

INVESTIGATION OF URBAN HEAT ISLAND BASED ON REMOTE SENSING AND GIS

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Abstract

In modern times, cities and cities' economy are the main causes of global problems. For this reason, the study of cities is an urgent issue. Our goal is to study the temperature of the elements of climate in Shirvan, one of the big cities in the Republic of Azerbaijan, and to analyze urban heat islands. Landsat satellite images were decoded and analyzed using Remote Sensing and GIS technologies during the study. It was determined that the surface temperature in the northwestern and western parts of the city is unfavourable for the health of the population in the summer months. At this time, the temperature indicators in the areas of the city close to the banks of the Kura river are quite favourable as a result of the influence of the river. The intensive development of the industry in the city and the large population have caused the energy consumption to be higher than in other areas. The presence of an urban lifestyle and the construction of asphalted roads have led to the creation of urban heat islands.

Key words: urban landscape, land surface temperature, urban heat island, Shirvan city, NDV index

Introduction. Urban heat islands are abnormal temperature differences between a city and its surrounding areas. For example, in a metropolis with at least one million people, the air temperature is on average 1–3 °C higher than in the suburbs. Heat islands are not limited to megacities [1]. Even a city of

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10 000 people with favourable conditions (for example, many stone and concrete houses, asphalt roads) produces small thermal anomalies. Urban heat islands occur in urban landscapes that generate more heat. In the city, there are more dark surfaces that absorb solar radiation [2]. Buildings and roads absorb more sunlight than green spaces. Air full of dust and industrial emissions creates a greenhouse effect. High-rise buildings can be considered thermal energy storage because they get very hot during the day and do not have time to cool down at night. Not all cities have a distinct heat island. It depends on the climate of the area where the settlement is located [3]. Wide streets and avenues covered with green boulevards make the city cooler and blow dirt and harmful substances into the air. If there is intensive development in the centre and sparser buildings on the outside, then heat accumulation will increase from the outside to the centre [4].

This effect can have significant consequences for the environment, human health and energy consumption [5].

The urban heat island has many negative consequences for city dwellers, which are exacerbated by climate change. For example, the temperature increase in the city due to this event may reach 2–8 °C in some cities [6].

Studies show that the urban heat island contributes to the exacerbation of chronic diseases of the respiratory and cardiovascular systems. This effect particularly affects children, the elderly, and the disabled [7].

Currently, about half of the world's population lives in metropolitan areas but by 2050 it is estimated that this will increase to almost two-thirds. Therefore, the urban heat island will be increasingly on the agenda and stimulate the search for solutions in various areas of construction, including facade glazing [8].

In urban heat islands, urban greenery, especially tall greenery, is of great importance, it increases humidity, improves local air circulation, and helps to clean it of pollutants. Protecting and increasing the area of biologically active zones in the spatial structure of the city is the optimal solution for softening the temperature regime [9].

This issue is related to the problem of urban planning. Although architects have tools for spatial planning, cities and suburbs experience chaos, which, among other things, results in a huge waste of space and energy [3]. The expansion of cities and the lack of social services in neighbourhoods leads to the excessive development of automobile transport, which clearly affects the state of the atmospheric air, increasing the impact of the city on the global climate. Thus, in order to normalize the microclimate in the urban space, it is necessary to stimulate the development of green objects [4].

The creation of a network of urban greenery should be considered one of the measures that ensure the safety of citizens' health. In densely built residential areas with little useful space, it should be increased with small solutions such as green roofs, parks, vertical gardens or green facades, which will lighten the heating regime and reduce thermal stress [5].

Material and methods. In the study area, we studied the issues of land surface temperature, NDV and urban heat island. At this time, we used the images of Landsat 8 satellite of August 2023.

When calculating the land surface temperature, we used the following sequence.

First of all, we need to convert the original DNs of TIRs into Top of Atmospheric Radiance (TOAr). Therefore, the original digital numbers (DN) of Landsat 8 TIR bands are converted into radiance based on the methods provided by CHANDER and MARKHAM [10]. Equation 1 is used to convert original DNs into TOAr as shown below:

$$(1) \quad \text{TOAr} = M * \text{DN} + B.$$

M – Radiance multiplier

B – Radiance add

The M, B values are in the metadata file of Landsat 8 data.

K_1 and K_2 are parameters of band-specific thermal conversion constant.

After we have got the TOAr values, now we are able to calculate brightness temperature using equation 2 [11]:

$$(2) \quad T_{\text{Kelvin}} = K_2 / \ln(K_1 / \text{TOAr} + 1).$$

By using K_1 and K_2 parameters, we have converted the TOAr values into temperature in degrees Kelvin.

In the calculation of land surface temperature, we also need the NDV index. For this reason, the NDV index was studied based on the satellite image of the research area belonging to the same period. In this case, we used the following formula.

$$(3) \quad \text{NDVI} = (\text{NIR} - \text{RED}) / (\text{NIR} + \text{RED}).$$

Heat islands caused by urban development were also analyzed. In this case, the following formula was used [12].

$$(4) \quad \text{UHI} = (\text{LST} - \text{LST}_m) / \text{SD}.$$

UHI – Urban heat island

LST – Land surface temperature

LST_m – The mean temperature of the land surface temperature in the area

SD – Standard deviation of temperature

Results and discussion. Our research area covers the city of Shirvan, located on the left bank of the Kura river in the Kura-Araz plain.

Based on satellite images and the topographical map of the city, we determined that the area of the city increased by 13 km² in 39 years and reached 28.2 km².

The city of Shirvan, located on the left bank of the Kura river, in the Shirvan plain, bore the name of Ali Bayramli until May 7, 2008. This area, which includes the villages of Haji Kahramanli and Bayramli, obtained the status of a city in 1963. Shirvan is an industrial city with a population of about 80 thousand people and an area of 28 km². This city, where oil and gas production is carried out in its surroundings and in some areas, is also called the city of “oil workers” and “energy workers”. After all, in addition to the oil industry, there is also the Shirvan State Inter-Regional Power Station in this city [13].

This settlement of people living a nomadic lifestyle has been called Arab-sakhverdi village since ancient times. In 1776, the camp of the famous Russian general Zubov was located here on the banks of the Kura river. In 1886, a water pumping station named after Zubov was built on the Kura river flowing from here. Therefore, the city was called Zubovka for a long time.

Established as an agricultural district in 1930, Shirvan received city status on January 4, 1963, and its villages and other farms were transferred to Salyan, Sabirabad and Shamakhi districts. Although the first oil wells were drilled here in the mid-50s. In 2005–2010, the city of Shirvan was among the leading cities of the republic in terms of the rate of industrial development. In 2010, the material living standard of Shirvan residents improved significantly, their monetary income was 42.9 million manats. This is 544 manat per resident.

In 2010, the heating and sewage systems of the buildings were completely updated within the framework of the State Program. The greenery of the Central City Hospital, whose territory is about 7 hectares, is under permanent protection.

The city of Shirvan is one of the most important energy centres of the country. Other industries were also developing in the city. This accelerates the process of urbanization. Intensive urbanization has a strong impact on the environment.

During the study of heat islands, the surface temperature in the city was first studied. For this, Landsat 8 satellite images from August 2023 were processed. As a result of the analysis, it was determined that the temperature here is less than 30 °C as a result of the influence of the Kura river passing through the southeastern part of the city. The influence of the river is evident in most parts of the city. However, as we move away from the river bank, we can see that the temperature increases sharply. This indicator increases to 41.16 °C in a short distance (Fig. 1).

During LST analysis, it is also important to analyze the NDVI map of the area. Analysis of the NDV index is one of the modern methods that allows to more accurately distinguish the degree of vegetation coverage of the surface. Areas where this index is negative indicate the presence of a water basin. As can be seen in Fig. 2, the areas with a negative index marked in blue correspond to the areas of the Kura river and its flowing lakes. Areas with an index of 0–0.1 characterize residential houses and roads.

Areas with an index of 0.1–0.2 correspond to fields, areas with an index of 0.2–0.3 are sparse bushes, areas with an index of 0.3–0.4 are shrubs, and areas

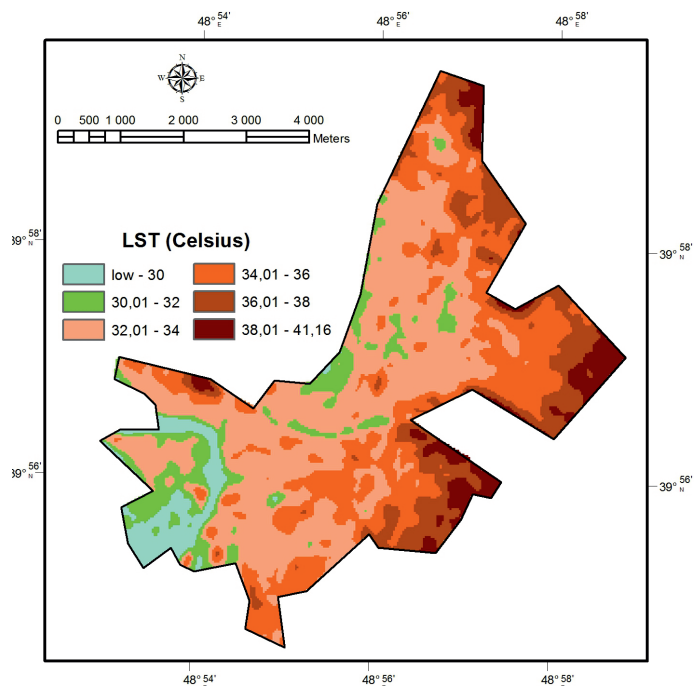


Fig. 1. Land surface temperature

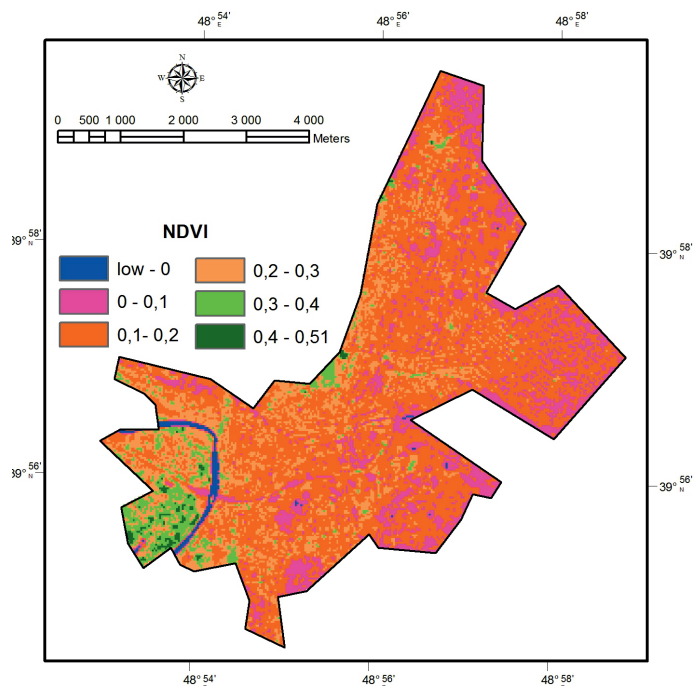


Fig. 2. Normalized difference vegetation index (NDVI)

with an index higher than 0.4 correspond to areas of forests. This clearly explains the effect of covering the surface with vegetation on the surface temperature index and the formation of heat islands. The analysis of the map clearly shows that the lack of habitation on the right bank of the Kura river led to the spread of forests. Here the index is mostly higher than 0.3. Due to the influence of the river, the settlement on the coast is also dense. However, as we move away from the coast, we can see that the cultivated areas and bushes increase.

We have conducted mapping using modern research methods to analyze urban heat islands. At this time, we drew up the AB profile and followed the temperature change on this profile. The analysis of the map characterizing the urban heat island shows that, despite covering a small area, there is a sharp temperature difference. As you move away from the bank of the Kura river, you can observe the formation of a heat island (Fig. 3).

For a more accurate analysis of the heat island, we have built an AB profile in the direction of the formation of the heat island from the right bank of the Kura river to the left bank. According to this profile, it is clear that the heat island is sharper compared to rural settlements on the left bank of the Kura river in the area far from the city centre (Fig. 4).

But there are also several strategies that can be used to eliminate or reduce the heat island effect in cities. Increasing the amount of vegetation in urban areas

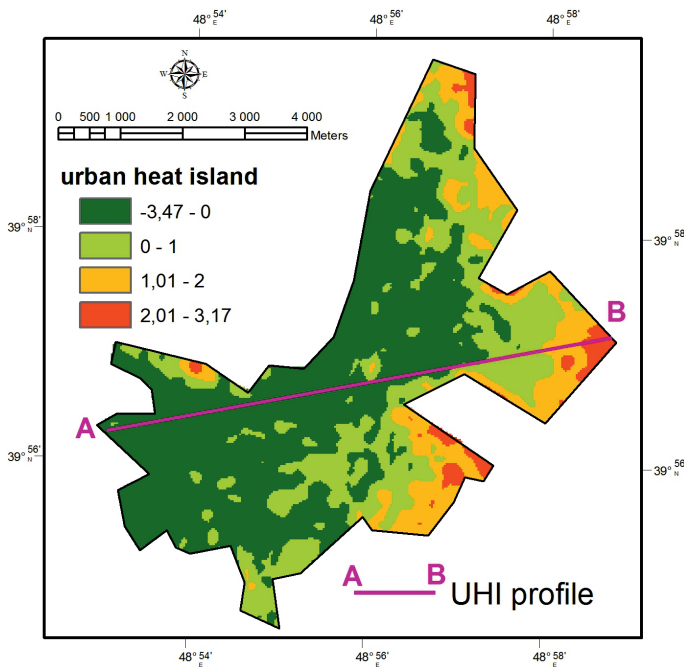


Fig. 3. Urban heat island

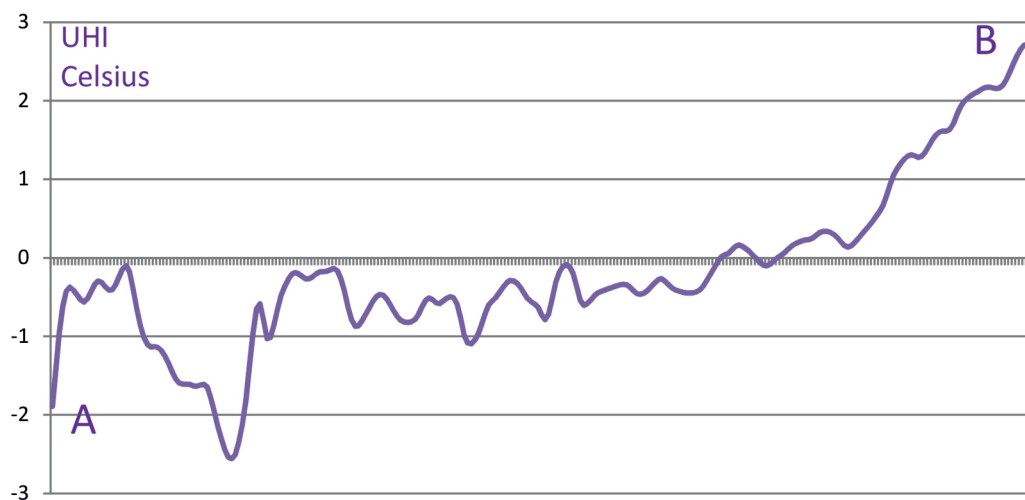


Fig. 4. Urban heat island indicator along AB profile line

can significantly reduce the heat island effect. Trees, grasses, and other plants help absorb and dissipate heat through evaporation; they cool the surrounding air, provide shade, and increase humidity in the atmosphere. Damp roofs are designed to reflect more sunlight and absorb less heat than traditional roofs, lowering the temperature of the building and surrounding air. This type of roofing can be obtained by using white or light coloured materials. Traditional surfaces such as asphalt and concrete retain heat and contribute to the heat island effect. Using permeable surfaces such as permeable pavement, porous concrete, or gravel can reduce the amount of heat absorbed by the surface and allow water to penetrate the ground. Implementation of urban development strategies is also important. Urban design strategies that prioritize open space, greenery, and pedestrian-friendly environments can help reduce the heat island effect. This may include designing wider sidewalks, creating bike lanes, and creating urban green spaces such as parks and gardens [6].

In conclusion, the heat island effect is a serious problem that can have a significant impact on the environment and human health.

Conclusion. Recent studies show that the urban heat island is highly likely to occur in all cities. This can be clearly seen in the city of Shirvan, which is our research area. In the western and southwestern parts of the city, the intense influence of the Kura river does not allow the formation of a heat island. The absence of settlements in the surrounding areas also has a positive effect here. However, on the left bank of the city, as people move away from the coast, the denser population and the presence of rural and urban settlements in the vicinity lead to the formation of heat islands. Here we clearly see that the temperature differs by 1–3 °C compared to the surrounding areas.

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