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ENVIRONMENTAL POLLUTION IN THE AIRPORT IMPACT AREA–CASE STUDY OF THE BORYSPIL INTERNATIONAL AIRPORT

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Abstract. The paper presents the analysis of soil and phytomass contamination due to the functioning of air transport. The major issues revealed include extremely high level of soil contamination with petroleum products and an increased content of heavy metals both in soil and phytomass. The toxicity testing has demonstrated considerable pathogenic potential of soil from the airport area.

Key words: soil pollution, phytomass pollution, phytotoxicity, heavy metals, total petroleum hydrocarbons.

1. Introduction

Airports are considered to be strategic objects due to their functional role and economic importance. However, the growing intensity of civil air transportation causes environmental problems in the security system as well as in aircraft maintenance. A wide range of research activities have been implemented to analyze and mitigate the impacts of the airports on the environment. The civil aviation environmental issues covered by the research works include noise pollution, electromagnetic impact, aircraft and ground transport emissions, wastewater management and thermal pollution. Despite this, the list of the real airport impact on the environment is not complete and it lacks attention to the state of soil contamination.

Petroleum products are among the main soil pollutants of aviation facilities. They can be termed as petroleum hydrocarbons, as they are a mixture of various carbon-containing substances. For this reason, it is not usually practical to measure the content of individual components and therefore the total amount of all hydrocarbons found together in a particular environment – total petroleum hydrocarbons (TPH) – should be defined [1].

The TPH have a negative impact on physical properties of soil by reducing the available porosity and, as a consequence, permeability to air and water [2-5]. Such chemical properties as pH and total organic carbon also change: the ratio of carbon to nitrogen increases, while hydrolytic acidity, the stability of soil ecosystems and fertility decrease [6, 7 Contaminated soils accumulate iron, manganese and reduce the content of phosphorus, potassium, and magnesium [8]. The studies have shown that the activity of most soil enzymes is impaired in contaminated soils [9]. The combination of these data produces a complex phytotoxic effect [10, 11]. In particular, the TPH suppresses the growth and development of plants, by disrupting physiological processes, including germination and photosynthesis [12–18]. Still, plants are also considered a reliable element of soil remediation after petroleum pollution [2, 19–22].

At the same time, soil microorganisms, after short-term inhibition, respond to contamination by increasing gross population and increasing activity but reducing diversity due to the disappearance of soil mesofauna [3, 23–25]. The microorganisms are also successfully applied for soil decontamination both alone and in symbiosis with plants in the form of rhizoremediation [25–27].

The additional threat from petroleum contamination, in particular, typical for airports, is associated with contamination of soils with heavy metals [2, 27]. Such soil is detrimental for plant growth, and any form of remediation turns to be problematic. Moreover, the processes of natural regeneration of biocenosis after petroleum contamination proceed slowly, and the rates of restoration of ecosystems diverse structure take up to 10–15 years [28].

Thus, considering a wide range of potential negative effects, the aim of the research is the study of the level of soil and plant contamination with petrochemicals and heavy metals as a result of airport activities.

2. Methods and Materials

Petrochemicals get into the airport soil due to leaks from tanks and pipelines; spilled fuel while refueling; surface flow from industrial fields and runway. The size and zoning of TPH distribution are determined by the composition of the petroleum products, relief, and the type of landscape, as well as the lithological characteristics of the soils, geological and hydrogeological condition of the area. In the process of natural separation of petroleum products into fractions in the soil, light fractions are distributed throughout the profile, partially evaporated into the atmosphere, and carried away by groundwater [28, 29]. The propagation of heavy fractions is associated with the lower elements of the relief, and therefore they do not form a continuous cover: they accumulate mainly in the humus complex and are stored in the soil for a long time, just like heavy metals [27].

Since the territory of the airport has a leveled relief and relatively uniform structure and composition of soil after anthropogenic transformation and manipulation for industrial purposes, it has been decided to take the samples of soil at a depth of 20 cm to analyze the distribution of petroleum products and heavy metals. These facilities were included in the study, but the runway was considered a major source and the distribution of pollutants was studied in detail to define the patterns, while pollution of the fuel depot was analyzed at the equal distances around the facility, where the soil cover was available.

Samples for heavy metal content analysis were taken with non-metal tools. Soil sampling was carried out using the 5x5 m “envelope” method. The final sample was prepared by mixing five spot samples. The aggregate sample weight was 1 kg.

Samples to analyze the distribution of petroleum products and heavy metals in the soil were taken vertically 20 cm down from the surface. The root systems of the plants remained in the soil sample.

Sampling has been carried out three times a year (spring, summer, autumn) for three years. Each round of the sampling in the runway's area impact included a series of 6 surface samples and 6 samples from the depth of 20 cm and 2 background samples. The total number of samples taken and analyzed was 126. In the area of the fuel depot, 4 samples were taken per round, and the total number of samples was 36.

The regulations on the preferable method of the THP content analysis are absent and thus there is a variety of options offered by the scholars [30-32] and state agencies (SW-846) [33]. The current research is based on the application of a gravimetric method.

The soil (50 g) was dried at room temperature and crushed in a porcelain mortar. Extraction of petroleum products and purification of the eluate from impurities of polar compounds were performed simultaneously in a chromatographic column, containing 3–5 g of aluminum oxide and carbon tetrachloride as a solvent. The process of extraction of petroleum products was carried out at room temperature with the eluate flow rate of 0.1–0.2 ml/min. For the complete extraction of petroleum products, 40–50 ml of solvent was used. The volume of the eluate was measured carefully, and the absorption intensity was measured on the infrared spectrophotometer in the wavelength range 2700–3100 cm^{-1}. Measurements were performed in the cells with windows with NaCl.

Soil toxicity was determined by bio testing of water extracts. Water extracts were prepared on distilled water. The water was poured into a 20-liter aquarium and saturated with oxygen (7.6–8.5 mg/l) until the water pH reached a constant pH = 7.5. The prepared water was tested for acute toxicity and only then used to prepare the water extract from the soil. The soil-water mixtures (1: 5) in round flasks (0.5–1 l) have been stirred on a shaker for 4 hours. The solution was then centrifuged to separate the fine fraction.

The content of heavy metals was determined by atomic absorption spectrometer - a method of quantitative elemental analysis of atomic absorption spectra using an AAS-30 spectrophotometer (Germany).

Conversion of the analyzed object into the atomized state was carried out in the atomizer in the

flame. The flame mixture of acetylene with air (t ≈ 2000 °C) was used. The radiation source was the corresponding hollow cathode lamps for each measured metal.

To compare the intensity of pollution, the samples of the same soil types were taken at a distance of 15 km from the airport at the territory not involved in any industrial or agricultural activity. The sequence of sampling was consistent with the procedure used in other sampling operations. The concentration of target pollutants was measured using the same analytical methods. It is further referred to as background concentration.

3. Results and Analysis

3.1. Contamination of soils with petroleum hydrocarbons

The soil samples taken in the area of air transportation have demonstrated significant excess of petroleum hydrocarbons at all sampling points (14 points at the runway impact area and 4 points around the fuel depot) compared to conditional controls and regulatory concentrations (Table 1).

Thus, the TPH content in surface soil samples in the runway impact area from 15 to 130 times exceeds the background concentration, depending on the distance. The soil samples, taken at a depth of 20 cm, show TPH concentration up to 126 times higher than those at the background territory. So, the general trend towards a decrease in the concentration of TPH in all soil samples away from the runway is confirmed. Surface soil samples in the territories next to the aviation enterprises accumulate more petroleum products than soil samples taken at a depth of 20 cm.

As for the pollution of surface layers of soil at the area of the fuel depot, it is on average (4 samples) 62.5±3.1 mg/kg, which is 69 times over the background concentration. However, the samples taken at a depth up to 20 cm are more polluted and reach a concentration of 93.1±3.4 mg/kg.

Table 1

TPH concentration in the soil cover

Distance from the runway, m	Concentration of petroleum products, mg/kg			
	on the soil surface (5 cm)		at a depth of 20 cm	
	Absolute value, C±Δ, mg/kg	Ratio to the background concentration	Absolute value, C±Δ, mg/kg	Ratio to the background concentration
0 (runway)	119.0 ±6.5	132.2	88.5 ±3.9	126.4
20	86.5 ±3.5	96.1	54.3 ±2.7	77.6
100	51.5 ±2.8	57.2	31.5 ±1.2	45.0
250	31.6 ±1.3	35.1	30.0 ±1.0	42.9
500	17.5 ±0.4	19.4	11.5 ±0.1	16.4
1000	13.5 ±0.2	15.0	11.5 ±0.2	16.4
Background concentration	0.9 ±0.05	–	0.7 ±0.03	–

3.2. Pollution with heavy metals

The results of testing for the content of heavy metals show considerable pollution (Table 2). Thus, the content of manganese in the samples of surface soil is 1.5-2 times higher than that in the background soils and 1.4-1.8 times over the background in the soil samples, taken at a depth of 20 cm. The general trend is also observed, but the reduction in concentration with the distance from the runway is not essential. The content of manganese in the soils at the fuel depot is by 42 % over that for the background area.

The concentration of copper exceeded the background values in all the samples. The surface soil samples near the runway contain 18 times more copper exceeding its background content, which gradually decreases to 10.6 times over the background and reaches again the level of 12.1 times at a distance of 1000 m.

In the soil samples taken at a depth of 20 cm, the concentration of copper exceeds the background concentration 10.6–22.3 times, dropping with the distance from the runway.

Copper content is 6.8 times over the background concentration also in the surface soil samples at the fuel depot and at a depth of 20 cm, the value of the concentration is almost the same.

The relative pollution of soils with lead is found in all the tested samples. Thus, in the surface soil, the lead content is 9.4–25 times over the background concentration. An extremely high concentration of lead is defined at the closest proximity to the runway. In the soil samples taken from a depth of 20 cm, the amount of lead increases to the level, which is 50 times higher than that established at the background territories.

Table 2

Selected heavy metal concentration in the soil cover, C*, mg/kg

Dis-tance from the run-way, m	Mn		Cu		Pb		Cd		Zn		Ni		Cr		Fe	
	SS	20 cm	SS	20 cm	SS	20 cm	SS	20 cm	SS	20 cm	SS	20 cm	SS**	20 cm	SS	20 cm
0	154	136	9	6.8	46	36	0.2	0.03	37.5	21	1.2	1	0.45	0.15	25	131
20	144	116	7.1	4.9	17	17	0.03	0.03	26	14	0.2	0.2	0.175	0.05	25	120
100	188	106	5.8	4.3	22	15	0.03	0.03	18	8	0.18	0.05	0.035	0.01	20	106
250	132	121	5.3	3.8	15	12	0.03	0.03	17	5	0.05	0.04	0.005	0.005	12	100
500	150	121	3.9	3.3	10	12.5	0.03	0.15	15	10	0.02	0.02	0.005	0.005	10	105
1000	149	135	6.3	5.4	45	30	0.03	0.04	4	3	0.02	0.01	0.005	0.005	9	136
Fuel depot	139	103	3.4	3.2	34	16	0.03	0.03	4.5	4	0.03	0.03	0.018	0.007	18	30
BC**	98	75	0.5	0.3	1.8	0.7	0.025	0.027	6.8	0.4	0.18	0.18	0.006	0.005	2.6	4.4

*The approximate error, determined by the measuring equipment used, spectrophotometer AAS-30, is ±1% and is not presented.

**BC – background concentration; SS – surface soil samples.

The samples from the fuel depot are also intensively polluted with lead up to the levels of relatively 19 times higher than background concentrations at a depth of 20 cm and 22 times more polluted at the surface layer.

The analysis of soil samples in the study area did not reveal a considerable excess concentration of cadmium: all samples have different concentrations within the range of ±20% relative to the background concentration, so they are considered to be the natural variability of the soil chemical composition.

The concentration of zinc in all soil samples 5.5 times exceeds the background concentration at a distance of 20 m, and it gradually decreases to 2.2 at a distance of 500 m. The samples taken at a depth of 20 m revealed comparable content of zinc, which is 4.8 times over the background near the runway. At a distance of 500 m, it is almost the same as on the surface. The same values have been established for the soil samples close to the fuel depot.

Nickel concentration above the background levels was determined only in the sample taken at a depth of 20 cm next to the runway and 20 m from it.

The area of the air transport impact is usually characterized by increased pollution with chromium, and that was established by the results of the analysis: the background concentration is 75 times lower than that defined in the surface soil by the runway. But such excess is attributed only to the closest area of the runway. At a distance of 20 m, it 25 times exceeds the background, and at 100 m, it is only 5 times higher than the background value. At a depth of 20 cm, the excessive content was found only at the first points–by the runway (9 times) and 20 m from the runway (3.8 times).

The content of chromium at the fuel depot was 3 times over the background value in the surface samples, while the samples from a depth of 20 cm showed concentration higher by 35-45%.

The concentration of iron in the soil is not regulated in most countries, but the comparison of the airport and background soil outcomes with the notably higher contents of the metal. The surface layer of soil contains 9,9 times more iron near the runway; this value gradually decreases but then reaches the same values again at a distance of 1000 m. The soil at a depth of 20 cm is even more polluted: 30 times near the runway, decreasing to 11 times at a distance of 1000 m. The fuel depot samples are 7 times over the background.

On the whole, we can conclude that the soil studied at the territory of the airport is heavily polluted with lead and copper; moderately polluted with zinc and chromium, and slightly polluted with nickel and manganese. Heavy metals are accumulated in the surface layers, and migration to the deeper layers is slowed under the influence of environmental factors. The greatest contamination with metals was observed near the runway.

To integrate the information about the pollution of the soil, the total pollution index was calculated by using the equation:

$$Z_c = \sum_{i=1}^{n} K_c - (n - 1),$$

where Kc is the concentration of a pollutant chemical element, defined as the ratio of the actual content in the soil C to its background level Cbg: Kc = C/Cbg; n is the number of heavy metal accounted. The results of calculations of the total index of pollution are presented in Table 3. According to the sanitary-hygienic assessment, four levels of medium pollution and corresponding risks are distinguished:

1 – permissible, low pollution, $Z_c < 16$;

2 – moderately dangerous, moderate level of pollution, $Z_c = 16 – 32$;

3 – dangerous, high level of pollution, $Z_c = 32 – 128$;

4 – extremely dangerous, extremely high level of pollution, $Z_c > 128$.

The results of calculations of the total index of pollution are presented in Table 3. Thus, the level of surface soil pollution near the runway and up to a distance of 100 m is extreme and highly dangerous, and at the distances of 250, 500, 1000 m, the level of pollution is dangerous. Soil samples taken at a depth of 20 cm near the runway and 20 meters from it are also extremely dangerous, and the pollution of the other samples is dangerous.

Table 3

Total pollution index of soils

Distance from the runway, m	Surface soil samples	Soil samples at a depth of 20 cm
0	142.9	187.8
20	63.0	109.7
100	37.1	77.7
250	22.7	62.0
500	16.1	79.0
1000	38.3	96.6
Fuel depot	32.1	47.4

3.3. Biotesting of soils

Water extracts, made from the studied soils were analyzed by the biotest methods. A 48-hour acute toxicity test using Daphnia Magna S. was applied to assess soil contamination, and bio testing of Lactuca Sativa L. root growth inhibition was performed to evaluate the toxicity.

The results of biotesting of soil water extracts using Daphnia Magna S. test objects (Table 4) show higher mortality rates (75–40 %) that water extracts from the soil taken at a depth of 20 cm (70–27 %). Similarly, the inhibition of the growth of the roots of Lactuca Sativa L. shows the suppression of root growth by 60–31 % in surface samples and 62–26 % in samples taken from the depth of 20 cm.

Table 4

Results of soils toxicity biotesting

Distance from the runway, m	Mortality rate of *Daphnia Magna S.*, %		Inhibition of the root growth of *Lactuca Sativa L.*, %	
	Surface samples of soil	Samples from the depth of 20 cm	Surface samples of soil	Samples from the depth of 20 cm
0	75	70	60	62
20	73	65	55	50
100	51	51	47	44
250	50	45	40	40
500	45	45	38	38
1000	40	27	30	26
Fuel depot	38	41	39	31

3.4. Characteristics of plant contamination with heavy metals

The results of the analysis on the content of heavy metals in the soil show the increased risk of their migration and accumulation in the phytomass. The samples of plant material were taken at the points of soil sampling to study the situation. The samples of plants are represented by a mixture of herbs with the root systems and branches with leaves (willow). The results are given in Table 5.

Table 5

Selected heavy metal concentration of in the phytomass, μg/kg

Distance from the runway, m	Mn	Cu	Pb	Zn	Ni	Fe	Total pollution index
0	73	6.0	42	5.8	0.04	36	117.7
20	60	7.5	22.5	3.5	0.01	65	66.9
100	50	4.0	22	2.7	0.03	42	60.1
250	94	4.2	36	3.3	0	38	97.5
500	54	2.8	22	3.0	0	27	59.3
1000	62	3.1	3	7	0	34	105.8
Background concentration	34	0.87	0.4	0.67	0	0	–

The concentration of manganese in plants in the airport area 1.1–2.1 times exceeded the value for the plants in the background area.

The concentration of lead in plants significantly exceeds the value of background concentrations (7.8-14.8 times) and indicates heavy contamination.

The copper content in the plants of the airport zone is 2.5-6.7 times, and the concentration of zinc in plants is 4.2-8.7 over the background.

Iron and nickel were not detected in the background samples, but in the plants from the study area, they reach the detectable levels at the runway and at the distances of 20 and 100 m.

Chromium was not detected in all plant samples.

The highest level of phytomass pollution is observed at a distance of 20 m from the runway. In terms of manganese, lead, zinc, and iron, significant contamination was recorded at a distance of 1000 m, which can be explained by the additional pollution caused by motor vehicle emissions.

The results of calculations of the total pollution index of plants (Table 5), excluding nickel and iron, show an extremely high level of pollution at the runway which drops dramatically at the next sampling points. This could be explained by the effect of pollution accumulation in the plants in the first line of the runway. The level of phytomass pollution at the distance of 100, 250, 500 and 1000 m is moderately dangerous, even though it grows again at a distance of 1000 m.

Conclusions

The impact of aviation facilities on the environment is diverse and complicated by the interaction of various sources. Among the receptors of the airport influence, the soils are the least studied. Runways and fuel depots are the most important sources affecting the pollution of soil.

The analysis of soils shows high pollution with total petroleum hydrocarbons both at the runway and fuel depots. The content of heavy metals is considerable, showing a high level of pollution with manganese, copper, lead, zinc, chromium, and iron as compared with the background soils out of the influence of the airport activities. The concentrations of cadmium and nickel are within the range of natural variation and don't pollute the environment. The total index of soil pollution attributes the studied samples to dangerous and extremely dangerous in terms of pollution levels.

The difference in the content of heavy metals on the surface and at a depth of 20 cm is in most cases in favour of higher concentrations on the surface. The distribution of pollution tends to decrease with the distance from the runway, though the content of copper, lead, and iron increases again after the decrease at a distance of 1000 m from the runway. This may be explained by the influence of other pollution sources, in particular ground transport.

The level of pollution with heavy metals from the fuel depot is lower than that by the runway. These samples didn't show considerable pollution with nickel, chromium and manganese. The samples taken at a depth of 20 cm have almost the same level of pollution and the pollution intensity is equally distributed around the depot facility.

The effect of soil contamination is also manifested in the shift of the soil solution reaction to an alkaline range and the 2–10-fold increase in the total carbon content in the soil.

The studies of plant pollution in the area of the influence of aviation transport confirm the results of the soil samples analysis. However, the distribution patterns differ from the soil pollution: the highest values of pollution are observed at the closest proximity to the runway but then it drops dramatically by almost an order. This might be conditioned by the buffer effect of the vegetation and retention of major pollution in the first line of contact between the pollutants and the phytomass.

Soil toxicity has been analyzed by biotesting, and considerable pathogenic potential of soil from the airport area has been found. Such a situation indicates the impossibility of using land close to aviation enterprises for agricultural purposes. Moreover, there is a need to carry out remediation of soil, even in the event of an accident-free operation of enterprises of this type.

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