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# Research on soil disturbance and pollution with heavy metals in military grounds

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Military grounds are territories of specific purpose. Various kinds of military installations, ammunitions and explosives are used in such areas. Soil in military grounds is very often polluted with heavy metals; because of continuous damages made to the top soil, vegetation is very scarce, in some spots missing – sandy wastelands are formed. Pollution with heavy metals is one of the biggest environmental problems in military grounds. The military ranges of Lithuania have an extremely great number of areas with completely ruined green surface. Richness of flora is determined by organic matter found in the surface layer of soil. It is obvious that physically damaged soil with a low content of organic matter is much more vulnerable and can be easily polluted; moreover, damaged soil is more permeable, so pollutants can easily reach groundwater. The aim of this work was to estimate the negative impact of military activities on the superficial layer of soil referring to two main parameters: decrease of soil organic mater because of explosions and soil pollution with heavy metals.

The results of the study have shown that the content of soil organic mater in territories used for military activities is several or ordinal times (from 66% to 99%) less than in undisturbed territories. The level of soil pollution with heavy metals depends on the type of a territory and the intensity of its use: soil in territories used for shooting practice is mostly polluted with lead and copper, while territories used for military transport needs are mainly polluted with metals characteristic of fuel composition (chromium, lead, manganese, etc.).

**Key words**: soil, military activities, soil organic matter, pollution, heavy metals

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## 1. INTRODUCTION

The most vivid trace of the use of Lithuanian nature for military purposes was left by military units of the Soviet Union. During the period of the Soviet army's stay in Lithuania, the country had 277 military areas of the Soviet Union (later, of Russian Federation) with 462 military units deployed on them. They covered the total area of 67 762 ha or 1.04 percent of the area of Lithuania (Baubinas, Taminskas, 1997–1998). The first Soviet military areas were established on the sites of the old military units. The new military areas were developing in two directions:

– new areas were annexed to the old areas;

– territories never used for military purposes were reclaimed.

The expansion of natural areas used for military purposes was not accompanied by any environmental measures. Ecologic conditions were not taken into consideration.

After withdrawal of the Soviet army, six military ranges were established in Lithuania. The use of the

ranges was approved by the Government. The following are the largest military ranges of Lithuania: the central range of the Lithuanian army in Pabradė, military ranges in Gaižiūnai (Jonava Region) and Kairiai (Klaipėda Region). Each military area consists of two parts: exercises areas of full use and of limited use (Baubinas, Taminskas, 1997–1998). Military areas of full use are land plots assigned to the Ministry of National Defence with the property rights. Such areas have special stationary structures necessary for exercises, defence infrastructure; moreover, exercises involving shooting real cartridges are held and heavy military war materials are used there. Military areas of limited use are land plots (usually those of forests) given to the military forces of Lithuania and used for training of military staff without changing the direct purpose of the land (forestry) (Baltrėnas and Ignatavičius, 2000).

Military grounds are territories of specific purpose. Various kinds of military installations, ammunitions and explosives are used in such areas. Therefore soil in military grounds is very often polluted with heavy metals; because of continuous damages made to the top soil, vegetation is very scarce, in some spots missing – sandy wastelands are formed (Mažvila, 2001). Explosions performed in military grounds can be characterized by both thermal and chemical effect (soil pollution with compounds like lead, zinc, copper, etc.) (Greičiūtė, Vasarevičius, 2003). During long years of military grounds exploitation, cartridge shells continually get into soil. Usually a cartridge of ammunition is comprised of a copper-covered shell and a lead core; it is the reason why pollution with lead and copper is extremely high in soils of military grounds (Greičiūtė, Vasarevičius, 2006). Because of other than shooting activities some other metals (like manganese, chromium, nickel and zinc) are getting into soil as well. Pollution with heavy metals is one of the biggest environmental problems in military grounds (Baltrėnas et al., 2001).

Soil is a vital component of the environment. Organic matter in soil carries out one of the main functions. It determines the physical, chemical and biological qualities of soil. The content of organic matter in soil may go down due to erosion, agriculture, military activities, etc. The areas of military ranges of Lithuania have an extremely great number of areas with a completely ruined green surface (Baltrėnas, Oškinis et al., 2001). The impact of explosions and damage to soil and to its surface may be defined not only by a physical (destruction of the soil surface, removal of mass) but also by a thermal impact (explosion heat burns out the surface layer of soil which is rich in organic remnants of plants and animals). Due to continuous damages, flora in those areas is especially poor, if any; sandy wastelands prevail there. It is obvious that the richness of flora is determined by organic matter found in the surface layer of soil (Seastedt et al., 1994).

Surface soil and the region of aeration are the systems that are affected directly whatever the level of pollution (Vasarevičius, Greičiūtė, 2005). This layer of soil cumulates pollutants and appears to be a specific barrier to protect groundwater from pollution. However, with time it becomes a secondary source of pollution, even though the direct source of pollution is eliminated: surface water, while penetrating through such dirty filters, dissolves and leaches pollutants and becomes polluted itself. Consequently, heavy metals pollute not only soils but also waters in the territories of military grounds. With water, pollutants spread outside the closed military grounds. It is obvious that physically damaged soil with a low content of organic matter is much more vulnerable and can be easily polluted; moreover, damaged soil is more permeable and pollutants can easily reach groundwater.

To determine and estimate the level of pollution and disturbance of the superficial layer of soil in military grounds, it is essential to do comprehensive research on physical (explosions and other mechanical effects) and chemical (pollution with heavy metals) effects on soil, caused by military activities.

Obviously, the main territories in every military ground are shooting ranges, tactical fields. They were used most intensively during the time when Soviet Army ruled all Lithuanian military grounds, and therefore the level of pollution in these territories is very high. Nevertheless, shooting ranges and tactical fields are still most intensively used territories in Lithuanian military grounds. Territories of such type were investigated several times, and there are some data on their environmental status. There were a few investigations into the environmental status of other military territories as well, mainly in the territories of specific use (like troopship traces, aerodromes, other territories for troopship racing, etc.). Yet until now such data have been very scarce, not sufficient for a serious study.

**The aim of this work was** to estimate the negative impact of military activities on the superficial layer of soil referring to two main parameters: decrease of soil organic matter (SOM) because of explosions, and soil pollution with heavy metals.

## 2. EFFECTS OF EXPLOSIONS ON THE DYNAMICS OF SOIL ORGANIC MATTER

The areas of military ranges of Lithuania have an extremely great number of areas with a completely ruined green surface. Pabradė and Gaižiūnai are the biggest military ranges of Lithuania. The impact of explosions and damage to soil and to its surface may be defined not only by a physical (destruction of the soil surface, removal of mass) but also by a thermal impact (explosion heat burns out the surface layer of soil which is rich of organic remnants of plants and animals) (Brady, 1990; Nelson et al., 1994).

Due to a continuous damage, the flora of those areas is especially poor, if any; sandy wastelands prevail there. The goal of the research was to examine and to

assess the negative impact of military activities on the concentration of soil organic matter, to find out the dependence between the concentrations of SOM and nature and the intensity of military activities. The quantity of soil organic matter was investigated in the soils of two biggest firing grounds in Lithuania: Pabradė and Gaižiūnai (Fig 1). Sites for soil sampling were chosen in the areas with different levels of disturbance but still in the fields which are intensively used for explosion training (three places were chosen: the tactical training field of the Pabradė military ground, and the 1st and 2nd tactical training fields of the Gaižiūnai military ground). Only the top layer of the soil was analysed, taking samples not deeper than 0–5 cm (Vasarevičius, Greičiūtė, 2004). To measure the damage done to the topsoil, six soil samples were taken in a mixed forest and six in pinewoods where military activities are not performed. The content of soil organic matter in the soil samples was determined using the method of weight loss on removing organic matter from the mineral fraction by ignition (Storer, 1984). For this procedure, an oven allowing heating to approximately 650 °C is needed. At first, about 200 g of dried ground soil was scooped into tarred crucibles. They were dried for two hours at 105 °C and the weight was recorded to +0.001 g. The procedure was repeated once again. Then 200 g of dried soil was heated at 550 °C for 5 h, cooled to 150 °C and weighed in a draught-free environment to 0.001 g. The difference in soil sample mass before and after the ignition showed the total mass of the soil organic matter. Figures were drawn using Surfer software. All the soil-sampling points were marked on the maps. The schemes of soil sampling points were loaded to the Surfer as a base maps and connected with appropriate data, i. e. each point in the scheme corresponded to the amount of SOM in the soil sample taken from that point (Greičiūtė, Vasarevičius, 2004).

The results of the investigation at the Pabradė firing ground have revealed a bigger mass of SOM in the soil samples taken before explosions. Decrease of SOM in the samples taken after explosions reached even 50–82%. The main two factors influencing the decrease of SOM in the soil are the heat of explosion and the physical damage made by the wave of explosion. The biggest part of SOM was lost in the epicentres of explosions (from 32% up to 82%) (Fig. 2). Moving away from the epicentres, the loss of SOM was not so significant (from 7% to 21%); this fact can be explained by the decrease of explosion heat. Analysis of the results revealed the dependence of SOM loss not only on the distance from the explosion epicentres, but also on the direction of the explosion wave, which may be influenced by the wind and other factors. The loss of SOM is bigger when more powerful charges are used. The bigger mass of TNT leads to a more powerful explosion and determines a bigger loss of SOM. Damage made to the topsoil by explosions is more severe in the territories used for military activities for a long time. This is clear from the results that were obtained in the Gaižiūnai training area testing sites. In the soil of the 2nd tactical field, the average mass of SOM was only 0.92 g, showing the biggest damage made to this territory. In the soil of the 1st tactical field, the average mass of SOM was higher (6.99 g), showing a lower damage. The 2nd tactical field has been incessantly used for more than 100 years, and the 1st tactical field is used for explosion training only for about 30 years. The content of soil organic matter in the soil of military areas was on the average by 70% lower than that in the pine forest soil and by 99% lower than in the mixed forest soil (Fig. 3).

Three types of territories were noted: territories with the extremely disturbed soil surface layer (1st tactical field of Gaižiūnai Military Ground and Pabradė Military Ground; the estimated SOM quantity was 0.46% to 0.52% of the total sample mass), territories with the medium disturbed soil layer (2nd tactical training field in Gaižiūnai; SOM content from 0.85% to 3.49% of the total sample mass), and specific purpose territories where regular explosions are made, but the dissipated soil is constantly refilled.

## 3. GROUND POLLUTION WITH HEAVY METALS BECAUSE OF EXPLOSIONS, FIRING AND OTHER MILITARY ACTIVITIES

This research was aimed at finding not only the distribution of heavy metals (Cu, Cr, Mn, Ni, Zn, and Pb), but also the dependence of their concentrations on the type, intensity and period of territory use. Thus, to compare research results, shooting areas (shooting ranges of both Gaižiūnai and Kairiai Military Grounds) and areas used for transport needs (airfield of Gaižiūnai Military Ground and motor-field of Kairiai Military Ground) of two military ranges – Gaižiūnai and Kairiai – were chosen for the research. Sampling only from the surface layer of the soil is not sufficient, as unless an area is extensively used for military purposes, it is likely that high concentrations of heavy metals will not be detected. However, if several years or decades ago an area was intensively exploited, accumulation of heavy metals in deeper layers of soil is possible. In order to verify this statement, sampling should be done at deeper layers of soil. In our study, sampling was done in five places within the territory of two military grounds of Lithuania (Gaižiūnai and Kairiai). Sampling was performed at a different depth in the same place (1-meter deep borings). Heavy metals analysis in soil samples was performed using the atomic absorption method. The basic parameter needed to estimate the pollution of a territory is the median concentration of heavy metals. As the methodology used for the estimation of heavy metals in soil samples was different from the one indicating the back-ground and the maximum allowed concentrations of heavy metals in Lithuanian soils (the Lithuanian hygiene norm HN 60:2004), the obtained results were compared not with these values but with the median concentration.

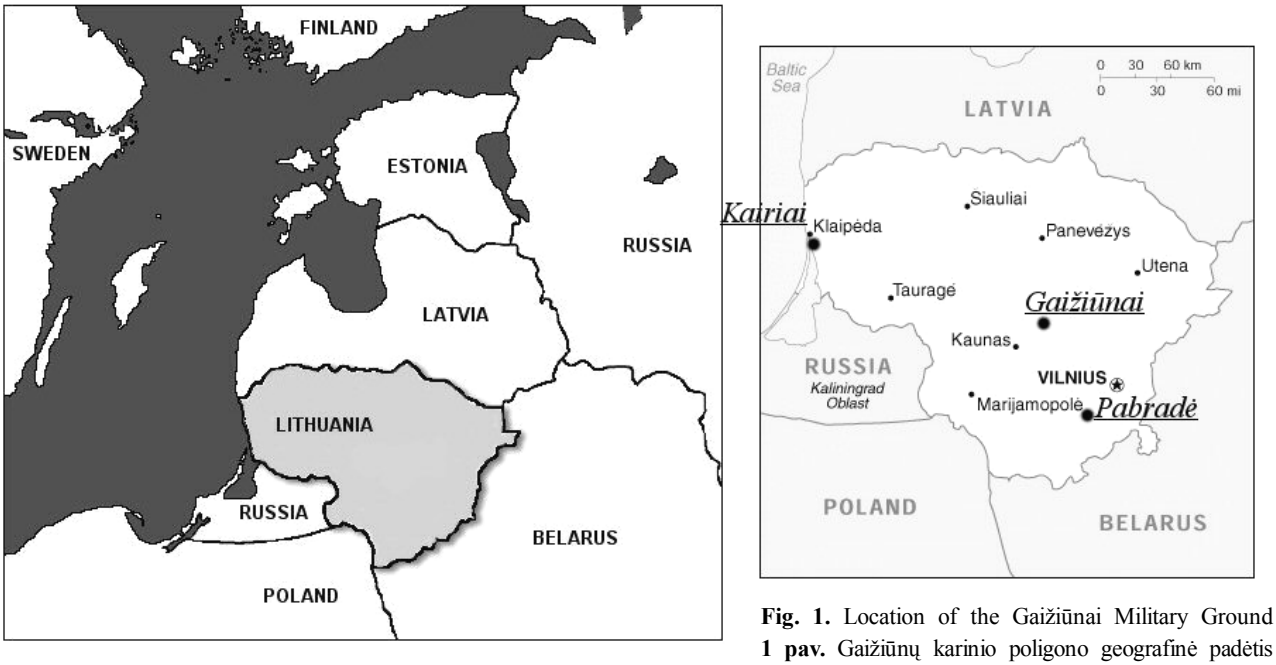


**Fig. 1.** Location of the Gaižiūnai Military Ground
**1 pav.** Gaižiūnų karinio poligono geografinė padėtis

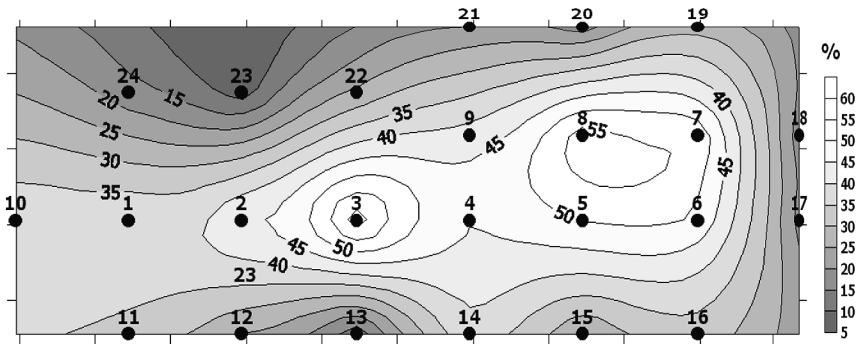


**Fig. 2.** Decrease of SOM quantity (per cent) when exploding 9 different constructions and using up to several kilograms of trotyl
**2 pav.** Organinių medžiagų procentinis sumažėjimas dirvožemiuose susprogdinus 9 skirtingas konstrukcijas iki kelių kilogramų svorio trotilo užtaisais

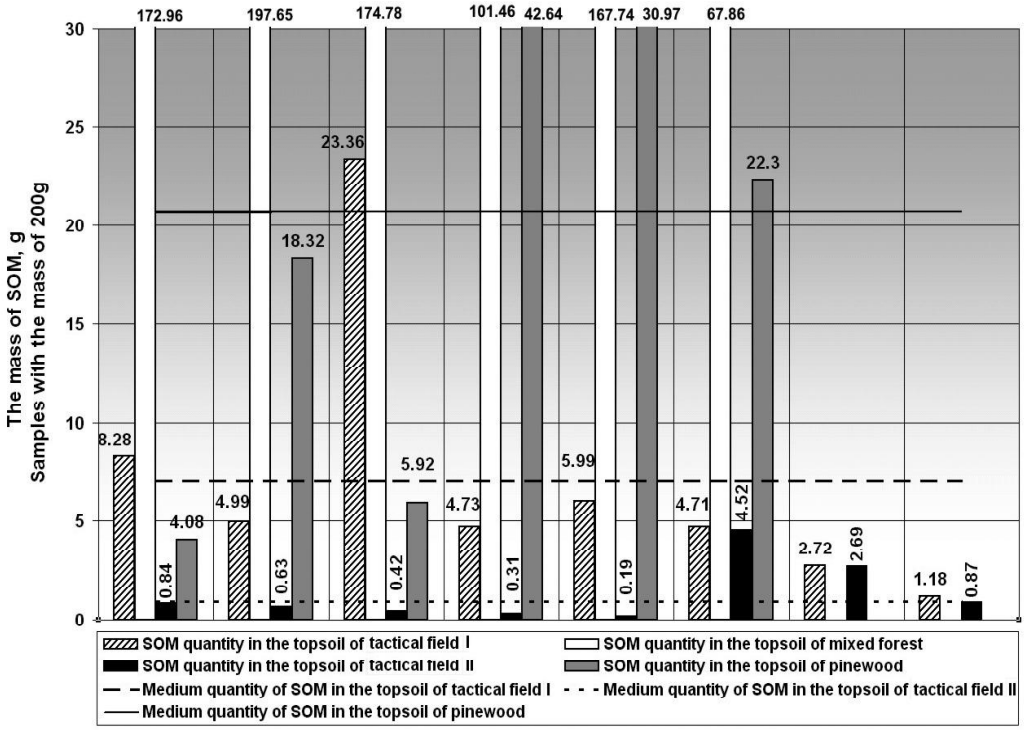


**Fig. 3.** Quantity of soil organic mater (SOM) in different soil types (disturbed and not disturbed by military activities)
**3 pav.** Organinių medžiagų sumažėjimas skirtinguose dirvožemiuose (pažeistuose ir nepažeistuose karinės veiklos)

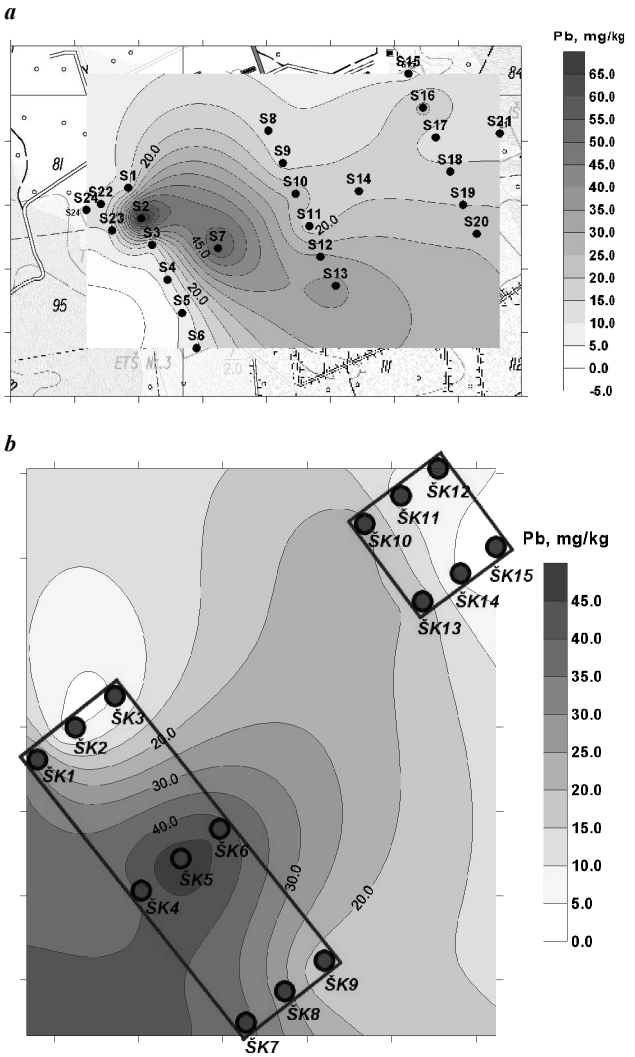


**Fig. 4.** Lead concentrations in soil of shooting ranges:
*a* – in Gaižiūnai Military Ground, *b* – in Kairiai Military Ground

**4 pav.** Švino koncentracijos šaudyklų dirvožemiuose:
*a* – Gaižiūnų poligone, *b* – Kairių poligone

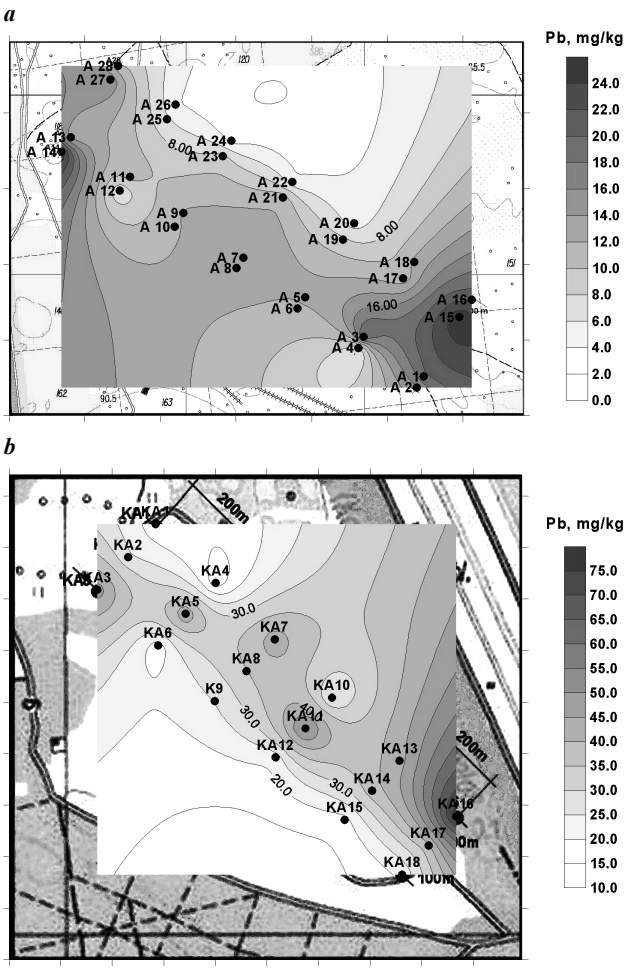


**Fig. 5.** Lead concentrations in territories used for military transport needs:
*a* – in airfield of Gaižiūnai Military Ground, *b* – in motorfield of Kairiai Military Ground

**5 pav.** Švino koncentracijos teritorijose, naudojamose karinio transporto reikmėms:
*a* – Gaižiūnų poligono aerodrome, *b* – Kairių poligono autodrome

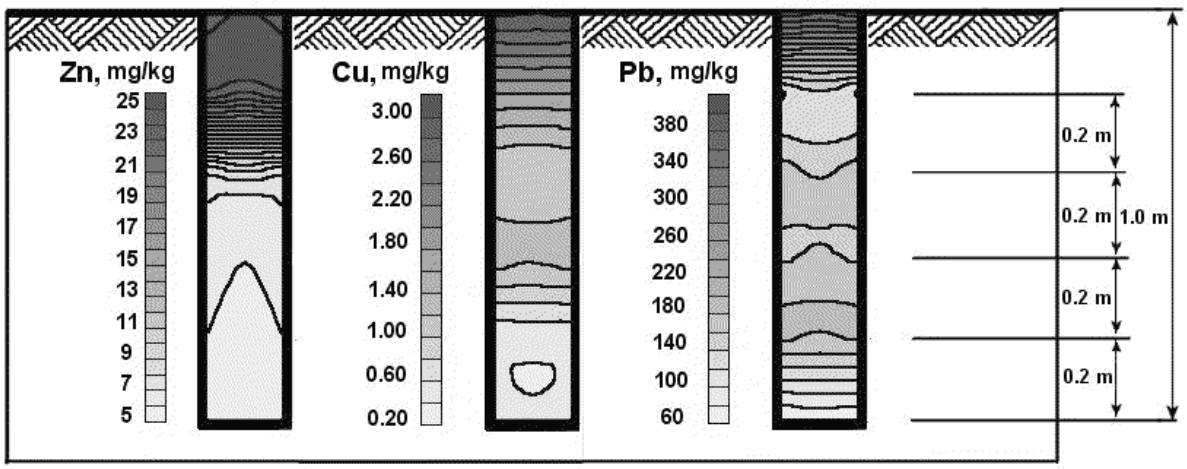


**Fig. 6.** Concentrations of heavy metals in depth bore from the territory of abandoned military settlement in Gaižiūnai Military Ground (depth varies from 0 to 1 meter)

**6 pav.** Sunkiųjų metalų pasiskirstymas apleisto karinio miestelio teritorijoje Gaižiūnų poligone (nuo 0 iki 1 m gylyje)

An inadmissible pollution with lead, nickel and manganese compounds was found at the shooting areas of the Gaižiūnai military range (maximum concentrations were higher than median respectively by 67%, 83% and 80%). The distribution of nickel and manganese concentrations was not even but in many spots bigger than the median concentration, undoubtedly showing pollution with these metals. Soils of the shooting ranges of the Kairiai Military Ground were mostly polluted with copper, manganese and lead (maximum concentrations were bigger than median respectively by 57% 61% and 62%) (Fig 4, a, b). In the Kairiai Military Ground, the biggest and most intensively used shooting range is highly polluted with almost all the above metals. The distribution of concentrations is rather even showing that shooting trainings are the reason of pollution. The airfield territory of the Gaižiūnai Military Ground is mostly polluted with manganese and nickel compounds. The estimated levels of these metals at some spots were higher that the median by 70% to 83%. Meanwhile, the maximum concentrations of zinc, chromium, and lead were higher that the median by 49% to 53%, and the biggest concentrations were estimated along the runways. The territory of the Kairiai motor-field is mostly polluted with copper, zinc and lead compounds (in some spots the estimated concentrations were bigger than the median by 71%, 74% and 61%) (Fig 5, a, b). These metals are components of fuel, and the study territory is used for intensive military transport and firing practice.

In the areas that at present are not extensively exploited for military purposes, concentrations of pollutants were found in deeper layers of soil (1 m deep). This fact could be explained by pollutant migration. The maximum concentrations of copper, zinc and lead in the territory of the Gaižiūnai Military Ground airfield and the 1st tactical field (where 1-meter deep borings were made) were estimated at a depth of 0.6 m to 1 m and in the abandoned military settlement at 0.2 m to 0.6 m. In the territory of the 1st tactical field and the airfield, pollution with lead has ceased, because in its surface lead concentrations were lower than in the deeper layers of soil. The results obtained at both military settlements of the military grounds have revealed the highest concentrations of heavy metals in the surface layer of the soil. In the abandoned military settlement of the Kairiai Military Ground, the highest concentrations of lead have exceeded ten times the background values and reached 390 mg/kg (Fig 6). Such results indicate that the soil pollution level in the above-mentioned areas is extremely high and the self-purification processes are very slow. Anyway, these areas are not used for military purposes any more, so soil pollution with heavy metals has stopped here.

## 4. CONCLUSIONS

1. During explosions, the biggest part of SOM is lost in the epicentre (32% to 82%), while recedenting from it the effect declines (SOM quantity decreases by 7% to 21%). In soils of tactical fields of Lithuanian military grounds the medium quantity of SOM is lower than in soil of a pine forest by 66% to 95%, and by 95% to 99% lower than in mixed forest soil.

2. Pollution with lead and copper (main compounds of ammunition) in the Gaižiūnai and Kairiai Military Grounds is particulary high – the maximum determined soil lead concentrations were bigger than median by 62% in the Kairiai and by 80% in the Gaižiūnai shooting ranges. The shooting ranges are also polluted with manganese, nickel and copper compounds.

3. Pollution of territories used for military transport needs is related with specific activities performed there: it was estimated that the aerodrome territory is mostly tainted with manganese and nickel compounds (the biggest concentration of these metals was higher than the median by 70% to 83%) and the autodrome territory with copper, zinc and lead compounds (the actual concentrations exceeded the median by 71% to 61%).

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## DIRVOŽEMIO PAŽEIDIMŲ IR TARŠOS SUNKIAISIAIS METALAIS TYRIMAS KARINIUOSE POLIGONUOSE

Santrauka

Kariniai poligonai – tai specifinės paskirties teritorijos, kuriose stovi įvairūs pratyboms reikalingi pastatai, vykdomos šaudymo bei sprogdinimo pratybos. Dėl šių priežasčių karinių poligonų dirvožemis dažnai užterštas sunkiaisiais metalais, o dėl nuolatinių paviršinio dirvožemio sluoksnio pažeidimų augalija tokiose teritorijose labai skurdi, kai kur jos visai nėra – vyrauja smėlingos dykynės. Tarša sunkiaisiais metalais yra viena didžiausių aplinkosaugos problemų kariniuose poligonuose. Nemažos dalies teritorijų Lietuvos kariniuose poligonuose vegetacinė danga yra visai sunaikinta. Augalijos vešėjimas priklauso nuo organinių medžiagų kiekio dirvožemyje. Akivaizdu, kad fiziškai pažeistas dirvožemis, kuriame labai mažai organinių medžiagų, yra labiau pažeidžiamas ir gali būti lengvai užteršiamas. Dar daugiau, pažeistas dirvožemis yra kur kas pralaidesnis, todėl teršalai gali lengvai pasiekti gruntinius vandenis. Šio straipsnio tikslas – įvertinti kariniuose poligonuose vykdomos veiklos neigiamą poveikį paviršiniam dirvožemio sluoksniui atsižvelgiant į pagrindinius du parametrus: dirvožemio organinių medžiagų kiekio sumažėjimą dėl sprogdinimų bei dirvožemio teršimą sunkiaisiais metalais.

Tyrimo rezultatai rodo, kad dirvožemio organinių medžiagų kiekis teritorijose, naudojamose karinėms reikmėms, yra kelis ar net keliasdešimt kartų (nuo 66 iki 99%) mažesnis nei nepažeistose teritorijose. Dirvožemio tarša sunkiaisiais metalais priklauso nuo tam tikro teritorijos tipo ir nuo jos panaudos intensyvumo: poligonų šaudyklos labiausiai užterštos švinu ir variu, tuo tarpu teritorijos, naudojamos karinio transporto reikmėms, labiausiai užterštos į kuro sudėtį įeinančiais metalais (chromu, švinu, manganu ir kt.).

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## ИССЛЕДОВАНИЕ ПОВРЕЖДЕНИЙ И ЗАГРЯЗНЕННОСТИ ПОЧВЫ ТЯЖЕЛЫМИ МЕТАЛЛАМИ НА ВОЕННЫХ ПОЛИГОНАХ ЛИТВЫ

Резюме

Военные полигоны – это территории специфического назначения, где проводятся учения, сопровождаемые стрельбой и взрывами, и зачастую строятся здания, необходимые для проведения учений. В результате интенсивного использования военной техники, оружия и разных взрывчатых материалов на таких полигонах наблюдаются аномалии, связанные с загрязненностью почвы тяжелыми металлами. Кроме того, из-за постоянного разрушающего воздействия растительность на таких территориях крайне скудна, часто преобладает песчаный грунт. Загрязненность тяжелыми металлами является одной из самых острых проблем на военных полигонах. В Литве много военных полигонов с уничтоженным растительным слоем. Важную функцию выполняют органические вещества, определяющие физические, химические и биологические особенности почвы, от которых зависит жизнь растений. Очевидно, что физически поврежденная почва, в которой количество органических веществ очень небольшое, легко подвергается загрязнению. Более того, поврежденная почва становится проницаемой, и по этой причине загрязняющие вещества легко попадают в грунтовые воды.

Цель данной работы – оценить негативное влияние, которое на поверхностный слой почвы оказывает человеческая деятельность на военных полигонах, учитывая при этом два основных параметра: сокращение органических веществ и загрязненность почвы тяжелыми металлами.

Результаты исследования показали, что количество органических веществ на территориях, которые используются под военные полигоны, в несколько раз (от 66 до 99%) меньше, чем в естественных условиях. Загрязненность почвы тяжелыми металлами зависит от типа и интенсивности использования территории полигонов: почва стрельбищ более всего загрязнена свинцом и медью, а территории, которые используются для потребностей военного транспорта, сильнее загрязнены металлами, входящими в состав топлива (хромом, свинцом, марганцем и т. п.).