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$PM_{2.5}$ and PM_{10} fine dust pollution of construction waste transloading at dwelling zone

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Abstract. In many cities, the problem of dust pollution from construction waste caused by fine dust particles $PM_{2,5}$ and PM_{10} is particularly acute. In the context of the rapidly developing construction industry in cities, issues of environmental safety of the urban air environment are becoming critically important for many states. The main source of urban waste in the context of growing urbanization has become construction waste, which accounts for more than 80% of the total urban waste in the Russian Federation. These areas of accumulation of construction debris not only take up space but also contribute to the deterioration of the urban environment due to dust that rises into the air during transportation and storage of waste. The purpose of this study is to determine the degree of impact of dust emissions of $PM_{2.5}$ and PM_{10} particles on the air environment in the dwelling zone, to obtain empirically parameterized «distance–concentration» relationship for PM_{10} and $PM_{2.5}$ particles during the loading of solid waste into an open container, and to present the results both in absolute units and in a standardized form using the concentration excess index *I*. Dust pollution monitoring was carried out at an active construction site located in a dense residential area in St. Petersburg, Russia. Concentration measurements were carried out during periods of dumping garbage into a container and transportation outside the construction site. The PM_{10} concentration decreased from 30.6 mg/m^3 at the dust source to 1.2 mg/m^3 at a distance of 50 m. The MPC limits of PM_{10} concentration (0.06 mg/m3) were determined at a distance of 37.5 m from the dust source. The $PM_{2.5}$ concentration at a distance of 0-50 m remained below the MPC limits (0.035 mg/m^3). From a practical point of view, the data obtained make it possible to organize an effective multi-level dust management system and can be integrated into summary calculations of emissions and an inventory of sources of pollutants.

Keywords: construction dust, construction and dismantling waste, PM10, PM2.5, unorganized emissions, open container, field monitoring, concentration excess index

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1. INTRODUCTION

In many cities, the problem of dust pollution from construction waste caused by fine dust particles $PM_{2,5}$ and PM_{10} is particularly acute [1]. In the context of the rapidly developing construction industry in cities, issues of environmental safety of the urban air environment are becoming critically important for many states [2, 3]. The main source of urban waste in the context of growing urbanization has become construction waste, which accounts for more than 80% of the total urban waste in the Russian Federation [4]. These areas of accumulation of construction debris not only take up space but also contribute to the deterioration of the urban environment due to dust that rises into the air during transportation and storage of waste. In particular, in St. Petersburg, Russia, the share of dust pollution from construction accounts for up to 60% of the total dust emissions in the city, which is becoming one of the main factors of pollution [5].

The results of a consolidated calculation of dust pollution from construction, including PM_{10} particles and suspended solids, carried out by VNII "Ecology", Moscow, showed that in the production work area, the level of dust pollution exceeds the maximum permissible concentration (MPC limits) by two times [6]. The zone of influence of this level of pollution extends within a radius of up to 40 meters, varying depending on the wind direction. Within a radius of 80 meters from the construction site, regardless of the wind direction, the concentration of suspended particles in the residential area in some cases increases to 1.5 MPC. At a distance of only 120 meters from the point of development, the dust level reaches acceptable values, taking into account the background concentration.

However, in addition to the implementation of construction production of buildings and structures in urban areas, local repair and construction works are carried out in large volumes [7]. Disorganized dust emissions are generated during the loading and unloading of construction and dismantling waste into open containers, excavation work on landscaping, and the movement of machinery [8]. These episodes are short-lived but intense, as local repair, construction, and restoration projects of existing buildings and structures in dense urban areas [9].

Such sources create an excess of the MPC limits in the dwelling zone adjacent to the construction waste storage area, which is often not monitored, but it is the excess of the MPC limits of suspended solids, especially $PM_{2.5}$ and PM_{10} (MPC limits: $PM_{2.5}$ – 0.035 mg/m^3 and PM_{10} – 0.06 mg/m^3), are the causes of complaints about dustiness and potentially significant short-term impacts on workers and residents of the surrounding area [10].

The scale of research on dust pollution from transportation or storage of construction waste and the development of measures to monitor it should be commensurate with the increasing volume of dust emissions from construction production in cities, and local means of combating dust emissions that control dust dispersion to the surrounding area should be improved, preventing dust from scattering by tens or even hundreds of meters [11].

Despite this fact, from the reviews of research results on the concentration of dust pollution from chiseled sources – waste storage areas, it is clear that the problem of dusting of construction waste is insufficiently covered, and there is also no data on field studies that determine the radius of exposure to dust emissions from the source, parameterized curves of decreasing concentrations for episodes of solid waste overload in open containers in in conditions of dense urban development of dwelling zone [12].

Moreover, there is no data on how climatic and meteorological parameters (wind speed/direction, humidity, temperature) affect the formation of dust clouds in an area surrounded by buildings, for example, in well yards in St. Petersburg, where garbage containers with construction waste are usually located.

The purpose of this study is to determine the degree of impact of dust emissions of $PM_{2.5}$ and PM_{10} particles on the air environment in the dwelling zone, to obtain empirically parameterized «distance–concentration» relationship for PM_{10} and $PM_{2.5}$ particles during the loading of solid waste into an open container, and to present the results both in absolute units and in a standardized form using the concentration excess index $I = C/MPC$. The results obtained are intended for engineering justification of local dust pollution control measures and operational assessment of areas of potential maximum permissible concentration exceedances near local repair and construction works.

The problem of dust emissions from construction waste transloading in dense urban development has been increasingly addressed in mining and industrial environmental studies [21, 22, 24]. In recent years, Journal of Mining Institute has published a series of works devoted to dust suppression technologies, environmental safety of mineral material handling, and dispersion processes of fine fractions under technogenic impact [26, 27, 28].

Studies of dust formation during bulk material handling show that the dominant contribution to atmospheric contamination is often made by the coarse fraction (PM_{10}), while the fine fraction ($PM_{2.5}$) becomes significant under conditions of mechanical grinding and dry dispersion [23, 29, 30]. Experimental investigations in mining environments demonstrate that aerodynamic confinement in urban courtyards may intensify local concentration peaks [22, 25].

Despite the available data on industrial dust, the issue of short-term unorganized emissions from open containers during construction waste transloading remains insufficiently quantified [24, 31]. Recent works emphasize the importance of integrating field monitoring data into emission inventories and environmental risk modeling systems [26, 32].

2. METHODS AND MATERIALS

The research construction site was located at 68 Prosveshchenie Avenue, Saint Petersburg. The research period – August 2025. The source of dust release is an open PUKHTO-type container used for loading solid waste, including broken bricks, plaster, concrete fragments, and fine particles of debris generated during repair and construction work of the kindergarten building.

Dust pollution monitoring was carried out at an active construction site located in a dense residential area, where the geometry of the courtyard and surrounding buildings limits dust dispersion and enhances the formation of dust clouds. Concentration measurements were carried out during periods of dumping garbage into a container and transportation outside the construction site.

The control points for measuring the concentration of dust emissions $PM_{2.5}$ and PM_{10} were determined relative to the distance from the edge of the container along the predominantly downwind side every 10 m, covering the near zone (0-50 m). There are 6 control points in total. The sampling height at each control point was 1.7 m, which corresponds to the average height of human inhalation.

Measurements of the concentration of dust emissions of $PM_{2.5}$ and PM_{10} were carried out during the landfill and transloading of construction waste from an open PUKHTO-type container. Fig. 1 shows the scheme of the experiment.

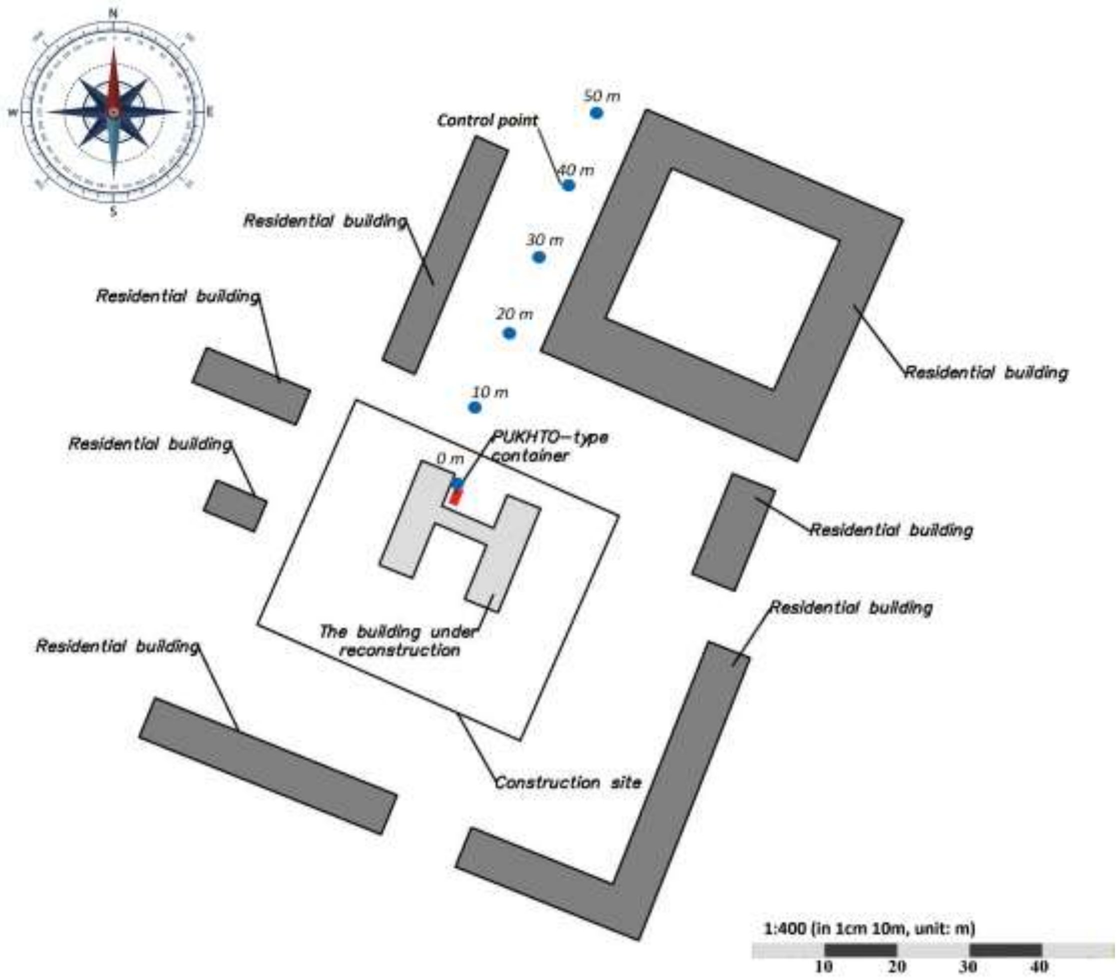

Fig. 1. Layout of the PUKHTO-type container – a source of dust emissions of $PM_{2.5}$ and PM_{10}.

The GANK-4 gas analyzer by NPO PRIBOR (Russia) was employed to measure the concentration of $PM_{2.5}$ and PM_{10} particles during the landfill and transshipment of construction waste, in accordance with the gravimetric measurement method in RD 52.04.893-2020 [13]. The device was equipped with an OP-1 dust filter. Control measurements were carried out daily for 10 days, with 10 air measures taken three times a day at six control points for 30 seconds. At the same time, a portable analyzer, Atmas by ATMOS MedizinTechnik (Germany), was used for repeated measurements of the concentration of $PM_{2.5}$ and PM_{10} particles, with 10 measurements at each control point. The equipment used in the process of measuring the concentration of dust emissions of $PM_{2.5}$ and PM_{10} is shown in Fig. 2.

a. b.

Fig. 2. Equipment used in the study: a – GANK-4 gas analyzer by NPO PRIBOR (Russia); b – portable analyzer, Atmas by ATMOS MedizinTechnik (Germany).

The calibration of the GANK-4 gas analyzer took place in laboratory conditions in «relatively clean» air or with an FS-1 filter. The measurement result was considered to be the average value of the concentration *Cav* after the last measurement. The remaining values of the concentration readings after all stack measurements were necessary for reference purposes. The following meteorological indicators were recorded for each stack concentration measurement: wind speed and direction, relative humidity, temperature.

During the measurement period, two characteristic weather conditions were observed:

1. Condition A – dry and windy:
- relative humidity – 35-40%;
- wind speed – 7-9 m/s;
- temperature – 15-18 °C;
- wind direction – northeast.
2. Condition B – wet and slightly windy:
- relative humidity – 75-80%;
- wind speed – 1-1.5 m/s;
- temperature – 15-18 °C;
- wind direction – northeast.

In order to guarantee the comparability of the concentration measurement results under the observed weather conditions, the data are presented as absolute concentration values of *C* (mg/m^3) and use the concentration excess index of $PM_{2.5}$ and PM_{10} above the standard values *I*, where

$$I = \frac{C}{MPC}, \tag{1}$$

there: MPC limits have the average daily standard values: $PM_{2.5}$ – 0.035 mg/m^3 and PM_{10} – 0.06 mg/m^3.

The values of the concentration excess index *I* in this study are used to assess the pollution of $PM_{2.5}$ and PM_{10} in the air environment in the dwelling zone. This corresponds to the practice of operational monitoring of dust pollution of $PM_{2.5}$ and PM_{10} [14].

Two kinds of approximation models were used in order to obtain the indicators determining the «distance-concentration» relationship:

1. Linear function

$$C = a - b \times l, \tag{2}$$

there: *C* – concentration, mg/m^3;

l – distance from the dust source to the control point, m;

a,b – concentration data at the control point, mg/m^3.

2. Exponential function

$$C = C_0 \times exp(-k \times l) + C_{bg}, \quad (3)$$

there: C_0 – initial concentration, mg/m^3;
k – scatting coeffitient, 1;
C_{bg} – background concentration, mg/m^3.

The linear model is presented as simple and convenient for operational use, while the exponential model is presented as a physically sound alternative, especially relevant at short distances.

The methodological approach of combining field monitoring with normalized concentration excess index I = C/MPC corresponds to modern practices applied in mining and environmental engineering studies [21, 27, 33]. Similar exponential decay behavior of particulate matter concentrations near point sources has been reported in both mining stockpile investigations and construction-related dust emissions [22, 34].

3. RESULTS AND DISCUSSION

Data on measurements of the concentration of $PM_{2.5}$ and PM_{10} yielded the following results: PM_{10} dust pollution concentration under dry and windy meteorological conditions shows a sharp decrease with increasing distance – within a radius of up to 37.5 m from the source of dust emissions, the concentration values exceed the MPC limits, which requires measures to reduce dust emission. The $PM_{2.5}$ dust pollution concentration in wet and slightly windy weather shows a moderate decrease and remains below the MPC limits at all considered distances. Table 1 and Fig. 3 show the example of measured PM_{10} concentration values depending on the distance to the open container. Concentration values decrease from 30.6 mg/m^3 at the dust source to 1.2 mg/m^3 at a distance of 50 m, which corresponds to a characteristic decrease in the dwelling zone.

Table 1. PM_{10} concentration from constraction waste transloading.

Distance from the dust source at control points *l*, m	Concentration excess index *I*, C/MPC	Concentration *C*, mg/m^3
1	2	3
0	5.1	30.6
10	4.0	24.0
20	2.6	15.6
30	1.4	8.4
40	0.3	1.8
50	0.2	1.2

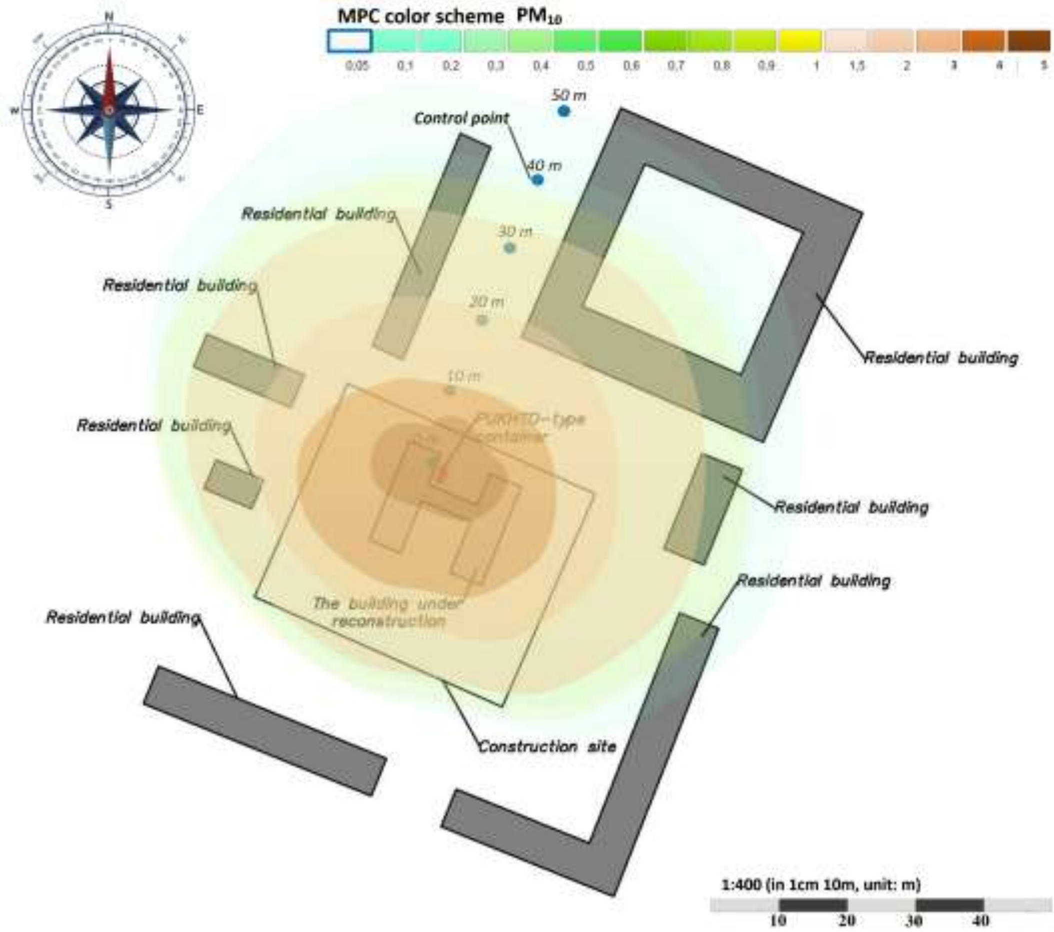

Fig. 3. PM_{10} concentration from constraction waste transloading.

The linear model of approximation of the results of measurements of the PM_{10} concentration at a distance of 0-50 m has the form

$$C_{PM_{10}}(l) \ = \ 29{,}81 \ - \ 0{,}6356 \times l\left(mg \ / \ m^3\right), R^2 \ = \ 0{,}968. \tag{4}$$

The linear approximation model can overestimate the values at a distance of > 40 m and formally give negative values at large *l*. It is recommended to use this model only within the observed range (0-50 m) for operational control of dust pollution. The exponential approximation model may be physically more reasonable for small distances, but with a sufficient number (6-10) of the control points for measuring the concentration of dust emissions, the linear model provides sufficient stability for monitoring dust pollution.

According to the linear approximation, the distance at which C_{PM10} drops below 0.06 mg/m^3 (below the MPC limits) is $l \approx 37.5$ m. This distance can be considered as an approximate boundary in the area of the dwelling zone, where priority application of measures to reduce dust emission or local dust suppression is required.

According to Table 2 and Fig. 4, the values of $PM_{2.5}$ concentrations remained below the MPC limits (0.035 mg/m^3) at all distances. The decrease in distance is moderate, and the absolute values are significantly lower than the levels for the coarse fraction. This is consistent with the dominance of coarse dust during construction waste overload.

Table 2. $PM_{2.5}$ concentration from constraction waste transloading.

Distance from the dust source at control points *l*, m	Concentration excess index *I*, C/MPC	Concentration *C*, mg/m^3
1	2	3
0	0.35	0.01225
10	0.32	0.01120
20	0.20	0.00700
30	0.22	0.00770
40	0.07	0.00245
50	0.01	0.00035

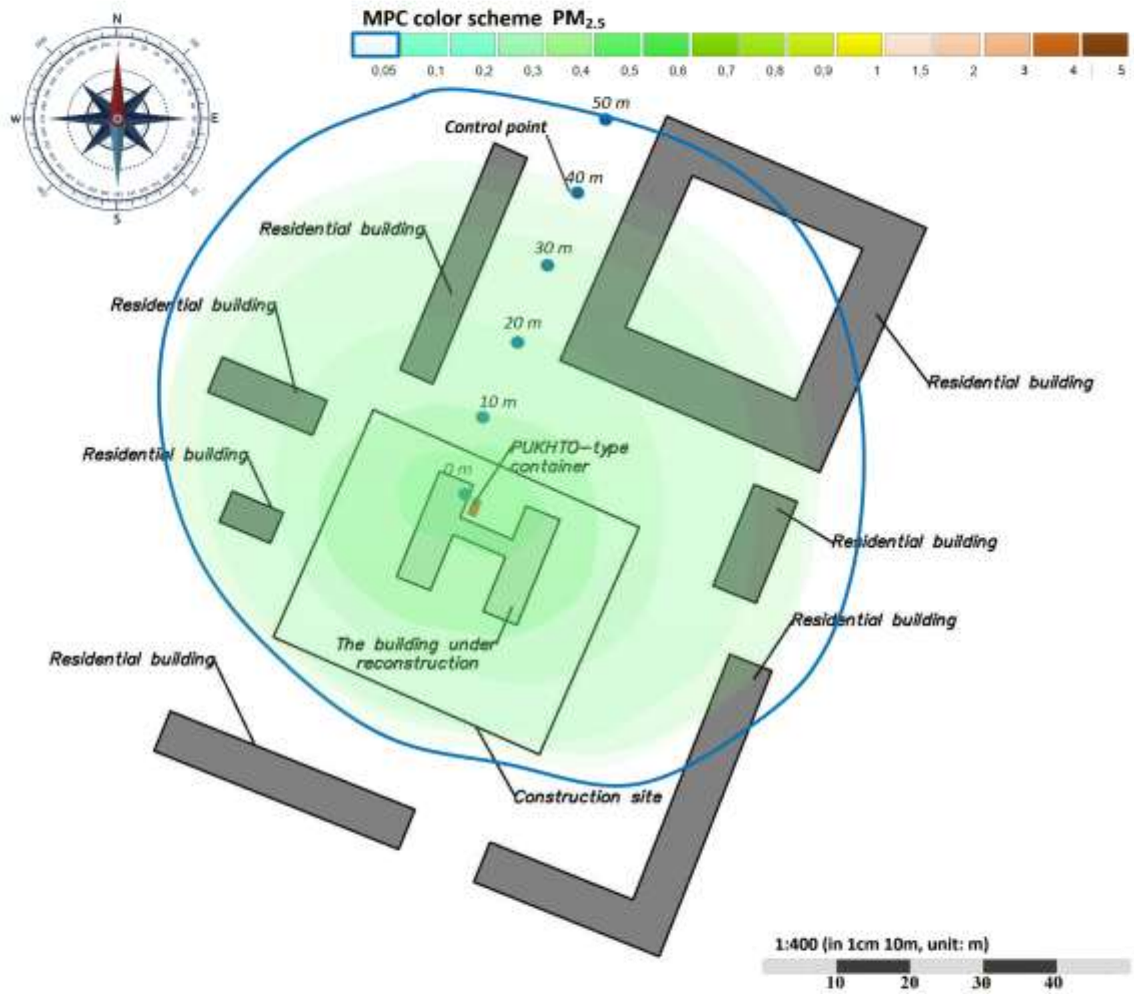

Fig. 4. $PM_{2.5}$ concentration from constraction waste transloading.

The linear model of approximation of the results of measurements of the PM_{10} concentration at a distance of 0-50 m has the form:

$$C_{PM_{2,5}}(l) = 0{,}01290 - 0{,}000243 \times l\left(mg / m^3\right), R^2 = 0{,}866. \quad (5)$$

The slope indicates an average decrease of about $2.43 \cdot 10^{-4}$ mg/m^3 for each meter of removal within the range under consideration. Small deviations of individual points are interpreted as a consequence of the aerodynamic characteristics of the air flow of dust pollution in the dwelling zone and changes in weather conditions.

Fig. 5 shows the empirically parameterized dependences for PM_{10} and $PM_{2.5}$ particles during the loading of solid construction waste into an open PUKHTO-type container to determine the impact of $PM_{2.5}$ and PM_{10} dust emissions on the air quality of the dwelling zone.

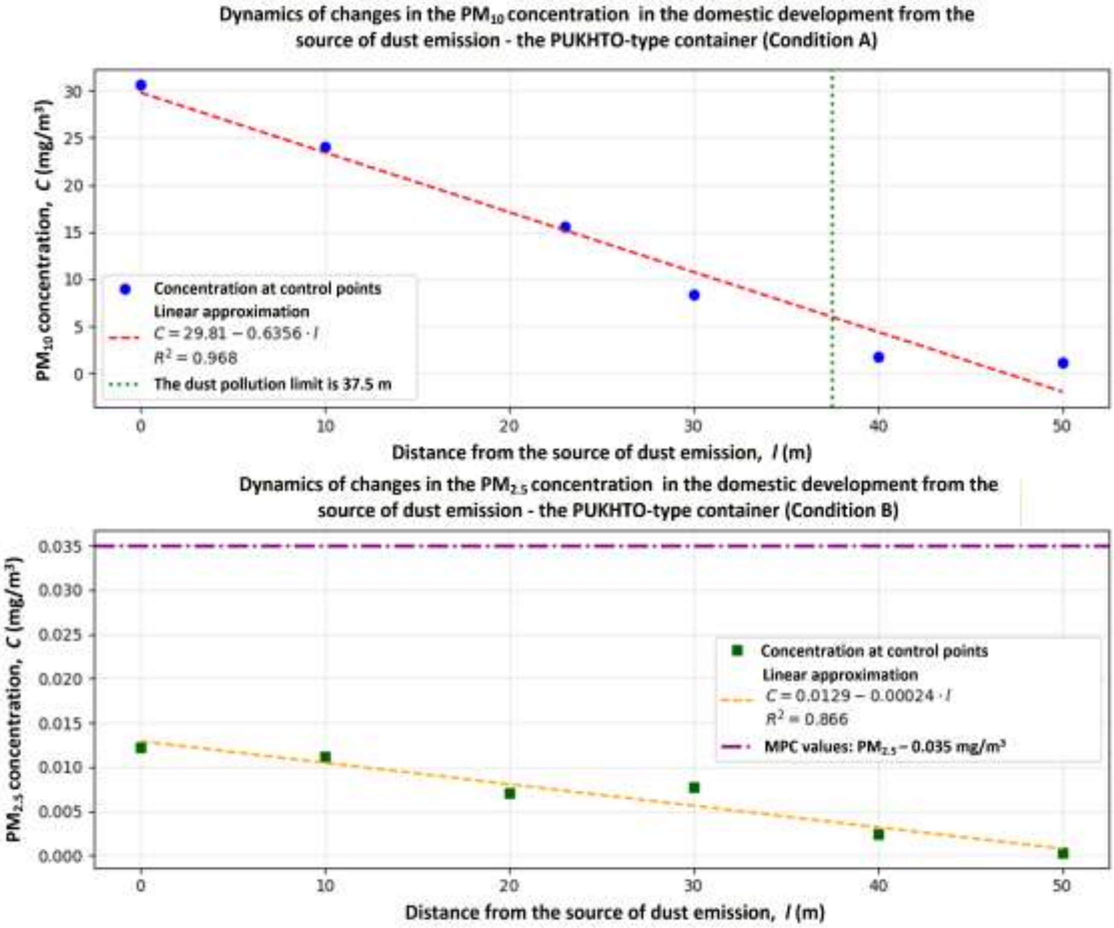

Fig. 5. Empirically parameterized dependences for PM_{10} and $PM_{2.5}$ particles during the loading of solid construction waste into an open PUKHTO-type container.

Fig. 6 shows the values of the concentration excess index *I* to assess the $PM_{2.5}$ and PM_{10} dust pollution of the dwelling zone air environment.

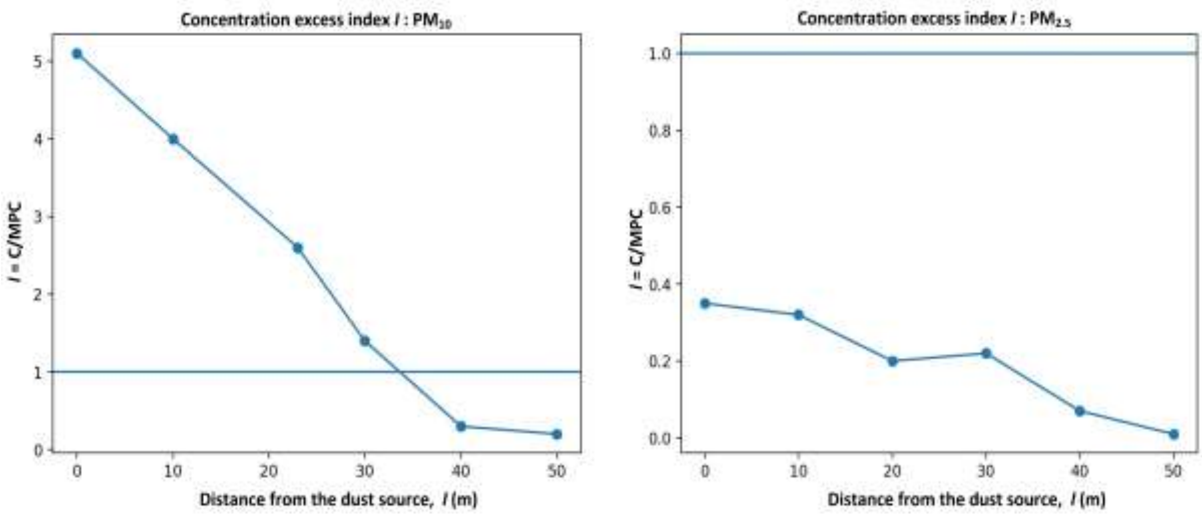

Fig. 6. Concentration excess index *I* for the $PM_{2.5}$ and PM_{10} dust pollution of the dwelling zone.

The increase in PM_{10} concentration is associated with dry and windy weather conditions, which contribute both to the formation of dust clouds during storage and transportation of construction waste (crushing waste, landfill) and the dispersion of particles in the atmosphere. The high wind speed accelerates the movement of PM_{10} particles in the downwind direction, contributing to their rapid dispersion. The data obtained on the dynamics of concentration decrease are typical for the dwelling zone and are consistent with observations of dust pollution caused by point-pattern development [15].

In contrast, the $PM_{2.5}$ concentration was measured at high humidity and low wind. In such conditions, coagulation and humidification of particles contribute to a decrease in the rate of dispersion, which leads to a decrease in the concentration of dust pollution in the surrounding area. The low values of the $PM_{2.5}$ concentration in this study indicate that when overloading construction waste, larger fractions make the main contribution to dustiness, while the concentration of the $PM_{2.5}$ particles may increase during other technological operations, for example, cutting bricks and gas blocks or grinding coatings [16].

For effective transshipment of construction waste into open containers, a comprehensive system of measures should be applied to reduce dust emissions: stabilization of the dust source (pre-humidification, lowering the height of the material drop, shielding and shelter), local suppression of dust emissions (use of water mist, foam technologies), control over the transfer of construction waste (regular cleaning, monitoring removal of soil by wheels of machinery, processing and covering of driveways) and control of technological operations (organization of work taking into account the direction of the wind, informing workers about the time of construction work, the use of personal protective equipment), table 3 [17, 18]. The examples of innovative dust suppression solutions are shown in Fig. 7.

Additional mining technological solutions for controlling dust pollution from transportation and storage of construction waste can be the use of steam condensation and aerial methods, as well as the use of special anti-dust additives when working with granular materials [19, 20].

In conditions of dense urban development, priority should be given to local measures in the near zone of the source of pollution, since it is there that the main contribution to the excess of PM_{10} concentrations is formed. The proposed index $I = C/MPC$ is convenient for monitoring dust pollution, as it allows comparing different fractions and scenarios without reference to units of measurement, which facilitates the calculation of the environmental risk of the dwelling zones. When interpreting the results and developing measures to reduce dust exposure to the dwelling zones, it is important to take into account the dependence of the $PM_{2.5}$ and PM_{10} concentration in dynamics with the standards calculated for the average daily period for atmospheric air.

The study is based on a limited number of episodes of measurements of the $PM_{2.5}$ and PM_{10} concentration, taking into account meteorological indicators. Future research should consider data on dust concentrations from construction production, indicators of the background concentration of the area where construction waste is stored, and an increase in the number of control points and measurements to improve measurement accuracy. This will enable us to establish a more stringent «distance–concentration» relationship between the dynamics of changes in $PM_{2.5}$ and PM_{10} concentrations and the distance at which the MPC limits are reached. These results can be integrated into summary calculations of emissions and an inventory of sources of pollutants.

The obtained decrease of PM_{10} concentration within 0–50 m is consistent with previously reported dust dispersion patterns near granular material transloading facilities [23, 24, 35-45]. The dominance of coarse particles during dry and windy conditions aligns with experimental findings presented in Journal of Mining Institute concerning dust suppression efficiency during bulk handling operations [25, 27, 28].

In contrast, $PM_{2.5}$ behavior under humid conditions reflects particle agglomeration mechanisms described in recent environmental studies on fine particulate matter [29, 30, 32].

Table 3. The comprehensive system of dust suppression methods and solutions for the PUKHTO-type containers.

Direction of control	Basic technological methods	Additional and innovative solutions	Examples of innovative solutions
1	2	3	4
Stabilization of the emission source	Pre-moistening of waste	Use of protective screens and shelters at transshipment hubs	The flexible PVC curtains by ThermoTarp (Russia) in the unloading areas of hoppers
	Minimizing the height of material fall		Telescopic dust-free discharge sleeves of the MZ or BEumer type by BEUMER Group GmbH & Co (Germany).
	Shielding and covering working areas		
Local emission suppression	Irrigation of fine particles	Generation of artificial high-pressure dry fog	The stationary high-pressure ultrasonic nozzles "Eco Mist" by Megafog (Russia).
	Application of foam technologies		The mobile dust suppression cannons Borey by TekhnoSpetsSnab (Russia) with a droplet size of up to 10 microns.
Control of logistics operations	Regular cleaning of driveways	Application of binding solutions for dirt roads	Treatment of technological passages with a specialized dust-removing composition "Bionord-Antidust" by Ural Plant of Deicing Materials (Russia) and the DustBlok reagent by Cypher Environmental Ltd (Canada)
	Washing and cleaning of vehicle wheels at the exit		
	Covering and treating access roads		
Technological regulations	Organization of work taking into account the wind rose	Optimization of dusty work schedules based on meteorological monitoring	Integration of digital ultrasonic weather stations Sokol-M by OKB Burrelief (Russia) for automatic blocking of conveyor or loader operation at critical wind speed. Integration of PM-Laser wireless sensors and ILS laser lidars into the IoT network for automatic predictive starting of injectors.
	Prompt informing of personnel		
	Mandatory use of personal protective equipment		

Continuation of Table 3

Transportation and storage	Covering the bodies with awnings during transportation	Introduction of anti-dust additives and polymer fixatives	Surface treatment of construction debris piles with film-forming latex compositions "Antipyl-Polymer" by Hermika Plant for Waterproofing and Anti-Corrosion Materials (Russia) or wetting agents such as "Neanol BS-1" by LLC BurSynthesis-M (Russia) to create a durable, wind-resistant crust. Use of electrostatic dust suppression guns StaticMist and lignin-based biodegradable protective membranes Eco-Korka by TechnoNICOL (Russia).

a.

b.

c.

d.

e.

f.

Fig. 7. The examples of innovative dust suppression solutions: a – flexible PVC curtains by ThermoTarp (Russia); b – telescopic dust-free discharge sleeves of the BEumer type by BEUMER Group GmbH & Co (Germany); c – stationary high-pressure ultrasonic nozzles "Eco Mist" by Megafog (Russia); d – mobile dust suppression can-nons Borey by TekhnoSpetsSnab (Russia); e – digital ultrasonic weather sta-tions Sokol-M by OKB Burre-lief (Russia); f – dust-removing composition "Bionord-Antidust" by Ural Plant of Deicing Materials (Russia).

4. CONCLUSIONS

This study examines the empirical «distance–concentration» relationship for PM_{10} and $PM_{2.5}$ particles formed during the transshipment of construction waste into open containers. The results are presented both in absolute values and in normalized form using the concentration excess index $I = C/MPC$, which makes it possible to quickly assess potential excess concentrations in the surrounding area.

In dry and windy conditions, the PM_{10} concentration decreased from 30.6 mg/m^3 at the source to 1.2 mg/m^3 at a distance of 50 m. The limit of reaching the standard concentration of PM_{10} (0.06 mg/m^3) is determined at a distance of 37.5 m from the source.

In conditions of high humidity and low wind, the concentration of $PM_{2.5}$ at a distance of 0-50 m remained below the standard values of 0.035 mg/m^3. This indicates the predominance of coarse particles in the studied source of dust emissions.

From a practical point of view, the data obtained make it possible to organize an effective multi-level dust management system, including pre-humidification and lowering the height of falling materials, local suppression of dust using fog or foam in the container area, control of pollution emissions from vehicle wheels, as well as operational monitoring with the setting of thresholds for adjusting operating modes taking into account meteorological conditions.

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