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Detection of thermal pollution of urban reservoirs using the method of IR-radiometry based on the example of the Lake Kenon, Zabaykalsky Krai

Detección de contaminación térmica de reservorios urbanos por el método de radiometría IR en el ejemplo del Lago Kenon, Zabaykalsky krai

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ABSTRACT

Water bodies (e.g., rivers, lakes, and reservoirs) are an integral part of the urban environment. The infrastructure of the city affects their condition, in particular, pollution, including heat, which can lead to an increase in phyto- and zooplankton, including blue-green algae, and the appearance of toxins in the water. Identification of places where warm water is discharged into reservoirs is an urgent task. One of the methods of solving this problem is the monitoring of reservoirs from space. Thus, with the help of infrared satellite images, thermal anomalies are visible. In the work, we studied Lake Kenon located in the city of Chita. The satellite images were obtained from the Lansat-8. The channels used were 10 and 11, with a resolution of 60 meters. We revealed that (1) the optimal time for detecting thermal anomalies is the time before freezing in calm weather; (2) the cause of the thermal anomaly of this reservoir is a thermal power plant; (3) analysis of the last 5 years has shown that the water area with an increased surface temperature of the reservoir does not change; (4) the temperature gradient between cold and warm areas is 5°C; (5) the area of the heat spot does not exceed 10% of the total area of the lake. The above conclusions were confirmed using field measurements.

Keywords: Thermal pollution, Urban reservoir, Infrared range, Lansat-8

RESUMEN

Los cuerpos de agua son una parte integral del entorno urbano: ríos, lagos, embalses, etc. La infraestructura de la ciudad afecta su condición, en particular, la contaminación, incluido el calor. Esto puede conducir a un aumento de fito y zooplancton, incluidas las algas verdeazuladas. Conducen a la aparición de toxinas en el agua. La identificación de los lugares donde se descarga agua caliente en los embalses es una tarea urgente. Uno de los métodos para resolver este problema es el monitoreo de reservorios desde el espacio. Entonces, con la ayuda de imágenes satelitales infrarrojas, las anomalías térmicas son visibles. En el trabajo, los autores estudiaron el lago Kenon ubicado en la ciudad de Chita. Las imágenes de satélite se obtuvieron del Lansat-8. Los canales utilizados son el 10 y el 11, con una resolución de 60 metros. Se demostró: (1) el tiempo óptimo para detectar anomalías térmicas es el tiempo antes de congelarse en tiempo tranquilo; (2) la causa de la anomalía térmica de este embalse es una central térmica; (3) el análisis de los últimos cinco años ha demostrado que el área de agua con una temperatura superficial aumentada del embalse no cambia; (4) el gradiente de temperatura entre las áreas frías y cálidas es de 5°C; (5) el área del punto de calor no exceda el 10% del área total del lago. Las conclusiones anteriores fueron confirmadas por mediciones de campo.

Palabras clave: contaminación térmica, embalse urbano, rango infrarrojo, Lansat-8.

1. INTRODUCTION

Water bodies (e.g., rivers, lakes, and reservoirs) are an integral part of the urban environment. The condition of water bodies reflects the infrastructure of the city (pollution and heat). In addition, industrial facilities are often located near water bodies, which also affects the ecological situation of reservoirs. Various kinds of pollution can increase phyto- and zooplankton, including cyanobacteria and brown algae, leading to the appearance of toxins in the water, which disastrously affects the biodiversity of the reservoir (Chorus & Bartram, 1999).

The rapid growth of cyanobacteria and brown algae can be caused by phosphates and increased temperature in the reservoir. The reason for its increase lies in both climatic features and human-made impact on the reservoir, which must be identified.

Water sampling from water bodies and their visual examination does not always provide the desired effect due to the small spatial coverage of surface waters. Also, in places where there are small sources of thermal water pollution or, conversely, a large area of a water body is already polluted, it is rather problematic to detect this source. The remote sensing of surface waters in a wide range of electromagnetic waves comes to the rescue. In the microwave range, it is possible to identify places of pollution of reservoirs in the winter period by the thermal radiation of the ice cover, which, in this case, will have an increased value of the radio brightness temperature (the thermal radiation power in the ultra-high frequency range). This method of detecting pollution was described in various papers (Bordonskii & Gurulev, 2008; Gurulev, Tsyrenzhapov & Orlov, 2014).

In the infrared [IR] range, thermal anomalies on the surface of a water body can be detected from various carriers, including artificial Earth satellites. An example of the detection of thermal pollutants based on IR thermal imaging is presented in many works (Lega & Napoli, 2010; Tronin & Shilin, 2008). The fact that the urban environment has an increased temperature value (compared to the surrounding city space) was also indicated in many studies. For example, in one paper (Gorny et al., 2017), the regularities of the distribution of the thermophysical characteristics of the surface of the urban environment were given, and its reaction to climate warming was determined. Using remote sensing methods, the fact of overheating of the urban environment was revealed, leading to an increase in the temperature of urban reservoirs, which, as mentioned above, disastrously affects their ecology.

Thus, the identification of thermal anomalies is an urgent topic, both for the ecology of the reservoir and the provision of the vital activity of urban settlements.

2. MATERIALS AND METHODS

The research object is Lake Kenon, located in the city of Chita (Zabaykalsky Krai) (Fig. 1). The lake stretches from east to west, and the length is 5.7×2.8 km^2, respectively. The surface area is 16.2 km^2, the maximum depth is 6.8 m. Ice formation on the reservoir is observed from the beginning of November to the beginning of May. The thickness of the ice reaches 150 cm. However, in the area of the combined heat and power plant (Chita CHPP-1), which is located on the shore of this reservoir, the lake is not covered with ice (Tsybekmitova et al., 2017).

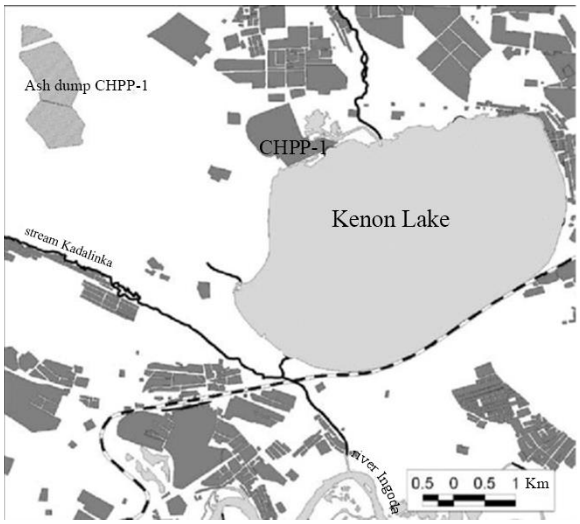

Fig. 1: Lake Kenon

CHPP-1 affects the ecology of the reservoir. This fact was reflected in several works (Itigilova et al., 1998; Tsybekmitova et al., 2017).

For the research of the thermal regime of Lake Kenon, we used IR devices installed on artificial satellites of the Earth. Thermal images of the Earth, obtained with the help of radiometers in the IR range, have become widespread. For example, extreme temperatures on the surface of the planet Earth were detected, the values of which are -93.2°C and 70.7°C, respectively. Climate change is also recorded not only by field measurements of the temperature of natural environments but also by remote recording methods. In particular, trend maps of the thermal characteristics of the seas, oceans, and continents were compiled (Duffy, Schwalm, Arcu & Koch, 2021).

More detailed information about the use of space thermal imaging can be found in other papers (Tronin & Shilin, 2015).

Recently, measuring devices that have an increased spatial resolution have attracted much attention. In this regard, images obtained using Lansat-8 were used during the research (Mondejar & Tongco, 2019). The software "QGis 3.1" was applied with the Semi-Automatic Classification Plugin [SACP] for image processing. The image processing methodology was given by other scholars (Matuzko & Yakubailik, 2018). The satellite channel was used under the number 10 with a wavelength from 10.5 to 11.2 microns.

3. RESULTS

Satellite images were obtained in the 10^{th} Lansat-8 channel of the Lake Kenon over the past 5 years in different seasons of the year. An example of such a thermal image is shown in Fig. 2. For a greater contrast of the image, averaging over temperature was performed.

Fig. 2: Distribution of the average water surface temperature of Lake Kenon, October 23, 2019

It was interesting to see the variations in the surface temperature of the reservoir during the formation of thin ice. This satellite image is shown in Fig. 3. During this period, the thickness of the ice cover did not exceed 5 cm. Also, Fig. 3 shows that the temperature near the thermal release of water from a thermal power plant is the same 6°C as before the beginning of ice formation. At the same time, the ice surface is the average daily air temperature on this day -6°C. That is, the temperature dependence can be used to determine the boundaries of the thin ice cover at the initial moment of its formation. In the visible range, thin ice is not always visually observed due to its high transparency.

When, in the winter period, large frosts are observed (i.e., the air temperature reaches -40°C), fog is observed over the open water surface. It contributes to the power of thermal radiation in the IR range. At this point, one can observe an erroneous temperature of a thin surface layer of water, the value of which will reach -15°C. There is a temperature of fog over the water surface. This issue requires more detailed consideration.

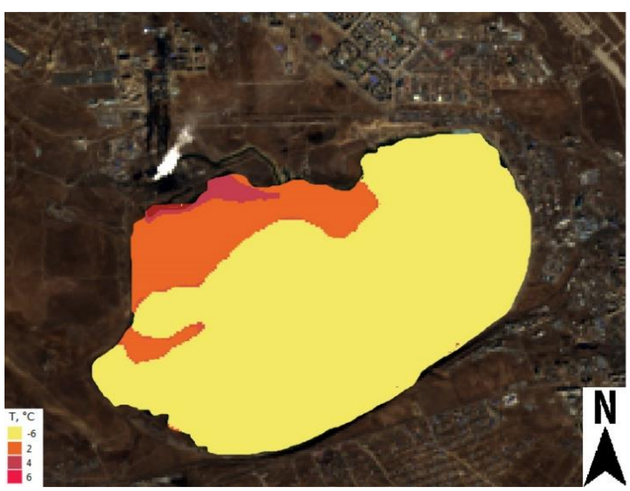

Fig. 3: Distribution of the average water surface temperature of Lake Kenon, November 2, 2017

4. DISCUSSION

Long-term thermal surveys have shown that the maximum temperature gradient of the lake surface is reached in the autumn, before the ice break. This situation can be explained by the fact that the ice cover has not yet covered the reservoir, but due to the beginning of the heating season in Chita, the capacity of the Chita CHPP-1 has slightly increased. This process leads to an increase in the discharge of warm water into the studied reservoir, and the gradient reaches values of 5–6°C. Moreover, this figure has not changed over the past five years, which indicates the stability of the thermal power plant. In the summer, this gradient reaches 1–2°C. In winter and spring, its value is difficult to assess because most of the lake is covered with ice cover. However, the temperature gradient in the open part of the reservoir also does not exceed 5–6°C.

As for the area of the warm spot on the surface of the reservoir, it does not exceed 10% of the total area in the autumn. Moreover, this area does not vary significantly but changes its position under the influence of external factors (wind and flows). However, at the same time, the source of thermal pollution is steadily located in one place, near a thermal power plant.

Compared to the nearest reservoirs located near the Chita, Lake Kenon has a slightly increased temperature value (as a rule, not exceeding 2°C). This situation once again proves that urban reservoirs are subject to the influence of the city, including heat.

A greater number of filamentous algae is located near the thermal power plant. The area of the Chita CHPP-1 is also recognized as the most polluted part of the reservoir (Kuklin, 2014). This section of the water area of the reservoir also has an increased temperature value, according to thermal surveys of the lake. Thus, it is possible to indirectly identify areas of the most polluted water of an urban reservoir based on the water surface temperature.

5. CONCLUSION

Thus, it was shown that urban reservoirs are subject to the thermal influence of the city. Based on the example of Lake Kenon, located in the Chita, a place of discharge of warm water was identified, associated with a thermal power plant, located on the shore of this reservoir. The optimal condition for detecting thermal anomalies is the time before ice formation in calm weather. The analysis of the last five years has shown that the area of the heated waters does not change, and the temperature gradient between the cold and warm parts of the lake surface is 5°C. The area of the heat spot does not exceed 10% of the total area of the lake. The above conclusions were confirmed by field measurements.

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