwestern	9379400	2	9082	48000
IV – Southern	1702982	2	16115	195100

The individual indicators of petrol station placement (by density), petrol station density per inhabitant, level of petrol station density in relation to the landscape and recreation area of the city districts, are presented in Table 2.

Table 2

The normalized individual indicators of petrol stations placement

District of the city	$S_н$	$N_н$	$L_н$	S	N	L
I – Northeastern	1.31	0.0002	30.2	1.00	1.0	0.604
II – Central	0.54	0.0001	13.3	0.41	0.5	0.266
III – Southwestern	0.21	0.0002	50.0	0.16	1.0	1.000
IV – Southern	1.18	0.0001	10.5	0.90	0.5	0.210

The integral indicators of ecological safety of the territory by the density of petrol stations placement, and their ranking are presented in Table 3.

Table 3

Integral indicators of the territory by the density of petrol stations placement

District of the city	D	Risk level	Class of environmental hazard
I – Northeastern	0.87	extremely high	extremely high
II – Central	0.39	moderate	moderate
III – Southwestern	0.72	high	high
IV – Southern	0.54	average	increased

Qualitative interpretation of the calculated values by identification of the received quantitative risk values according to the proposed scale indicates the timeliness of the conducted evaluation. The received results allow performing integral assessment and defining districts of Kamyanets-Podilsky, which are situated in the zone of dangerous man-made load. The futrther improvement of the methodology will allow conducting more detailed evaluation in the future, and applying its results for adoption of management solutions concerning planning of the settlement territory.

Conclusions

1. The development of urbanized territories and rapid growth of the number of vehicles in the vicinity of urban ecosystems led to the increase in the number of petrol stations. But the issues concerning boundary capacity of the territory and capabilities of the urban ecosystem to withstand the load caused by the increase in the density of placement of high danger objects are almost not studied.

2. Modern legislative and town-planning documentation regulate local conditions and limitations of petrol station placement, but do not provide assessment of the impact on the environmental safety level of the whole urban ecosystem, which significantly differs in the peculiarities of structural organization and technological scheme of petrol stations exploitation.

3. The ecological threats during petrol station exploitation are caused by getting pollutant substances into the air, water, soil, through emission of steam and air mixture from the reservoirs of the station, and car tanks during refueling, exhaust gases of automobile engines, oil spills during drainage from tank-vehicles into the tanks of the station and during refueling of vehicles, oil leaks and oil spills during repairs and maintenance of technological equipment, emergency situations.

4. According to monitoring results it was found that there are 20 petrol stations within the urban ecosystem of Kamyanets-Podilsky. It means that the density of stations concentration within the urbanized area is 0.72 n./km^2 and $1.98 \cdot 10^{-4}$ n./per.

5. The integral indicators of ecological safety of Kamyanets-Podilsky city by the density of fuel stations placement are: I – 0.87, II – 0.39, III – 0.72, IV – 0.54. Thus, the city districts belong to the following classes of ecological danger: I – extremely high, II – moderate, III – high, IV – increased. The further improvement of the methodology will allow conducting more detailed evaluation in the future and applying its results for the adoption of management solutions concerning planning of the settlement territory.

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