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Complex assessment of ambient particulate matter in a small settlement with coal-handling port

A.S. Kholodov[1]✉, K.Yu. Kirichenko[2], I.A. Vakhniuk[2], P. Duan[3], K.S. Golokhvast[2]

[1] Far East Geological Institute FEB RAS, Vladivostok, Russian Federation
[2] Siberian Federal Scientific Center of Agrobiotechnology RAS, Krasnoobsk, Russian Federation
[3] China University of Mining and Technology, Jiangsu, China

✉alex.holodov@gmail.com

Abstract. ***Relevance.*** Russian coal exports have been steadily increasing in recent years, and Far Eastern ports, originally not adapted to dusty cargoes, have switched to coal operations. Unoptimized coal handling leads to increased content of coal-containing particles in the air and to various environmental problems. ***Aim.*** To analyze the concentration of particulate matter in the air and the chemical composition of particles on the surface of conifer needles in the Posyet settlement (Primorsky Krai, Russia), where a large coal terminal operates. ***Materials and methods.*** The chemical composition was studied on the surface of conifer needles by X-ray fluorescence and in washout of conifer needle samples using Raman spectroscopy and energy dispersive analysis. Concentrations of particles with the diameter of 2.5 and 10 µm ($PM_{2.5}$ and PM_{10}, respectively) were measured using automatic monitoring stations. ***Results and conclusions.*** Chemical composition was dominated by mineral particles (calcite, silicates, etc.). However, the presence of coal particles (up to 8.3%) and metal particles was also observed. Mean concentrations of $PM_{2.5}$ and PM_{10} were within the Russian and international health standards, but close to their upper limits. Concentrations of both measured particle fractions were highest during the winter months (as well as in March, which is traditionally a cold month in the Far East), followed by a gradual decrease. The study obtained new data on the annual variations of concentrations of $PM_{2.5}$ and PM_{10}, as well as on the basic composition of particles from the surface of woody vegetation (needles) as an indicator of the state of air pollution in this settlement.

Keywords: particulate matter, air pollution, $PM_{2.5}$, PM_{10}, coal dust, heavy metals

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Комплексная оценка содержания твердых частиц в атмосферном воздухе поселка, в порту которого ведется перевалка угля

А.С. Холодов[1]✉, К.Ю. Кириченко[2], И.А. Вахнюк[2], П. Дуань[3], К.С. Голохваст[2]

[1] Дальневосточный геологический институт Дальневосточного отделения РАН, Россия, г. Владивосток
[2] Сибирский федеральный научный центр агробиотехнологий РАН, Россия, п. Краснообск
[3] Китайский горно-технологический университет, Китайская Народная Республика, г. Сюйчжоу

✉alex.holodov@gmail.com

Аннотация. ***Актуальность.*** В последние годы экспорт российского угля непрерывно растет, причем на работу с углем перешли дальневосточные порты, изначально не приспособленные для отгрузки пылящих грузов. Перевалка угля открытым способом приводит к увеличению содержания твердых частиц в воздухе и различным экологическим проблемам. ***Цель:*** изучение и анализ содержания микроразмерных частиц в атмосферном воздухе и в смыве с хвои в поселке Посьет (Приморский край), где работает крупный угольный терминал. ***Методы.*** Химический состав атмосферных взвесей был изучен непосредственно на поверхности хвои методом рентгенофлуоресцентного анализа и в смыве с проб хвои с помощью рамановской спектроскопии и энергодисперсионного анализа. Концентрации $PM_{2.5}$ и PM_{10} измеряли с помощью автоматических метеостанций. ***Результаты и выводы.*** Исследование показало, что в химическом составе преобладают частицы минералов (кальцит, силикаты и др.), но также отмечается наличие углесодержащих частиц (до 8,3 %) и частиц металлов. Усредненные данные по концентрации частиц $PM_{2.5}$ и PM_{10} находятся в пределах российских и зарубежных санитарных норм и правил, но подбираются к их верхним границам. Концентрации обеих измеренных фракций взвешенных частиц были наиболее высоки в зимние месяцы (а также в марте, который на Дальнем Востоке традиционно является холодным), затем наблюдалось их постепенное снижение. В исследовании получены новые данные о годовом ходе концентраций взвешенных в воздухе частиц $PM_{2.5}$ и PM_{10}, а также об основном составе частиц взвеси с поверхности древесной растительности (хвои) как индикаторе состояния загрязнения атмосферы в данном населенном пункте.

Ключевые слова: твердые частицы в атмосфере, загрязнение атмосферы, $PM_{2.5}$, PM_{10}, угольная пыль, тяжелые металлы

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Introduction

Russian coal exports to the Asia-Pacific region have grown steadily in recent years. Far Eastern ports, which were not originally equipped to handle dusty cargoes, have switched to coal. Coal handling operations cause air, water and soil pollution in areas adjacent to coal terminals. Large coal handling sites have a significant impact on the environment of urban areas as a whole, mainly on the composition of ambient particulate matter (PM) [1, 2].

Coal dust is one of the most potent air pollutants [3, 4]. Coal can contain more than 20 toxic and potentially toxic elements (Hg, As, Sb, Cd, Pb, etc.) [5, 6]. Coal dust can cause a number of chronic respiratory diseases, including pneumoconiosis, bronchitis, etc. [7, 8].

In general, the contribution of air pollution to the frequency and severity of the most common diseases of the respiratory system, digestive system, skin, allergic reactions, etc. is up to 30% of the total sum of factors affecting health [9, 10]. According to the World Health Organization (WHO), in 2016, 24% of all stroke deaths, 25% of coronary heart disease cases and deaths, 28% of lung cancer cases and deaths, and 43% of chronic obstructive pulmonary disease cases and deaths were related to air pollution [11, 12].

In addition, there is a statistically recognized relationship between airborne PM and morbidity and mortality [13]. PM (including coal particles) can be transported by wind far beyond the sanitary zones of industrial and storage areas [14]. Particles with diameters of 2.5 and 10 μm ($PM_{2.5}$ and PM_{10}, respectively) are often reported to pose a health risk [15–17].

These factors emphasize the important social and environmental role of continuous monitoring of air pollution for timely action to reduce the negative impact of coal dust on the environment.

This paper continues a series of works aimed at studying PM in the air and in other media (snow, surface of conifer needles) in cities and settlements of the Far Eastern region of Russia with the aim to single out the influence of various production processes on the environment and to work out a complex approach to the assessment of the content and concentration of PM, including further toxicological assessment on test objects and modeling the distribution of particles.

The site under study in this paper is the settlement of Posyet (Primorsky Krai), which has a large seaborne coal terminal. The settlement is located in a natural pristine environment, and the port infrastructure is not fully suitable for handling dusty bulk cargo, which contributes to the airborne migration of anthropogenic PM.

Using a combination of methods, we aimed to estimate PM concentration in the ambient air of the settlement and PM composition on the surface of conifer needles and in the dried washout from these needles. Conifer needle samples were chosen as the objects of study because they are available for sampling in any season and they accumulate a considerable amount of dust on their surface, which serves as a reliable medium for assessing air pollution [18–20]. The chemical composition was studied using Raman spectroscopy, X-ray fluorescence, and energy dispersion analysis. Concentrations of $PM_{2.5}$ and PM_{10} were measured using automatic monitoring stations.

Materials and Methods

Study area

The urban-type settlement Posyet is located in the Khasansky District of Primorsky Krai on the Novgorodsky Peninsula in the Posyet Gulf. Posyet has a monsoon climate with moderately cold winters and humid summers. The bays Novgorodskaya, Ekspeditsii and Raid Pallada in the Posyet Gulf have a special nature protection status and scientific value. At the same time, the port of Posyet is the site of a large enterprise with an impact on the environment (a coal terminal). In 2016, the port capacity allowed for the handling of up to 12 million tonnes of coal per year [21], and the turnover is growing every year.

The port of Posyet was not originally designed to handle bulk cargo (including coal), and residential houses were built directly in front of the port (Fig. 1). Despite ongoing modernization of the port facilities, there are frequent reports in the public media of coal spillage and coal dust entering the bay. Due to the monsoon climate, humidity is very low in winter, around 20–30%. The coal piles dry out and the wind spreads the dust, especially in winter, which we have previously observed during snow sampling and analysis in the settlement in 2018 [22].

The population of the settlement was about 1,650 people in 2021. AO Trade Port Posyet is the main employer in the area. According to the official data, 350 residents of the settlement work for the company.

Conifer needle samples

To study the ambient air pollution regardless of the season, we analyzed the washout from conifer tree needles. Due to their structure, conifer needles capture particulate matter on their surface and can be used as an indicator of ambient air quality [23, 24].

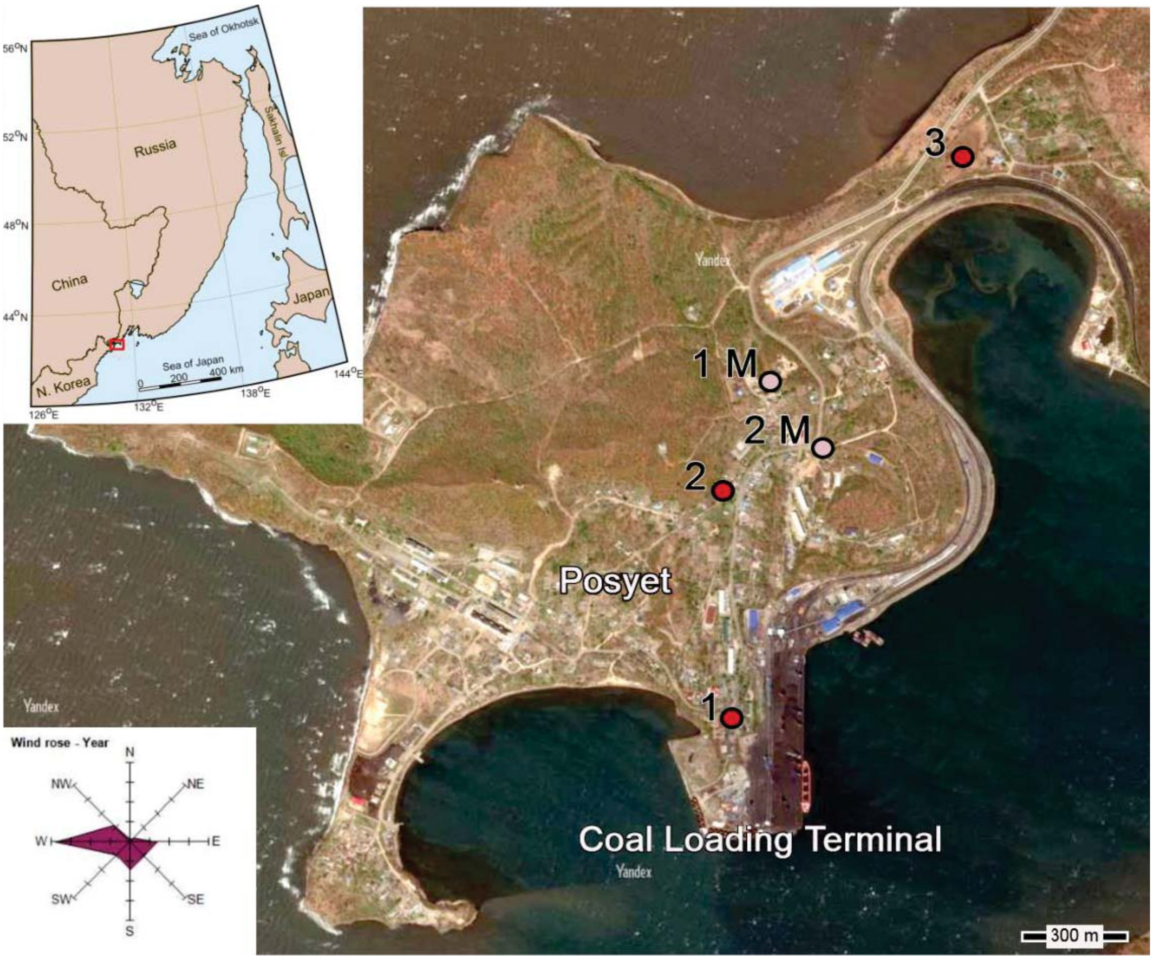

Fig. 1. *Sampling area in Posyet settlement. Numbers 1–3 – conifer needle sampling sites: 1 – near the coal terminal (distance from the port 100 m); 2 – in the yard of a private house (distance from the port 400 m); 3 – along the road to the settlement, not far from the railway. Numbers 1 M and 2 M are the locations of automatic monitoring stations: 1 M – private house on a hill (42°39'31.5"N 130°48'25.8"E, distance from the port 680 m); 2 M – on top of a one-storey building at an intersection (42°39'24.6"N 130°48'31.2"E, distance from the port 500 m). Map data (c) Yandex*

Рис. 1. *Район отбора проб в п. Посьет. Номера 1–3 – точки отбора проб хвои: 1 – возле угольного терминала (расстояние до порта 100 м); 2 – во дворе частного жилого дома (расстояние до порта 400 м); 3 – вдоль автодороги к поселку, недалеко от железной дороги. Номера 1 М и 2 М – места размещения автоматических метеостанций: 1 М – частный жилой дом на возвышенности (42°39'31.5"N 130°48'25.8"E, расстояние до порта 680 м); 2 М – крыша одноэтажного строения на перекрестке (42°39'24.6"N 130°48'31.2"E, расстояние до порта 500 м). Картографические данные (c) Яндекс*

Needles were collected from trees at a height of 1–1.5 m, placed in PET containers prewashed with distilled water, and transported to the laboratory. Samples 1 and 2 are from Manchurian fir (*Abies holophylla*) and Sample 3 is from Scots pine (*Pinus silvestris*). Conifer needle sampling points were chosen near the coal terminal (south), in the center of the settlement and near the railroad (north) to reflect all types of air pollution common for the settlement (Fig. 1).

To prepare the washout, we treated the needles with ultrasound using a method that has been previously tested in ambient PM analysis [24, 25]. The containers with sample needles were filled with double-distilled water and cleaned with ultrasound using a Sonopulse 3100 HD ultrasonic homogenizer (Bandelin electronic GmbH & Co. KG, Berlin, Germany) at 22 kHz, 100 watts, and a 5-min exposure time to remove the dust particles from the needles. The resulting liquid was filtered through a 0.22 µm Millipore filter, and then the filter was dried in an oven to obtain dry PM suitable for analysis.

Raman spectroscopy

The chemical composition of the dried sample material was determined by Raman spectroscopy using the Morphologi G3-ID instrument (Malvern Instruments Ltd., UK) at the Nanotechnology Laboratory of the Far Eastern Federal University (FEFU), Vladivostok. In this method, a beam of a specific wavelength passes through a sample of the studied material and scatters on contact with the sample. The resulting beams are focused into a single beam by a lens and then passed through a filter, which separates the weak Raman beams from the more intense ones. The 'pure' beams are amplified and sent to a detector which records their frequency.

The advantages of this method include the ability to determine the size and basic chemical composition of each individual particle in the sample by comparing its spectra with reference spectra from databases [26, 27]. For example, Raman spectroscopy can be used to identify different mineral phases in ordinary Portland cement without special sample preparation [28]. The content of reference substances in the collected PM samples was determined using chemical correlation analysis software (supplied with the instrument).

A total of 100,000 particles were scanned in each sample. Spectra of 200 particles of 5–10 µm diameter were then analyzed in manual mode and 400 particles of 20–25 µm diameter were analyzed in automatic mode. Statistical processing of the results was performed automatically in the software supplied with the instrument.

X-ray fluorescence analysis of the surface of conifer needles

The analysis of needle samples required a non-destructive method, so a portable X-ray fluorescence spectrometer Innov-X SyStemS (USA) was used. The XRF method collects and analyzes the spectrum produced when the material is irradiated with X-rays. The analysis was conducted at the Interdepartmental center for analytical control of the environment, FEFU, Vladivostok.

Imaging and microanalysis of particles

The elemental composition of the particles was also studied using an electron probe microanalyzer JXA 8100 (JEOL, Japan) equipped with three wave spectrometers and energy dispersive spectrometer INKA-sight (Oxford Instruments, UK). The studies were carried out in the secondary electrode (SE) mode to image the morphology of the particles in the samples and their surface topography, and in the reflected electron mode (BE COMPO), which has a different contrast depending on the average atomic number of the element. The study was carried out by Point and ID method. Metal-containing and coal particles were analyzed first of all, as the main task of this study was to detect coal. The choice of substances for the study was based on the results of X-ray fluorescence analysis of the samples. Quantitative and semi-quantitative analysis was carried out using the PhyRoZ method. The analytical studies were carried out in the Laboratory of Micro- and Nanoresearch, Far East Geological Institute, Far East Branch of the Russian Academy of Sciences (Vladivostok).

Measurement of $PM_{2.5}$ and PM_{10} concentrations with automatic monitoring stations

Measurements were made using two automatic monitoring stations deployed in Posyet settlement, one in the yard of a private house surrounded by trees, and the other one at a road intersection, in a location presumably subject to higher air pollution levels (Fig. 1, 2). The locations were chosen to reflect both supposedly polluted and background areas. The monitoring stations measure air temperature, relative humidity, wind speed and direction, and concentrations of ambient $PM_{2.5}$ and PM_{10}. Data from the automatic monitoring stations (averaged over 10 min) are transmitted via GSM/GPRS/EDGE/2G/3G communication channels to a remote FTP/HTML server with a frequency of 1–2 times per day. The stations of this design were previously used in a similar study in a larger port city that also handles coal [29].

In this work, the data received on the server from automatic monitoring stations from 20 January 2021 to 31 July 2021 were analyzed. The daily volume of data from each station was 144 records. Statistical analyses were performed using the STATISTICA 10 software package (StatSoft, Inc., USA). Mean and standard deviation were calculated for each set of values.

Fig. 2. Automatic monitoring station for the measurement of ambient air parameters, deployed at point 1 M
Рис. 2. Автоматическая метеостанция, установленная в точке 1 М

Results

Raman spectroscopy of particles in the dried washout from conifer needle samples

To compare the chemical composition of the samples, we took Raman spectra of the most common group of particles in the samples. The spectra were then compared to a library of common minerals and coals consisting of 347 spectra. The library included spectra of coal, calcite, silicates, apatite, alumina (corundum), fayalite, chrysoberyl, hydroxyapatite, zircon, enstatite, fluorite, lazurite, quartz, zeolite, azurite, carnelian, hedenbergite, galena, andradite etc.

Table 1. *Chemical analysis of particles by Raman spectroscopy*
Таблица 1. *Химический анализ частиц по данным рамановской спектроскопии*

Material Вещество	Material content in samples, % Содержание вещества в пробах, %		
	Sample/Проба		
	1	2	3
Calcite/Кальцит	87	82.1	89.1
Coal/Уголь	8.3	4.3	6
Silicate particles Силикатные частицы	3.6	9.3	4.1
Galena/Галенит (PbS)	0.8	2.7	0.7
Sphalerite Сфалерит (ZnS)	N/D не обнаруж.	0.9	N/D не обнаруж.

Chemical analysis of a selection of 200 particles for each sample showed the following correlation of the main minerals and coal particles (Table 1). The highest proportion of coal-containing particles (8.3%) was observed in the sample collected close to the port infrastructure.

X-ray fluorescence analysis of the surface of conifer needles

Samples from sampling points 2 and 3 were analyzed on an Innov-X SyStemS X-ray fluorescence spectrometer. Unfortunately, the sample from point 1 could not be analyzed by this method due to the fact that it was collected from a small stunted tree in the port area and there was only enough material for Raman analysis. The results are summarized in Table 2. The highest concentrations were found for Fe, Zn and Pb.

Studies on the Electron Probe Microanalyzer

Based on the results of the X-ray fluorescence analysis, it was decided to further analyze the 2nd and 3rd samples on an electron probe microanalyser, in search of particles of metal compounds and coal. The composition of both samples was visually similar under the microscope. Fig. 3 shows a typical section of the suspension from sample 2, including the energy dispersive composition of several metal-containing and coal particles. The chemical composition is summarized in Table 3.

Table 2. *Composition of metals on the surface of needle samples from X-ray fluorescence analysis*
Таблица 2. *Состав металлов на поверхности проб хвои по данным рентгенофлуоресцентного анализа*

Sample Проба	Element, mg/kg/Элемент, мг/кг															
	Ti	Cr	Mn	Fe	Zn	As	Pb	Sr	Cd	Sb	Ba	Co	Ni	Cu	Mo	Sn
2	2426	58.5	1882	32393	15110	1058	6974.6	413.6	25.6	77	434.5	105.4	131	1177	4.01	27.3
3	5866	153.8	1214	63550	1317.7	244.3	284.7	454.7	10.9	68.6	322.3	126.6	420.1	2715	8.03	30.8

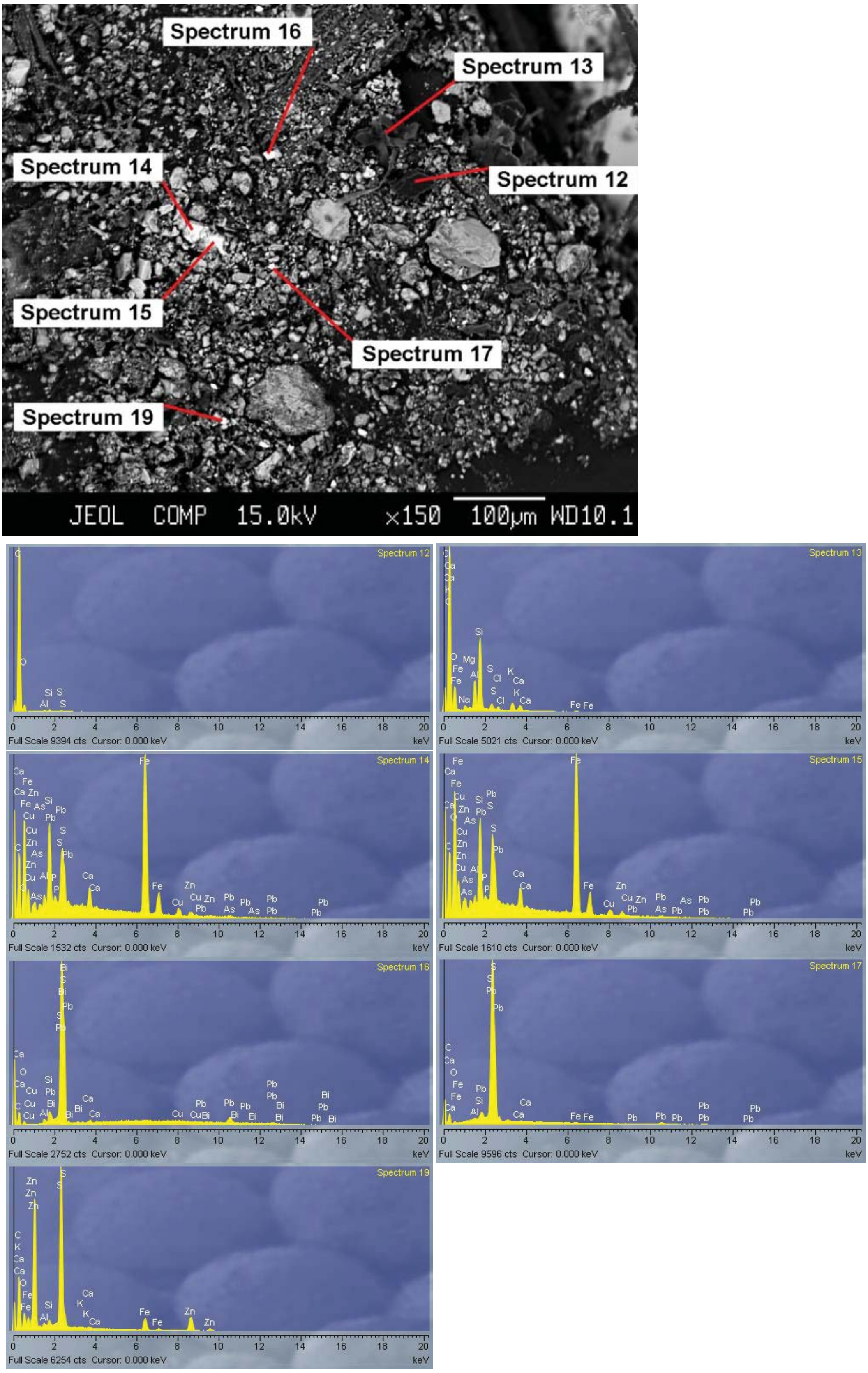

Fig. 3. *Electronic micrograph and energy dispersive composition of particles from a section of sample No. 2. Marked: coal particles (spectra 12 and 13); irregular, torn particles containing Fe, PbS, Cu, Zn and other elements (spectra 14 and 15); PbS particles (spectra 16 and 17); particles containing Fe, Zn and S (spectrum 19)*

Рис. 3. *Электронная микрофотография и энергодисперсионный состав частиц участка взвеси из пробы № 2. Отмечены: частицы угля (спектры 12 и13); частицы неправильной, рваной формы, содержащие Fe, PbS, Cu, Zn и другие элементы (спектры 14 и 15); частицы PbS (спектры 16 и 17); частица, содержащая Fe, Zn, S (спектр 19)*

Table 3. *Chemical composition of the particles marked in Fig. 3, according to energy dispersive analysis, wt %*

Таблица 3. *Химический состав частиц, отмеченных на рис. 3, по данным энергодисперсионного анализа, вес. %*

Element	Spectra/Спектр						
Элемент	12	13	14	15	16	17	19
O	3.6	17.07	14.81	19.51	1.89	4.15	15.56
Na	–	0.94	–	–	–	–	–
Mg	–	0.31	–	–	–	–	–
Al	0.18	3.54	0.6	0.55	0.26	0.3	0.79
Si	0.31	9.3	3.87	3.99	0.65	0.5	1.07
P	–	–	0.41	0.31	–	–	–
S	0.27	0.91	0.36	0.41	3.83	13.02	29.66
Cl	–	0.54	–	–	–	–	–
K	–	1.73	–	–	–	–	0.24
Ca	–	1.33	1.46	1.45	0.3	0.36	0.37
Ti	–	–	–	–	–	–	–
Mn	–	–	–	–	–	–	–
Fe	–	0.79	33.4	35.34	–	0.55	9.73
Cu	–	–	3.15	3	0.9	–	–
Zn	–	–	2.66	2.67	–	–	37.2
As	–	–	0.61	0.93	–	–	–
Pb	–	–	7.57	9.69	24.62	83.71	–
Bi	–	–	–	–	5.29	–	–

Concentrations of $PM_{2.5}$ and PM_{10}

Data on $PM_{2.5}$ and PM_{10} concentrations were averaged over months. According to the observations, the concentrations of both particulate matter fractions measured were highest in the winter months (as well as in March, which is traditionally cold in the Russian Far East), and then a gradual decrease was observed (Fig. 4).

Concentrations of $PM_{2.5}$ were within the range of 17.5 μg/m^3 at both sites, with a mean of 12.1 μg/m^3 at site 1 and 10.7 μg/m^3 at site 2 for the whole period. The mean monthly values at the first site were slightly higher than those at the second site.

The mean concentration of PM_{10} was 36.8 μg/m^3 at site 1 and 32 μg/m^3 at site 2. The peak of PM_{10} was observed in March 2021, when the concentrations increased to 53.6 μg/m^3 (site 1) and 44.9 μg/m^3 (site 2).

Discussion

According to the results of the correlation analysis of Raman spectra (Table 1), most of the studied particles in the samples of dried washout from the surface of conifer needles in Posyet settlement (more than 80% in all samples) were calcite. Some amount of coal particles was present in all samples (from 4.3 to 8.3%). The remaining particles were silicates, particles containing Pb and Zn (probably as part of galena and sphalerite) and other impurities in small amounts.

These observations are confirmed by the results of the electron probe microanalysis study. In addition to calcite, there were many silicates, pieces of organic matter and irregularly shaped particles containing metals. Coal particles were found, but in small numbers. The small amount of coal in the samples could be related to the prevailing westerly winds, which carry coal dust from the terminal into the Posyet Gulf, polluting the water area. In addition, the dust suppression equipment used in the port washes some of the coal dust into the gulf.

This composition of the solid component of the ambient PM is typical for the cities and towns of the Primorsky Krai. However, the component of PM of natural origin varies from area to area, while the anthropogenic component is common to all areas of human activity and depends directly on the nature of this activity. The main stationary sources of ambient air pollution are heat and power facilities.

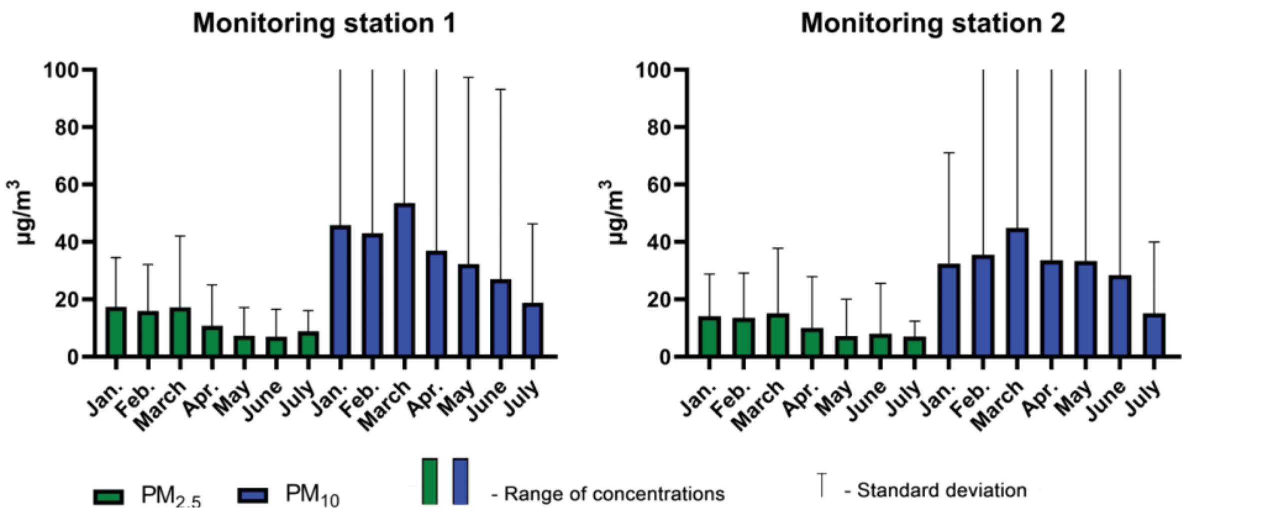

Fig. 4. *Mean concentrations of $PM_{2.5}$ and PM_{10} in Posyet from January to July 2021 measured by the monitoring stations*

Рис. 4. *Средние концентрации частиц $PM_{2.5}$ и PM_{10} в п. Посьет за период с января по июль 2021 г. по данным измерений метеостанциями*

The entire thermal energy production chain, from extraction to transport, processing of raw materials and energy production, is a source of polluting emissions that affect the population of both small settlements and large cities. Finding a correlation between particle composition and wind direction helps to link the origin of particles, their trajectories and their chemical composition Aerosols that have travelled for a long time over rural areas are characterized by a high content of mineral particles. When airflows pass over densely populated areas, the amount of particles containing coal and soot and particles associated with exhaust gases increases [30].

In this case, the content of coal-containing particles in the samples is relatively low (up to 8.3%), which indicates that coal dust spreads beyond the sanitary protection zone but does not have a significant impact on PM in the ambient air of the settlement, except for the area adjacent to the port facilities. It is worth noting that winter snow samples collected near the port contained visible traces of coal dust contamination [22]. Other obvious sources of coal particles are boiler houses and stove heating. Due to the low number of cars in the settlement, motor traffic does not have a significant impact on ambient PM, in contrast to cities and more developed settlements [31]. Calcite particles are most likely of natural origin (including waste shells from seashore) [32], while silicate particles include both natural and anthropogenic sources (round silicate particles may the result of high temperature burning of all kinds of fuel) [33]. The mineral particles described above are most likely of natural origin, while other metal-containing particles (Cu, Fe, As) may originate from road traffic and also from fuel combustion.

In addition to the chemical composition of particulate matter, the second most important characteristic is its concentration in ambient air. We compared the mean concentrations of $PM_{2.5}$ and PM_{10} with the maximum 24-hour and annual concentration standards specified in the Russian and US (NAAQS) documents (Table 4) [34, 35].

The mean concentrations for the whole observation period can be compared with the annual concentration standards from the relevant documents. The mean $PM_{2.5}$ concentrations from January to July 2021 (12.1 μg/m^3 at station 1 and 10.7 μg/m^3 at station 2) are well within the Russian standards (annual concentration), but at the upper end of the US NAAQS range (12 μg/m^3).

Table 4. *Comparison of $PM_{2.5}$ and PM_{10} concentrations in Posyet in January–July 2021 with the US and Russian standards*

Таблица 4. *Сопоставление концентраций взвешенных частиц $PM_{2.5}$ и PM_{10} в п. Посьет за период январь–июль 2021 г. С нормативами СанПиН 1.2.3685-21 и NAAQS (США)*

Title Наименование	$PM_{2.5}$ concentration (μg/m^3) Концентрация взвешенных частиц $PM_{2.5}$ (мкг/м^3)		Title Наименование	PM_{10} concentration (μg/m^3) Концентрация взвешенных частиц PM_{10} (мкг/м^3)	
	Site 1 Точка № 1	Site 2 Точка № 2		Site 1 Точка № 1	Site 2 Точка № 2
January/январь	17.4	14.1	January/январь	46.0	32.5
February/февраль	16.0	13.5	February/февраль	43.0	35.6
March/март	17.2	15.1	March/март	53.6	44.9
April/апрель	10.8	10.0	April/апрель	37.0	33.7
May/май	7.3	7.2	May/май	32.2	33.3
June/июнь	7.0	8.1	June/июнь	27.1	28.4
July/июль	8.9	7.0	July/июль	18.8	15.2
Mean concentration of $PM_{2.5}$ in January–July 2021 Средняя концентрация частиц $PM_{2.5}$ за период январь–июль 2021 г.	12.1	10.7	Mean concentration of PM_{10} in January–July 2021 Средняя концентрация частиц PM_{10} за период январь–июль 2021 г.	36.8	32.0
Russian 24-hour concentration standard [21] Среднесуточная концентрация $PM_{2.5}$ (СанПиН) [21]	35		Russian 24-hour concentration standard [21] Среднесуточная концентрация PM_{10} (СанПиН) [21]	60	
Russian annual concentration standard [21] Среднегодовая концентрация $PM_{2.5}$ (СанПиН) [21]	25		Russian annual concentration standard [21] Среднегодовая концентрация PM_{10} (СанПиН) [21]	40	
US 24-hour concentration standard [22] Среднесуточная концентрация $PM_{2.5}$ по NAAQS (США) [22]	35		US 24-hour concentration standard [22] Среднесуточная концентрация PM_{10} по NAAQS (США) [22]	150	
US annual concentration standard [22] Среднегодовая концентрация $PM_{2.5}$ по NAAQS (США) [22]	12		N/A Отсутствует		

The mean PM_{10} concentrations over the whole period of observation (36.8 μg/m^3 at station 1 and 32.0 μg/m^3 at station 2) were within the Russian standards (annual mean 40 μg/m^3). However, during the cold months PM_{10} content exceeded these values and reached 53 μg/m^3, probably indicating the influence of boiler houses and stove heating.

These data correlate with our previous study (analysis of fresh snow cover), which showed that the area of Posyet settlement is under the influence of a major source of air pollution. The proportion of PM_{10} measured in thawed fresh snow, according to the results of this study, ranged from 15.4 to 45.3% (average 32.5%) [22].

It is known that there is a correlation between time of day and particle concentrations [36]. In this study, we did not find this correlation, but there were individual overshoots of particle concentrations at different times of day.

These data can also be compared with the results of a similar study carried out by the authors in the city of Nakhodka, which also has a coal handling facility in its port and is much larger than Posyet settlement [29]. There, too, a gradual decrease in PM concentrations was observed as the temperature outside the window increased. The maximum mean $PM_{2.5}$ concentration for the whole observation period (January–May 2021) there reached 17.2 μg/m^3, and PM_{10} was 41.7 μg/m^3, which correlates with the data obtained in Posyet.

Conclusion

In this work we studied particulate matter in the air of Posyet settlement using a complex of methods. The chemical composition of particulate matter was studied in a washout of conifer needle samples using Raman spectroscopy and energy dispersive analysis. Concentrations of $PM_{2.5}$ and PM_{10} were measured using automatic monitoring stations.

According to the ranges of PM content in the air of Posyet, averaged over months, the highest PM_{10} and $PM_{2.5}$ concentrations were observed in winter months, followed by a gradual decrease in concentrations at all monitoring sites. At the same time, the measured concentrations were within Russian and US standards.

In terms of chemical composition, particles of natural origin (calcite, a certain part of silicates) predominated in the samples, but coal particles (up to 8.3%) and metal-containing particles were also found. In addition to the coal handling activities of the port, the industrial component of ambient particulate matter in the settlement (measured in the washout from conifer needles) is affected by fuel combustion (boilers and stove heating).

From a practical point of view, this study has shown that this small settlement has medium to high concentrations of $PM_{2.5}$–PM_{10} (as shown by instrumental measurements). In terms of health and hygiene, particles in this size range are the most dangerous for human health. However, most of the unalyzed particles in the dried washout samples seem to be of natural origin, with the exception of particles near the port. A system for continuous monitoring of coal dust air pollution near the coal terminal in Posyet settlement is needed. It can be a network of sensors that will allow receiving daily accurate data on PM content in the air. With the help of such data, it will be possible to react promptly to the exceeding of the maximum permissible concentration of suspended particles in the air and to take timely decisions to reduce the negative impact on the environment.

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Information about the authors

Aleksei S. Kholodov, Cand. Sc., Senior Researcher, Far East Geological Institute FEB RAS, 159, 100-letiya Vladivostoka avenue, Vladivostok, 690022, Russian Federation. alex.holodov@gmail.com; https://orcid.org/0000-0001-6916-0596

Konstantin Yu. Kirichenko, Cand. Sc., Senior Researcher, Siberian Federal Scientific Center of Agrobiotechnology RAS, 2b, Tsentralnaya street, Krasnoobsk, 630501, Russian Federation. kirichenko@sfsca.ru; https://orcid.org/0000-0002-2715-3758

Igor A. Vakhniuk, Junior Researcher, Siberian Federal Scientific Center of Agrobiotechnology RAS, 2b, Tsentralnaya street, Krasnoobsk, 630501, Russian Federation. vakhniuk@sfsca.ru; https://orcid.org/0000-0002-4530-2577

Piaopiao Duan, PhD, Associate Professor, China University of Mining and Technology, 1, Daxue Road, Xuzhou, Jiangsu, 221116, China. duanpiaopiao@163.com

Kirill S. Golokhvast, Dr. Sc., Professor, Director, Siberian Federal Scientific Center of Agrobiotechnology RAS, 2b, Tsentralnaya street, Krasnoobsk, 630501, Russian Federation. golokhvast@sfsca.ru; https://orcid.org/0000-0002-4873-2281

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Информация об авторах

Алексей Сергеевич Холодов, кандидат географических наук, старший научный сотрудник, Дальневосточный геологический институт Дальневосточного отделения РАН, Россия, 690022, г. Владивосток, пр. 100-летия Владивостока, 159. alex.holodov@gmail.com; https://orcid.org/0000-0001-6916-0596

Константин Юрьевич Кириченко, кандидат биологических наук, старший научный сотрудник, Сибирский федеральный научный центр агробиотехнологий РАН, Россия, 630501, п. Краснообск, ул. Центральная, 2б. kirichenko@sfsca.ru; https://orcid.org/0000-0002-2715-3758

Игорь Анатольевич Вахнюк, младший научный сотрудник, Сибирский федеральный научный центр агробиотехнологий РАН, Россия, 630501, п. Краснообск, ул. Центральная, 2б. vakhniuk@sfsca.ru; https://orcid.org/0000-0002-4530-2577

Пяопяо Дуань, PhD, доцент, Китайский горно-технологический университет, Китайская Народная Республика, 221116, г. Сюйчжоу, Цзянсу, Дасюэ Роуд, 1. duanpiaopiao@163.com

Кирилл Сергеевич Голохваст, доктор биологических наук, профессор, директор, Сибирский федеральный научный центр агробиотехнологий РАН, Россия, 630501, п. Краснообск, ул. Центральная, 2б. golokhvast@sfsca.ru; https://orcid.org/0000-0002-4873-2281

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