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THE EFFECT OF PETROLEUM PRODUCTS POLLUTION ON ENVIRONMENTAL SOIL CONDITION AT AIRPORT ADJACENT TERRITORY

Purpose. Determination of the impact of oil pollution at the territory adjacent to the airport on the ecological state of the soil.

Methodology. The authors evaluate the impact of petroleum products on the ecological conditions of the soil at the territory adjacent to the airport. In particular, it was done experimentally, using the method of biotesting of soil sample data. Also, the component composition of chemical soil pollution was analyzed applying chromatographic analysis. Using the method of mathematical modeling, a two-factor model was built taking into account the factor of "content of oil products (X1)" in the soil and "distance from the runway (X2)" to describe the impact of air transport processes on the condition of the soil at the territory adjacent to airports.

Findings. Based on the obtained experimental data, the level of soil pollution at the territory adjacent to the airport was determined. It was established that for two soil samples, taken at a distance of 50 and 500 m from the runway of the airport, the content of oil products is below the established approximately permissible concentration. For samples taken at distances of 1,000, 1,500 and 2,000 m, an excess was established. The results of the chromatographic analysis of the composition of chemical contamination of the soil indicated a significant amount of hydrocarbons characteristic of the fuel fractions of oil. The obtained results demonstrate the dependence of the level of soil contamination with petroleum products on the distance to the runway and the presence of technogenic influence of this enterprise on the ecological state of the soil, which was confirmed with the results of biotesting of these soil samples. A two-factor model was built taking into account the factors of "content of petroleum products (X1)" in the soil and "distance from the runway (X2)" and their influence on soil phytotoxicity. The adequacy of the proposed model is evidenced by the coefficient of determination $R^2 = 0.9153$ for the tested soil samples.

Originality. The results of the experimental studies show that chemical pollution negatively affects the ecological condition of the soil at the territory adjacent to the airport; has a multi-component composition, and, in addition to hydrocarbons, which are characterize petroleum products used for refueling and operating vehicles, there are products of decomposition and aging of polymers, components of additives. The dependence of the ecological state of the soil on the technologically loaded territory adjacent to the airport on the level of petroleum products pollution and on the distance to the airport runway was determined. To find out the significance of the impact on the level of phytotoxicity of the soil of each of the two factors (the content of petroleum products and the distance from the runway), a multifactor statistical analysis of the obtained data was carried out and a two-factor model was built. This made it possible to establish that the contribution of the factor X1 (content of oil products) to the change in the soil phytotoxicity indicator is significantly greater than the contribution of the factor X2 (distance from the airport).

Practical value. Based on the results of the analysis of the obtained experimental data, a two-factor model is proposed, which takes into account the factors X1 and X2 and can be used for further studies of the impact of air transport processes on the state of the soil at the areas near airports.

Keywords: *petroleum products, soil, chemical pollution, environmental condition, environmental safety, airport*

Introduction. Soil pollution with petroleum products is a serious environmental problem all over the world. This is, in particular, the result of the intensification of man-made activities in the transport sector, where oil products are used in significant quantities every day. The consequence of such an impact on the soil cover is its degradation, change in physical and chemical characteristics, and a decrease in self-recovery ability, as a result of which the ability of entire ecosystems to self-recovery deteriorates. Among other transport enterprises that belong to technologically dangerous objects, airports are characterized with a certain peculiarity of impact on all components of the environment (atmospheric air, soils and water bodies). At these enterprises, chemical, physical and biological impacts on the environment are carried out simultaneously. According to the authors, in addition to monitoring the state of the atmospheric air and the noise level, which, mainly due to the requirements of regulatory documents on environmental protection, are considered carefully by ecologists at these enterprises, an important component of ensuring an appropriate level of environmental safety at man-made hazardous facilities, in particular airports and other enterprises of the aviation industry, is the control of the condition of the soil in the territories of these enterprises and in the territories adjacent to them [1, 2]. In the conditions of our country's movement towards the European Union and Ukraine's ratification of international rules and standards on environmental safety for aviation enterprises, the issue of ensuring control over the environmental performance of airports and the need to reduce the level of negative impact on all components of the environment, which will allow the airport to meet the requirements of the rules on environmental safety [3] and ensure the sustainable development of these enterprises in the aviation industry.

Literature review. In recent years, in Europe and the world in general, more and more attention has been paid to the emissions of pollutants at airports due to the rapid growth in the use of air transport and the expected expansion of airport capacity in the near future [4].

In particular, the authors of [5] demonstrated a significant contribution of aircraft take-off and landing operations to the concentration of ultra-small particles in the immediate vicinity of runways with evidence of the rapid evolution of the plume in the near field.

However, accurately determining the contribution of aviation to total emissions is a difficult task due to high spatio-temporal variability together with periodic aviation emissions. The authors' findings [6] indicate a significant but periodic contribution of the arriving planes to the environment in the communities near the airports.

At the same time, soils on areas near airports are a less dynamic system than the atmosphere and hydrosphere, and accumulate pollutants deposited from atmospheric air. They accumulate them, experiencing, as a result, a significant man-made load. Research [7] showed that fluctuations in the level of groundwater and/or changes in the moisture content of soil contaminated with petroleum products affect the vertical dispersion and redistribution of components of petroleum products in the capillary border, increasing their release into groundwater and air. And, as a result, an increase in the radius of the territory of oil pollution around the airport.

Despite the fact that recently the global aviation community has made many efforts to assess and mitigate the environmental impact of new airports or reconstruction of existing aviation enterprises, these efforts were directed more at the socio-economic component and improving the quality of atmospheric air, noise reduction and surface water quality, as reflected in a number of technical documents and special regulatory acts on environmental management, in particular ICAO regulatory and technical documents [3]. But the quality of soils in the territories of airports and in the territories adjacent to them is not given enough attention, which would correspond to the importance of soil cover among the functions of the biosphere. As a result of technogenic activity, the soils in these territories and in the adjacent territories are subject to chemical pollution not only by pollutants deposited from the atmospheric air, but also by petroleum products [8], which is caused by the implementation of various technological operations, in particular: refueling airplanes with fuel and lubricants, parking of vehicles, maintenance of aircraft and special vehicles and other equipment, leaks from fuel storage and distribution sites, fuel tanks, gas stations, warehouses, hangars and workshops. The cause of soil and groundwater contamination by aviation fuels on the territory of airports and adjacent territories is various types of losses (emergency and/or technological) of fuels during technological operations of fuel storage, transportation and delivery to aircraft refueling.

As a result of emergency and operational losses, hydrocarbon fuels of various components pollute the soil.

Different brands of motor gasoline, diesel fuel, and natural gas are usually used on the territory of airports to ensure the movement of ground vehicles. Also, to ensure operational reliability of the equipment, various lubricants are used, in particular oils and greases. The main brands of aviation fuel that can be used in our country for refueling aircraft are TS-1, RT and Jet A-1.

Aviation fuels consist of more than 98 % of paraffinic, naphthenic and aromatic hydrocarbons. Also, aviation fuels include heteroatomic compounds. On average, it is 1–2 %. In particular, these are sulfur compounds represented by mercaptans, sulfides, thiophenes, and theophanes. Oxygen-containing compounds include naphthenic acids, phenols, hydro peroxides and resinous substances. Alicyclic carboxylic (naphthenic) acids predominate among the naphthenic acids included in aviation fuels. As for phenols, their content in kerosene fractions is insignificant. As for nitrogenous compounds, homologues of quinoline, pyridine and other nitrogenous compounds are characteristic for jet fuels.

The most widely used brand of aviation fuel abroad is Jet A-1 fuel, which, unlike fuels of the TS-1 and RT brands, is characterized by a heavier fractional composition and a higher temperature of the beginning of fuel crystallization. In Ukraine, the analogue of this brand of fuel is Jet A-1 brand aviation fuel. Aviation fuel is a mixture of hydrocarbons with a minor inorganic component.

Therefore, taking into account the diverse component composition, aviation fuel can be a source of components entering the environment (atmospheric air, soil and groundwater) with different levels of danger to the environment. In addition, fuel combustion products cause air and soil pollution along the runways and in the areas adjacent to the airport runway. Taking into account the fact that in the low-gas mode, the fuel combustion coefficient is approximately 99 % and CnHm and CO emissions are maximum [7], it is important to study the impact of aviation fuel combustion products not only on the state of the atmospheric air, but also on the state of the soils near the runway and at the areas adjacent to the airport [9].

The results of relevant studies [10, 11] indicate that the presence of more than 60 different hazardous substances, some of which belong to carcinogens (benzene, formaldehyde, benz(a)pyrene and others) can be detected in the zone of direct influence of the airport).

Because most major airports are located near densely populated urban areas, they collectively have a potentially significant impact on the environment and the health of the people living near them. For example [12], 150 airports in the USA are located at areas identified as not meeting one or more air pollutant criteria. Therefore, when developing effective strategies to reduce the negative impact of airport activities on the environment, it is important to take into account all aspects related to the entire "airport system", which contains a significant number of various sources of chemical pollution of the environment. However, current information is lacking on many aspects of this pollutant source, including detailed hydrocarbon specification, particle physicochemical characteristics, volatile and solid emissions, and especially secondary transformations aircraft exhaust gaseous and other airport-related emissions [12].

Airports are significant sources of emissions and the impact of these emissions on humans and, taking into account the increase in the intensity of air transport processes, are a growing problem for people's health and an increase in the level of environmental hazards of the areas where they are located. However, collecting data on the impact of airport operations on the health of staff and people living nearby is quite difficult. After all, commercial airports are large, complex enterprises with a large number of personnel, where aircraft, ground support equipment and related vehicles cause emissions of various intensity and nature [13].

Consequently, concerns about the human health effects of engine emissions have prompted a large number of studies over the past twenty years [12]. The attention of specialists who carried out these studies was primarily focused on traditional sources of environmental pollution such as transport, for example. The result of these studies was that the emissions of pollutants by land transport in Europe are clearly controlled and regulated by relevant regulatory and technical documents. Conversely, until recently, little research has been specifically aimed at measuring direct emissions from aircraft or their potential impact on people living in areas adjacent to airports. As a result, there are a number of gaps in our understanding of these emissions, their behavior in the atmosphere, and their potential impact on the health of people living near the airport and on other components of the environment. In particular, the impact of aircraft engine emissions on the condition of the soil in the territories around the airport [12]. As we can see, aviation emissions can significantly affect air quality near airports and in their surroundings [14]. And settling from the air, chemical pollutants formed as a result of incomplete combustion of fuel, in particular hydrocarbons, settle on the surface of the soil, worsening its ecological condition.

Aviation activities are closely associated with elevated levels of many chemical pollutants in the air and other environ-

mental components. This is evidenced with the results of monitoring field studies of the concentration of pollutants in the air in the environment on the territory of the airport and at the surrounding areas. But near the airport, as a rule, there are many different types of sources that emit similar fuel combustion products, including local traffic caused by the presence of the airport, and this makes it difficult to accurately determine the sources of environmental pollution as a result of air transport processes [15].

Therefore, it is quite difficult to establish exactly what are the sources of emissions of pollutants in the territory located near the airport, within the limits of the take-off and landing cycle of the aircraft, and it is important to constantly monitor the ecological state of the components of the environment, in particular the soil, as in the territory of the airport, as well as in the territory adjacent to it. After all, the nature of chemical pollution of the environment in the territories near airports is quite dynamic. And it is important to carry out a study of the state of the environment specifically for each airport, taking into account the location near additional sources of chemical pollution of the environment.

Therefore, the activity of airports is not only accompanied with an impact on the state of the environment, but also indirectly manifests itself in the form of negative effects on human health. Other disease-causing effects of the carcinogens listed above are possible, including respiratory tract and skin diseases, kidney and liver dysfunction, heart, mental and nervous disorders. Analysis of statistical data on the hospitalization of people living in the immediate vicinity of airports showed an increase by 57 % in cases of asthma, 28 % in pneumonia or influenza, 26 % in upper respiratory tract diseases, 83 % in pregnancy complications, 50 % higher than the regional average. And the mortality rate for settlements located near airports for all causes of death: 57 % higher, mortality from heart disease, 36 % higher mortality from cancer, and the value of the average life expectancy is 70.4 % in contrast to the established norm, at the age of 76 [7].

The toxic effect of a substance, as is known [16], depends on the ways of its entry into the human body. The ways in which chemicals enter the human body, in particular the components of aviation fuel, are primarily determined by the components of the environment where the polluting substance is located, then by their physical and chemical properties, the nature of the substance's impact, and other circumstances.

In the territory chosen by us for the research near the airport, biotic and abiotic elements of the biosphere are affected:

- atmospheric air pollution by stationary and mobile sources, as a result of emissions of exhaust gases from vehicles, evaporation of chemicals (in particular, hydrocarbon fuels) and the operation of thermal power plants;
- changes in the state of surface waters, which leads to disruption of self-cleaning processes;
- qualitative and quantitative depletion of water resources, as well as groundwater pollution;
- reduction of biodiversity;
- soil pollution as a result of spills of oil products and other chemical substances and the deposition of pollutants from atmospheric air, which leads to changes in physical and chemical properties, changes in fertility, disruption of the soil structure and other negative changes that affect its ability to self-renew.

Taking into account the volatility of the main fuel components and fuel combustion products, the main route of entry into the human body is inhalation, as well as penetration through the skin. At the same time, the quality of wastewater from the Ihor Sikorsky Kyiv (Zhuliany) International Airport, surface waters of the Nyvka River, and groundwater, which is the source of water supply for wells in the areas adjacent to the airport, showed [3] that they can be a source of exposure to the body of human petroleum products and other chemical pollutants. Although aviation kerosene is not included in the official list of WHO carcinogens [17, 18], some of its components have a carcinogenic effect. Therefore, the task of determining the level of influence of oil pollution on the ecological condition of the soil in the territory near the airport (within 2 km) is urgent.

Purpose. In order to determine the level of environmental safety of the soils in the area near Kyiv Airport based on the indicator of "content of petroleum products in the composition of the soil", we took soil samples at different distances from the runway and determined the content of petroleum products in them.

The purpose of the work was to determine the impact of pollution by photoproducts on the ecological state of the soil in the territory adjacent to the airport.

To achieve the goal, the following tasks were solved:

1) the state of the problem of chemical soil pollution as a result of air transport processes is analyzed;

2) soil samples were taken at different distances from the runway of the Ihor Sikorsky Kyiv (Zhuliany) International Airport in the area of the runway and, for comparison, in the area located in the non-technogenically loaded territory (park zone);

3) the concentration of petroleum products in the selected soil samples was determined;

4) analysis of the component composition of the re-dissolved residue, after determining the mass fraction of the oil product in the sample of the soil using chromatographic analysis according to the standard method;

5) the level of phytotoxicity of the soil selected in the territory adjacent to the airport using the biotesting method was determined;

6) using the method of mathematical modeling, a two-factor model was built, taking into account the factor of the content of petroleum products (X1) in the soil and the distance from the runway (X2) to describe the impact of air transport processes on the condition of the soil in the area near airports.

For the study, we chose a zone of ecotoxicity – chemical pollution with a traditionally permanent negative impact on the environment as a result of anthropogenic activity, namely, an technogenically loaded territory near the airport. The ecological situation in this technogenically loaded territory leads to the formation of chronic diseases in people, as noted earlier. However, today the main attention of environmental specialists from the aviation industry is paid to the impact on the atmosphere and water bodies. At the same time, in our opinion, the appropriate level of attention is not paid to such an important component of the environment, which is a natural barrier between the atmosphere and groundwater, such as soils. Therefore, it is important to assess the ecological state of the soil in this area near the airport and build a two-factor model taking into account the factor of the content of petroleum products (X1) in the soil and the distance from the runway (X2) to describe the impact of air transport processes on the state of the soil on territories near airports.

Methods. Control of the level of soil pollution in the area of operation of the airport was carried out taking into account the relief of the area, meteorological conditions and special characteristics of the area [19]. During sampling, two sites were identified for research. One of them is experimental, which is located in the zone of influence of air transport processes, and the other is the control one, which is located in an artificially non-invaded territory. The soil samples taken at the control site had the same natural composition as the test sample. Soil samples were taken according to the standard method [20] using the "envelope" method with a site size of 5 × 5 m at a distance of 50, 500, 100, 1,500 and 2,000 m from the airport territory, after which a combined sample was formed for further determination of the content of oil products.

Combined samples, for further research, were formed by mixing five point samples taken from one site [21]. Then the samples were numbered and sent to the laboratory to determine the content of oil products. In general, 6 soil samples were formed, taken at a distance of 50 m (sample No. 2), 500 m (sample No. 3), 1,000 m (sample No. 4), 1,500 m (sam-

ple No. 5) and 2,000 m (sample No. 6), from the runway the control sample (sample No. 1), taken in a parking area, where there are no ecologically hazardous enterprises nearby, and the soil is considered conditionally clean.

The content of oil products in the selected soil samples was determined by the gravimetric method according to standard No. 081/12-0116-03 "Soils. Methodology for measuring the mass fraction of oil products by the gravimetric method" [21]. This research method consists of the following stages: extraction of organic substances from soil samples (prepared accordingly from selected soil samples); dissolution of the residue, after evaporation of chloroform, in hexane; then separation of polar compounds on a column with a sorbent (aluminum oxide); removal of hexane by weathering; measurement of the mass of the residue in the flask after the evaporation of hexane; calculation of the mass fraction of the oil product. The results of the study of the content of petroleum products in the soil depending on the distance from the airstrip are presented in Table 1.

In addition, the re-dissolved residue was analyzed after determining the mass fraction of the oil product in the sample of the soil using chromatographic analysis according to the standard method. It was carried out using an HP 5890 Series II chromatograph with a DB-5MS capillary column (made in the USA).

The phytotoxicity of the soil was determined using the growth test according to the method by A. Horova [22, 23]. Watercress Lepidium sativum variety "Azhur" was used as a test plant. The weight of the soil was 1 g and 20 pieces of seeds were distributed evenly on the surface of the Petri dish, then 7 ml of settled boiled tap water was poured. Lettuce seeds were germinated at a temperature of 23–24 °C. 96 hours after the start of germination, the length of the ground and root parts of watercress seedlings was measured. As is known, the application of biotesting using plant test systems makes it possible to determine the level of soil toxicity due to the effect on plant growth parameters, in particular [2]. The phytotoxic effect (Y_{PhE}, %) was calculated according to the formula

$$Y_{PhE} = \frac{L_0 - L_x}{L_0} \cdot 100\,\%. \quad (1)$$

Results. So, for the study, a soil sample was used on the territory within 2 km, adjacent to the International Airport "Kyiv" located at a distance of 8 km from the center of the city of Kyiv. The choice of the object for research is justified by the fact that, taking into account the location of the airport within the city limits, there is no possibility of compliance with regulatory requirements regarding the size of the sanitary protection zone, which confirms the importance of determining the ecological condition of the soils in the territory adjacent to the Kyiv airport.

The structure of this airport includes buildings of the main and auxiliary purpose (airfield, passenger and cargo service facilities, aviation and technical base, air traffic control facilities, facilities of the fuel and lubricant service (F&L service) of the airport), as well as transport routes [24, 25].

Table 1

The content of oil products in the analyzed soil samples

Distance from the airport, m	Content of petroleum products, mg/kg	
	Absolute value (test sample), $C \pm \Delta$, mg/kg	In relation to the control sample, %
50	200 ± 3.6	200
500	150 ± 2.8	150
1,000	1,640 ± 4.8	1,640
1,500	500 ± 3.2	500
2,000	300 ± 2.5	300
Control sample	100 ± 3.0	–

The main sources of soil pollution with petroleum products on the territory of the airport include F&L service service facilities, surface drains, places of technological operations for refueling vehicles, and the aviation and technical base.

Analyzing the obtained results (Table 1), we can conclude that for two soil samples taken at a distance of 500 m and the control sample, the content of oil products is below the established limit of 0.2 g/kg [17] and is equal to the approximately permissible concentration for the sample taken at a distance of 50 m from the runway.

For samples taken at distances of 1,000, 1,500 and 2,000 m from the airport, the limit value of petroleum products in the soil was exceeded. The soil sample taken at a distance of 1,000 m is characterized by the highest level of contamination. The soil samples, respectively, taken at the control site, are characterized with practically no contamination with oil products.

It is known that a feature of chemical pollution of soils in technogenically loaded territories is their multicomponent nature [22].

The results of the chromatographic analysis of the component composition of the organic part, which was isolated from the selected soil samples using the gravimetric method, indicate the presence of hydrocarbons, which are characteristic of aviation fuels.

The compounds identified in all samples can be conditionally divided into several groups of hydrocarbons:

- alkanes C10–C22;
- arenes (benzene, ethylbenzene, trimethylbenzene, naphthaline);
- carboxylic acids;
- fatty acid esters;
- esters of carboxylic acids.

The obtained data demonstrate that, as a rule, chemical pollution of soils in technogenically loaded territories has a multicomponent composition. And, as we can observe in our case, in the territory near the airport, in addition to hydrocarbons included in the composition of fuels, there are products of decomposition and aging of polymers, components of additives. It is important to note that toxic substances, in particular benzene, are present among the identified pollutants. Therefore, we used both physico-chemical research methods and biological research methods to study the ecological state of the soil. The next stage of our research was the determination of the ecological state of the soil and the calculation of the phytotoxicity of YFe from the data of soil samples, followed by statistical processing of the obtained experimental data.

We chose the following signs as factor indicators of changes in soil phytotoxicity:

X1 – the content of oil products in the soil, mg/kg;

X2 – distance from the runway, m.

The results of the study of the impact of air transport processes on the level of soil phytotoxicity are presented in Table 2.

The preliminary analysis of the obtained data shows that the indicator of soil phytotoxicity is most closely related to the first factor (oil content) and less closely related to the second factor (distance from the airport). Corresponding paired dependencies can be represented by us in the form of paired linear regressions (Figs. 2–3).

Table 2

Initial data of the level of soil toxicity

No.	Y_{PhE} %	X1	X2
1	5	200	50
2	7	150	500
3	35	1,640	1,000
4	0.7	500	1,500
5	3.9	300	2,000

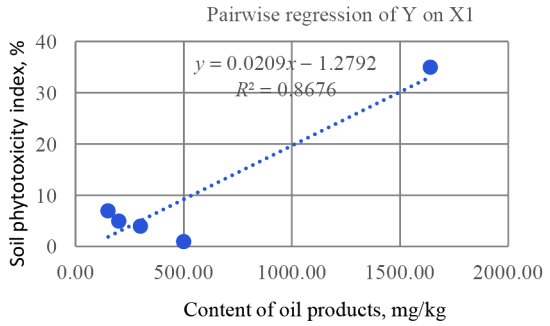

Fig. 1. Modeling the dependence of the phytotoxicity indicator of the tested soil samples on the concentration of petroleum products

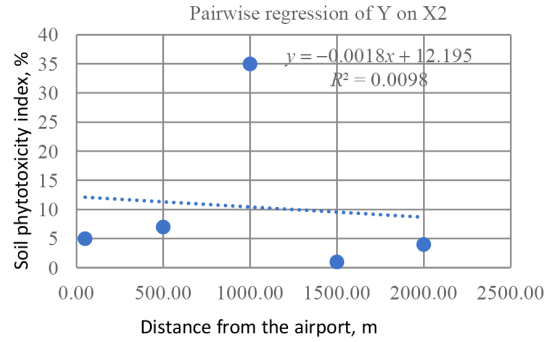

Fig. 2. Modeling the dependence of the phytotoxicity indicator of the tested soil samples on the distance to the airfield of the airport

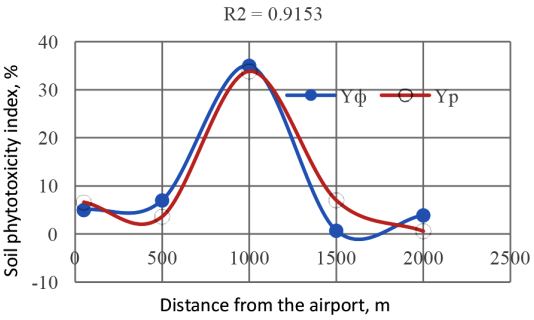

Fig. 3. Modeling the dependence of the phytotoxicity indicator of the tested soil samples on the distance to the airfield of the airport

Further, in order to compare and clarify the significance of the influence on the level of soil phytotoxicity of each of the factors, we conducted a multivariate statistical analysis of the obtained data (Table 3).

Table 3 uses the following designations: Y – experimentally determined indicators of soil phytotoxicity; Yp – indicators of phytotoxicity, calculated according to the multiple model built by us; r – paired linear index of correlation with the corresponding factors and indicator; R – coefficient of multiple correlation; b0 is the free term of the multiple regression equation; b1 and b2 are coefficients of the multiple regression equation for factors X1 and X2, respectively.

From the results of the analysis of the obtained results of experimental data processing, it follows that the obtained two-factor model, taking into account the factors X1 and X2, is quite acceptable for conducting further studies of the impact of air transport processes on the condition of the soil in the territory near airports (Figs. 1–2). This model is presented in the form of the following equation

Table 3

Results of calculations of coefficients of two-factor multiple regression

Initial Date				Two-factor model X1, X2			
	X1	X2	Y_{PhE}	b0	b1	b2	Y_p
	200	50	5	2.47	0.02	-0.004	6.6
	150	500	7				4.0
	1,640	1,000	35				34
	500	1,500	0.7				7.0
	300	2,000	3.9				0.6
r	0.9829	0.0996					$R = 0.9567$

$$Y = 2.47 + 0.02X1 - 0.004X2. \quad (2)$$

The coefficient of determination testifies to the adequacy of the proposed model $R^2 = 0.9153$ for the investigated soil samples.

The significance of the coefficient of determination R^2 was determined using Fisher's test. For the obtained results, $F = 10.81$. The critical value of the F criterion for the 95 % confidence level is 10.23. So, with 95 % reliability, it can be stated that the obtained coefficient of multiple determination is statistically significant and the factors chosen by us describe the variation of the phytotoxicity index of the soil adequately 3 .

Therefore, analyzing the obtained data, we can conclude that the contribution of the X1 factor to the change in the soil phytotoxicity indicator is significantly greater than the contribution of the X2 indicator.

It is known [17] that under certain conditions and level of pollution, soils have mechanisms of self-cleansing from oil products for a certain period of time and appropriate favorable conditions, which contributes to the restoration of the ecological state of the soil contaminated by oil products. However, the fact that oil products are a multi-component mixture whose components have different rates of biodegradation after entering the environment, particularly the soil, is also important. For example, C10–C22 alkanes are not easily biodegradable in soil and water. In the soil samples taken by us in the area near the airport, the total content of alkanes increases depending on the distance to the runway from 10 to 28 %. The content of arenes in all samples ranges from 3 to 5 %. The speed and depth of biodegradation of petroleum products depend on their hydrocarbon composition. Hydrocarbons with a linear structure of molecules break down faster than their branched isomers. Alkanes are often less biostable than arenes. The amount of esters of fatty and carboxylic acids decreases in samples taken at a greater distance from the runway. This can be explained by the fact that on the surface of the soil, esters of fatty and carboxylic acids undergo decomposition processes, quickly enough (up to 3 months), are processed by microorganisms and disappear [26] and that more intensive pollution by chemical substances occurs at distances smaller than runway.

Therefore, it is important to carry out constant monitoring of the ecological state of the soil in the territory adjacent to the airport, using both physic-chemical and biological methods of research, in order to respond in a timely manner to critical violations of the ecological state of the soil, in which the soil on the technogenically loaded the area near the airport may lose its ability to self-heal. Monitoring of the ecological state of the soil should involve taking soil samples on the territory of the airport (and within a radius of 2 km near the territory of the airport) with a set frequency and at a set distance from the specified main sources of soil contamination with oil products.

This should be followed with further determination of the level of phytotoxicity of the selected soil samples using biotesting methods. And, in the case of establishing a high level of soil phytotoxicity in these territories, determining the content of petroleum products using physical and chemical methods. Today, there is no regulated system for monitoring the condition of the soil on the territory of the airports and in the adjacent territories.

Conclusions. As a result of the analysis of the state of the problem of chemical soil pollution caused the air transport processes the main sources of soil pollution of the territory adjacent to the airport were determined with oil products and the level of influence of oil products on the ecological state of the soil. As a result of experimental studies using physico-chemical methods of analysis, it was established that for two soil samples, taken at a distance of 50 and 500 m, the content of petroleum products is below the established maximum limit at the level of 0.2 g/kg. For samples taken at distances of 1,000; 1,500 and 2,000 m, an exceedance of the approximately permissible concentration value of petroleum products in the soil was established. The results of the chromatographic analysis of the composition of chemical contamination of the soil indicated a significant amount of hydrocarbons, characteristic of the fuel fractions of oil. The presence of chemical contamination of the soil was also confirmed by the results of biotesting of the selected soil samples. This is probably due to the proximity of the aircraft glide zone – a technologically dangerous zone, as well as the increase in the intensity of aviation transport processes at this airport after reconstruction and a significant increase in the number of flights in the period 2012–2021. Based on the obtained results of experimental studies using the method of mathematical modeling, a two-factor model was built, taking into account the factor of the content of petroleum products (X1) in the soil and the distance from the runway (X2), which can be used in the future to describe the impact of air transport processes on the condition of the soil in the territory near airports in studies of the impact of the activities of these enterprises on the ecological condition of the soil.

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Вплив забруднення нафтопродуктами на екологічний стан ґрунту на території поблизу аеропорту

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Мета. Визначення впливу забруднення нафтопродуктами на території, прилеглій до аеропорту, на екологічний стан ґрунту.

Методика. Автори здійснюють оцінку впливу нафтопродуктів на екологічний стан ґрунту на території, прилеглій до аеропорту. Зокрема, експериментально, із використанням методики біотестування даних проб ґрунту. Також, проаналізовано компонентний склад хімічного забруднення ґрунту з використанням хроматографічного аналізу. Із застосуванням методу математичного моделювання побудована двофакторна модель з урахуванням фактору «вміст нафтопродуктів (Х1)» у ґрунті та «відстань від злітно-посадкової смуги (ЗПС) (Х2)» для опису впливу авіатранспортних процесів на стан ґрунту на території поблизу аеропортів.

Результати. На основі отриманих експериментальних даних визначено рівень забруднення ґрунту на території, прилеглій до аеропорту. Встановлено, що для двох проб ґрунту, відібраних на відстані 50 та 500 м від злітно-посадкової смуги аеропорту, вміст нафтопродуктів нижче встановленої орієнтовно-допустимої концентрації (ОДК). Для проб відібраних на відстанях 1000, 1500 та 2000 м встановлене перевищення. Результати хроматографічного аналізу складу хімічного забруднення ґрунтів вказали на значну кількість вуглеводнів, характерних для паливних фракцій нафти. Отримані результати демонструють залежність рівня забруднення ґрунтів нафтопродуктами від відстані до злітно-посадкової смуги й наявність техногенного впливу даного підприємства на екологічний стан ґрунтів, що підтвердили результати біотестування даних проб ґрунту. Побудована двофакторна модель з урахуванням фактору «вміст нафтопродуктів (Х1)» у ґрунті й «відстань від злітно-посадкової смуги (Х2)» та їх впливу на фітотоксичність ґрунту. Про адекватність запропонованої моделі свідчить коефіцієнт детермінації $R^2 = 0{,}9153$ для досліджуваних проб ґрунту.

Наукова новизна. Результати експериментальних досліджень показують, що хімічне забруднення негативно впливає на екологічний стан ґрунту на території, прилеглій до аеропорту; має багатокомпонентний склад, а також, крім вуглеводнів, характерних для нафтопродуктів, що використовуються для заправлення та експлуатації транспортних засобів, присутні продукти розкладання та старіння полімерів, компоненти присадок. Визначена залежність екологічного стану ґрунту на техногенно навантаженої території, прилеглій до аеропорту, від рівня забруднення нафтопродуктами та від відстані до ЗПС аеропорту. Для з'ясування суттєвості впливу на рівень фітотоксичності ґрунту кожного із двох факторів (вміст нафтопродуктів і відстань від злітно-посадкової смуги) проведено багатофакторний статистичний аналіз отриманих даних і побудована двофакторна модель. Це дало можливість встановити, що внесок фактора Х1 (вміст нафтопродуктів) до зміни показника фітотоксичності ґрунту значно більший за внесок показника Х2 (відстань від ЗПС).

Практична значимість. За результатами аналізу отриманих експериментальних даних, запропонована двофакторна модель, що враховує фактори Х1 та Х2 та може бути застосована для подальших досліджень впливу авіатранспортних процесів на стан ґрунту територій поблизу аеропортів.

Ключові слова: *нафтопродукти, ґрунт, хімічне забруднення, екологічний стан, екологічна безпека, аеропорт*

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