# Using space images for analysis of thermal anomalies in the city

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**Abstract.** Paper analyzes thermal anomalies of Kazan city according to satellite images in thermal infrared range. Main goal of the study is to create maps of thermal anomalies in Kazan city, followed by recommendations to reduce impact of "heat island" phenomenon on the environment. Landsat satellite images for May and February were used as initial materials. Configuration of the "heat island" in different seasons of the year was studied. The study allowed us to identify areas in the city where differences in temperature and associated heat radiation were less intense, almost unchanged, or showed an increase. Thus, it was shown that within big industrial centers of a city separate foci of abnormally high temperatures are revealed. Classification of conditions according to the temperature level of city territories is developed. According to the results of the study, set of recommendations to reduce the negative consequences of the "heat island" impact on the urban ecosystem is proposed.

## 1 Introduction

The island of heat is a direct link between anthropogenic transformations of urban landscapes and a set of microclimatic changes [9-10]. Abnormally high temperatures of certain territories relative to the average for the season, form zones of seasonal thermal anomalies and negatively affect the state of environment and microclimate of the city. Despite the fact that thermal anomalies cover, as a rule, certain areas of urban landscapes, they have a noticeable impact on the daily activities of entire population of the city [1-3].

The purpose of this work was to build a series of maps of thermal anomalies of Kazan based on satellite images, identify the largest hotbeds of thermal pollution in the city, substantiate the causes of their occurrence and analyse the dynamics of changes in the seasonal and annual temperature background in the city in the 2018-2022 period.

Territorial expansion of modern cities inevitably leads to changes in their landscape and environmental components of the city and its suburbs. With intensive development, expansion density often increases, which contributes to rapid increase in number and area of zones of thermal anomalies. Most often these phenomena are observed in industrial zones, which is associated with a large area of roofs covered with thermal insulation material [7].

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## 2 Materials and methods

In this paper, the method for the analysis of thermal pollution based on the NDVI index [6] was used. To obtain the temperature index in degrees Celsius, the formula (1) for estimating the Earth's surface temperature by the brightness temperature At-Satellite Brightness Temperature TB [4, 8] was applied:

$$T = \frac{TB}{1 + (\lambda * TB/c^2) * ln(e)} \quad (1)$$

λ - the average wavelength of the channel; c - speed of light; e - the emissivity of the surface; TB - data from infrared channel #10.

Due to rate of emission of objects, it is possible to obtain data on temperature of the Earth's surface, analyse its dependence on natural or anthropogenic factors, and build maps of thermal anomalies [5].

The satellite images used in the research were selected on the basis of two criteria:

- The time when the image was taken, because for more accurate analysis, images taken at approximately the same time points are needed.
- Cloud cover, because clouds affect radiation, both themselves and shadow they cast, and cover a significant part of the territory [6].

## 3 Results and Discussion

To analyse the heat distribution in the city and suburbs of Kazan in winter the following map based on the past 5 years satellite images for February was constructed (Figure 1).

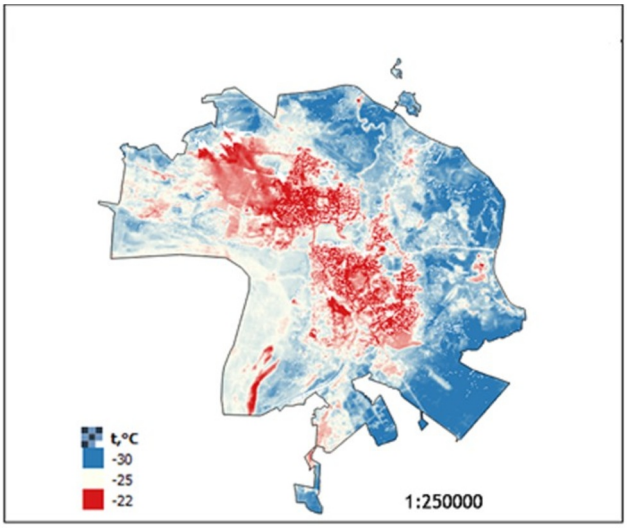


**Fig. 1.** Map of the thermal anomalies in Kazan for February.

The map shows that in winter period, the temperatures of the Central districts and suburban (peripheral) territories of the city differ significantly. The difference is 8°C. Within the boundaries of the entire analysed territory, one large zone of heat concentration is allocated, in which two subzones are distinguished. They are separated by a small, colder band, where the Kazanka river and coastal territories are located.

Technology-related objects with an expressed positive thermal anomaly are particularly characteristic to the cold period of the year. As a result of their functioning, a large amount of heat is stably released into atmosphere, changing the ambient temperature. Also, during the heating season, heat losses in residential buildings lead to intense heat radiation, which increases the temperature background of residential areas of the city. This shows that industrial and residential areas with their high-density development significantly affect the microclimate of Kazan, which changes the state of its ecosystem.

Spring and summer satellite images also allow you to identify specific areas of increased surface temperatures in Kazan. At the same time above-zero temperatures allow you to observe the temperature difference in the Central, industrial and suburban areas of the city more clearly.

The map of the zones of thermal anomalies in Kazan is modelled on the basis of the surface temperature raster images, created by the satellite images for May for the past 5 years. It can be used to track which observable objects in Kazan emit a greater amount of heat against the general background and how large the temperature differentiation of various areas of the city is (Figure 2).

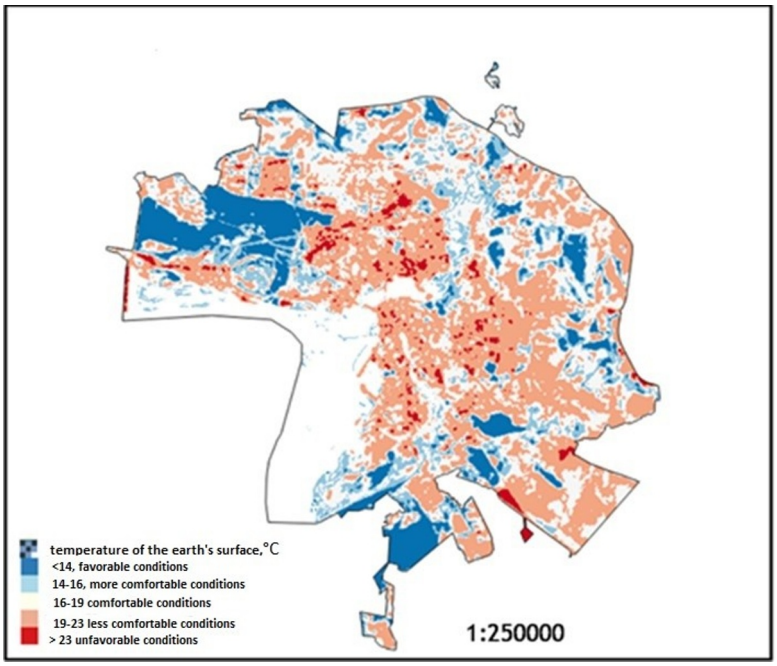


**Fig. 2.** Map of the thermal anomalies in Kazan for May.

The local areas and zones of high temperatures and thermal anomalies shown on the map are smaller in size and have a higher dispersion compared to the winter period. The observed temperature changes are significant and amount to about 9°C, that resulting in zones of increased threats to human life and activities, reducing the level of environmental comfort, deterioration of natural conditions and the change of ecological situation on a significant, more than 15%, part of the city area.

Most of the areas of thermal anomalies occur in the territory of dense development in the territories of the Small and Large transport rings of Kazan. Zones with low temperatures, marked in light blue and blue on the map, are forest zones characterized by strong water transpiration and low absorption capacity.

Based on the above, the following classification of environmental conditions by the temperature level of the city's territories is possible:

- Less than 14°C - favourable environmental conditions.
- 14-16°C - more comfortable environmental conditions.
- 16-19°C - comfortable environmental conditions.
- 19-23°C - less comfortable environmental conditions.
- More than 23°C - adverse environmental conditions.

The concentration of the zones with high temperatures is more typical for the territories of Novo-Savinovsky and Vakhitovsky districts of Kazan, located in the Central part of the city. The areas of adverse conditions in these areas are mainly industrial facilities and large community centres. The temperature above them ranges from 25 to 28°C. Such a strong excess of temperatures over the city average, being a stable seasonal thermal pollution, entails a change in the microclimate of these territories, which worsens general condition of the ecological environment of the city, provoking the growth of cardiovascular and oncological diseases.

For a detailed assessment of the dynamics of thermal anomalies for the four years from 2018 to 2022, two four-year series of maps of winter and summer temperatures were overlaid.

Calculation of the difference in values of the raster cells of digitized temperature images allows you to determine the zones where the differences in temperature and associated thermal radiation were less intense, practically unchanged, or grew dynamically (figure 3).

Analysis of raster maps of the urbanized territory of Kazan built during given period allowed us to conclude that there were no significant changes in the temperature background in most of the city. At the same time, there is an increase in the dynamics of average temperatures in suburban areas, which are characterized by soil treatment and crops cultivation, as well as large areas occupied by vegetation. In addition, vegetation intensively affects the radiation in the fields after sowing, when the crop has not yet risen, because the uncovered land absorbs a lot of heat.

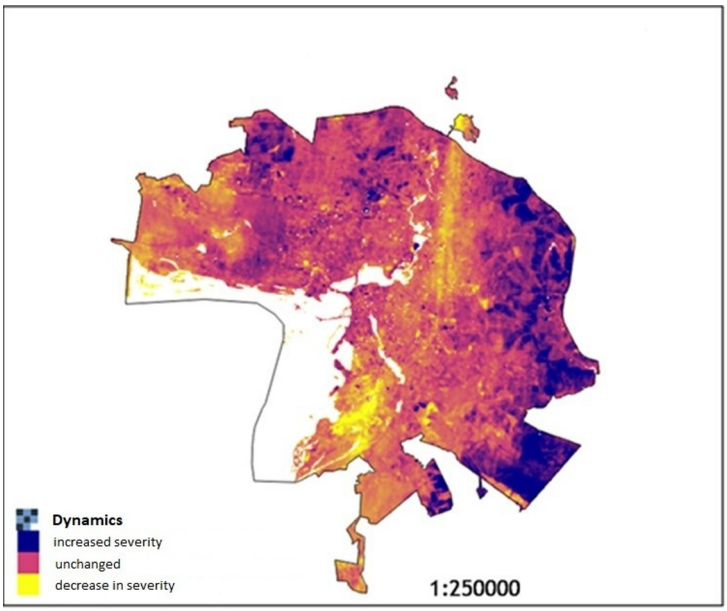


**Fig. 3.** Map of the degree of manifestation dynamics of thermal anomalies in the territory of Kazan for 2018-2022.

On the territories of modern buildings, the temperature background is mostly stable. The expansion of public spaces and the growth of the city's landscaping rate during the analysed period led to positive changes in the ecological framework of the city and contributes to reducing total number and area of thermal anomalies, increasing the comfort of temperature background. In residential areas, due to growing landscaping, average seasonal temperatures are stabilized. Within the large industrial centres of the city, individual foci of abnormally high temperatures occur.

## 4 Conclusion

According to the research results, it can be concluded that among the factors that affect the occurrence of thermal anomalies, the greatest degree of influence on the average seasonal temperatures has anthropogenic factors. The transformation of urban space with an increase in the proportion of anthropogenic environment leads to an increasing rate of change in the temperature background and microclimate. The rapid growth of the population of Kazan, accompanied by an increase in the residential blocks area, and the total buildings density, leads to an increase in risk of large foci of thermal pollution.

Taking into account the fact that in Kazan the main localization of thermal anomalies occurs in the zones of industrial and commercial enterprises, it is possible to suggest works to improve the characteristics of roofs of industrial and commercial buildings in order to reduce their heat release, for example, by using special coatings that reflect radiation. A number of Kazan enterprises already use such materials.

For public spaces, it is necessary to expand constantly the area of green spaces, the effectiveness of which in terms of temperature control has been proven by world experience. This will not only reduce radiation, but also improve the city's microclimate and increase the number of visitors to beautified areas.

The research made it possible to draw the following conclusions:

- It is found that in winter time one large zone of high temperatures and thermal anomalies is formed over Kazan. This is due to the large heat output of industrial enterprises and residential buildings, although the latter are often located near people’s places of work. The temperature difference on the urban area in the given period averaged 7-8 ° C.
- In the spring-summer period, the foci and zones of high temperatures and thermal anomalies in Kazan differed in size and had high dispersion compared to the winter period. The observed temperature differences were more significant than in winter, and average temperature difference in the analysed period was about 9-10°C.
- It has been proved that the main sources of heat are industrial and shopping centres of the city. 32 large foci of thermal pollution have been identified in the Novo-Savinovsky and Vakhitovsky districts of Kazan.
- The data obtained as a result of satellite images interpretation, and a series of raster cartographic images based on them, provided the basis for analysing the dynamics of changes in thermal anomalies in the period. It allowed us to conclude that there were no significant changes in the temperature background in most of the city's territories. There is an increase in the dynamics of average temperatures in its suburban areas.

On the territories of modern buildings, the temperature background is mostly stable. The expansion of public spaces leads to a reduction in total number and area of thermal anomalies, increasing the comfort of the temperature background. In residential areas, due to their growing landscaping, average seasonal temperatures are stabilized. Separate foci of abnormally high temperatures occur within the large industrial centres of the city.

- A set of measures aimed at equalizing the temperature background of territories will contribute to reducing the number and total area of temperature anomalies in the city.

These measures must be based on reducing maximum average seasonal temperatures by working to improve the characteristics of the roofs of industrial buildings in order to reduce its heat irradiation. For public spaces, it is necessary to permanently expand the area of green spaces.

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