The resource-climatic potential of urbanized territories (a case study of the city of Irkutsk)

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Abstract. A combination of average conditions for the diffusion of pollutants in the city of Irkutsk and significant volumes of emissions are the chief cause of a very high air pollution index during a long (longer than 20 years) period. In current conditions, the influence of the climate/atmosphere of the city of Irkutsk on the living conditions of the population implies an exceedance of hygiene standards in a year, on the average, for 5–6 pollutants. Furthermore, the composition and concentrations of pollutants are changing but the concentration of suspended material remains stably high (up to 2.4 MPC). Of particular concern is the largest exceedance of MPC for benzo(a)pyrene (up to 7.8 MPC), which is due primarily to a low quality of fuel used by mobile and stationary sources of emissions. The microclimatic characteristics of the city in the winter period were used to identify territories with a different temperature regime. The air temperature in low places is lower by 1.0–3.6 °C than at the Basic Irkutsk Observatory weather station. A large scatter in the deviations is caused by the warming influence of the Angara and by the infrastructural characteristics of the city. On the slopes and in elevated areas in the city center and outskirts, the temperature deviations do not exceed ± 0.5 –2.0 °C, respectively.

1. Introduction
Because of the natural characteristics of climate formation, urbanized territories of northeastern Asia are often affected by chronic air pollution, which is one of the main problems for their sustainable development. On the basis of an expanded concept of natural resources and using GIS technologies, we consider the influence of the climate/atmosphere of Irkutsk on the living conditions of the population.

The ecological conditions for human life are determined by the location of the city on the Irkutsk-Cheremkhovo piedmont plain, a combination of the cooling (in winter) and warming (in summer) influence of the water masses (of the Angara, Irkut and Irkutsk reservoir) and the characteristics of the location of facilities at different elevations. The climate of the city differs dramatically from its surroundings, primarily by changes in the atmospheric air quality.

A very high air pollution potential of Irkutsk, like the entire territory of northeastern Asia [1], is due to the strength of long-lasting seasonal and diurnal inversions which promote a deceleration of the process of mixing and diffusion of pollutants entering the atmosphere. Over the last 50 years Irkutsk was included at least 40 times on the list of cities with the most polluted air. In assessing the diffusion of pollutants from heat and energy generating facilities, it was shown that the isolines of absolute concentrations (MPCm.o.t.) and frequencies of exceedance of MPCad (nitrogen dioxide, soot, sulfur...
dioxide and dust in December) largely extend from the northwestern part of the city to the southeastern part along the direction of the main flow of air masses [2].

However, a low recurrence of winds capable of intensifying atmospheric self-purification, orographic dissection of the relief, with elevations of up to 140 m, and the characteristic of the contrasting character of the underlying surface can make adjustments in the concentration of local pollution zones.

It is important to consider the dynamics of the state of the atmospheric air quality over recent years and update the microclimatic differences of the city in current conditions using GIS technologies.

2. Objects, data and methods

The cartographic-geoinformation approach was used to analyze the set of all factors promoting the formation of the atmospheric air quality. Emissions of pollutants from stationary sources and the pollution level of the city were considered according to [3, 4]. The city’s climate was characterized using the long-term database (1881-1980) [5]. The characteristics of the temperature regime of the particular years were examined by using observations (Data archives of the All-Russian Research Institute of Hydrometeorological Information–World Data Center Obninsk: http://www.meteo.ru).

To identify the possible local zones of stagnation phenomena on the territory of the city used results of the microclimatic survey as reported in a monograph [6], and observations from four meteoposts equipped with automatic stations for monitoring the atmospheric air quality (Irkutsk Office for Hydrometeorology and environmental monitoring). Air temperature deviations (at 14 hr local time) were considered for separate days of January (2015 and 2016) from the respective observations at the Irkutsk, Observatory weather station.

3. Results and discussion

With current global climate fluctuations, the city shows a clear tendency for a rise in temperatures, especially winter and annual temperatures. The mean monthly air temperature in Irkutsk over the last 30 years (1981-2010), against the preceding 100-year period (1881–1980), increased in December-February by 2.8-3.7°C, from November to March by 2-4°C, and for a year by 1.8°C due to a reduction of the number of days with low temperatures. The development of the infrastructure contributed to an increase in temperature. The area of the city has increased considerably since the 1970s. Territories with wooden houses were replaced by multistoried stone buildings, which has influenced the microclimate formation conditions.

The period 1991-2017, compared with 1966-1991, showed an increase in the recurrence frequency of calms (by 6%) and a reduction in the recurrence frequency of substantial (more than 6 m/s) wind velocities in Irkutsk [7].

When compared with the surrounding space, the city is distinguished by higher temperatures and by a low atmospheric air quality. On the whole, the self-purification capacity of the atmosphere of Irkutsk, for a year according to the technique suggested by V.V. Kryuchkov [8], is estimated as moderate. It forms under the influence of a combination of low wind velocities (2.3 m/s), the annual precipitation amount (466 mm) and the recurrence frequency of calms (10%) favorable for the dissipation of pollutants [5].

However, chronic pollution of the city is favored by significant volumes of pollutants entering the atmosphere. The dynamics of emissions of pollutants from stationary sources is escalating (table 1) and reflects the periods of intensification and deceleration of macro-economic processes in the city. Heat and energy generating facilities are the major sources accounting for about 40% of total municipal emissions. In the annual context, the main volume of emissions of pollutants corresponds to a long-lasting heating season (mid-September – mid-May). In determining the heating period from the dates at which the air temperature is below (in autumn) and above (in spring) 8 °C, it was found that this period in Irkutsk varies from 218 to 245 averaging, however, 231 days [9]. This period is also characterized by the formation and prevailing position of the Siberian Anticyclone...
(November–March) with which a deceleration of the diffusion processes of pollutants in the atmosphere is associated.

Table 1. Characteristic of the state of the atmospheric air [3, 4].

| Indicators                                      | 2008 | 2010 | 2012 | 2014 | 2016 | 2018 |
|------------------------------------------------|------|------|------|------|------|------|
| Emissions from stationary sources, thou t      | 52.0 | 65.5 | 66.8 | 68.0 | 73.0 | 70.5 |
| APIa                                          | Very high | Very high | Very high | Very high | High | Very high |
| Substances determining the APb level           | BP, F, NO₂, SP, CO, NOx, soot | BP, F, NO₂, SP, NOx, soot | BP, F, NO₂, SP | BP, F, NO₂, SP, NOx, H₂S | BP, F, NO₂, SP | BP, SP, O₃, SO₂, PM₁₀ |
| Exceedance of MPC for SP, times               | 1.6  | 1.7  | 1.4  | 1.6  | 2.4  | 1.5  |
| Exceedance of MPC for BP, times               | 4.4  | 4.2  | 2.6  | 5.2  | 3.6  | 7.8  |

a API – air pollution index.
bAP – atmospheric pollution, pollutants. F – formaldehyde. SP – suspended particles. BP – benzo(a)pyrene. PM₁₀ – fine suspended particles. NO₂ – nitrogen dioxide. NO – nitrogen oxide. SO₂ – sulfur dioxide. CO – carbon oxide. H₂S – hydrogen sulfide. O₃ – ozone.

A considerable contribution to the deterioration of the state of the atmosphere is made by mobile sources. An intense increase of the number of motor vehicles, their technical condition and fuel quality promote an increase in emissions. During the period from 2008 to 2012 their volumes varied within 59–62% of the total emissions for the city [4].

A combination of the average conditions for the dissipation of pollutants with significant volumes of emissions is the chief cause of a very high air pollution index (API) during a long (longer than 20 years) period. An exceedance of the hygiene standards, on the average for a year) is observed for 5–6 pollutants (table 1). Furthermore, the composition and concentration of major pollutants are changing but the concentration of suspended matter remains stably high (up to 2.4 MPC). Of particular concern is the largest exceedance of MPC for benzo(a)pyrene (up to 7.8 MPC), which is primarily due to a low fuel quality of mobile and stationary sources of emissions. The fuel balance of enterprises of the fuel and energy complex (FEC) changes little and more than 84% of it corresponding brown coal, the burning of which releases a great number of pollutants (benzo(a)pyrene, suspended matter, sulfur, nitrogen and carbon oxides, etc.).

A similar (and even more acute) situation is also characteristic for Ulaanbaatar. According to WHO data, the population of the city has increased has more than tripled over the last 30 years. And more than half the population lives in gers with stove heating [10].

An increase of the number of motor vehicles and in consumption of coal by FEC enterprises and in the private sector is considered to be responsible for most wintertime air pollution because of the more powerful and intense inversions than in Irkutsk. Therefore, an improvement of human living conditions in the urbanized territories of northeastern Asia is a multifarious challenge.

The aforementioned parameters of atmospheric air quality in Irkutsk characterize the mean state of the air for a year as a whole. In the seasonal regime, a substantial degradation of the living conditions of the population occurs in the winter due to a significant increase in pollutants emissions and a
deceleration of the diffusion capacity of the atmosphere. In this case, the longest duration of impacts and the highest intensity of pollutants will occur, all other factors being the same, in localities with stagnation phenomena. Air temperature changes on a hilly terrain (the foot, middle and the upper part of the slope) \[11\] are adjusted by characteristic features in urban development.

A correlated analysis of data of microclimatic survey in January [6] and observations at meteoposts and at the Irkutsk Observatory weather station (January 2015 and 2016) showed that the warming influence of water masses (by 1.8-1.9°C) is observed not further than 100-200 m from the water edge. The air temperature in low places is lower by 1.0-3.6°C than at the Irkutsk Observatory basic station. A larger scatter in deviation is due to the warming influence of the Angara and to the infrastructural characteristics of the city. On the slopes and in elevated areas in the city center and in its outskirts, the temperature deviations do not exceed ± 0.5°C and -2.0°C, respectively.

Thus, according to existing conditions, three types of microclimate of low places comprising the zone can be identified, which are affected the most by stagnation phenomena. The first type includes the locations around the unfreezing section of the Angara, with temperature deviations of up to 1.9°C; the second type is characteristic for the central part of the city, with temperature deviations of up to -1.5°C, and the third type, the largest in area, encompasses the valleys of the Irkut, Angara, Ushakovka and Kaya with their tributaries. Temperature deviations of up to -3.6°C are possible there.

The slope and planate surfaces are distinguished by smaller temperature contrasts.

4. Conclusions

The mean self-purification capacity of the atmosphere of Irkutsk, coupled with large volumes of emissions from stationary and mobile sources, has been responsible for a very high API during many years. The presence of especially hazardous pollutants in the ground air layer and a significance exceedance of MPC, specifically for fine-dispersed dust particles and benzo(a)pyrene, pose a serious threat to the state of human health.

The fact that the city has an extensive area affected the most by stagnation phenomena can promote emergence of intense air pollution in residential and recreation territories.

Analysis of the existing chronically low quality of the atmosphere in Irkutsk dictates a need to seek possible ways to improve it, with due regard for the resource-climatic potential of the city. The main measure to be undertaken in order to improve the living conditions of the population is a decrease in emissions, that is, a change in the fuel balance of FEC with fuel switching to gas, as well as an improvement of the fuel quality in mobile sources.

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