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Features of Forming the Composition of the Atmosphere in the City of Murmansk

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Abstract

The article is devoted to the issues of planning and development of urban environment in the Arctic region of the Russian Federation, the city of Murmansk located beyond the Arctic Circle is investigated as an example. The article provides a description of the natural and climatic conditions, characteristic of the latitude of the city, it also gives a detailed analysis of the site development and the microclimate it formed, impacting greatly on the distribution of pollutants in the city's outside air and, consequently, on the comfortable conditions for the northerners living. The conclusions are based on the surveys of more than 200 industrial facilities located on the territory of Murmansk and the city's transport as well. The analysis of their combined impact on the outside atmosphere of the city was conducted by the specialists of JSC Research Institute "Atmosphere" applying the system of summary calculation.

Keywords: the city of Murmansk, the Arctic region, air pollution, green construction, microclimate

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1. Introduction

Murmansk is the largest city on the planet, which is situated beyond the Arctic Circle [1].

The territory of Murmansk is of elongated shape, oriented from south to north along the eastern coast of the Kola Bay, stretches for more than 20 kilometers. The part of the territory, including the microdistricts Abram-Mys, Tri Ruchya and Drovyanoye, is located on the western coast. The area is 154.4 km^2 [2]. On the eastern side, Murmansk is surrounded by a number of hills; their absolute heights reach 100--250 m. The location between the European continent in the south and the Arctic Ocean basin in the north, as well as the proximity of the warm Nordkapp current in the Barents Sea off the coast of the Kola Peninsula, has a huge impact on the climate [2, 3].

1.1. Natural conditions in the city

Natural conditions for the people's living are scarcely favorable in the north and moderately unfavorable in the south of the region. Murmansk belongs to the Atlantic-Arctic band of the temperate zone. This zone is characterized by dominant air masses of Arctic and Atlantic origin, as well as by the intensification of cyclonic processes in the cold part of the year (October -- April) and their weakening in the warm (May -- September) part of the year. In the cold season over the Norwegian and Barents Seas, cyclonic activity predominates, causing unstable weather with frequent storms and sharp temperature fluctuations [4].

Owing to the Gulf Stream, the average annual temperatures on the territory of the Murmansk region are much higher than in other regions of similar latitudes. Winter is long (from January to March), but relatively soft, with cold snaps and thawing heavy snowfalls are quite frequent. Summer is short (June - August) and cool with short-term periods of heat weather and intense showers, frosts are possible. From October to May is the period for the development of icing conditions and hoarfrost [5].

The wind in Murmansk is of a monsoon character. In winter, southern winds from the mainland prevail, and in summer, northern winds from the Barents Sea are more frequent. In spring and autumn, the wind direction is less stable, southern winds are prevailing.

Wind speed also experiences significant annual fluctuations.

The transition of the average temperature through the points -5, 0, +5 and + 10 ° occurs in Murmansk annually, but it doesn't reach + 10 ° every winter. In 12% of winters, there is no stable transition of the average temperature through the piont -10 °. The dates when the average temperature passes the point + 8 ° are of great practical interest. This date in autumn determines the beginning, and in spring - the end of the heating season.

Very early and late dates for the start of the heating season range from August 18 to September 29. The dates for the end of the heating season range from May 21 to July 10.

Advection of air masses of different origin influence the formation of temperature regime of Murmansk, especially in summer and in winter, when the temperature differences of air masses coming from the Barents sea or the mainland, are the most significant.

The coldest wind in winter is of South-Eastern direction. The warm wind in winter is of North-West direction. The warmest wind in summer is from the South-West and South. In addition to the direction of wind, temperature is affected by the wind speed.

When the temperature decreases from 0 to -20° the average wind speed decreases, and at its further decrease it remains constant.

The combination of the seasonal average temperatures with the certain directions of the wind strongly impacts the temperature inside the premises depending on their location considering the cardinal directions. For example, in the cold season, from October to April, in the apartments, facing South, situated in the direction of the most prevailing and cold winds and having the same thickness of the walls and intensity of heating, it is much colder than the apartments facing the North, towards warmer and less frequent winds in the Northern districts. Unfortunately, this fact is seldom taken into account when designing buildings [4].

Air humidity in the conditions of Murmansk largely depends on the wind direction. Minimal values are observed in January and February, and the highest are in August, and the lack of saturation is noted in July.

Precipitation in Murmansk, as in other areas of the temperate climate, is mainly formed as a result of cyclonic activity. Most of the rainfall in Murmansk (about 500 mm) per year falls from June to September, the peak of cloudy days and days with precipitation is in August. Snow lays in the city for 210 days in average and completely disappears by May. Snowfalls are frequent in the first half of June. The duration of the snow cover is 180--200 days.

The greatest number of foggy days and the longest duration of fog are observed in December during the polar night, and the smallest - in June during the polar day. The average duration of fog per day ranges from two hours in June to eight in December.

Snowstorms are represented by three types: overall drifting snow, low-level snow drifts and snow drifting. Thunderstorms are quite rare for Murmansk, occurring just 6 days per year.

The Murmansk region occupies the northeastern outskirts of the enormous Baltic Shield; the Kola Peninsula descends to the Barents Sea on steps-terraces. The city is located on the eastern shore of the Kola Bay on 4 terraces between Cape Zeleny and Khaldeev, from the Rosta River, which is located in the north and to the Fadeev Stream, which is located in the south [1]. The features of the relief create a significant difference in altitude in the city.

1.2. History of development

The official date of the foundation of the city of Murmansk is on October 4, 1916.

The process of the most active urban development in the Kola High North was in the Soviet period of the Russian culture. Since in this period the culture of the region was influenced by global socio-cultural processes within the state policy common to all regions of the country, Murmansk and other towns of the region, mainly represent the so-called typical "new" Soviet city. Geographically, Murmansk is divided into 3 administrative districts - Leninsky, Oktyabrsky, Pervomaysky (Figure 1).

The development of districts was subordinated to the interests of the city's main industry -- industrial or military enterprise, trade and fishing port, military units, etc., and the stages of construction were focused on building factories, enterprises, and on the rapid construction of model housing for workers and sailors.

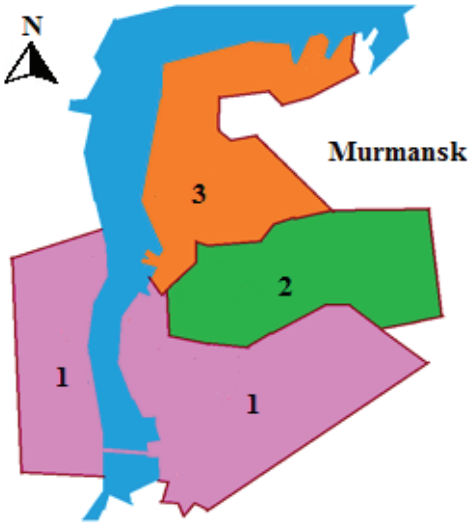

Figure 1: Territorial division of the city of Murmansk into areas indicating the historical parts of the city: Pervomaysky district (1), Oktyabrsky district (2), Leninsky district (3).

At the initial stage of the city's development, the buildings in Murmansk were mostly made of wood. For the pre-war period, there were nearly 30 stone buildings and 2800 wooden ones, occupying the total area of 450 thousand square meters. By the end of 1955, the stock of stone buildings included 200 thousand square meters. The planningof new streets and houses that appeared in the period from 1950 to 1955 did not differ from the planningof the best streets of the old cities of the country - stone houses on Lenin Avenue, Karl Marx, Perovskaya, Chelyuskintsev, Pushkinskaya Streets [6].

The planning of the Oktyabrsky district is characterized by high-density and compact site development. The western, historical part has features of quarter construction, formed mainly by five-story, to lesser extent two-story houses of the prewar and first postwar years. The stock of five-story buildings in the center of Murmansk forms its front facade. In the area of Zhilstroy panel residential buildings appear, houses were

built like from construction kits quickly and accurately [7]. On Kirov Avenue, five-story panel houses were built.

Five-story residential buildings were constructed from the northern part of the city. There was a development of territories near the Severomorskoye Highway with two-story residential buildings. First of all, the 62nd and 69th quarters were built up. (Geroyev-Severomortsev Ave., Sixth Komsomol Battery St., Kalinin St.)

In the southern region of Murmansk, the construction of panel houses was carried out. The southern quarters, microdistricts of Orlikova, 402, 404, 406, Papanina streets were built up with houses of improved design, developed specifically for the conditions of Murmansk [8]. I.A. Nerush, A.S. Rastorguev, Sh.Z. Azizov, L.I. Klepikova and T.V. Nemolyaeva in 1983 received a prize of the Council of Ministers of the USSR for the construction project of the 305th microdistrict. The houses of the microdistrict are designed so that in any corner of the structure there is a so-called wind shadow. There is a kindergarten, a school, a shop and green area in close proximity of the houses. The outline of the microdistrict - imitates a honeycomb. Typical nine-story buildings are connected by packing blocks.

In the southern district of the city there was a village for builders, where the main type of housing was prefabricated-panel houses.

Residential zones of the Leninsky and Pervomaisky districts are formed by microdistricts of high-riseand high-density buildings, however, some parts of the microdistricts are built based on the principle of free planning, and the microdistricts of the recent years of construction have a closed planning structure that takes into account microclimatic conditions and the features of the landscape.

The development of the western coast of the Kola Bay is represented by low-rise individual buildings; in the microdistrict Abram-Mys there are 5-storey fundimental buildings.

Each district of the city has quarters of low-value pre-war buildings with a low level of engineering support: old one-story houses - ``half-huts'', and two-story wooden houses. The cottage housing stock in compact quarters is located on the periphery of the city's residential areas.

2. Methods and Equipment

The article analyzes the microclimate of the urban environment, characteristic for industrial cities in the Arctic region, which developed in the Soviet times (20s - 90s of the 20th century).

One of the factors significantly impacting the formation of the microclimate in the city is the state of atmospheric air, while its composition depends on enterprises located in the city, as well as on vehicles - an integral part of any modern city.

Until recently, the effects of industrial and transport emissions on the atmosphere of the Russian cities were recorded independently, however, at present, a system of summary calculations - calculations of surface concentrations of pollutants based on their emissions, which use the information of emissions of all air pollution sources located in the considered city or region, including industrial enterprises and vehicles [9, 10]. In Murmansk, consolidated calculations are carried out by specialists of the Research Institute ``Atmosphere».

In general, information on emissions of 290 industrial enterprises and traffic flows on all major city highways was analyzed. In total, more than 1500 sources of industrial and motor vehicle emissions into the atmosphere and more than 120 harmful substances distinctive for the emissions within the city of Murmansk were taken into account.

When doing the summary calculations, the values of maximum concentrations of pollutants in MPC fractions were recorded at 20 control points located in residential quarters of different districts of the city and near the highways. Particular attention was paid to the enterprises and sources that mainly contribute to the level of air pollution.

Detailed survey was carried out for 9 harmful substances simultaneously present in the emissions from industry and vehicles: nitric oxide, nitrogen dioxide, sulphur dioxide, carbon monoxide, hydrocarbons (for gasoline), hydrocarbons (for kerosene), soot, formaldehyde, benz (a) pyrene, as well as for 13 groups of summation, which include at least one of these substances. Each summation group has a unique number in the system of accounting for pollutants of atmospheric air in Russia and is a group of substances that have a unidirectional effect on the body, thereby enhancing the effect of each other.

The processing of the information was carried out using the unified software product "Ecologist-city", which implements Calculation Methods for dispersing the emissions of harmful (polluting) substances in the air, approved by Order of the Ministry of Nature, Russia, dated 06.06.2017 N 273 and binding on January 1, 2018 [11].

The results obtained are mapped on the city's topobase, which allowed obtaining a pattern of the pollutants distribution, according to which hygienic criteria for the quality of the outside air are exceeded at the control points in residential areas of the city.

3. Discussion

3.1. Analysis of the microclimate of certain areas of Murmansk

For different areas of the city of Murmansk there is a relationship between their microclimatic features and their location off the Kola Bay and the height of the site. The relief of Murmansk is not uniform, there are strong elevation changes that affect the formation of specific microclimates in different areas. It is also influenced to a considerable extent by the emissions of industry and motor transport in the cold season, they contaminate the lower layers of the city's outside air with the products of incomplete combustion. Contaminated air prevents heat, sent by the soil, from escaping at night and in winter. Thus the weakening of the air lower layer cooling occurs creating a temperature difference between the northern and southern parts of the city. According to the literature sources the city of Murmansk can be divided into 7 areas, where landforms and altitude position feature the microclimate:

1) the Area of the first terrace -- coast of the Kola Bay, commercial and fishing port, a railway hub;

2) the Area of the first lower terraces of the southern part of the city;

3) the second Area of the upper terrace in the Northern part of the city;

4) the districts of the most elevated areas over the surrounding area -- hill Varnichnaya, 401st, 402-d, 403-d, Skalny districts (third and fourth terraces);

5) the Area of the first lower terraces of the Northern part of the city;

6) the Area of the second upper terraces in the Central and southern part of the city;

7) the southern outskirts of the city;

The average monthly temperature in different areas does not change significantly, the warmest month is July, and the coldest are January and February. In summer, the coldest temperature is observed in the area located off the coast of the Kola Bay, in winter, on the contrary, in the most remote from the bay. According to the studies of elevations raised above the surrounding area and farthest from the coast of the Kola Bay, in any of the months the temperature is lower than in the areas off the coast. The greatest differences in temperature are 0.8--0.9 ˚ in the autumn-winter period, and the smallest 0.2--0.3 ˚ in the spring-summer period. In the building zones of the city's district, during the daytime it is warmer throughout the year than on the coast of the Kola Bay, which is especially obvious in the period of cloud cover reduction (March-April) and intensification of daytime heating (March-April, June-July). The city's higher terrace is slightly cooler than the lower terrace. Inversion is formed at different heights

in the surface air layer in winter, in clear and calm weather. Raisingtemperatures with the increasing altitude are explained by the flow of cold and denser air from the elevations to lowlands, which is observed both on the coast of the Kola Bay and at the foot of hills.

Microclimatic differences in the city and on its outskirts due to the speed and direction of wind are explained by the landforms protecting, by direction of streets, etc. In all parts of the city South and South-West wind in winter, North or northeast in summer are prevailing. The wind speed in the city and on its southern edge depends on the distance from the Gulf, site's height and the extent of the city's development. When winds blow along the streets, built up with tall buildings, the wind speed increases. Therefore, the streets parallel to the prevailing wind directions (South and southwest), are much affected by the wind, especially in winter, when both frequency, predominant wind direction and the speed increase. In the city areas located on the hill sthe wind speed is higher than in the coastal districts throughout the year [4].

The greatest number of days with fog is observed in winter on the coast of the Kola Bay, which is due to high evaporation level above the surface. In summer and autumn, fogs are formed, which are more likely in the areas far from the coast.

According to the report on the state and environmental protection in the Murmansk region [12], air quality control is performed in 9 industrial centers of the Murmansk region at stationary observation posts. Samples are taken daily for the subsequent laboratory tests on the content of the main pollutants emitted everywhere: suspended solids (dust), nitrogen oxides, sulphur dioxide, carbon monoxide. Taking into account the emissions from the enterprises, monitoring was carried out on the content of metals, lead - emissions of vehicles, formaldehyde, benz (a) pyrene, hydrocarbons (emissions of industrial enterprises, incomplete combustion of any kind of fuel). A network of stationary observation posts is operating in Murmansk to control the quality of outside air. Unfortunately, this network tends to decrease. Only three of five observation posts are currently working.

The measurement sites were chosen in a way to better characterize the areas of greatest pollution, however, at present, their locations are far from the main places of traffic accumulation and cannot fully present the level of city pollution by polluting emissions (Figure 2).

The impact of pollutant emissions on the formation of the surface layer of the city's air is quite different: along with the substances, concentrations of which are sufficiently high in the surface air, for a number of substances, low values of the concentrations significantly below the maximum permissible level can be expected. Active cyclonic

activity with moderate and strong winds contributes greatly to the dispersion of pollutants in the outside air of the Murmansk region. According to long-term climate data the maximum number of days with unfavorable meteorological conditions (UMC), leading to the accumulation of harmful impurities in the atmosphere are in the cold season: January, February, March, November, December. The prolonged winds from industrial plants, power plants in the direction of the residential areas of the cities are an additional cause of increasing contaminant concentrations to MPC and above. According to Rosstat and Federal Service for Supervision of Natural Resource Usage the air contamination in the Murmansk region is mainly driven by the emissions from stationary sources of industrial enterprises (242,9 thousand tons).

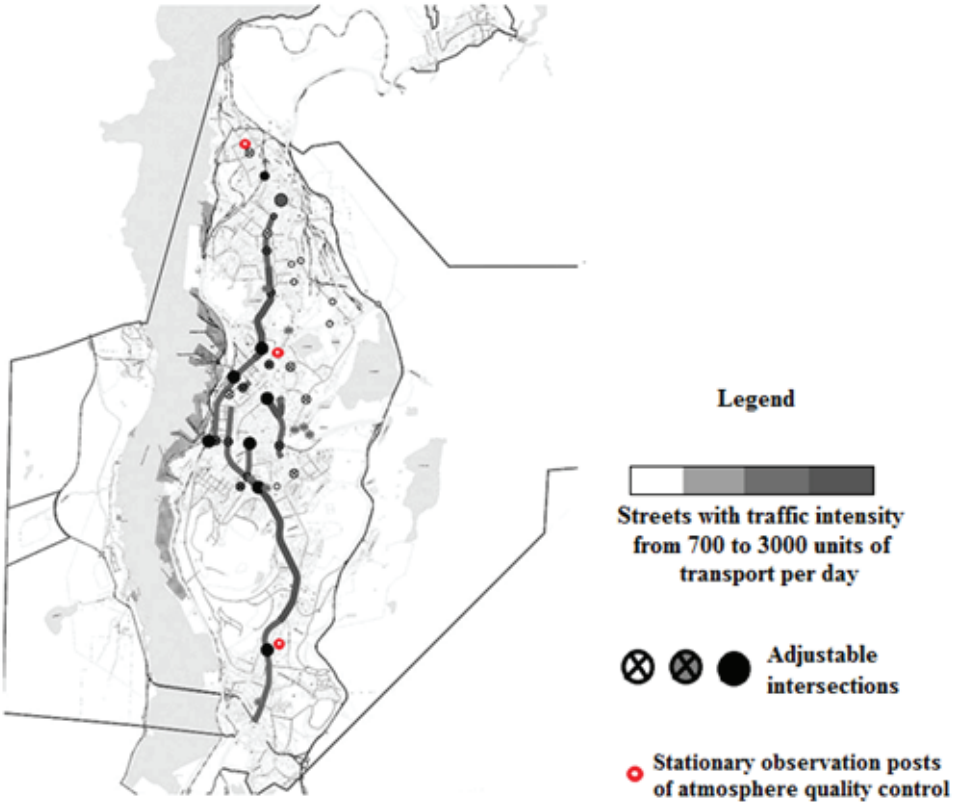

Figure 2: Location of the busiest streets in the city [15] and the network of stationary observation posts of atmosphere quality control.

According to studies and reports [13, 14], the major substances polluting the atmosphere of the city of Murmansk are suspended substances, nitrogen dioxide, sulphur dioxide, carbon monoxide, formaldehyde, benz (a) pyrene, hydrocarbons, vanadium, lead and manganese oxides.

In general, in 2017, major pollutants emissions into the atmosphere from stationary sources (242.9 thousand tons) increased by 11.1 thousand tons compared to 2016

(231.8 thousand tons), emissions from mobile sources (road transport) increased by 1.2 thousand tons.

In 2017, compared to 2016, emissions of solids increased by 1.182 thousand tons, carbon monoxide by 3.124 thousand tons, nitrogen oxides (in terms of NO_2) by 1.984 thousand tons, hydrocarbons (without volatile organic compounds) by 1.447 thousand. tons, volatile organic compounds by 3.677 thousand tons. In 2017, the region tends to decrease sulphur dioxide emissions.

3.2. The main sources of air pollution

Currently in the city there are more than 290 companies, containing the sources of air pollution.

According to the analysis of available data, the main contributors to the air pollution are the enterprises of thermal power complex, the companies working for overloading of loose cargoes (mostly coal), railway transport (locomotives) operating on the territory of the city and automobile transportation.

As a result of the combined calculations it was found that 2 substances (nitrogen dioxide and sulphur dioxide) and 11 groups of summation values of maximum concentrations exceed MPC at the sites of residential development. These summation groups include: summation group №№ 6006 (nitrogen dioxide, nitrogen oxide, sulphur dioxide, fuel oil ash of power plants), 6010 (nitrogen dioxide, sulphur dioxide, carbon oxide, phenol), 6034 (lead oxide and sulphur dioxide), 6038 (sulphur dioxide and phenol), 6040 (nitrogen dioxide, ammonia, nitrogen oxide, sulphur dioxide), 6041 (sulphur dioxide and sulphuric acid), 6042 (sulphur dioxide and Nickel metal), 6043 (sulphur dioxide and hydrogen sulphide), 6204 (sulfur dioxide and nitrogen dioxide) and so on.

4. Conclusion

It has been established that the development of a modern city plays a significant role in the formation of its microclimate. The early development of Murmansk was carried out without considering the climatic features of the region, quickly providing the staff of new industrial enterprises with housing. City districts that appeared in the 2nd half of the 20th century were planned so as to protect houses from the wind. Such a ``closed'' layout can, on the one hand, become a barrier to pollutants coming from the enterprises, but on the other hand, can contribute to the appearance of ``islands'' of pollution inside the courtyards due to personal vehicles and poor ventilation. Currently, the increased

concentration of two pollutants and 11 summation groups is recorded in the atmospheric air of residential areas of the city. The sources and the ways of reaching the residential areas is an issue of additional research.

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Conflict of Interest

The authors have no conflict of interest to declare.

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