Air Quality in a Large City in the Baikal Natural Territory: the Social Dimension (a Case Study of Ulan-Ude)

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Abstract: In this article, we propose a new approach to the development of measures to reduce the negative impact of pollutant emissions from stationary sources. For the first time, a systematic approach was applied to the development of measures to reduce the negative impact of emissions into the atmosphere for a large city in the Baikal Natural Territory (a case study of Ulan-Ude). The use of a systematic approach helped us to achieve the following outcomes: to develop a geographic information system with sources of emissions into the air of Ulan-Ude (GIS "Air of Ulan-Ude"); to identify natural factors of atmospheric air pollution in Ulan-Ude; to develop registers of stationary sources of emissions; to assess the impact of air pollution on public health; to carry out a sociological survey using questionnaires; to propose suitable technical solutions to reduce the emissions. The research methodology involved the concept of sustainable development, in terms of preserving living conditions for future generations of mankind. The institutional approach was also used to study the environmental situation from the perspective of the interaction of social institutions. A sociological study of private households in the context of financial and environmental aspects of heat supply for different types of heating systems led us to the conclusion that the problem of pollutant emissions by households is related to the standard of living and the availability of green fuel. The following measures were proposed to improve the quality of atmospheric air. The functional zoning of residential areas for industrial and housing development should take into account climatic, natural, and technogenic factors affecting the redistribution of pollutants in the surface layer of the atmosphere. The authorities should assist in connecting residential buildings to central heating. State support for the transition to clean fuels (gas, electricity, smokeless fuel, etc.) through subsidies, partial compensations, and other incentive programs. State support for the development of small-scale power generation and alternative energy; raising public awareness of the need to reduce emissions into the atmosphere.

Key-Words: Air quality, sources of air pollution, sociological study, types of heating systems in private households, measures to improve air quality.

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1 Introduction

Atmospheric air is a vital component of the environment, largely determining the ecological well-being and health of the population. In cities, the quality of atmospheric air is affected by a variety of natural and anthropogenic factors. The main

natural ones are the character of the underlying surface and air mass circulation, and their combined effect is most pronounced in mountainous terrain and sharply continental climates. In low wind conditions, the atmospheric emissions mostly accumulate in the air basin nearby their sources. During the cold season, this area faces specific adverse conditions, associated with the development of the Siberian High (the Siberian anticyclone). In some Siberian cities, this anticyclonic effect is exacerbated by the terrain topography, especially if a settlement is located in an intermountain basin. The city of Ulan-Ude is located in such a basin: poor air circulation leads to the accumulation of pollutants in the surface layer of the atmosphere and the emergence of smog under adverse meteorological conditions. Under these conditions, it is especially important to control and reduce emissions of air pollutants (including emissions from stationary sources of households).

2 Problem Formulation

Over the past 30 years, the population of Buryatia has decreased by 66.6 thousand people, while the population of Ulan-Ude has increased by about 20%, currently reaching 985 thousand people. In the post-Soviet period, people migrated to Ulan-Ude from rural areas of Buryatia, as well as from Ust-Orda autonomous okrug (Irkutsk oblast), and Agin-Buryat autonomous okrug (Zabaikalsky krai) in search of work and education. These reasons led to the mass construction of low-rise houses in urban and suburban areas that are not provided with central heating. This, in turn, causes a high level of air pollution in the surface layer of air in Ulan-Ude. At present, 67 thousand households in Ulan-Ude and its suburbs are heated with cheap and "dirty" fuels that produce carcinogens when burned. During the heating season of 2020/2021, it was individual households that produced the vast majority of emissions of harmful substances into the air of Ulan-Ude – more than 76% (Fig. 1).

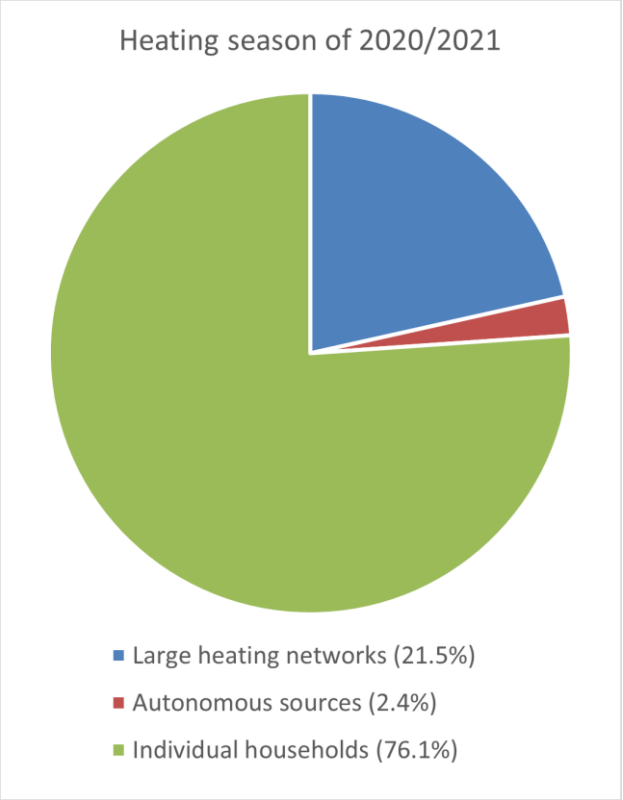

Fig. 1: Distribution by sources of emissions of harmful substances into the air of Ulan-Ude (stationary sources, the heating season of 2020/2021).

In recent years, air pollution in Ulan-Ude has increased, mainly due to the development of transport, an increase in the number of households, and small coal-fired boilers of private enterprises. This ecological problem raises concerns of the population, authorities, scientific community, and mass media [1-7]. To reduce the negative impact of emissions from stationary sources, it is necessary to develop measures that take into account the interests of residents of households not connected to central heating (thus making a significant contribution to the air pollution).

3 Problem Solution

3.1 Materials and Methods

To address the problem of emissions from stationary sources in Ulan-Ude, it is necessary to develop measures using a systematic approach, which in this paper considers the object of study as a system – an integral set of interrelated elements, according to I.V. Blauberg, V.N. Sadovsky, E.G. Yudin [8] and concerning the study of S. White with a critique of systems methodology [9].

This approach helped us to perform the following:
develop a geographic information system with sources of emissions into the air of Ulan-Ude (GIS "Air of Ulan-Ude"); identify natural factors of atmospheric air pollution in Ulan-Ude; develop registers of stationary sources of emissions; assess the impact of air pollution on public health; carry out a sociological survey using questionnaires; propose suitable technical solutions to reduce the emissions.

Modern studies have revealed the need to improve air monitoring systems using new methods, such as the "big data method" [10], and drones [11]. At the same time, measures to improve monitoring should be supplemented by the introduction of environmentally friendly technologies [12], reducing emissions, improving waste management, and transition to clean fuels and technologies [13].

The Russia's federal Clean Air Project is designed to mitigate air pollution by helping businesses comply with environmental regulations through a variety of regulatory, financial, and organizational improvements and technological process upgrades.

The research methodology involved the concept of sustainable development, in terms of preserving living conditions for future generations of mankind [14]. This also includes equal access to cost-effective and reliable modern energy sources [15]. The sustainability research program is interdisciplinary and focuses on "the dynamic interaction between nature and society, with equal attention to how social change shapes the environment and how environmental change shapes society" [16].

We also used the institutional approach to study the environmental situation from the perspective of the interaction of social institutions of the state, civil society, and business. In this regard, the methodology of the study envisages the involvement of regulatory, economic, socio-cultural, and other institutions in activities to improve air quality.

In this paper, we used the results of a sociological survey of the population to reveal the types of solid fuel used, its consumption, types of heating equipment, as well as other heat, financial and environmental aspects.

Our analysis of heating systems included conventional wood-burning stoves (pine, larch, birch) as well as other heating facilities: solid fuel boilers (wood, wood pellets, wood briquettes, coal), liquid fuel boilers (fuel oil, diesel), boilers based on liquefied gas, electricity, as well as alternative energy sources (solar panels, heat pump, etc.).

The results of the survey showed the amount of fuel consumed by households during the entire heating season and per day, as well as the approximate cost of heating depending on the equipment used – conventional stoves or individual boilers. Most of the questions in the questionnaire reflect the opinion of respondents on the main problems related to fuel (purchase costs, availability, and quality), the level of maintenance costs for the heating system, the complexity of the operation, etc. Some questions were designed to determine the differences in fuel consumption depending on whether the building is insulated. Several questions help to determine how satisfied a respondent is with the quality of atmospheric air (an indicator of the federal Clean Air Project), how informed they are about air quality, and how they perceive air quality in Ulan-Ude.

This study proposes measures to improve air quality in Ulan-Ude and its suburban areas, taking into account the views of respondents. The answers allow correlating the area of housing with the normative standards of housing provision to estimate the proportion of the population entitled to compensation for the use of smokeless fuel through budgetary subsidies.

Table 1. Residential areas of the respondents.

No	Residential areas	Number of respondents
1	Spirtzavod	12
2	Poselye, Soldatsky	14
3	Komuskha	15
4	Svetly, Zverosovkhoz	26
5	Istok	16
6	Solnechny	6
7	Levyi bereg	47
8	Shishkovka and Arshan	29
9	the 100th city blocks	2
10	Verkhnyaya Berezovka	10
11	Aviazavod	14
12	Sosnovka	8
13	Other (high-rise buildings with central heating)	51
	Total	**250**

The sociological study used multistage sampling with quota selection (n = 199), which included households living in 12 model areas with a high concentration of low-rise private housing. The questionnaires were processed using IBM SPSS Statistics 23.

A total of 250 respondents were interviewed (199 residents of the private sector, and 51 residents of high-rise buildings with central heating). Table 1 shows the residential areas of the respondents.

3.2 Results and Discussion

In 2020, the average living area per capita in Ulan-Ude was 20.8 sq.m. [17, p.128], which for a

typical housing corresponds to only a minimum level of comfort [18, p.45], [19, p.41-42], not to mention a high quality of life. That is why some people have chosen to build private homes.

The distribution of respondents' answers to the question about the area of their house is as follows (Table 2).

Table 2. Distribution of respondents' answers: housing area.

Area of house, sq.m.	%
<24	1.01
25-40	12.53
41-60	30.15
61-80	28.64
81-100	28.64
101-120	7.54
141-160	1.01
>161	4.52

Survey results show that families of 4 and 3 people are more likely to have houses where the area is 41-60 sq.m. and 61-80 sq.m., respectively. Answers to the question "How is your house/apartment heated?" show that the majority of respondents use stove heating – 67.8%; solid (liquid) fuel boiler – 27.7%; electric heating (electric boiler, underfloor heating, radiators, etc.) – 12.0%.

Our findings correlate with the results of the Comprehensive Survey of population living conditions, conducted in 2020 by the Territorial Office of Rosstat in Buryatia [20].

In addition to stove heating and coal-fired boilers, there are a lot of various greener heating systems, which, however, are expensive and have a long payback period. For example, the cost of equipping a 60 sq.m. house with a heat pump is about 600 thousand rubles. [21], which is almost 24 times more than the average per capita income of the population [22]. Unfortunately, none of the respondents has heating using alternative energy sources (solar panels, heat pumps, etc.). Respondents used the following sources of thermal energy:

wood – 68%, coal – 18%, electricity – 12%, fuel pellets – 1%, diesel – 1%.

By the time of day, heat production was distributed

as follows: in the morning and evening – 59%, in the evening – 27%, in the afternoon – 7%, in the morning – 7%.

In the morning and evening hours, there is dense smog, consisting of car exhausts, emissions from stoves in private houses, stand-alone boilers, and the city's combined heat and power plants (CHPPs).

By the time of active combustion of fuel (at a single fuel load) the answers were distributed as follows: less than 2 hours – 41%; 2.1-4 hours – 35%;

4.1-6 hours – 6%; 6.1-10 hours – 7%; more than 10 hours – 5%; automatic heating – 6%. This is quite an expected pattern: residents actively stoke stoves and boilers before/after the working day to heat their homes, and peak levels of atmospheric air pollution are registered by devices from 19:00 to 24:00 and from 07:00 to 09:00 [23]. By duration

of the heating season (according to the results of comprehensive observation of households not connected to central heating): 85.7% – 8-9 months per year, 7.7% – 6-7 months and 7.0% – 3-5 months [20].

Every third respondent is not satisfied with the way of heating their house. Respondents noted the following heating related problems: the high cost of fuel – 40%; high level of air pollution – 16%; it takes a lot of time to maintain the heating system – 14%, there is a lot of waste and difficulties with its disposal – 27%, high cost of maintaining the heating system – 8%; difficulties in operating the system – 31%; availability of fuel – 6%; low-quality fuel – 8%.

69% of respondents prefer firewood to other types of fuel. In this group the expenses of respondents for buying 1 cubic meter of pine firewood are distributed as follows: 83% spend up to 2000 rubles, 13% – up to 4000 rubles, and 4% – more than 4000 rubles during the heating season. The cost depends on the season and the amount of fuel purchased.

Coal is used by 18% of the respondents. Within this group, 46% of respondents buy coal for up to 2000 rubles per ton; 49% – for up to 4000 rubles per ton, and 5% – for more than 4000 rubles per ton.

The reason for such a distribution is the difficult financial situation of some respondents, and as a consequence, their inability to buy a large amount of fuel (coal, firewood) at a favorable price at one time. At the same time, the purchase of a smaller amount of fuel can be made at a higher price.

It is important to note that 14.7% of households, that are not connected to central heating, do not have sufficient funds to maintain the necessary temperature in their house [20]. 14% of the respondents receive a subsidy for utilities (including the purchase of solid fuel and its delivery), and 10% noted that they are in the process of applying for this subsidy.

Most of the respondents heat their houses with pine firewood: 41% of them consume up to 10 cubic meters; 47% – 10-20 cubic meters; 12% – more than 20 cubic meters. Households that use coal for heating, consume the following amounts: 39% – up to 9 tons, 51% – 10-20 tons, and 10% – more than 20 tons during the entire heating season. Less than half of the respondents insulate their homes (46%), a third of respondents – do not insulate (33%), and every fifth found it difficult to answer (21%).

Mineral wool as insulation is used by 35% of respondents; 9% use polystyrene foam and 19% indicated another type of insulation. Almost every third respondent (28%) could not specify the type of insulation. By type of insulation used: 35% of respondents use mineral wool, 9% – foamed plastic, 9% – foamed polystyrene, 19% indicated another type of insulation. Almost every third respondent (28%) could not specify the type of insulation.

Most respondents are willing to invest in home insulation: fully (39%) or partially (35%). Almost every fifth respondent (18%) is not ready to invest in home insulation. Modern studies show that it is possible to reduce the amount of fuel burned, and reduce emissions by improving the energy efficiency of the house: insulation of walls, and ceilings, installation of heating using alternative energy sources, etc. [24-27].

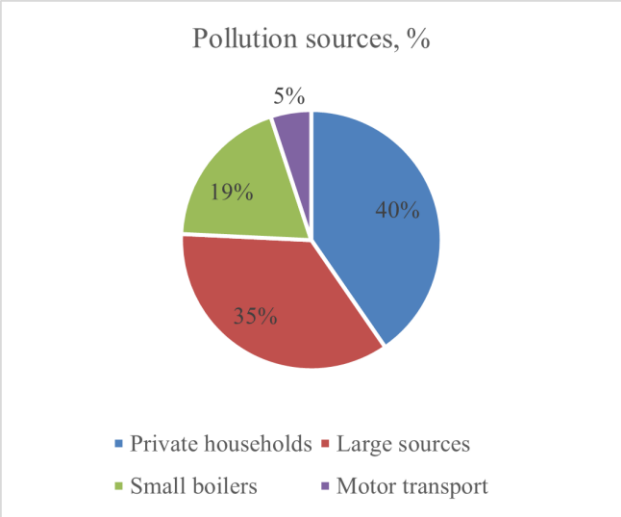

Fig. 2: Distribution of responses to the question: "What, in your opinion, is the main source of air pollution in Ulan-Ude?"

Residents of Ulan-Ude are concerned about the condition of atmospheric air: 47% of respondents assessed it as 'unfavorable'; 41% – as 'rather unfavorable' and a total of 8% – as 'favorable' and 'rather favorable'. The respondents indicated the following as the main sources of air pollution for their area of residence: 40% – private houses; 35% – emissions from large sources (CHPP-1, CHPP-2, boiler facilities of Aeroport, Zagorsk, Aviazavod settlements, etc.); 19% – boilers of small enterprises and individual entrepreneurs; 5% – motor transport (Fig. 2).

More than half of the respondents are satisfied with the provision of information about air quality, 35% found it difficult to answer, and 13% are not satisfied with the provision of information.

Engagement of mass media and local authorities in the dissemination of information about environmental pollution problems in cities can motivate residents and then governments at various levels to take steps to protect the air from pollution. Depending on the level of government agencies that can be reached, these actions can manifest themselves in different ways, from the imposition of fines on offending enterprises to the emergence of federal programs aimed at improving the environmental situation in cities, the implementation of which is monitored at the highest level [28].

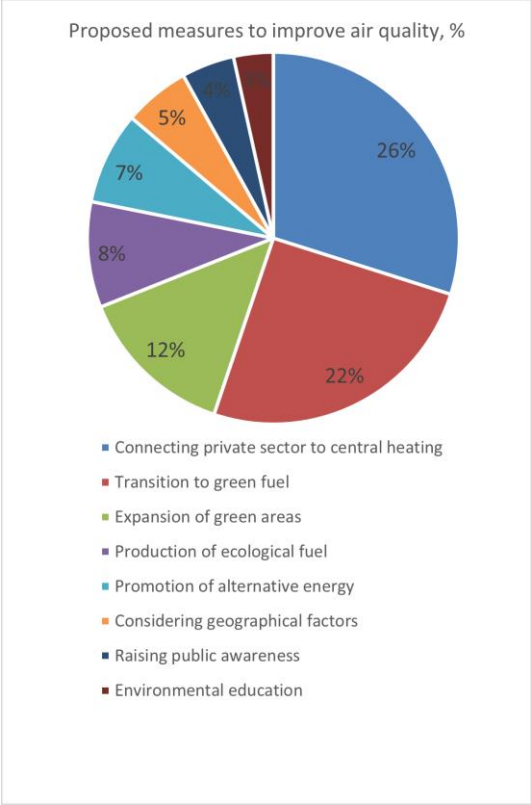

Fig. 3: Distribution of responses to the question: "What would you suggest to improve air quality in Ulan-Ude?"

To improve air quality in Ulan-Ude, respondents suggest: connecting the private sector

to central heating – 26%; the state-subsidized transition of private houses and boiler facilities to green fuel (gas, smokeless fuel, etc.) – 22%; expansion of green areas in settlements – 12%; promoting the production of ecological fuel – 8%; promotion of small-scale power generation and alternative energy – 7%; consider geographical factors contributing to the reduction of pollution when planning new residential areas and businesses – 5%; raising public awareness about air pollution and recommendations to reduce harm; deploying a network of air quality monitoring – 4%; introduce environmental education in kindergartens, schools, colleges, and universities – 3% (Fig. 3).

Most of the respondents surveyed are partially (35%) or completely (40%) ready to switch to clean fuel.

4 Conclusion

In Ulan-Ude, atmospheric air pollution poses a serious environmental threat to public health. Analysis shows that a third of the population of Ulan-Ude lives in conditions of the highest risk of morbidity and mortality from polluted atmospheric air, and about 46% live in conditions of high risk. Depending on population density and the specifics of the distribution of pollutants in the city's atmosphere, the residents of the Oktyabrsky District are at the highest risk (1.5 times higher than in the Sovetsky District, and 1.3 times higher than in the Zheleznodorozhny District). Within each district, it is also possible to identify micro districts with a high health risk: Lazo settlement, the CHPP-1 area, the 40th city blocks, the meat-packing plant microdistrict, and settlements with households that are heated by coal. [29, p.96]. According to the summary data on the number of households in settlements and micro districts within the city and its suburbs, as well as their total emissions into the air of Ulan-Ude, it is necessary to develop effective measures to mitigate the negative impact of emissions of pollutants into the air from stationary sources.

The Republic of Buryatia has become the first region in Russia that has legally restricted the use of solid fuels for autonomous boilers. Amendments to the law of the Republic of Buryatia "On Atmospheric Air Protection" were introduced in December 2020 and have already entered into force since
September 15, 2021. Legal entities and individual entrepreneurs who use their boilers are now required (if technically possible) to connect to the district heating or use environmentally friendly ways of heating. Now they cannot use solid fuel (coal, lignite, firewood) for heating.

The analysis of the scientific literature and the results of our comprehensive study allow us to propose several measures to improve the quality of atmospheric air. The functional zoning of residential areas for industrial and housing development should take into account climatic, natural, and technogenic factors affecting the redistribution of pollutants in the surface layer of the atmosphere. It is necessary to assist in connecting residential buildings to central heating.

State support for the transition to clean fuels (gas, electricity, smokeless fuel, etc.) through subsidies, partial compensations, and other incentive programs can be particularly effective, as the number of households experiencing financial difficulties
has been identified.

Thus, the following measures will contribute to reducing the negative impact of emissions of harmful substances into the atmosphere – state support for the development of small-scale power generation and alternative energy; raising public awareness of
the need to reduce emissions into the atmosphere, and encouraging the production of environmentally friendly (smokeless) fuel.

In this study, we developed a methodology for the environmental and economic evaluation of measures to mitigate the impact of pollutant emissions into the air of Ulan-Ude from stationary sources. The methodology used the opinions of the population not connected to the centralized heating system and thus making a tangible contribution to total air emissions. The findings and recommendations of this study can be used by national and foreign executive authorities, civil society, and businesses to improve measures to reduce the negative impact of emissions of pollutants into the atmosphere.

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