Meteorological potential of the atmosphere: Irkutsk – Beijing – Ulan-Bator

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Abstract. The air quality is one of most relevant problem connected with the quality of life for human population and preservation of the Earth’s ecosystem. Here we examined and analyzed the atmospheric ability to self-purification according to the method proposed by T.S. Selegay over the cities of Irkutsk, Beijing, and Ulan-Bator. The meteorological potential of the atmosphere (MPA) was chosen as a criterion for estimating of the atmospheric self-purification. In summer season 2017 meteorological conditions over the cities of Irkutsk and Ulan-Bator contributed to the dispersion of impurities in the atmosphere. MPA in Irkutsk in summer was 0.99, in Ulan-Bator 0.78. In summer 2017 and in winter 2017-2018 in Beijing occurred unfavorable meteorological conditions (UMC) which did not contribute to self-purification of the atmosphere from pollution. Summer MPA in Beijing varied from 2.14 to 4.66 with an average of 3.69. During the winter months in all three cities MPA was >1 which indicates the accumulation of impurities in the atmosphere. In Ulan-Bator unfavorable conditions for dispersion were developed and the maximum MPA index (9.5) was observed in December. Calm weather made the biggest contribution to the deterioration of the self-purification ability of the Ulan-Bator atmosphere in winter. The maximum accumulation of pollutants in the atmosphere over Beijing occurs in winter. MPA varied from 15.0 in February to 19.0 in December with average value of 16.7. The fogs made the biggest contribution to the deterioration of the self-purification ability of the Beijing atmosphere in December-February.

1. Introduction
The monitoring of atmospheric composition and air quality control in cities is now of great attention around the world. Studies of the meteorological conditions for the dispersion of impurities in the surface layer of atmosphere in urban areas are promising [1]. Spatial and temporal variability of the atmospheric dispersion potential has the greatest significance in industrial centers [2]. In recent decades, the growth of megacities has led to increase in the anthropogenic pressure both on megacities themselves and surrounding regions. Strong air pollution leads to a significant increase in morbidity and premature mortality among the population. Studies carried out in recent years showed that the causes of many diseases were the negative effects of polluted air. In particular, this is applied to Moscow, Beijing, and Ulan-Bator. The level of air pollution depends on the variability of anthropogenic emissions and meteorological conditions of dispersion of impurities in the atmosphere. There are many characteristics and coefficients that describe the influence of meteorological conditions on the dispersion of pollution in the surface layer of the atmosphere [3]. Previously, specialists in atmospheric physics considered the "potential for atmospheric pollution", which took into account the climatic characteristics of surface air and the vertical stratification of the atmosphere...
At present, the spatial frequency of aerological atmospheric sounding has decreased. Therefore, it is not possible to use the information about the vertical temperature distribution with necessary resolution. Specialists began to develop criteria for assessing the accumulation of pollutants in the air, based on surface meteorological observations [5]. Meteorological conditions are the main factors that influence the concentrations of pollutants in the atmosphere [6]. Weak wind, fog, inversions refer to unfavorable meteorological conditions (UMC), under which pollutants accumulate in the surface layer of the atmosphere. When the UMCs are observed, the quality of atmospheric air deteriorates and pollutants exceed the maximum allowable concentration (MAC). Precipitation and strong wind (with speed more than 6 m s⁻¹) refer to favorable meteorological conditions, which reduce concentrations of pollutants and contribute to self-cleaning of atmospheric air. The purpose of this study was to calculate the meteorological potential of the atmospheric (MPA) for Irkutsk, Beijing and Ulan-Bator and to assess the possibility of self-cleaning the atmosphere over these cities. In this work we used the MPA index developed by T.S. Selegay [5].

2. Study area and methods

The studies were conducted in three cities: Irkutsk, Beijing and Ulan-Bator (figure 1). Irkutsk is located in the Asian part of Russia in the territory of Eastern Siberia in 520 km north from Ulan-Bator, and 1650 km northwest from Beijing. Irkutsk is located on the two banks of the Angara River on the southern edge of the Irkutsk-Cheremkhovo Plain. Geographical coordinates of Irkutsk 52° 17' N, 104° 16' E. The elevation is 420-550 m above sea level. The climate of Irkutsk is sharply continental, with long and frosty winter and warm and rainy summer.

![Figure 1. Geographical position of the studied cities.](image)

Ulan-Bator is the capital of Mongolia, stretched for 20 km in length along the valley of the Tuul River. The city is surrounded by mountains from all sides. The geographical coordinates of Ulan-Bator are 47° 54’ N, 106° 52’ E. The elevation is 1300-1350 m above sea level. The climate of Ulan-Bator is sharply continental with long and frosty and dry winter and cool summer. Among all capitals, Ulan-Bator has the lowest average annual temperature (-0.4 °C). Beijing is the capital of the People's Republic of China. From north and west sides Beijing is surrounded by the mountains of Xishan and Yangshan. Its geographical coordinates are 39° 54’ N, 116° 23’ E. The elevation is 40-50 m above sea level. The climate of Beijing is wet continental. The East Asian monsoon affects the climate in
summer. The summer monsoon brings heat and heavy rains. Siberian anticyclone affects the climate in winter.

The study period was June-August 2017 and December-February 2017-2018. Meteorological data was taken from the site (https://rp5.ru/).

The meteorological potential of the atmosphere (MPA) was calculated according to the method of Selegay [5].

\[
MPA = \left( \frac{F_c + F_f}{F_p + F_v} \right)
\]

where \( F_c \) is the frequency of wind speed 0-1 m s\(^{-1}\) (%), \( F_f \) is the frequency of days with fogs (%), \( F_p \) is the frequency of days with precipitation (%), and \( F_v \) is the frequency of wind speed \( \geq 6 \) m s\(^{-1}\) (%).

The parameters of the formula were calculated from the data of meteorological stations. Repeatability of wind speed was calculated as follows: the number of cases with wind speed of 0-1 m s\(^{-1}\) per month was divided by the total number of cases for this month. Repeatability of days with precipitation and fog was divided by the number of days in a month. The results were expressed as a percentage. The numerator of the formula characterizes the processes in the atmosphere that contribute to the accumulation of impurities, and the denominator, respectively, the processes that contribute to the scattering of impurities. At \( MPA \leq 1 \), the processes favoring dispersion are predominant, in the case of \( MPA > 1 \) the impurities are accumulated in the atmosphere.

We used quantitative estimation of meteorological conditions by MPA criterion:

- \( MPA > 1.25 \) – unfavorable conditions for scattering;
- \( 0.8 < MPA \leq 1.25 \) – relatively unfavorable conditions for scattering;
- \( 0.4 < MPA \leq 0.8 \) – relatively favorable conditions for scattering;
- \( 0.25 < MPA \leq 0.4 \) – favorable conditions for scattering;
- \( MPA \leq 0.25 \) – extremely favorable conditions for scattering

3. Results
According to the formula (1), MPAs of Irkutsk, Ulan-Bator and Beijing were calculated. The results of the MPA calculations for three cities are presented in table 1.

| City        | Month (Season) | Dec | Jan | Feb | Winter | Jun | Jul | Aug | Summer |
|-------------|----------------|-----|-----|-----|--------|-----|-----|-----|--------|
| Irkutsk     |                | 0.80| 1.16| 1.10| 1.04   | 0.57| 0.60| 1.81| 0.99   |
| Beijing     |                | 19.03| 16.02| 15.00| 16.68 | 4.66| 4.28| 2.14| 3.69   |
| Ulan-Bator  |                | 9.50| 7.00| 7.00| 7.83   | 0.60| 1.66| 0.09| 0.78   |

During the winter months in all three cities MPA was > 1, indicating the accumulation of impurities in the atmosphere during this season. In Irkutsk, the MPA changed from 0.80 in December to 1.16 in January. The contribution of calm, precipitation and fog to the formation of MPA for December-February is shown in figure 2. In Irkutsk January and February are characterized by relatively unfavorable conditions for scattering of impurities in the atmosphere, and December relatively favorable conditions for scattering. The contribution of precipitation to the self-purification of the Irkutsk atmosphere in December was 58%. Contribution of calms diminishing the dispersing capacity of the atmosphere in Irkutsk amounted to 32-39% in January-February (figure 2a). The haze was observed 19 times in Irkutsk in winter. In Beijing, during all winter months there were unfavorable conditions for dispersion. In 50% of cases, there was a fog in the city. MPA in December reached a maximum value of 19.03. The fogs made the biggest contribution to the deterioration of the
self-cleaning ability of the Beijing atmosphere in December-February. Their contribution was 48-50% (figure 2b). In Ulan-Bator, unfavorable conditions for scattering were also developed throughout the winter months. The maximum index of MPA (9.5) was observed in December. Calms made the biggest contribution to the deterioration of self-cleaning ability of the Ulan-Bator atmosphere in winter. In January, the contribution of calms was 90%, in December and February 61 and 71%, respectively (figure 2c). The haze was observed in winter every day in this city. The contribution of calm, precipitation and fog to the formation of MPA for December-February in Irkutsk, Beijing and Ulan-Bator is shown in figure 3.

**Figure 2.** The contribution of calm, precipitation and fog to MPA during the winter months in the cities of Irkutsk (a), Beijing (b), Ulan-Bator (c).

**Figure 3.** The contribution of calm, precipitation and fog to MPA for the summer months in the cities of Irkutsk (a), Beijing (b), Ulan-Bator (c).

During the summer season over the cities of Irkutsk and Ulan-Bator, the processes contributed to the dispersion of impurities were prevailing in the atmosphere. The contribution of precipitation in the self-purification of the Irkutsk atmosphere in June-July amounted to 23-32% (figure 3a). However, not all summer months were favorable for purifying the atmosphere in these cities. Meteorological conditions of August in Irkutsk did not contribute to the dispersion of impurities. Contribution of calm for this month was 39%. In July, unfavorable conditions for scattering were observed in Ulan-Bator (MPA is 1.66). The maximum contribution to the formation of highest MPA was made by calms, up to 48% (figure 3c). In Ulan-Bator extremely favorable conditions for dispersion occurred in August. The contribution of precipitation during this month was 35%. Hazes in summer were observed in 10% of cases, and sandstorms in 5%. In Beijing, during the summer season, the MPA varied from 2.14 in
August to 4.66 in June. In this city the observed UMCs contributed to the accumulation of pollutants in the atmosphere. The contribution of fogs to the deterioration of the self-cleaning ability of the Beijing atmosphere in June-July was 93-96% (figure 3b). The gloom was observed in 60% of cases during the summer season in Beijing. Thus, it can be concluded that during summer periods of 2017 in Irkutsk and Ulan-Bator meteorological conditions reduced the concentration of pollutants in the atmosphere. In Beijing, summer 2017 and winter 2018 were characterized by UMCs, which reduced the self-cleaning ability of the atmosphere.

4. Discussion

Atmospheric air pollution is most often considered using the values of air emissions, calculating the maximum allowable concentration (MAC), not taking into account the synoptic conditions under which these emissions occur. Accumulation or dispersion of impurities occurs in different synoptic conditions. Synoptic situations associated with anticyclonic processes contribute to increase in the pollutant concentrations. In winter, the atmospheric circulation over Irkutsk, Ulan-Bator and Beijing is determined by the impact of the Asian maximum and the prevalence of anticyclonic processes. The Asian anticyclone (Mongolian, Siberian) determines the weather conditions of winter months over these cities. A high atmospheric pressure is observed (figure 4).

**Figure 4.** Monthly variation of atmospheric pressure, reduced to sea level in Irkutsk, Ulan-Bator and Beijing June-August (a), December-February (b).

In Irkutsk, the mean sea level pressure in winter period varied within 759-792, in Beijing 759-780, and in Ulan-Bator 765-794 mm Hg. In this case, the descending air movements are predominated, with little precipitations and developed calm. Calms hampered the exchange processes in the surface layer of the atmosphere. UMCs were observed, pollutants accumulated in ground layer of the atmosphere of the cities. This was often the cause of smog situations. Three main factors, mountain-hollow relief, Mongolian anticyclone, and coal burning contributed to reducing the dispersing capacity in Ulan-Bator atmosphere in winter [7]. The capital of Mongolia is one of the cities of the world with the dustiest atmosphere, which is confirmed by ecological and chemical research of the last decade [8]. In winter months, there was a maximum of atmospheric pollution in all three cities [9]. The exception
was for December 2017 in Irkutsk, with MPA of 0.80 which is relatively favorable for scattering. The monthly precipitation in December in Irkutsk is 19 mm. However in December 2017 about 50 mm was dropped out (263% of the monthly precipitation norm). Thus, the contribution of precipitation to self-purification of the atmosphere of the city was 58%. In summer, there is a weakening of west to east air transfer and at the ground surface the lowered pressure field prevails (figure 4). In summer, the mountain-valley circulation is well expressed in Ulan-Bator which brings clean air from the mountains. In August, cyclonic circulation intensifies and large amount of precipitation falls out. Perhaps, these factors influenced the Ulan-Bator MPA during summer months. In August, the self-cleaning ability of the atmosphere in the city was maximal. The East Asian monsoon affects the weather in Beijing in summer. Synoptic situations associated with cyclonic processes and rapid air transport contributed to increased scattering power of the atmosphere. However, despite the fact that the mechanism of summer monsoon circulation is associated with cyclones, the Beijing MPA in summer was high. Perhaps such high level of air pollution is observed because of geographical location of the city: from the north and west, Beijing is surrounded by the mountains of Xishan and Yangshan. Thus, when the air pressure increases, there is no movement of air masses in the city. The coal industry and transport also contribute to the formation of smog in this city [10]. Beijing is recognized as one of the most environmentally dirty cities in the world.

5. Conclusion
The used method of determining the meteorological potential of self-purification of the atmosphere allows to promptly assessing the changing climatic conditions that determine the degree of atmospheric air pollution. The atmospheric processes of June-July 2017 were favorable for a limited dispersion for impurities (MPA=0.57-0.6) in Irkutsk, and in June in Ulan-Bator (MPA=0.6). The most favorable conditions for dispersion occurred in August in Ulan-Bator (MPA=0.09). This was facilitated by precipitation ≥0.5 mm, and their contribution was 35%. Precipitation leads to a noticeable purification of air from impurities. Unfavorable conditions for the dispersion over the entire period were observed in Beijing (MPA=2.14-19.03). UMCs contributed to high urban air pollution. The greatest contribution to UMC of Beijing was made by fogs (50-96%). Thus, the peculiarities of relief, synoptic processes, and wind and precipitation regimes have formed the MPA of Irkutsk, Ulan Bator and Beijing during the studied period.

Acknowledgements
The present study was carried out within the framework of part of the research project (project # 0347-2016-003)

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