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The Content and Sources of Potentially Toxic Elements in the Road Dust of Surgut (Russia)

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Abstract: The chemical and particle size composition of road dust in Surgut, which is a rapidly developing city in Western Siberia, was studied for the first time. Contents of major and trace elements were determined using ICP-MS and ICP-AES, respectively. It was found that the road dust had an alkaline pH (from 7.54 to 9.38) and that the particle size composition was dominated by the 100–250-µm fraction. The contamination assessment based on calculations of the enrichment factor (*EF*) showed that the road dust was significantly enriched in Sb and Cu and moderately enriched in Zn, Pb, Mo, Ni and W. The sources of these elements are probably associated with the abrasion of car tires and brake pads. Based on calculations of global pollution index (PIr) and total enrichment factor (*Ze*), the road dust of Surgut was characterized by a generally low level of potential ecological risk, except for stretches of road subject to regular traffic jams, where a moderate ecological risk level was identified. In comparison to the other Russian cities (Moscow, Chelyabinsk, Tyumen, etc.) where studies of road dust composition have been carried out, Surgut had similar contents of Cr and Cu and relatively lower contents of Sb, Cd, As and Pb.

Keywords: Western Siberia; urban pollution; road dust; potentially toxic elements; traffic-related contamination

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1. Introduction

Road dust is currently one of the main materials used in assessments of the ecological state of urban and industrial environments. Studies on road dust composition help to assess the total accumulation of pollutants from the atmosphere, soils and technogenic sources and to forecast the effects of those pollutants on human health. The advantages of using road dust in such assessments include its ease of sampling, ubiquity and non-point source nature, as well as its strong relationship with car exhaust emissions [1].

The road dust deposited within transport zones is regarded as a multicomponent mixture of different fractions that are formed as a result of soil erosion, abrasion of road surfaces and vehicle parts, incomplete combustion of fuel, application of de-icing agents, etc. [2–5]. Particles of road dust can accumulate many potentially toxic metals, metalloids and organic compounds [6–9]. The deposition rates of road dust and its chemical composition depend on factors such as vehicle emissions; abrasion of road tarmac, road markings, car tires and brake pads; and the corrosion of metal parts of vehicles, as well as traffic densities, speed and frequencies of car maneuvers such as braking and stopping [10–12]. At the same time, resuspended particles can be one of the most important sources of microparticles in the atmosphere [13]. The high concentration of harmful substances in the dust makes it hazardous to human health. Microparticles can be lifted by air currents and inhaled by humans and, therefore, increase the risks of respiratory, cardiovascular and oncological diseases [14]. Globally, road dust is a major source of inhalable particulate matter in any urban environment [15].

According to the Russian Federal Service for State Statistics, 75% of the country's population live in cities [16]. Numerous studies have reported that transport-related air pollution is one of the dominant sources of urban air pollution and is a continuously contributing emission [17–19]. In many cities of Russia, numerous dangerous environmental situations resulting from atmospheric air pollution have been repeatedly noted [20,21]. Therefore, ecological assessments of such cities are highly important for providing comfortable and safe conditions for their residents. However, the majority of such assessments are conducted in large cities, with a lack of attention given to medium-sized and smaller cities.

There have been few studies on road dust within the territory of the former Soviet Union. Determinations of road dust composition have been carried out in Moscow [13,22–26], cities of the Perm Region [27], Chelyabinsk [20] and Alushta [28]. In Tyumen (West Siberia), Konstantinova et al. [29] have analyzed 20 samples of road dust, which were found to have high concentrations of Cr, Ni and Co.

Surgut has one of the highest concentrations of motorized vehicles in Russia, with about 200,000 vehicles registered within this city. Busy highways running through Surgut connect different cities and numerous oil fields of Western Siberia. There is also a railway running across Surgut. The city streets and roads have a total length of 266.7 km, which corresponds to about 10% of the total area of urban constructions [30]. Such a high intensity of traffic has negative effects on the health of Surgut residents, in particular elevating the risks of cancer [31]. Traffic densities within the city drastically increase during certain peak hours of the mornings and evenings, when the traffic becomes very heavy and moves at an average speed of less than 10 km per hour. Nevertheless, the impacts of such traffic on the content of trace elements, including potentially toxic elements (PTEs), within the road dust of Surgut have not been studied until the present time. The objectives of this study were as follows: (i) to determine the total concentrations of major and trace elements, including PTEs, in the road dust of Surgut city, (ii) to assess the degree of contamination using contamination indices, (iii) to identify the potential sources of PTEs and (iv) to evaluate the human health risks of road dust.

2. Materials and Methods

2.1. Study Area

Surgut is located in the center of the West Siberian Plain, within the taiga zone. The climate is continental, with a mean annual temperature of −1.8 °C and a mean annual precipitation of 652 mm [32]. Southern and western winds prevail. The rapid development of Surgut began in the 1960s, following the discovery of numerous oil fields in the vicinities of the city. The population of Surgut grew from just over 6 thousand people in the early 1960s to 200 thousand in the mid-1980s and has reached nearly 400 thousand at the present time.

Surgut is one of the fastest growing cities in Russia. It is characterized by well-developed power engineering, food production, printing, building, publishing and sewing industries. Surgut's two largest gas-fired power stations, with a total output of 8.9 thousand MW, provide most of the regional power supply.

The ecological conditions of Surgut have been insufficiently studied, with only very few assessments within small areas. It has been found that the snowpack in Surgut is contaminated by heavy metals [33] and that Pb concentration in road-side soils exceeds its maximal permissible concentration [34]. Dumps of domestic and industrial waste also negatively affect the surrounding soils, where heavy metal concentrations exceed their maximal levels according to the ecological standards [35]. Moreover, there is a lack of data on the composition of the native soils of the Surgut region. It is only known that sandy soils with low contents of trace elements prevail within the Fedorovskoye Oil Field at distances of 20–50 km to the north of Surgut [36,37].

2.2. Sampling and Laboratory Analyses

Road dust sampling was undertaken in July 2021 during dry weather periods, i.e., no less than 36 h after any low-intensity rainfall. Samples of 200–300 g each were collected from

road surfaces within 1 × 1 quadrats using a plastic brush and a scoop, placed into plastic bags and delivered to the laboratory. Sampling sites were located on roads with different traffic densities within different land use areas of the city. High, moderate and low traffic densities corresponded to >2, 1–2 and <1 thousand cars per hour. The traffic data were sourced from the municipal program for the development of transport infrastructure in Surgut [30]. The different types of land use were recorded at the sampling sites as follows:

(1) Industrial and warehouse area.
(2) High-rise residential area.
(3) Low-rise residential area.
(4) Power plant area.
(5) Public and business area.
(6) Transport hubs (railway station and airport).

A total of 25 samples were taken. It has been shown that a relatively low number of samples (16–31) is sufficient for evaluating the level of pollution of road dust in cities with a medium population, e.g., Thessaloniki, Greece [38], Ma'an City, Jordan [39] and Sakaka city, Saudi Arabia [40]. Locations of the sampling sites are shown in Figure 1. A detailed description of the sampling sites is presented in Supplementary Materials, Table S1.

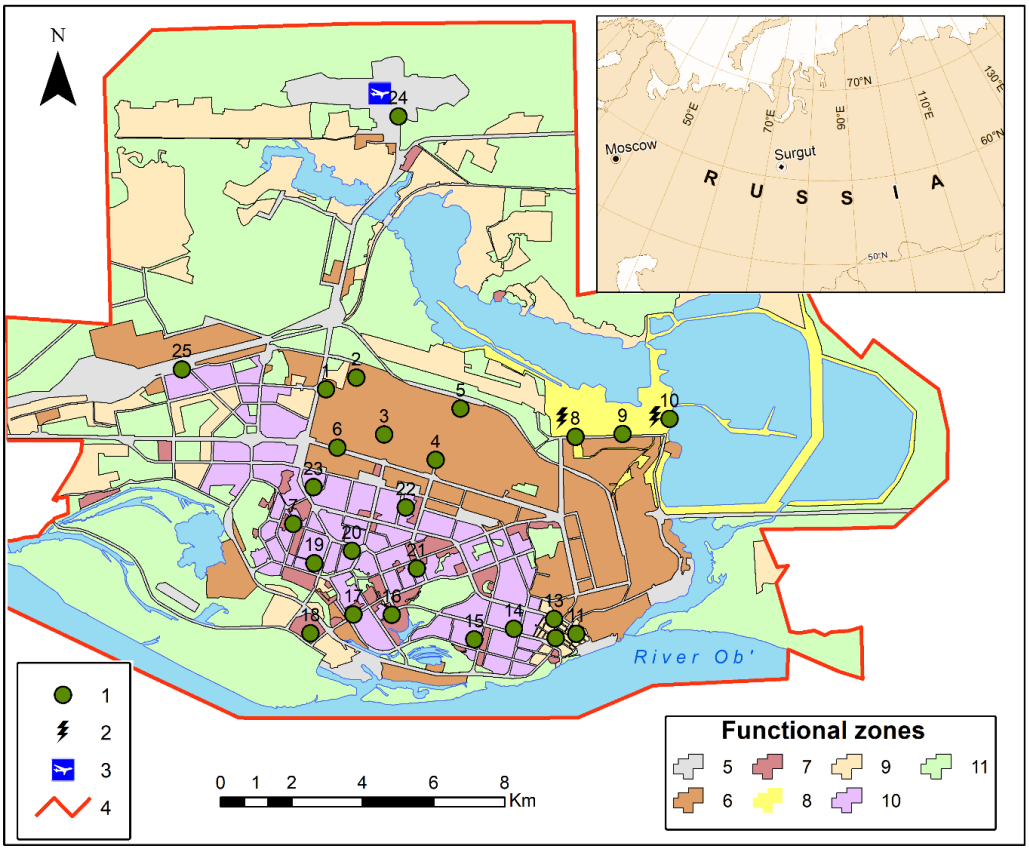

Figure 1. Sampling sites and land use areas within the city of Surgut: 1—sampling sites; 2—power plants; 3—airport; 4—city border; 5—transport area; 6—industrial and warehouse area; 7—public and business area; 8—power plant area; 9—low-rise area; 10—high-rise residential area; 11—recreation area, urban forests, green spaces.

In the laboratory, the samples were passed through a sieve with an aperture of 1 mm in order to remove coarse inclusions (fragments of plants, rubbish, etc.). Although the pollutant concentrations in fine fractions (PM1 and PM10) of road dust are known to be higher than those in coarse fractions [13], we analyzed bulk samples in order to be able to compare our results from Surgut with the data from other cities. Bulk samples have been

used in the majority of studies on road dust composition, whereas fine fractions have been separately analyzed in only a few studies [7,13,26,41].

The pH values were measured potentiometrically in continuously mixed 1:2.5 dust:water suspensions using a Starter3100 conductivity meter (OHAUS, Baden-Wuerttemberg, Germany). The particle size distribution was determined using a Mastersizer 3000 laser diffraction particle size analyzer. Concentrations of 54 trace elements (Li, Be, Sc, V, Cr, Co, Ni, Cu, Zn, Ga, As, Se, Rb, Sr, Y, Zr, Nb, Mo, Rh, Pd, Ag, Cd, Sn, Sb, Te, Cs, Ba, La, Ce, Pr, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb, Lu, Hf, Ta, W, Re, Ir, Pt, Au, Hg, Tl, Pb, Bi, Th, U) and 8 major elements in weight percent oxide for the particulate fraction (Na_2O, MgO, Al_2O_3, P_2O_5, S, K_2O, CaO, Fe_2O_3) were measured by inductively coupled plasma mass spectrometry (ICP-MS) (Thermo Elemental—X7 spectrometer, Omaha, NE, USA) and inductively coupled plasma atom emission spectrometry (ICP-AES) (Thermo Scientific iCAP-6500 spectrometer, Thermo Fisher Scientific, Waltham, MA, USA), respectively. The analyzed samples, 100 mg each, were prepared by acid digestion in an open beaker system. The samples were placed in Teflon beakers (volume 50 mL); 0.1 mL of a solution containing 8 μg dm^{-3} 145Nd, 61Dy and 174Yb was added (control of the chemical yield during the sample decomposition procedure); and the mixture was moistened with several drops of deionized water. Then, 0.5 mL of $HClO_4$ (perchloric acid fuming 70% Supratur, Merck), 3 mL of HF (hydrofluoric acid 40% GR, ISO, Merck KGaA, Darmstadt, Germany) and 0.5 mL of HNO_3 (nitric acid 65%, max. 0.0000005%% GR, ISO, Merck) were added and evaporated until intense white vapors appeared. The beakers were cooled, their walls were washed with water and the solution was again evaporated to wet salts. Then, 2 mL of HCl (hydrochloric acid fuming 37% OR, ISO, Merck KGaA, Darmstadt, Germany) and 0.2 mL of 0.1 M H_3BO_3 solution (analytical grade) were added and evaporated to a volume of 0.5–0.7 mL. The resulting solutions were transferred into polyethylene bottles, 0.1 mL of a solution containing 10 mg L^{-1} In (internal standard) was added, diluted with deionized water to 20 mL and analysis was performed.

In addition to the studied samples, measurements were also taken for the blank and reference samples. We used the certified reference materials for soils—Gabbro Essexit STD-2A (GSO 8670-2005) and Andesite AGV-2 (United States Geological Survey)—in order to verify the accuracy of determinations. The comparison with the standard samples showed a sufficient repeatability (85–115%) for the majority of the analyzed elements, except for Sn (59%), Ba (70%), Ag (153%), Mo (78%) and W (63%), the measurements of which were excluded from the calculations. The analysis was performed in the Institute of Microelectronics Technology and High Purity Materials (Russian Academy of Sciences). The methods, recoveries, detection limits (DLs) and analytical results of the certified reference materials are given in the Supplementary Materials (Table S2).

2.3. Calculations and Data Processing

The processing of the statistical data was performed using Statistica 10.0 software (TIBCO, Palo Alto, CA, USA). Statistical parameters of the road dust composition (mean, standard deviation, maximum and minimum values) were determined. The significance of differences between the mean values for roads with different traffic intensities was assessed using the Mann–Whitney test.

Assessments carried out by two or more methods can improve the accuracy of the assessment result [42]. Therefore, to improve the accuracy of the result and make the assessment more comprehensive and systematic, additional methods were applied. Assessments of road dust contamination levels were based on calculations of generally accepted indices, including the global pollution index (*PIr*), enrichment factor (*EF*) and potential ecological risk index (E_r^i), as well as the total potential ecological risk index (*RI*) and total enrichment factor (*Ze*), the latter being commonly used in Russia.

The values of *PIr* were calculated using the following equation:

$$PIr = Cr/K, \quad (1)$$

where *Cr* is the concentration of an element in road dust and *K* is the concentration of the same element in the upper continental crust [13].

The *EF* of an element, which is an important parameter for evaluating the contribution of human impact to its enrichment, is the normalization of a measured element against a reference element in a studied sample [43]. The *EF* was calculated according to the equation:

$$EF = \frac{Cx}{CAl}(sample) \,/\, \frac{Cx}{CAl}(crust), \quad (2)$$

where *Cx* (*sample*) is the measured concentration of the element of interest, *Cx* (*crust*) is the concentration of the same element in the Earth's crust and *CAl* is the concentration of the reference element (aluminum) in the same sample or the Earth's crust. Aluminum is most commonly used for calculations of *EF* [44–46]. The low mobility and crustal abundance of Al makes it a suitable reference element. The composition of the upper continental crust was used as a reference for normalization because of the lack of a background analogue for road dust, which is a specific anthropogenic object [13]. The same method of calculation was applied in the other Russian cities studied [13,20,24,26,28]. The use of world average values in the continental crust is acceptable only within regions where there are no geochemical anomalies associated with the features of the geological structure. In this case, the element contents of soils, which are the source of particles in the atmosphere, are close to continental crust values. According to the scientific research on the contents of some heavy metals and metalloids in Western Siberia soils [47,48], they are not very different from continental crust values. Indeed, the average contents of the elements in the soils of Western Siberia are as follows (mg kg^{-1}): Co—13, Cr—84, Cu—31, Ni—42, Pb—18, Zn—73 and Zr—295 [47]. These values are quite close to continental crust values according to Rudnick and Gao [49]. Therefore, comparisons with the distribution of elements in the Earth's crust are considered reasonable.

The potential ecological risk index E_r^i, which characterizes the degree of the ecological risk of a single element [50], was calculated by using the following equation:

$$E_r^i = PIr \cdot T_r^i \quad (3)$$

where *PIr* is the global pollution index and T_r^i is the toxicity response coefficient. This index provides for the probability assessment of adverse ecological effects caused by exposure by to one or more pollutants [44]. In this study, we used the response T_r^i values according to [50] as follows: Zn, Mn, Fe, W, Sr = 1; Cr, Mo, Sn, Sb = 2; Pb, Cu, Co, Ni = 5; As = 10 and Cd = 30. For risk assessments, we adopted the following gradation: E_r^ii < 40 describes low risk; 40 < E_r^i < 80 indicates moderate risk; 80 < E_r^i < 160 indicates considerable risk; 160 < E_r^i < 320 indicates high risk; and E_r^i > 320 indicates extreme risk [50,51].

The total rate of accumulation of PTEs and other chemical elements was estimated using two indices, the total potential ecological risk index (*RI*) and the total enrichment factor (*Ze*), because the use of different indices provides for the most accurate assessment of the ecological situation. The *RI* index, which characterizes the overall degree of the ecological risk of all metals under investigation [50], was calculated according to equation:

$$RI = \sum E_r^i \quad (4)$$

where E_r^i is a potential ecological risk index of a single element. Risk levels were graded as follows: *RI* < 150, low; 150 < *RI* < 300, moderate; 300 < *RI* < 600, considerable and *RI* > 600, high ecological risk.

The values *Ze* were calculated using the following equation:

$$Ze = \sum EF - (n - 1) \quad (5)$$

where *EF* of *n* elements with *EF* > 1.5 were summed up [24].

Criteria for assessment of road dust contamination are presented in Table 1.

Table 1. Grades of enrichment factor (*EF*), potential ecological risk index (E_r^i), total potential ecological risk index (*RI*) and total enrichment factor (*Ze*).

Enrichment Factor		Potential Ecological Risk Index		Total Potential Ecological Risk Index		Total Enrichment Factor	
EF values	Enrichment level [1]		E_r^i grades [50]	*RI* values	*RI* levels [50]	*Ze* values	Environmental hazards [13,25,26]
$EF \leq 2$	Minimal	$E_r^i < 40$	Low	$RI < 150$	Low	<32	Non-hazardous
$2 < EF \leq 5$	Moderate	$40 < E_r^i < 80$	Moderate	$150 \leq RI < 300$	Moderate	32–64	Moderately dangerous
$5 < EF \leq 20$	Significant	$80 < E_r^i < 160$	Considerable	$200 \leq RI < 600$	High	64–128	Dangerous
$20 < EF \leq 40$	Very High	$160 < E_r^i < 320$	High	$RI \geq 600$	Very High	128–256	Very dangerous

Varimax-rotated principal component analysis (PCA) was applied to investigate the sources of PTEs. PCA is widely used to reduce data and to extract a small number of latent factors (principal components, PCs) for analyzing relationships among the observed variables [52].

The influence of road dust on the health of the Surgut population was evaluated using the U.S. Environmental Protection Agency (EPA) human health evaluation method [53]. This method implies that dust can induce negative effects when it is assimilated by the human body in three different pathways—ingestion, inhalation and dermal contact. Carcinogenic and non-carcinogenic risks can be calculated by summing up the risks from the three exposure pathways.

The calculations of such risks were based on the average daily dose (ADD) of the total assimilation of a certain element in three different ways. The equations and parameter values used for the calculations are presented in Table S3. Following the ADD calculations, we conducted determinations of non-carcinogenic hazard quotient (HQ) and carcinogenic risk assessment (CRA) using the following equation:

$$\mathrm{HQ} = \mathrm{ADD}/\mathrm{RfD},$$

where reference dose RfD (mg kg^{-1} day^{-1}) is an estimation of the maximum permissible risks to the human population through daily exposure with consideration of sensitive groups during their lifetime.

Hazard index (HI), the sum of HQ(Ing/Der/Inh), was used by us to estimate the health risk of different exposure pathways. HI values of ≤ 1 indicate no adverse health effects and HI values > 1 indicate possible adverse health effects [54].

For carcinogenic risk (CRA), the dose was multiplied by the corresponding slope factor (SF) to produce an estimate of cancer risk [55] as follows:

$$\mathrm{CRA} = \mathrm{ADD\ ing,\ dermal,\ inh} \times \mathrm{SF}$$

Total cancer risk (CRAsum) was calculated as the sum of CRA for three exposure pathways (ingestion, inhalation and dermal contact).

3. Results

3.1. The pH and Particle Size Distribution

The analyzed dust had an alkaline reaction, with a pH ranging from 7.54 to 9.38. The roads with low, moderate and high traffic densities were characterized by mean pH values of 8.04, 7.80 and 7.82, respectively. The data on road dust pH in other cities of the world fall within generally the same range, between 7 and 9.5 [56–59]. The alkaline reaction of city road dust is explained by the presence of microparticles of building materials as well as different pollutants originating from vehicle exhaust emissions. Acidifying gaseous compounds (mainly nitrogen oxides) of car exhausts are removed by air currents, whereas alkaline particulate matter stays on the road surface. According to [34], the urban soils of

Surgut have neutral and alkaline pH values, as opposed to acid background soils around the city.

The particle size distribution of road dust was characterized by the predominance of the 100–250-μm size fraction (fine sand), which ranged from 19.5 to 50.1% with a mean of 39%. The content of the 100–250-μm size fraction (very fine sand) was significantly lower, with a mean of 14.4%. Sand-sized particles (>50 μm) composed between 45 and 95% of the total mass (with a mean of 82.5%). The 2–10-μm size fraction and the 10–50-μm size fraction had mean contents of 3.2 and 13.8%, respectively. The content of clay (<2 μm) ranged from 0.1 to 2.5%.

Sand (mainly fine sand) is known to be the predominant particle size fraction of road dust in many Russian cities. For example, in Chelyabinsk, which is not very far from Surgut, road dust is characterized by the predominance of particles from 30 to 300 μm [21]. In Moscow, road dust has the following mean contents of fractions: PM1—1.8%, PM10—12.8%, 10–50-μm size fraction—16.3% and >50 μm size fraction—69.1% [24]. The predominance of coarse particles in road dust has been reported from many cities of the world. For example, the urban sediments collected from Manchester were made up primarily of medium sand-sized particles ranging in size from 200 to 300 μm [60]. The 125–500-μm fraction was prevalent in the road dust of Thessaloniki, Greece [38].

It is generally believed that the predominance of particles of 180–240 μm in road dust is indicative of deposition of soil particles together with particles produced by the movement of vehicles, i.e., the abrasion of road surfaces, tires and metal parts of cars [61]. Smaller particles usually originate from industrial emissions [21]. It has been found that dust from metallurgical enterprises has a median particle size ranging from 1.0 to 200 mm and volumes of PM10 from 10 to 84% depending on the technological processes and the raw materials used [62]. Therefore, the composition of road dust from Surgut mainly resulted from the deposition of soil particles and particles produced by traffic, with only a low contribution of particles originating from industrial plants.

The distribution of fractions of road dust depending on traffic densities is shown in Table 2. The highest contents of PM10 particles, which are easily carried by winds and create the highest risks for human health, were observed on roads with moderate and high traffic densities. The lowest contents of fine particles combined with the predominance of sand were found on small roads with low traffic densities. However, such differences between the roads with different traffic intensities were only very small. The Mann–Whitney test showed that the differences between the mean values of contents of those particle size fractions were insignificant. The highest percentage (26.5%) of fine (<50 μm) particles was found within the public and business area, which is located in the southern part of Surgut (sampling sites 16–18, see Figure 1). Such a high content of fine particles can be explained by the predominance of fine-textured alluvial soils within that area.

3.2. The Chemical Composition of Road Dust

Summary statistics for the studied chemical element contents in the road dust of Surgut are presented in Table 3. The predominant major elements include Al_2O_3 (with a mean of 4.2%), CaO (3.9%), MgO (2.8%) and Fe_2O_3 (2.4%), with the other major elements having mean contents of <1%. The upper part of continental Earth's crust has a different descending order of major element concentrations: Al_2O_3 (15.4%), Fe_2O_3 (5.0%), CaO (3.6%), Na_2O (3.27%), K_2O (2.8%) and MgO (2.48%), according to [49]. In comparison with the latter, Surgut's road dust has relatively low contents of aluminum and iron but a relatively high content of magnesium.

The majority of trace elements in the road dust had lower contents as compared to those in the upper part of the continental Earth's crust, which was indicated by the PIr values (see Table 3). For example, the contents of Li, Be, Ga, As, Rb, Zr, Nb, all rare earth elements, Th and U were 3–10 times as low as their Clarke numbers. Most PTEs (Hg, As, Ni, Cr, Co, V) do not accumulate in the road dust of Surgut. Such low contents of trace elements can be explained by the predominance of sand fractions and low contents of fine

fractions in the particle size composition of the studied samples. It has been repeatedly shown that fine particles are most enriched in trace elements [63,64].

Relative enrichment as compared to the world average values in the Earth's continental crust was observed in Sb, Cu, Zn, Cd and Pb (Table 3). The elements accumulated in Surgut's road dust can be defined as typical urban pollutants, including Cd, Pb, Sb, Ti, Ba, Zn and, to a lesser degree, Cu [65–68]. A similar assemblage of pollutants (Sb, Pb, Zn, Cd, Cu and Sn) has been found in the road dust of Moscow [13].

Table 2. The percentage of particle size fractions (mm) in road dust depending on (a) traffic densities and (b) land use within Surgut city.

Area	<0.002	0.002–0.01	0.01–0.05	0.05–0.1	0.1–0.25	0.25–0.5	0.5–1.0
Traffic Densities:							
Low (n = 8)	0.5 ± 0.1 [1]	2.6 ± 0.7	14.9 ± 5.1	14.6 ± 6.7	36.7 ± 5.4	26.1 ± 7.4	4.4 ± 0.4
Moderate (n = 14)	0.7 ± 0.7	3.8 ± 3.2	14.0 ± 8.5	14.5 ± 4.0	40.0 ± 6.9	24.2 ± 7.8	2.7 ± 1.9
High (n = 3)	0.4 ± 0.1	2.1 ± 0.7	12.0 ± 5.1	15.0 ± 6.7	42.0 ± 5.4	26.2 ± 7.6	2.4 ± 0.4
Land use Areas							
Industrial and warehouse area (n = 6)	0.25 ± 0.3	2.0 ± 1.1	8.9 ± 3.6	11.9 ± 2.8	44.4 ± 3.4	29.5 ± 4.6	3.1 ± 1.4
High-rise residential area (n = 6)	0.5 ± 0.32	2.6 ± 0.8	13.2 ± 5.7	16.0 ± 6.0	39.0 ± 5.0	25.1 ± 7.5	3.5 ± 1.9
Low-rise residential area (n = 5)	0.7 ± 1.0	4.4 ± 5.0	13.6 ± 13.8	12.2 ± 5.3	36.9 ± 9.4	27.1 ± 12.2	4.8 ± 3.9
Power plant area (n = 3)	0.9 ± 0.7	4.5 ± 2.6	14.5 ± 7.5	14.8 ± 2.4	39.3 ± 4,2	23.2 ± 7.3	3.1 ± 2.6
Public and business area (n = 3)	0.9 ± 0.6	3.0 ± 0.9	26.5 ± 13.4	21.0 ± 2.9	31.0 ± 9.4	15.8 ± 7.4	1.9 ± 0.9
Transport hubs (n = 2)	0.7 ± 0.2	3.6 ± 1.0	10.8 ± 5.8	11.9 ± 4.4	43.8 ± 3.4	27.3 ± 7.5	2.0 ± 0.6

[1] Mean ± SD.

Table 3. Summary statistics for the contents of PTEs and other chemical elements in Surgut's road dust, n = 25 (Na_2O- Fe_2O_3 in %, Li-U in mg kg^{-1}).

Element	DL	Mean	Sd	Min	Max	V, %	WA	PIr
Al_2O_3	0.009	4.2	0.97	2.6	6.68	23	15.4	0.3 (0.2–0.4)
CaO	0.005	3.9	1.42	2.0	7.81	36	3.59	1.1 (0.5–2.2)
Fe_2O_3	0.01	2.4	0.60	1.2	3.86	25	5.04	0.5 (0.2–0.8)
K_2O	0.002	0.80	0.16	0.55	1.26	20	2.8	0.3 (0.2–0.5)
MgO	0.005	2.8	1.06	1.4	5.48	37	2.48	1.1(0.5–2.2)
MnO	0.0004	0.043	0.013	0.024	0.071	29	0.1	0.4 (0.2–0.7)
Na_2O	0.001	0.91	0.22	0.65	1.48	24	3.27	0.3 (0.2–0.5)
P_2O_5	0.005	0.06	0.03	0.025	0.15	58	0.15	0.4 (0.2–1.0)
S	0.002	0.064	0.021	0.028	0.12	33	0.062	1.0 (0.4–2.0)
TiO_2	0.0005	0.27	0.09	0.12	0.55	35	0.64	0.4 (0.2–0.9)
As	0.1	1.29	0.65	0.4	3.3	51	4.8	0.3 (0.1–0.7)
Be	0.03	0.42	0.12	0.3	0.72	28	2.1	0.2(0.1–0.3)
Bi	0.01	0.067	0.046	0.02	0.22	69	0.16	0.4 (0.1–1.4)
Cd	0.04	0.11	0.15	0.04	0.66	136	0.09	1.2 (0.4–7.4)
Ce	0.008	15.5	8.1	8.4	45.4	52	63	0.2 (0.13–0.7)
Co	0.08	6.9	1.7	3.8	11.2	25	17.3	0.4 (0.2–0.7)
Cr	0.7	46.4	15.4	18.4	83.9	33	92	0.5 (0.2–0.9)
Cs	0.01	0.43	0.17	0.24	1.0	39	4.9	0.1 (0.05–0.2)
Cu	0.8	42.8	27.3	9.3	144.9	64	28	1.5 (0.3–5.2)
Dy	0.007	1.12	0.44	0.74	2.59	39	3.9	0.3 (0.2–0.7)
Er	0.003	0.60	0.24	0.40	1.34	39	2.3	0.3 (0.2–0.6)
Eu	0.006	0.40	0.19	0.26	1.17	47	1	0.4 (0.3–1.2)
Ga	0.1	3.74	0.84	2.6	6.1	23	17.5	0.2 (0.1–0.3)
Gd	0.007	1.20	0.53	0.77	3.13	44	4	0.3 (0.2–0.8)

Table 3. *Cont.*

Element	DL	Mean	Sd	Min	Max	V, %	WA	PIr
Hf	0.02	0.72	0.24	0.5	1.7	33	5.3	0.14 (0.1–0.3)
Ho	0.005	0.21	0.08	0.13	0.48	40	0.83	0.2 (0.2–0.6)
La	0.009	7.05	3.03	4.0	17.7	43	31	0.2 (0.13–0.6)
Li	0.03	5.16	1.04	3.7	7.57	20	24	0.2(0.2–0.3)
Lu	0.005	0.091	0.035	0.06	0.20	39	0.31	0.3 (0.2–0.6)
Nb	0.02	2.85	1.55	1.5	8.9	55	12	0.2 (0.1–0.7)
Nd	0.009	6.78	3.83	3.86	22.5	56	27	0.3 (0.14–0.8)
Ni	0.7	41.1	17.0	12.1	90.1	41	47	0.9 (0.3–1.9)
Pb	0.06	19.0	25.5	5.6	126.1	134	17	1.1 (0.3–7.4)
Pr	0.005	1.77	0.96	0.95	5.50	54	7.1	0.2 (0.13–0.8)
Rb	0.1	19.8	4.21	13.0	33.3	21	84	0.2 (0.2–0.4)
Sb	0.06	0.89	0.57	0.38	3.13	64	0.4	2.2 (1.0–7.8)
Sc	0.09	5.62	1.30	3.7	8.5	23	14	0.4(0.3–0.6)
Sm	0.004	1.42	0.73	0.85	4.26	51	4.7	0.3 (0.2–0.9)
Sr	0.07	119.6	27.8	91.0	210.6	23	320	0.4 (0.3–0.7)
Ta	0.01	0.19	0.13	0.1	0.7	69	0.88	0.2 (0.1–0.8)
Tb	0.004	0.18	0.08	0.12	0.48	44	0.7	0.3 (0.2–0.7)
Th	0.01	1.45	0.65	0.7	3.2	45	10.5	0.1 (0.07–0.3)
Tl	0.005	0.08	0.02	0.05	0.15	23	0.9	0.1 (0.06–0.16)
Tm	0.004	0.086	0.034	0.06	0.20	40	0.3	0.3 (0.2–0.7)
U	0.01	0.61	0.27	0.4	1.6	44	2.7	0.2 (0.1–0.6)
V	0.8	42.1	11.9	20.6	67.6	28	97	0.4 (0.2–0.7)
Y	0.02	6.03	2.29	4.1	13.2	38	21	0.3(0.2–0.6)
Yb	0.003	0.66	0.27	0.45	1.54	41	2	0.3 (0.2–0.8)
Zn	0.5	89.9	50.6	35.6	262.7	56	67	1.3 (0.5–3.9)
Zr	0.04	28.6	10.1	18.2	68.8	35	193	0.1 (0.1–0.4)

Note: WA—world average [49]; Se, Rh, Pd, Te, Re, Ir, Pt, Hg and Au contents were below their detection limits in 50% samples, and hence, they were excluded from calculations.

The Pb, Cu and Zn contents in the soils of Western Siberia are similar to world average values and occasionally even lower [47]. It has also been shown that the Sb content in soils in the north of Western Siberia is below its world average value [69]. Therefore, enrichment in those trace elements in the road dust of Surgut is connected with the impact of anthropogenic sources, which is indirectly confirmed by significant variations in Cd (CV of 136%), Pb (134%) and Sb (64%). Elements originating predominantly from natural sources are expected to have a relatively lower variability, while those from anthropogenic sources should display a greater variability [70,71]. Significant variations in PTE concentrations indicate significant contributions from anthropogenic sources and a spatial heterogeneity of human impacts on the roads [13]. In addition, such variations reflect differences in the rates of pollution depending on road traffic, industrial emissions and street cleaning.

It should be mentioned that dust particles separated from the snowpack within Western Siberia, including remote background areas, are enriched in Sb, Zn, Cd and As [72]. Therefore, the assemblage of air pollutants within Surgut city is similar to the region-scale assemblage of air pollutants, which is indicative of their broad distribution. It is likely that the composition of atmospheric particulate matter within Western Siberia is generally predetermined by emissions from different cities and other point sources, the specific contributions of which can only be assessed when a larger database on such sources is available, but at the present time it is impossible to provide such an assessment with sufficient reliability.

The mean *EF* values of Sb (8.3) indicated significant enrichment. A very high level of enrichment ($20 < EF < 40$) in both Sb and Pb was observed in only one sample, which was collected from a stretch of road with a high traffic intensity within the industrial and warehouse area. Such a combined Sb and Pb contamination of road dust can be explained by emissions of those elements from worn car batteries that were made with the use of Sb–Pb alloys up until very recently [73].

Of the studied samples, 48% were significantly enriched in Cu, 32% in Zn, 20% in Ni, 12% in Pb and 4% in Cd. The mean *EF* values of Pb (4.3), Ni (3.3) and 36% *EF* of Cr were between 2 and 5, indicating moderate enrichment. Other trace elements were characterized by mean *EF* values of <2, i.e., belonging to the category of "deficiency to minimal enrichment" according to [1].

The data obtained on the distribution of *EF*, *Ze* and *RI* values over the city territory depending on the land use areas and road traffic intensities are shown in Table 4. The highest total contamination levels were observed in the industrial area and the roads with high traffic intensities (with the *Ze* values of 43 and 44, respectively). There was a clear relationship between the contamination level and the traffic density.

Table 4. The values of enrichment factor (*EF*), total potential ecological risk index (*RI*) and total enrichment factor (*Ze*) in the road dust of Surgut.

Area	Contamination Levels and *EF* Values		*Ze*	*RI*
	Significant (*EF* = 5–20)	Moderate (*EF* = 2–5)		
Land Use Areas				
Industrial and warehouse area (n = 6)	Sb 12 Pb 9 Cu7	Ni3	43	55
High-rise residential area (n = 6)	Cu 5 Zn 5	Ni3 Pb2	31	79
Low-rise residential area (n = 5)	Sb 6	Ni4 Cu4 Zn4 Cr2	27	47
Power plant area (n = 3)	Sb 9	Cu5 Zn5 Ni4 Cr2 Pb2	32	39
Public and business area (n = 3)	Zn 7 Cu 6 Sb 6	Pb2	29	87
Transport hubs (n = 2)	Sb 8	Cu4 Ni3 Zn3 Fe2	30	30
Traffic Density				
Low (n = 8)	Sb 5	Cu4 Zn3 Ni3 Pb2	28	39
Moderate (n = 14)	Sb10 Cu 6 Pb 6	Zn5 Ni3	40	53
High(n = 3)	Zn9 Sb8 Cu8	Ni4 Pb3 Cd2	44	144
Total for Surgut	Sb 8.1 Cu 5.5	Zn 4.9 Pb 4 Ni 4	37	59

Note: the numbers after the elements correspond to their mean *EF* values. Elements with *EF* < 2 are not shown.

The dust samples from roads with low traffic densities only had a significant enrichment in Sb. Roads with heavier traffic were characterized by dust enrichment in practically all pollutants, including Sb, Zn, Cu and Pb. In particular, the roads with moderate and high traffic intensities as compared to the roads with low traffic intensities were characterized by the following increases in pollutant concentrations: Zn by multiples of 1.4–2.8, Cu—1.3–1.7, Pb—1.1–2.5, Cd—1.3–2.8, Sb—1.5–1.9 and Bi by multiples of 1.7–2.0. Verification using the Mann–Whitney test showed that small roads significantly differ from medium and large ones in the enrichment of road dust with Zn, Sb and Pb ($p = 0.01$). The dust samples from roads with low, moderate and high traffic densities were characterized the total enrichment factor *Ze* values of 28, 40 and 44, respectively, with an overall mean of 37. As compared to Moscow, where the mean for *Ze* is 54 [13], Surgut has a lower level of road dust contamination, which can be easily explained by Moscow's much higher intensities of traffic and industrial emissions, both being sources of PTEs. However, it should be taken into account that concentrations of some elements (Mo, W and Sn) were excluded from the calculations, and therefore, the index values could be slightly underestimated.

The spatial distribution of *Ze* values is shown in Figure 2. The highest values are found within the road stretches where traffic jams regularly occur, which causes the increase in emissions of fine particles and soot.

The total potential ecological risk index (*RI*) had values between 150 and 300 in only two samples, which corresponded to the category of "moderate risk" according to [50]. Those abnormal values resulted from a sporadic occurrence of high Cd concentrations in the road dust. The samples from business areas had high Cd concentrations (0.33 and 0.66 mg kg^{-1}) as well as a high concentration of Zn. Solid waste incinerators are known to be an important source of both Cd and Zn [74]. It is likely that solid waste incineration was practiced near our sampling sites. In addition, car tire wear is also a source of Cd [75]. All

other studied samples belonged to the category of low risk, with the maximal values of total potential ecological risk index *RI* found on roads with high traffic densities.

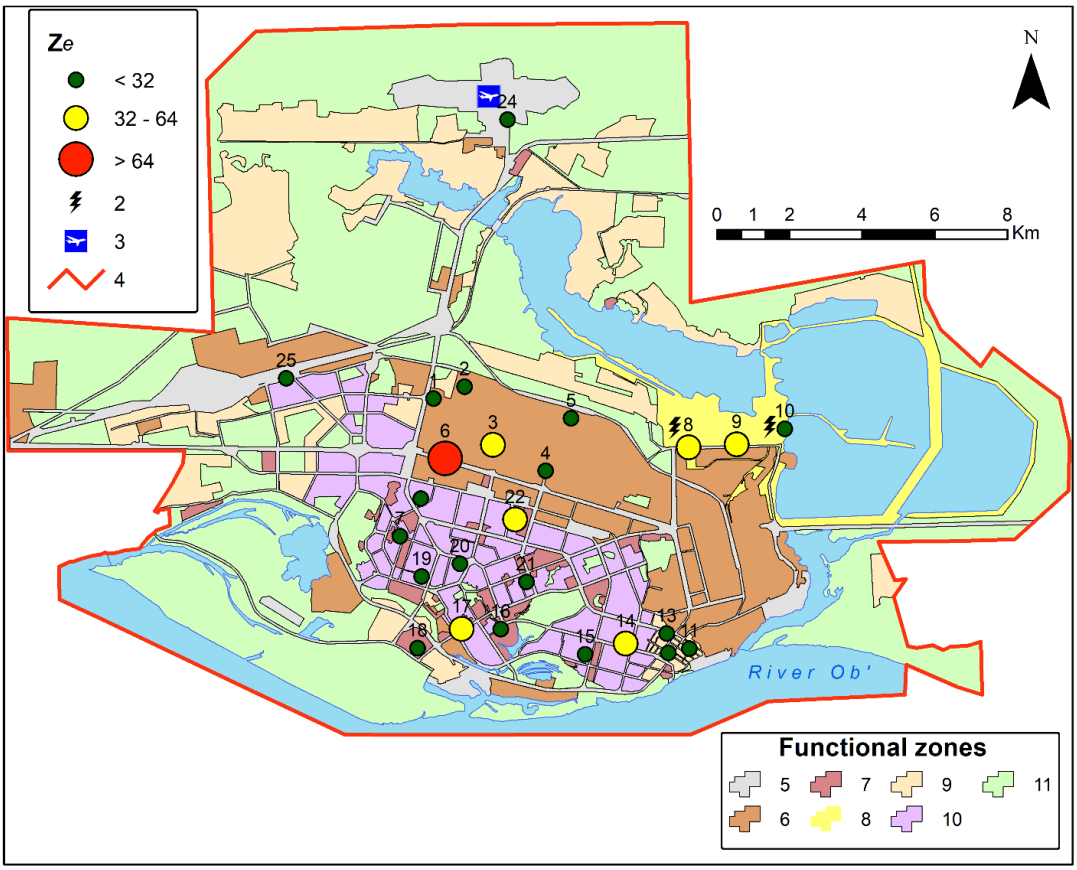

Figure 2. Spatial distribution of *Ze* values: 1—sampling sites; 2—power plants; 3—airport; 4—city border; 5—industrial and warehouse area; 6—high-rise residential area; 7—low-rise residential area; 8—power plant area; 9—public and business area; 10—modern business zones; 11—recreational area, urban forests, green spaces.

3.3. Source Identification

The most significant contributors to PTE pollution from vehicles are considered to be brake wear, tire erosion, exhaust emissions and oil losses [76]. The other source of PTEs, which include V, Cr, Co, Ni, Cu, Zn and Pb, is the abrasion of road tarmac [77,78]. Calculations of *EF* values showed that Sb, Zn, Mo, Cu and Pb were the main pollutants of Surgut's road dust (See Table 3). The main source of Sb in road dust is brake wear [79]. Antimony pentasulfide is used as a pigment in the production of car tires [80]. On the road stretches where traffic regularly slows and stops (traffic lights, cross-roads, etc.), Sb concentrations are generally eight times as high as those in the background [81]. Antimony is also used for the production of car batteries.

Tire erosion is also a source of Zn, because zinc oxide is used as a vulcanization agent in tire production [78,82]. The concentration of Zn in car tires is about 1% [77]. Research on the variability in the chemical composition of road dust in Spain by Amato et al. [7] has shown that contents of Sb, Zn and Mo are increased within stretches of roads where traffic slows and stops, which confirms their relationship with tire wear.

Principal sources of Cu in the atmosphere include fossil fuel burning, traffic emissions, fuel combustion and industrial combustion [83]. The erosion of brake pads is an important source of Cu in road dust. It is known that up to 47% of Cu in urban sewage is also sourced from brake pad wear [84]. The degradation of brake pads over time contributes Fe, Cu, Pb, Cr, Zn and Sb to road dust [85].

It should be noted that Cu and Zn are the main PTE components within high-rise residential areas that have the highest number of traffic lights (see Figure 2). Traffic jams where vehicles move at a speed of 20 km/h result in a 30% increase in car exhaust emissions [86]. Therefore, we believe that the high content of Cu in the road dust of Surgut mainly resulted from brake pad erosion.

To verify the sources of pollution, we conducted a PCA analysis of the obtained data set on the contents of PTEs, pH values and the content of fine particles (<2 and 2–10 μm). Elements of geogenic origin with concentrations similar to their world crust average were excluded from the analysis, which therefore included only the ecologically hazardous elements (Cr, Co, V, etc.). Our choice of the fine fraction was based on the fact that fine fractions have the highest PTE contents, e.g., the PM10 fraction of Moscow's road dust is 1.2–6.4 times more polluted by PTEs than bulk samples of the dust [13].

The essence of PCA analysis is to restrict a multicomponent data set to a limited, user-selected number of factors that determine the sample variance. The results obtained made it possible to identify four main factors which predetermine the chemical composition of road dust (Table 5).

Table 5. Varimax principal component loadings for PTE concentrations, pH and PM10 in the studied samples of road dust.

Elements and Parameters	PC1	PC2	PC3	PC4
V	0.61	0.04	−0.04	0.52
Cr	0.78	0.06	0.23	0.15
Co	0.86	0.14	−0.01	0.16
Ni	0.85	−0.03	−0.02	−0.28
Cu	0.16	0.57	0.28	0.41
Zn	0.16	0.92	0.10	0.17
As	0.55	0.01	−0.18	0.17
Cd	0.09	0.87	−0.06	0.05
Sb	0.18	0.16	0.90	−0.01
Pb	−0.10	0.05	0.94	−0.01
pH	−0.10	−0.0	0.01	−0.69
PM10	0.70	0.073	0.13	0.12
Expl. Var	3.39	2.62	1.97	1.33
Prp. Totl	0.26	0.20	0.15	0.10

The four PCs together account for 71% of the variance. The first PC explains 26% of the total variance and has a strong loading of Cr, Co, Ni and PM10. The concentrations of Cr, Co and Ni in Surgut's road dust were generally low as compared to their world crust average values (*PIr* = 0.4–0.5). However, some sampling sites, in particular within the low-rise residential area and the power plant area, were characterized by Ni enrichment. Relatively higher concentrations of metals such as Ni and Co are caused by the adsorption of these metals by Fe–Mn colloids [87]. Both Ni and Co originate from geogenic sources. The abrasion of road surfaces is an additional source of Ni, which is a component of asphalt bitumen and gabbro rock material [88]. High Ni contents have also been noted in gabbro rocks of the Ural Mountains [89], which are not far from Surgut.

The PC2 is dominated by Zn and Cd. Our observations showed that Zn and Cd probably originated from the same anthropogenic source. Previous studies [90–92] have reported that vehicle emissions and diesel and fossil fuel combustion are known as the primary anthropogenic sources of Cd and Zn atmospheric pollution. PC 3 is dominated by Sb and Pb, accounting for 15% of the total variance. This group of elements, as shown above, is associated with traffic. PC4, dominated by pH, explains 10% of the total variance. The soil acidity to a large extent predetermines the mobility of metals [65] and, therefore, their concentrations in soils.

3.4. Comparisons with Other Cities

Table 6 compares the concentrations of PTEs in this study with some other world cities. Our selection of cities for such a comparison was based on the presence of comparable assemblages of the analyzed elements. A comparison allowed us to determine the geochemical properties of the road dust of Surgut as follows: low contents of As, Cd, Sb and Zn but a 1.6–2 times higher content of Ni in comparison with those in Moscow and Chelyabinsk. The high content of Ni has been previously identified in the road dust of Tyumen, which is a large city in Western Siberia [29]. The latter is explained by the fact that the road construction there involved the use of fine gravel of ultramafic and mafic rocks imported from the Urals. High concentrations of Ni and Cr are often mentioned in descriptions of Uralian ultramafic rocks such as gabbro [89]. Regarding the levels of Cu, Co and Cr in road dust, Surgut occupies an intermediate position among other cities.

Table 6. Literature data on published metal median concentrations (mg kg^{-1}) in street dust from cities around the world.

City	Cr	Co	Ni	Cu	Zn	As	Cd	Pb	Sb	Reference
Surgut, this study	46	6.9	41.1	42.8	89.9	1.3	0.11	19.0	0.89	This study
Chelyabinsk	48.5	6.3	21.9	55.9	154	3.8	0.4	14.4	1.3	[20]
Moscow	50	8.0	26	93	252	2.8	0.61	53	4.6	[23]
Alushta	31	7.4	33	44	127	8.0	0.3	37	1.5	[28]
Tyumen	415	25.6	324	51.3	105	8.8	0.19	20.1	1.83	[29]
Ahvaz, Iran	51.5	9.2	59.7	74.4	309	-	0.5	85.4	2.1	[93]
Hangzhou, China	51	20	26	116	321	-	1.59	202	-	[94]
Houston, TX, USA	67	4.8	119	183	557	-	-	40	-	[95]
Kabul, Afganistan	38.4	8.52	66.4	43.6	122.5	-	1.16	28.7	-	[96]
Kuala Lumpur, Malaysia	74.1	3.36	11.3	87.0	314	**68.8**	0.71	98.8	-	[19]
Katowice, Poland	211	-	43.7	239	**2030**	-	0.35	**430**	-	[97]
Luanda, Angola	26	2.9	10	42	317	5.0	1.1	351	3.4	[98]
Nicosia, North Cyprus	321	-	65	52	136	17.5	-	35.6	-	[99]
Ottawa, Canada	43.3	8.3	15.2	65.8	112	1.3	0.6	39	0.89	[100]
Seul, Korea	151	-	-	396	795	-	-	144		[101]
Shanghai, China	159	-	84	197	734	-	1.23	295	-	[102]
Thessaloniki, Greece	105	-	89	**662**	452	-	**1.76**	209	-	[17]
Tongchuan, China	106.5	31.7	25.3	32.4	142	6.7	-	75.2	-	[103]
Toronto, Canada	198	-	58.8	162	233	-	0.51	183	-	[12]
Xi'an, China	145	30.9	30.8	54.7	268.6	-	-	125	-	[104]

Note: the values in bold font correspond to the highest concentration in the areas compared.

4. Exposure and Risk Assessment

The results of calculations of non-carcinogenic and carcinogenic risk indices through all exposure pathways (ingestion, inhalation and dermal contact) are presented in Tables 7 and 8.

Table 7. Non-carcinogenic hazard quotient (HQ) and hazard index (HI) values of trace elements through all exposure pathways in Surgut city.

Element	HQ Ing		HQ Derm		HQ Inh		HI	
	Childr	Adults	Childr	Adults	Childr	Adults	Childr	Adults
Pb	3.4×10^{-2}	3.8×10^{-3}	2.5×10^{-4}	2.8×10^{-5}	1.6×10^{-4}	2.7×10^{-4}	3.4×10^{-2}	3.8×10^{-3}
Ni	2.4×10^{-2}	2.7×10^{-3}	4.4×10^{-4}	4.9×10^{-5}	4.9×10^{-2}	8.1×10^{-2}	7.3×10^{-2}	8.4×10^{-2}
Cu	2.7×10^{-2}	3.1×10^{-3}	3.5×10^{-5}	4.0×10^{-6}	3.2×10^{-5}	5.4×10^{-5}	2.7×10^{-2}	3.1×10^{-3}
Zn	1.9×10^{-3}	2.2×10^{-4}	1.4×10^{-5}	1.6×10^{-6}	4.5×10^{-5}	7.6×10^{-5}	1.9×10^{-3}	2.2×10^{-4}
As	2.7×10^{-2}	3.1×10^{-3}	2.1×10^{-5}	2.4×10^{-6}	9.1×10^{-5}	1.5×10^{-4}	2.8×10^{-2}	3.2×10^{-3}
Cd	6.9×10^{-4}	7.7×10^{-5}	2.0×10^{-5}	2.3×10^{-6}	1.1×10^{-3}	1.9×10^{-3}	1.8×10^{-3}	2.0×10^{-3}
Sb	1.4×10^{-2}	1.6×10^{-3}	7.0×10^{-5}	7.9×10^{-6}	3.2×10^{-4}	5.3×10^{-4}	1.5×10^{-2}	2.1×10^{-3}

Table 8. Carcinogenic risk (CRA) values of Pb and As through all exposure pathways in Surgut city.

Element	CRA Ing		CRA Derm		CRA Inh		CRA Sum	
	Childr	Adults	Childr	Adults	Childr	Adults	Childr	Adults
Pb	1.0×10^{-6}	1.2×10^{-6}	7.6×10^{-9}	8.5×10^{-10}	2.4×10^{-8}	4.0×10^{-8}	1.1×10^{-6}	1.6×10^{-7}
As	1.2×10^{-5}	1.4×10^{-6}	9.5×10^{-9}	1.1×10^{-9}	5.9×10^{-7}	9.8×10^{-7}	1.3×10^{-5}	2.4×10^{-6}

The non-carcinogenic risk assessment was based on metal concentrations, which were above their Clarke (world crust average) values ($PIr > 1$). The results showed that non-carcinogenic risk in Surgut was mainly associated with the ingestion of dust particles. Data from other cities confirm that ingestion is the most hazardous pathway [21,40,96,98,105]. Children tend to be at higher risk than adults, because their relatively lower body weight implies that the impact of road dust contaminated with heavy metals can be relatively higher. The obtained HI values show that Sb, Ni, Cu and As are generally the most harmful elements within Surgut, with additional health risks associated with Cd and Pb within some areas of the city. It should be noted that despite the low Ni enrichment of road dust, its health risk is high due to the high toxicity of this element.

The carcinogenic risks of As and Pb were also mainly associated with the ingestion pathway, whereas the risks from dermal contact are very low. The total carcinogenic risk values (CRA sum, see Table 8) ranged from 10^{-5} to 10^{-7}. According to the U.S. EPA, any value of cancer risk within the range of 10^{-6} to 10^{-4} is an acceptable or tolerable risk, and any value below 10^{-6} can be ignored. Therefore, the present study showed that carcinogenic risks from the PTEs in the road dust of Surgut were insignificant due to their low concentrations.

5. Conclusions

The road dust of Surgut, as in the majority of cities of the world, has an alkaline reaction due to the presence of carbonate microparticles. The 100–250 μm fraction, which was predominant in the particle size distribution of the studied dust samples, originates from geogenic sources and abrasion processes caused by road traffic. Fine particles (<50 μm), which mainly originate from industrial emissions, had a mean content of 17.5% in the studied samples. Therefore, the composition of road dust was mainly predetermined by contributions from sources associated with road traffic and soil erosion. The texture of Surgut's road dust is relatively homogeneous. Fluctuations in the particle size distribution for roads of different categories and different land use areas are small.

It was found that Surgut's road dust was rich in Sb, Cu, Zn, Cd and Pb as compared to their mean contents in the upper part of the Earth's crust. These elements are regarded as typical urban pollutants that accumulate in the road dust of many cities. Those element concentrations in the road dust of Surgut increased by multiples of 1.4–2.8 on average with increasing traffic densities. The highest concentrations were found within stretches of roads, where traffic jams regularly occur. The main source of these elements is from the abrasion of car tires and brake pads. In addition to traffic densities, the road dust composition was influenced by solid waste incineration, which led to the Cd and Zn contamination of the studied samples.

Based on the values of the total potential eco-logical risk index (PI) and the total enrichment factor (Ze), levels of the total contamination of Surgut's road dust were mostly low. The moderate contamination levels were only detected in samples from high-traffic roads. The generally low contamination can be explained by the predominance of coarse particles in the road dust. Taking into account that the PTE concentrations in fine fractions (PM10) is significantly higher than in the coarse fraction, further research should focus on the analysis of the fine fraction.

The present study on PTEs showed that their greatest potential risks to human health were associated with the ingestion pathway; however, both carcinogenic and non-

carcinogenic risks of such PTEs were generally acceptable or tolerable due to their low concentrations in the road dust of Surgut.

The results obtained in this study can be used in the planning and further development of the transport network of Surgut city and also help improve the efficiency of the street cleaning practices by the municipal services.

Supplementary Materials: The following are available online at https://www.mdpi.com/article/10.3390/atmos13010030/s1, Table S1: Description of sampling sites, Table S2: Methods of analysis, analytical results and recovery of certified reference material, Table S3: Exposure parameters used for the health risk assessment.

Author Contributions: D.M.: conceptualization, original draft writing; R.P.: sample collection, data processing; A.S.: conceptualization, visualization, reviewing the manuscript; V.T. sample collection, reviewing the manuscript. All authors have read and agreed to the published version of the manuscript.

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Conflicts of Interest: The authors declare no conflict of interest.

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