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SOILS, SEC 3 • REMEDIATION AND MANAGEMENT OF CONTAMINATED OR DEGRADED LANDS • RESEARCH ARTICLE

The occurrence of selected organic pollutants in the soils of the Songnen Plain, China

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Abstract

Purpose To protect and improve the soil environment of the Songnen Plain, detailed identification of organic pollutant contamination features in the soil and the degree of contamination is required. The primary goals of this research are to measure the levels of organic pollutants detected in the soil of the Songnen Plain, to correlate the levels of organic pollutants with different land use practices, and to assess the environmental quality of the soil using various pollution indicators.

Material and methods Contaminated soil was collected at three types of areas: residential (n = 26), agricultural (n = 22), and industrial (n = 12) in the Songnen Plain of Jilin Province, at 0–20 cm and 20–40 cm depths. The concentrations of dichlorodiphenyltrichloroethane, benzene hexachloride, toluene, ethylbenzene, xylene, benzo (a) pyrene (BaP), trichloromethane, tetrachloromethane, hexachlorobenzene, and atrazine in the soil samples were determined using gas chromatography (GC), gas chromatograph-mass spectrometer-mass spectrometer (GC-MS-MS), and high-performance liquid chromatography (HPLC).

Results and discussion Soil BaP had the highest concentration with a mean value of 20.59 ng/kg, followed by atrazine, hexachlorobenzene, benzene hexachloride, dichlorodiphenyltrichloroethane (DDT), trichloromethane, toluene, ethylbenzene, xylene, and tetrachloromethane with mean concentrations of 0.46, 0.44, 0.34, 0.28, 0.21, 0.14, 0.06, 0.03, and 0.02 ng/kg, respectively. Soil organic pollutants at all sampling sites did not exceed the secondary environmental quality standard values. The most serious soil contamination was found in landfill sites, followed by urban areas, industrial areas and farmland areas.

Conclusions Soil contamination is more severe in locations where human activity is more prevalent. The subsoil can better reflect the characteristics of soil pollution in the area compared to the upper layer of soil. Although contamination is low in the research region, the presence of these pollutants must be taken seriously in order to maintain the quality and safety of agricultural products and human health.

Keywords: Soil pollution · Organic pollutants · Land use · Songnen plain

1 Introduction

Soil quality has become one of the most important environmental issues in China's modernization process. Soil pollution is related to the safety of agricultural production, arable land quality, and people's health. The data from the National Soil Pollution Survey Bulletin for 2014 shows that the total exceedance rate of soil pollutants in China is as high as 16.1%, indicating that the soil condition in China is not optimistic. Soil is an important nutrient and pollutant reservoir, and it plays a vital role in social-ecological stability and safety (Benlaribi and Djebbar 2020; Jia et al. 2021; Xu et al. 2018; Yang et al. 2017; Zhao et al. 2020). More and more environmental problems stem from soil pollution. In recent decades, soil pollution has become an

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important obstacle to regional development and human health(Li 2018; Liang et al. 2017; Peng et al. 2017; Wu et al. 2018; Sankar et al. 2023). Some human activities, such as construction, industrial facilities, transportation, and the consequences of densely populated environments, can lead to the release of high concentrations of various pollutants, such as persistent organic pollutants (POPs) (Ambade and Ghosh 2013; Ciarkowska et al. 2019; Gu et al. 2016; Kumar et al. 2020; Khan et al. 2021; Murray et al. 2011; Qu et al. 2020). People become more aware of the harmful effects of soil pollution on production systems and livelihoods as their understanding of sustainable development and environmental protection grows. Soil contamination is the buildup of pollutants such as metals and organics in soil, causing imbalances in plant nutrient availability, changes in the soil's microbial community abundance and framework, soil ecosystem degradation, and groundwater contamination, all of which have an impact on crop quality and safety as well as human health.

Persistent organic pollutants are toxic substances that are highly resistant to environmental degradation and have become an important part of soil pollution, which has chemical decomposition, photolysis resistance, and biological degradation (Chen et al. 2021; Gu et al. 2016). Their degradation in the soil is a slow and complex process, affected by a variety of environmental factors, including moisture status, organic matter content, soil pH, and temperature (Ren et al. 2018a, b; Umulisa et al. 2020). According to the Quality Standard for Soil (GB 15618 – 2008), organic pollutants include 60 compounds, including volatile organic pollutants, semi-volatile organic pollutants, persistent organic pollutants, and organic pesticides. A total of 10 indicators were detected in the soil in this study, including dichlorodiphenyltrichloroethane (DDT), benzene hexachloride, toluene, ethylbenzene, xylene, benzo (a) pyrene (BaP), trichloromethane, tetrachloromethane, hexachlorobenzene, and atrazine. No other indicators were detected, so these 10 indicators were used as evaluation factors. These pollutants will enter the food chain or contaminate surface and groundwater, which may cause harm to human health (Khan et al. 2008; Zhang et al. 2018; Zheng et al. 2014; Ambade et al. 2022a, b).

Nowadays, due to the significant advancement of science and technology, the emission of various pollutants into the environment has increased (Mihankhah et al. 2020). Soil can accumulate a variety of pollutants and can be used as a medium for indirectly integrating historical and recent sources of pollution (SEPAC. 2004; Wang et al. 2015; Wang et al. 2020).

It is generally believed that due to the influence of mineral composition and sedimentation processes, soil properties are different in space. Soil properties depend on several factors and not only on rock mineral composition and sedimentation processes (Wang et al. 2014; Fedotov et al. 2014; Kotov and Agapkin 2021). To verify this statement, we measured the content of organic pollutants in the soil at different depths.

The Songnen Plain boasts a level topography and fertile soil, making it highly conducive to the cultivation of crops. The region serves as a vital hub for grain production in China, with crops like wheat, rice, and corn being extensively cultivated. In the process of urbanization and engineering in the Songnen Plain, the scope of unreasonable land development is increasing. To protect and enhance the soil environment in the Songnen Plain, it is essential to accurately identify the characteristics of organic pollution in the soil. Specifically, comprehending the extent of organic pollutant contamination in the soil and identifying their sources are fundamental prerequisites for preventing and mitigating soil pollution. Information on the levels of organic pollution in soils across different land use types is highly significant as it provides a foundation for preventing, controlling, and treating soil pollution in various land use categories. Reasonable land use measures and improvement strategies that meet the actual conditions are put forward to promote the sustainable development of land and the maintenance of ecological balance in the study area, which can not only provide a scientific basis for the protection of land resources and soil security in the Songnen Plain, but also provide a reference for the development planning of the area.

The main objectives of this study were: firstly, to measure the concentrations of organic pollutants in the soils of the Songnen Plain; secondly, to analyze the correlation between the concentrations of organic pollutants and different land use types; and thirdly, to evaluate the environmental quality of the Songnen Plain by employing various pollution indices. The outcomes of this study can furnish relevant departments with a scientific foundation for decision-making.

2 Materials and methods

2.1 Study area and soil sampling

The research was carried out in Jilin Province's Songnen plain (43°33′55″ – 46°28′48″ N, 121°20′56″ – 127°09′00″ E). The average annual temperature for this area is 4.9–5.5 °C (Dou et al. 2019; Yin et al. 2018). This area presents a temperate continental monsoon climate with semi-humid and semi-arid characteristics (An et al. 2019), and the rainfall is mainly concentrated in summer (from June to September), with the average annual rainfall ranging from 206.3 to 799.6 mm.

Sixty soil samples in total were collected from the three types of areas: residential (n = 26), agricultural (n = 22), and industrial (n = 12). Five mixed samples were collected at each site, with each mixed sample consisting of three subsamples. Two soil depths were collected for each sampling point (0–20 cm and 20–40 cm). Soil samples were randomly collected from the selected area (50 cm × 50 cm) using a stainless-steel shovel for each subsample. Samples were stored in aluminum foil bags, then transported to the laboratory and stored at 4 °C before analysis. The soil samples were dried at room temperature before being sieved through a 2 mm mesh to remove plant residues, roots, and stones. A map of the sampling sites is presented in Fig. 1.

2.2 Sample preparation and laboratory analyses

The concentrations of DDT, benzene hexachloride, toluene, ethylbenzene, xylene, BaP, trichloromethane, tetrachloromethane, hexachlorobenzene, and atrazine in the soil samples were determined using gas chromatography (GC), gas chromatograph-mass spectrometer-mass spectrometer (GC-MS-MS), and high-performance liquid chromatography (HPLC), respectively. Sample blanks, duplicates, and standards were routinely analyzed to ensure quality control of analytical data. The collection, transportation, pretreatment and determination of soil samples were in accordance with The Technical Specification for Soil Environmental Monitoring (Zhao et al. 2018). The analytical procedures employed for performing the analyses can be found in Table 1. All mathematical and statistical computations were made using IBM SPSS version 19.

2.3 Pollution analysis

Soil environmental quality standards are divided into three levels according to the degree of soil pollution. The soil in Grade I is near concentrated drinking water sources, tea gardens, pastures, and other protected areas; soils in Grade II

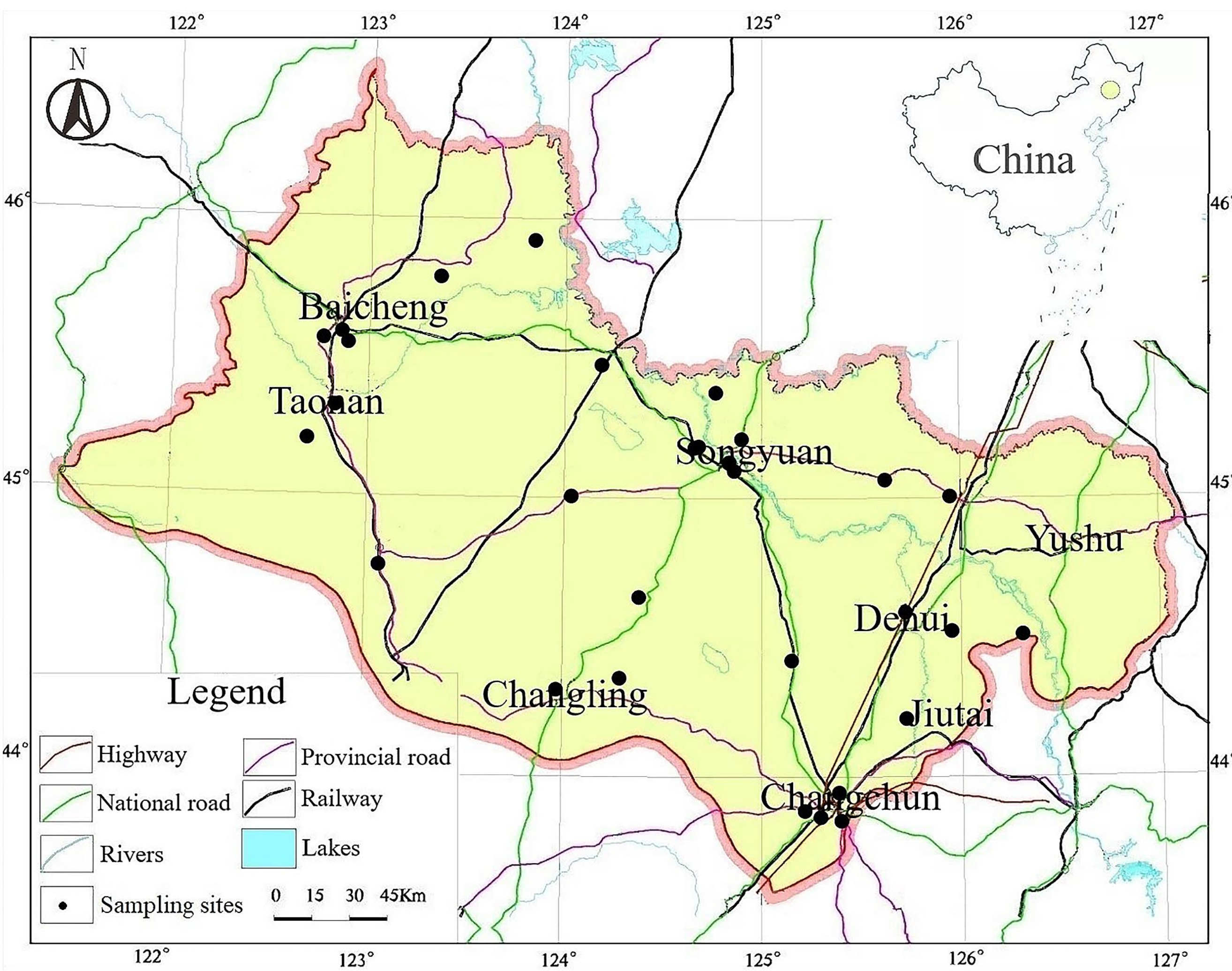

Fig. 1 Study area map

Table 1 Methods for the determination of pollutants

Analysis	Method
Toluene, Ethylbenzene and Xylene	GB/T 23990 – 2009
BaP	HJ 805–2016
DDT, Benzene hexachloride	HJ 835–2017
Trichloromethane	GB/T 682–2002
Tetrachloromethane	GB/T 688–2011
Hexachlorobenzene	HJ 922–2017
Atrazine	HJ 1052–2019

(AQSIQ 2009; MEPPRC 2016; MEPPRC 2017a; AQSIQ 2002; AQSIQ 2011; MEPPRC 2017b; MEPPRC 2019)

are generally farmland, vegetable fields, tea gardens, and pastures; and soil in Grade III is near mines and woodlands. The study area is located in the Songnen Plain, which has many types of soils. Due to the influence of local agricultural development and petroleum exploitation, the content of soil background values in the study area is not consistent, and the investigation of soil background value has not been done. Therefore, the evaluation criteria for all organic pollutants in the soil of this study area are the second-level standards in the national standards. The national secondary standard values of organic pollutants in China and the Canadian soil standard values are shown in Table 2.

3 Results

3.1 pollutions situation

Table 3 shows the descriptive statistics of different organic pollutants in different soils of the Songnen Plain. The detection rate of hexachlorobenzene was 25%, BaP was 21.67%, and benzene hexachloride and atrazine were also 10%. Dichlorodiphenyltrichloroethane, toluene, xylene, trichloromethane, ethylbenzene, and tetrachloromethane detection rates were relatively low, at 6.67%, 5%, 3.33%, 3.33%, 1.67%, and 1.67%, respectively. Comparing the measurement results with the soil quality standard values in Table 2, the results indicated that the organic pollutant content in the soils of the study area remained within the limits set by the secondary standard of the Chinese soil quality standard. Compared with the Canadian soil quality standards, the mean values of toluene, ethylbenzene, xylene, BaP, trichloromethane, and tetrachloromethane in this study area were all smaller than the Canadian soil quality standard values.

In this study, the content of BaP in the soil was the highest, with an average value of 20.59 ng/kg, followed by atrazine, hexachlorobenzene, benzene hexachloride, DDT, trichloromethane, toluene, ethylbenzene, xylene, and tetrachloromethane, with an average concentration of 0.46, 0.44, 0.34, 0.28, 0.21, 0.14, 0.06, 0.03, and 0.02 ng/kg, respectively. Among them, in residential areas, the concentration of BaP in the soil was the highest, with an average value of 41.13 ng/kg, followed by hexachlorobenzene, benzene hexachloride, DDT, trichloromethane, atrazine, toluene, and tetrachloromethane, with an average concentration of 0.98, 0.57, 0.56, 0.49, 0.32, 0.20, and 0.04 ng/kg, respectively. In agricultural areas, the concentration of atrazine in the soil was the highest, with an average value of 0.88 ng/kg, followed by BaP, ethylbenzene, and xylene, with an average concentration of 0.18, 0.17, and 0.08 ng/kg, respectively. In industrial areas, the concentration of BaP in the soil was the highest, with an average value of 13.52 ng/kg, followed by Benzene hexachloride, Toluene, DDT, and Hexachlorobenzene, with an average concentration of 0.43, 0.24, 0.19, and 0.05 ng/kg, respectively. In general, the standard deviation of BaP in the soil of the study area is large, while that of other pollutants is small, indicating that the concentration of BaP in the study area fluctuates greatly, which may be greatly influenced by human activities.

Table 2 Environmental quality of soil organic pollutants

	China standard			Canadian standard		
Compounds (mg/kg)	Agricultural land	Residential land	Industrial land	Agricultural land	Residential land	Industrial land
Toluene	—	100	500	0.37 (Coarse)	0.37 (Coarse)	0.37 (Coarse)
Ethylbenzene	—	20	250	0.082 (Coarse)	0.082 (Coarse)	0.082 (Coarse)
Xylene	—	5	50	11 (Coarse)	11 (Coarse)	11 (Coarse)
BaP	0.55	0.5	1	20	20	72
DDT	0.1	1	4	—	—	—
Benzene hexachloride	0.1	1	4	—	—	—
Trichloromethane	—	—	—	0.1	5	50
Tetrachloromethane	—	0.5	2	0.1	5	50
Hexachlorobenzene	—	0.5	3	—	—	—
Atrazine	0.1	2	6	—	—	—

Coarse: Compounds concentrations in coarse soil

The monitored concentration of soil pollutants was compared with the standard values according to the Quality Standard for Soil (GB 15618 – 2008), the Quality Standard for Soil (GB 15618 – 2018), and the Canadian Environmental Quality Guidelines (MEPPRC 2008; MEPPRC 2018; CCME)

Table 3 Descriptive statistics of different organic pollutants (ng/kg) in different soil from Songnen Plain

		DDT	Benzene hexachloride	Toluene	Ethylbenzene	Xylene	BaP	Trichloromethane	tetrachloromethane	hexachloro-benzene	atra-zine
Study area	min	-	-	-	-	-	-	-	-	-	-
	max	14.15	11.77	3.05	3.83	1.29	895.77	8.70	1.01	6.26	14.28
	mean	0.28	0.34	0.14	0.06	0.03	20.59	0.21	0.02	0.44	0.46
	SD	1.84	1.62	0.61	0.49	0.18	116.39	1.23	0.13	1.21	1.99
Residential	min	-	-	-	-	-	-	-	-	-	-
	max	14.15	11.77	3.05	-	-	895.77	8.70	1.01	6.26	4.17
	mean	0.56	0.57	0.20	-	-	41.13	0.49	0.04	0.98	0.32
	SD	2.77	2.32	0.73	-	-	175.29	1.85	0.20	1.71	1.02
Agricultural	min	-	-	-	-	-	-	-	-	-	-
	max	-	-	-	3.83	1.29	3.23	-	-	0.07	14.28
	mean	-	-	-	0.17	0.08	0.18	-	-	-	0.88
	SD	-	-	-	0.82	0.29	0.70	-	-	0.01	3.09
Industrial	min	-	-	-	-	-	-	-	-	-	-
	max	1.67	4.25	2.93	-	-	97.91	-	-	0.37	-
	mean	0.19	0.43	0.24	-	-	13.52	-	-	0.05	-
	SD	0.50	1.23	0.85	-	-	30.52	-	-	0.12	-

Max Maximum, *Min* Minimum, - Not detected, *SD* standard deviation

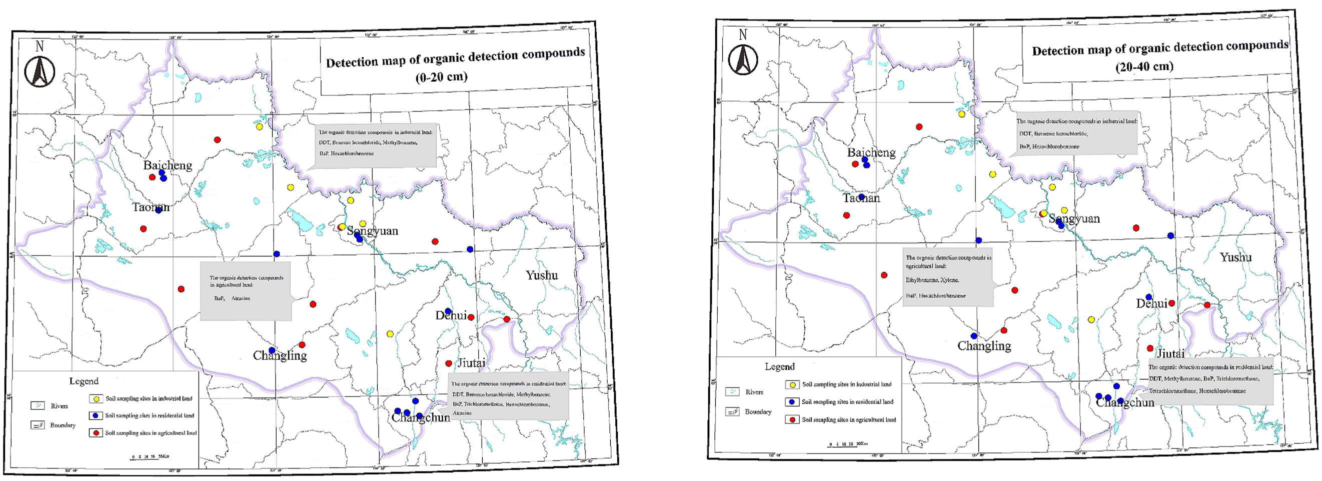

Fig. 2 Soil organic compounds detection atlas of different land use types in Songnen Plain (Jilin), China

3.2 Soil pollution assessment based on land use type

Due to the type of land use, this is divided into residential plots (garbage dump, urban area), agricultural land (farmland, agricultural pollution source), and industrial land (oil field area, oil refinery, industrial pollution source). The map of organic compounds distribution in soils from Songnen Plain is shown in Fig. 2.

According to the national soil environmental quality standards, soils from all sampling points do not exceed the second level of environmental quality standard values for soil organic pollutants (Table 2), indicating that the soil quality of the Songnen Plain (Jilin) can be called "clean" and generally non-polluting, as long as preventive measures are taken.

However, organic pollutants have been detected in different land use types. Organic compounds detected near a garbage dump include DDT, benzene hexachloride, BaP, hexachlorobenzene, and atrazine. This is because the garbage produced by urban residents on residential land is not classified; all kinds of garbage are piled together, and the garbage leaching due to rainfall and fermentation infiltrates into the soil, causing soil contamination.

The organic compounds in urban areas include toluene, BaP, trichloromethane, tetrachloromethane, and hexachlorobenzene. This is due to the use of organic waste, improper disposal and accidental leakage and leakage of harmful chemicals into the soil, as well as the emission of urban vehicle exhaust and the discharge of domestic sewage. (Li et al. 2016 ; Iwegbue et al. 2023; Ravanipour et al. 2022; García-Delgado et al. 2020).

The organic compounds in farmland soils include ethylbenzene, xylene, BaP, hexachlorobenzene, and atrazine. The extensive application of pesticides and fertilizers in agricultural practices results in the presence of residual organic matter in the soil. At the same time, Wildfires are common in this area, and incomplete combustion makes it easy to produce BaP, which contaminates the soil.

No organic pollutant was detected in the soils of the agricultural pollution source site (cattle farm).

Toluene, BaP, and hexachlorobenzene were identified as present in the oil field area's soil. This is due to the falling oil produced in oilfield mining, which is produced when precipitation seeps into the soil.

No organic pollutants were detected in the soils of the refinery.

The organic detection compounds found in the soils of industrial pollution sources (furfural plant sewage, waste residue discharge site) include DDT, benzene hexachloride, BaP, and hexachlorobenzene. The furfural plant's sewage and waste residue discharge sites did not implement anti-seepage measures, and the sewage and waste residue were disposed of and discharged at will, thus polluting the soil and groundwater. This shows the seriousness of soil pollution caused by industrial activities.

3.3 Soil pollution assessment based on sample collection depth

In the Songnen Plain (Jilin), there are 30 sampling points for collecting soil organic samples. Each sampling point consists of two soil layers: one collected at a depth of 0–20 cm below the surface, and the other at a depth of 20–40 cm. A total of sixty soil samples were collected, with thirty samples obtained from a depth of approximately 0–20 cm below the surface, and the remaining samples obtained from a depth of 20–40 cm. A comparison was made between the organic detection results of representative soil samples collected at depths of 0–20 cm and 20–40 cm. The comparison results are presented in Fig. 3.

It can be seen from Fig. 3 that the organic detection compounds in the 0–20 cm soil layer include DDT, benzene hexachloride, toluene, BaP, trichloromethane, hexachlorobenzene, and atrazine. The organic detection compounds in the 20–40 cm soil layer include DDT, benzene hexachloride, ethylbenzene, xylene, BaP, trichloromethane, tetrachloromethane, and hexachlorobenzene. The organic indicators contained in the 0–20 cm of soil are detected in the 20–40 cm of soil. The content of BaP in the soil was the highest. Organic substances from the shallow soil infiltrate into the deeper layers, resulting in contamination of the deep soil. However, it is essential to consider that the soil layer at 0–20 cm depth may act as an overlying layer with lower pollutant concentrations.

(1) residential land

Among the nine sampled points of the garbage dump, the detected concentration of the 0–20 cm soil organic index in five sample points was greater than that in the 20–40 cm. Among the four sample points within the urban area. The detected concentration of the 0–20 cm soil organic index in two sampled points was greater than that in the 20–40 cm.

(2) agricultural land

Among the eight sampled points within the farmland. The detection concentration of the 0–20 cm soil organic index in two sampled points was greater than that in the 20–40 cm.

(3) industrial land

Among the four sampled points within the oilfield area. The detected concentration of the 0–20 cm soil organic index in two sampled points was greater than that in the 20–40 cm. There is a total of one sampled point for industrial pollution sources. However, the detected concentration of the 0–20 cm soil organic index at this point is less than that in the 20–40 cm.

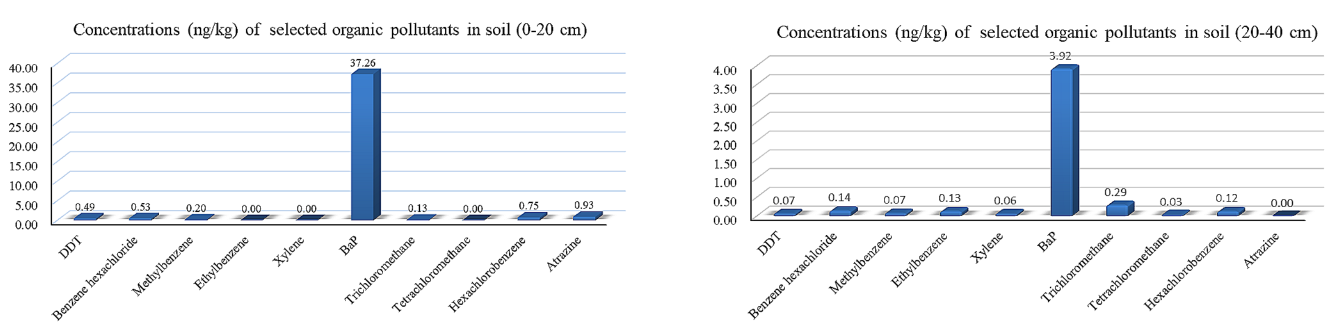

Fig. 3 Concentrations (ng/kg) of selected organic pollutants in soil in Songnen Plain (Jilin), China

4 Discussion

The large standard deviation of the concentrations of some pollutants in the soils of the study area indicates a high level of anthropogenic influence on the pollution in the study area. The high of BaP ratio in the individual sampling sites of the residential land, resulting in a large standard deviation, is because the sampling site is located in a landfill and the pollution is more serious than in other areas. The BaP ratio in individual sampling points of industrial land is higher, resulting in a large standard deviation, because the sampling point is near the furfural factory sewage and waste discharge point, and the pollution situation is more serious than in other areas.

Compared to the pollution levels, the soil pollution in the garbage dump area is most serious, followed by pollution in urban areas and industrial areas, and then in farmland areas. This shows that the greater the impact of human activities, the more serious the soil pollution, and the more serious the soil pollution in the area where the harmful substances are more concentrated. Organic pollutants are produced by the use of energy, chemicals, and fertilizers. For instance, chemicals, decoration materials, detergents, and fuels used by people in residential areas will produce some organic pollutants such as toluene, BaP, trichloromethane, tetrachloromethane, etc., while fertilizers and pesticides used in agricultural areas will produce organic pollutants such as ethylbenzene, xylene, atrazine, etc. With the advancement of urbanization, industrial, transportation, and domestic waste discharge have overwhelmed the ecological carrying capacity of urban soil.

The change of pollutant concentration in soil of different layers (0–20 cm and 20–40 cm) is relatively less regular, but at the same time it reflects the inevitability that the layers of soil are relatively fixed compared with groundwater. Due to human activities, the top layer of soil is easily disturbed, especially the soil in agricultural areas, dumpsites, oilfield areas and other areas is significantly disturbed by seasonal and working periods, so there is no obvious regularity in the change of pollutant concentration in the upper and lower layers. However, relatively speaking, the lower layer of soil is more polluted, while the lower layer of soil is more stable and less disturbed compared to the upper layer of soil, and because many of the upper layer of soil may be foreign fill, fill, and decontaminated soil so it is less polluted, so the lower layer of soil is more reflective of the characteristics of soil pollution in this area compared to the upper layer of soil.

A lot of factors impact the fate and distribution of concentrations of organic pollutants in soils. As for the levels of organic pollutants in soils of other countries or cities, the concentration of atrazine in this study area is lower than that in agricultural soil in the south of Iran (with a range of 15–550 mg/kg) (Dehghani et al. 2010), and lower than that in agricultural soil in Baiyangdian Lake of Hebei Province (with a range of 10.2–86.9 ng/g) (Ye et al. 2001). The mean value of DDT in the soil of this study area was lower than its soil concentration in the Czech Republic (with a mean value of 24.3 ng/g), and the mean value of hexachlorobenzene in the soil of this study area was lower than its soil concentration in the Czech Republic (with a mean value of 3.2 ng/g)(Kubošová et al. 2009), the value of DDT in the soil of this study area was lower than its soil concentration in the Nyabarongo lower catchment (with a range of not detectable to 247.3 µg/kg) (Umulisa et al. 2020). The concentration of toluene in this study area is lower than that in an abandoned petrochemical plant in North China (ranging from 1–594 g/kg) (Zhang et al. 2014). The value of BaP in this study area's soil was lower than that in Shandong (ranging from not detectable to 173.1 g/kg) (Chai et al. 2017), and the value of BaP in this study area's soil was lower than that in Shanxi (ranging from not detectable to 72 ng/g) (Zhao et al. 2014). In comparison, the concentrations of PAHs in this study were low. The presence of these contaminants poses a risk to human health and should continue to be of concern for protecting the quality and safety of agricultural products as well as human health.

During China's social and economic development, industrial production has experienced significant growth, leading to an increase in energy consumption and the emergence of soil pollution problems. To address this issue, it is crucial for relevant departments to conduct comprehensive research on soil pollution remediation techniques, including physical, biological, and chemical methods, in order to mitigate the damage caused by pollutants and safeguard the soil ecosystem. Additionally, environmental protection agencies need to prioritize soil pollution in future ecological protection efforts, disseminate awareness on soil pollution prevention and control through various channels, establish a comprehensive soil pollution monitoring system, enhance vegetation coverage, and ensure the preservation of the soil ecosystem. Furthermore, it is vital to reinforce land regulation and ecological resource protection in the Songnen Plain, as well as optimize the land use structure, as these measures will lay a solid foundation for achieving green and sustainable development.

5 Conclusion

Ten organic compounds, including DDT, benzene hexachloride, toluene, ethylbenzene, xylene, BaP, trichloromethane, tetrachloromethane, hexachlorobenzene, and atrazine, were analysed to determine the concentrations and pollution levels in the soil of the Songnen Plain. The quantification outcomes are then classified into two groups: evaluation based on land use type and evaluation by soil sampling horizon. Benzo (a) pyrene had the greatest concentration in the soil, followed by atrazine, hexachlorobenzene, benzene hexachloride, DDT, trichloromethane, toluene, ethylbenzene, xylene, and tetrachloromethane. For soil organic contaminants, all sampling points do not exceed the second level of environmental quality standard values. The garbage dump has the worst soil pollution, followed by the urban, industrial, and farmland areas.

Although the soil organic pollution in the study area did not exceed the soil quality standard, all the ten organic compounds in this study were detected, and the detection rates of hexachlorobenzene and BaP were high, indicating that soil in this area has been affected by human production and life, and some of them were found to be polluted. The results show that soil pollution is more serious in areas with a greater influence of human activity. The subsoil can better reflect the characteristics of soil pollution in this region than the upper soil layer. Future research will focus on the main sources and pollution characteristics of pollutants under different land use types to provide a reference for decision-making by relevant local authorities.

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Data availability The data underlying this article will be shared on reasonable request to the corresponding author.

Declarations

Institutional review board statement Not applicable.

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Conflicts of interests The authors declare no conflict of interest.

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