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INDUSTRIAL UKRAINE

Impact of pollution on inhabitants and the environment in five industrial cities

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TRANSITION

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Impact of pollution on inhabitants and the environment in five industrial cities in Ukraine
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Contents

List of abbreviations

ADI – Acceptable Daily Intake
CSOs – Civil Society Organizations
DDD – Dichlorodiphenyldichloroethane
DDE – Dichlorodiphenyldichloroethylene
DDT – Dichlorodiphenyltrichloroethane
DW – Dry weight
ELCR – Excess Lifetime Cancer Risk
GC – gas chromatograph
HCB – Hexachlorobenzene
HCH – Hexachlorocyclohexane
HQ – Hazard Quotient
IARC – International Agency for Research on Cancer
JSC – Joint-stock Company
LLC – Limited Liability Company
LOAEL – Lowest Observed Adverse Effect Level
MPCs – Maximal Permissible Concentrations
NOAEL – No Observed Adverse Effect Level
OJSC – Open Joint-stock Company
PAHs – Polycyclic Aromatic Hydrocarbons
PJSC – Private Joint-stock Company
RfD – Reference Dose
RISC – Risk-Integrated Software for Cleanups
RSL – Regional Screening Levels
US EPA – United States Environmental Protection Agency
USSR – Union of Soviet Socialist Republics
WHO – World Health Organisation

1. Introduction

Ukraine is the most energy-intensive country in the world and one of the most polluted countries in the region. According to the WHO, four times more people die because of polluted air than in the five cleanest countries of the planet (120 per 100 thousand inhabitants). In terms of the ratio of death to population, it is the country with the most polluted air of the 120 countries surveyed. The sources are metallurgy, the chemical industry, mining and electricity generation. The National Environmental Strategy 2020 identifies air pollution as one of the most serious problems and causes of health hazards. In 2013, 42% of the burden was reflected in the Donetsk region. Virtually all major cities exceed the WHO recommended limits – in 22 out of 47 cities the level of pollution was very high or high.

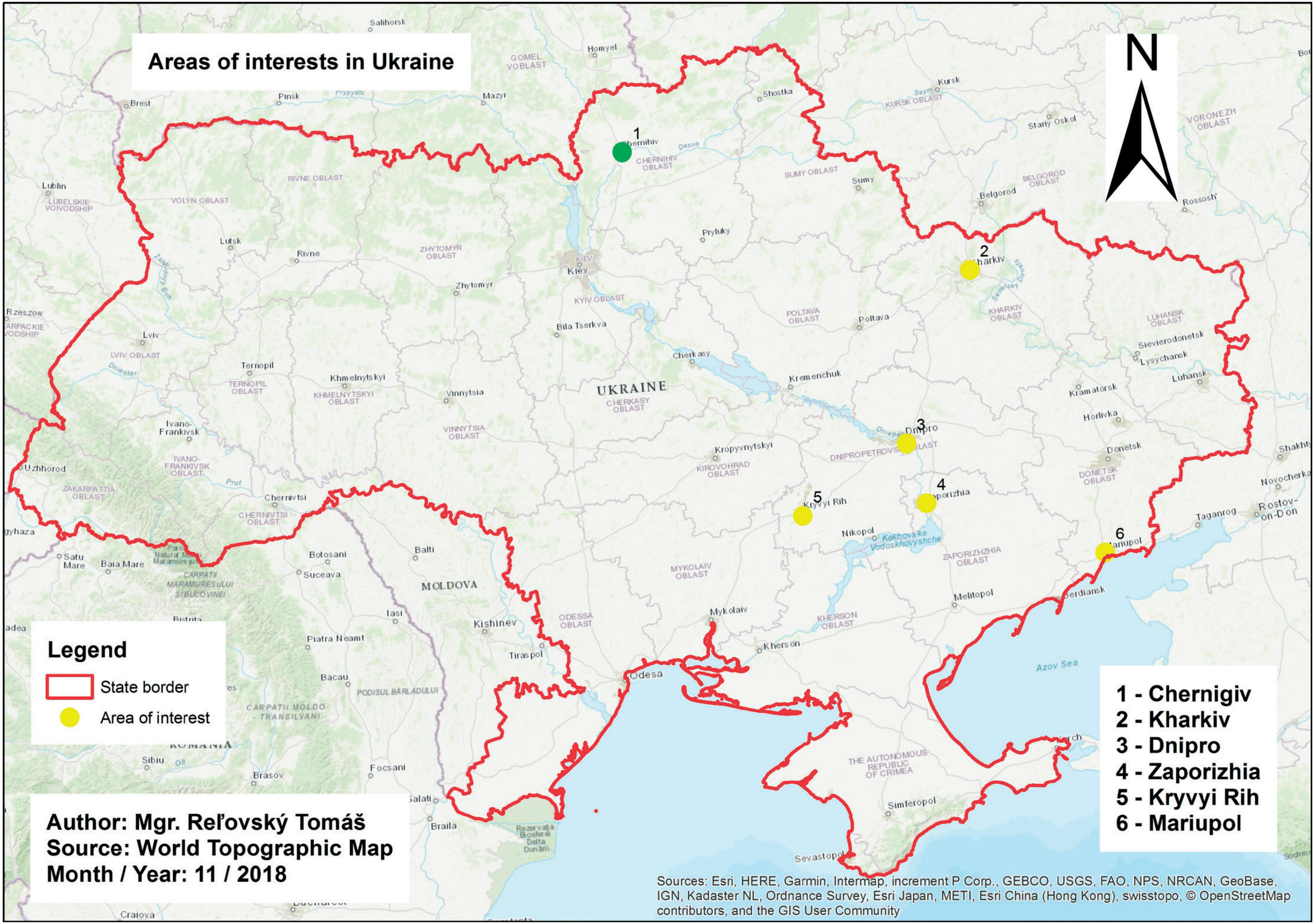
This unfortunate situation is partly a legacy of the Soviet Union; factories built between the wars are still in operation, but without investment in technology. The worst situation is in large cities with a heavy concentration of industry – Kryvyi Rih, Dnipro, Kharkov, Zaporozhye, Mariupol, Luhansk, and Donetsk. Although the state has developed good strategies, pollution is not a priority. One reason is the fact that factories often belong to oligarchs with political and economic influence.

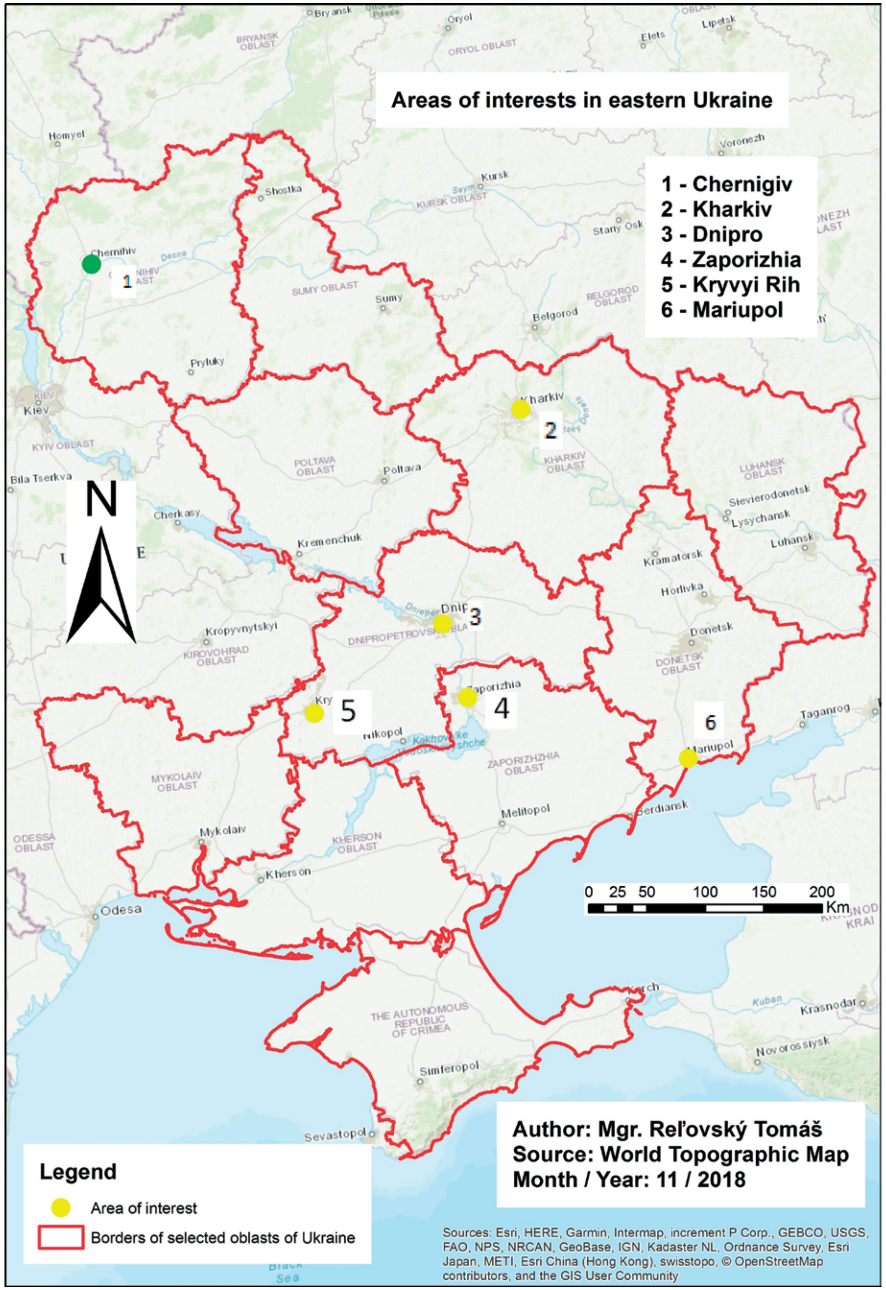
Ukraine is one of the countries where environmental and human health standards are systematically violated. The country faces a number of institutional challenges, including weak public administration, human rights violations, and the lack of enforceability of the law; it also faces a high level of corruption. These issues, together with political instability, the continued occupation of the Crimea, and the unresolved conflict in eastern Ukraine, cast a shadow over the prospects of improving the standard of living and achieving the Sustainable Development Goals.

In 1999, Ukraine joined the Aarhus Convention and promised citizens to guarantee access to information, the right to participate in environmental decision making, and the right to a fair trial. However, the rights are systematically violated, as repeatedly pointed out by the Compliance Committee (since 2005, the last report being in 2017). The Committee notes that mechanisms for involving the public in the discussion of buildings and projects are inadequate and that the legal framework of Ukraine does not meet the requirements for a democratic way of making decisions. Civic initiatives from five industrial centres that seek to address the catastrophic situation agreed in 2017 to create an informal coalition, "It was enough to digest Ukraine!". Their bottom-up response is a response to the research presented in this report.

This study is focused on the presentation and discussion of data related to contamination by heavy metals, petroleum hydrocarbons, polycyclic aromatic hydrocarbons, and organochlorine pesticides in five hot-spot areas in Ukrainian cities. The hot-spot areas are as follows: Kharkiv, Dnipro, Kryvyi Rih, Mariupol, and Zaporizhia. A series of inorganic samples (sediments and sands from child playgrounds) was taken from the selected areas for chemical analysis. The aim of this study was to evaluate the influence of pollution on the local inhabitants and on the environment. Environmental samples were obtained during a sampling campaign conducted in Ukraine in May 2018. Samples from agricultural and the, as expected, clean region of Chernihiv were also collected to ascertain the background levels of selected pollutants.

The sampling campaign represent a part of the project "Stop Poisoning Ukraine: Coalition for Clean Air", a joint activity of the non-governmental organizations Arnika – Citizens Support Centre from the Czech Republic and Ecoaction from Ukraine, sponsored by the Transition Promotion Programme of the Czech Ministry of Foreign Affairs. The main objectives of the project are: 1. strengthening


Areas of interests in Ukraine
N
1
2
3
4
5
6
UKRAINE
MOLDOVA
Azov Sea
Legend
State border
Area of interest
1 - Chernigiv
2 - Kharkiv
3 - Dnipro
4 - Zaporizhia
5 - Kryvyi Rih
6 - Mariupol
Author: Mgr. Reľovský Tomáš
Source: World Topographic Map
Month / Year: 11 / 2018
Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, © OpenStreetMap contributors, and the GIS User Community



civil society for fighting air pollution, 2. improving public access to information, 3. supporting national and regional cooperation. The main target group of the project is the citizens' initiatives "Stop poisoning Ukraine", a coalition connecting CSOs from five Ukrainian industrial cities (Kharkiv, Dnipro, Kryvyi Rih, Mariupol, and Zaporizhia) trying to fight air pollution caused by heavy industries.

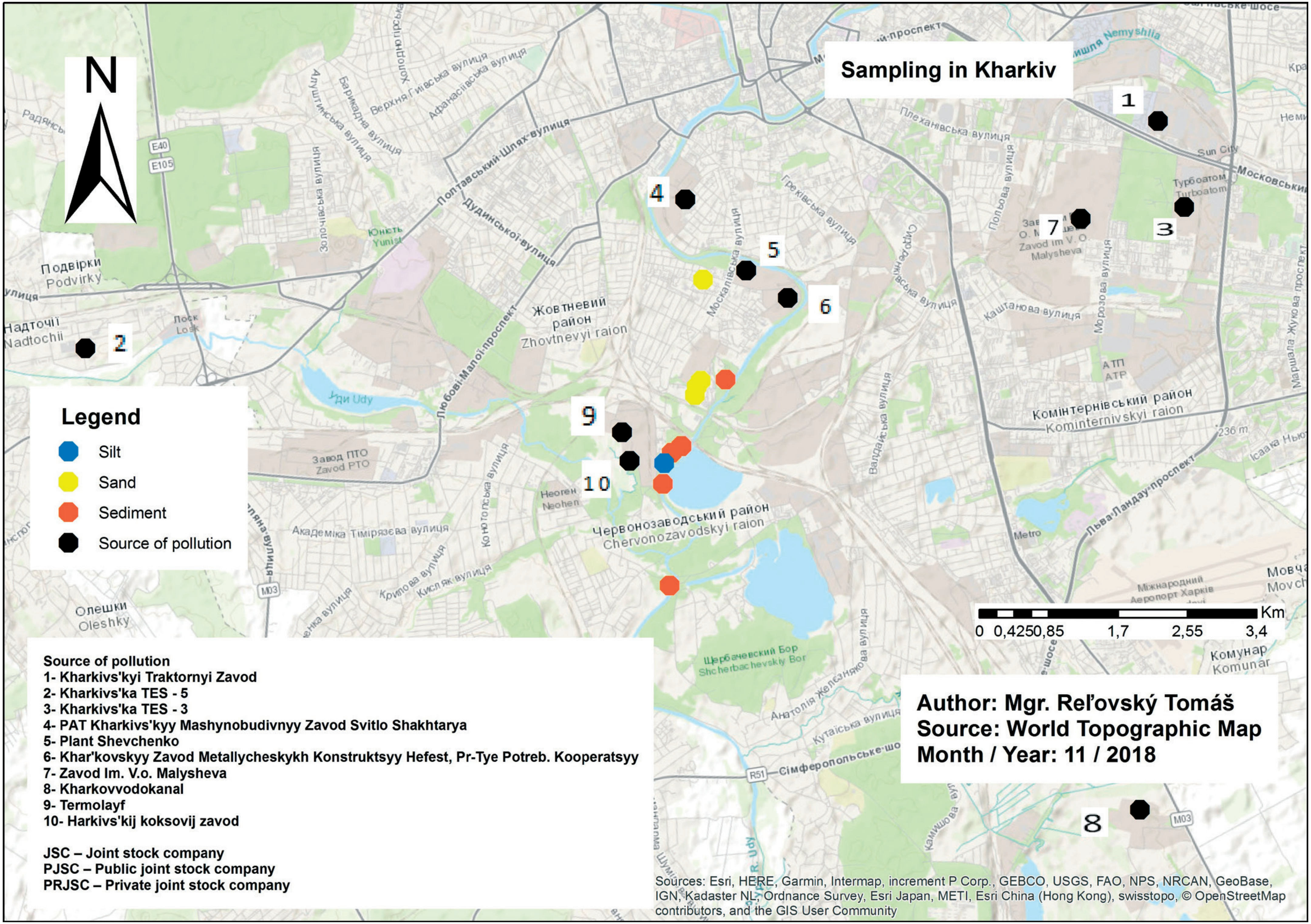
2. Sampling sites

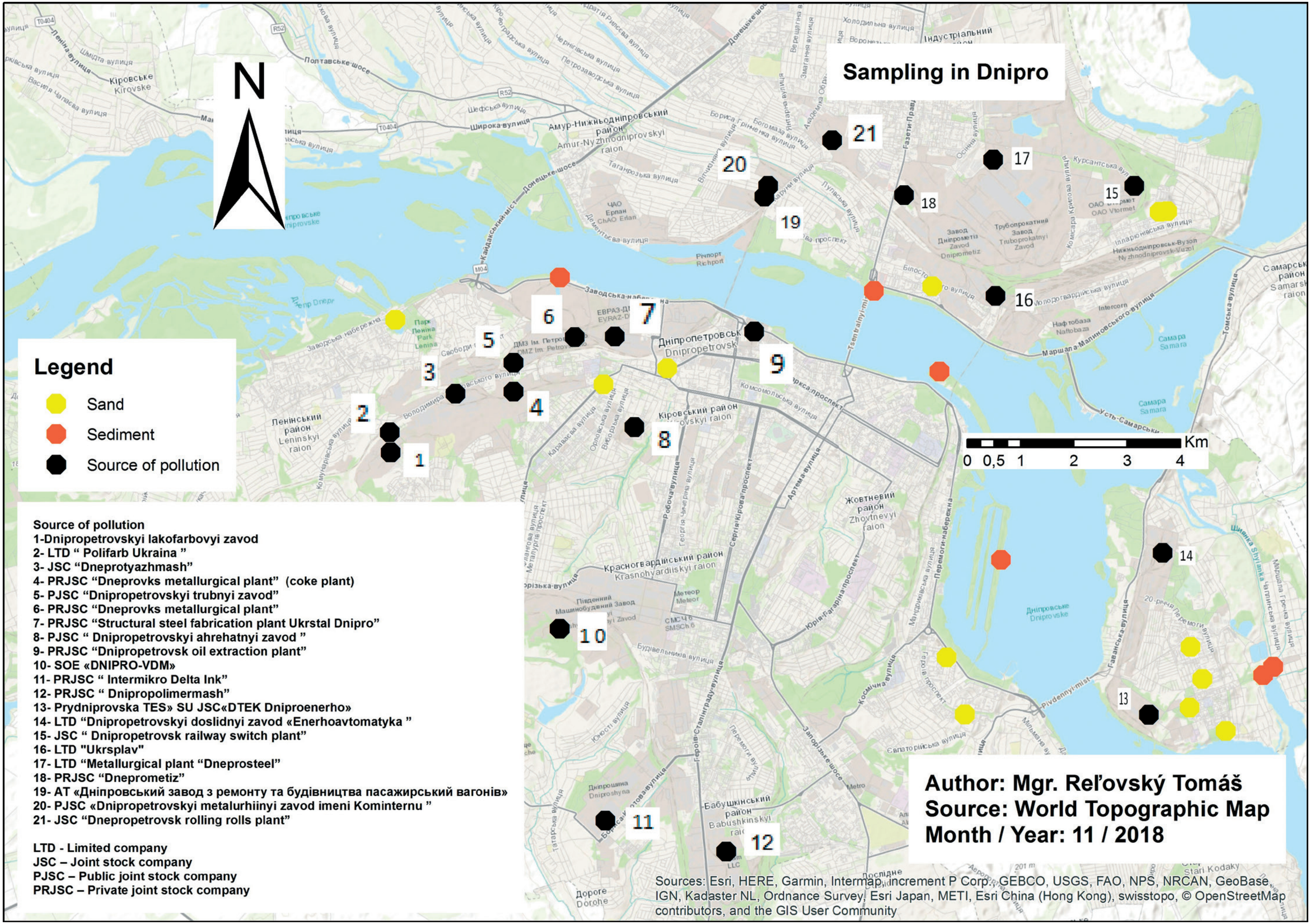
Samples of sediments and sand from children's playgrounds were taken in five big Ukrainian industrial cities:.Kharkiv, Dnipro, Kryvyi Rih, Mariupol, and Zaporizhia. In each city, 4-12 playgrounds and 6-11 spots in bodies of water were examined. additionally, sediments and sands were collected in the city of Chernihiv for background samples from an area where industry has a low effect. A description of the hot-spot areas and the background city is provided below. A detailed list of samples is presented in Table 8 in Annex I.

2.1 Kharkiv

Kharkiv is the second-largest city in Ukraine. Kharkiv is the administrative centre of the Kharkiv Region. The population of the city is about 1,440,000 inhabitants. Residents of the Kharkiv Region have suffered from air pollution for many years. About 5.3 thousand inhabitants of this region die of cancer each year, most often from lung cancer.

There are many industrial plants in the city. Among the main polluters of the city are Thermal Power Station-3, Thermal Power Station-5, the Kharkiv Tractor Plant, and the State Enterprise "Malyshev plant". The area most affected by pollution is the Novobavarskyi


Sampling in Kharkiv
N
Legend
Silt
Sand
Sediment
Source of pollution
1
2
3
4
5
6
7
8
9
10
Km
0 0,4250,85 1,7 2,55 3,4
Source of pollution
1- Kharkivs'kyi Traktornyi Zavod
2- Kharkivs'ka TES - 5
3- Kharkivs'ka TES - 3
4- PAT Kharkivs'kyy Mashynobudivnyy Zavod Svitlo Shakhtarya
5- Plant Shevchenko
6- Khar'kovskyy Zavod Metallycheskykh Konstruktsyy Hefest, Pr-Tye Potreb. Kooperatsyy
7- Zavod Im. V.o. Malysheva
8- Kharkovvodokanal
9- Termolayf
10- Harkivs'kij koksovij zavod
JSC – Joint stock company
PJSC – Public joint stock company
PRJSC – Private joint stock company
Author: Mgr. Reľovský Tomáš
Source: World Topographic Map
Month / Year: 11 / 2018
Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, © OpenStreetMap contributors, and the GIS User Community
Жовтневий район
Zhovtnevyi raion
Червонозаводський район
Chervonozavodskyi raion
Комінтернівський район
Kominternivskyi raion
Подвірки
Podvirky
Надточії
Nadtochii
Олешки
Oleshky
Комунар
Komunar
Уди Udy
Завод ПТО
Zavod PTO
Zavod im V. O. Malysheva
Щербачевский Бор
Shcherbachevskiy Bor
Міжнародний Аеропорт Харків
Турбоатом
Turboatom
Sun City
Неоген
Neohen
Полтавський Шлях вулиця
Московський
Академіка Тімірязєва вулиця
Плеханівська вулиця
Греківська вулиця
Москалівська вулиця
Любові Малої проспект
Льва Ландау проспект
Сімферопольське шосе
E40
E105
M03
R51


Sampling in Dnipro
N
Legend
Sand
Sediment
Source of pollution
0 0,5 1 2 3 4 Km
Source of pollution
1-Dnipropetrovskyi lakofarbovyi zavod
2- LTD “ Polifarb Ukraina ”
3- JSC “Dneprotyazhmash”
4- PRJSC “Dneprovks metallurgical plant” (coke plant)
5- PJSC “Dnipropetrovskyi trubnyi zavod”
6- PRJSC “Dneprovks metallurgical plant”
7- PRJSC “Structural steel fabrication plant Ukrstal Dnipro”
8- PJSC “ Dnipropetrovskyi ahrehatnyi zavod ”
9- PRJSC “Dnipropetrovsk oil extraction plant”
10- SOE «DNIPRO-VDM»
11- PRJSC “ Intermikro Delta Ink”
12- PRJSC “ Dnipropolimermash”
13- Prydniprovska TES» SU JSC«DTEK Dniproenerho»
14- LTD “Dnipropetrovskyi doslidnyi zavod «Enerhoavtomatyka ”
15- JSC “ Dnipropetrovsk railway switch plant”
16- LTD "Ukrsplav"
17- LTD “Metallurgical plant “Dneprosteel”
18- PRJSC “Dneprometiz”
19- AT «Дніпровський завод з ремонту та будівництва пасажирський вагонів»
20- PJSC «Dnipropetrovskyi metalurhiinyi zavod imeni Kominternu ”
21- JSC “Dnepropetrovsk rolling rolls plant”
LTD - Limited company
JSC – Joint stock company
PJSC – Public joint stock company
PRJSC – Private joint stock company
Author: Mgr. Reľovský Tomáš
Source: World Topographic Map
Month / Year: 11 / 2018
Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, © OpenStreetMap contributors, and the GIS User Community

district in the western part of the city. There are two big industrial factories located in this district, in the valley at the confluence of the Udy and Lopan rivers. The first of them, Termolife Private JSC, a mineral wool plant, was put into operation in 2006. The second one, the PJSC Kharkiv Coke Plant, was built in 1932 as the state-owned Diprocoks coke research centre. The experimental laboratory ceased operation in 1952, but new owners began coke production with obsolete technology under the current name Kharkiv Coke Plant in 2003.

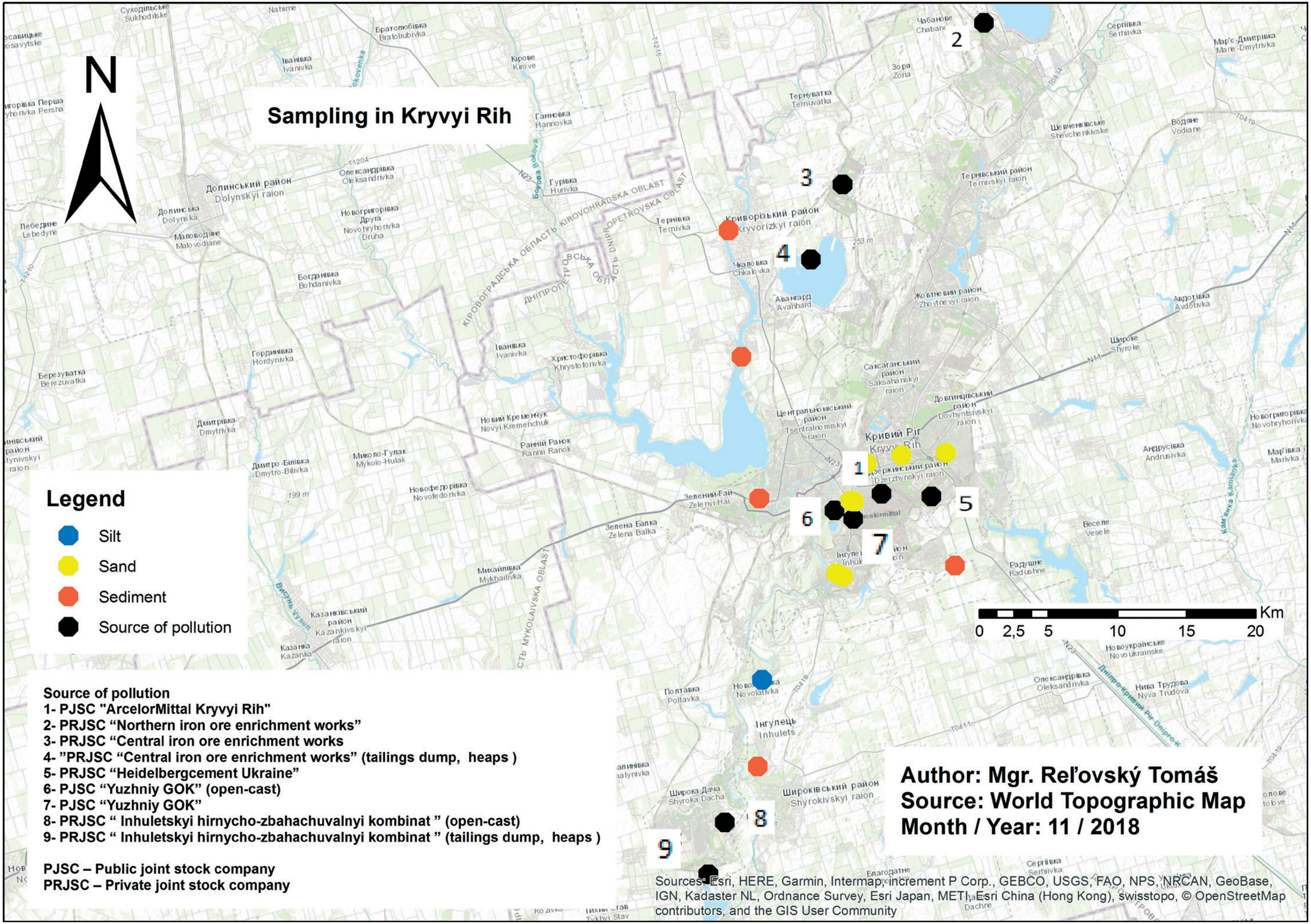
2.2 Dnipro

The city of Dnipro is Ukraine’s fourth-largest city, with a total area of more than 400 square kilometres. The population of the city reaches one million inhabitants. It is the centre of the Dnipropetrovsk Region. As one of the largest industrial cities in Ukraine, Dnipro has a polluted environment as a result of the historical features of the development of the city and the specific features of existing industries. The residential districts of the city are located right between the industrial zones.

The industrial production of the city is historically specialised in the fields of ferrous metallurgy and machine production. Additionally, there are energy industry, coke production, the chemical industry, processing of non-ferrous metals, production of plastics and polymers, special engineering, the production of inorganic and organic building materials, the pharmaceutical industry, the food industry, and primary and secondary processing of agricultural products. The biggest factories in the city include: the Pridniprovska Thermal Power Plant, Dneprovsk Metallurgical Plant, Interpipe Steel, Interpipe Nizhnedneprovsky Tube Rolling Plant, SE “PA Yuzhny Machine-Building Plant named after A. Makarov”, PJSC Dneprometiz, Production Association OJSC Dniprovsky Machine-Building Plant,

Dnipro


Dnipro



Sampling in Kryvyi Rih
N
Legend
Silt
Sand
Sediment
Source of pollution
Km
0 2,5 5 10 15 20
Source of pollution
1- PJSC "ArcelorMittal Kryvyi Rih"
2- PRJSC “Northern iron ore enrichment works”
3- PRJSC “Central iron ore enrichment works
4- ”PRJSC “Central iron ore enrichment works” (tailings dump, heaps)
5- PRJSC “Heidelbergcement Ukraine”
6- PJSC “Yuzhniy GOK” (open-cast)
7- PJSC “Yuzhniy GOK”
8- PRJSC “ Inhuletskyi hirnycho-zbahachuvalnyi kombinat ” (open-cast)
9- PRJSC “ Inhuletskyi hirnycho-zbahachuvalnyi kombinat ” (tailings dump, heaps)
PJSC – Public joint stock company
PRJSC – Private joint stock company
Author: Mgr. Reľovský Tomáš
Source: World Topographic Map
Month / Year: 11 / 2018
Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, © OpenStreetMap contributors, and the GIS User Community

Dneprotyazhmash, the Dniprovodokanal Municipal Enterprise, and others. Altogether, there are more than seven thousand stationary sources of emissions into the atmosphere in the city of Dnipro.

2.3 Kryvyi Rih

Kryvyi Rih is a city in the Dnipropetrovsk Region and the eighth most populous city in the country. It is a large industrial city and the development centre of the Kryvyi Rih iron ore basin. Historically, the city has been connected with metallurgy and iron mining; it is often called the metallurgical heart of the country. It produces up to 80% of Ukraine's iron ore and smelts a significant part of the iron and steel from the total amount produced in Ukraine. The total area of the city of Kryvyi Rih is 410 square kilometres, and the industrial areas occupy more than a quarter of the city.

Nowadays there are five mining and processing plants, a number of quarries and mines, the largest metallurgical plant in Ukraine – PJSC ArcelorMittal Kryvyi Rih, machine-building factories, and chemical and food industries in the city. The PJSC ArcelorMittal Kryvyi Rih metallurgical plant is the source of 80% of the atmospheric emissions in the city and 40% of those in the whole Dnipropetrovsk Region. The plant was built in 1934 as the Kryvorizhstal complex (Kryvyi Rih Metallurgical Works), privatised in June 2004, and then sold in June 2005 to the global company Mittal Steel. In 2007, the plant was renamed PJSC ArcelorMittal Kryvyi Rih. Exporting to more than 160 countries, Ukraine was the world's sixth largest steel exporter in 2016.

Kriviyi Rih

Sampling in Kriviyi Rih

2.4 Mariupol

Mariupol is a city of regional significance in south-eastern Ukraine, situated on the north coast of the Sea of Azov at the mouth of the Kalmius River, in the Pryazovia Region. It is the tenth-largest city in Ukraine, with a population of 449,498 inhabitants. A full 10% of all Ukrainian industrial production comes from Mariupol. During the 20th century, the iron and steel industries predominated in the city.

There are more than 50 large enterprises in the city. The two large metallurgical plants based in Mariupol are the Azovstal Iron and Steel Works and the Ilyich Iron and Steel Works. Established during the Soviet era, in the early 1930s, both plants are technologically obsolete, with outdated equipment lacking environmental safety controls. The Azovstal Iron and Steel Works is located right on the shore of the Sea of Azov, in the centre of Mariupol.

2.5 Zaporizhia

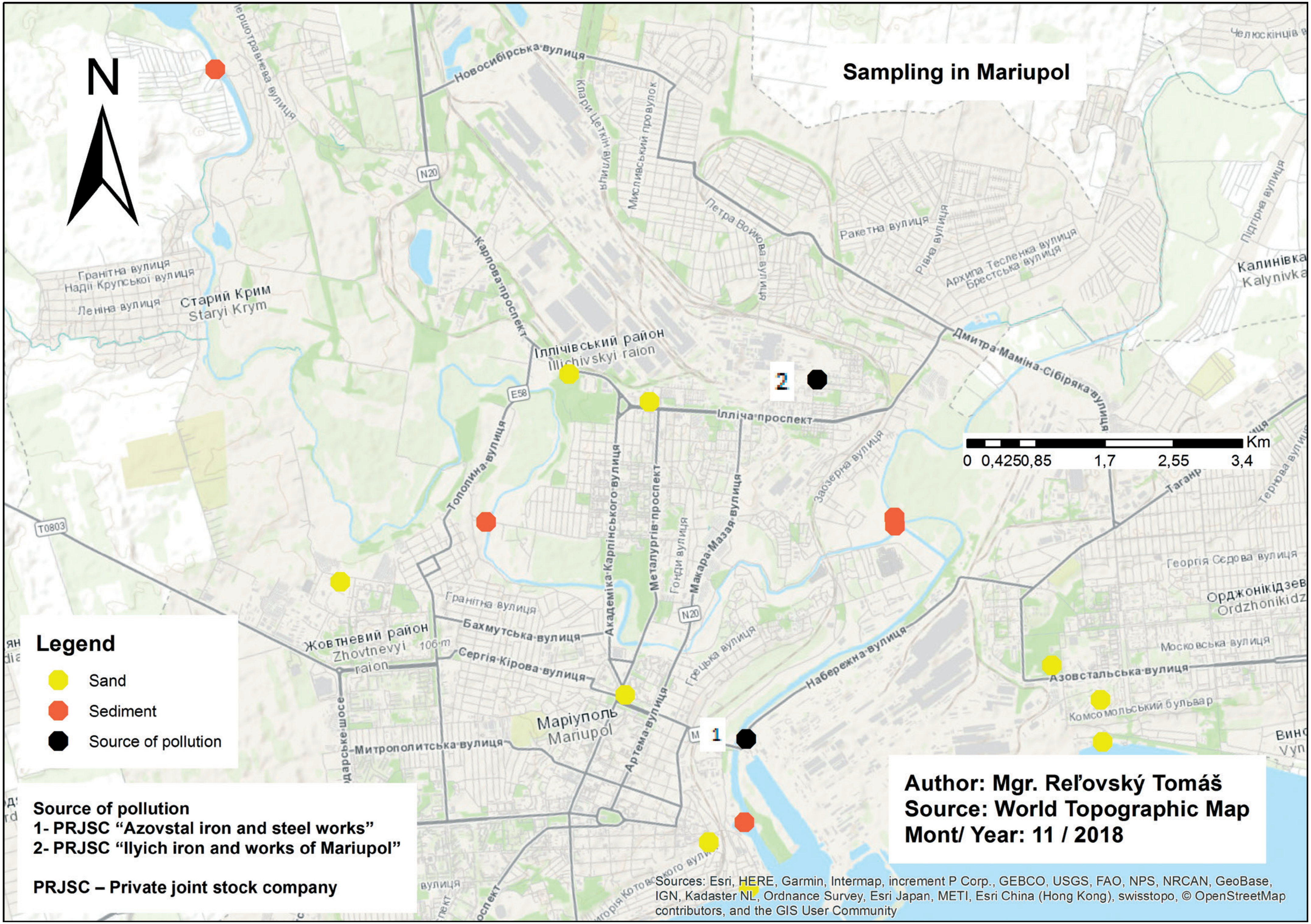
Zaporizhia is a city in south-eastern Ukraine, situated on the banks of the Dnipro River. It is the administrative centre of the Zaporizhia Region. The city's population is the sixth largest in Ukraine, at 743,113. A lot of industrial plants are concentrated almost in the centre of the city.

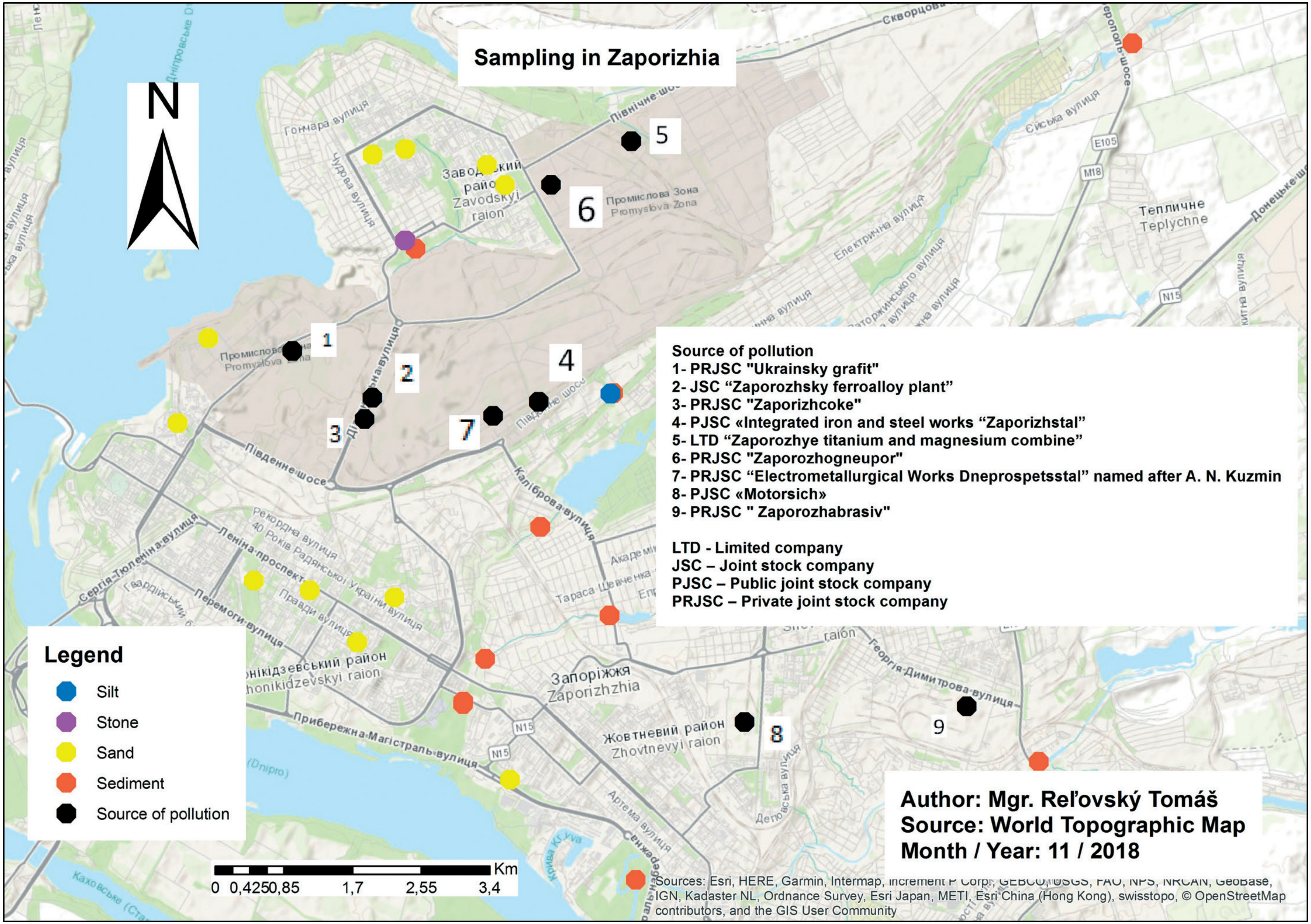
Zaporizhia has been one of the largest industrial centres of Ukraine since the beginning of the Soviet Union. Thanks to the available reserves of coal, iron ore, and manganese, engineering, heavy industry, metallurgy, the chemical industry, automobile production, and aircraft engines are concentrated here. A graphite producer, the PJSC Ukrainsky Grafit, was founded in 1933. The JSC Zaporozhsky Ferroalloy Plant was constructed in 1931 and produces various ferroalloys: ferrosilicomanganese, ferrosilicon, ferromanganese, and manganese metal. Zaporozhkoks is one of the largest coke chemical plants in Ukraine, constructed in 1934. In August 1997 Zaporozhkoks was included in the list of enterprises of strategic importance for the economy and security of Ukraine. PrJSC Dneprospetsstal is a manufacturer of special stainless steel, founded as a state-run enterprise in 1932. Now it is a publicly traded company which manufactures and sells metal products made of stainless, tool, high-speed, bearing, structural, alloyed, and carbon steel grades. PC Zaporozhye Metallurgical Plant Zaporizhstal is Ukraine's fourth-largest steelmaker, and was constructed in 1933. In 2015, the company produced 3.81 million tonnes of cast iron, 3.98 million tonnes of steel, and 3.35 million tonnes of rolled steel. Zaporizhya Titanium-Magnesium Combine LLC is a company founded in 1935 under the name Dneprovsky Magnesium Plant and was the first industrial producer of magnesium in the USSR. Nowadays it is the only manufacturer of sponge titanium in Europe. The main products of the plant are sponge titanium, purified titanium tetrachloride, shaped titanium castings, titanium ingots, ferrotitanium, and titanium slag.

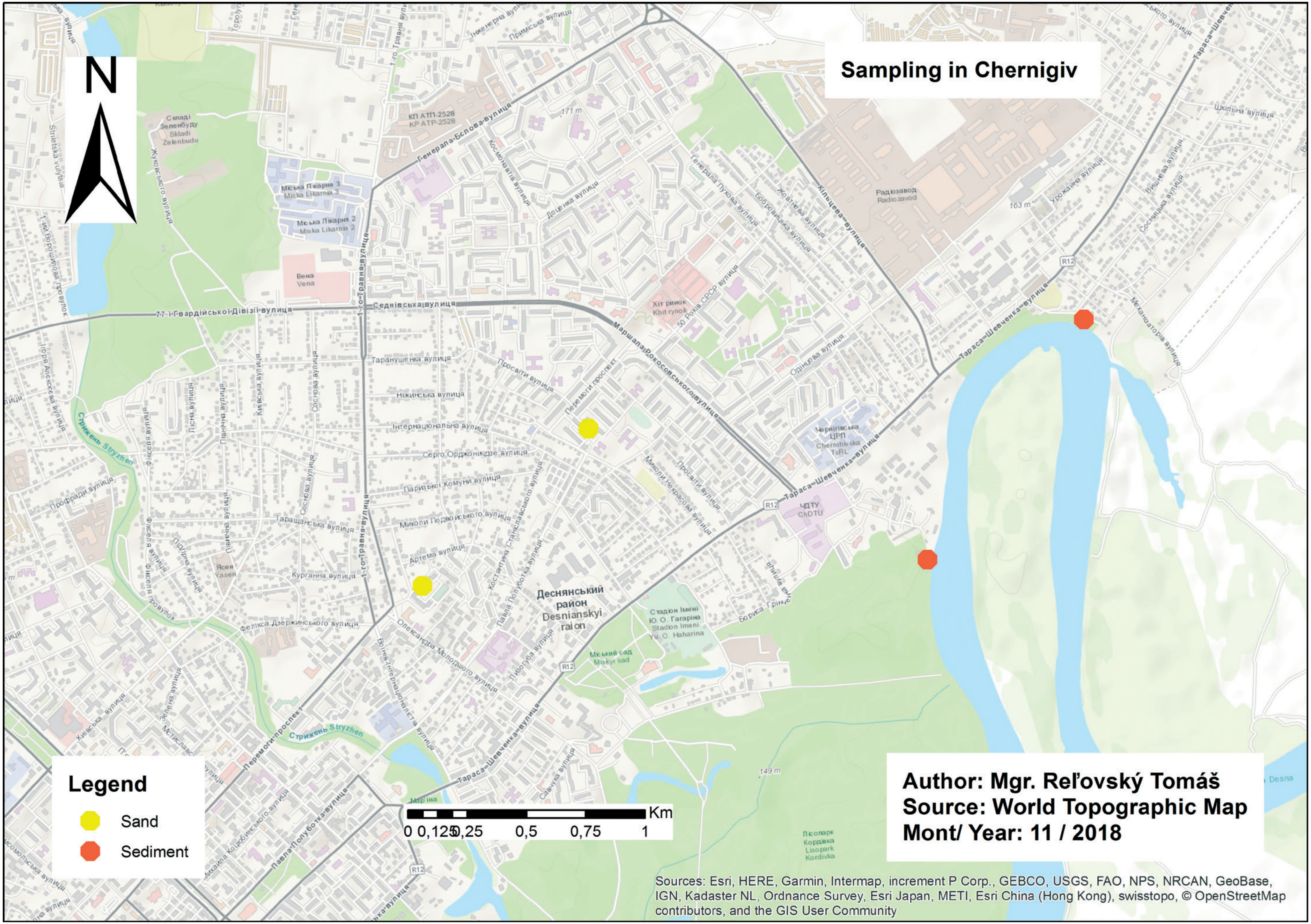
2.6 Chernihiv – background locality

Chernihiv is a historic city in northern Ukraine, which serves as the administrative centre of the Chernihiv Region. The population of the city is 294,727 inhabitants. Chernihiv occupies 79 square kilometres. Numerous ancient monuments dating back to the 11th-12th centuries are concentrated in the historical part of the city. This makes Chernihiv a popular tourist destination. Chernihiv is only affected in a small way by heavy industry, and therefore it was chosen for the background sampling of children's playground and river sediments.

However, there are a number of factors that might negatively affect the environment of the city and should be mentioned. The city


Sampling in Mariupol
N
Legend
Sand
Sediment
Source of pollution
Km
0 0,4250,85 1,7 2,55 3,4
1
2
Source of pollution
1- PRJSC “Azovstal iron and steel works”
2- PRJSC “Ilyich iron and works of Mariupol”
PRJSC – Private joint stock company
Author: Mgr. Reľovský Tomáš
Source: World Topographic Map
Mont/ Year: 11 / 2018
Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, © OpenStreetMap contributors, and the GIS User Community
Маріуполь
Mariupol
Старий Крим
Staryi Krym
Іллічівський район
Illichivskyi raion
Жовтневий район
Zhovtnevyi raion
Калинівка
Kalynivka
Орджонікідзе
Ordzhonikidz
Іллічa проспект
Набережна вулиця
Азовстальська вулиця
Новосибірська вулиця
Карпова проспект
Дмитра Маміна-Сібіряка вулиця
N20
E58
T0803


Sampling in Zaporizhia
N
Source of pollution
1- PRJSC "Ukrainsky grafit"
2- JSC “Zaporozhsky ferroalloy plant”
3- PRJSC "Zaporizhcoke"
4- PJSC «Integrated iron and steel works “Zaporizhstal”
5- LTD “Zaporozhye titanium and magnesium combine”
6- PRJSC "Zaporozhogneupor"
7- PRJSC “Electrometallurgical Works Dneprospetsstal” named after A. N. Kuzmin
8- PJSC «Motorsich»
9- PRJSC " Zaporozhabrasiv"
LTD - Limited company
JSC – Joint stock company
PJSC – Public joint stock company
PRJSC – Private joint stock company
Legend
Silt
Stone
Sand
Sediment
Source of pollution
Km
0 0,4250,85 1,7 2,55 3,4
Author: Mgr. Reľovský Tomáš
Source: World Topographic Map
Month / Year: 11 / 2018
Запоріжжя
Zaporizhzhia
Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, © OpenStreetMap contributors, and the GIS User Community


Sampling in Chernigiv
N
Legend
Sand
Sediment
0 0,1250,25 0,5 0,75 1
Km
Author: Mgr. Reľovský Tomáš
Source: World Topographic Map
Mont/ Year: 11 / 2018
Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), swisstopo, © OpenStreetMap contributors, and the GIS User Community
Деснянський район
Desnianskyi raion

is negatively affected by emissions from car traffic and industries. The largest stationary pollutant in the atmosphere of the city is the Chernihiv Thermal Power Station, owned by the TechNova Company. Other possible sources of pollution are the PJSC Chernihiv Automotive Plant, Chernigov Chemical Fibre Plant, and other industrial plants. The leading sectors of the industrial sector of Chernihiv are the chemical industry, light industry, food, building materials, and woodworking.

3. Sampling procedures and analytical methods

Samples of sediments and sand were taken as mixed samples formed of several partial samples taken in various places in the given location. The samples were taken by means of a trowel into polyethylene containers (V = 500 ml or V = 250 ml) with screwed-on lids. Mixed samples were homogenised in a steel bowl, and some of them were quartered after homogenisation. During the soil sampling, the sampling trowel and core sampler were washed with tap water or with available river or lake water. The samples were stored in a cold and dark environment before analysis.

The analytical procedures for the samples of soils and sediments were as follows: after transport to the laboratory, the samples were homogenised and a representative part (50 g) was used for the determination of dry matter by a gravimetric method. Another representative part was taken for analysis of heavy metals by means of a mineralisation procedure. The analytical procedure used for the mineralisation was as follows: 5 g of the sample was placed into a beaker together with 40 ml of distilled water and 10 ml of concentrated acid (hydrochloric acid : nitric acid = 3 : 1). The sample was boiled for a period of two hours. Then it was filtered through a fluted filter paper. Metals were determined in the mineralisation procedure by means of a Microwave Plasma Atomic Emission Spectrometer (Agilent Technologies). Mercury was measured directly in solid samples by means of an Advanced Mercury Analyser (AMA 254, Altec). Water samples were measured by means of a Microwave Plasma Atomic Emission Spectrometer (Agilent Technologies). The analysis was conducted at the University of Chemistry and Technology in Prague.

Organic pollutants were determined using extraction methods. 5 g of the sample was placed, together with 10 ml of hexane and acetone mixture (95% hexane, 5% acetone), into an extraction bottle, and extracted in an ultrasound water bath for a period of 15 minutes. Subsequently, the extract was analysed by means of gas chromatography. GC ECD Hewlett Packard 5890 was used for the determination of organochlorine pesticides, GC MS Focus DQ/DCS (Thermo Corporation) was used for the determination of petroleum hydrocarbons. Aromatic hydrocarbons were determined as follows: 5 g of the sample was placed, together with 10 ml of heptane, into an extraction bottle, and extracted in an ultrasound water bath for a period of 15 minutes. Subsequently, the extract was analysed by means of gas chromatography using GC MS ISQ (Thermo Corporation). The analysis was conducted at the University of Chemistry and Technology in Prague.

Kharkiv

Kharkiv

Kriviyi Rih

Dnipro

Mariupol

Zaporizhia


Sampling in Chernihiv


Sampling in Kriviyi Rih

Sampling in Chernihiv


Dnipro

Mariupol

Zaporizhia

Zaporizhia

4. Results

The results of the analytical measurement of heavy metals, petroleum and aromatic hydrocarbons, and organochlorine pesticides are presented in Tables 9, 10, and 11 in Annex II.

5. Discussion

Various legal standards and auxiliary evaluation criteria are presented in this chapter. Then the pollutant concentrations determined in samples from the sites that were investigated are compared to the respective legal standards. Finally, target samples with a high content of metals were chosen for calculation of the carcinogenic and non-carcinogenic risks associated with them.

5.1 Legal standards

The pollutant concentrations determined in the samples from the sites that were investigated were compared to the maximum or approximate allowed concentrations of these pollutants as defined in decrees, norms, and laws. The pollution criteria of heavy metals, petroleum and aromatic hydrocarbons, and organochlorine pesticides for sediments and soils are presented in Tables 1, 2, and 3, respectively.

In Ukraine, the values of the maximal permissible concentrations (MPCs) of pollutants are used to assess the level of environmental safety of natural objects. The MPC indicator is understood as showing the maximum concentration of the soil-polluting substance which does not cause a negative direct or indirect influence on the environment and human health. Currently, Ukraine is actively reforming the regulatory policy system and normalising the negative impact on the environment.

At the moment, in Ukraine, there are no direct values for the MPCs of pollutants in the bottom sediments, muds, and sediments of bodies of water. In the practice of normative ecological assessment of these natural objects, the MPC of pollutants in similar environmental component such as soils or sewage sludge is used. For this purpose allowable concentrations of pollutants in sewage sludge that can be used as fertiliser could be used. These levels establish the MPCs of heavy metals for the use of sewage sludge as fertilisers and can be used for the ecological assessment of the state of the bottom sediments of reservoirs (adopting the analogy of environmental components).

For a long time, the MPCs established by norms developed in the USSR were used for the ecological and sanitary evaluation of soils on populated areas in Ukraine. In early 2016, the Cabinet of Ministers of Ukraine suspended the environmental and sanitary standards that were developed in the USSR on the territory of Ukraine. Thus, at the moment there are no norms in Ukraine that directly establish the MPCs of pollutants in soils in populated areas, as well as the bottom sediments of water bodies.

In practice, there is a normative document called "Hygienic requirements for the management of industrial wastes and the definition of their hazard class for public health" applied to the protection of soils in populated areas. This norm uses the same values of MPCs for measured heavy metals as the previous regulation developed in the USSR. It should be noted that the legal status of this normative document is not currently defined because of a decision of the State Regulatory Administration. Despite this legal formality, the MPC values of this normative document were used for the evaluation of sand samples from children playgrounds. For the purpose of comparison, the values of specific MPCs of agricultural soils according to the National Standard of Ukraine called: "Wastewater. Requirements for wastewater and its precipitation for irrigation and fertilisation" are also presented.

The concentrations of pollutants in the sediment samples were also compared with Regional Screening Levels (RSL). These levels were derived using exposure parameters and factors representing the maximum justifiable chronic exposure. This exposure is based on direct contact with the target compounds. Regional screening levels were derived by the United States Environmental Protection Agency (US EPA) for some compounds, which have a CAS registration number. RSLs are the concentrations of chemical compounds in the environment (soils, sediments, water, or air). If the RSLs are exceeded, further exploration or removal of contamination should be carried out. Some specific features are taken into account when RSLs are used, such as the content of some substances as a result of geological conditions.

If sediments are intended for use on agricultural land (e.g. after the dredging of a pond or river bed), the concentration of pollutants in sediments can be compared with the limits in Czech Decree no. 257/2009 for the use of sediments on agricultural soils. This decree defines the maximum possible concentrations of hazardous metals in sediments in this case.

The concentrations of pollutants in sand samples collected in children's playgrounds were also compared with the Czech hygienic limits for sand in playgrounds established by Czech Edict no. 238/2011 about the Assessment of Hygienic Criteria for Swimming Pools, Saunas and Hygienic Limits for Sand in Outdoor Children's Playgrounds. This decree defines the maximum possible concentrations of hazardous metals in sand from children's playgrounds.

Table 1: Legal standards for heavy metals in soils and sediments.

	Zn [mg/kg DW]	Cd [mg/kg DW]	Cu [mg/kg DW]	Ni [mg/kg DW]	Pb [mg/kg DW]	Cr[1] [mg/kg DW]	As [mg/kg DW]	Hg [mg/kg DW]
Ukrainian allowable concentrations of sewage sludge used as fertiliser[2]	2 500	30	1500	200	750	–	–	15
Ukrainian maximum allowable concentrations in soils of populated areas[3]	23	–	3	4	32	6	2	2.1
Ukrainian maximum allowable concentrations in agricultural soils[4] [5]	300 (500)	3 (5)	100 (200)	50 (70)	100 (150)	100 (300)	–	–
Levels of pollution limits – industrial areas (based on US EPA)[6]	310,000	800	41,000	20,000	800	–	2.4	43
Levels of pollution limits – other areas (based on US EPA)[6]	23,000	70	31,000	1500	400	–	0.61	10
Czech hygienic limits for sand in playgrounds[7]	150	0.5	100	60	60	100	10	0.3
Czech limit levels for use of sediments on agricultural soils[8]	300	1	100	80	100	200	30	0.8

1) Cr means total concentration of chromium.
2) Annex 3 "Allowable concentrations of heavy metals in sewage sludge used as fertilizer", Rules for sewage intake to centralized sewage systems, Order of the Ministry of Regional Development, Construction and Housing and Utilities of Ukraine dated January 1, 2017 No. 316
3) Sanitary Norms and Rules 2.2.7.029-99 "Hygienic requirements for the management of industrial waste and the definition of the class of their hazard to the health of the population", the decision of the Chief State Sanitary Doctor of Ukraine No. 29 of 01.07.99 p.
4) National Standards of Ukraine 7369: 2013 "Sewage. Standards for sewage and its sediments for irrigation and fertilization», put into effect by the order of the Ministry of Economic Development and Trade of Ukraine dated 22.0.2013 under No. 1010
5) The values are for forest-steppe soils and those in parentheses are the values for steppe soils.
6) Methodological instruction of the Czech Ministry of Environmental Affairs: Indicators of contamination 2013.
7) Czech Edict no. 238/2011 about Assessment of Hygienic Criteria for Swimming Pools, Saunas and Hygienic Limits for Sand in Outdoor Children's Playgrounds.
8) Czech Edict no. 257/2009 about Sediment Usage on Agricultural Soils.

Table 2: Legal standards for petroleum hydrocarbons and polycyclic aromatic hydrocarbons in soils and sediments.

	Maximum allowable concentrations in soils of populated areas[2)]	Levels of pollution limits – industrial areas (based on US EPA)[3)]	Levels of pollution limits – other areas (based on US EPA)[3)]	Czech limit levels for use of sediments on agricultural soils[4)]
Petroleum hydrocarbons (C10 – C40) [mg/kg DW]	–	1500	500	300
Acenaphthene [mg/kg DW]	–	33000	3400	–
Anthracene [mg/kg DW]	–	170	17	–
Benz[a]anthracene [mg/kg DW]	–	2.1	0.15	–
Benzo[a]pyrene [mg/kg DW]	0.02	0.21	0.015	–
Benzo[b]fluoranthene [mg/kg DW]	–	2.1	0.15	–
Benzo[k]fluoranthene [mg/kg DW]	–	21	1.5	–
Dibenz[a,h]anthracene [mg/kg DW]	–	0.21	0.015	–
Fluorene [mg/kg DW]	–	22	2300	–
Fluoranthene [mg/kg DW]	–	22	2300	–
Chrysene [mg/kg DW]	–	210	15	–
Indeno[1,2,3-cd]pyrene [mg/kg DW]	–	2.1	0.15	–
Naphthalene [mg/kg DW]	–	18	3.6	–
Pyrene [mg/kg DW]	–	17	1700	–
Σ 12 PAHs[1)] [mg/kg DW]	–	–	–	6

1) Σ 12 PAHs means the sum of anthracene, benz[a]anthracene, benzo[b]fluoranthene, benzo[k]fluoranthene, benzo[a]pyrene, benzo[ghi]perylene, phenanthrene, fluoranthene, chrysene, indeno[1,2,3-cd]pyrene, naphthalene, and pyrene.

2) ДСанПіН 2.2.7.029-99 «Гігієнічні вимоги щодо поводження з промисловими відходами та визначення їх класу небезпеки для здоров'я населення», постанова Головного державного санітарного лікаря України №29 від 01.07.99 р.

3) Methodological instruction of the Czech Ministry of Environmental Affairs: Indicators of contamination 2013.

4) Czech Edict no. 257/2009 about Sediment Usage on Agricultural Soils

Table 3: Legal standards for organochlorine pesticides in soils and sediments.

	HCB [μg/kg DW]	α–HCH [μg/kg DW]	β–HCH [μg/kg DW]	γ–HCH [μg/kg DW]	δ–HCH [μg/kg DW]	heptachlor [μg/kg DW]	Σ DDT[1] [μg/kg DW]	DDD[2] [μg/kg DW]	DDE[3] [μg/kg DW]	DDT[4] [μg/kg DW]	metoxychlor [μg/kg DW]
Levels of pollution limits – industrial areas (based on US EPA)[5]	1100	270	960	2100	–	380	–	7200	5100	7000	3 100 000
Levels of pollution limits – other areas (based on US EPA)[5]	300	77	270	520	–	110	–	2000	1400	1700	310 000
Czech limit levels for use of sediments on agricultural soils[6]	–	–	–	–	–	–	100	–	–	–	–

1) Σ DDT means the sum of DDT and its metabolites.
2) DDD means the sum of 2,4'DDD and 4,4'DDD.
3) DDE means the sum of 2,4'DDE and 4,4'DDE.
4) DDT means the sum of 2,4'DDT and 4,4'DDT.
5) Methodological instruction of the Czech Ministry of Environmental Affairs: Indicators of contamination 2013.
6) Czech Edict no. 257/2009 about Sediment Usage on Agricultural Soils

5.2 Evaluation of heavy metal levels

The main objective of the research was to determine the concentration of heavy metals, petroleum and polycyclic aromatic hydrocarbons, and organochlorine pesticides in various samples taken at selected locations in the Ukrainian cities and compare the measured data with legal standards and limits and with concentrations shown in other studies.

Background levels

The general values for the average total **zinc** contents in soils of different groups, all over the world, range between 60 and 89 mg/kg. Contents of zinc are closely associated with soil texture and are usually lowest in light sandy soil. An elevated concentration is often observed in calcareous and organic soils. The average background concentration of zinc in the sediment samples (94 mg/kg DW) from Chernihiv is a little higher than the range of worldwide averages mentioned above and the background average in the sand samples (77 mg/kg DW) is in the range of these worldwide averages.

The world average soil **cadmium** concentration is estimated as 0.41 mg/kg. The main factor determining the cadmium contents of soils is parent material. The average contents of cadmium in soils lie between 0.2 and 1.1 mg/kg. Surface soils from major agricultural production areas of the United States contain cadmium within the range of <0.01 to 2.0 mg/kg (geometric mean 0.175). The cadmium content in reference soils from different countries ranges from 0.06 to 4.3 mg/kg. Soils from Sichote-Alin (remote region of Russia) contain cadmium from 0.2 to 1.14 mg/kg, with the greatest concentration in flooded soils. Relatively high cadmium contents, up to 8.9 mg/kg (on average 0.3 mg/kg), are reported for some topsoils in the Slovak Republic. The background concentrations of cadmium in the sediment and sand samples (0.1 mg/kg DW and lower for both) from Chernihiv are lower than the worldwide average and in the worldwide ranges mentioned above.

The general values for the average total **copper** contents in soils of different groups all over the world range between 14 and 109 mg/kg. Contents of copper are closely associated with soil texture and are usually lowest in light sandy soils and highest in loamy soils. The average background concentrations of copper in the sediment (10.2 mg/kg DW) and sand (11.2 mg/kg DW) samples from Chernihiv are lower than the averages mentioned above.

Soils throughout the world contain **nickel** in a very broad range. This means that concentrations as reported for various countries are within the range 13–37 mg/kg. The average background concentrations of nickel in the sediment (1.8 mg/kg DW) and sand (3.3 mg/kg DW) samples from Chernihiv are lower than the worldwide range mentioned above.

The overall mean value of total **lead** for different soils is estimated as 27 mg/kg. The background average contents given for soils in different countries vary from 18 mg/kg in Sweden to 27 mg/kg in China. The average background concentrations of lead in the sediment (6.6 mg/kg DW) and sand (7 mg/kg DW) samples from Chernihiv are lower than the averages mentioned above.

The world average content of **chromium** in soils has been established as 60 mg/kg. The average background concentrations of chromium in the sediment (3.5 mg/kg DW) and sand (7.4 mg/kg DW) samples from Chernihiv are lower than the worldwide average mentioned above.

The overall mean value of the total **arsenic** for different soils is estimated as 6.83 mg/kg. The background contents of various soil groups range from <0.1 to 67 mg/kg. The range in arsenic in soils in the United States is broad, from <0.1 to 93 mg/kg, and the geometric mean for arsenic in topsoils in the United States is reported to be 5.8 mg/kg. An arsenic content of 9.7 mg/kg is reported for surficial materials in Alaska and an arsenic range of 4–15 mg/kg in uncontaminated soils in Canada. The background value in Slovakia is given as 7.2 mg/kg. The range of arsenic in soils in Poland is 0.9–3.4 mg/kg. Western Siberian soil has an arsenic content from 18 to 32 mg/kg. The average background concentrations of arsenic in the sediment (lower than 2 mg/kg DW) and sand (3.8 mg/kg DW) samples from Chernihiv are lower than the worldwide average and in the ranges mentioned above. Most of our sediment and sand samples, including the background samples, exceeded US EPA levels of pollution limits of industrial areas for arsenic. This fact is probably not caused by industrial pollution but as result of its release from the bedrock.

The background levels of **mercury** in soils are not easy to estimate because of the widespread mercury pollution. Data reported for various soils on a worldwide basis shows that mean concentrations of mercury in surface soils do not exceed 1.5 mg/kg. Most topsoils contain increased amounts of mercury, especially near mining and smelting areas. Generally, the range of mercury in soils is usually between 0.004 to 0.3 mg/kg. The average mercury concentration of background sand samples from Chernihiv (0.012 mg/kg DW) is in the worldwide range mentioned above.

Kharkiv

The levels of heavy metals in sediments are generally increased in the city of Kharkiv. In comparison with the background levels mentioned above, there are increased concentrations of zinc and cadmium in almost all of our sediment samples and of copper, lead, chromium, arsenic, and mercury in at least a few sediment samples. The most widespread heavy metal in the sediments of the hot spot area is cadmium. The concentrations of cadmium in all six sediment samples exceeded Czech limit levels for the use of sediments on agricultural soils and three of them also the Ukrainian maximum permissible concentrations in agricultural soils. The concentrations of zinc in four of the six sediment samples exceeded the Czech limit levels for the use of sediments on agricultural soils. Two samples (KH-S-2 and KH-S-3) also exceeded the Czech limit levels for the use of sediments on agricultural soils and the Ukrainian maximum permissible concentrations in agricultural soils for copper and chromium.

The concentrations of heavy metals in sand samples from children's playgrounds in the city of Kharkiv do not significantly exceed background levels. All the sand samples collected in the city of Kharkiv were in compliance with the Czech hygienic limits for sand in playgrounds.

Dnipro

Four sediment samples in the city of Dnipro have increased levels of several heavy metals. In comparison with the background levels mentioned above, there are increased concentrations of zinc, chromium, arsenic, and lead in at least one sediment sample. Only two sediment samples from the hot spot area exceeded the Czech limit levels for the use of sediments on agricultural soils: sample DN-S-01 for arsenic and sample DN-S-04 for chromium. The second one also exceeded the Ukrainian maximum permissible concentration of chromium in agricultural soils.

The concentrations of heavy metals in sand samples from children's playgrounds in the city of Dnipro exceed background levels in two cases. Two sand samples (DN-P-08 and DN-P-06) have elevated levels of zinc and lead. Moreover ,one of them (DN-P-08) also exceeds the Czech hygienic limits for sand in playgrounds for zinc and lead.

Kryvyi Rih

The levels of heavy metals in sediments are, in two samples, only slightly increased in the city of Kryvyi Rih. In comparison with the background levels, there are slightly increased concentrations of zinc, cadmium, and arsenic in one sediment sample (KR-N-01) and zinc and arsenic in another sediment sample (KR-S-01) from the hot spot area. All the sediment samples collected in the hot-spot area were in compliance with the Czech and Ukrainian legal standards.

The concentrations of heavy metals in sand samples from children's playgrounds in the city of Kryvyi Rih do not significantly exceed the background levels. All the sand samples collected in the hot spot area were in compliance with the Czech hygienic limits for sand in playgrounds. According to local people sand on children's playgrounds is frequently replaced.

Mariupol

The levels of heavy metals in sediments are increased in five samples taken in the city of Mariupol. On the evidence of the measured data, increased levels mainly of zinc, cadmium, lead, chromium, arsenic, and mercury were found in sediment samples in the city of Mariupol. Two sediment samples in the hot spot area exceeded some legal standard. Sample MA-S-02 exceeded the Czech limit levels of zinc and cadmium for the use of sediments on agricultural soils. Sample MA-S-01 exceeded two standards for zinc: the Czech limit levels for the use of sediments on agricultural soils and the Ukrainian maximum permissible concentrations in agricultural soils.

In two samples the concentrations of heavy metals in sand from children's playgrounds in the city of Mariupol exceed the background levels. Elevated levels of zinc were found in one sample (MA-P-04) and elevated levels of arsenic in another one (MA-P-02). Moreover, both sand samples also exceed the Czech hygienic limits for sand in playgrounds for these heavy metals.

Zaporizhia

Levels of heavy metals in sediments are generally increased in the city of Zaporizhia. In comparison with the background levels, there are increased concentrations of zinc, cadmium, lead, chromium, and arsenic in many of our sediment samples and of copper, nickel, and mercury in at least one sediment sample. The most widespread heavy metal in the sediments of the hot spot area is cadmium. The concentrations of cadmium in five out of eleven sediment samples exceeded the Czech limit levels for the use of sediments on agricultural soils and two of them also the Ukrainian maximum permissible concentrations in agricultural soils. The concentrations of zinc in three out of eleven sediment samples exceeded the Czech limit levels for the use of sediments on agricultural soils and the Ukrainian maximum permissible concentrations in agricultural soils. Two sediment samples exceeded the Czech limit levels for lead for the use of sediments on agricultural soils. The lead concentration (767.3 mg/kg DW) in the sample ZA-S-06 was even higher than the Ukrainian allowable concentrations of sewage sludge used as fertiliser, the Ukrainian maximum permissible concentrations in agricultural soils, and the US EPA level of the pollution limit for non-industrial areas. The levels of copper in two sediment samples exceeded theCzech limit levels for the use of sediments on agricultural soils. The most polluted sample (ZA-S-06) was not in compliance with the legal standards for six heavy metals (cadmium, zinc, lead, copper, nickel, and chromium).

The concentrations of heavy metals in sand samples from children's playgrounds in the city of Zaporizhia do not significantly exceed background levels. All the sand samples collected in the hot spot area were in compliance with the Czech hygienic limits for sand in playgrounds.

Table 4: Number of samples from each hotspot area that exceed the Czech limit levels for the use of sediments on agricultural soils in the case of sediment samples or the Czech hygiene limits for sand in playgrounds in the case of sand samples. The proportions of these samples from the number of sediment or sand samples from each hotspot area are expressed in brackets.

	Kharkiv	Dnipro	Kryvyi Rih	Mariupol	Zaporizhia
Sediment	6 (100%)	2 (33.3%)	0 (0%)	2 (40%)	6 (54.5%)
Sand	0 (0%)	1 (8.3%)	0 (0%)	2 (33.3%)	0 (0%)

5.3 Evaluation of petroleum hydrocarbons, polycyclic aromatic hydrocarbons, and organochlorine pesticides

There is widespread pollution with petroleum hydrocarbons in the hot spot areas. The concentrations of petroleum hydrocarbons (C10 – C40) were measured in thirty sediment samples and one sand sample collected in the five hot spot areas. Twelve sediment samples exceed the Czech limit level (300 mg/kg DW) for the use of sediments on agricultural soils and the same samples are also higher than the level of the pollution limit set by the US EPA for non-industrial areas (500 mg/kg DW). Moreover, eight of these samples also exceeded the level of the pollution limit set by the US EPA for industrial areas (1500 mg/kg), with the highest value, 7 740 mg/kg DW (sample ZA-S-07), being found in the city of Zaporizhia. The most extensive pollution was found in the cities of Kharkiv and Zaporizhia. All five sediment samples collected in the Kharkiv hot spot area and four out of nine sediment samples taken in the city of Zaporizhia exceeded at least the level of the pollution limit set by the US EPA for non-industrial areas. On the evidence of the measured data, high levels of petroleum hydrocarbons were found in sediments collected in the hot spot areas.

Levels of polycyclic aromatic hydrocarbons (PAHs) were generally low in the sediment samples from the hot spot areas. Concentrations of polycyclic aromatic hydrocarbons were measured in twenty-nine sediment samples and in one sand sample from five hot spot areas. All thirty samples have lower levels of these contaminants than the legal standards listed in Table 2.

There are residues of DDT in some sediment samples from the hot spot areas. Concentrations of organochlorine pesticides were measured in eight sediment samples and in fourteen sand samples from five hot spot areas. The only organochlorine pesticide that was detected in the samples is DDT and its residues. One sediment sample from the city of Kharkiv and four sand samples from the Dnipro hot spot area have detectable levels of DDT. Unfortunately, no maximum allowable limit of DDTs in sand from children's playgrounds exists, but if we compare our results with the Czech limit level for the use of sediments on agricultural soils (100 µg/kg DW), one sand sample from the city of Dnipro (DN-P-08) exceeds this value. On the evidence of the measured data, there is some DDT pollution persisting in the hot spot areas.

5.4 Health risk assessment

The health risk assessment is based on the assumption that under certain specified conditions there is a risk of damage to human health, while the risk rate from zero to maximum is determined by the type of activity, length of stay in the location, and the environmental conditions. A zero health risk is not really possible; however, the risk of damage must be minimised to an acceptable level in terms of health and environmental risks. To determine the risk, it is necessary to clarify the most important transport routes and then specify exposure scenarios for potentially threatened recipients. There are two approaches to the evaluation of the dose effects – for substances with a threshold (non-carcinogenic) and non-threshold (carcinogenic) effect.

For substances with a non-carcinogenic effect it is anticipated that the body repair processes are able to cope successfully with exposure to a toxic substance, but only up to a certain dose, and then the effect is already apparent. The threshold, known as NOAEL (No Observed Adverse Effect Level), is the exposure level at which no adverse effects are observed. Alternatively, LOAEL (Lowest Observed Adverse Effect Level) values can be used. They correspond to the lowest dose levels at which negative health effects are observed. ADI (Acceptable Daily Intake) and RfD (Reference Dose) are derived using NOAEL or LOAEL values and the relevant UF (Uncertainty Factors) or MF (Modifying Factors). These factors have to compensate for all the uncertainty and variability in determining the NOAEL or LOAEL values. The results of calculation (ADI or RfD) are usually much lower than NOAEL or LOAEL and represent the estimation of the daily exposure of the human population (including sensitive population groups) which is very likely to pose no risk of adverse effects to human health, even if it lasts throughout a lifetime. In the case of carcinogenic substances, it is assumed that there is no such thing as a dose that would not cause modifications at the molecular level and subsequently lead to the development of malignant disease. Evaluation of the dose-effect relation uses the SF (Slope Factor) parameter , which indicates the possible top edge of the probability of malignant disease per unit of average daily dose received throughout a lifetime.

For the calculation of risk exposure to substances with a non-carcinogenic effect a received and absorbed dose with acceptable toxicological intake of the substance is compared (i.e. RfD – Reference Dose). The risk level then represents the Hazard Quotient (HQ). The calculation is performed according to the equation:

$$HQ = \frac{E}{RfD}$$

E – parameter Average Daily Dose (ADD) or Lifetime Average Daily Dose (LADD), or Chronic Daily Intake (CDI) (mg/kg.day);
RfD – Reference Dose (mg/kg.day).

The calculation method for substances with a carcinogenic effect uses the ELCR – Excess Lifetime Cancer Risk parameter (a dimensionless indicator corresponding to the probability of developing cancer with lifetime exposure, which can be described by the following equation):

$ELCR = CDI \cdot SF$ $ELCR = LADD \cdot SF$

CDI – parameter Chronic Daily Intake, or Lifetime Average Daily Dose (LADD) relative to lifetime exposure over 70 years (mg/kg. day);
SF – Slope Factor (mg/kg.day).

Table 5: Agents classified by the IARC monographs.

The International Agency for Research on Cancer (IARC) recognises:

Group 1	Carcinogenic to humans	arsenic and inorganic arsenic compounds
Group 2A	Probably carcinogenic to humans	inorganic compounds of lead
Group 2B	Possibly carcinogenic to humans	lead
Group 3	Not classifiable regarding its carcinogenicity to humans	organic compounds of lead
Group 4	Probably not carcinogenic to humans	

5.5 RISC model

Risk-Integrated Software for Cleanups (RISC) is a software package developed to assess human health risks in contaminated areas. It can integrate up to fourteen possible exposure pathways, and calculates the risks associated with them, both carcinogenic and non-carcinogenic.

If the carcinogenic risk (ELCR) is $<10^{-6}$, it is considered that there are no significant adverse health effects. If it is between 10^{-6} and 10^{-4}, adverse effects may occur in the future, and thus factors need to be taken into consideration. Finally, if it is $>10^{-4}$, the risk is unacceptable and serious measures must be taken immediately . A hazard quotient (HQ) <1 considers that there are no significant adverse health effects, whereas a HQ >1 implies that potential adverse health effects exist. More research must be done in order to determine any toxic threats. The results are based on standard calculation coefficients defined in Risk-Integrated Software for Cleanups (RISC). The results are related to the average population.

Samples collected in the hot spot areas were used to perform a human health risk assessment. On the basis of the toxicological data, a risk assessment using the RISC software was performed for five heavy metals: arsenic, mercury, cadmium, nickel, and lead. Samples with results of the calculation of human health risks which exceeded 10^{-6} for ELCR and 1 for HQ for children or adults are presented in Tables 6 and 7.

Table 6: Results of the calculation of carcinogenic human health risks (ELCR) associated with arsenic in the hotspot areas in Ukraine. ELCR values exceeding 10^{-6} are in bold. Only samples with ELCR values exceeding 10^{-6} are listed in the table.

Hot spot area	Sample	Concentration [mg/kg]	ELCR for adults				ELCR for children			
			Exposition pathway				Exposition pathway			
			Ingestion of soil	Dermal contact of soil	Ingestion of vegetables	Total	Ingestion of soil	Dermal contact of soil	Ingestion of vegetables	Total
Kharkiv	KH-S-02	12,5	1,5E-07	4,6E-08	4,3E-06	4,4E-06	3,4E-06	2,0E-07	6,4E-06	**1,0E-05**
	KH-S-03	15,1	1,8E-07	5,6E-08	5,1E-06	5,4E-06	4,1E-06	2,4E-07	7,7E-06	**1,2E-05**
Dnipro	DN-S-01	36,2	4,3E-07	1,3E-07	**1,2E-05**	**1,3E-05**	9,8E-06	5,8E-07	**1,8E-05**	**2,9E-05**
Mariupol	MA-S-01	13,7	1,6E-07	5,1E-08	4,7E-06	4,9E-06	3,7E-06	2,2E-07	7,0E-06	**1,1E-05**
	MA-S-02	18,1	2,2E-07	6,7E-08	6,2E-06	6,4E-06	4,9E-06	2,9E-07	9,2E-06	**1,4E-05**
Zaporizhia	ZA-S-06	21,8	2,6E-07	8,1E-08	7,4E-06	7,8E-06	5,9E-06	3,5E-07	**1,1E-05**	**1,7E-05**

Table 7: Results of the calculation of non-carcinogenic human health risks (HQ) associated with cadmium in the hotspot areas in Ukraine. HQ values exceeding 1 are in bold. Only samples with ELCR values exceeding 10^{-6} are listed in the table.

Hot spot area	Sample	Concentration [mg/kg]	HQ for children			
			Exposition pathway			
			Ingestion of soil	Dermal contact with soil	Ingestion of vegetables	Total
Kharkiv	KH-S-02	9.1	3,9E-02	5,8E-05	**1,0E+00**	**1,0E+00**
	KH-S-03	9.1	3,9E-02	5,8E-05	**1,0E+00**	**1,0E+00**
Zaporizhia	ZA-S-06	13.4	5,8E-02	8,6E-05	**1,5E+00**	**1,5E+00**

The carcinogenic and non-carcinogenic risks from arsenic for local residents via several exposure pathways were evaluated for all the hot spot areas. This evaluation included assessing exposure to arsenic by ingestion of soil (including dust ingestion), dermal contact, and the consumption of crops (vegetables). The total Excess Lifetime Cancer Risk values for arsenic are between 10^{-6} and 10^{-4} in one and six sediment samples for adults and children, respectively. These sediment samples were collected in four out of five hot spot areas: Kharkiv (samples KH-S-02 and KH-S-03), Dnipro (sample DN-S-01), Mariupol (samples MA-S-01 and MA-S-02), and Zaporizhia (sample ZA-S-06). In these cases adverse effects may occur in the future, and thus factors need to be taken into consideration at the relevant locations. The problematic exposure pathway for arsenic is the ingestion of vegetables. On the other hand, the carcinogenic risks posed by arsenic were not exceeded in any of the samples of sand from children's playgrounds. Hazard quotients (HQ) which represent non-carcinogenic risks posed by arsenic did not exceed a value of 1 in any sediment or sand sample. According to the evaluation of our samples, arsenic is the most problematic heavy metal for human health in the hot spot areas.

The non-carcinogenic risks posed by mercury, cadmium, lead, and nickel to local residents via several exposure pathways were also evaluated for sediment and soil samples collected in the hot spot areas. Unacceptable risks (HQ >1) to children posed by cadmium were identified in three sediment samples from two hot spot areas: Kharkiv (samples KH-S-02 and KH-S-03) and Zaporizhia (sample ZA-S-06). The problematic expositional pathway for cadmium is the ingestion of vegetables. These results make cadmium the second most risky heavy metal for human health in the hot spot areas. The hazard quotients for mercury, lead, and nickel did not exceed the value of one in any of the sediment and sand samples, and therefore these metals do not represent unacceptable non-carcinogenic risks.

6. Conclusions

This study focused on the monitoring and evaluation of concentrations of heavy metals, petroleum and polycyclic aromatic hydrocarbons, and organochlorine pesticides in sediments and sands from playgrounds in five industrial cities in Ukraine, where the population suffers from serious air pollution. A series of samples were taken in the hot spot areas and compared with the legal pollution criteria with the objective of examining the extent to which the pollution affects segments of the environment, and how serious it might be for human health.

Increased levels of zinc, cadmium, copper, nickel, lead, chromium, and arsenic were found in sediments in the five hot spot areas. The levels of these pollutants could represent a threat to the environment and human health. The most widespread heavy metal in the hot spot areas is cadmium, followed by zinc. The concentrations of heavy metals in multiple sediment samples exceed various legal standards, most frequently the Czech limit levels for the use of sediments on agricultural soils, but in some cases also the Ukrainian allowable concentrations of sewage sludge used as fertiliser, the Ukrainian maximum permissible concentrations in agricultural soils, and the US EPA level of the pollution limit for non-industrial areas. The sediments most polluted by heavy metals were found in the Kharkiv and Zaporizhia hot spot areas. On the other hand, the least polluted sediments are from the Kryvyi Rih hot spot area.

Generally, the sand samples from children's playgrounds in the hot spot areas are not significantly polluted by heavy metals. The concentrations of heavy metals in most of the sand samples from children's playgrounds do not significantly exceed background levels. Three heavy metal concentrations in sand samples exceeded the Czech hygienic limits for sand in playgrounds for zinc and lead. One sand sample from the city of Dnipro exceeded the Czech hygienic limits for zinc and lead in sand in playgrounds. Two sand samples from the city of Mariupol exceeded the Czech hygienic limits for sand in playgrounds for these heavy metals: one for zinc and another for lead. All the sand samples collected in the cities of Kharkiv, Kryvyi Rih, and Zaporizhia were in compliance with the Czech hygienic limits for sand in playgrounds. The authors of the study, however, did not search for information on how old the sand in playgrounds was or whether it is regularly replaced. Children's playgrounds – as places that are expected to be safe and clean – were specially selected to indicate the quality of the environment in these industrial cities. In this regard, even a relatively low level of pollution shows a potential risk for human health at the location.

There is widespread pollution with petroleum hydrocarbons in the hot spot areas. Twelve sediment samples exceed the Czech limit level of petroleum hydrocarbons for the use of sediments on agricultural soils and the same samples are also higher than the level of the pollution limit set by the US EPA for non-industrial areas. The most extensive pollution of petroleum hydrocarbons was found in the city of Kharkiv and Zaporizhia. The levels of polycyclic aromatic hydrocarbons were generally low in the sediment samples from the hot spot areas. There are DDT residues in the hot spot areas. One sediment sample from the city of Kharkiv and four sand samples from the Dnipro hot spot area have detectable levels of DDT.

Analysis using the Risk-Integrated Software for Cleanups (RISC) indicated the following results. The most risky heavy metal in the hot-spot areas was arsenic, followed by cadmium. Several samples polluted with arsenic showed that adverse carcinogenic effects may occur in the long term. Moreover, three samples polluted with cadmium exceeded the hazard quotient (HQ). Potential adverse health effects exist in this case. More research should be done in order to determine this toxic threat at the sites that were studied. The severity of the risks identified in the hot-spot areas depends on the particular use of the local site.

Unfortunately, our sampling possibilities did not cover the required extension of the necessary monitoring of heavy metals. We collected only a limited number of sediment and sand samples from huge areas of the cities and the samples were analysed for a limited number of potential pollutants; therefore, this study cannot give comprehensive evidence about the pollution situation in the cities. Moreover, there is not enough literature in reviewed scientific journals about pollution in Ukrainian cities. Therefore ongoing research and permanent monitoring should be carried out to detect the spread of possible contamination resulting in any toxic threats to human health and the environment in the future. Several possible improvements could be carried out. In some hot spot areas improvement assessment for better environmental practices is recommended, especially at metallurgical industry plants and thermal power plants, because of the pollution by heavy metals.

For proper evaluation of the pollution caused by heavy metals in sediment, soil, and sand, legally binding maximum allowable concentrations should be implemented in Ukraine. These maximum allowable concentrations should be appropriate to the natural occurence of heavy metals ("not too low") and able to detect contamination that could represent a danger for the environment and human health ("not too high").

The playgrounds in Dnipro are of particular concern because of their contamination by DDT. Contamination of playground sand ultimately requires a solution which breaks the pathway from the contamination to the child by removing surface soils from human contact. Remediation efforts for contaminated playgrounds should involved 'dig and dump' sand removal, disposal, and replacement. Moreover, the same treatment should be performed for the playgrounds in Dnipro and Mariupol where contamination by heavy metals (zinc, lead, and arsenic) was found.

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Annex I.: List of sampling sites

Table 8: List of samples taken in Ukraine.

Hot spot area	Sample code	Date of sampling	Sample type	GPS coordinates
Kharkiv	KH-S-01	18.5.2018	Sediment	49°57′15.036″N 36°13′2.238″E
	KH-S-02	18.5.2018	Sediment	49°56′36.839″N 36°12′12.746″E
	KH-S-03	18.5.2018	Sediment	49°56′48.583″N 36°12′16.654″E
	KH-S-04	18.5.2018	Sediment	49°56′49.628″N 36°12′22.594″E
	KH-S-05	18.5.2018	Sediment	49°56′3.374″N 36°12′13.807″E
	KH-N-01	18.5.2018	Sediment	49°56′48.583″N 36°12′16.659″E
	KH-P-01	18.5.2018	Sand	49°57′59.256″N 36°12′58.004″E
	KH-P-02	18.5.2018	Sand	49°57′18.503″N 36°12′44.509″E
	KH-P-03	18.5.2018	Sand	49°57′15.223″N 36°12′43.540″E
	KH-P-04	18.5.2018	Sand	49°57′20.751″N 36°12′47.051″E

Hot spot area	Sample code	Date of sampling	Sample type	GPS coordinates
Dnipro	DN-S-01	19.5.2018	Sediment	48°24′34.912″N 35°8′56.878″E
	DN-S-02	19.5.2018	Sediment	48°24′30.738″N 35°8′46.263″E
	DN-S-04	20.5.2018	Sediment	48°29′28.701″N 34°58′56.721″E
	DN-S-05	20.5.2018	Sediment	48°28′54.115″N 35°3′41.981″E
	DN-S-06	20.5.2018	Sediment	48°25′55.606″N 35°5′0.567″E
	DN-S-07	20.5.2018	Sediment	48°28′0.162″N 35°4′32.726″E
	DN-P-01	19.5.2018	Sand	48°24′16.907″N 35°7′35.480″E
	DN-P-02	19.5.2018	Sand	48°24′0.301″N 35°8′5.671″E
	DN-P-03	19.5.2018	Sand	48°24′35.090″N 35°7′51.177″E
	DN-P-04	19.5.2019	Sand	48°24′54.818″N 35°7′45.984″E
	DN-P-05	20.5.2018	Sand	48°29′15.558″N 34°56′23.425″E
	DN-P-06	20.5.2018	Sand	48°28′20.056″N 34°59′25.662″E
	DN-P-07	20.5.2018	Sand	48°28′24.848″N 35°0′24.014″E
	DN-P-08	20.5.2018	Sand	48°28′51.946″N 35°4′35.208″E
	DN-P-09	20.5.2018	Sand	48°29′19.381″N 35°8′9.732″E
	DN-P-10	20.5.2018	Sand	48°29′18.896″N 35°8′16.922″E
	DN-P-11	20.5.2019	Sand	48°25′7.695″N 35°4′1.944″E
	DN-P-12	20.5.2019	Sand	48°24′31.420″N 35°4′12.180″E

Hot spot area	Sample code	Date of sampling	Sample type	GPS coordinates
Kryvyi Rih	KR-S-01	21.5.2018	Sediment	47°46′14.817″N 33°15′24.272″E
	KR-S-02	21.5.2018	Sediment	47°42′56.131″N 33°14′45.596″E
	KR-S-03	22.5.2018	Sediment	48°3′44.025″N 33°16′27.267″E
	KR-S-04	22.5.2018	Sediment	47°58′52.327″N 33°16′23.128″E
	KR-S-05	22.5.2018	Sediment	47°53′14.944″N 33°16′31.089″E
	KR-N-01	21.5.2018	Sediment	47°46′15.822″N 33°15′24.947″E
	KR-X-01	21.5.2018	Slag	47°49′53.499″N 33°20′414″E
	KR-P-01	21.5.2018	Sand	47°54′10.040″N 33°22′55.077″E
	KR-P-02	21.5.2018	Sand	47°52′44.326″N 33°21′57.936″E
	KR-P-03	21.5.2018	Sand	47°52′46.809″N 33°21′45.550″E
	KR-P-04	21.5.2018	Sand	47°50′1.160″N 33°20′28.492″E
	KR-P-05	21.5.2018	Sand	47°54′13.844″N 33°27′33.696″E
	KR-P-06	21.5.2018	Sand	47°54′20.565″N 33°25′2.471″E

Hot spot area	Sample code	Date of sampling	Sample type	GPS coordinates
Mariupol	MA-S-01	24.5.2018	Sediment	47°5′33.233″N 37°34′16.136″E
	MA-S-02	24.5.2018	Sediment	47°7′49.841″N 37°32′17.943″E
	MA-S-03	24.5.2018	Sediment	47°11′5.570″N 37°30′23.931″E
	MA-S-04	25.5.2018	Sediment	47°7′20.441″N 37°36′12.404″E
	MA-S-05	25.5.2018	Sediment	47°7′25.002″N 37°36′12.791″E
	MA-B-01	24.5.2018	Beach Sand	47°5′7.412″N 37°34′11.226″E
	MA-B-02	24.5.2018	Beach Sand	47°5′41.667″N 37°37′50.450″E
	MA-X-01	24.5.2018	Sand-Soil	47°8′40.854″N 37°33′24.555″E
	MA-P-01	24.5.2018	Sand	47°6′31.007″N 37°33′17.840″E
	MA-P-02	24.5.2018	Sand	47°5′26.835″N 37°33′54.733″E
	MA-P-03	24.5.2018	Sand	47°5′57.824″N 37°37′51.655″E
	MA-P-04	24.5.2018	Sand	47°8′26.502″N 37°34′2.349″E
	MA-P-05	24.5.2018	Sand	47°7′35.212″N 37°30′45.350″E
	MA-P-06	25.5.2018	Sand	47°6′15.422″N 37°37′29.491″E

Hot spot area	Sample code	Date of sampling	Sample type	GPS coordinates
Zaporizhia	ZA-S-01	23.5.2018	Sediment	47°52′51.685″N 35°9′5.357″E
	ZA-S-02	23.5.2018	Sediment	47°49′49.646″N 35°8′57.989″E
	ZA-S-03	23.5.2018	Sediment	47°49′48.527″N 35°8′57.768″E
	ZA-S-04	23.5.2018	Sediment	47°50′5.515″N 35°9′13.010″E
	ZA-S-05	23.5.2018	Sediment	47°50′14.726″N 35°10′30.655″E
	ZA-S-06	23.5.2018	Sediment	47°50′54.448″N 35°9′56.04″E
	ZA-S-07	23.5.2018	Sediment	47°51′44.362″N 35°10′48.114″E
	ZA-S-08	23.5.2018	Sediment	47°53′32.047″N 35°16′22.036″E
	ZA-S-09	23.5.2018	Sediment	47°48′53.663″N 35°14′31.422″E
	ZA-S-10	23.5.2018	Sediment	47°48′25.336″N 35°10′23.403″E
	ZA-N-01	23.5.2018	Sediment	47°51′44.362″N 35°10′48.114″E
	ZA-P-01	23.5.2018	Sand	47°51′37.957″N 33°5′39.237″E
	ZA-P-02	23.5.2018	Sand	47°51′56.155″N 35°6′30.498″E
	ZA-P-03	23.5.2018	Sand	47°52′28.197″N 35°6′56.427″E
	ZA-P-04	23.5.2018	Sand	47°53′12.6″N 35°10′03.2″E
	ZA-P-05	23.5.2018	Sand	47°53′21.282″N 35°9′53.133″E
	ZA-P-06	23.5.2018	Sand	47°53′32.309″N 35°9′7.597″E
	ZA-P-07	23.5.2018	Sand	47°53′31.561″N 35°8′47.809″E
	ZA-P-08	23.5.2018	Sand	47°50′47.455″N 35°7′3.399″E
	ZA-P-09	23.5.2018	Sand	47°50′42.117″N 35°7′35.020″E
	ZA-P-10	23.5.2018	Sand	47°50′33.420″N 35°8′23.138″E
	ZA-P-11	23.5.2018	Sand	47°49′10.438″N 35°9′33.191″E

Hot spot area	Sample code	Date of sampling	Sample type	GPS coordinates
Chernihiv	CG-S-01	27.5.2018	Sediment	51°30′5.235″N 31°20′32.632″E
	CG-S-02	27.5.2018	Sediment	51°30′39.740″N 31°21′13.989″E
	CG-P-01	27.5.2018	Sand	51°30′11.502″N 31°18′43.135″E
	CG-P-02	27.5.2018	Sand	51°30′31.278″N 31°19′22.931″E

Annex II: Results

Results of the analytical measurement of heavy metals, non-polar extractable substances (organic pollutant C10 – C40), polycyclic aromatic hydrocarbons (PAHs), and organochlorine pesticides (OCPs) are presented in the tables below.

Table 9: Content of heavy metals in sediment and sand samples. The content of elements is given in mg/kg of dry matter. NA means not analysed.

Hot spot area	Sample code	Cd [mg/kg DW]	Pb [mg/kg DW]	Cu [mg/kg DW]	Cr[1)] [mg/kg DW]	Ni [mg/kg DW]	Zn [mg/kg DW]	As [mg/kg DW]	Hg [mg/kg DW]
Kharkiv	KH-S-01	1.5	43.2	74.1	44.4	16.2	264.1	8.7	0.197
	KH-S-02	9.1	49.3	156.9	357.7	43.4	440.8	12.5	0.351
	KH-S-03	9.1	50.8	144.2	266.2	37.2	385	15.1	0.512
	KH-S-04	3.4	34.6	97.8	114.2	22.2	317.7	9.4	0.172
	KH-S-05	1	7.6	24.1	46.7	5.8	48.5	2.9	0.057
	KH-N-01	2.7	35.5	83.3	80.4	17.9	300.6	9.7	NA
	KH-P-01	<0.1	12.5	9.6	8.6	3.8	37.2	4	NA
	KH-P-02	0.1	5.8	6.6	5.7	2.7	46.8	4	NA
	KH-P-03	0.1	10.2	7	6	3.8	47.9	3.4	NA
	KH-P-04	0.1	12.6	9	10.2	4.3	87.8	3.6	NA
Dnipro	DN-S-01	<0.1	11.1	22.9	29.6	19.3	31.3	36.2	0.582
	DN-S-02	<0.1	3.4	4.5	6.6	5.3	14	6.6	0.021
	DN-S-04	<0.1	98.2	12.4	221.8	9.4	30.7	7.9	NA
	DN-S-05	0.1	10.2	24	8.9	3.3	158.2	< 2.0	0.037
	DN-S-06	<0.1	0.4	0.6	1.3	0.3	4.3	< 2.0	0.002
	DN-S-07	0.4	28	23.7	14.9	10.4	195.6	< 2.0	0.003
	DN-P-01	<0.1	6.3	5.3	5.2	3.7	33.1	2.9	NA
	DN-P-02	<0.1	2.4	1.7	2.8	1.2	17.7	< 2.0	NA
	DN-P-03	<0.1	8	5.5	4.3	3.5	29.2	3	NA
	DN-P-04	0.1	10.6	6	10.5	5.7	49.6	3.3	NA
	DN-P-05	0.1	4.8	4.5	8.7	2.8	30.8	2.9	NA
	DN-P-06	0.1	49.9	16.5	12.1	7.8	109.4	7.8	NA
	DN-P-07	0.1	11.5	13.1	8.4	3.5	59.8	4	NA
	DN-P-08	0.2	500.4	13.7	12	6.2	184.6	3.2	NA
	DN-P-09	0.1	32.2	8.6	8.6	5.3	75	3.5	NA
	DN-P-10	<0.1	6.8	15.2	38.2	19.4	38.6	3.9	NA
	DN-P-11	0.1	11.2	4.8	5.7	2.8	46.3	< 2.0	NA
	DN-P-12	<0.1	9.2	2.6	2.7	1.7	21.3	< 2.0	NA

[1)] Cr is total concentration of chromium.

Hot spot area	Sample code	Cd [mg/kg DW]	Pb [mg/kg DW]	Cu [mg/kg DW]	Cr[1] [mg/kg DW]	Ni [mg/kg DW]	Zn [mg/kg DW]	As [mg/kg DW]	Hg [mg/kg DW]
Kryvyi Rih	KR-S-01	0.4	7.6	7.5	8.6	4	120.4	9.1	0.076
	KR-S-02	0.2	7.6	8.2	11.1	6.3	109.4	7.1	0.064
	KR-S-03	<0.1	7	6.5	4.2	4	29.9	4.2	0.013
	KR-S-04	<0.1	2.2	4.2	7.5	5.5	14.5	4	0.008
	KR-S-05	0.1	2.7	10.2	6	2.3	25	4.7	0.045
	KR-N-01	0.7	24	14	10.9	5.2	229.2	9.8	NA
	KR-X-01	<0.1	0.2	0.7	1	0.4	2.3	3	NA
	KR-P-01	<0.1	2.6	4	5.1	3.7	21.6	3.8	NA
	KR-P-02	<0.1	1.2	9.8	3	3	28	< 2.0	NA
	KR-P-03	<0.1	3.4	5.8	6.5	3.3	31.6	5.3	NA
	KR-P-04	<0.1	4.4	2.6	5.9	2.1	31.9	7.2	NA
	KR-P-05	<0.1	1.2	2.1	2.3	1	4.7	< 2.0	NA
	KR-P-06	0.1	7.9	7	8.4	7.5	41.5	6.2	NA
Mariupol	MA-S-01	0.2	42.9	66.6	43.7	18.1	515.4	13.7	0.214
	MA-S-02	1.9	63.8	43.5	65.2	22.4	469.3	18.1	0.158
	MA-S-03	0.2	8.6	12.8	15.2	12.7	74.6	10.4	0.021
	MA-S-04	0.1	13.1	21.6	20.3	15.4	71	9.5	0.033
	MA-S-05	0.3	14.4	18.8	25	16.9	93	11.5	0.1
	MA-B-01	0	4.4	4.4	3.9	3.5	97.7	10.7	NA
	MA-B-02	<0.1	6.2	9.4	155.9	4.6	129.5	12.4	NA
	MA-X-01	0.4	5.6	4.7	3.6	1	76.4	< 2.0	NA
	MA-P-01	0.1	1.8	8.8	3	1.4	17.2	2.8	NA
	MA-P-02	0.2	30.9	15.6	5.6	4.9	93.5	10	NA
	MA-P-03	0.1	6.9	9.4	8.1	4.6	67	5.2	NA
	MA-P-04	0.4	13.4	9.8	1.2	5.8	181.6	8.8	NA
	MA-P-05	0.1	3.4	21.1	42.9	18.4	80.3	6.2	NA
	MA-P-06	<0.1	1.5	0.9	1.9	0.7	9.2	< 2.0	NA
Zaporizhia	ZA-S-01	0.5	14.1	20.2	2.8	3.1	41.1	< 2.0	0.119
	ZA-S-02	2.9	104.5	40.2	78.4	32.9	502.5	11.7	0.064
	ZA-S-03	2.8	84.4	36	58.2	26.8	470	11.2	0.055
	ZA-S-04	1.7	52.1	21.2	32.6	19.7	335.1	NA	NA
	ZA-S-05	0.2	73.6	29.9	25	10.6	44.3	6.6	0.007
	ZA-S-06	13.4	767.3	128.7	397	106.9	2330.6	21.8	0.285
	ZA-S-07	<0.1	0	136.4	72.4	22.5	29.8	11.1	0.018
	ZA-S-08	0.1	22.9	12.6	21.2	14.5	84.2	8.8	0.012
	ZA-S-09	0.1	10.3	6.3	9.4	6.1	35.2	3.8	0.003
	ZA-S-10	3.7	37.7	88	140.4	39.2	105.7	3.6	0.123
	ZA-N-01	<0.1	0	18.3	87.8	11.9	4.2	8.7	NA
	ZA-P-01	0.1	9.4	4	5	3.3	40	5.7	NA
	ZA-P-02	0.1	9.5	7.6	9.3	6.7	39.8	5.1	NA
	ZA-P-03	0.1	13.5	6.2	5.7	5.1	31.1	4.5	NA
	ZA-P-04	0.2	25.8	9.2	14.4	7.4	50.6	5.3	NA
	ZA-P-05	0.2	10.8	7.6	8.1	6.6	32.2	< 2.0	NA
	ZA-P-06	0.1	54.4	9	10.5	7.6	80.3	5.3	NA
	ZA-P-07	0.1	9.3	4.8	6.5	3.6	40.3	3.3	NA
	ZA-P-08	0.1	8	3.2	4.3	2.8	19.3	3.9	NA
	ZA-P-09	<0.1	15.8	7.4	6.9	5.5	32.7	3.4	NA
	ZA-P-10	0.1	28.9	10.1	8.1	7.3	37.2	4.3	NA
	ZA-P-11	0.1	5.2	3.5	2.8	2.1	22.5	< 2.0	NA
Chernihiv	CG-S-01	<0.1	2.6	1.9	2.6	1.3	106.5	< 2.0	NA
	CG-S-02	0.1	10.6	18.4	4.3	2.2	81.4	< 2.0	NA
	CG-P-01	0.1	10.6	19	8.4	3.8	131.2	3.7	0.013
	CG-P-02	<0.1	3.3	3.3	6.4	2.8	22.9	3.9	0.011

[1] Cr is total concentration of chromium.

Table 10: Content of petroleum hydrocarbons (C10 – C40) and polycyclic aromatic hydrocarbons in sediment and sand samples. The content organic pollutants is given in mg/kg of dry matter. NA means not analysed. ND means not detected.

Hot Spot	Sample code	C10 – C40 [mg/kg DW]	Acenaphthene [µg/kg DW]	Acenaphthylene [µg/kg DW]	Anthracene [µg/kg DW]	Benz[a]anthracene [µg/kg DW]	Benzo[b]fluoranthene [µg/kg DW]	Benzo[k]fluoranthene [µg/kg DW]	Benzo[ghi]perylene [µg/kg DW]	Benzo[a]pyrene [µg/kg DW]	Chrysene [µg/kg DW]	Dibenz[a,h]anthracene [µg/kg DW]	Fluoranthene [µg/kg DW]	Fluorene [µg/kg DW]	Indeno[1,2,3-cd]pyrene [µg/kg DW]	1-Methylnaphthalene [µg/kg DW]	2-Methylnaphthalene [µg/kg DW]	Naphthalene [µg/kg DW]	Phenanthrene [µg/kg DW]	Pyrene [µg/kg DW]	Σ 18 PAHs [µg/kg DW] 1)	Σ 12 PAHs [µg/kg DW] 2)
Kharkiv	KH-S-01	1652	0.069	0.193	0.177	1.079	1.127	0.738	0.554	0.651	0.792	0.199	1.794	0.127	0.589	0.080	0.064	0,088	1,794	1,430	11,544	10,812
	KH-S-02	1945	0.115	0.230	0.248	0.911	0.998	1.555	0.684	0.595	0.776	0.396	1.426	0.175	0.681	0.113	0.103	0,111	1,426	1,150	11,693	10,561
	KH-S-03	3282	3.110	0.367	0.681	2.476	2.480	1.815	1.239	1.732	2.217	0.382	5.752	2.565	1.475	2.553	5.834	5,116	5,752	4,808	50,353	35,542
	KH-S-04	3035	0.184	0.294	0.278	1.405	1.559	1.194	0.981	0.991	1.079	0.355	2.376	0.181	1.110	0.099	0.084	0,125	2,376	1,897	16,569	15,372
	KH-S-05	800	0.039	0.067	0.079	0.233	0.417	0.526	0.199	0.178	0.208	0.110	0.378	0.054	0.196	0.034	0.035	0,035	0,378	0,304	3,472	3,132
	KH-N-01	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	KH-P-01	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	KH-P-02	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	KH-P-03	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	KH-P-04	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Dnipro	DN-S-01	< 200	0.029	0.030	0.049	0.047	0.036	0.049	0.078	0.000	0.043	0.087	0.045	0.034	0.082	0.027	0.026	0,030	0,045	0,045	0,783	0,549
	DN-S-02	ND	0.043	0.107	0.157	0.509	0.357	0.107	0.240	0.385	0.482	0.098	1.259	0.117	0.269	0.027	0.027	0,036	1,259	0,845	6,326	5,906
	DN-S-04	ND	0.040	0.034	0.063	0.371	0.343	0.353	0.185	0.251	0.333	0.102	0.361	0.047	0.228	0.028	0.026	0,030	0,361	0,309	3,465	3,187
	DN-S-05	637	0.099	0.120	0.344	1.277	0.908	0.706	0.406	0.744	1.044	0.143	2.533	0.176	0.481	0.051	0.044	0,087	2,533	1,680	13,377	12,744
	DN-S-06	ND	0.027	0.027	0.061	0.065	0.128	0.096	0.070	0.076	0.059	0.000	0.067	0.033	0.073	0.025	0.021	0,032	0,067	0,058	0,985	0,851
	DN-S-07	ND	0.029	0.037	0.063	0.136	0.090	0.104	0.092	0.000	0.125	0.084	0.182	0.043	0.108	0.033	0.027	0,038	0,182	0,130	1,502	1,248
	DN-P-01	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	DN-P-02	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	DN-P-03	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	DN-P-04	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	DN-P-05	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	DN-P-06	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	DN-P-07	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	DN-P-08	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	DN-P-09	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	DN-P-10	ND	0.023	0.034	0.043	0.137	0.058	0.103	0.102	0.107	0.083	0.077	0.152	0.027	0.091	0.019	0.019	0,023	0,152	0,120	1,368	1,170
	DN-P-11	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	DN-P-12	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

1) Σ 18 PAHs means the sum of acenaphthene, acenaphthylene, anthracene, benz[a]anthracene, benzo[b]fluoranthene, benzo[k]fluoranthene, benzo[ghi]perylene, benzo[a]pyrene, chrysene, dibenz[a,h]anthracene, fluoranthene, fluorene, indeno[1,2,3-cd]pyrene, 1-methylnaphthalene, 2-methylnaphthalene, naphthalene, phenanthrene, and pyrene.

2) Σ 12 PAHs means the sum of anthracene, benz[a]anthracene, benzo[b]fluoranthene, benzo[k]fluoranthene, benzo[a]pyrene, benzo[ghi]perylene, phenanthrene, fluoranthene, chrysene, indeno[1,2,3-cd]pyrene, naphthalene, and pyrene.

Hot Spot	Sample code	C10 – C40 [mg/kg DW]	Acenaphthene [µg/kg DW]	Acenaphthylene [µg/kg DW]	Anthracene [µg/kg DW]	Benz[a]anthracene [µg/kg DW]	Benzo[b]fluoranthene [µg/kg DW]	Benzo[k]fluoranthene [µg/kg DW]	Benzo[ghi]perylene [µg/kg DW]	Benzo[a]pyrene [µg/kg DW]	Chrysene [µg/kg DW]	Dibenz[a,h]anthracene [µg/kg DW]	Fluoranthene [µg/kg DW]	Fluorene [µg/kg DW]	Indeno[1,2,3-cd]pyrene [µg/kg DW]	1-Methylnaphthalene [µg/kg DW]	2-Methylnaphthalene [µg/kg DW]	Naphthalene [µg/kg DW]	Phenanthrene [µg/kg DW]	Pyrene [µg/kg DW]	Σ 18 PAHs [µg/kg DW] 1)	Σ 12 PAHs [µg/kg DW] 2)
Kryvyi Rih	KR-S-01	< 200	0.036	0.041	0.056	0.128	0.000	0.079	0.112	0.086	0.153	0.104	0.117	0.040	0.109	0.031	0.028	0,033	0,117	0,107	1,376	1,096
	KR-S-02	ND	0.046	0.066	0.086	0.127	0.213	0.115	0.161	0.124	0.132	0.141	0.207	0.071	0.169	0.040	0.036	0,040	0,207	0,175	2,154	1,754
	KR-S-03	ND	0.101	0.170	0.302	1.024	0.382	0.878	0.646	0.998	1.056	0.199	2.408	0.137	0.789	0.042	0.041	0,041	2,408	1,699	13,320	12,631
	KR-S-04	592	0.040	0.049	0.085	0.384	0.247	0.236	0.223	0.263	0.191	0.119	0.454	0.046	0.238	0.035	0.027	0,034	0,454	0,479	3,601	3,286
	KR-S-05	ND	0.061	0.074	0.103	0.221	0.125	0.336	0.218	0.000	0.167	0.200	0.260	0.075	0.231	0.060	0.052	0,069	0,260	0,217	2,731	2,208
	KR-N-01	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	KR-X-01	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	KR-P-01	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	KR-P-02	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	KR-P-03	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	KR-P-04	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	KR-P-05	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	KR-P-06	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Mariupol	MA-S-01	ND	0.072	0.064	0.101	0.166	0.000	0.216	0.168	0.161	0.102	0.000	0.310	0.079	0.167	0.054	0.044	0,061	0,310	0,240	2,316	2,003
	MA-S-02	3134	0.070	0.098	0.155	0.459	0.989	0.410	0.327	0.372	0.386	0.238	0.892	0.094	0.363	0.064	0.053	0,082	0,892	0,769	6,714	6,097
	MA-S-03	ND	0.063	0.057	0.093	0.161	0.191	0.195	0.164	0.150	0.113	0.166	0.253	0.066	0.172	0.055	0.046	0,057	0,253	0,192	2,447	1,995
	MA-S-04	ND	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	MA-S-05	ND	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	MA-B-01	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	MA-B-02	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	MA-X-01	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	MA-P-01	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	MA-P-02	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	MA-P-03	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	MA-P-04	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	MA-P-05	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	MA-P-06	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

1) Σ 18 PAHs means the sum of acenaphthene, acenaphthylene, anthracene, benz[a]anthracene, benzo[b]fluoranthene, benzo[k]fluoranthene, benzo[ghi]perylene, benzo[a]pyrene, chrysene, dibenz[a,h]anthracene, fluoranthene, fluorene, indeno[1,2,3-cd]pyrene, 1-methylnaphthalene, 2-methylnaphthalene, naphthalene, phenanthrene, and pyrene.

2) Σ 12 PAHs means the sum of anthracene, benz[a]anthracene, benzo[b]fluoranthene, benzo[k]fluoranthene, benzo[a]pyrene, benzo[ghi]perylene, phenanthrene, fluoranthene, chrysene, indeno[1,2,3-cd]pyrene, naphthalene, and pyrene.

Hot Spot	Sample code	C10 – C40 [mg/kg DW]	Acenaphthene [µg/kg DW]	Acenaphthylene [µg/kg DW]	Anthracene [µg/kg DW]	Benz[a]anthracene [µg/kg DW]	Benzo[b]fluoranthene [µg/kg DW]	Benzo[k]fluoranthene [µg/kg DW]	Benzo[ghi]perylene [µg/kg DW]	Benzo[a]pyrene [µg/kg DW]	Chrysene [µg/kg DW]	Dibenz[a,h]anthracene [µg/kg DW]	Fluoranthene [µg/kg DW]	Fluorene [µg/kg DW]	Indeno[1,2,3-cd]pyrene [µg/kg DW]	1-Methylnaphthalene [µg/kg DW]	2-Methylnaphthalene [µg/kg DW]	Naphthalene [µg/kg DW]	Phenanthrene [µg/kg DW]	Pyrene [µg/kg DW]	Σ 18 PAHs [µg/kg DW] 1)	Σ 12 PAHs [µg/kg DW] 2)
Zaporizhia	ZA-S-01	< 200	0.245	0.116	0.240	1.327	1.066	0.856	0.575	0.673	0.816	0.256	1.512	0.163	0.585	0.160	0.095	0,335	1,512	1,367	11,899	10,864
	ZA-S-02	1550	0.054	0.059	0.099	0.604	1.268	0.401	0.363	0.407	0.329	0.155	0.601	0.060	0.416	0.071	0.049	0,079	0,601	0,668	6,282	5,835
	ZA-S-03	872	0.047	0.039	0.103	0.586	0.804	0.445	0.230	0.298	0.360	0.106	0.713	0.055	0.241	0.062	0.041	0,072	0,713	0,683	5,598	5,247
	ZA-S-04	NA	0.000	0.028	0.055	0.059	0.000	0.047	0.077	0.000	0.056	0.087	0.056	0.033	0.079	0.023	0.021	0,022	0,056	0,051	0,750	0,558
	ZA-S-05	< 200	0.132	0.042	0.314	1.217	1.021	1.046	0.373	0.773	0.832	0.129	2.277	0.123	0.641	0.064	0.047	0,079	2,277	1,582	12,967	12,430
	ZA-S-06	3902	0.065	0.054	0.109	0.931	0.976	0.990	0.273	0.311	0.339	0.130	0.684	0.069	0.296	0.092	0.060	0,084	0,684	0,938	7,083	6,614
	ZA-S-07	7740	0.040	0.087	0.072	0.643	0.278	0.213	0.153	0.189	0.126	0.114	0.184	0.071	0.143	0.039	0.033	0,036	0,184	0,344	2,949	2,565
	ZA-S-08	ND	0.033	0.031	0.051	0.085	0.038	0.083	0.090	0.000	0.067	0.093	0.119	0.038	0.090	0.035	0.029	0,037	0,119	0,096	1,134	0,875
	ZA-S-09	ND	0.046	0.043	0.093	0.333	0.245	0.244	0.171	0.196	0.249	0.091	0.463	0.068	0.187	0.037	0.033	0,048	0,463	0,326	3,337	3,018
	ZA-S-10	< 200	0.058	0.078	0.200	0.262	0.498	0.363	0.281	0.228	0.214	0.179	0.340	0.078	0.272	0.065	0.055	0,073	0,340	0,279	3,863	3,350
	ZA-N-01	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	ZA-P-01	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	ZA-P-02	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	ZA-P-03	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	ZA-P-04	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	ZA-P-05	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	ZA-P-06	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	ZA-P-07	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	ZA-P-08	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	ZA-P-09	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	ZA-P-10	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	ZA-P-11	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Chernihiv	CG-S-01	ND	0.000	0.040	0.073	0.059	0.000	0.000	0.104	0.115	0.066	0.000	0.065	0.044	0.109	0.039	0.032	0,044	0,065	0,062	0,917	0,763
	CG-S-02	ND	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	CG-P-01	ND	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	CG-P-02	ND	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

1) Σ 18 PAHs means the sum of acenaphthene, acenaphthylene, anthracene, benz[a]anthracene, benzo[b]fluoranthene, benzo[k]fluoranthene, benzo[ghi] perylene, benzo[a]pyrene, chrysene, dibenz[a,h]anthracene, fluoranthene, fluorene, indeno[1,2,3-cd]pyrene, 1-methylnaphthalene, 2-methylnaphthalene, naphthalene, phenanthrene, and pyrene.

2) Σ 12 PAHs means the sum of anthracene, benz[a]anthracene, benzo[b]fluoranthene, benzo[k]fluoranthene, benzo[a]pyrene, benzo[ghi]perylene, phenanthrene, fluoranthene, chrysene, indeno[1,2,3-cd]pyrene, naphthalene, and pyrene.

Table 11: Content of organochlorine pesticides in sediment and sand samples. The content of organic pollutants is given in µg/kg of dry matter. NA means not analysed. ND means not detected.

Hot Spot	Sample code	HCB [µg/kg DW]	alfa HCH [µg/kg DW]	beta HCH [µg/kg DW]	gama HCH [µg/kg DW]	delta HCH [µg/kg DW]	heptachlor [µg/kg DW]	2,4'DDE [µg/kg DW]	4,4'DDE [µg/kg DW]	2,4'DDD [µg/kg DW]	4,4'DDD [µg/kg DW]	2,4'DDT [µg/kg DW]	4,4'DDT [µg/kg DW]	Σ DDT [µg/kg DW]	metoxychlor [µg/kg DW]
Kharkiv	KH-S-01	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	KH-S-02	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	KH-S-03	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	KH-S-04	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	KH-S-05	ND	ND	ND	ND	ND	ND	ND	11	ND	ND	13	31	55	ND
	KH-N-01	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	KH-P-01	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	KH-P-02	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	KH-P-03	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	KH-P-04	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Dnipro	DN-S-01	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	DN-S-02	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	DN-S-04	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	DN-S-05	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	DN-S-06	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	DN-S-07	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	DN-P-01	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	DN-P-02	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	DN-P-03	ND	ND	ND	ND	ND	ND	ND	56	ND	ND	15	25	96	ND
	DN-P-04	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	DN-P-05	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	DN-P-06	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	11	74	85	ND
	DN-P-07	ND	ND	ND	ND	ND	ND	ND	29	ND	ND	ND	48	77	ND
	DN-P-08	ND	ND	ND	ND	ND	ND	ND	31	27	ND	10	65	133	ND
	DN-P-09	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	DN-P-10	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	DN-P-11	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	DN-P-12	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Kryvyi Rih	KR-S-01	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	KR-S-02	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	KR-S-03	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	KR-S-04	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	KR-S-05	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	KR-N-01	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	KR-X-01	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	KR-P-01	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	KR-P-02	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	KR-P-03	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	KR-P-04	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	KR-P-05	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	KR-P-06	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

Hot Spot	Sample code	HCB [µg/kg DW]	alfa HCH [µg/kg DW]	beta HCH [µg/kg DW]	gama HCH [µg/kg DW]	delta HCH [µg/kg DW]	heptachlor [µg/kg DW]	2,4'DDE [µg/kg DW]	4,4'DDE [µg/kg DW]	2,4'DDD [µg/kg DW]	4,4'DDD [µg/kg DW]	2,4'DDT [µg/kg DW]	4,4'DDT [µg/kg DW]	Σ DDT [µg/kg DW]	metoxychlor [µg/kg DW]
Mariupol	MA-S-01	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	MA-S-02	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	MA-S-03	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	MA-S-04	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	MA-S-05	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	MA-B-01	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	MA-B-02	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	MA-X-01	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	MA-P-01	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	MA-P-02	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	MA-P-03	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	MA-P-04	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	MA-P-05	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	MA-P-06	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Zaporizhia	ZA-S-01	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	ZA-S-02	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	ZA-S-03	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	ZA-S-04	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	ZA-S-05	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	ZA-S-06	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	ZA-S-07	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	ZA-S-08	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	ZA-S-09	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	ZA-S-10	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	ZA-N-01	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	ZA-P-01	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	ZA-P-02	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	ZA-P-03	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	ZA-P-04	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	ZA-P-05	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	ZA-P-06	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	ZA-P-07	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	ZA-P-08	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	ZA-P-09	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	ZA-P-10	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	ZA-P-11	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Chernihiv	CG-S-01	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	CG-S-02	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	CG-P-01	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	CG-P-02	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND