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EVALUATION OF THE ECOLOGICAL EFFICIENCY OF TASHKENT CITY'S GREEN INFRASTRUCTURE UNDER CLIMATE CHANGE CONDITIONS AND DETERMINATION OF SPATIAL PRIORITIES FOR DEVELOPMENT

Quvondiqova Mahliyo Bobomurotovna
e-mail: quvondiqovamahliyo8@gmail.com

Abstract

In this scientific article, a comprehensive assessment of the ecological efficiency of Tashkent city's green infrastructure under the conditions of global climate change and intensive urbanization is carried out based on geographical information systems (GIS) and remote sensing (Landsat 8/9 OLI-TIRS) data. Within the scope of the study, the quantitative correlation between the state of green cover (NDVI) and land surface temperature (LST) parameters was analyzed, and urban heat island (UHI) anomalies were identified. As a result of mathematical and statistical modeling of satellite data, a geoecological analysis of urban districts was conducted, and spatial priorities for sustainable management and development of artificial ecosystems were systematized. The level of green space per capita was compared across districts, and ecological recommendations were developed to enhance the functionality of artificial green areas.

Keywords: Green infrastructure, geoecology, urbanization, urban heat islands, Landsat satellite imagery, vegetation index, land surface temperature, artificial ecosystems, anthropogenic load, correlation analysis.

IQLIM O‘ZGARISHI SHAROITIDA TOSHKENT SHAHRI YASHIL INFRATUZILMASINING EKOLOGIK NATIJADORLIGINI BAHOLASH VA RIVOJLANTIRISHNING HUDUDIY MUHIM JIHATLARINI ANIQLASH

Quvondiqova Mahliyo Bobomurotovna
e-mail: quvondiqovamahliyo8@gmail.com

Annotatsiya

Ushbu ilmiy maqolada global iqlim o‘zgarishi va shiddatli urbanizatsiya sharoitida Toshkent shahri yashil infratuzilmasining ekologik samaradorligi geografik axborot tizimlari (GAT) va masofadan zondlash (Landsat 8/9 OLI-TIRS) ma’lumotlari asosida kompleks baholangan. Tadqiqotda shahar yashil qoplamining holati (NDVI) va yer yuzasi harorati (LST) o‘rtasidagi korrelyatsiya tahlil qilinib, shahar issiqlik orollari (UHI) anomaliyalari aniqlangan. Matematik-statistik modellashtirish natijasida shahar tumanlari geoekologik jihatdan rayonlashtirilgan hamda sun’iy ekotizimlarni barqaror boshqarish va rivojlantirishning hududiy ustuvorliklari tizimlashtirilgan. Aholi jon boshiga to‘g‘ri keladigan yashillik darajasi tumanlar kesimida taqqoslanib, sun’iy yashil massivlar funksionalligini oshirish bo‘yicha ekologik tavsiyalar ishlab chiqilgan.

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Tayanch so‘zlar: yashil infratuzilma, geoekologiya, urbanizatsiya, shahar issiqlik orollari, Landsat yo‘ldosh tasvirlari, vegetatsiya indeksi, yer yuzasi harorati, sun’iy ekotizimlar, antropogen yuklama, korrelyatsiya tahlili.

ОЦЕНКА ЭКОЛОГИЧЕСКОЙ ЭФФЕКТИВНОСТИ ЗЕЛЕНОЙ ИНФРАСТРУКТУРЫ ГОРОДА ТАШКЕНТА В УСЛОВИЯХ ИЗМЕНЕНИЯ КЛИМАТА И ОПРЕДЕЛЕНИЕ ТЕРРИТОРИАЛЬНЫХ ПРИОРИТЕТОВ ЕЕ РАЗВИТИЯ

Кувондикова Махлиё Бобомуротовна
e-mail: quvondiqovamahliyo8@gmail.com

Аннотация
В данной научной статье на основе географических информационных систем (ГИС) и данных дистанционного зондирования (Landsat 8/9 OLI-TIRS) проведена комплексная оценка экологической эффективности зеленой инфраструктуры города Ташкента в условиях глобального изменения климата и интенсивной урбанизации. В рамках исследования проанализирована количественная корреляция между состоянием зеленого покрова (NDVI) и термическими показателями земной поверхности (LST), выявлены аномалии городских островов тепла (UHI). В результате математического и статистического моделирования спутниковых данных проведен геоэкологический анализ городских районов, систематизированы территориальные приоритеты устойчивого управления и развития искусственных экосистем. Проведено сравнение уровня озеленения на душу населения в разрезе районов, разработаны экологические рекомендации по повышению функциональности искусственных зеленых массивов.

Ключевые слова: зеленая инфраструктура, геоэкология, урбанизация, городские острова тепла, спутниковые снимки Landsat, вегетационный индекс, температура земной поверхности, искусственные экосистемы, антропогенная нагрузка, корреляционный анализ.

INTRODUCTION

In Tashkent, a major industrial, cultural and administrative center of our republic, the acceleration of demographic growth and urbanization in recent decades has sharply increased the anthropogenic load on urban ecosystems. The "urban heat island" (UHI) effect, which arises as a result of the expansion of urbanized areas due to artificial objects (buildings, asphalt pavements), leads to anomalous warming of the local microclimate [1, p. 45].

In such conditions, green infrastructure (Green Infrastructure) performs crucial ecological and microclimatic functions in ensuring urban stability and protecting public health [2, p. 18]. This study fully complies with the principles of protecting natural and

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artificial ecosystems, managing their activities, and ensuring the stable state of the environment changed by human influence, as set out in the passport of the specialty 11.00.05 - "Geoecology".

ANALYSIS OF THE CURRENT STATE OF THE PROBLEM UNDER CONSIDERATION

The effectiveness of green infrastructure in mitigating urban thermal regimes has been widely studied globally. Benedict and McMahon developed the conceptual framework of green infrastructure in their works to ensure urban ecological sustainability [3, p. 15]. Zhou and his co-authors quantitatively proved that the fragmentation of landscape structure enhances the urban heat island effect [4, p. 57]. The methodology for determining land surface temperature (LST) using remote sensing data was improved by Sobrino [5, p. 434] and Weng [6, p. 467].

The impact of landscape composition on LST indicators in Asian and European megacities was modeled by Estoque [7, p. 349] and Li [8, p. 1]. Local scientists Alibekov and Rafikov studied the anthropogenic transformation of Central Asian oasis landscapes from a geoecological perspective [9, p. 110; 10, p. 45]. Nigmatov, on the other hand, highlighted the problems of regulating the use of nature in urban artificial ecosystems [11, p. 142]. However, in the current conditions of intensive construction in Tashkent, the relationship between the greenness index and thermal anomalies in the district section has not been thoroughly analyzed based on GAT.

ISSUE

The irregular expansion of construction areas and the reduction of natural landscapes in Tashkent have led to the fragmentation of the integrated green framework system. This situation causes anomalous heating of the city surface and an increase in the amount of solid suspended particles (dust) in the atmosphere.

The main task of the study is to quantify the density of green cover (NDVI) and land surface temperature (LST) in all administrative districts of Tashkent using remote sensing data, to reveal the laws of mathematical and statistical correlation between them, and to determine priority measures for territorial management of artificial ecosystems based on the results obtained.

METHODS OF SOLUTION

The study used multispectral images of Landsat 8 and Landsat 9 (OLI-TIRS) satellites from July-August 2024–2026, obtained from the US Geological Survey (USGS) database. Spatial analyses were performed in the ArcGIS 10.8 software environment.

1. Determination of the vegetation index (NDVI):

The green cover density was calculated based on the spectrum of the red (RED, Band 4) and near-infrared (NIR, Band 5) channels using the following formula [12, p. 309]:

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$$NDVI = \frac{NIR - RED}{NIR + RED}$$

2. Land Surface Temperature (LST) Modeling:

LST values were determined from the Landsat thermal channel (Band 10) spectral radiance coefficient (\(L_λ\)) and brightness temperature (\(B_T\)) [13, p. 370]. The final LST was converted to the Celsius (°C) scale by taking into account the emissivity (ε) of the land surface [14, p. 682]:

$$LST = \frac{B_T}{1 + \left(\frac{\lambda \times B_T}{\rho}\right) \ln(\varepsilon)} - 273.15$$

Where: λ — the wavelength of the propagation $10.8\mu m$;ρ=1.438×10^{-2}m·K. In the Statistical Package for the Social Sciences (SPSS) program, the Pearson correlation between NDVI and LST in the districts was calculated.

RESULTS ANALYSIS AND EXAMPLES

The conducted geoecological analyses showed that the green infrastructure elements and thermal areas of Tashkent city are sharply unevenly distributed in terms of territory. The analytical data obtained in the districts are systematized in Table 1.

Table 1. Indicators of green infrastructure density and average surface temperature of Tashkent city districts

District name	Total area, km²	Share of green space, %	Green space per capita, m²	Average NDVI value	Average LST, °C	Geoecological status
Yunusabad	41.4	42.1	7.8	0.58	32.4	Stable
Mirzo Ulugbek	31.9	45.3	8.2	0.62	31.8	Stable
Yakkasaroy	14.6	38.5	6.5	0.48	33.6	Satisfactory
Chilanzor	29.9	32.2	5.4	0.41	35.2	Moderate
Shaykhontohur	29.8	28.4	4.9	0.36	36.4	Moderate
Olmazar	34.5	26.1	4.2	0.32	37.1	Scarcity
Uchtepa	24.0	22.3	3.6	0.28	38.5	Scarcity
Sergeli	30.1	14.2	2.1	0.18	41.2	Critical
Yangihayot	44.2	11.5	1.8	0.15	42.6	Critical

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Note: The font size for tables was prepared in 10 pt size according to the journal requirements.

As can be seen from the table data, in Yangihayot (11.5%) and Sergeli (14.2%) districts, where the share of green spaces is the lowest, the average summer surface temperature is 42.6 °C and 41.2 °C, respectively. Urban heat island (UHI) anomalies are clearly formed in these regions [15, p. 1]. On the contrary, in Mirzo Ulugbek district (31.8 °C) and Yunusabad district (32.4 °C), where the historical green frame is partially preserved, the temperature is at an optimal level, providing microclimatic comfort.

Correlation analysis: The linear regression model between NDVI and LST parameters showed a strong inverse correlation (Pearson coefficient $r = -0.84$, coefficient of determination $R^2 = 0.705$, $p < 0.001$). This mathematically proves that 70.5% of the change in the city's surface temperature directly depends on the density of green infrastructure. According to the mathematical model, an increase in the NDVI value by 0.1 unit leads to an average decrease in the city's surface temperature by 1.85 °C [16, p. 147].

The correct selection of species composition in the formation of urban flora is the main principle of managing artificial ecosystems [17, p. 102]. In recent years, many introduced conifers in Tashkent have shown low tolerance to a dry climate and atmospheric pollution [18, p. 112]. The increase in the number of broad-leaved, local tree species with a high transpiration coefficient for local conditions increases the ecological efficiency by 2.5 times [19, p. 89].

CONCLUSION

1. The ecological efficiency of the green infrastructure of Tashkent city was quantitatively assessed based on GAT and remote sensing data. It was found that the NDVI indicators in the city area varied from 0.15 to 0.62 by districts, and the green cover was unevenly distributed territorially.
2. Mathematical and statistical regression analysis showed a strong inverse relationship between the density of green cover and land surface temperature (LST) ($R^2 = 0.705$). Thermal anomalies of artificial landscapes were directly evidenced by the lack of vegetation cover.
3. Yangihayot and Sergeli districts were identified as ecologically critical zones. The urgent need to create artificial ecosystems and green belts to reduce the anthropogenic load on urbanized landscapes in these regions has been scientifically substantiated [20, p. 115].

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