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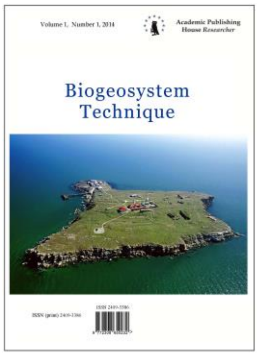

Soils Pollution with Oil Products (Ulaanbaatar, Mongolia)

Gantumur Sambuu [a, *], Haliun Gantumur [a, b], Galina V. Kharitonova [c]

[a] Mongolian State University of Science and Technology, Mongolia
[b] China University of Petroleum, People's Republic of China
[c] Institute of Water and Ecological Problems, Far East Branch of the Russian Academy of Sciences, Khabarovsk, Russian Federation

Abstract

As for most megacities, the problem of soil pollution with oil products is acute for the capital of Mongolia. In Ulaanbaatar, it is provided (aggravated) with dust pollution from the burning of brown coal, containing heavy metals and As, used in fuel and industrial complex and yurt part of the city. In this paper soil contamination of Mongolian capital Ulaanbaatar with oil products was investigated. In addition, the state of soils in the zone of influence of gas stations was studied to reveal the patterns of accumulation of oil products and heavy metals (and arsenic), which fall into the soil due to atmospheric dust. Such surveys for Ulaanbaatar have not been conducted previously. Based on soil-geochemical survey, a map of soil contamination of the city with oil products was constructed. According to the obtained data, the content of oil products in the presence of local anomalies with medium and heavy soil contamination of Ulaanbaatar are classified as slightly contaminated. Elevated (above the maximum allowable concentration of 100 mg/kg) content of oil products in soils was found along the city's main highway, industrial zone, CHPP and yurt zone, high value were found in oil tank farms and filling stations (up to 1000 mg/kg soil and more). The visualization of the obtained data (the content of oil, heavy metals and As in soils) by GIS methods showed cumulative effect of As accumulation with petroleum products most likely due to atmospheric dust from the burning of brown coal.

Keywords: soil, pollution, oil products, coal.

1. Introduction

At present, due to the rapid growth of the urban population and the formation of large agglomerations, the assessment of pollution of urban soils acquires a special relevance (Davies, Wixson, 1987; Li et al., 2001; Lu et al., 2003; Lado et al., 2008; Andersson et al., 2010; Chen et al., 2010; Dao et al., 2010; Wei, Yang, 2010; Kasimov et al., 2011; Xia et al., 2011; Tóth et al., 2016). The growth of the urban population occurs around the world and Mongolia is no exception. Almost half of the country's population lives in the capital of Mongolia, Ulaanbaatar. Over the past 25 years, the population of Ulaanbaatar has increased from 600 thousand to 1.4 million people. In Mongolia, migration processes have a historical tradition and are closely related to economic management and living conditions. Securing on the legislative level the rights of citizens to free movement and choice of residence led to uncontrolled settlement of the capital by nomads, chaotic placement of yurts and cottages in the territory of Ulaanbaatar. The active construction of yurts

* Corresponding author
E–mail addresses: gntm2000@mail.ru (Gantumur Sambuu)

began after 2003, when each family was allowed to occupy 0.07 hectares of land. This led to a negative impact on urban areas, and primarily on soils and atmospheric air. The process of migration is intensifying, and its consequences acquire a social character. The influx of people and the growth of the capital's territory causes an exacerbation of environmental problems related not only to large–scale construction, development of the industrial sector and the yurt sector of the city, but also to the fleet and network of filling stations (Cogbadrahyn, 2003; Bajarsajhan , 2009a, 2009b; Sambuu, 2016).

The most common contaminants in urban soils are oil products and heavy metals (and As). According to recent studies, the content of heavy metals and As in the presence of local anomalies with moderate and severe soil contamination, Ulaanbaatar are classified as slightly contaminated (Bathishig, 1999; Dorzhgotov, Bathishig, 2008; Batjargal et al., 2010; Kosheleva et al., 2010; Kasimov et al., 2011). Regarding the regional background, urban soils are enriched with Pb, Zn, Cu, As, Cr and Mo. Excess of MPC is revealed for As, Pb and Zn. The strongest tendency to the accumulation of pollutants is manifested in the central part of the city, which includes blocks of multi-story buildings, industrial zone and the largest thoroughfares.

In the urban environment, pollution of soils with oil and oil products is the most dangerous, as it leads to prolonged multicomponent pollution with toxic substances (Galitskaya, Pozdnyakova, 2011; Zektser, 2001; Banwart, Thornton, 2010; Bauer et al., 2009; Vela et al., 2012). The composition of oil and oil products includes a large number of various toxic substances, differing in both the degree of solubility and the degree of resistance to biodegradation. The hydrophobic component of oil products remains in soils for a long time, in the aeration zone, and in aquifers, is gradually microbiologically transformed and is a source of secondary pollution of the components of the natural environment. At the same time, water–soluble constituents of oil products migrate at different rates in the soil system – groundwater (Luckner, Schestakow, 1991; Widdel et al., 2010; Stempvoort Van, Biggar, 2008). It should be noted that for Ulaanbaatar studies of soil contamination with oil products are few, and the level of study of polycomponent pollution of soils (oil products and heavy metals) remains extremely weak.

The purpose of this work is to assess the pollution of the city's soil with oil products, its degree and spatial structure. The work is a continuation of geoecological studies of the authors of the Ulaanbaatar soils (Sambuu, 2016). A feature of this work is the visualization of polycomponent pollution of the most representative sites using GIS technologies.

Environmental conditions

The area of Ulaanbaatar at present is 4704.4 km^2, the population according to data for 2017 is 1405 thousand people. The city includes areas with urban buildings (multi-story apartment houses, buildings of various institutions and organizations, industrial, transport enterprises, etc.) and areas of private yurt housing, most of which were formed on the outskirts of the city after 2003 (Boldyn, 2004; Bajarsajhan , 2009a, 2009b).

The city is located in an intermountain basin, drained by the Tuul River, stretching from west to east for 30–35 km and from north to south for 6–10 km. The slopes of the surface in the bottoms of the intermontane depressions make the first degrees, towards the mountain framing they increase to 20–25°, sometimes steeper slopes are noted (Zaitsev et al., 1982). The valley of the Tuul River has a width of 5–10 km with absolute elevations of 1230–1240 m. Within the city the river accepts a number of small tributaries (Salbe, Uliastai, Gachuurt, etc.).

The Urginian Basin refers to the Khangai soil-bioclimatic provincia, the Prehentei district with chestnut and dark chestnut soils under eluvial and trans-eluvial conditions and alluvial stony-pebble soils in the accumulative landscapes of the Tuul River valley and its tributaries (Nogina, 1984). The main soil-forming rocks in the city are quaternary deposits of light granulometric composition with a low content of most trace elements. In intermontane depressions they are represented by alluvial-proluvial deposits of loamy and sandy loam composition with inclusions of crushed stone, gravel and pebbles. In some places there are outcrops of Paleogene–Neogene sediments enriched with Fe, Mn and Co. The indigenous rocks are represented by Archean granites, coal metamorphic clay shales and Neogene variegated clays. Slates and clays are enriched in Fe, Mn, Cr, Co, Pb, Ni, Ti, while granites, sandy sediments and river alluvium are impoverished by them (Bathishig, 1999).

The region is characterized by a sharply continental climate with large annual and daily fluctuations in air temperature. Winter is long and severe, summer is cool. Precipitation is low all in the summer, in winter there is almost no precipitation. The high altitude also greatly reduces the temperature in the city, the average annual temperature is –0.4 ° C. Among all the capitals of states, Ulaanbaatar has the lowest average annual temperature and the coldest winters (colder than in Moscow, Astana and Helsinki). The average annual rainfall in Ulaanbaatar is 240–260 mm, of which 60–90 % falls on July and August, and they have a stormy character (Beresneva, 2006). In winter, due to the prevalence of a windless anticyclone weather regime, stable temperature inversions are formed in the city.

Soil formation in the region under study proceeds in extracontinental conditions characterized by a slowed down rate of chemical weathering, biological cycling, short–term periods of biologically active temperatures and the activity of living matter, the duration of the cold period with strong supercooling of the upper horizons of the soil and their deep freezing (Nogina, 1989). Soils of sandy loamy and light loamy granulometric composition with high water permeability, low humus content (0.5–1.5 %), medium to neutral reaction (pH 7.5–9.0) and $CaCO_3$ content from 0.7 to 5.0 % predominate. On the slopes of the Bogdo-Ula Mountains, soils (mountain sod–taiga and mountain meadow–forest soils) are formed with humus content higher than 7.0 %.

Within Ulaanbaatar, soils are subject to a strong anthropogenic transformation, the extent of which is decreasing in the direction from the central part of the city to the areas of yurt housing. In the central part of the city, in connection with the construction of modern multi–stored buildings, the paving of asphalt roads, the soil cover undergoes a radical transformation – from mixing and "sealing" until its complete destruction and formation of man–made surface formations. In the areas of yurt housing there are no profound changes in the soil cover. The negative impact of urbanization in these areas is manifested in the elimination of natural vegetation and the reduction of the sludge of soils, which accelerate the processes of water and wind erosion and increase the dustiness of the atmosphere.

Sources of pollution

Ulaanbaatar is a megapolis with a diversified industry (machinery construction, metal-working, woodworking, homebuilding, food and other industries). The main part of industrial enterprises and all the CHPPs are located in the western part of the city. The districts of the yurt housing surround the central districts of the city, rising to the south, south-west and south-east spurs of the Baga-Hentay Range. The predominance of winds of western and north-western bearings creates increased pollution in the eastern and south-eastern part of the city.

The fuel and energy complex is one of the main sources of pollution of the environment of Ulaanbaatar. It includes three operating CHP plants, inter-district boiler houses and boiler houses of industrial enterprises. The main type of fuel is the brown coals of the deposits of Baga-Nura, Nalaiha and Chulut, which are enriched with Pb, As and Mo by a factor of ten, compared with clark values. Elevated values are also noted for Cu, Sr, Cd, and Ni (Kosheleva et al., 2010). The maximum emissions fall on the heating season, which lasts in Ulaanbaatar from October to May (Gunin et al., 2003).

Half of the volume of pollutants entering the city's atmosphere is emissions from the combustion of brown coal in the yurt part of the city. In Ulaanbaatar there are about 134 thousand yurts and they occupy more than half of the territory of the capital (Fig. 1A). In the yurts there are more than 600 thousand inhabitants. For heating and household needs in the yurt zone 443 thousand tons of coal are used per year (Report, 2010). With the heating of yurts is associated with the emergence of smog, which affects half the city of Ulaanbaatar. In winter, the windless anticyclone weather regime and stable temperature inversions create an ecologically unfavourable environment in the city, associated with an increased content of many toxic substances in the air, which are gradually deposited in the snow cover and in the upper horizons of the soils. Due to winter smog, Ulaanbaatar has turned into one of the most environmentally unfriendly cities in the world (Arguchintsev et al., 2009; Sambuu, 2016).

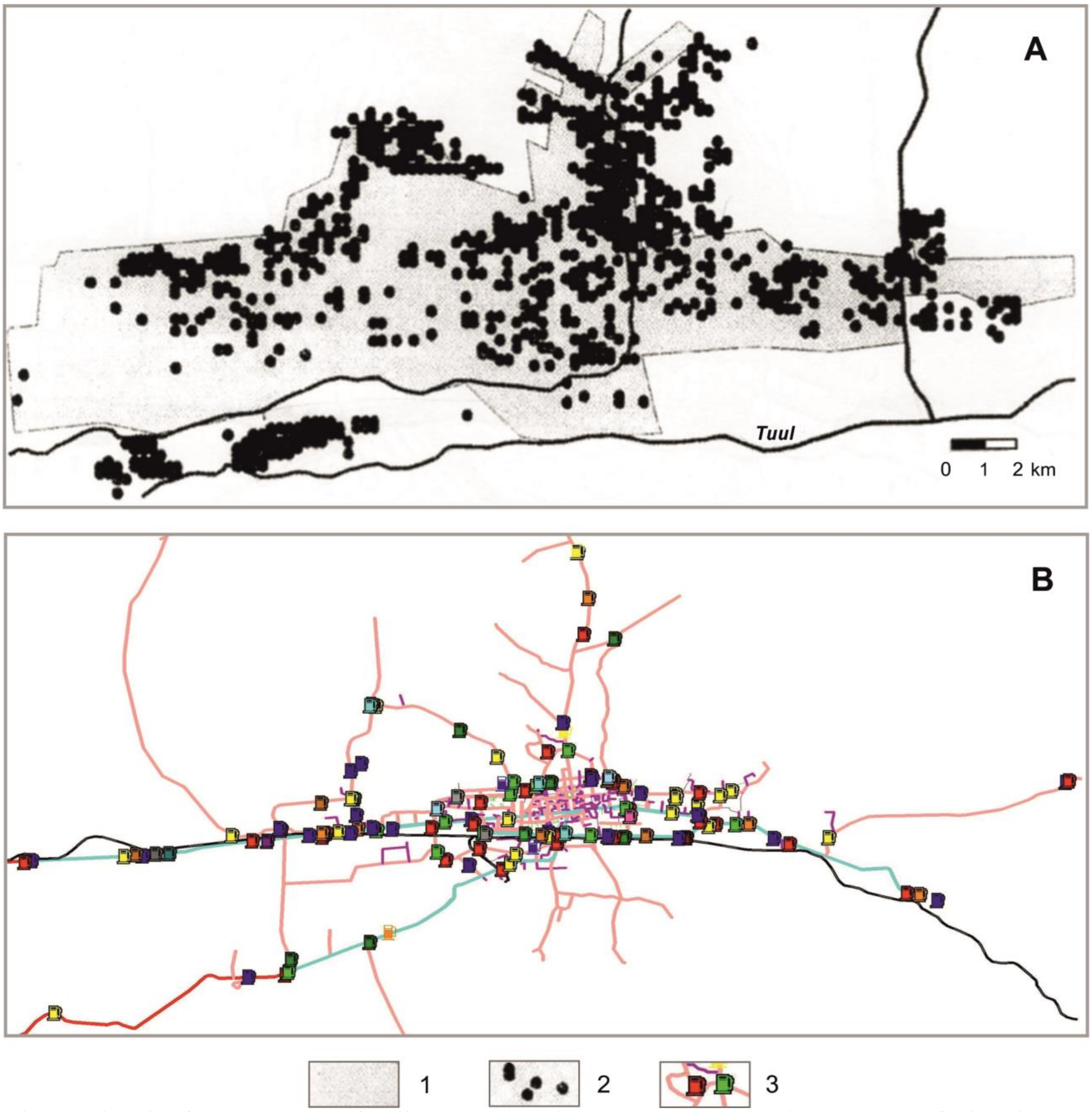

Fig. 1. Sketch of yurt sources of pollution (A) and gas stations (B) in the territory of Ulaanbaatar: 1 – the main part of the city, 2 – yurts (Arguchintsev et al., 2009), 3 – gas stations

The influx of people and the growth of the capital's territory caused an exacerbation of environmental problems related not only to the development of the industrial sector and the yurt part of the city, but also to the vehicle fleet and, accordingly, the gas station network. According to the information agency REGNUM for 2016, more than 458 thousand cars were registered in the capital. The sphere of oil products supply is developing rapidly and chaotically, which contributes to contamination and degradation of soil ecosystems (Sarapulova et al., 2007). In Mongolia, there are more than 130 fuel depots and oil depots, about 1200 gas stations, of which 186 are in Ulaanbaatar. The location and density of the gas station network in the territory of Ulaanbaatar are presented in Fig. 1B. At modern gas stations with sealed equipment, the probability of fuel leaks is minimized. However, an analysis of the operation of the gas station network by a company alone revealed that the number of straits in the fuel dispensers and on the fuel discharge site remains high: up to 100 g per 1 ton of gasoline and 50 g per 1 ton of diesel fuel. Surface water run–up contains oil products up to 28.7; lead to 0.005, copper to 0.05, zinc to 0.08 mg /L (Sambuu et al., 2010). The concentration of the gas stations network of increases the negative impact of oil products on the city's soils and can lead to the formation of geochemical abnormal pollution fields.

The absence of a system of environmental control of soils creates a risk of both primary and secondary pollution of the environment by oil products. In conditions of multifactorial impact on urbanized soils, the ecological danger of pollution of the territory increases.

2. Materials and methods

To identify areas and assess the pollution with oil products in the city's soil, the sites and districts of the city that are subject to negative impact of man–made facilities and oil products facilities were chosen as research objects. Such areas were the districts in the center of the city, the territory along the main highway, the areas of CHPP–3 and CHPP–4, the central market area and others. According to disparate surveys (Bajarsajhan, 2009a, в; Boldyn, 2004; Gonchigzhav, 2005; Sarapulova et al., 2007, 2009, 2010; Sambuu et al., 2010; Sorokina, Enkh–Amgalan, 2012), soils of these areas are polluted with oil products.

On the selected sections of the city with a single topographic grid samples of soils were taken with account the "packing" of the territory. The coordinates of the points were determined with GPS. Sampling was carried out from a depth of 0–30 cm (the boundary of the root–habitat zone) during 2009–2014 in spring and autumn. In total, more than 200 samples were selected (in each region from 10 to 30 samples). To assess the content and identification of soil contamination with oil products, an express method of IR spectroscopy and a standard gravimetric method for determining the mass fraction (GOST, 2011) were used. In addition, the content of organic carbon in soils was determined (GOST, 2008). To build a map–scheme for the distribution of oil products in the city soils, the GIS MapInfo Professional (version 5.0) was used. The map-scheme is a continuous raster surface obtained by interpolating point data.

Of particular interest was the study of the state of soils in the zone of influence of gas stations in order to reveal the patterns of distribution of oil products and heavy metals (and arsenic) falling into the soil due to atmospheric dust. These territories are a kind of polygon for studying geochemical features of polycomponent soil pollution. These studies are carried out for the first time for Ulaanbaatar. According to the environmental standards of Mongolia, only the content of oil products in the ambient air is monitored at the gas station. The monitoring of the state of the territory adjacent to the gas station is not carried out. Analysis of soils in the city is carried out singly during engineering and geological surveys. The main tasks of the study were (1) to identify zones of accumulation and areas of soil contamination with pollutants (oil products and heavy metals), (2) to obtain thematic landscape maps of their (pollutants) distribution.

The studies were carried out at the gas stations №14 and №90 OOO MT (Magnai Trade). Both are located in the eastern part of the city, which, due to the prevalence of winds in the west and north–west of the city, is experiencing an increased impact of dust pollution from the emissions of thermal power plants and stoves in the yurt part of the city. The first of them was built in 1992, the total number of oil products (gas and diesel fuel) released on it is 23,000 L / day. The second more modern one was launched in 2011; the quantity of oil products released is significantly less – 3,500 L / day. Sampling for dust pollution was taken from a depth of 0–5 cm in the spring and autumn of 2015. In total, more than 200 samples were taken, determination of the content of oil products was performed (GOST, 2011). The Pb, Zn, Hg, Cu, and As contents were determined by atomic absorption spectroscopy using a Perkin Elmer–5000 instrument in accordance with the ISO / TC190 / SC3 / WG1 method. The choice and list of identified chemical elements is determined by the specificity of contamination of the territory under study: lead, mercury, zinc, arsenic and copper. The measurements were carried out at the Institute of Physics and Technology Mongolian Academy of Sciences.

3. Results and discussion

According to the obtained data, the content of oil products in the presence of local anomalies with medium and severe soil contamination of Ulaanbaatar are classified as slightly contaminated (Fig 2). Increased content of oil products in soils (above the MPC of 100 mg/kg) was found along the main highway of the city, industrial zone, CHPPs and yurt zone, high – in the territories of oil depots and gas stations (up to 1000 mg/kg soil and more). So, in the territory of the gas station № 8 "Zhast-Oil" (the city center, from the Burd market to the northwest), where oil spills often occur, their content is more than 1000–1200 mg/kg. The content of oil products on the territory and in the area of the Tolgoit tank farm, where leakages (filling equipment) are also often fixed, is

800 to 1200–1500 mg/kg (multiples of MPC). The size of the distribution zone of oil products is about 200x1200 m^2 with the thickness of a highly contaminated layer of 10–15 cm. There are practically no plants on this area. And the pollution spreads up to 3 km from the source.

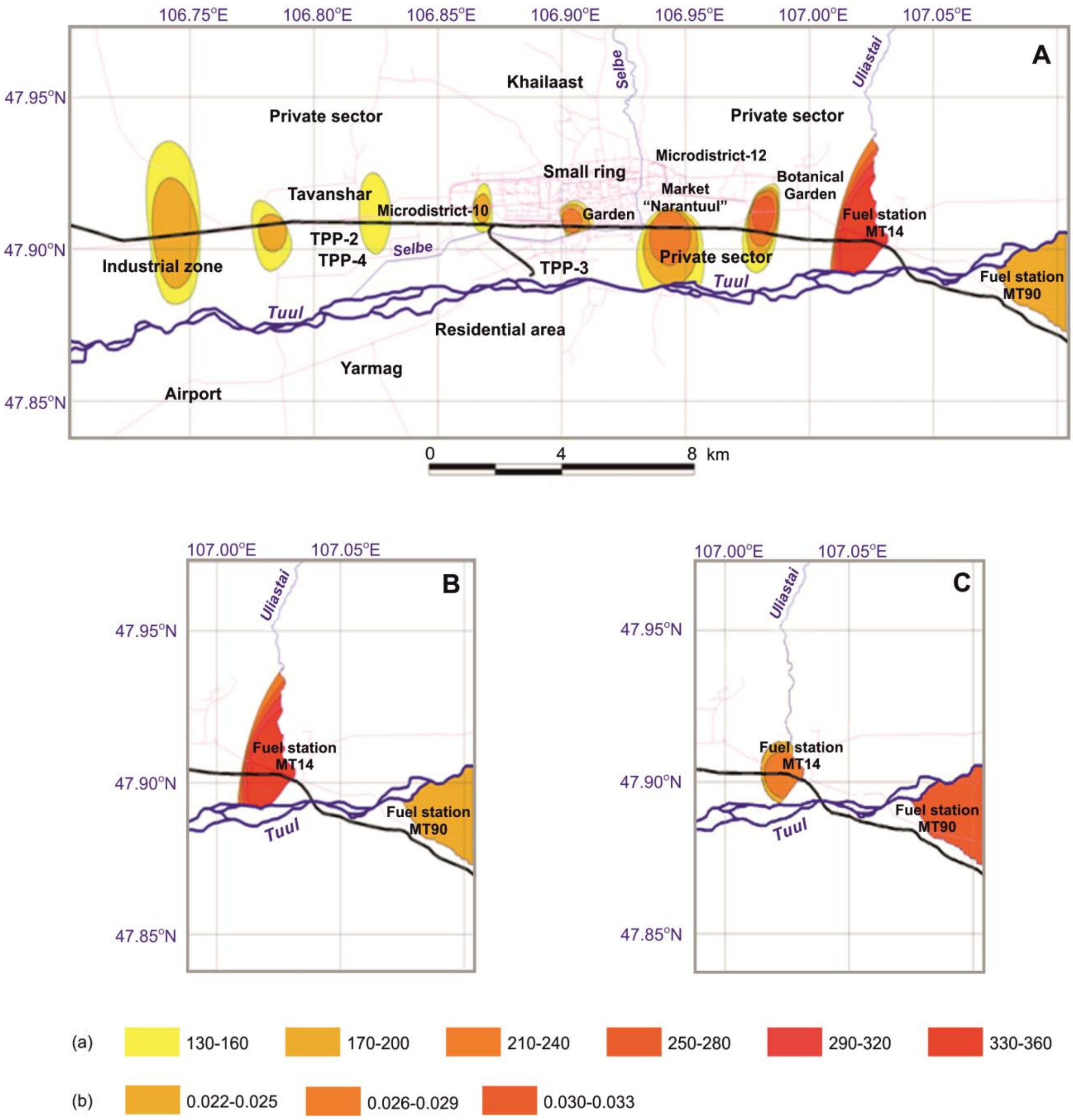

Fig. 2. Distribution of oil products (A, B) and C_{org} (C) in the territory of Ulaanbaatar: a – scale for oil products (mg/kg), b – scale for C_{org} (g / g). The remaining explanations see in the text

The quantitative approaches adopted in various countries to standardize the content of oil products in soils are determined by the nature of regional pollution, the degree of its industrialization, environmental policy, and the physic geographical conditions on which self–purification of the environment depends. In many countries, the oil content level of about 1000 mg/kg is increased pollution, which requires observation, analysis and elimination of the cause of pollution (VROM, 1988; Pikovskii et al., 2003).

A comparative analysis of soil contamination with oil products for the gas station AZS–14 MT and the adjacent territory indicates their significant accumulation in the station itself and lateral removal along the slope towards the Tuul River (Fig. 3a). The direction of their migration is subject to the landscape slope of the surface (the catenary principle for geochemical components). At a distance of about 100 m from the source of pollution, the content of oil products is 800 mg/kg. And at a distance of 250 m from the source, the content of oil products in the soil at 500 mg/kg does not comply with generally accepted standards (minimum content is 100 to 300 mg/kg soil). This creates a risk of contamination of the territory in general and surface water: the gas station is 1.6 km away from the Tuul River.

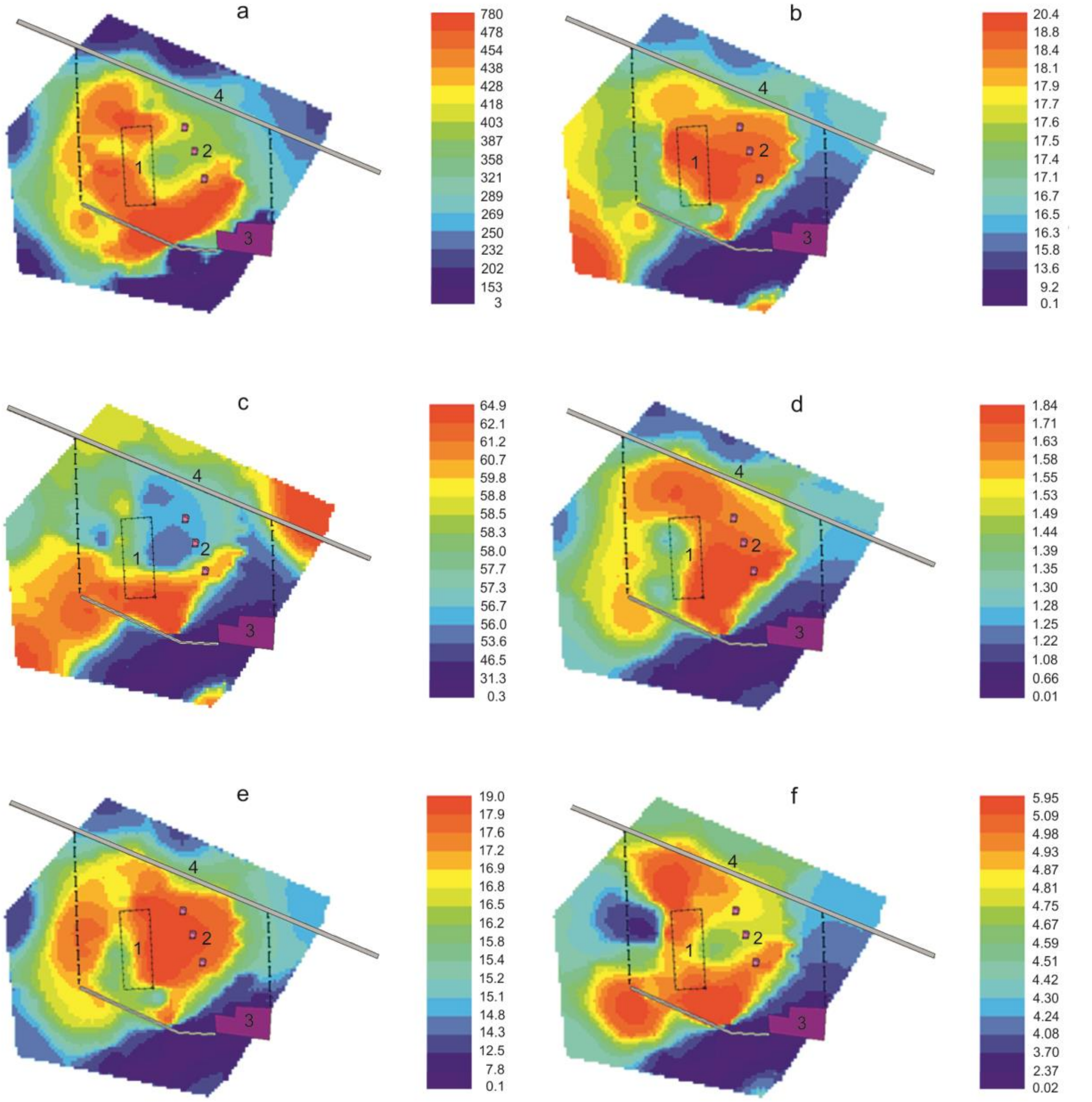

Fig. 3. Distribution of pollutants at gas station №14 MT and the surrounding area: a – oil products, b – Pb, c – Zn, d – Hg, e – Cu and f – As (mg/kg). Other explanations see in the text

An analysis of the spatial distribution of Pb, Hg, Cu and Zn in the territory under consideration indicates their higher concentrations in the oil leakage zone compared to the surrounding area (Fig. 3 b–e). For Zn, there is an increased migration activity compared to Pb, Hg and Cu, the solubility of compounds of which is much less. However, the content of Pb, Hg, Cu and Zn in the territory under consideration, with the exception of the latter, does not exceed the maximum permissible concentration – 32, 2.1, 33 and 55 mg/kg, respectively. For Zn excess is less than 20 %. But it is noteworthy that soil contamination with As exceeds the MPC by more than 2.5 times (Figure 3f). Excess of MPC for As content was also noted in the city soils before (Kosheleva et al., 2010; Kasimov et al., 2011), but in our case it is important that the area of its accumulation practically coincides with that of oil products. The latter allows assuming the affinity of As to oil products and the joint accumulation of pollutants with a cumulative effect as a result.

For the new gas station №90 MT, lower pollution levels were detected as oil products (90–190 mg/kg), Pb, Hg, Cu and Zn content does not exceed the MPC (Fig. 4). With a low variance (difference) of the obtained analytical data, the tendency of migration of these pollutants beyond the territory of the gas station is clearly recorded. As for As, the joint accumulation of it with oil products both at gas station №14 MT is not even observed as a trend. Its (As) content on the entire gas station and the adjacent territory is high (4.2–4.4 mg/kg). The result is somewhat unexpected, even taking into account the fact that the gas station №90 MT is relatively new, launched in 2011. But if we turn to the data of organic carbon content in soils (Fig. 1C), the picture becomes clear. Soils of the region under consideration are much more humus than in the area of gas station №14 MT. The latter is located in the mouth of the valley of the mountain river Uliastai, alluvial and proluvial deposits of which are mainly represented by cobble and gravel. Accordingly, the organic matter in the soils of this region is less and the absolute values of sorption by them (organic matter) of arsenic are also smaller (Vodyanitskii, 2009).

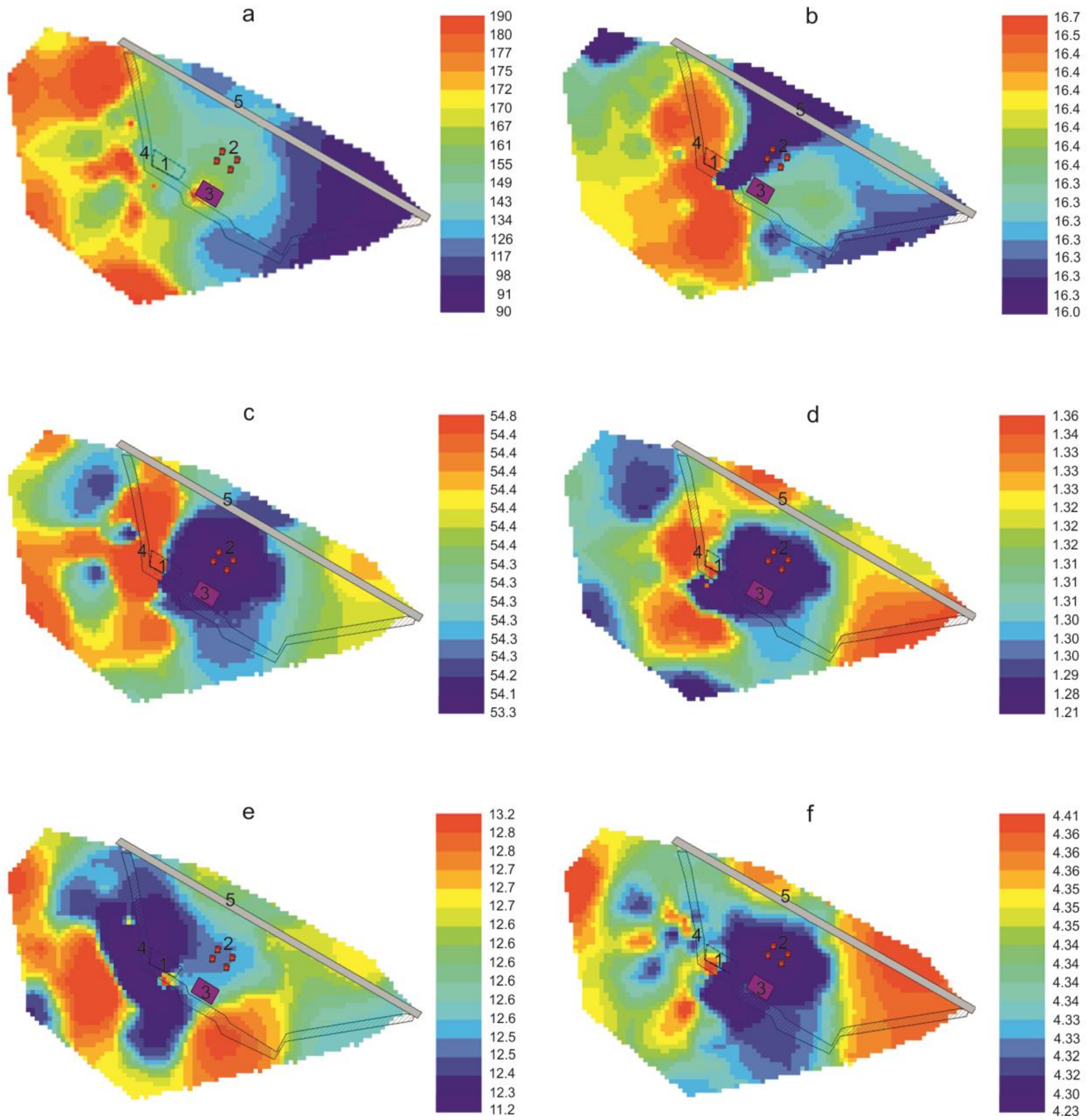

Fig. 4. Distribution of pollutants at gas station №90 MT and the surrounding area: a – oil products, b – Pb, c – Zn, d – Hg, e – Cu and f – As (mg/kg). Other explanations see in the text

The main source of arsenic in the city's soils is the dust from the combustion of used brown coal (fuel and industrial complex and yurt). The problem of soil contamination with arsenic is a problem not only for Ulaanbaatar, where emissions from burning solid fuels in the yurt part are half of the volume of pollutants entering the atmosphere of the city. Arsenic is found widely in nature. Annual global emissions from natural sources have been estimated to be approximately 8,000 tons per year (Becher, Wahrendorf, 1992; WHO, 1987) whilst emissions from anthropogenic sources have been estimated to be approximately three times higher, in the region of 23,600 tons per year (WHO, 1987). The main source of arsenic emissions has been the combustion of fossil fuel (notably coal), other sources being small in comparison. The arsenic contamination exists in UK, Slovakia, Turkey, and the Guizhou Province of China. This occurs primarily as a result of the concentration of arsenic in coal which is known to vary from trace to 1–2 % (Yudovich, Ketris, 2005; Garelick et al., 2008).

Consider, for example, England. In the 70s of the last century a big problem of air and soil pollution with arsenic arose. The UK National Air Emissions Inventory (NAEI) indicate that combustion of fossil fuels such as lignite (brown coal), hard coal and heating oil account for the largest proportion of total UK emissions of arsenic (Maggs, 2000). At the government level, the solution to the problem was initiated with the organization of pollution monitoring, followed by a decrease in the use of fossil fuel and the introduction of new technologies. The reduction of arsenic emissions in United Kingdom over the past decades has resulted as a consequence of a decline in coal use, in favour of natural gas use as a cheaper alternative. NAEI results show that emissions have declined by 78 % since 1970.

Currently, the Government of Mongolia is extremely concerned about the problems of environmental pollution and is doing a great job to improve life in the city. So in the yurt part of the city, to replace the dust emissions, a significant part of the furnaces was replaced by new ones, regular measures were taken for landscape gardening. But the problem of soil and air pollution in the capital is still far from the solution. At this stage in Mongolia, it is important and realistic to organize the monitoring of pollution. As our studies have shown, the main attention should be paid to monitoring soil contamination with oil products (areas of the city with levels of about 1000 mg/kg) and arsenic, analysis and eliminating the causes of pollution.

4. Conclusions

The soil contamination of Mongolia's capital Ulaanbaatar with oil products was investigated. To identify areas and assess the pollution of the city's soil with oil products, the sites and districts of the city that are subject to negative impact of man-made facilities and oil products facilities were chosen as research objects. Based on soil-geochemical survey, a map of city pollution was built. According to the obtained data, soils of Ulaanbaatar on the content of the oil products are classified as slightly contaminated. However, there are local anomalies with medium and strong pollution. Elevated (above the maximum allowable concentration of 100 mg/kg) values for oil products were found along the city's main highway, CHPPs, industrial and yurt zones, high in oil tank farms and gas stations (up to 1000 mg/kg soil and more).

Of particular interest was the study of the soils state in the zone of influence of gas stations in order to reveal the patterns of distribution of oil products and heavy metals (and arsenic) falling into the soil with atmospheric dust from burning brown coal (fuel and industrial complex and yurt part of the city).

These territories are a kind of polygon for studying geochemical features of polycomponent (oil products, heavy metals and As) soil contamination. Such studies for Ulaanbaatar have not been carried out previously. Visualization of obtained data by GIS methods made it possible to establish that at high oil content (of the order of 1000 mg/kg), there is a symbate accumulation of As, which exceeds the MPC at times. Areas of accumulation of arsenic practically coincide with those of oil products. The latter allows assuming the affinity of As for oil products and the joint accumulation of pollutants with a cumulative effect as a result. With less contamination of soils with oil products (up to 200 mg/kg), As content corresponds to the content of humus (organic matter) in them – more humus soils contain more As.

Currently, the Government of Mongolia is extremely concerned about the problems of environmental pollution and is doing a great job to improve life in the city. So in the yurt part of the city, to replace the dust emissions, a significant part of the furnaces was replaced by new ones, regular measures were taken for landscape gardening. But the problem of soil and air pollution in the capital is still far from the solution. At this stage in Mongolia, it is important and realistic to organize the monitoring of pollution. As our studies have shown, the main attention should be paid to monitoring soil contamination with oil products (areas and areas of the city with levels of about 1000 mg/kg) and arsenic, analysis and eliminating the causes of pollution.

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