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Editorial

Road Dust in Urban and Industrial Environments: Sources, Pollutants, Impacts, and Management

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Abstract: Road dust (RD) is one of the most important sources of particles in the atmosphere, especially in industrial areas and cities. In this special issue, we collected 16 original articles that describe field, experimental, and modeling studies related to RD and its various size fractions as a key issue in understanding the relationships between several urban and industrial environments and in the identification of pollution sources. Articles in the special issue focus primarily on the following main topics: (1) study of the chemical composition and speciation of RD and its source attribution; (2) assessment of RD and aerosol pollution levels (including express technique), environmental hazards and public health risks; (3) distribution of stable and radioactive isotopes in RD; (4) determination of factors affecting the level of dust accumulation on roads and the intensity of its pollution; and (5) study of the effect of RD on the atmosphere and other environments. Based on the results presented in this special issue, but not limited to, some of the current challenges in studying RD are formulated, including the need for further geographically wider and analytically deeper work on various aspects of the formation, transport pathways, and accumulation of RD in urban, industrial and other areas.

Keywords: air pollution; road dust and road pavement; particle size distribution; source apportionment; environmental interactions; toxic elements and compounds; nanoparticles and microplastic; spatial variation and modeling; health and ecological risks; mitigation strategies

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1. Introduction

Resuspended road dust (RD), enriched with toxic elements, polycyclic aromatic hydrocarbons (PAHs), black carbon, etc., is one of the most important sources of coarse, fine, and ultrafine particles in the atmosphere, which is especially true for industrial sites and cities with a high density of road network and large areas sealed under road pavements [1]. In turn, the chemical composition of RD is determined by the impact of a wide range of anthropogenic sources, as well as by the deflation and erosion by rainfall of roadside soils in summer (especially in the relatively dry climate), blowing out de-icing agents in winter and after snowmelt, transportation of particles with stormwater runoff, deposition of suspended atmospheric particles, and precipitation. The chemical and physical characterization of RD size fractions is a key issue in understanding the relationships between several urban and industrial environments and in the identification of pollution sources. However, in many cities and towns, there is a significant lack of knowledge of the composition of RD and its individual size fractions, dust loadings, the anthropogenic impact on the degree of RD pollution, and potential risks of RD to public health and ecosystems.

In this special issue, we collected 16 original articles that describe field, experimental, and modeling studies related to detailed analyses of RD and its various size fractions as a significant source of air pollution. Priority attention is paid to modern techniques, approaches, and methods for assessing the contribution of various sources to the chemical composition of RD size fractions (i.e., source apportionment) and the assessment of public health and ecological risks, as well as other related issues of particulate matter, including ultrafine particles.

The field data that formed the basis of the papers in this special issue were collected worldwide, which proves the considerable interest of researchers from the regions of North, Central and South America, Europe, Asia, and Africa in the study of RD, and countries including Brazil [2], Canada [3], Colombia [2], Costa Rica [2], Egypt [4], India [5], Mexico [6,7], Pakistan [8], People's Republic of China [8,9], Republic of Korea [10,11], Russian Federation [4,12–14], Spain [2], Taiwan (Republic of China) [15], the United States of America [16,17], and Vietnam [15]. The study areas included roads of various types and sizes within different land-use areas (commercial, residential, industrial, recreational, educational, etc.) in megacities [2,5,6,8,15], large [3,4,7,12,13] and medium-sized cities [2,12–14], industrial areas [9–11], paved and unpaved roads between cities and settlements [16,17]. In the literature, various terms are usually used to denote particles that accumulate on the roadway surfaces, such as "road dust(s)," "street dust(s)," "road-deposited sediments," "sweepsand", etc. The authors of the special issue predominantly used the term "road dust" [2,3,5–8,10,14], although terms such as "street dust" [15], "urban dust" [11], "road sediments" [2], "urban sediments" [12], "urban surface deposited sediments" [4,13] are also used.

Articles in the special issue focus primarily on the following main topics: (1) study of the chemical composition of dust and sources of various substances in it, (2) assessment of RD and aerosol pollution levels, environmental hazards and public health risks, (3) distribution of stable and radioactive isotopes in RD, (4) determination of factors affecting the level of dust accumulation on roads and the intensity of its pollution, and (5) study of the effect of dust on the atmosphere and other environments.

2. Chemical Composition and Source Apportionment

The study of the composition of RD and an assessment of their probable sources is one of the main topics of most work on RD worldwide, which was also reflected in our special issue. The largest number of papers in the special issue is devoted to the study of RD chemical elements, such as metals and heavy metals (HMs) [3,6,8,9,11,15], potentially toxic elements (PTEs) [7,10,14], major, mineral, minor, and trace elements [2,5,11,13], and ions [2]. Among the analytical methods, inductively coupled plasma mass spectrometry (ICP-MS) [2,3,8–10,14,15], inductively coupled plasma optical spectrometry (ICP-OES) [3,5,6,11], inductively coupled plasma atomic emission spectroscopy (ICP-AES) [14], X-ray fluorescence with dispersed energy (XRF-ED) [7], scanning electron microscope equipped with an energy-dispersive spectrometer (SEM-EDS) [7,13] are most frequently used. H. Jeong et al. [10] also measured the magnetic susceptibility of RD.

Several articles are devoted to studying the mineralogical composition and type of individual RD particles. For example, Y. Aguilar et al. [7] found that calcite, quartz, ankerite, anorthoclase, and albite are the main minerals of RD of the city of Mérida Yucatán, Mexico, and natural minerals such as hematite, goethite, boehmite, dikite, sanidine, tosidite, and yeelimite are found in smaller quantities; among the anthropogenic minerals, maghemite is the most common, which determines the highest magnetic signal to RD. A. Seleznev et al. [13] showed that 19% and 13% of particles in the urban surface-deposited sediments in the residential areas of ten Russian cities located in different economic, climatic, and geological zones are characterized as technogenic (e.g., plaster, car tires, household waste, glass, coal, paint, brick, silicate and iron microspheres, granulated and lithoid slag) in particle size fractions of 0.1–0.25 and 0.25–1 mm, respectively, and the rest of the particles is represented by the mineral and natural organic fragments. The results in this special issue prove the need for a detailed study of the mineralogy of RD and adjacent environments (such as soils, atmospheric depositions, and parent rocks), pavement condition, land use, etc. to obtain more accurate information about their mineral matrix and color variation features (see Section 3).

For source identification and apportionment of elements in RD and aerosols, a wide range of approaches and methods have been used, among which the most common are: enrichment factors (EFs) [2,5,11,14,15], Zn/Cu ratio to assess the contribution of traffic activities related to the abrasion of brake pads and tires [10], Cu/Sb ratio to evaluate the contribution of brake wear emissions in RD [2], as well as a hierarchical clustering analysis (HCA) [3,5,15], principal component analysis (PCA) [2,10,14,15], and positive matrix factorization receptor model (PMF) [9]. One of the EF calculation problems is the choice of the reference element [18]. In the special issue, Al and Fe are the most frequently used reference elements in the study of mineral environments [2,14,15]. However, Li was also used due to possible precipitation of Al and Fe hydroxides when the salinity is changed in an estuary environment [11], as well as Ti since it is a stable, non-reactive, and inert element with respect to the physicochemical parameters of the environment, and is negligibly added by anthropogenic activities [5].

In the work of S. Sun et al. [9], using data on the concentrations of HMs in atmospheric $PM_{2.5}$ in Huludao City, an industrial city in northeast China, and the results of PMF, it was shown that in the heating and non-heating periods the leading sources of pollutants are coal combustion (at Huagong Hospitals) and industrial emissions (Xinqu Park); the contribution of traffic emissions is 10–31%. S. Vanegas et al. [2], comparing the chemical composition of RD from two cities in Colombia, proved that volcanic ash could be an important source of SO_4^{2-}, Cl^-, and elements that form the mineral matrix of RD; while Cu, Pb, Cr, Ni, V, Sb, and Mo are mainly associated with exhaust and non-exhaust traffic emissions. D. Moskovchenko et al. [14] for Surgut, a rapidly developing city in Western Siberia, Russia, found that RD particles of size 100–250 μm originate from geogenic sources and abrasion processes caused by road traffic, while particles < 50 μm mainly originate from industrial emissions; the chemical composition of RD is mainly predetermined by contributions from sources associated with road traffic (the abrasion of car tires and brake pads), soil erosion, and solid waste incineration.

Articles of the special issue did not cover studying the chemical fractionation of elements in RD and its particles of various sizes, although this information is essential for understanding the potential sources of elements, their mobility, and environmental hazard [19].

3. Pollution Levels and Health Risks Assessment

The second central area of research in the special issue is the assessment of RD pollution levels, environmental hazards, and public health risks. The level of RD contamination with individual chemical elements was estimated using the enrichment factor, which was mentioned above, as well as the geo-accumulation index (Igeo) [8,10,15], pollution index (PI) or contamination factor (CF) [5,8,15], degree of contamination (Cdeg) [5], and global pollution index (PIr) [14]. Comprehensive assessment of contamination with several pollutants is carried out using pollution load index (PLI) [6,15], and total enrichment factor (Ze) [14]. To assess the environmental hazard of toxicants in RD, the potential ecological risk factor (Er) is calculated, and for the integral assessment, the comprehensive ecological risk (PER) is used [5,10,14,15].

H. Jeong et al. [10] showed that among PTEs in RD from nine industrial areas in the Republic of Korea, the potential ecological risk index is in the decreasing order of Cd > Pb > Hg > Cu > As > Zn > Ni > Cr, and the highest concentration of PTEs was at the Onsan Industrial Complex with many smelting facilities. M.-S. Kim et al. [11] found that the concentrations of Mn, Zn, Cd, and Pb in RD in a residential area near Donghae port, Republic of Korea, and in the port are approximately up to 112 times higher in comparison with the control area. S. Vanegas et al. [2] studied differences in the level of RD pollution in the Bogotá megacity and Manizales city, Colombia. In Bogotá, EFs show extremely high values for Mo and Sb, very high for Cu and Pb, high for Ni, Se, and Cr, while in Manizales, EFs are extremely high for Mo, Se, Sb, and Mn, very high for Cu and As, and high for Ni, Cr, and Pb; the results proved the need to study Se in RD of other cities due to its intense accumulation. A study of street dust from Ha Noi highway, Ho Chi Minh City, Vietnam, by V.T. Nguyen et al. [15], showed moderate contamination levels for Pb, Cd, Cu, Sn, Mo, and Zn (based on Igeo), moderate levels for Cd, Cu, Mo, and Sn and moderate–severe levels for Zn (based on EFs), while PER indicates a high potential ecological risk; also, Igeo levels for B close to the main pollutants were established, which can be helpful when choosing elements for ecological and geochemical monitoring of RD pollution. S. Beauchemin et al. [3] studied the chemical composition of ultrafine particle fraction (UFP) of RD in the City of Toronto, Canada, and showed up to 2 times higher concentrations of Cd, Cr, Zn, and V in UFP compared to the total dust, as well as higher levels of pollution (up to 2 times for Cd, Zn, and V and nine times for Cr) of UFP from arterial roads compared to local roads. The elevated concentrations of transition metals in UFP can cause oxidative stress in human lung cells.

Y. Aguilar et al. [7] developed a proxy methodology and innovative tool to identify RD samples contamination with PTEs using the RGB system and the Munsell color cards. This approach was verified by a discriminant analysis, which confirmed the identification of five groups of RD samples by colorimetric indices and PTE concentrations. Contamination level reaches high in "dark gray" (III) and "very dark gray" (V) samples, decreases to medium in "gray" (II) samples, and low in "greyish brown" (I) and "dark grayish brown" (IV) RD samples. At the same time, the "very dark gray" RD contains the highest concentrations of Pb, Cu, Zn, and Y; the redness and saturation rates showed high correlations with PTEs in "dark gray" and "very dark gray" RD. An important conclusion is that samples of "grayish brown" and "dark grayish brown" colors can be discarded from the chemical analysis when monitoring urban RD pollution.

Using U.S. EPA methodology, M. Faisal et al. [11] estimated non-carcinogenic and carcinogenic risks of Cr, Cu, Ni, Zn, Cd, As, Pb, and Hg in $PM_{2.5}$ portion of RD from five different land use areas of Zhengzhou, China. PI and Igeo show the extreme pollution of RD with Hg, Cd, and Zn. The most significant non-carcinogenic exposure to children is the exposure of Pb in commercial and industrial areas. Both children and adults in Zhengzhou's commercial, residential, and park areas are exposed to higher Cu, Pb, and Zn levels. However, the cancer risk value of Cr was more likely to be at the lower limit of the threshold value, particularly in the industrial area.

Using similar approaches, D. Majumdar et al. [5] assessed the health risks associated with pollution of RD by chemical elements at a few major commercial, traffic, and residential sites in the Kolkata megacity. They establish that Cd and Li have the highest enrichment level relative to the average composition of the earth's crust, among which only Cd posed significant ecological risk due to its high ecological toxicity. Although individual chemical elements do not form significant non-cancer health risks (except for Li for children), the cumulative non-cancer risk for children was almost four times higher than the acceptable level, being ingestion the primary exposure pathway. Lifetime exposure to carcinogenic elements at the current level may pose up to six times higher cancer risk in the adult population than the acceptable risk.

Using U.S. EPA methodology, D. Moskovchenko et al. [14] assessed the health risk to the population of Surgut (Russia) posed by RD contaminated with a large number of PTEs. EFs showed significant enrichment level of RD with Sb and Cu, and moderate enrichment with Zn, Pb, Mo, Ni, and W. Based on PIr and Ze, the RD was characterized by a low level of potential ecological risk, except for stretches of road subject to regular traffic jams, where a moderate ecological risk was identified. The greatest potential risks to human health were associated with the ingestion pathway. Children tend to be at higher risk than adults because of their relatively lower body weight. Sb, Ni, Cu, and As are generally the most harmful elements within Surgut, with additional health risks associated with Cd and Pb within some city areas. Despite the low Ni enrichment of RD, its health risk is high due to the high toxicity. However, both carcinogenic and non-carcinogenic risks of PTEs were generally acceptable or tolerable due to their low concentrations in the RD in Surgut.

S. Sun et al. [9] evaluated non-carcinogenic and carcinogenic risks for the population from HMs in atmospheric $PM_{2.5}$ using the U.S. EPA methodology and the entropy weight method (EWM) during heating and non-heating periods at two sites in Huludao City (China). $PM_{2.5}$ pollution with HMs is higher in the heating period than in the non-heating period. Human health risks are determined by differences in the contributions of HMs in $PM_{2.5}$ from various sources and differ significantly between children, adult men, and adult women. Children have the highest, and adult females have the lowest non-carcinogenic risk, whereas adult males have the highest and children have the lowest carcinogenic risk. In general, the traditional U.S. EPA and EWM methods give close estimates of health risks, but in cases where the differences are quite high, it is recommended to use EWM to estimate non-carcinogenic health risks due to the smaller dispersion of the result.

The special issue did not cover studies on environmentally hazardous chemical compounds and substances, which are both good indicators of pollution sources, such as black carbon and PAHs, environmentally persistent free radicals (EPFRs), organophosphate esters (OPEs) and other organic micro-pollutants [20], micro and nanoplastics [21], glass microspheres [22], platinum group elements (PGE) and rare earth elements (REE) [23], etc. In addition, no source-specific risk assessment nor characterization of bioaerosols in RD were conducted.

4. Isotopic Composition and Radioactivity of Road Dust

The isotopic composition of RD and its radioactivity remain rather poorly studied. However, these parameters can play a significant role in identifying and understanding the geochemical processes of sedimentation and migration of solid particles in urban and industrial areas. The special issue presents two studies to fill the gaps on this topic.

The first one, by M.Y. Hanfi et al. [4], is devoted to assessing gross alpha and gross beta activity in the road- and surface-deposited sediments in three Russian cities in different geographical zones (Ekaterinburg, Nizhny Novgorod, Rostov-on-Don). New methods dealing with low mass and low volume of dust-sized samples obtained after the size fractionation procedure were applied. Due to the presence of radionuclides transferred through natural and anthropogenic processes, the highest gross beta activity concentrations are in the 2–10 μm fraction size in Nizhny Novgorod and Rostov-On-Don and particles of 50–100 μm in Ekaterinburg. On the other hand, the highest gross alpha activity concentrations are characteristic of large particles of 50–100 μm compared to finer particles of 2–10 μm and 10–50 μm due to natural partitioning of the main minerals constituting the urban surface-deposited sediment and are found in Rostov-on-Don. In general, gross alpha and gross beta activity in the studied cities are associated with natural radionuclides, which are found in various cities regardless of climate, geographical location, and industrial development and whose primary sources are geological formations and natural building materials.

M.-S. Kim et al. [11] used isotopic compositions (^{13}C, $^{208/207}Pb$, $^{207/206}Pb$) of urban dust, topsoil, and PM_{10} samples from a residential area near Donghae port surrounded by various types of industrial factories and raw material stockpiled on empty land, and the Stable Isotope Analysis Bayesian mixing model within the R software to assess the contributions of the main pollution sources. It is shown that, depending on the influence of one or another source (cement, Zn ore, coal, coke, Mn ore, soil), isotopic values significantly change in the RD. The application of this method made it possible to prove a significant impact of wind-blown dust from raw material stockpiles near ports and factories, that is, port activities affect the air quality of residential areas in the city. The authors conclude that stable isotope compositions of metals can predict environmental changes and be used as a powerful tool to trace the present pollution and the history of contamination in complex contexts associated with peri-urban regions.

5. Factors of Road Dust Accumulation and Contamination

The chemical composition and particle-size distribution of RD and the amount of particles emitted during the movement of vehicles depend on meteorological, geochemical, anthropogenic, and other factors. Several articles of the special issue are devoted to this topic.

A. Aguilera et al. [6] studied the influence of various city parameters (namely, population density, job density, street intersections, road surface, distance to the airport, distance to the city center, manufacturing units, potentially polluting units, gray area, entropy index, vegetation, distance to vegetation, median strip area, and marginalization index) on Cr, Cu, Pb, Zn, and Ni accumulation in the RD of Mexico City using spatial autocorrelation (Global Moran's I) and applying ordinary least squares and spatial regression models. Low positive spatial autocorrelations in all HMs prove the greater relevance of the local aspects over regional processes as the determinants of the HM content in urban RD. Most variables, including the population density, street intersections, distance to the city center, a gray area, distance to vegetation, and marginalized areas, do not detect any relationship with HMs. The potentially polluting units positively impact the dust load, while vegetation, job density, and road surface significantly reduce the dust load. The median strip area in the roads has a weak but consistent positive relationship with Cr, Cu, Ni, Pb, and the PLI. The distance to the airport has a weak and inverse relationship with Pb. Manufacturing units are associated with an increase in Cu, while the entropy index is associated with an increase in Ni.

I. Yarmoshenko et al. [12] estimated natural and anthropogenic factors influencing the sedimentation processes in urbanized catchments in the residential areas of six large Russian cities based on field landscape surveys. The most significant impact on a high urban sediment formation potential in residential areas is formed by a low adaptation of infrastructure to a high density of automobiles, poor municipal services, and poor urban environmental management in the course of construction and earthworks. The significant impact of motor vehicles in the urban environment includes mechanical sediment transport that sharply increases the sediment connectivity within the urban landscape.

H. Jeong et al. [10] estimated the median total loading of RD in nine industrial sites in the Republic of Korea as 822 g/m^2, ranging from 334 to 1669 g/m^2, which is 2.1–6.5 and 15–16.4 times higher than that in the heavy traffic and urban (commercial and residential) areas, respectively. In Mexico City, the total loading of road dust particles of size < 250 μm ranges from 5.4 g/m^2 to 173.3 g/m^2, with a median value of 43 g/m^2 [6]. In Bogotá, the total loading of RD particles of <10 μm is within 1.8–45.7 mg/m^2 with an average of 11.8 mg/m^2, while in Manizales, it ranges between 0.8–26.7 mg/m^2 with an average of 5.7 mg/m^2; construction and demolition activities are identified as relevant emitters of RD [2]. According to M. Kim et al. [11], an important factor of RD contamination with Mn, Zn, Cd, and Pb is the distance to the source (port), with an increase in which the concentrations of pollutants decrease. Additionally, metal concentrations in ultrafine particles depend on the amount of traffic, the ratio of different types of transport (including light to heavy-duty vehicles), and the speed of transport [3]. Road dust pollution increases on sections of roads with traffic jams [14].

The special issue does not contain articles devoted to various aspects of RD management, assessment of the efficiency of various methods to reduce the amount of dust generated during traffic, methods of its disposal, etc., although these topics are very relevant [20]. Nevertheless, in some papers in the special issue, based on the results obtained, conclusions are drawn about the need for the urgent introduction of an efficient management strategy to reduce RD in industrial areas to protect the health of employees and residents around industrial complexes. In addition, to reduce coastal pollution induced by RD wash-off during rainfall events [10], to increase the coverage and frequency of cleaning roads from dust, especially in areas with possibilities of substantial human exposure and mainly using vacuum-assisted road sweeping machines to remove the most contaminated fine dust fractions [5], as well as the need for cleaning primary roads and areas with "dark gray-" and "very dark gray"-colored dust to more effectively reduce the risk to public health [7].

6. Resuspension of Road Dust and Relationships with Other Environments

Road dust is an essential source of particulate matter in the atmosphere [24], so many papers in the special issue are devoted to assessing the RD resuspension, highlighting the relationship between RD and the atmosphere.

D.R. Fitz and K. Bumiller using the SCAMPER method for measuring PM_{10} emission rates from roadways estimated mitigation methods for public unpaved sections of two different Arizona state highways and a treated mine haul road near the Cricket Mountains in Utah, USA [17], as well as for a wide variety of paved roads in the Phoenix metropolitan area, Arizona, USA, in March, June, September, and December [16]. The suppressant applied five months ago reduces PM_{10} emissions by five times, and applied a year ago reduces PM_{10} emissions by sixty times. The measured emission rates for unpaved roads are approximately seven times higher on a mass basis than those predicted by the AP-42 unpaved road equation. Loaded haul trucks blow almost twice as many PM_{10} particles as unloaded trucks. For paved roads in the Phoenix metropolitan area, the PM_{10} emission rates vary from 0 to 2000 µg per vehicle meter travelled (with an average of 79 µg per vehicle meter travelled) and are generally low unless the road is impacted with dust deposited by activities such as construction, sand and gravel operations, agriculture, and vehicles traveling on or near unpaved shoulders and roads. There is no significant difference in emission rates between seasons. There is a major drop in emission rates over a weekend, when dust generation activities such as construction are expected to be much reduced. By Monday, the PM_{10} emission rates had risen to the levels of the previous Friday, which indicates a rapid achievement of equilibrium in PM_{10} generating potential. The accuracy of the SCAMPER method is about 20% for unpaved sections of state highways and about 25% for paved roads in urban areas.

The efficiency of dust resuspension from the road surfaces, its hazard to public health and ecosystems, the ability to migrate over considerable distances, and the possibility of participation of its components in chemical reactions largely depend on the particle size distribution of dust. Therefore, in the special issue, studies are carried out on the particle size distribution of RD [3,5,10,13,14], as well as on the chemical composition of dust particles and aerosols of different sizes: 0.01–0.018 µm, 0.018–0.032 µm, 0.032–0.056 µm, 0.056–0.1 µm, 0.1–0.18 µm, 0.18–0.32 µm, 0.32–0.56 µm, 0.56–1.0 µm, 1.0–1.8 µm, 1.8–3.2 µm, 3.2–5.6 µm, 5.6–10 µm, and 10–21.1 µm [3], <2.5 µm [8,9], <10 µm [2,11,16,17], 2–10 µm, 10–50 µm, and 50–100 µm [4], <28 µm, 28–45 µm, 45–63 µm, and 63–106 µm [5], 100–250 µm, and 250–1000 µm [13], <149 µm [15], <250 µm [6], <500 µm [11], <1000 µm [10,14], <2000 µm [7]. D. Majumdar et al. [5] showed that with an increase in the particle size of RD, the concentrations of Cd, Cr, Co, Pb, Mn, Ni, Sr, Zn, Ti, and Cu decrease, while the concentrations of Li increase.

In our opinion, from the point of view of their health effects, it is crucial that many of the papers presented in the special issue are devoted to the study of fine and ultrafine particles, or size-segregated RD, which made it possible to obtain accurate information about the chemical composition of the most dangerous particles that blow within urban and industrial environments. Further researches are likely to be devoted to the thoracic fraction (<10 µm) [25–29], as well as fine, ultrafine particles and nanoparticles, which have been actively studied in recent years in various cities and industrial areas [30–33].

In addition to the links between RD and the atmosphere, the article by H. Jeong et al. [10] shows the RD as a potential pollution source for coastal environments: particles of <125 µm contribute up to 41% of the total load of suspended solids in stormwater runoff at intensive industrial areas of the Republic of Korea. However, the effect of RD on pollution of other environments (soils, surface waters, crops, suspended sediments, bottom sediments, etc.) has not been studied in detail in the special issue, although such an effect and the feedback of other environments on the chemical composition of RD may be significant [34,35].

7. Conclusions and Further Research Needs

The studies presented in this special issue are a snapshot of the RD investigations and, at the same time, point to the need for further geographically more extensive and analytically more profound studies of various aspects of the formation, migration, and accumulation of dust and its individual particles in urban, industrial, and other areas. Therefore, we formulate the following main directions for further research, which, in our opinion, will allow us to take a fresh look at the role of RD in the environment.

- More detailed studies of the distribution of black carbon, organic compounds, and their derivatives (PAHs, EPFRs, etc.) in RD are required to clarify the possibility of their use as indicators of individual sources of adverse impact in urban and industrial areas and combined use with chemical elements for source apportionment.
- It is necessary to include the determination of the content of cations and anions in the water extract in the list of routine indicators when studying the RD, as well as to expand the list of interests by B, P, Se, REE, PGE, which will improve the reproducibility of source apportionment results.
- Studies of radioactivity and stable isotope ratios can provide new insights into the relationship between resource and fuel consumption in industry and transport (burning specific fuel grades, consuming ore from certain locations with their typical isotope ratios, etc.) and isotopic "response" in RD and other environments.
- To improve the accuracy of assessments of environmental hazards and public health risks from contaminated RD, it will be useful to develop a methodology and make comprehensive observations in different cities to assess the ratio of the forms of chemical elements (geochemical fractionation) and determine the biological availability of elements, the distribution of pollutants in particle size fractions of RD (especially in fine particles and nanoparticles), conducting a source-specific risk assessment based on the results of the modern source apportionment methods (PMF and other receptor models), clarifying the risk assessment methodology (for example, using the EWM method, and also by taking into account data on the bioavailable fraction of pollutants instead of the total content) and assessing the intensity of RD resuspension into the atmosphere.
- From a methodological point of view, it will be helpful to unify dust sampling methods (sweeping, use of vacuum cleaners with dry sampling, wet vacuuming, etc.), methods for particle separation (air classification, dry and wet sieving, sedimentation with or without sonication and centrifugation, etc.), the choice of a more appropriate geochemical fractionation scheme (e.g., Tessier et al. scheme, BCR, etc.), to develop of a system of indices for assessing the intensity and hazard level of pollution (EF, Igeo, CF, PLI, NPI, etc.) with justification for the choice of comparison standards (background soils, atmospheric depositions, aerosols, the upper continental crust, etc.) and reference elements (Al, Sc, Ti, Fe, Rb, La, Ta, etc.) used for their calculations, as well as to introduce a methodology for the comprehensive analysis of RD and adjacent environments, such as atmospheric aerosols and precipitation, soils, stormwater, surface waters, bottom and suspended sediments.
- Considering the deleterious effects on human health of exposure to airborne microorganisms and the potential accumulation of bioaerosols in RD, research on the characterization of biological contaminants and the risks of exposure after resuspension of this material could be carried out.
- Quantification of the impact of RD to anthropogenic aerosol radiative forcing in climate change studies and potential feedbacks.

Of course, the list of problems of studying RD raised in the special issue is not exhaustive, but, in our opinion, this special issue makes a significant contribution to further research in various scientific areas, interacting with such an interesting and relatively challenging to study environmental object as road dust.

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