Assessment of impact of combined heat on the environment of urbanized areas (case study of Ulan-Ude, Russia)

A V Dmitrieva, V N Khertuev, P V Konovalov and I A Barmitova
Banzarov Buryat State University, Ulan-Ude, 670000 Russia

E-mail: dmitrieva_zzk@mail.ru

Abstract. Combined heat and power plants (CHPP) are an important component of the energy balance in many countries. However, of all types of power plants, CHPPs have the largest impact on the environment. In recent years, the urban ecology has become one of the key indicators that determine the quality of life of city residents. The article evaluates the impact of the CHPPs in Ulan-Ude on the example of CHPP-1. The main sources of environmental pollution, and, accordingly, the zone of exposure of CHPP-1’s pollutants have been identified. Virtually the entire territory of the city of Ulan-Ude falls under this zone, but since north-western winds prevail in this area, the north-western part of the city is most affected. Based on the results of a detailed dispersion calculation, we defined the following substances which should be monitored: nitrogen dioxide, sulfur dioxide, mineral oil, and inorganic dust (70-20% SiO2 and coal dust). The concentration of these substances in the air is significant.

1. Introduction
Throughout its life, humanity has used, uses and will use the energy accumulated in environment. At the same time, throughout the history of mankind, the ways of its use have been developed to obtain maximum efficiency, because all people’s life is associated with energy consumption.

Creation of thermal, hydro, and nuclear power plants of huge capacities, high and ultra-high voltage power lines, powerful energy systems, oil and gas supply systems and the development of new methods of production, transformation, and transmission of energy played a huge role in the development of civilization in 20th century.

Since the 20th century, the construction of large power plants has contributed to solving the problems of electricity shortages without which progress would not have been possible. However, this situation is considered quite ambiguous. Large and small enterprises contribute to a negative environmental impact. Substances emitted by CHPP’s change the chemical composition of soil, thus reducing their fertility, as well as shoaling natural water bodies and the extinction of fish, thermal pollution and an increase in diseases.

Also, the operation of CHPPs requires huge areas being developed for coal extraction, which cannot but affect the environment. In addition, once mineral exploitation is terminated, the disturbed lands are no longer of value for agriculture. It should be noted that coal is the main source for electricity production which is necessary for all activities [1], but it also has a negative impact on human health [2].
All of this is a result of the development of energy sector, which is one of the most polluting industries. Our future depends on solving the problem of the need to develop the energy sector, while coming up with methods and ways to reduce the harmful effects on nature resulting from the operation of power plants.

Pollution of the environment is a change in its natural properties: physicochemical, mechanical, and biological ones that occur as a result of natural or artificial processes and lead to a deterioration in the functions of the environment in relation to living, inanimate or man-made objects.

According to the Buryat Centre for Hydrometeorology and Environmental Monitoring, the city of Ulan-Ude has been on the list of cities with high levels of air pollution for more than 10 years. The air circulation in the city is hindered, as the city is in the Ivolgino-Udinsk intermountain depression. Due to such location, pollutants accumulate in the surface layer of the atmosphere, and smog is formed in conditions of high humidity.

In addition to CHPPs influence, this situation is aggravated by the private sector, which includes about 45,000 houses, as well as the city’s road infrastructure. Currently, the transport industry of the Republic of Buryatia comprises 6,904 km of bus routes, 1,374 km of railways, 4 airports, 1,872 km of local air lines, 56.6 km of tram lines, and more than 100,000 passengers are transported in Ulan-Ude every day. Due to the continuous growth in the number of vehicles, the road infrastructure has not been able to keep up with development.

CHPPs significantly pollute the atmospheric air, and through the atmosphere cause soil pollution, shoaling of rivers and lakes, thermal pollution. Large areas of urban land are withdrawn for the operation of CHPPs to make room for ash dumps and huge amounts of ash waste. In addition, winds contribute to the removal of dust particles from the surfaces of ash dumps, because of which they are deposited in the soil, thus changing their natural content of trace elements [1].

2. Models and Methods

2.1. Monitoring of pollutant emissions and discharges from CHPP-1

According to the Trans-Baikal Interregional Administration of Rosprirodnadzor in the Sphere of Natural Resource Use for Buryatia, For the period from 2016 to 2019, Ulan-Ude CHPP-1 emits an average of 8,954.6 tonnes per year of harmful substances, and during this period the indicator increased by 6.31 tonnes/year.

According to the Buryat Centre for Hydrometeorology and Environmental Monitoring, the greatest exceedance of the maximum allowable concentration (MAC) for benzopyrene and nitrogen dioxide is observed during the heating season from September to May. For example, in January 2018, the average monthly benzopyrene concentration was 34 higher than MAC, and for nitrogen dioxide it was 1.4 higher than MAC. In the summer months, these indicators were normal.

From 2014 to 2015 Ulan-Ude CHPP burned about 514,048 tonnes of coal per year. According to the plan, the enterprise has increased the consumption up to 637,000 tonnes/year since 2016, which has affected the environmental indicators. According to their data, Ulan-Ude is on the list of environmentally unfavourable cities of Russia. In addition, the unfavourable situation is aggravated by the ash dumps.

CHPP-1 has two ash dumps: buffer and seasonal. The ash dumps are sources of coal ash emission into the atmospheric air during the snowless, dry and windy period of the year. Moreover, the intensity of dust release depends on the wind speed and humidity of ash dump surface layer, and reaches its maximum at a wind speed of more than 7 m/s, with recurrence, according to the Buryat Central Hydrometeorological Service, not more than 5% of cases per year.

At the buffer ash dump, the moisture content of the ash was 13.16%. The nearest residential area is 102 m away. The ash and slag wastes are fed to the buffer ash dump through a closed slurry pipeline in the form of suspended matter. Dusting of ash and slag occurs along the perimeter from the northern and eastern sides of the ash dump; the rest is the water surface area. Dusting produces inorganic dust containing 70-20% SiO₂. In the summer period wet extraction of ash is carried out by hydromonitors,
and the resulting pulp is pumped into the permanent (seasonal) ash dump. Wetting the surface of the ash dump contributes to a significant reduction in dust release. The area of the territory is 12 hectares, the capacity is approximately 150,000 tons.

The seasonal ash dump site is located outside the city, near the Taltsy station, about 14.5 km from the main site. The total area is 102 hectares. Dusting occurs from the northern part of the ash dump; the rest is the water surface area. The moisture content of the ash is 13.16%. The nearest residential area is located 73 m from the ash disposal area. The maximum wind speed in the given area is 9 m/s (the frequency of exceedance is within 5%). The ash dump capacity is about 8,067,370 m$^3$ (8,560,000 tonnes).

The main sources of pollution are power-generating boilers. Ulan-Ude CHPP-1 operates 7 power boiler units: 4 of them are high pressure sections (HPS) and 3 ones are intermediate pressure sections (IPS). A mixture of coal from the Tugnuisky and Cheremkhovsky deposits is used as fuel. The central site of Ulan-Ude CHPP-1 is 345-465 m close to residential areas from the south-east, and 10-675 m from the west. The direction of the winds is mainly north-west.

According to Sanitary Regulations and Norms (SanPiN) 2.2.1/2.1.1.1200-03 “Sanitary protective zones and sanitary classification of enterprises, buildings and other facilities”, CHPPs and district boiler houses with a thermal capacity of 200 Gcal and above, operating on coal and fuel oil, belong to the second class of hazard with a sanitary protective zone (SPZ) not less than 500 m [3]. For the sites of the CHPP-1, there is no project of the estimated SPZ, and SPZ boundaries for emission sources have not been approved.

During combustion of hard coal, the sulphur present in it is converted into sulphur dioxide. There are also many sulphur compounds in burning fuel oil. Sulfur dioxide causes acid precipitation, which negatively affects the health of people, animals, vegetation, soil, and causes economic losses.

Emissions also contain nitrogen oxides including 10-15% of nitrogen dioxide and 85-90% of nitrogen oxide. In the atmosphere, the amount of nitrogen dioxide increases to 70%. Nitrogen dioxide is more toxic than nitrogen oxide. These substances are also released into the upper layers of the atmosphere [4].

2.2. Calculation of pollutant emissions from CHPP-1
Combustion of fossil fuels produces heat energy in the form of hot water and steam. The volume of pollutant emissions and discharges can be estimated based on the data of the material balance of the coal-fired CHPP-1 with a capacity of 148.77 MW, operating on the coal from the Tugnuisky and Cheremkhovsky deposits. As of December 2014, such a CHPP burns about 939 tonnes of coal per hour. Its calorific value is about 20.83 and 22.61 MJ/kg, ash content – 20.9%, and sulfur content – 0.3 to 1.79%. The bottom ash is removed from boiler furnaces (2.49 tonnes/hour); 20.82 tonnes/hour of captured ash is removed from the hoppers of electrostatic precipitators (that clean 99% flue gases from ash). The captured ash and bottom ash in the amount of 23.31 tonnes/hour ends up in the ash dump of the power plant, littering and clogging huge areas.

Emission capacities (grams/sec, tonnes/year) were determined by calculation balance methods according to standard national and departmental methods. Calculations of the dispersion of atmospheric pollutants for Site 1 and Site 2 were carried out for the winter and summer periods. For Site 3, the dispersion was calculated for the summer period only.

Feasibility of detailed calculations of the dispersion of pollutants contained in the site emissions as well as groups of substances with the summation effect of harmful effects is determined in accordance with paragraph 3.1.1 of OND-86 “Methodology for calculating the concentration of harmful substances in the atmospheric air contained in enterprises emissions”.
According to this document, the detailed calculations of atmospheric pollution may be carried out if the following conditions are met:

$$\sum C_{m_i} / MAC_i \leq \varepsilon$$  \hspace{1cm} (1)

where $\sum C_{m_i}$ is the sum of the maximum concentrations of the $i$-th substance from all sources of a given enterprise, $\text{mg/m}^3$; $MAC_i$ – is the highest one-time maximum allowed concentration of the $i$-th substance $\text{mg/m}^3$; $\varepsilon$ – is the coefficient of expediency of calculation, equal to 0.1 when taken.

Accounting for background pollution is mandatory for all enterprises, all pollutants for which the condition is met:

$$AGC_i > 0.1$$ \hspace{1cm} (2)

where $AGC_i$ is the highest value of the above-ground concentration (AGC) of $i$-th pollutant formed (not including background) by the plant’s emissions at the boundary of the nearest residential area. If this condition is not met for any substance, then no consideration of background air pollution is required when rationing emissions of such a substance by the enterprise (in fractions of MAC).

In order to determine the impact of pollutant emission sources on the boundaries of residential areas, design points are additionally allocated, due to which the points of maximum concentrations of pollutants are determined. Background concentration of a harmful substance (background) is a characteristic of atmospheric pollution created by all sources of emissions in the studied area, excluding the source for which the background is determined [5]. Based on the results of dispersion calculation, the substances for which the background accounting is required were defined: nitrogen dioxide, sulfur dioxide, mineral oil, and inorganic dust (70-20% $\text{SiO}_2$ and coal dust).

### 3. Results and Discussion

As a result of the study, more than 30 substances were identified, which are emitted by CHPP-1 resulting from its activities. The zone of influence of the enterprise due to pollutants has been defined. It has been established that high chimney stacks of CHPP-1 contribute to the long-range propagation of emissions. Virtually the entire territory of the city of Ulan-Ude falls under this zone of exposure to the pollutants, but since north-western winds prevail in the territory, the north-western part of the city is most affected. Outside the zone, the concentration of pollutants is less than 0.05 $MAC$.

Harmful emissions affect the soils, and the cadastral value of land depends on the quality of soil. A comparative analysis of the price per square metre of land plots in gardeners’ non-commercial partnerships (GNP) was carried out (Table 1).

| No. | Name            | Min price, RUB/m² | Average price, RUB/m² | Max price, RUB/m² | Distance from the central site of CHPP-1 | Distance from the seasonal ash dump |
|-----|-----------------|-------------------|-----------------------|-------------------|----------------------------------------|-----------------------------------|
| 1   | Teplovik GNP    | 151.49            | 235.16                | 303.45            | 11.8 km to the E                        | 0.073 km to the N                  |
| 2   | Metallist GNP   | 339.07            | 471.24                | 527.66            | 6.0 km to the E                         | 5.7 km to the NW                   |
| 3   | Pichshevik GNP  | 746.90            | 747.12                | 747.12            | 6.8 km to the E                         | 5.1 km to the NW                   |
| 4   | Stroitel GNP    | 306.72            | 407.96                | 428.59            | 7.2 km to the E                         | 4.5 km to the NW                   |
| 5   | Gavan GNP       | 368.69            | 471.61                | 487.32            | 6.4 km to the E                         | 5.8 km to the NW                   |
| 6   | Veteran GNP     | 202.54            | 202.54                | 202.54            | 10.5 km to the NE                        | 4.5 km to the S                    |
| 7   | Profsoyuznik GNP| 286.44            | 747.46                | 747.46            | 7.0 km to the NW                         | 18.5 km to the NW                  |
| 8   | Tsagatu GNP     | 582.46            | 598.17                | 613.87            | 8.2 km to the SW                         | 19.2 km to the W                   |
| 9   | Ranet GNP       | 520.44            | 823.59                | 993.28            | 4.6 km to the NW                         | 13.9 km to the W                   |
| 10  | Timiryazev GNP  | 341.45            | 509.58                | 645.88            | 6.1 km to the NE                         | 11.2 km to the NW                  |
These land plots are intended for gardening. The lowest cadastral value for land was registered in Veteran GNP and Teplovik GNP. The territory of Teplovik GNP is located very close to the seasonal ash dump, on the northern side, and the winds also carry dust particles in their direction. The highest cadastral price for land was registered in Ranet GNP, Pishchevik GNP, and Profsoyuznik GNP. When calculating the value of the lands in dacha owners’ non-commercial partnerships, no strong regularity was revealed.

Detailed calculations of the dispersion of pollutants contained in the emissions of the facility, as well as groups of substances with the summation of the harmful effect, were carried out for 36 substances, of which for 25 substances the feasibility of calculations was established.

4. Conclusion

Air pollution is one of the most pressing problems for mankind. Among them, CHPPs are one of the main sources of air pollution. The emission of pollutants into the atmosphere due to power generation at CHHPs, poses a serious hazard and a threat to human health, biodiversity, and the environment [6, 7].

One of the sources of pollution in Ulan-Ude is CHPP-1 – the largest and oldest power plant, that supplies almost the whole city with electricity and hot water. However, its operation causes environmental harm, namely, it emits pollutants into the atmosphere. In addition to polluting the air, the particles are deposited on soils and rivers, and winds contribute to the spread of particles over long distances. Waste is also generated in the form of ash and slag. CHPP-1 accounts for 33% of air pollution. The maximum concentrations of harmful substances are revealed in the residential area that is in the north-western part of the CHPP-1 territory and directly on the CHPP-1 territory itself.

The points of maximum concentrations of harmful substances were calculated considering the background. It turned out, they are concentrated in the vicinity of the CHPP site, as well as in the nearest residential area. Based on the results of the dispersion calculation, the substances or which background accounting is required have been identified: nitrogen dioxide, sulfur dioxide, mineral oil, and inorganic dust (70-20% SiO₂ and coal dust). Such concentrations of these substances in the air are significant.

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