Exploring the environmental properties and resource utilization of construction waste in Beijing-Tianjin-Hebei region

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Abstract

Beijing-Tianjin-Hebei region is a capital economic circle for the future. Promoting the coordinated development of its population, economy, resources and environment is a major national strategy. And as towns and cities continue to expand, the volume of construction waste is gradually expanding, posing a major challenge to the sustainable development of the construction industry. In order to solve this problem, this paper used portable XRF to realize the on-site rapid monitoring of heavy metals in construction waste, and the correlation analysis result was R^2 = 0.9622. The visualization of enrichment factor evaluation results was realized through ArcGIS. Beijing-Tianjin-Hebei region is mainly polluted by heavy metal elements Cr, Zn, Pb and Hg, showing regional pollution characteristics. The reason can be traced to the heavy industrial production in Tangshan, which is in line with the principle of industrial ecology. The results of leaching toxicity and cation anion analysis showed that the construction waste in Beijing-Tianjin-Hebei region had environmental risks to the surrounding surface water and groundwater. The resource treatment and disposal path were determined by means of XRD, ternary phase diagram and oxide composition analysis to avoid secondary pollution. This study explores the environmental properties and resource utilization pathways of construction waste in the Beijing-Tianjin-Hebei region, laying the foundation for research work on construction waste in the development of national urban agglomerations, effectively solving regional environmental pollution problems, and promoting the sustainable development of the construction industry.

1. Introduction

In recent years, with the acceleration of urbanization in China, the amount of construction waste is increasing, which has caused serious damage to the ecological environment and hindered the rapid development of urban economy. Buildings in major cities are facing renovation, decoration, reconstruction and expansion. The following problems of construction waste monitoring and management and resource utilization have gradually attracted people's attention. The gradual expansion of the volume of construction waste also poses a major threat to the sustainable development of the construction industry. According to statistics, the average annual production of construction waste in the world has exceeded 8 billion tons (Tang et al. **2020**). China alone produces no less than 3.5 billion tons of construction waste every year, accounting for 30% ~ 40% of the total amount of urban waste (Huang et al. **2018**). However, the resource disposal technology of construction waste in China is still backward, and the utilization rate of renewable resources is less than 10%, which not only occupies a lot of land for landfill, but also causes serious pollution of land, atmosphere and water resources, and even endangers human physical and mental health. This situation has attracted extensive attention at home and abroad (Ying et al. **2016**; Yuanyun et al. **2019**; Ding et al. **2018**; Silverstre et al. **2014**).

With the rapid development of economy and the emergence of urban agglomeration, China's environmental pollution presents regional characteristics. Environmental quality is affected not only by local pollution sources, but also by certain external influences. Under specific geographical space and meteorological conditions, pollutant emissions diffuse and accumulate on a certain spatial scale, making the pollution problems in a certain region converge (Yang et al. **2011**; Qing et al. **2010**; Suying et al. **2009**). Beijing-Tianjin-Hebei region is a capital economic circle built for the future, which helps to explore and improve the layout and form of urban agglomeration. It is the need to promote the coordination of population, economy, resources and environment, so as to drive the development of the economic region around the Bohai Sea. Therefore, combined with the layout of urban agglomeration, it is of certain practical significance and necessity to study the pollution of construction waste in Beijing-Tianjin-Hebei region and choose its resource disposal path, so as to build the construction of ecological civilization.

With the promotion of establishing a "waste free city" in China, the simple stacking of construction waste has had a serious negative impact on the ecological environment (Rahman et al. **2014**). Under the joint action of wind sand and rain, toxic and harmful substances in construction waste will penetrate into the surrounding soil, thus affecting the growth of crops (Xiaowen **2019**); It naturally flows into the surface water or infiltrates into the underground water body after rainfall, resulting in the pollution of the water source; Dust pollution will be generated during the transportation of construction waste from the place of generation to the stacking yard; The combustible components in construction waste will even cause certain potential safety hazards (Shuang et al. **2018**). Markey AM and others analyzed and tested the content of heavy metals in soil samples by flame atomic absorption spectrometry and X-ray analysis. The results show that the data obtained by the two analysis methods have good correlation, but it is still difficult to directly apply X-Ray Fluorescence spectrometry (XRF) to field detection (Markey et al. **2008**). Due to the cumbersome pretreatment steps, long time and high cost of conventional laboratory detection methods, XRF detection methods have been quite mature and are widely used in the fields of geology, biology, food, alloy and surface film. In recent years, people began to pay attention to the separation and discrimination of natural and man-made anomalies, and judged others as heavy metal pollution through pollution grey clustering method (Jing et al. **2007**; Xiuyan and Ende **2004**), ground accumulation index method (Yuan and Jianhua **2009**). Hakanson proposed the potential ecological hazard index method (Lars **1980**) to evaluate the potential ecological hazards of heavy metals, which provides an important scientific basis for rational planning and utilization of urban soil. For the mixed stacking of construction waste, there are also safety risks for the leaching substances in the actual environment. Praagh M V et al. found that there are harmful heavy metals and other substances in the leaching solution of concrete samples from the demolition waste of a factory in Sweden (Praagh and Modin **2016**). As an advanced technology, ion chromatography has the advantages of high resolution and high sensitivity. It has been widely used in various analytical fields. The U.S. National Environmental Protection Agency (U.S.EPA) stipulates that inorganic ions in water can be detected by ion chromatography (Zhixiong et al. **2001**). For the treatment and disposal of construction waste, China should achieve the goal of reduction, recycling and harmlessness at this stage. Therefore, it is necessary to explore the resource and environmental attributes of construction waste and judge its potential impact on the surrounding environment. For construction waste with pollution risk, the corresponding treatment and disposal path shall be formulated through phase analysis of samples to avoid secondary pollution.

The research object is various types of construction waste in Beijing-Tianjin-Hebei region. Combined with industrial ecology, portable XRF was used to quickly detect and analyze the collected samples. The key heavy metal elements include chromium, nickel, copper, zinc, arsenic, lead, manganese, mercury, cadmium, etc. Using the enrichment factor evaluation method, the visualization of heavy metal pollution degree in different regions was realized through ArcGIS. For the construction waste with significant or more pollution, the potential environmental impact on the surrounding surface water was preliminarily judged through leaching toxicity analysis and anion content analysis. For the construction waste with environmental pollution risk, by judging its XRD phase composition, combined with the ternary phase diagram and the oxide composition of the sample, the corresponding resource treatment and disposal path can be formulated to avoid secondary pollution. The research results prove that, combined with the layout of urban clusters, the resource and environmental properties of construction waste in the Beijing-Tianjin-Hebei region can be analyzed to determine the environmental risks of construction waste, and according to the principles of industrial ecology, the causes of pollution can be traced to the source, so as to control from the source and avoid the environmental pollution caused by the process of transportation and piling, and through resource utilization, the harmless treatment of construction waste can be realized, forming a technical system with regional characteristics to solve the problem of resource and environmental pollution in the process of national construction and development.

2. Experimental

2.1 Sample collection and pretreatment

2.1.1 Sample collection

As shown in Fig. 1, construction waste sampling sites are mainly concentrated in the Beijing-Tianjin-Hebei region of China, according to the principle of uniform grid placement. Among them, the sampling sites were mainly distributed in Haidian District and Fangshan District of Beijing, as shown in Fig. 2, Luquan District of Shijiazhuang City, Hebei Province, and Lubei District and Kaiping District of Tangshan City, as shown in Fig. 3. GPS was used to locate the latitude and longitude of sampling points, record the number of sampling points, geographic location, and type of construction waste, and use ArcGIS software to mark them on the map.

Among them, the construction waste samples include engineering residue, engineering slurry, engineering waste, demolition waste and decoration waste, and the specific sample numbers and sample types are shown in Table 1. Beijing mainly collected the waste generated in the process of demolition and renovation in a region, and the engineering waste generated by an environmental protection company. Shijiazhuang mainly collected demolition waste such as bricks, concrete and slag. Since Tangshan City is a heavy industrial city, samples of various types of construction waste from mining plants, steel plants, power plants, ceramic plants, cement plants, and a demolition district were selected to explore their resource and environmental properties.

Table 1
Number and type of construction waste samples

Urban area	Sample number	Sample type
Beijing	A1 ~ A29	Brick, concrete, plaster, slag, muck, fly ash, cement clinker, aggregate, plastering mortar
Shijiazhuang City	J1 ~ J9	Brick, concrete, muck, ceramic tile
Tangshan City	H1 ~ H26	Brick, concrete, earth, marble, slag, ceramics, cement clinker, putty powder

2.1.2 Sample pretreatment

All samples were sorted according to different types, and then placed in an electric constant temperature drying oven (WGL-230B) for 24 h and dried at 100 ± 5°C for 24 h, and then 1 kg of each sample was ground using a powerful hammer universal crusher (9F6-260) to obtain samples with particle size less than 2 mm to be tested, and the remaining samples were ground using an environmentally friendly roller crusher (KXHB-200*75) to obtain samples with particle size less than 5 mm to be stored for subsequent use.

2.2 XRF rapid monitoring and enrichment factor evaluation analysis

2.2.1 XRF rapid monitoring

The 5 ± 0.5 g sample powder was placed in a polyethylene sample box, compacted and at least 1 cm thick, with a polypropylene film closure at the top (Lelièvre et al. **2020**). The samples to be tested were subjected to a portable Thermo Scientific XRF with a 30 s calibration before each test, and the system automatically calibrated the algorithm to ensure the lowest deviation in the counts of all elements to be measured, including Cr, Ni, Cu, Zn, As, Pb, Mn, Hg, and Cd.

2.2.2 Evaluation analysis of enrichment factors

Based on the XRF test results, a preliminary evaluation analysis of the contamination level of the construction waste samples was performed by the enrichment factor method (Ukwatta and Mohajerani **2017**).

The evaluation of enrichment factor is as follows:

$$EF = \frac{(C_x / C_{ref})_{\text{sample}}}{(C_x / C_{ref})_{\text{baseline}}}$$

1

where:

C_x the concentration of heavy metal element X;

C_{ref} concentration of reference element;

sample the sample;

baseline background.

The degree of pollution caused by construction waste to the environment is determined according to the enrichment factor grading table, as shown in Table 2. The pollution degree is visualized by ArcGIS, and different colors represent different levels of pollution, including no pollution, slight pollution, moderate pollution, significant pollution, strong pollution, extreme pollution. The scope of application is the existence of spatial correlation of regionalized variables, which can not only quantify the spatial autocorrelation between known points, but also explain the spatial distribution of sampling points within the predicted area, so as to predict the overall distribution of pollution level in the area.

Table 2
Pollution grade table of enrichment factors

EF	Level	The degree of pollution
<2	1	EF<1 no pollution, 1<EF<2 slight pollution
2 ~ 5	2	Moderate pollution
5 ~ 20	3	Significant pollution
20 ~ 40	4	Strong pollution
>40	5	Extreme pollution

2.3 Environmental risk assessment

Construction waste leaching toxicity experiments were performed according to the method in the standard Solid Waste-Extraction Procedure for Leaching Toxicity-Sulphuric Acid & Nitric Acid Method (HJ/T 299–2007). The leached heavy metals Cr, Ni, Cu, Zn, Pb, Mn, and Cd contents were detected and analyzed by Inductively Coupled Plasma Mass Spectrometer (Nex10N 350), and As and Hg contents were detected and analyzed by Atomic Fluorescence Spectrophotometer (AFS-933). The anion and cation contents were detected and analyzed by Ion Chromatograph (ECO-IC), where the anions included F^-, Cl^-, NO_2^-, NO_3^-, SO_4^{2-}, and the cations included Li^+, Na^+, K^+, Mg^{2+}, Ca^{2+}.

2.4 Analysis of resource and environmental properties

To further investigate the resource utilization pathway of construction waste, X-Ray Polycrystalline Diffractometer (XRD, Model D8 ADVANCE, Bruker AXS Ltd., Karlsruhe, Germany) was used to analyze the physical phase composition of the samples, and Thermo Scientific XRF, USA was used to determine the oxide content of the samples, including SiO_2, CaO, Al_2O_3, Fe_2O_3, MgO, K_2O, combined with the silicate ternary phase diagram, as shown in Fig. 4, to verify that the sample oxide percentage is within the desired interval.

3. Results And Discussions

3.1 Correlation analysis

According to the research, advanced large-scale instruments have achieved accurate detection of heavy metals, but rely on the laboratory environment to carry out, its pre-processing steps are cumbersome, time-consuming and expensive, and cannot achieve on-site monitoring. Then how to quickly and accurately detect heavy metal content in construction waste, so as to conduct timely environmental risk assessment, has become one of the current research priorities to solve the problem of construction waste pollution.

Therefore, this study used XRF rapid monitoring means, in order to verify the accuracy of XRF test results, selected the national scope of each region without contaminated soil, each heavy metal detection results and geoenvironmental chemical background values for correlation analysis, the results are shown in Fig. 5, R^2 is 0.9622, a linear relationship, with good correlation, indicating that XRF as a field rapid monitoring means, can be used for the construction of This indicates that XRF can be used as an on-site rapid monitoring tool for monitoring the heavy metal content in construction waste.

3.2 Regional pollution assessment

The distribution maps of different heavy metal pollution levels in Haidian District, Beijing are shown in Fig. 6, and the distribution maps of different heavy metal pollution levels in Fangshan District, Beijing are shown in Fig. 7. Eight heavy metal elements, Cr, Ni, Cu, Zn, As, Pb, Mn and Hg, were selected for evaluation and analysis. The evaluation results of Cr element show that some samples have significant and above contamination, among which waste incineration slag has extreme contamination. Ni element evaluation results show that all samples are contaminated to a lesser extent except for waste incineration slag with strong contamination, refuse stone with extreme contamination and fly ash with significant contamination. For Cu element, only waste incineration slag and fly ash have extreme contamination. For Zn element, the wall tiles in the decoration waste are strongly contaminated and some samples are significantly contaminated. As element, except for the strong contamination of fly ash, the rest of the samples are lightly contaminated. Pb element, except for the extreme contamination of fly ash, some samples are significantly contaminated. Relatively speaking, the overall contamination of Mn element is light. For the more hazardous Hg element, Liushui clinker is strongly contaminated, the fly ash is extremely contaminated, and the rest of the contaminated samples are moderately contaminated and above. In summary, it can be seen that, according to the sampling points by different heavy metal pollution situation, so as to predict the overall pollution degree distribution of the region, the Beijing area as a whole by the heavy metal Cr, Zn, Pb, Hg pollution degree is more obvious, where the waste incineration slag and fly ash samples are the key pollution source objects.

Beijing has a complete range of landform types, including mesas, low hills and plains, and more soil types, with flooded alluvium as the main soil in the plains. Waste incineration pollution products in the ash contains a certain amount of heavy metal elements, including Cr, Zn, Cu, etc. The amount of slag is generally 5–20% of the total weight of waste before incineration, especially the fly ash, fly ash is the fuel combustion process discharged in tiny ash particles, also known as fly ash or soot, incineration fly ash contains a large number of Cr, Ni, Cu, Zn, Pb, Hg and other heavy metals, if not directly discharged without treatment, will cause pollution to the soil, surface water and groundwater sources, the atmosphere, causing great damage to the environment. A large amount of fly ash will form dust and enter water bodies through rainfall thus causing heavy enrichment of Hg elements and seriously endangering the life and health of organisms and human beings. The results show that different types of construction waste in Beijing have different degrees of pollution to the environment and need to be treated and disposed of by certain means before they can be placed. Cement kiln co-disposal is a new means of waste disposal proposed by the cement industry. It refers to the process of harmless disposal of solid waste that meets or is pre-treated to meet the requirements for entry into the kiln by putting it into the cement kiln and carrying out cement clinker production at the same time. At this stage, 80% of solid hazardous waste generated by waste incineration plants in all districts and counties of Beijing are harmlessly disposed of by cement kiln co-disposal technology, which not only effectively reduces the risk of environmental pollution caused by construction waste, but also forms certain economic and social benefits and realizes the promotion value.

The distribution of different heavy metal pollution levels in Luquan District, Shijiazhuang City, Hebei Province, is shown in Fig. 8, and eight heavy metal elements, Cr, Ni, Cu, Zn, As, Pb, Mn and Hg, were selected for evaluation and analysis. The evaluation results of Cr, Ni, Cu, As and Mn elements showed that the samples were contaminated to a lesser extent. The evaluation results of tile samples in Liujie Village showed that there was strong contamination of Zn elements and significant contamination of Pb elements. The evaluation results of Hg elements showed that there was strong contamination of sintered brick samples in Liujie Village and extreme contamination of concrete in Liujie Village, while the rest of the samples were not contaminated. In summary, it can be seen that the Shijiazhuang city area as a whole is contaminated with heavy metal Hg to a more significant extent.

Shijiazhuang city area spans two major geomorphological units, Taihang Mountain and North China Plain, and Shijiazhuang city soil types mainly include brown loam, brown soil, tidal soil and other 11 soil types. The industry of Luquan District started from relying on traditional industries to develop mineral resources and formed four leading industries, namely, construction materials, metallurgical machinery, light industrial food, pharmaceutical and chemical industries, while coal-fired power plants are the largest source of global Hg emissions in the atmosphere, and if fly ash is produced during the production process, thus forming dust, which falls to the ground or water bodies through wet deposition or dry deposition, will cause different degrees of enrichment of Hg elements. Hg in soil can volatilize into the atmosphere or be washed by precipitation into surface water and groundwater, thus polluting surrounding water sources. At the same time, the contamination results of concrete and sintered brick samples indicate that risk evaluation of environmental hazards is needed for both the disposal and utilization of construction materials and recycled products to avoid secondary contamination.

The distribution of different heavy metal pollution levels in Lubei District, Tangshan City, Hebei Province is shown in Fig. 9, and the distribution of different heavy metal pollution levels in Kaiping District, Tangshan City, Hebei Province is shown in Fig. 10. Nine heavy metal elements, Cr, Ni, Cu, Zn, As, Pb, Mn, Hg and Cd, were selected for evaluation and analysis. The results of the Cr elemental evaluation showed that the samples of waste ceramics from the ceramics factory and the samples of porcelain, porcelain bowls and sanitary ware from the demolition waste in Shangzhuang, Kaiping were significantly contaminated, while the rest of the samples were contaminated to a lesser extent. The evaluation results of Ni, Cu and Mn elements showed that the samples were contaminated to a lesser extent. For Zn and Pb elements, both the ceramic factory raw soil and waste ceramic samples were extremely contaminated, and the relevant porcelain utensils in Kaiping Shangzhuang demolition waste were strongly contaminated or above. The Kaiping Shangzhuang demolition porcelain sample was extremely contaminated with element As, and the rest of the samples were contaminated to a lesser extent. The results of the elemental Hg evaluation showed that the bricks removed from the state mining building, the soil outside the steel plant and the cement clinker from the cement plant were contaminated to a strong degree and above. Except for Kaiping Shangzhuang dismantled porcelain bowl which was extremely contaminated with element Cd, the rest of the samples were not contaminated. In summary, it can be seen that the whole area of Tangshan City is polluted by heavy metals Cr, Zn, Pb and Hg to a more significant extent, and individual samples have extreme pollution of As and Cd elements, of which Tangshan ceramic factory and cement factory are the key pollution source objects.

The terrain in Tangshan City can be divided into two major geomorphic areas: the Yanshan Mountain Hills and the Luan River Plain, with a warm temperate semi-humid continental monsoon climate and a full range of mineral resources, with more than 50 kinds of mineral deposits found and with proven reserves. As raw materials for cement production, including siliceous raw materials, limestone, and iron raw materials, the high temperature oxidation of chromium in these raw materials in the rotary kiln can have an impact on the water-soluble hexavalent chromium content in the final cement product, resulting in varying degrees of Cr element enrichment. Tangshan has a long history of ceramics and is the northern porcelain capital of China and one of the major ceramic producing areas in China, with a history of nearly 600 years. The raw materials for ceramic production contain zinc oxide substances, so it leads to the enrichment of Zn elements. During the production of sanitary ceramics, solid small particles of dust are produced during injection molding, and ceramics produce large amounts of Pb during kiln firing, resulting in a serious enrichment of Pb elements. Hg easily forms alloys with most common metals, and iron powder has been used to replace Hg, so during the production of iron and steel, Hg elements are replaced, and the same will cause different degrees of enrichment of Hg elements. Fly ash as cement mix or concrete admixture has become the most important auxiliary cementitious material in modern concrete materials. the process of Hg release from the surface of fly ash is composed of the process of Hg desorption from the surface of the particles and Hg diffusion in the pores inside the particles. Traceability of fly ash in cement raw materials leads to the release of Hg, which results in severe enrichment of elemental Hg contamination. As is mainly used in the manufacture of pesticides and hard alloys, in addition to glass, pigments, dyes, coatings, semiconductors and pharmaceuticals. Cd is mainly used in the manufacture of batteries, pigments, and alloys, and nitrate compounds of Cd are used as photographic sensitizing emulsions and can be used to color glass and ceramics.

In summary, the results show that this demolition waste taken from Tangshan Kaiping Shangzhuang demolition district, the sample type are demolition porcelain ware, the source of pollution can be traced back to Tangshan ceramics factory, compared with the enrichment factor calculation results, Cr, Zn, Pb elements are moderate and above degree of pollution, pollution and Tangshan ceramics factory raw materials to maintain a high degree of consistency, so the cause of pollution can be fully traced back to the source. Meanwhile, the individual samples of element As and Cd showed extremely strong contamination cases, which were closely related to the preparation of raw materials, while considering the influence of surrounding human activities and demolition of waste dumps.

3.3 Environmental risk assessment

3.3.1 Leaching toxicity analysis

The leaching toxicity of solid waste is the concentration of pollutants in the leachate measured by using the specified leaching procedure for leaching solid waste. Referring to the Identification Standards for Hazardous Wastes-Identification for Extraction Toxicity (GB 5085.3–2007), Environmental Quality Standards for Surface Water (GB 3838 – 2002) Class III standard limits, as shown in Table 3, if the concentration of pollutants in the leachate exceeds the standard limits, it is determined that this solid waste has leaching toxicity and may bring potential pollution risks to the water environment, etc. Therefore, leaching toxicity is an important evaluation index for the resource utilization of solid waste and an important basis for guiding the selection of waste treatment and disposal methods.

Table 3
Standard limits for basic items (mg/L)

Hazardous component items	Cr	Ni	Cu	Zn	As	Pb	Mn	Hg	Cd
Standard limits for leaching toxicity identification	5	5	100	100	5	5	-	0.1	1
Standard limits for class III surface water	0.05	0.02	1	1	0.05	0.05	0.1	0.0001	0.005

The results of the leaching toxicity analysis of the Beijing samples are shown in Fig. **11**, the source of the samples with significant and above degree of heavy metal contamination, compared with the leaching toxicity identification standard limits, all samples were not exceeded. Compared with the standard limits of surface water category III, individual samples of heavy metals Cr, Ni, Pb, Mn and Hg exceeded the standard limits, while other heavy metal elements did not exceed the standard limits. Shijiazhuang samples leaching toxicity analysis results are shown in Fig. **12**, the source is the presence of significant and above degree of contamination of heavy metals samples, compared with the leaching toxicity identification standard limits, all samples are not exceeded. Compared with the standard limits of surface water category III, individual samples of heavy metals Cr, Ni and Mn exceeded the standard limits, while other heavy metals did not exceed the standard limits. The results of leaching toxicity analysis of Tangshan City samples are shown in Fig. **13**, the source is the presence of significant and above degree of contamination of heavy metals samples, compared with the leaching toxicity identification standard limits, all samples are not exceeded. Compared with the standard limits of surface water category III, individual samples of heavy metals Cr, Ni, Zn, Mn, Hg exceeded the standard limits, while other heavy metal elements did not exceed the standard limits.

The results showed that the contamination evaluation of the samples using the enrichment factor method was consistent with the results of leaching toxicity analysis, further confirming that XRF can be used as an on-site rapid monitoring tool for the preliminary evaluation of the realistic risk of construction waste to the environment. Among them, the existence of variability is due to the migration and transformation laws of different heavy metal elements in different media, which are closely related to their own valence state and form of existence (Zhangxiong et al. **2017**), when the heavy metal elements are in the exchangeable state they are easily leached, while in the stable state, they are generally difficult to release. In summary, the leaching toxicity results in the Beijing-Tianjin-Hebei region, there are heavy metal exceedances, confirming that the region's construction waste on environmental water bodies are a certain degree of pollution, for the risk of environmental pollution of construction waste, the need to develop a corresponding treatment and disposal path to avoid secondary pollution.

3.3.2 Environmental impact analysis of cation and anion

Solid waste by water washing, soaking, the harmful components will be transferred to the water phase and lead to secondary pollution, pollution sources, including heavy metals, while also need to consider the impact of leachate anion and cation content on the surrounding water environment. Referring to the Environmental Quality Standards for Surface Water (GB 3838 – 2002) and Standard for Groundwater Quality (GB/T 14848 – 2017) III standard limits, as shown in Table 4, if the concentration of anions and cations in the leaching solution exceeds the standard limits, there is a potential environmental impact on the surrounding surface water and groundwater.

Table 4
Basic project standard limits (mg/L)

Hazardous component items	F^-	Cl^-	NO_2^-	NO_3^-	SO_4^{2-}
Standard limit	1.0	250	1.0	10	250

The samples were sourced from various types of construction waste in Tangshan City, and the anion and cation contents in the leachate were detected by leaching experiments using ion chromatography, and the results are shown in Fig. 14. The figure shows the average concentration after removing the anomalies, where the anomalies are listed separately in the following, and the upper and lower edges of the box represent the maximum and minimum values of a certain ion concentration, respectively. Overall, the concentrations of F^-, Cl^-, NO_2^-, NO_3^-, Li^+, Na^+, and Mg^{2+} were all lower than 10 mg/L. The average concentration of SO_4^{2-} was 34.6 mg/L, the average concentration of K^+ was 6.21 mg/L, and the average concentration of Ca^{2+} was 27.8 mg/L. As can be seen from the figure, the average concentration of Cl^- was 24.4 mg/L, which was far above the overall level, indicating the existence of samples with high concentrations, which should be taken seriously.

The results of exceeding the standard limit values are summarized in Table 5. Among them, the F^- concentration of raw clay in H14 ceramic plant is 1.5 mg/L, and the F^- concentration of H21 demolition tile is 1.0 mg/L, both of which exceed the standard limit value. The Cl^- concentration of H24 cement clinker is 459.0 mg/L, which far exceed the standard limit value. The NO_2^-concentration of H10 mine plant bricks is 1.4 mg/L, the NO_2^- concentration of H26 water-resistant putty powder is 1.2 mg/L, and the SO_4^{2-} concentration is 321.7 mg/L, all of which exceed the standard limits. In summary, ceramic plants, mining plants, cement plant products in the production process, should consider whether the content of anions and cations in it exceeds the standard limit, and then put into later use.

Fluorine is a cumulative toxicant, fluorine pollution can poison animals and plants, affecting agricultural and pastoral production, and the concentration of fluoride in drinking water should not exceed 1.0 mg/L (Dianjun et al. **2001**). Excessive chlorine content in water is harmful to the respiratory system and can easily react with organic matter in water to generate carcinogens such as chloroform and trichloromethane, which can even contaminate groundwater and drinking water sources in severe cases (Bo and An **2015**). Large doses of nitrite are capable of causing methemoglobinemia, leading to tissue hypoxia, and also lowering blood pressure by vasodilatation, as well as being one of the most acutely toxic substances in food additives (Zhifeng **2007**). There are many metal ions in the environment that can combine with sulfate to form stable sulfate, and sulfur dioxide gas formed by sulfate in the atmosphere has a corrosive and destructive effect on materials, endangering the health of plants and animals, and can play a catalytic role, aggravating the toxicity of sulfuric acid fog, and destroying the soil structure after reaching the ground with precipitation, reducing soil fertility and causing corrosion to the water delivery system (Yonghong and Kun **2015**). The results show that the construction waste in this area has potential environmental impact on the surrounding surface water and groundwater, and should not be piled up at will, but need to be harmless and resourceful to reduce the existing environmental risks and improve the environmental benefits.

Table 5
Some test results of cation and anion exceeding the standard limit (mg/L)

Hazardous component items	F^-	Cl^-	NO_2^-	NO_3^-	SO_4^{2-}
H10	0.5	1.7	1.4	1.3	18.7
H14	1.5	0.5	0	1.5	3.3
H15	1.4	0.5	0	1.2	3.6
H21	1.0	0.5	0	0.9	18.0
H24	0.2	459.0	0	1.1	119.0
H26	0.6	6.1	1.2	1.0	321.7

3.4 Resource and environment attribute analysis

3.4.1 XRD analysis

Selected demolition waste samples from this study area, including slag type, waste brick type, dust collection ash, and cement type, were analyzed for their mineral composition as shown in Fig. 15, which showed that the main phase compositions were quartz, sodium feldspar, calcite, dolomite, hydrous calcium zeolite, and mullite. The renovation waste samples included mud type, waste brick type, concrete, and gypsum, and their mineral compositions were analyzed as shown in Fig. 16, which showed that the main phase compositions were dolomite, quartz, silica-calcite, sodium feldspar, and mullite.

Among them, dolomite and mullite can be used in building materials, ceramics, glass and refractory materials, chemical industry as well as agriculture, environmental protection, energy saving and other fields. Quartz lumps, also known as silica, are mainly used as raw materials for the production of quartz sand, as well as quartz refractories and for firing ferrosilicon. Hard calcium silica, soda feldspar and calcite can be used as industrial raw materials for manufacturing cement, glass, ceramics, etc. The results of regional pollution evaluation in Beijing show that fly ash samples are the key pollution source objects, while the main physical phase of fly ash is vitreous, accounting for 50%~80%, containing crystal minerals such as mullite, calcite, etc., which have been widely used in the production and manufacture of cement and various light building materials, effectively solving the environmental pollution problem while bringing certain economic benefits.

In summary, it can be seen that due to the real environmental risk of construction waste, it cannot be directly disposed of in piles, and the physical phase analysis of the samples is carried out to provide a theoretical basis for its resourceful disposal path.

3.4.2 Oxide content analysis

In the process of construction waste resource treatment and disposal, sintered bricks, cement and ceramic pellets can be used as recycled products and applied in practical production and life. The oxide composition of some construction waste samples and the ideal intervals of major oxide contents in raw materials are listed in Table 6, respectively. Among them, H5, H6, J1, J7 and J8 are waste brick type, H8 is demolition marble type, H22 is waste porcelain type, H24 and H25 are cement clinker and other samples in cement plants. As can be seen from the table, the composition and percentage of oxides in the samples of waste bricks, demolition marble and waste porcelain are basically in accordance with the firing requirements of sintered bricks and ceramic granules, and the content of the main mineral components in the samples of cement clinker are within the desired interval.

Sintered bricks undergo a series of changes in the mineral composition as well as mineral structure in the material during the heating and roasting stage, while the recycled products undergo changes in color, weight capacity, water absorption, etc. due to different oxide content. SiO_2 is an important component of the sintered brick material, and this type of mineral has an effect on the frost resistance and mechanical strength of the recycled product. CaO as a common co-solvent in brick manufacturing, mainly affects the firing temperature range of the sintered brick process, its content should not exceed 5%, when the content is high, it will narrow the firing temperature range of clay-based materials, increasing the technical requirements of the roasting process. When the Al_2O_3 content is high, it increases the firing temperature of the recycled product and, in addition to that, affects the mechanical strength of the fired product (Shukun et al. **2014**). The action of SiO_2 and CaO generates calcium silicate, the main mineral of silicate cement clinker, and silicate minerals are the main minerals of cement strength, if the SiO_2 content is insufficient will lead to low strength of cement, the appropriate increase of SiO_2 content at the same time can enhance the corrosion resistance of cement. Al_2O_3 and Fe_2O_3 are the main oxides that produce the liquid phase during the firing of cement clinker and play an important role in the firing of cement (Khudyakova et al. **2019**). As a new type of material, ceramic pellets have the characteristics of heat insulation, light weight and durability, earthquake and frost resistance, etc. They have been widely used in construction, greening and environmental protection in recent years. SiO_2 and Al_2O_3 are skeletal components, providing strength to the pellets, and Fe_2O_3 is a gas-generating component, causing the pellets to expand. Other oxides are fluxing components, which can reduce the sintering temperature. The pellet expansion performance is better when the SiO_2 content is 50 ~ 70%, Al_2O_3 content is 14 ~ 20%, and the sum of co-solvents (Fe_2O_3, MgO, CaO, Na_2O, K_2O) is 4.5 ~ 31% (Chen et al. **2020**).

In summary, all the selected samples of this part of construction waste have different degrees of pollution problems, and the content and proportion of their main oxide components are within the ideal range, which can be applied to the production and reuse of sintered bricks, cement and ceramic granules. This shows that the determination of the oxide content of the sample, combined with the analysis of the ternary phase diagram of silicate, can be used as an important reference basis for the manufacture of recycled products, which not only effectively solves the environmental pollution problem of the sample, but also can further determine its resource disposal path.

Table 6
Oxide composition of some construction waste samples

The sample number	Al_2O_3(%)	Fe_2O_3(%)	SiO_2(%)	CaO(%)	MgO(%)	K_2O(%)
H5	21.72	6.67	61.68	3.65	1.11	1.92
H6	12.90	3.31	58.02	1.44	1.33	1.89
H8	11.73	1.59	61.23	1.55	0.67	3.69
H22	23.16	1.16	60.02	1.25	0.70	2.11
H24	7.19	10.65	18.34	35.85	3.96	0.38
H25	3.72	15.45	15.16	36.33	4.64	0.32
J1	14.65	4.61	51.74	1.31	1.01	2.04
J7	14.96	4.33	57.37	3.26	1.10	1.82
J8	13.19	4.90	56.20	3.32	0.84	1.89
Brick	10 ~ 25	3 ~ 10	55 ~ 70	<5	3	-
Cement	4 ~ 8	3 ~ 6	20 ~ 23	64 ~ 67	<5	-
Ceramsite	14 ~ 20	5 ~ 10	50 ~ 70	<7	<7	<4

4. Conclusion

By exploring the environmental properties and resource utilization of construction waste in the Beijing-Tianjin-Hebei region, the following conclusions can be drawn.

(1) The results of correlation analysis show that XRF can be used as a convenient field detection method for the rapid and accurate detection of Cr, Ni, Cu, Zn, As, Pb, Mn, Hg, Cd and other heavy metals in construction waste, as opposed to the traditional complex laboratory detection methods, and the preliminary screening of the collected samples, which provides a certain theoretical guidance basis for subsequent laboratory monitoring and environmental risk assessment.

(2) The evaluation results of enrichment factors show that the degree of heavy metal pollution in different regions can be visualized by ArcGIS, and the Beijing-Tianjin-Hebei region is mainly contaminated by heavy metal elements Cr, Zn, Pb and Hg, and individual samples are contaminated by heavy metal elements As and Cd, showing the characteristics of regional pollution, and combined with industrial ecology, the cause of pollution can be traced to the heavy industrial production in Tangshan City, which is closely related to the preparation of raw materials, while considering the influence of surrounding human activities and demolition dumps. Therefore, the construction waste in the region should be controlled at source to avoid environmental pollution caused by the process of transportation and piling.

(3) The results of leaching toxicity and anion analysis show that construction waste in the Beijing-Tianjin-Hebei region has potential environmental impact on the surrounding surface water and groundwater, and the corresponding treatment and disposal paths need to be developed to avoid secondary pollution.

(4) Meanwhile, using XRD physical phase analysis, ternary phase diagram and oxide composition analysis methods, it can be used as an important reference standard for manufacturing recycled products, such as sintered bricks, cement and ceramic pellets, to determine their resourceful disposal path, which truly realizes the harmless treatment of construction waste and brings certain economic benefits at the same time.

In summary, this study evaluates the environmental risk of construction waste in the Beijing-Tianjin-Hebei region and determines its resource and harmless disposal path through the analysis of resource and environmental properties, and forms a technical system with regional characteristics by combining the layout of urban agglomerations, which lays the foundation for the research work on construction waste in the development of national urban agglomerations, and effectively solves the national regional environmental pollution problem and promotes the sustainable development of the green construction industry based on the principles of industrial ecology.

Declarations

Author contribution

Shuxin Hu designed the framework and wrote the manuscript. Fumin Ren was responsible for financing the acquisition and contributed to writing the manuscript. Jinming Jia, Can Cui, Nana Cui, Tong Lu, Guotao Liu, Boyu Zhang, Junshi Liu provided technical and editorial assistance. Changhong Guo, Li Ma, Han Si provided experimental technical support.

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Data availability

The datasets used and analyzed during the current study are available from the corresponding author on reasonable request.

Ethics approval and consent to participate. Not applicable.

Consent for publication. Not applicable.

Competing interests. The authors declare no competing interests.

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Figures

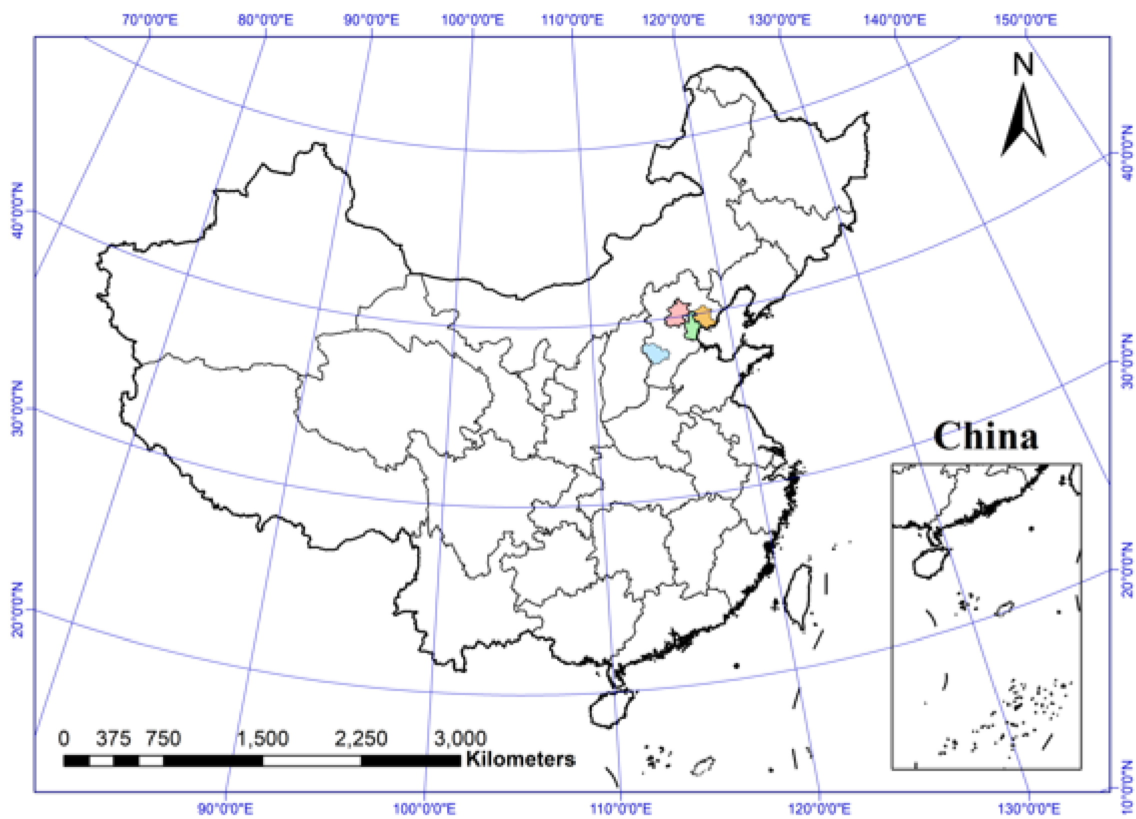

Figure 1

Sampling sites in the Beijing-Tianjin-Hebei region

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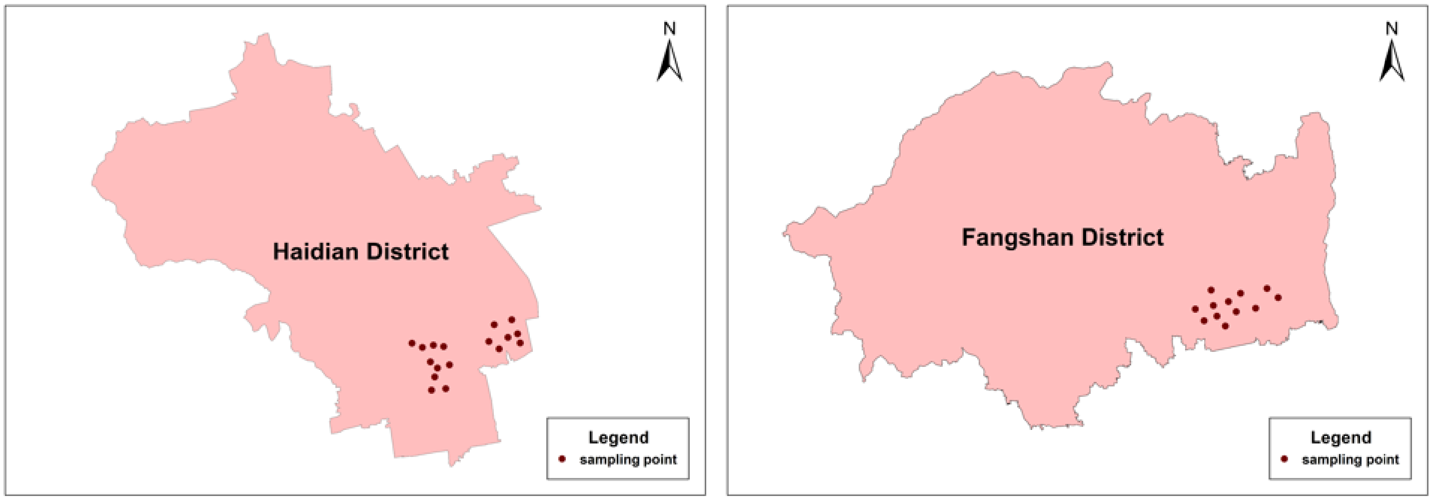

Figure 2

Sampling sites in Haidian and Fangshan (areas in Beijing, China)

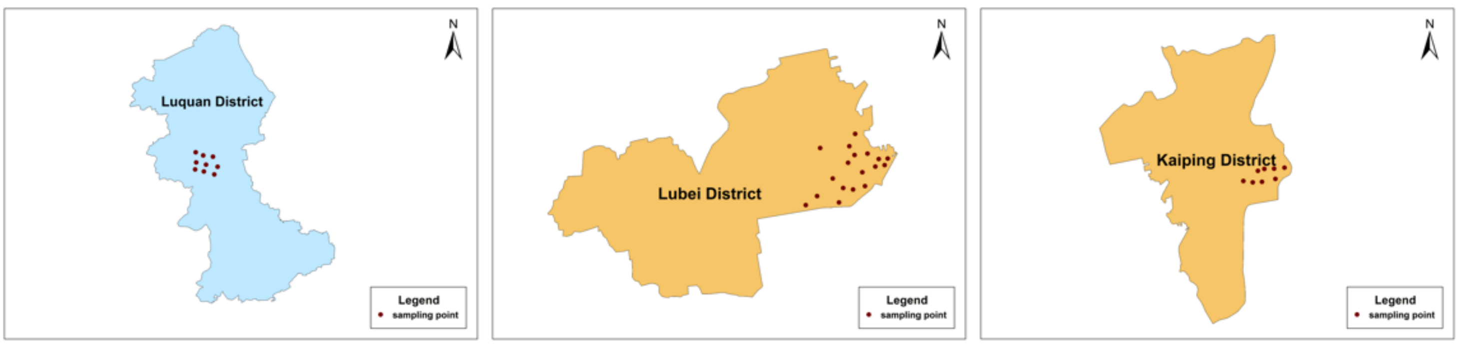

Figure 3

Sampling sites in Luquan, Lubei and Kaiping (areas in Hebei, China)

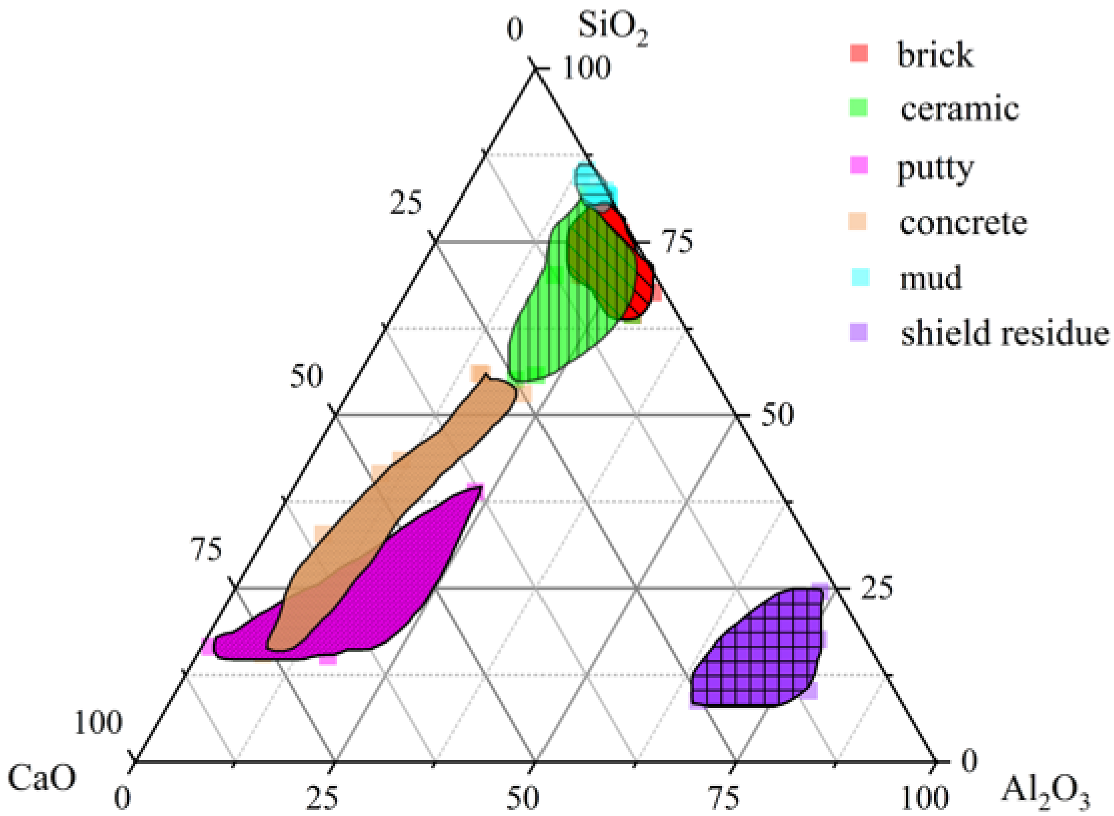

Figure 4

Silicate ternary phase diagram

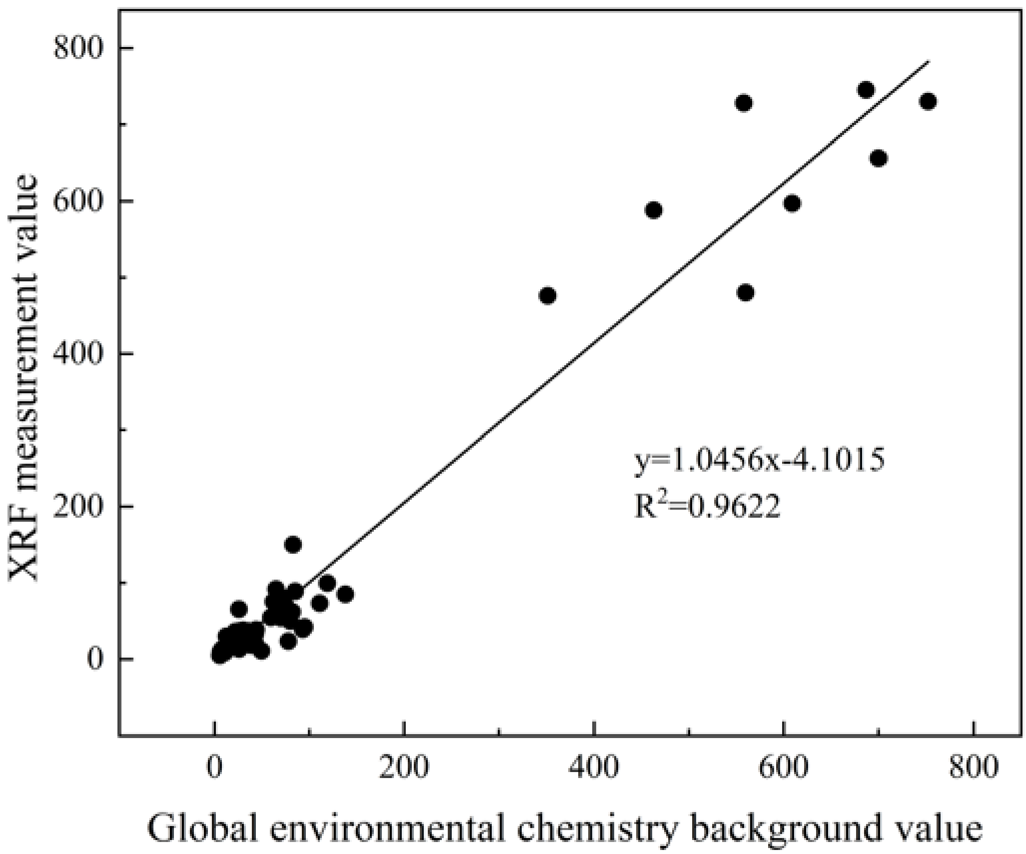

Figure 5

The correlation between Global environmental chemistry background value and XRF measurement value

Figure 6

Distribution map of different heavy metal pollution levels in Haidian District, Beijing

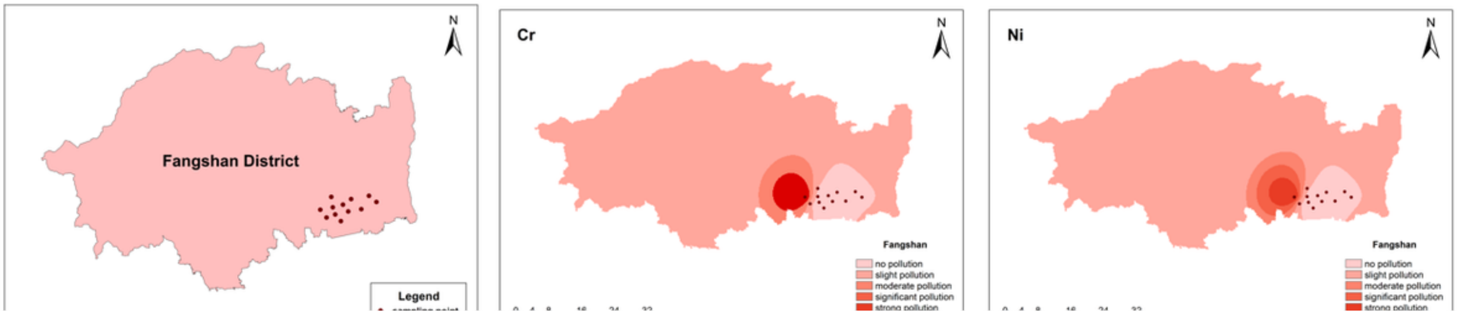

Figure 7

Distribution map of different heavy metal pollution levels in Fangshan District, Beijing

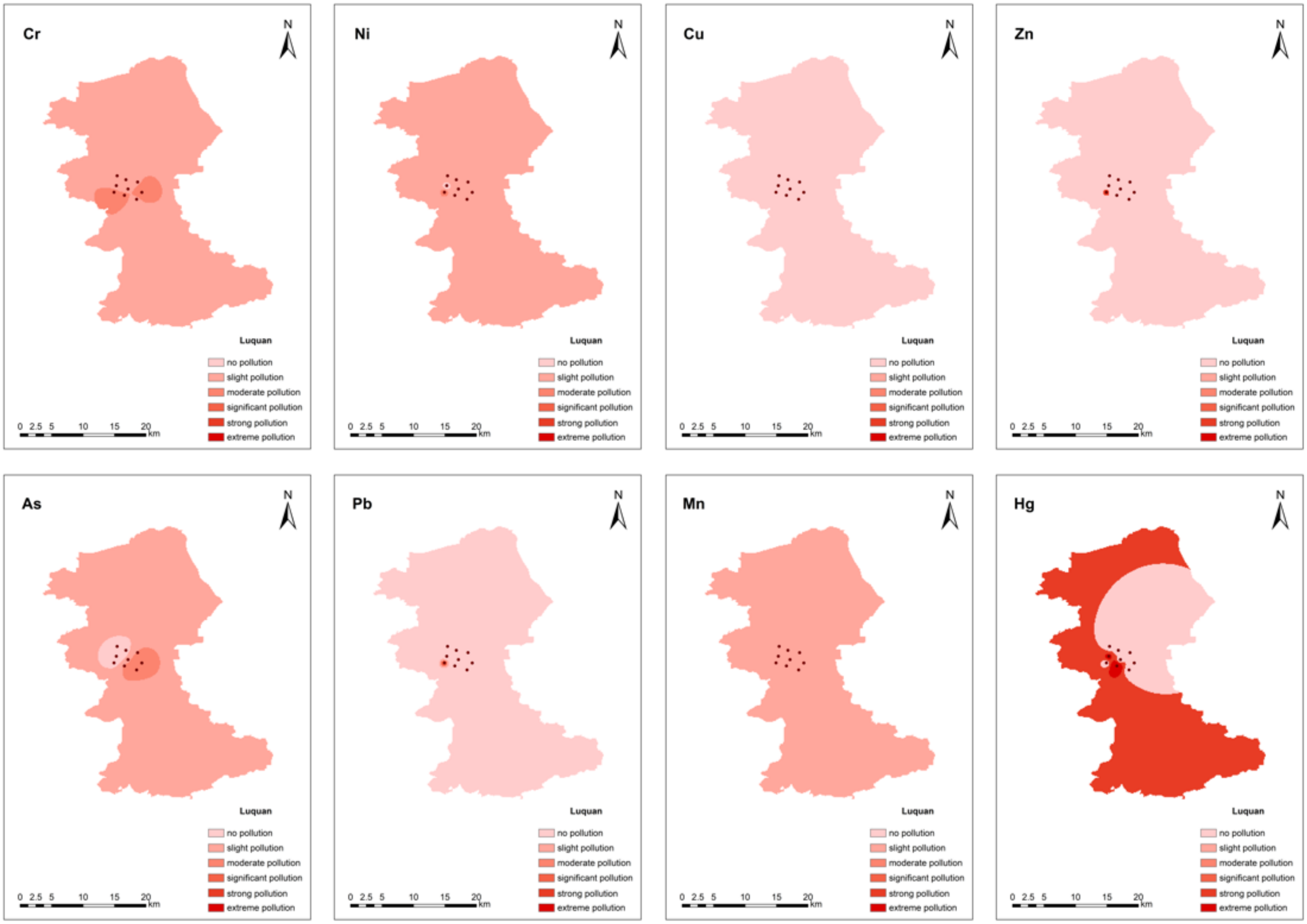

Figure 8

Distribution map of different heavy metal pollution levels in Luquan District, Hebei Province

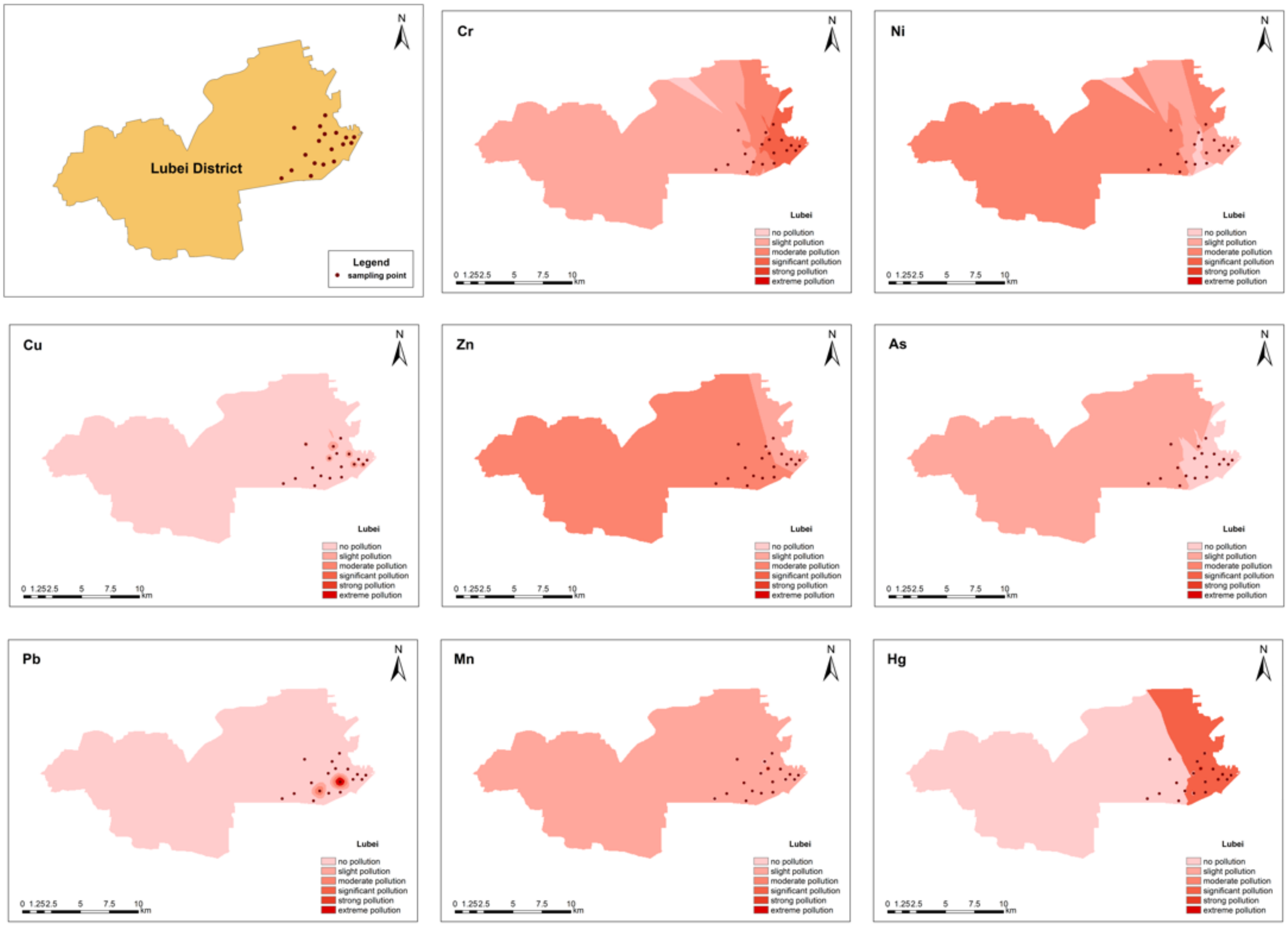

Figure 9

Distribution map of different heavy metal pollution levels in Lubei District, Hebei Province

Figure 10

Distribution map of different heavy metal pollution levels in Kaiping District, Hebei Province

Figure 11

Leaching toxicity results of heavily polluted samples in Beijing

Figure 12

Leaching toxicity results of heavily polluted samples in Shijiazhuang

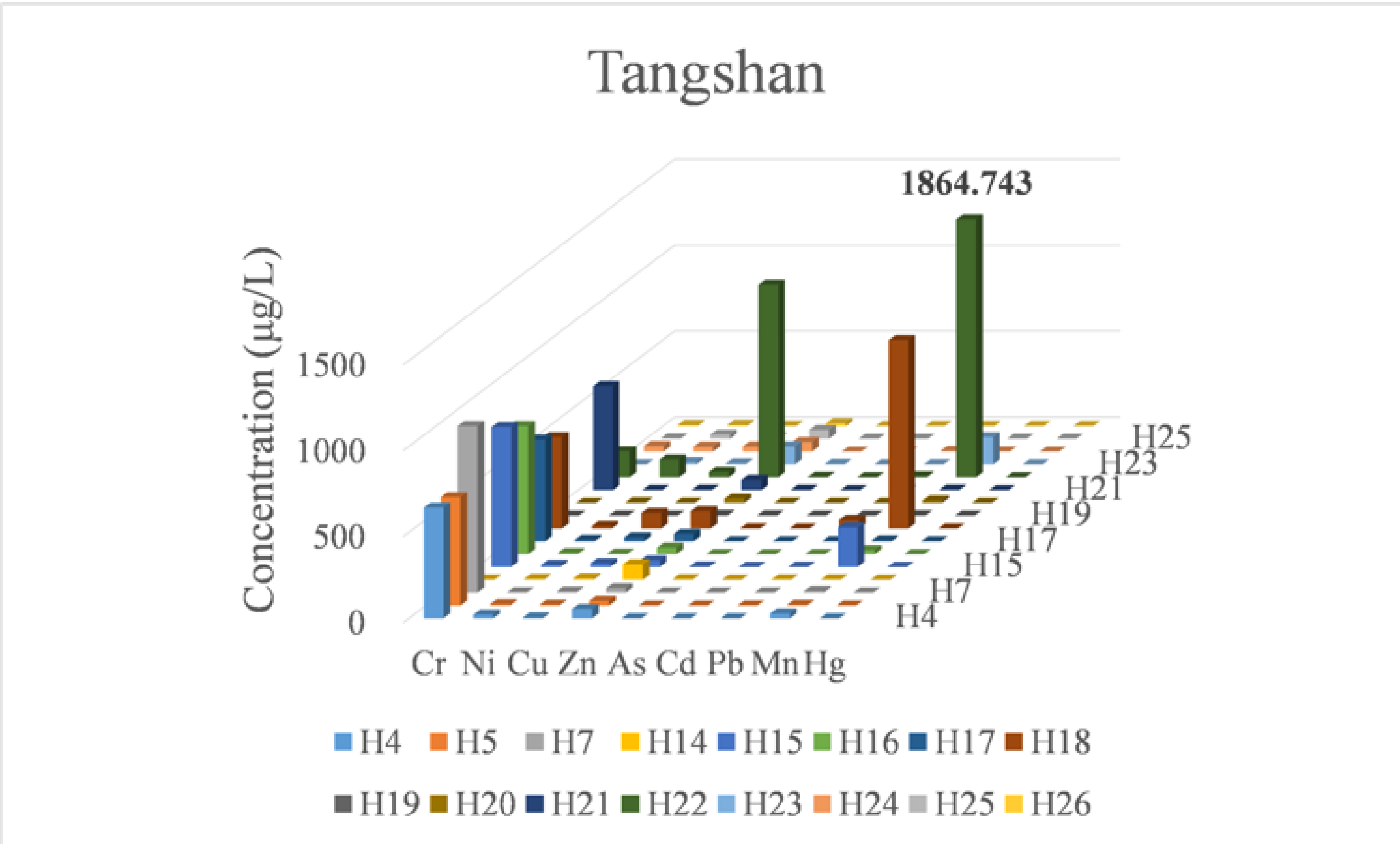

Figure 13

Leaching toxicity results of heavily polluted samples in Tangshan

Figure 14

Test results of cation and anion content

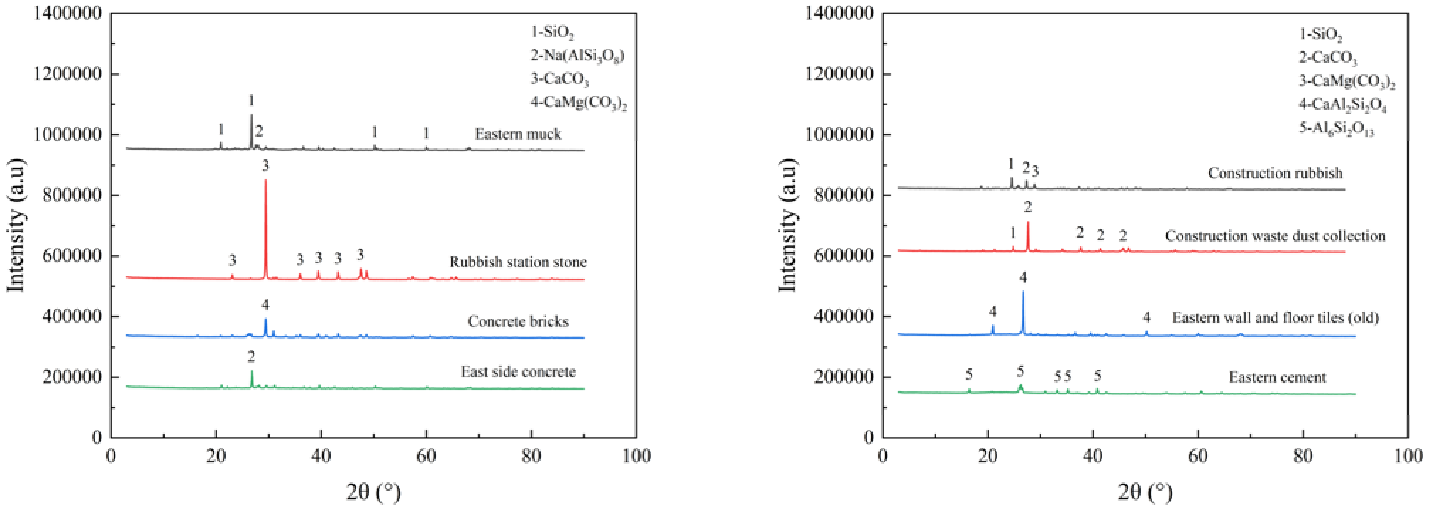

Figure 15

Phase composition of demolition waste in study area

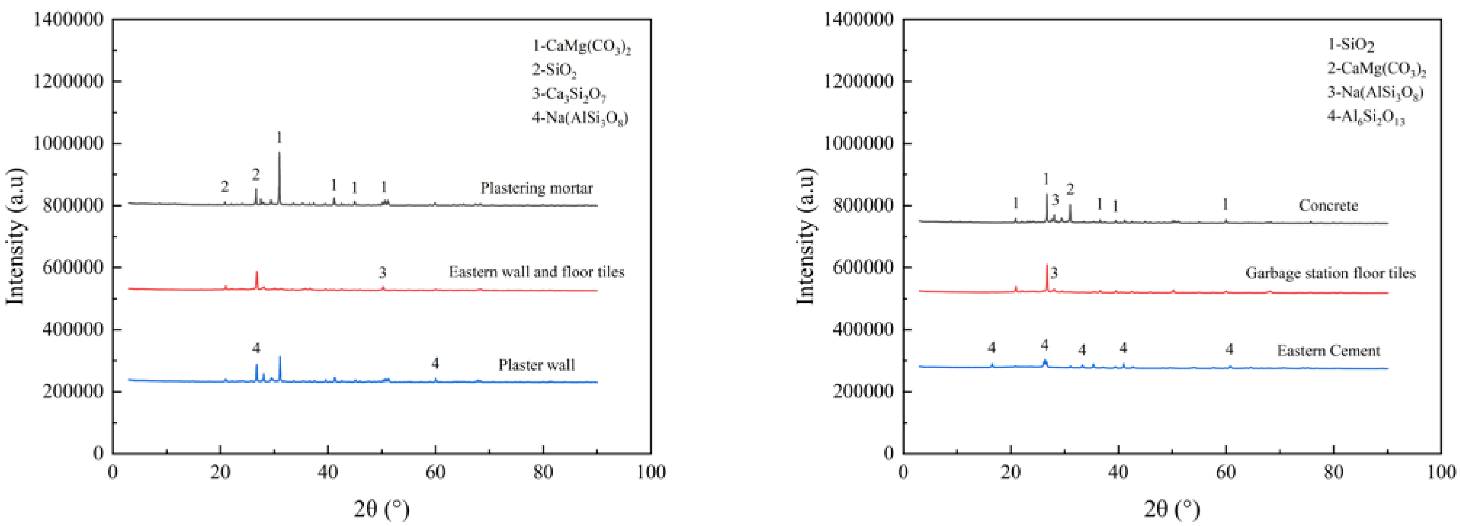

Figure 16

Phase composition of decoration waste in study area