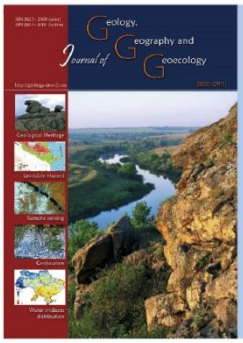

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Geoecological analysis of the impact of anthropogenic factors on outbreak of emergencies and their prediction

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Abstract.The purpose of this study is geoecological analysis of the risk of natural fires and other emergencies of an ecological nature based on the location of high-risk objects in the territory of the Kharkiv region. The following tasks were solved in the work: calculation of the risk of an ecologically dangerous event depending on the density of placement of objects of high danger in the region; Creation of a chart-map on the level of danger of environmental threat in the districts of the region; the search for the dependence of the area of forest fires on the density of the population, the number of high risk facilities, etc. An analysis of the influence of anthropogenic factors on the occurrence of natural fires on the example of the Kharkiv region was carried out. Distribution of potential risk and population density in the studied area allows us to obtain quantitative estimation of social risk for the population. Excessive population density in some areas of the region is one of the factors that increase the material and social risk of the territory and population of the region from natural disasters and man-made disasters. We created mapping zoning of multi-level districts of the region, the risk of an emergency reflects the patterns of spatial structure of potential sources of emergency situations and allows to increase the readiness of the executive and authorized services to act in the event of sudden emergencies and to act for their prevention. Available data allowed us to estimate the density of the placement of potential sources of man-made emergency situations for all districts of the region, which gives us the right, with a certain degree of conditionality, to speak about the extent of the technogenic danger of the territory of the studied areas of the Kharkiv region. We propose to apply a complex factor taking into account the population density, density of placement of objects of high danger and the proportion of high risk objects in the area of the forestry organization in comparison with the total number of objects in the region. For the simultaneous evaluation of both natural and anthropogenic conditions of forest fires in the region, we propose to use the methodology of scoring on which they are evaluated in a four-point system, taking into account the five main characterizing indicators : population density; forest area; the density of high risk facilities; climatic and weather conditions; the share of high risk facilities. Comparison of information on the average number of fires on the lands of the forest fund of Kharkiv region over the past ten years with the results of our typology of the areas shows some correlation. The results of studies on the assessment of the risks of the occurrence of fires depending on natural and anthropogenic factors can be used for zoning similar areas and forecasting the fire situation.

Key words: geoecological analysis, natural fires, risk of occurrence, man-caused loading, high-risk objects.

Геоекологічний аналіз впливу антропогенних чинників на виникнення надзвичайних ситуацій та їх прогноз

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Анотація. Мета даного дослідження – геоекологічний аналіз ризику виникнення природних пожеж та інших надзвичайних ситуацій (НС) екологічного характеру на основі розміщення об'єктів підвищеної небезпеки на території Харківській області. У роботі були вирішені наступні завдання: розрахунок ризику виникнення екологічно небезпечної події у залежності від щільності розміщення об'єктів підвищеної небезпеки (ОПН) у регіону; створення картосхеми за рівнем небезпеки екологічної загрози за районами області; пошук залежності площі лісових пожеж від щільності населення, кількості об'єктів підвищеної небезпеки та ін. Проведений аналіз впливу антропогенних факторів на виникнення природних пожеж на прикладі Харківського регіону. Розподіл потенційного ризику і щільності населення в досліджуваному районі дозволяє отримати кількісну оцінку соціального ризику для населення. Надмірна щільність населення в окремих районах області є одним з чинників, що підвищують матеріальний і соціальний ризик території і населення регіону від стихійних лих і техногенних аварій. Створено картосхему районування різнорівневих районів регіону, ризик надзвичайної ситуації відображає закономірності просторової структури потенційних джерел НС і дозволяє підвищити готовність виконавчої влади і уповноважених служб до дій при раптовому виникненні НС і до їх попередження. Наявні дані дозволили нам оцінити щільність розміщення потенційних джерел техногенних НС для всіх районів області, що дає право з відомою долею умовності говорити про міру техногенної небезпеки території вивчених районів Харківського регіону. Нами запропоновано застосовувати комплексний коефіцієнт, що враховує щільність населення, щільність розміщення ОПН та долю об'єктів підвищеної небезпеки у районі розташування лісгоспу у порівнянні із загальною кількістю даних об'єктів у регіоні. Для одночасної оцінки і природних, і антропогенних умов виникнення лісових пожеж в регіоні нами пропонується використовувати методику бальної оцінки, по якій вони оцінюються за чотирибальною системою з урахуванням п'яти основних показників, що характеризують: щільність населення; лісистість території; щільність ОПН; кліматичні і погодні умови; частка ОПН. Зіставлення інформації про середню кількість пожеж на землях лісового фонду Харківської області за останні десять років з результатами проведеної нами типізації районів показує певну їх кореляцію. Результати досліджень з оцінки ризиків виникнення пожеж в залежності від природних і антропогенних факторів можуть бути використані при зонуванні аналогічних територій і прогнозування пожежної обстановки.

Ключові слова: геоекологічний аналіз, природні пожежі, ризик виникнення, техногенне навантаження, об'єкт підвищеної небезпеки.

Introduction. Currently very few studies focus on geoecological analysis of the impact of antropogenic factors on occurrence of emergencies. One of them is the study by Y.A. Andreev (Andreev, 2003), which contains results of study of patterns of ignition of technogenic and naturally-driven wildfires. Modeling and assessment of factors, both technogenic and natural character, are essential for development of methods for preventing emergencies of pyrogenic character (Vacchiano, Foderi, Berretti, Marchi, 2018).

Among the anthropogenic factors, we should note technogenic and social (Fig. 1). Social risk and danger of fires was assessed in a study (Borisova, 2017) on the example of Buryatia.

In one study (Andreev, 2003), the author attributes ignition of wildfires to weather conditions, the population and number of inhabited localities per unit area. We think that such an approach is worthy of attention, but more effective would be the study of the number of fires relative to density of the population rather than the absolute number of inhabitants. Furthermore, values and functions of inhabited settlements can significantly vary. The most probable occurrence is the ignition of fires on the high-risk facilities or potentially dangerous objects. In particular their number should be taken into consideration for assessment of risk of emergency, including of pyrogenic character.

The objective of this study was geoecological analysis of risk of ignition of wildfires and other emergencies of ecological character on the basis of location of high-risk facilities in the territory of Kharkiv Oblast.

For achieving the goal, the following tasks were solved: assessment of risk of ecologically dangerous events depending on the density of location of high-

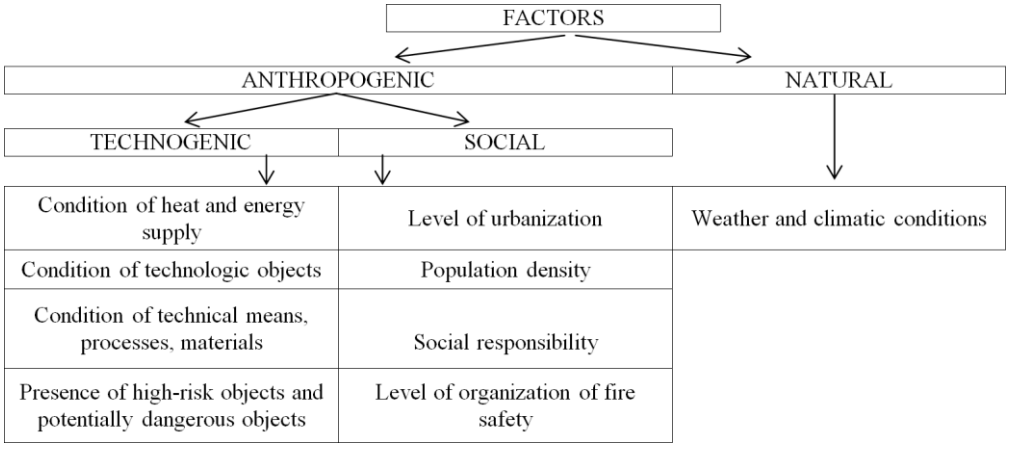

Fig. 1 Factors of ignition of wildfires

risk facilities (HRF) in the region; developing a map-scheme by the level of danger of ecological threat by the districts of the Oblast; search for dependence of the area of wildfires on density of population, number of high-risk facilities, etc.

Materials and methods. The authors conducted a geoecological analysis of the impact of anthropogenic factors on ignition of wildfires on the example of Kharkiv region. Distribution of potential risk and density of population in the studied district allows one to obtain quantitative assessment of social risk for the population. Excessive density of population in certain districts of the Oblast is one of the factors which increase the material and social risk of natural disasters and technogenic catastrophes for the territories and the population of the region (Buts, Asotskyi, Kraynyuk, Ponomarenko, 2018; Buts, 2018, Krainiuk, Buts, 2018, Buts, Asotskyi, Kraynyuk, Ponomarenko, 2019). We developed a map-scheme of zoning of different-level districts of the region, risk of emergency reflects the patterns of spatial structure of potential sources of emergencies and allows one to increase the readiness of the executive power to counter and prevent sudden emergencies.

Because wildfires are the leader among the emergencies, we performed a geoecological analysis of risk of potential emergency of ecological character on the basis of location of high-risk objects in the territory of Kharkiv Oblast and compared the obtained results with possible dangerous events of a pyrogenic character. In total, according to the state register of HRF, 381objects are located in the territory of the region, and 9,382 in Ukraine.

The risk of an ecologically dangerous event occurring depends on the density of locations of HRF in region. For all the districts of the Oblast, coefficient *f* (density of threat objects in the territory) was calculated, indicating the area for each HRF (Tables 1, 2).

Density of hazardous objects in the territory was calculated for point objects per unit area (km^2). By the density of hazardous objects in the territory, with a certain degree of accuracy, one can state the probability of emergency of technogenic character. The greater the density, the higher is the likelihood of emergency.

Results and their analysis. On the basis of the analyzed parameters, we performed grouping of the districts of the Kharkiv region according to the level of geoecological safety (Fig. 2). According to the calculations, the most dangerous districts were Kharkivsky district with a high-risk object every 11.3 km^2. In Derhachi and Chuhuiv districts one high-risk object is located per each 25.7 and 33.7 km^2 respectively. Using the provided data the authors produced a map-scheme of Kharkiv Oblast (Fig. 2), where this group of districts was coloured with red.

Pink colour-filled districts have HRF located every 70-83 km^2. This category includes Bohodukhiv and Zmiiv, Izium, Krasnohrad, Kupianskyi and Pervomaiskyi districts. Zolochiv, Balakliia, Lozova, Nova Vodolaha and Sakhnovshchyna districts are coloured in light green, having HRF located every 130-200 km^2. Other districts have the lowest density of HRF, i.e. one HRF per over 200 km^2. On average, one high-risk object is located in each 81.2 km^2 of the region.

For geoecological analysis of ecological danger, it is also expedient to take into account number of inhabitants in each district. For this purpose coefficient *d* was calculated (Table 1). The highest coefficient was determined for Iziumsky district with one HRF per every 935 people. Coefficients were also high for Kharkivsky, Chuhuiv and Kupianskyi districts with one HRF per every 1,379-1526 people. These districts have the largest circle chart on the map-scheme.

One HRF is located per 2,000 to 3,000 people in Sakhnovshchyna, Pervomaiskyi, Lozova, Derhachi and Bohodukhiv districts, indicated with smaller charts. Even smaller charts mark Velykyi Burluk, Dvorichna, Zachepylivka, Zmiiv, Zolochiv, Krasnohrad, Nova Vodolaha, Sakhnovshchyna districts, in which one HRF is located per every 3,000-6,000 inhabitants. Other districts are marked by the smallest chart, because there one HRF is located for each 7,000 inhabitants. In general, across the region, one high-risk object for 2,811 people is located.

Risk of emergency in one of the considered objects was estimated as ratio of number of HRF in the district to the total number of similar objects in the territory of the entire country (Table 1). The highest risk was determined for Kharkivsky district – $1.2 \cdot 10^{-2}$, the lowest in Kolomak district – $1.0 \cdot 10^{-4}$. In general, risk of technogenic emergency in Kharkiv region is high, equaling $4.0 \cdot 10^{-2}$.

The present data allowed us to estimate the density of location of potential sources of technogenic emergencies for all districts of the oblast, therefore, with a certain degree of conditionality indicate the level of technogenic threat in the territory of the studied districts of the Kharkiv region.

Let us compare the obtained results with territorial structure of the Kharkiv Oblast Management of Forestry and Hunting Grounds) with division into forestries and area of forest fires (Table 2). We assessed the average area affected by fire for each forestry according to the statistics of the fires over

Табл. 1. Number of population and HRF in Kharkiv Oblast (distribution by districts)

District	Number of inhabitants, M Thou people	Number of high risk objects, n	Area S, km^2	Coefficient which indicates the are for each HRF, f=S/n, km^2	Coefficient which includes the number of population for each HRF, d=M/n	Risk of outbreak of emergency R=n/9382
Zachepylivka District	16.1	3	794	264.6	5.366	$3.2 \cdot 10^{-4}$
Kehychivka District	21.8	3	782.5	260.8	7.266	$3.2 \cdot 10^{-4}$
Nova Vodolaha District	34.9	9	1,182.7	131.4	3.877	$9.6 \cdot 10^{-4}$
Krasnohrad District	45.8	14	985.1	70.3	3.271	$1.5 \cdot 10^{-3}$
Sakhnovshchyna District	22.5	7	1,169.9	167.1	3.214	$7.5 \cdot 10^{-4}$
Vovchansk District	48.7	6	1,888.6	314.7	8.116	$6.4 \cdot 10^{-4}$
Balakliia District	84.6	13	1,986.5	152.8	6.507	$1.4 \cdot 10^{-3}$
Kupianskyi District	26	17	1,280.3	75.3	1.529	$1.8 \cdot 10^{-3}$
Borova District	17.8	3	875.3	291.7	5.933	$3.2 \cdot 10^{-4}$
Velykyi Burluk District	23.7	5	1,220.8	244.1	4.740	$5.3 \cdot 10^{-4}$
Zmiiv District	73	18	1,364.7	75.8	4.055	$1.9 \cdot 10^{-3}$
Zolochiv District	27.8	5	968.6	193.7	5.560	$5.3 \cdot 10^{-4}$
Valky District	32.6	2	1,010.5	505.2	16.300	$2.1 \cdot 10^{-4}$
Kolomak District	7.7	1	329.5	329.5	7.700	$1.0 \cdot 10^{-4}$
Derhachi District	94.9	35	900.1	25.7	2.711	$3.7 \cdot 10^{-3}$
Kharkivsky District	183	124	1,403.4	11.3	1.475	$1.2 \cdot 10^{-2}$
Chuhuiv District	46.9	34	1,148.6	33.7	1.379	$3.6 \cdot 10^{-3}$
Pechenihy District	10.5	2	467.5	233.7	5.250	$2.0 \cdot 10^{-4}$
Shevchenkove District	21.2	4	977.4	244.3	5.300	$4.2 \cdot 10^{-4}$
Bohodukhiv District	40.4	14	1,160.3	82.8	2.885	$1.5 \cdot 10^{-3}$
Krasnokutsk District	29.3	5	1,040.8	208.1	5.860	$5.3 \cdot 10^{-4}$
Izium District	18.7	20	1,553.5	77.6	0.935	$2.1 \cdot 10^{-3}$
Barvinkove District	24.7	3	1,364.5	454.8	8.233	$3.2 \cdot 10^{-4}$
Blyzniuky District	20.7	3	1,380	460	6.900	$3.2 \cdot 10^{-4}$
Lozova District	30.7	10	1,403.5	140.3	3.070	$1.8 \cdot 10^{-3}$
Pervomaiskyi District	48.2	17	1,194.5	70.2	2.835	$1.8 \cdot 10^{-3}$
Dvorichna District	18.8	4	1,112.4	278.1	4.700	$4.3 \cdot 10^{-4}$
Total	1071	381	3,0945.5	81.2	2.811	$4.0 \cdot 10^{-2}$

10 years (2008-2017). This value was compared with the number of inhabitants in the districts of forestry location (Fig. 3).

Also, we consider it practical to compare the data on density of the high-risk objects with images of forest fires, obtained using satellite monitoring (Krainiuk, Buts, Nekos, 2019).

Earlier, it was already noted that it would be possibly more expedient to study the number or area of fires not with respect to] the total population, but rather from the density of population, as we did. As shown in the chart 4, stronger correlation is seen between the area of fires and density of the population of a given district.

Technogenic load in the region was assessed on the basis of number of HRF in such way that impact of the technogenic constituent on ignition of forest fires was assessed according to this indicator (number of HRF). The obtained dependence of the area of forest fires on the number of HRF in the district is shown in Fig. 5.

The dependence between the area of forest fires

Table 2. Number of population and HRF in Kharkiv Oblast (distribution by districts)

Forestry	Average area of forest fires according to the data of 10 years (2008-2017) ha	Number of inhabitants, M Thou people	Number of high risk objects, n	Area of districts S, km^2	Area of forestry, thou ha	Density of population, people/km^2	Coefficient which indicates area for each HRF, f=S/n, km^2	Coefficient which indicates the number of population for each HRF, d=M/n	Share of HRF in district regarding their total number in the region D
Krasnohradsky (Zachepylivka, Kehychivka, Nova Vodolaha, Krasnohrad, Sakhnovshchyna districts)	22.22	141	36	4914.3	14.6	28.71	136.51	3.92	0.095
Vovchansky	1.72	48.7	6	1888.6	27.9	25.78	314.7	8.11	0.015
Balakliisky	7.50	84.6	13	1986.5	28.3	42.58	152.8	6.50	0.034
Kupianskyi (Kupianskyi, Borova, Velykyi Burluk districts)	37.70	67.5	25	3376.4	37.4	19.99	135.0	2.7	0.066
Zmiivsky	2.60	73	18	1364.7	32.3	5.35	75.8	4.05	0.047
Zhovtnevy (Zolochiv, Valky, Kolomak, Derhachi, Kharkivsky districts)	10.65	318.2	162	3643.5	48.4	87.33	22.4	1.96	0.429
Chuhuievo-Babchansky (Chuhuiv, Pechenihy, Shevchenkove districts)	7.84	78.6	40	2593.5	22.6	30.30	64.8	1.96	0.106
Hutiansky (Bohodukhiv, Krasnokutsk districts)	3.87	69.7	19	2201.1	31.1	31.66	115.8	3.66	0.050
Iziumsky (Izium, Barvinkove)	8.44	43.4	23	2918	53.0	14.87	126.8	1.88	0.061

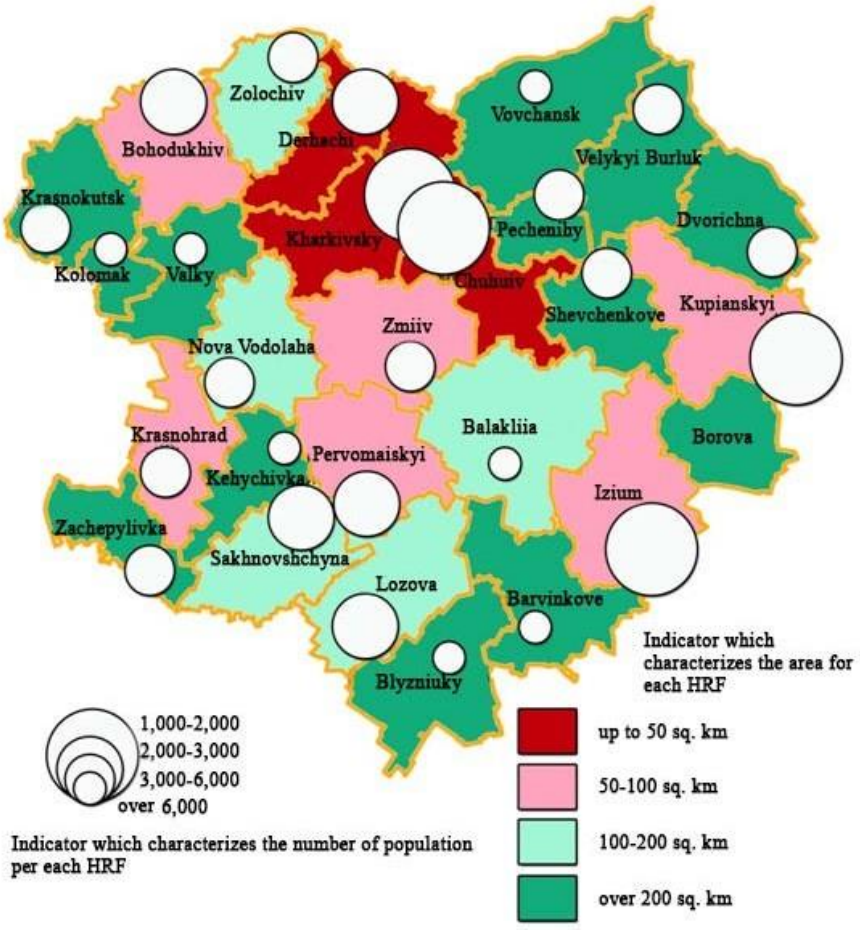

Fig. 2. Geoecological analysis of the level of ecological threat by regions of the Oblast

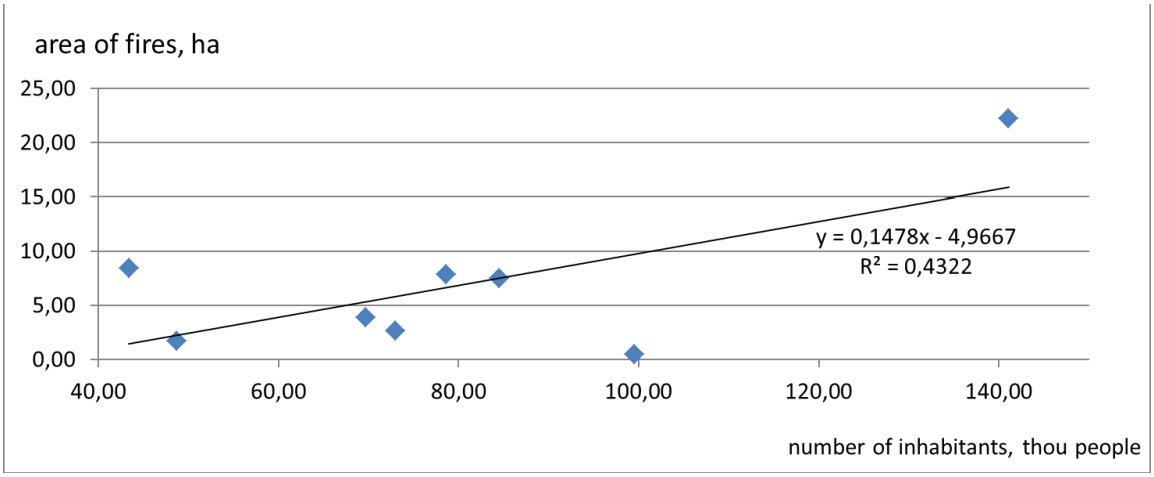

Fig. 3. Dependence of forest fires on the number of inhabitants

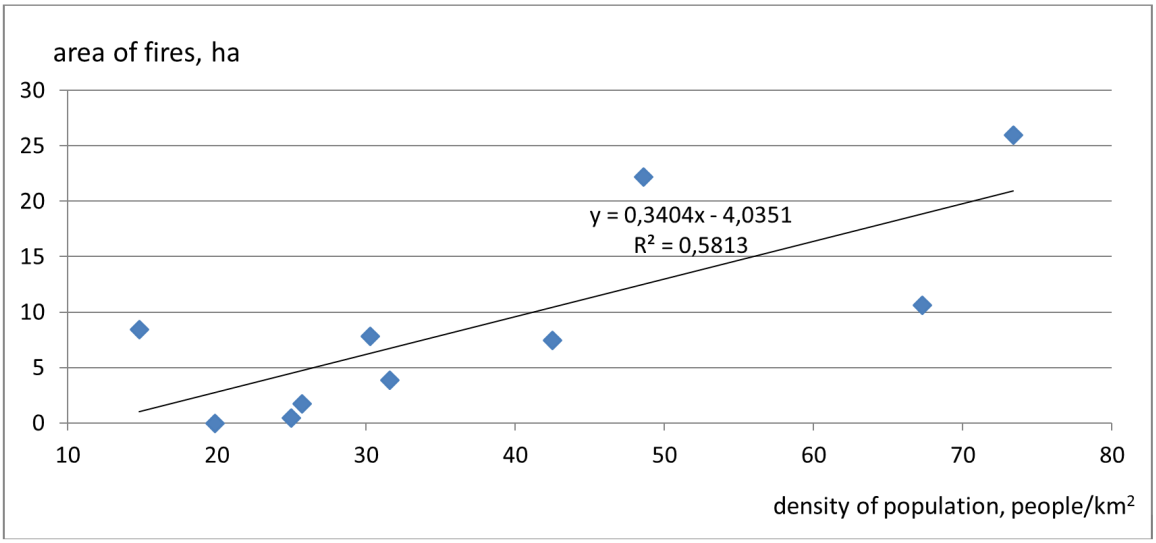

Fig. 4. Dependence of area of forest fires (ha) on the density of population

and density of HRF in district is shown in the same way (Fig. 6). Similarly to density of population, we observe stronger correlation.

We suggest using a complex coefficient which takes into consideration the density of population, density of HRF and share of HRF in the district of forestry compared to the total number of these objects in the region.

$$\mu = d \cdot f \cdot D, \quad (1)$$

Where μ – total coefficient which takes into consideration the technogenic load, d – density of population (people/km^2), f – density of HRF (objects/km^2), D – share of HRF in the total number of HRFs in the region.

Assessment of dependence of area of forest fires on this coefficient is shown in Fig. 7.

According to the presented calculations, quite good correlation is observed. Correlation coefficient equals 0.9.

Thus, the area of forest fires can be predicted using the formula:

$$A = 2.54 \cdot \mu + 2.12 \quad (2)$$

or

$$A = 2.54 \cdot d \cdot f \cdot D + 2.12 \quad (3)$$

where A – average area of forest fires in a forestry over a year.

Of course, the record of anthropogeic factors of forest fires is obligatory. According to Nikischenko N.G. (Nikischenko, 2007), the cause of 96.9% of forest fires is anthropogenic (i.e. social) factor, 2.1% – technogenic, and only 0.8% – natural. According to the statistics provided by Sobolev S.A. (Sobolev, 2006), 69% of forest fires are related to negligence with fires in places of the population`s recreation.

For simultaneous evaluation of both natural and anthropogenic conditions of ignition of forest fires in the region, we suggest using methods of point assessment, according to which, using a 5-point scale sys-

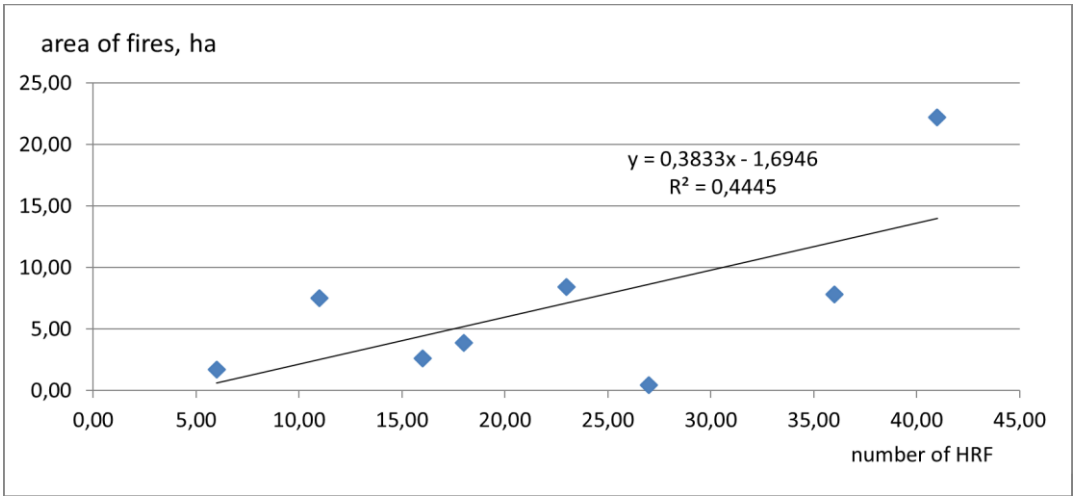

Fig. 5. Dependence of the area of forest fires (ha) on the number of HRF

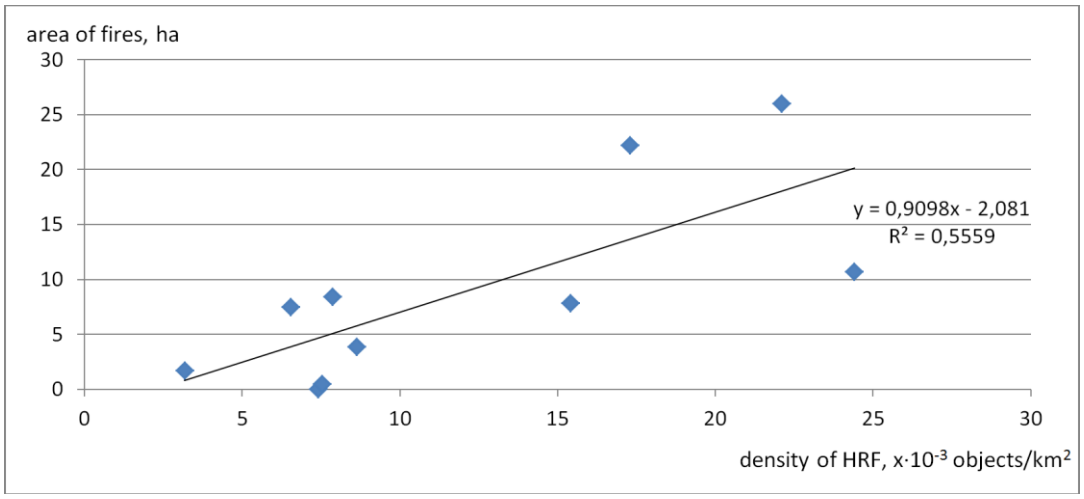

Fig. 6. Dependence of the area of forest fires (ha) on the density of HRF

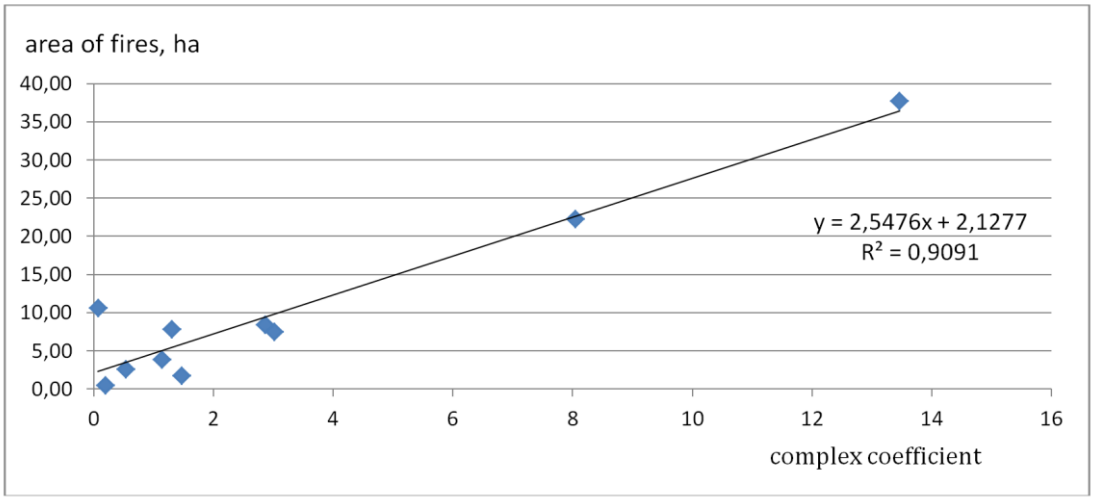

Fig. 7. Dependence of area of forest fires (ha) on the complex coefficient

tem, the five main parameters are taken into account. The five factors characterize:

Density of population;

Forest-cover of the territory;

Density of HRFs;

Climatic and weather conditions;

Share of HRFs.

As a result of studying the conditions of ignitions of forest fires in Kharkiv Oblast, we determined that the most significant are forest cover of the territories

Table 3. Assessment of the level of threat of ignition of forest fires

Level of threat	Points	Main factors				
		X_1	X_2	X_3	X_4	X_5
Extremely high	4	>41	>15	< 10	< 100	< 2,5
high	3	26–40	11–15	8–9	100–150	2,5–2,7
Moderate	2	11–25	5–10	4–7	150–200	2,6–3,0
insignificant	1	< 10	<5	> 4	>200	>3

Where X_1 – density of population, people/km^2; X_2 – forest area, %; X_3 – share of HRF,%; X_4 – area for each HRF; km^2; X_5 – ratio of amount of precipitations to the average air temperature in June-August.

Table 4. Determining integral indicator of forest fires and anthropogenic ignition of forest fires

Forestry	X_1	X_2	X_3	X_4	X_5	Integral parameter
Zhovtnevy	4	3	4	4	3	3.7
Chuhuievo-Babchansky	3	2	4	4	3	3.1
Kupiansky	3	4	2	3	4	3.2
Krasnohradsky	3	2	3	3	4	3.1
Balakliisky	4	3	1	2	3	2.95
Iziumsky	2	4	2	3	4	2.8
Hutiansky	3	3	2	3	3	2.5
Zmiivsky	1	4	2	4	3	2.4
Vovchansky	2	3	1	1	3	1.8

(λ = 0.3), and density of the population (λ = 0.3). To a less extent, the intensity of the fires depends on the share of HRF (λ = 0.15), area per one HRF (λ = 0.15), and also climatic factors (λ = 0.10). For each of the factors, we developed an assessment scale (Table 3).

As a result of summing up the points for the main factors, with consideration of the coefficients of their significance, for each administrative district, we determined an average value, an integral indicator of natural-anthropogenic condition of ignition of forest fires (Table 4).

These parameters allowed us to construct a geoecological typology of the administrative districts of Kharkiv Oblast distinguishing the areas with extremely high, high, moderate and low threats of ignition of forest fires in the lands of the forest fund.

As we determined, the highest such threat exists in the central part of the Oblast – in Zhovtnevy and Chuhuievo-Babchansky forestries, for they are located in the administrative districts with the highest density of the population and a high number of HRF. These territories are near the center of the region the city of Kharkiv and are characterized by dominance of pines, the most flammable trees, in the forest fund. Also, the highest threat was determined for Kupianskyi and Krasnohrad districts, in which over the last 10 years the largest area was damaged by fire (over 10% of the forest territory). A high threat of forest fires was determined also in Balakliisky, Iziumsky forestries. In those territories, the density of the population which uses the forest for recreation is also high. In the rest of the territories of the Oblast the threat of forest fires is much lower (Table 4).

Comparing of the data on the average num- ber of the fires in the lands of the forest fund of Kharkiv Oblast over the last ten years with the results of the typologisation of the districts, which we made, shows their certain correlation. Thus, for the districts with quite a high threat of ignition of forest fires and integral indicator higher than 3, the average area of forests damaged by the fires over the last 10 years is over 7%; with high threat (2.6–3.0

Table 5. Results of geoecological typologisation of lands by the conditions of ignition of forest fires and their factual number in Kharkiv Oblast (2008-2017)

Types of administrative districts by threat of ignition of forest fires	Integral indicator	Area, %	Integral parameter of threat	Area of forests damaged by forest fires over the 10 recent years, %
1. Very high threat	> 3	58.37	3.3	7.7
2. High threat	2.6– 3.0	19.70	2.9	2.1
3. Moderate threat	2.0– 2.5	14.32	2.5	1.0
4. Relatively low threat	<2	7.58	1.8	0.6

points), the area of the territories damaged by the fires - 2.1%; with moderate threat (2.0–2.5 points) – 1% of the territory damaged, low (below 2 points) – 0.6% (Table 5).

Conclusions. Geoecological analysis of the risk of ignition of forest fires and other emergencies of ecological character on the basis of location of the high-threat objects in the territory of Kharkiv oblast and depending on the ecological and anthropogenic factors can be used in geoecological zoning of similar territories and predicting emergencies.

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