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Research article

Tourism-Oriented Spatial Analysis of Tangible Cultural Heritage in Bukhara (Uzbekistan)

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Abstract

This study examines the spatial distribution and tourism utilization of 829 officially registered architectural heritage sites in the Bukhara, Uzbekistan. Spatial analysis methods including the Gini Index (0.569), Lorenz Curve, Nearest Neighbor Analysis, Kernel Density Estimation, and Bivariate Moran's I were applied to examine clustering patterns and disparities across districts. The findings reveal unequal heritage distribution: over 50% of the sites are located in two districts, mainly in the eastern region, while others remain underrepresented. The Bukhara city shows strong clustering, whereas several districts exhibit random or dispersed patterns. Despite a sharp rise in tourist arrivals from 13,300 international visitors in 2020 to over 1.7 million in 2024 only 146 sites (17.6%) are actively used for tourism. This increased tourism pressure, with visitors per site growing from 1,798 to 39,351. Typological analysis showed uneven spatial patterns among major religious, administrative, residential, and public groups. Bivariate Moran's I ($I = -0.0621$, $p = 0.498$) indicated no significant spatial correlation between population density and heritage distribution. The study recommends adopting circular tourism strategies to reduce pressure, balance regional disparities, and promote sustainable heritage-based tourism development. Findings offer a basis for balanced heritage management and tourism development in Uzbekistan with comparable regions.

Keywords: cultural heritage; spatial analysis; sustainable tourism; circular tourism; Kernel density estimation; Nearest neighbour analysis; Gini index; Moran's I.

1. Introduction

Cultural heritage consists of tangible and intangible assets that embody society's historical, cultural, and spiritual values. It is displayed in various forms, including traditions passed down through generations, works of art, architectural monuments, religious and ceremonial customs, languages, songs, and epics (Shrestha *et al.*, 2024). Tangible cultural heritage includes historical buildings, monuments, works of art, manuscripts, archaeological sites, and similar objects. On the other hand, intangible cultural heritage includes oral traditions, forms of creative expression, rituals, and craftsmanship skills (Ramón-Cardona & Sánchez-Fernández, 2022; Sethaba & Scholes, 2021).

Cultural heritage plays a pivotal role in shaping society's self-awareness and cultural identity (Lu & Wan, 2018). Historical monuments and traditions are essential for preserving national distinctiveness and fostering tourism development (Shirokalova *et al.*, 2023). Furthermore, preserving cultural heritage and its transmission to future generations is considered as a global mission, with various conventions and programs being implemented by international organizations to protect it, especially UNESCO (UNESCO, 1972).

Preserving cultural heritage includes various aspects, such as scientific research, restoration efforts, education, and raising awareness (Li & Tang, 2024; Piñar & Sterflinger, 2021). With globalization, the risk of losing cultural heritage is increasing (Vallianatou *et al.*, 2025). Therefore, governments and international organizations must strengthen cooperation to protect and promote these values (Folorunso, 2021; Holtorf, 2018). This scientific study conducts a spatial analysis of the registered tangible cultural heritage in the Bukhara region of Uzbekistan, including archaeological monuments, architectural landmarks, monumental art objects, and historically significant sites.

Spatial analysis is a method used to study geographic data and apply it to analyze various regional processes and issues, primarily through Geographic Information Systems (GIS) tools. This analysis enables examining location-based data, identifying relationships between objects, and understanding specific spatial trends within a given area (Ye & Andris, 2021). It is widely applied in various fields, including urban planning, environmental monitoring, tourism planning,

transportation system optimization, and healthcare (Huang & Wang, 2020). Additionally, spatial analysis is crucial in decision-making processes, particularly in studying tourism flows in a given area, assessing accessibility to cultural heritage sites, and developing sustainable development strategies (Malaperdas, 2022).

Spatial analysis provides a means of observing spatial patterns and a practical framework for evaluating the distribution and accessibility of cultural resources. GIS technologies enable precise mapping of historical sites, measurement of spatial concentration, and identification of regions with tourism development gaps (Rong & Jianwei, 2023; Chen *et al.*, 2025). These tools support the strategic planning of tourism infrastructure, improve the efficiency of heritage site management, and contribute to more informed policy-making.

GIS-based spatial analysis is crucial in balancing heritage preservation with tourism growth in regions like Bukhara, where cultural heritage is dense and unevenly distributed. Visualising high-density clusters and peripheral voids makes it possible to prioritise interventions, design heritage routes, and ensure more equitable access to historical sites (Bai *et al.*, 2024). This spatial insight is significant for planning sustainable tourism that respects local contexts and reduces development disparities. Such GIS-informed approaches also lay the groundwork for adopting circular tourism strategies, which aim to revitalise heritage areas, extend visitor engagement, and distribute tourism benefits more evenly across the region (Strippoli *et al.*, 2024).

The concept of circular tourism is regarded as a critical approach to achieving sustainability goals (Graham *et al.*, 2000). Circular tourism promotes the efficient use of resources, their reuse, restoration, and the redistribution of tourist flows, particularly in areas where cultural heritage potentials are underutilized (Rudan, 2023). This approach is highly relevant for the Bukhara region as well, as spatial disparities highlight opportunities to revitalize unknown heritage sites through the principles of circular tourism.

Based on the above, the results of the spatial analysis methods applied to the 829 registered heritage sites in the Bukhara region have been presented and highlighted in the study. Notably, this research represents the first attempt to conduct a comprehensive spatial analysis of Bukhara's cultural heritage.

2. Literature review

Research on the relationship between cultural heritage and tourism has expanded significantly in recent years, and various theoretical approaches have emerged in this area (Chen *et al.*, 2022; Qiu *et al.*, 2022). While previous studies have focused mainly on ensuring a balance between cultural heritage conservation and tourism, modern research has also added technological and economic approaches to this process (Rueda Márquez de la Plata *et al.*, 2022). A growing number of studies also aim to assess the spatial distribution of cultural heritage sites and their impact on tourism using spatial analysis methods (Wang *et al.*, 2021; Zhang *et al.*, 2024).

2.1. The relationship between cultural heritage and tourism

Many recent scientific studies have been conducted based on the relationship between cultural heritage and tourism. Cultural heritage is one of the most attractive segments of tourism and includes various forms of heritage, such as historical monuments, museums, archaeological sites, and religious and national ceremonies (Geçikli *et al.*, 2024; Qiu *et al.*, 2022). On the other hand, tourism allows these objects to be introduced to the general public and maintains them economically sustainable (Barnes, 2022). Therefore, cultural heritage and tourism are complementary concepts.

2.2. The role of cultural heritage in tourism development

Cultural heritage is an essential resource for tourism, attracting visitors and contributing to the socio-economic development of a region (Cerisola & Panzera, 2024). According to data provided by the European Commission (2025), cultural tourism accounts for approximately 40% of Europe's tourism, which continues to grow yearly. In Uzbekistan, the cultural heritage of historical cities such as Bukhara, Samarkand, and Khiva has turned these locations into major tourist centers, leading to the development of service infrastructure and having a significant positive impact on the local economy (Juraturgunov *et al.*, 2023). Moreover, cultural heritage tourism helps balance the regional distribution of tourists (Cerisola & Panzera, 2024). While tourism flows are typically concentrated in large cities and natural landscapes, destinations with cultural heritage also attract visitors to more remote regions expanding the geographical scope of tourism activity (Espino Hidalgo, 2020; Huang *et al.*, 2016). Heritage is significant for ensuring sustainable tourism development at the local level.

An additional approach to enhancing the role of cultural heritage in tourism development is the application of circular tourism principles. Circular tourism develops tourism activities through resource efficiency, minimizing waste, and regenerating the local economy. For heritage tourism, this includes extending the lifecycle of cultural attractions, promoting the reuse and revitalization of heritage sites, and fostering greater community participation (Rudan, 2023; Axhami *et al.*, 2023). In regions such as Bukhara, where there is an unequal distribution of resources, adopting circular tourism strategies can help redirect tourist flows to underdeveloped areas, stimulate local artisanal production, and preserve the authenticity of both major and minor heritage assets.

2.3. The impact of tourism on cultural heritage

Tourism can serve as a strong economic incentive for preserving and developing cultural heritage (Rueda Márquez de la Plata *et al.*, 2022). Revenues generated from visitor fees, tourism-related services, and investments from international organizations can be directed towards restoring, conserving, and maintaining cultural heritage sites (Chenavaz, 2022). Notably, the World Heritage List of UNESCO attracts global attention, ensuring economic sustainability through tourism (UNESCO, 2014).

However, tourism also has negative impacts on cultural heritage. Excessive tourist traffic can physically damage heritage sites, while overdevelopment of infrastructure may disrupt the historical and ecological balance of an area (Cerisola & Panzera, 2024; Almasri & Ababneh, 2021). For instance, in some notable cultural-tourism hubs, such as Venice and Barcelona, an overwhelming influx of tourists has adversely affected the daily lives of residents and raised challenges in preserving the authenticity of heritage sites (Mazzamuto & Picone, 2022; Bertocchi & Visentin, 2019). As well, tourism can lead to the commercialization of cultural heritage. Local culture may be altered or misrepresented in such cases to cater to tourist expectations (Cerisola & Panzera, 2024). As a result, certain cultural elements will have a risk of losing their authenticity, with commercial interests of the tourism industry taking precedence over genuine cultural values (Tang *et al.*, 2019).

2.4. The role of spatial analysis and GIS technologies in cultural heritage research

Digital technologies are one of the key strategies for the balanced development of heritage and tourism, requiring significant research efforts (Maietti, 2023; Lian & Xie, 2024). GIS technologies and spatial analysis methods have been widely applied in cultural heritage studies, expanding the possibilities of examining the spatial relationships between tourism and heritage sites (Huang, 2024; Liu *et al.*, 2024). Research by Ciski *et al.* (2019) demonstrates that GIS serves as a crucial tool for mapping cultural heritage sites and studying their spatial distribution through spatial statistical methods.

The Kernel Density Estimation (KDE) method has been widely used in research to assess the geographic density of cultural heritage sites and determine the development levels of tourist zones (Bonnier *et al.*, 2019; Yuan *et al.*, 2022; Wei *et al.*, 2024). KDE has been employed to analyze the concentration of cultural heritage sites and tourism resources, leading to the development of recommendations for tourism planning. The Nearest Neighbor Analysis (NNA) method has been applied to determine the spatial clustering of cultural heritage sites and assess its impact on tourist flows (Yuan *et al.*, 2022). Research by Thompson *et al.* (2022) suggests that NNA is an effective tool for identifying the spatial relationships among cultural sites and their regional interactions.

The Gini Index and Lorenz Curve have been used to analyse inequalities in the spatial distribution of cultural heritage sites. Martín *et al.* (2018) applied the Gini coefficient to evaluate the spatial concentration of cultural heritage sites, demonstrating main tourism spots in Europe, the Balearic Islands in Spain. Additionally, Zhang *et al.* (2022) showed that the Lorenz Curve can be applied to assess the distribution of cultural heritage sites.

Moran's I is another spatial statistical method increasingly applied in cultural heritage research to measure spatial autocorrelation, whether cultural sites are randomly dispersed, clustered, or evenly distributed. This method evaluates the degree to which the presence of heritage sites in one location is similar to those in neighbouring areas, thereby uncovering underlying spatial structures (Heydari & Niknami, 2024). Moran's I is particularly effective in identifying spatial dependencies across large geographic regions, contributing to more precise heritage management and tourism planning. Studies have demonstrated its utility in diagnosing spatial imbalances and guiding policies for spatial equity in tourism development (Rodríguez & Sánchez, 2020)

A relevant study by Valjarević *et al.* (2017) applied GIS-based geostatistical modelling to evaluate the tourism potential of Lukovska Spa, Serbia. Their work demonstrates how spatial interpolation, natural attribute indexing, and geosite assessment can be integrated to identify tourism

development zones and manage underutilized areas, which aligns closely with the methodology and objectives of this research. The overall conclusion from these studies is that spatial analysis methods play a vital role in effectively managing the cultural heritage sites, analysing their connection to tourism infrastructure, and developing sustainable tourism strategies. Therefore, when combined with GIS technologies, KDE, NNA, the Gini Index, Moran's I, and the Lorenz Curve are recognized as effective methods for examining spatial inequalities, the distribution of tourist flows, and the spatial characteristics of heritage sites in cultural heritage research.

However, these analyses have primarily been applied at a global scale or to tourist regions in some countries, while GIS-based spatial analyses of Uzbekistan's cultural heritage and tourism infrastructure, particularly in Bukhara region, remain insufficiently explored. Therefore, this study is not only one of the first to examine the spatial relationships between cultural heritage and tourism in the Bukhara region but also serves as a crucial scientific foundation for developing cultural tourism strategies using GIS-based spatial approaches in other regions of Uzbekistan in the future.

3. Research Methods

3.1. Study Area and Data Sources

1. Brief overview of the Bukhara Region

Bukhara region is located in the southwestern part of Uzbekistan (Figure 1), along the Kyzylkum Desert and the banks of the Amu Darya River. The geographical coordinates of the region range from 38°30' to 40°00' N latitude and 63°45' to 65°30' E longitude.

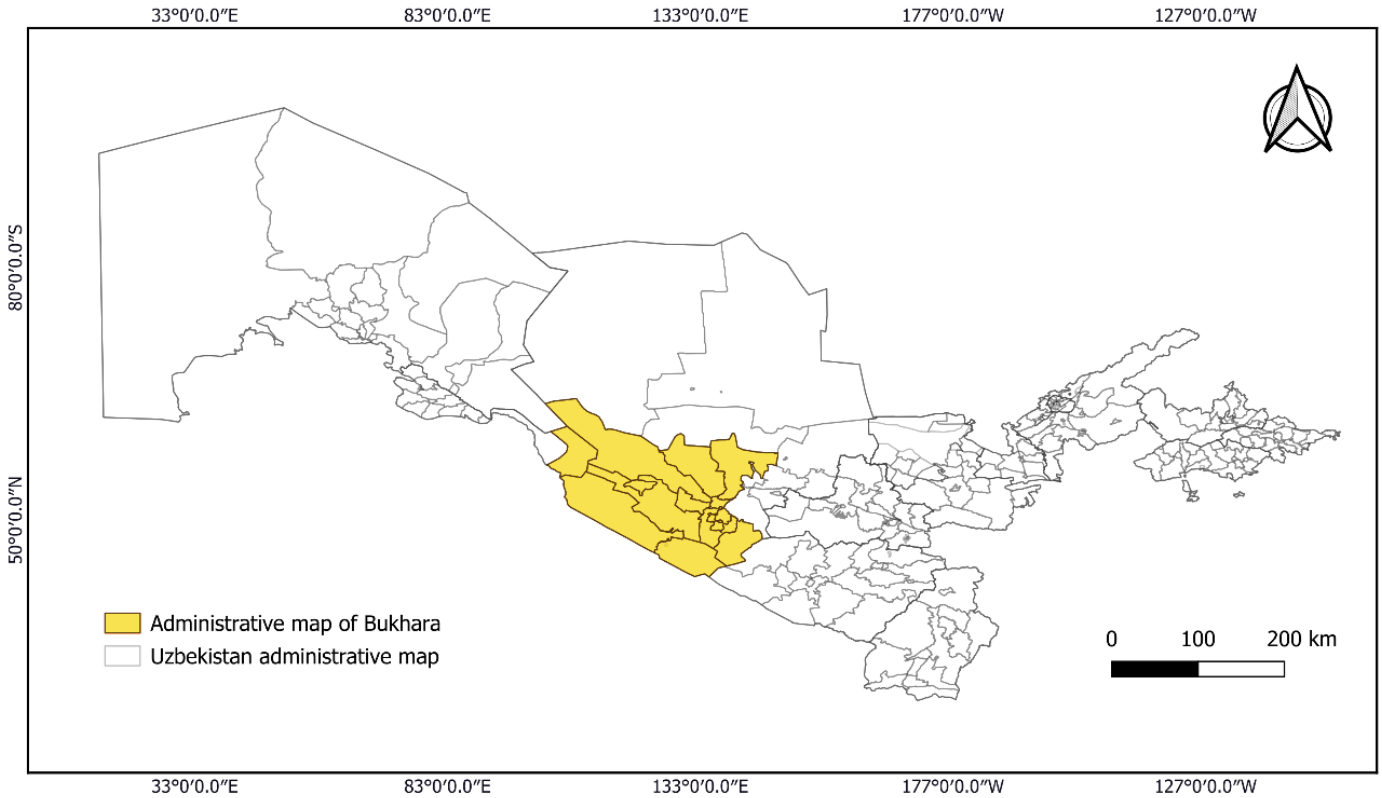

Figure 1. Administrative Location of Bukhara Region within Uzbekistan.

Administratively, Bukhara is divided into 13 districts, including Bukhara city (regional center), Kagan city (center of Kagan district), and the districts of Olot, Koravulbazar, Karakul, Peshku, Romitan, Shafirkan, Gijduvan, Vobkent, Kagan, Jondor, and Bukhara. Bukhara region has a continental climate, characterized by hot and dry summers and cold, relatively dry winters. In July, the average temperature can reach +37°C, with occasional spikes above this level.

During winter, temperatures range between -2°C and +3°C, with sporadic short-term snowfall. The annual precipitation is quite low, averaging between 100–200 mm, mostly occurring in spring and autumn. Dry desert winds are frequently observed during spring and summer. The climate of Bukhara is favorable for tourism, particularly during spring and autumn, making these seasons the most suitable periods for visiting the region.

2. Formation of Research Sources

The study and data collection of cultural heritage sites in the Bukhara region began in 2021 and is still ongoing. The research on heritage sites was conducted based on the list approved by the Cabinet of Ministers of the Republic of Uzbekistan under Resolution No. 846, which confirms the National Register of Immovable Tangible Cultural Heritage Objects related to the Bukhara region, 2019. The geographical locations (coordinates) of the heritage sites were collected through Google Maps, Yandex Maps, and field trips mainly. All heritage sites were categorized based on their original function (purpose of construction), based on the data provided by the Bukhara Regional Department of Cultural Heritage (Table 1).

Table 1. Classification of Heritage Sites in Bukhara Region Into Seven Groups Based on Their Functions.

No	Groups of Heritage Sites	Objects and their functions
1	Religious and Spiritual Sites	Mosque: A place for congregational worship (for Muslims). Madrasa: A religious education and learning center. Khanaqah: A place of worship and residence for Sufis. Mausoleum: The burial site of religious and historical figures. Chillakhana: A place for spiritual purification and private worship. Shrine: Sacred sites for prayer and pilgrimage. Synagogue: A place of worship for Jews. Church: A place of worship for Christians. Cemetery: An area for burials and graves.
2	Defensive and Administrative Structures	Palace: The residence of rulers and an administrative center. Fortress: A military defense structure. Mounds: Designed for strategic or defensive purposes. Fortress Wall: The protective wall of a fortress. Fortress Gate: The entrance to the fortress area. Prison: A place for holding prisoners.
3	Social and Public Facilities	Hammam: A bathhouse for hygiene and relaxation. Ghuslkhana: A place for hygiene and religious purification. Sardoba: A specialized structure for water storage. Reservoir (Hauz): A structure for storing and supplying water. Water Canal: A channel for irrigation and water supply. Caravanserai: A resting place for travelers and caravans. Bridge: A structure designed for crossing water bodies.
4	Commercial and Economic Sites	Tim and Toki: Marketplaces and trading centers. Square: A space for markets and social gatherings.
5	Cultural and Artistic Monuments	Theater: A venue for art and cultural events. Statue and Bust: Artistic works commemorating historical figures. Bas-relief: A sculptural artwork created for decorative purposes. Ayvan and Pavilion: Places for relaxation and social gatherings.
6	Educational and Medical Institutions	School Buildings: Educational institutions. Hospital Buildings: Medical service facilities.
7	Residential and Housing Structures	Ancient Houses and Courtyards: Historically significant residential places.

The heritage register includes mosques, madrasas, khanaqahs, palaces, fortresses, mounds, mausoleums, chillakhonas, minarets, reservoirs, water canals, hammams, caravanserais, fortress walls, fortress gates, prisons, covered bazaars (tim) and arches (toki), ancient houses and courtyards, theaters, statues, busts, squares, sardobas (water resevour), bridges, synagogues, churches, ghuslkhonas (bathing - ablution houses), ayvons (verandas), sheds, bas-reliefs, cemeteries, banks, schools, hospitals, shrines, and memorial complexes. Furthermore, all 829 heritage sites were chronologically classified into five historical periods, providing a diachronic understanding of heritage accumulation in the region (Table 2).

The largest share of heritage sites belongs to the Islamic period (8th century–1917), comprising 559 sites, followed by the pre-Islamic period (110 sites), the Soviet period (36 sites), and the independence period (28 sites). For the remaining 96 heritage sites, the historical period of origin could not be precisely determined, and thus they were categorized as “unspecified.” This chronological classification complements the functional one and reveals how Bukhara’s heritage developed across historical periods, showing that religious and educational architecture dominated during the Islamic era, while administrative and social infrastructure emerged in later stages.

All 829 heritage sites approved by Cabinet of Ministers Resolution No. 846 were studied (Figure 2). To substantiate the analyses mathematically and statistically, Gini Index, Average Nearest Neighbor (NNA), and Kernel Density Estimation (KDE), Moran’s I analyses were conducted

Table 2. Period Based Heritage Site Classification.

Historical Period	Time Range	Number of Sites
Pre-Islamic Period	3rd century BCE – 8th century CE	110
Islamic Period	8th century – 1917 CE	559
Soviet Period	1917 – 1991 CE	36
Independence Period	From 1991 to present	28
Unspecified	Not specified / not available	96
Total		829

This research aims to support the implementation of circular tourism strategies in the Bukhara region by enhancing spatial productivity and increasing the concentration of cultural heritage assets (Ottaviani *et al.*, 2023). Spatial statistical methods such as the Gini Index, Nearest Neighbor Analysis (NNA), and Kernel Density Estimation (KDE), Moran's I are applied to explore spatial disparities and clustering patterns, while also uncovering practical opportunities to promote more balanced and regenerative tourism (Puttanapong, 2022; Qi *et al.*, 2022). These tools facilitate the identification of underutilized heritage areas and enable the effective application of circular tourism practices. Spatial analysis in this context provides a strong scientific foundation for maximizing existing tourism potential, reducing environmental pressure, and advancing sustainable regional development.

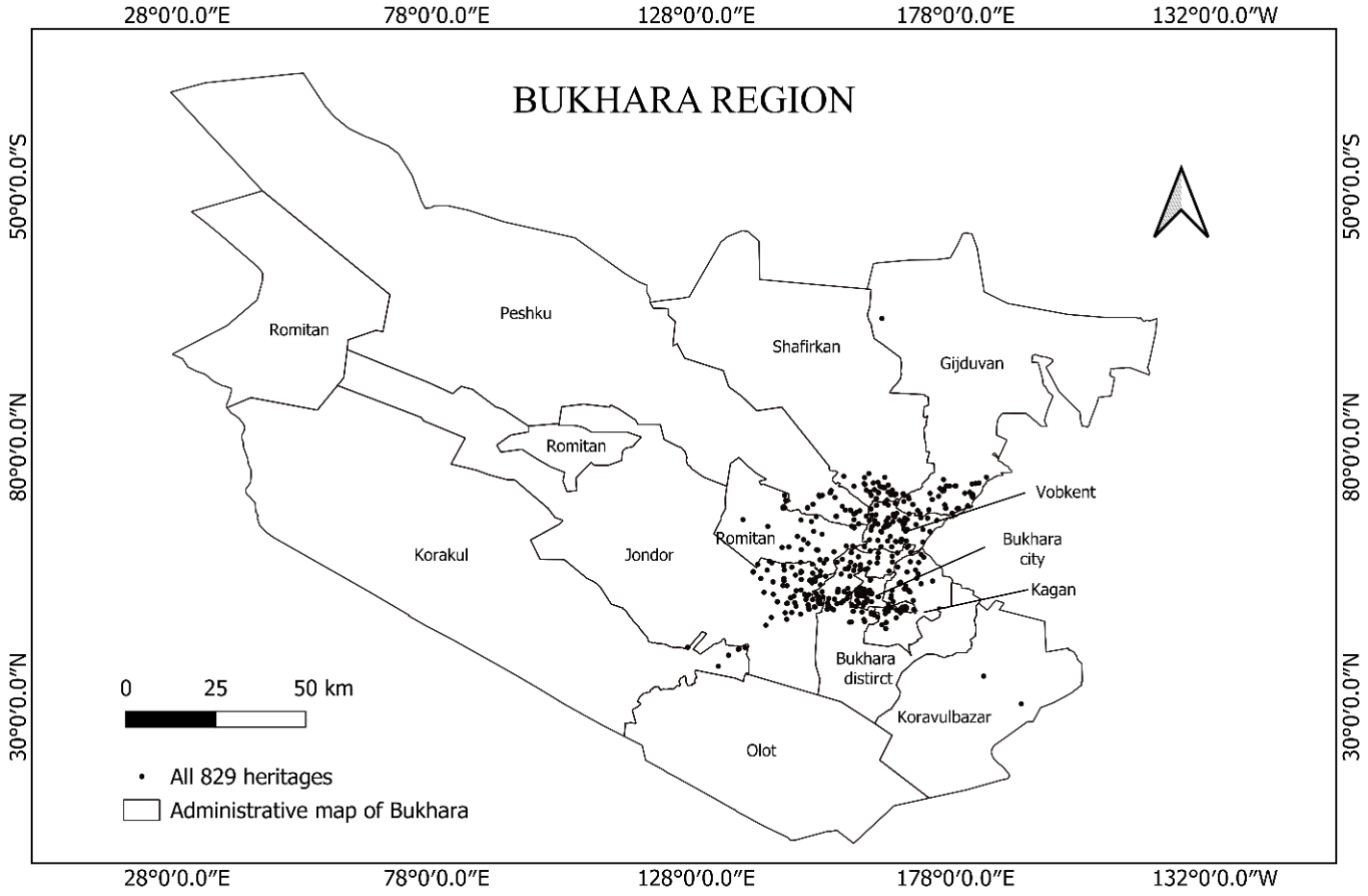

Figure 2. Distribution of Heritage Sites in Bukhara Region.

3.2. Gini Index and Its Application in Cultural Heritage and Tourism

The Gini index is a statistical tool used to measure equality and inequality in the distribution of resources or indicators (Ultsch & Lötsch, 2017; Biro & Neda, 2020). This index ranges between 0 and 1, where 0 represents perfect equality and 1 indicates maximum inequality. The primary purpose of the Gini index is to analyze fairness in the distribution and accessibility of resources. It is widely used in economics to assess income inequality, in resource management to evaluate the distribution of natural resources, and in cultural tourism to examine how cultural heritage sites are spatially distributed across different regions. In this study, the Gini index was applied to identify disparities in the distribution of cultural heritage sites across different regions of Bukhara and to evaluate how this level of inequality affects the development of cultural tourism. The

analysis revealed challenges, such as overconcentration of heritage sites in certain areas and scarcity in some areas of Bukhara, which limit equal access to tourism opportunities.

This insight helps determine which regions require resource redistribution to ensure a more balanced and equitable tourism sector. Moreover, the Gini index provides an opportunity to assess the role of cultural heritage sites in tourism development. If sites are excessively concentrated in one region, other areas might remain underdeveloped regarding tourism potential. By revealing such inequalities, the index assists in strategic tourism planning. Within the framework of this study, analyzing the Gini index across regions serves as a key indicator for strategic decision-making in tourism development. The levels of inequality identified through the index will help maximize regional tourism potential and pinpoint underdeveloped areas. This approach establishes the foundation for regional planning that supports the broad-scale development of cultural tourism.

The following Equation 1 was used to calculate the Gini index, where G: Gini index, n: Number of regions, X_i: i -Cumulative share of regions (in order), Y_i: i -Cumulative share of Heritage sites.

$$G = 1 - \sum_{i=1}^{n-1} (Y_i + Y_{i+1}) \cdot (X_{i+1} - X_i) \quad (1)$$

The calculation steps are as follows

1. The regions were sorted in ascending order based on the number of heritage sites.
2. The cumulative share of each region (X_i) and the cumulative share of heritage sites (Y_i) were calculated (Table 3).
3. Using the cumulative shares, the Gini index was calculated based on the formula provided above.

3.3. Nearest Neighbor Analysis (NNA)

Nearest Neighbor Analysis (NNA) is a key statistical method used to analyze the spatial patterns of objects within a region, such as cultural heritage sites. This method helps determine whether heritage sites are clustered, randomly distributed, or dispersed (Zhang *et al.*, 2024; Wei *et al.*, 2024; Thompson *et al.*, 2022).

In cultural heritage research, NNA plays a crucial role in identifying spatial patterns, aiding in the development of heritage conservation and tourism strategies. Identifying clusters is particularly important for optimizing resource management and prioritizing the development of specific areas. Additionally, NNA results serve as a foundation for other geostatistical analyses, such as density and accessibility assessments.

The Nearest Neighbor Analysis (NNA) calculation is based on the nearest neighbor index (R), which is determined using the following Equation 2.

$$R = \frac{d_0}{d_e} \quad (2)$$

here, $\boldsymbol{d_0}$: the observed average nearest neighbor distance between points, $\boldsymbol{d_e}$: the expected average distance in a random distribution, calculated as Equation 3.

$$d_e = \frac{1}{2\sqrt{\frac{N}{A}}} \quad (3)$$

Where $\boldsymbol{N}$: the total number of points (heritage sites), $\boldsymbol{A}$: the area of the studied region.

If $\boldsymbol{R}$ <1 the objects are clustered (concentrated in specific areas).

If $\boldsymbol{R}$ =1 the objects are randomly distributed.

If $\boldsymbol{R}$ >1 the objects are dispersed (spread out over the region).

The statistical significance of the spatial pattern is evaluated using the z-score, calculated as Equation 4,

$$Z = \frac{d_0 - d_e}{\sigma} \quad (4)$$

where σ represents the standard error of the observed distances. A negative z-score indicates a cluster, a positive z-score indicates dispersion. The further the z-score deviates from zero, the more significant the spatial pattern.

3.4. Kernel Density Estimation (KDE) Method

Kernel Density Estimation (KDE) is a statistical method used in spatial analysis to examine the geographic distribution of objects, allowing for the identification of density levels within a Bukhara region. This method serves as an essential tool for visualizing spatial patterns and analyzing distribution mathematically based on geographic data. KDE-generated density maps play a strategic role in the effective management and development of cultural heritage sites and tourism resources. By applying KDE, it is possible to determine where objects are most concentrated and conceptualize their distribution as a continuous surface. This method helps in managing tourist flows, optimizing infrastructure, and identifying underdeveloped areas. In particular, assessing the spatial density of cultural heritage sites provides valuable insights for allocating resources and making informed decisions on tourism development strategies.

KDE mathematically expresses density as Equation 5.

$$f_n(x) = \frac{1}{nh}\sum k\left(\frac{x - x_i}{h}\right) \quad (5)$$

Where $f_n(x)$: the density function, representing the density value for a given area, n: the total number of objects (829 sites in this study), h: the bandwidth, defining the radius of influence in the calculation, x: the analyzed point, x_i: the coordinates of the heritage sites, k: the Kernel function, which estimates the distribution based on mathematical formulas. For this research, the Gaussian Kernel function was applied, expressed in Equation 6.

$$k(u) = \frac{1}{\sqrt{2\pi}} e^{-\frac{1}{2}u^2} \quad (6)$$

Where $u = \frac{x - x_i}{h}$, represents the distance of the object from the analyzed point.

The density maps produced through KDE provide a scientific basis for identifying geographic disparities between regions, studying underdeveloped areas, and strategically managing tourist flows. KDE is recognized as an effective tool in scientific research for optimizing resource allocation and developing tourism infrastructure. In this study, KDE played a crucial role in analyzing the distribution of cultural heritage sites in Bukhara region, forming a key part of the research. The findings from this method will be employed to develop recommendations for enhancing tourism at heritage sites.

3.5. Analysis of Socio-Spatial Correlation Using the Bivariate Moran's I Method

Bivariate Moran's I is a statistical method designed to identify spatial autocorrelation between two variables, allowing for the determination of their interregional spatial association. In this study, the method was applied to analyze the spatial relationship between the number of tangible cultural heritage sites and population density.

The use of the bivariate form enabled the integration of demographic and spatial factors into the analysis, thereby implementing a socioeconomic integration approach. The spatial interaction between the number of cultural heritage sites (x) and population density (y) across 13 districts of the Bukhara region was calculated using the GeoDa software. This approach served to analyze how the distribution of the population and demographic pressure influence access to and utilization of cultural heritage.

The calculation was carried out based on Equation 7.

$$I = \frac{n}{s_0} \cdot \frac{\Sigma_i \Sigma_j w_{ij}\left(x_i - \underline{x}\right)\left(y_j - \underline{y}\right)}{\Sigma_i \left(x_i - \underline{x}\right)^2} \quad (7)$$

Where n: number of districts, x_i: number of cultural heritage sites in each district, y_j: population density in neighboring areas, $\underline{x}$, $\underline{y}$: mean values, w_{ij}: spatial weights matrix (based on queen contiguity), s_0: sum of weights.

Through this analysis, the distribution of cultural heritage resources in densely populated areas, as well as the level and accessibility of their utilization, were identified. Method plays an important role in studying spatial inequality and the principles of equity in resource utilization. Although indicators such as income levels, economic dependency on tourism, and employment have not been included at this stage due to current statistical limitations, the analysis is planned to expand in the future based on the availability of relevant data.

4. Results and Discussion

4.1. Lorenz Curve and Gini Index of Cultural Heritage Site Distribution

The calculations and visualization were performed using Python (version 3.13.1). The Gini index was computed following the given method. The results of this calculation of the cumulative share of the variable to calculate the Gini Index are presented in Table 3. Based on the Gini index formula, data arrangement, and the calculation of each summation were using the paired values of X_i, X_{i+1}, Y_i and Y_{i+1}. The results obtained for each pair are presented in Table 4. As a result, the Gini index value was calculated as G = 0.569. The Gini index indicates a significant disparity in the distribution of cultural heritage sites across the Bukhara region. With a value of G = 0.569, the results confirm that a large proportion of heritage sites are concentrated on a few areas, particularly in Bukhara city. Since the Gini index approaching 1 signifies increasing inequality, this result highlights the uneven spatial distribution of heritage sites.

Table 3. Cumulative Share Results of Regions and Objects.

Region	Number of objects (H_i)	Cumulative share of regions (X_i)	Cumulative share of objects (Y_i)
Olot district	0	1/13=0.0769	0/829=0.0000
Koravulbazar district	2	2/13=0.1538	2/829≈0.0024
Karakul district	5	3/13=0.2308	5/829≈0.0084
Peshku district	24	4/13=0.3077	24/829≈0.0374
Romitan district	29	5/13=0.3846	29/829≈0.0723
Shafirkan district	31	6/13=0.4615	31/829≈0.1097
Kagan city	40	7/13=0.5385	40/829≈0.1580
Gijduvan district	50	8/13=0.6154	50/829≈0.2183
Vobkent district	61	9/13=0.6923	61/829≈0.2924
Kagan district	63	10/13=0.7692	63/829≈0.3680
Jondor district	76	11/13=0.8462	76/829≈0.4597
Bukhara district	94	12/13=0.9231	94/829≈0.5725
Bukhara city	354	13/13=1.0000	354/829=1.0000

Table 4. Calculation of Gini Index Variable Values.

i	X_i	X_{i+1}	Y_i	Y_{i+1}	Summation of calculation
1	0.0769	0.1538	0.0000	0.0024	(0.0000 + 0.0024) (0.1538 - 0.0769) = 0.00018
2	0.1538	0.2308	0.0024	0.0084	(0.0024 + 0.0084) · (0.2308 - 0.1538) = 0.00086
3	0.2308	0.3077	0.0084	0.0374	(0.0084 + 0.0374) · (0.3077 - 0.2308) = 0.00345
4	0.3077	0.3846	0.0374	0.0723	(0.0374 + 0.0723) · (0.3846 - 0.3077) = 0.00837
5	0.3846	0.4615	0.0723	0.1097	(0.0723 + 0.1097) · (0.4615 - 0.3846) = 0.01412
6	0.4615	0.5385	0.1097	0.1580	(0.1097 + 0.1580) · (0.5385 - 0.4615) = 0.02064
7	0.5385	0.6154	0.1580	0.2183	(0.1580 + 0.2183) · (0.6154 - 0.5385) = 0.02848
8	0.6154	0.6923	0.2183	0.2924	(0.2183 + 0.2924) · (0.6923 - 0.6154) = 0.03782
9	0.6923	0.7692	0.2924	0.3680	(0.2924 + 0.3680) · (0.7692 - 0.6923) = 0.04864
10	0.7692	0.8462	0.3680	0.4597	(0.3680 + 0.4597) · (0.8462 - 0.7692) = 0.06100
11	0.8462	0.9231	0.4597	0.5725	(0.4597 + 0.5725) · (0.9231 - 0.8462) = 0.07506
12	0.9231	1.0000	0.5725	1.0000	1.0000) · (1.0000 - 0.9231) = 0.11667

These findings provide critical insights for regional planning and resource management, emphasizing the need for strategic redistribution of tourism and heritage conservation efforts. The Lorenz curve, presented in Figure 3, further illustrates the unequal distribution of cultural heritage resources. The analysis shows that in excess of 50% of heritage sites are concentrated in Bukhara city and Bukhara district, accounting for a total of 54%. Meanwhile, six districts—Shafirkan, Romitan, Peshku, Karakul, Koravulbazar, and Olot—collectively contain only around 10% of all heritage sites. This distribution is significantly influenced by economic, social, and geographical factors, which must be considered when analyzing spatial disparities. Moreover, the results justified the necessity of considering the spatial distribution of heritage sites while planning heritage utilization and tourism development.

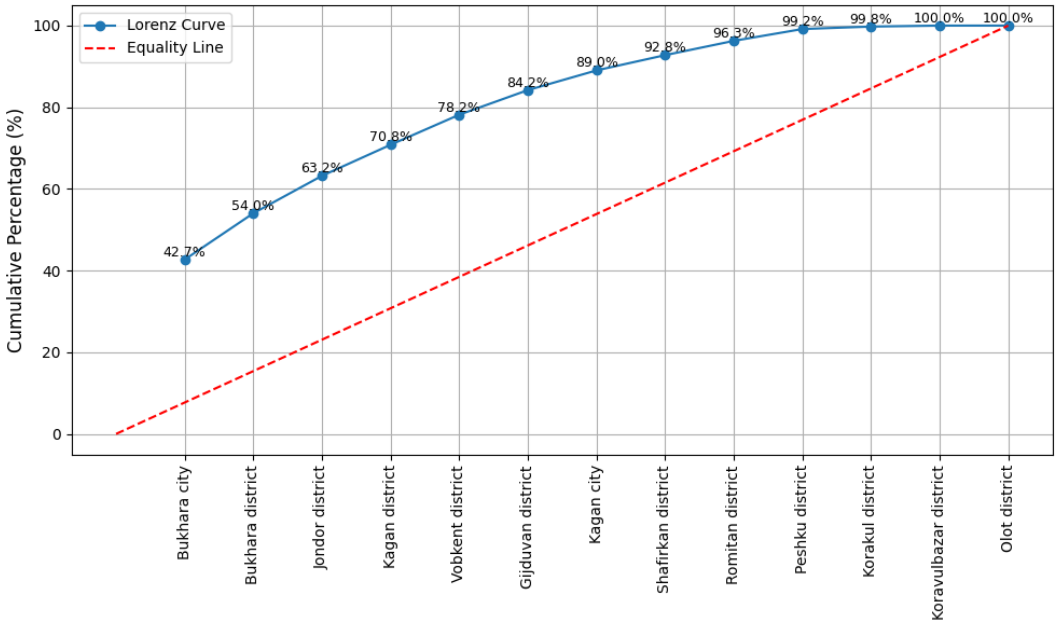

Figure 3. Lorenz Curve for the Distribution of Cultural Heritage Sites in Bukhara Region.

4.2. The Nearest Neighbor Analysis (NNA)

Proved to be highly useful in determining the geographic distribution of 829 cultural heritage sites in Bukhara region and assessing their spatial patterns. This analysis provided insights into heritage site utilization and the potential for regional development. Using NNA, the spatial arrangement of heritage sites was evaluated at both the regional level and within individual districts, categorizing them into three main distribution patterns: dispersed, random, or clustered. The analysis was conducted using QGIS 3.40. The NNA results provided scientifically grounded insights into the spatial distribution of cultural heritage sites in Bukhara (Table 5), contributing to an understanding development patterns of cities and districts. Based on the findings, the following results were drawn.

Table 5. Spatial distribution of cultural heritage sites in Bukhara Region based on NNA results.

No	Region Name	Number of points	Observed distance (d_0)	Expected distance (d_e)	*R*	*Z*	Description
1	Bukhara region	829	670.52	1992.29	0.3366	-36.54	Strong clustering
2	Bukhara city	354	76.33	227.16	0.3360	-23.90	Strong clustering
3	Bukhara district	94	810.27	1397.82	0.5797	-7.80	Clustered
4	Jondor district	76	1127.26	1991.34	0.5661	-7.24	Clustered
5	Kagan district	63	784.02	1251.65	0.6264	-5.67	Clustered
6	Vobkent district	61	1091.92	1170.52	0.9329	-1.00	Near-random
7	Gijduvan district	50	2030.87	3063.31	0.6630	-4.56	Clustered
8	Kagan city	40	625.76	1227.27	0.5099	-5.93	Clustered
9	Shafirkan district	31	1149.33	1139.53	1.0086	0.09	Random
10	Romitan district	29	2111.35	2737.56	0.7713	-2.36	Slightly clustered
11	Peshku district	24	1176.04	1745.43	0.6738	-3.06	Clustered
12	Karakul district	5	2123.82	1584.69	1.3402	1.46	Slightly dispersed
13	Koravulbazar district	2	14603.14	3653.72	3.9968	8.11	Strongly dispersed

NNA analysis of the spatial distribution of cultural heritage sites in Bukhara Region**.** The analysis was conducted for 12 districts of the region, as Olot district was excluded due to the absence of cultural heritage sites. Using this method, the spatial distribution patterns of heritage sites—clustered, random, or dispersed—were identified, providing valuable insights for the management of tourism and cultural heritage.

According to the NNA results, cultural heritage sites in Bukhara city and its surrounding districts exhibit strong clustering. Specifically, in Bukhara city, the nearest neighbor index (R) = 0.336, indicating a high concentration of sites in historical centers. This confirms the city's cultural and historical importance. Similarly, Bukhara district (R = 0.579) and Jondor district (R = 0.566) also show the evidence of clustering, reflecting the concentration of heritages in these areas. Meanwhile, Gijduvan district (R = 0.663) and Kagan city (R = 0.509) demonstrate moderate clustering, with a relatively lower density of cultural heritage sites.

In contrast, Vobkent district (R = 0.933) and Shafirkan district (R = 1.009) indicate that the heritage sites are randomly distributed. These areas do not exhibit a clear systematic pattern. Random distribution may create unique opportunities for tourism development, while at the same time, it can complicate tourism infrastructure planning. Similarly, the Koravulbazar district (R = 3.997) and Karakul district (R = 1.340) show a dispersed distribution of heritage sites, which are related to the geographical or economic characteristics of the region.

Based on the NNA results, the following conclusions were drawn for tourism development in the Bukhara region. Clustered areas, especially Bukhara city and its surrounding districts, should be developed as tourism centers. In these areas, the creation of tourist routes and the expansion of service networks should be a priority. Randomly and dispersedly distributed areas can be developed by improving infrastructure and creating routes that connect heritage sites. This approach helps balance tourism flows across the region and ensures the efficient use of all heritage sites. This analysis also provides an important foundation for concluding the cultural heritage of the Bukhara region and for developing strategic regional management plans.

4.3. Kernel Density Estimation (KDE)

Analyses were conducted using QGIS 3.40 and Python 3.13.1 to examine the spatial distribution of heritage sites in each region separately. The analysis of each region yielded the following results. The geographical area of Bukhara city (Figure 4) contains 354 heritage sites, with almost all located near the western part of the city, showing strong clustering. This area includes the Historic Center of Bukhara, which was inscribed on the UNESCO's (2025) World Heritage List in 1993. 2000 A 2000-year-old region served as a social, economic, and political center historically, and many heritage sites have been preserved. In the remaining areas, heritage sites are either scarce or absent, concentrating tourism development in a single area and showing a highly unequal distribution across the city. While this situation facilitates heritage management, it also results in excessive tourist density in one location and the centralization of infrastructure facilities. The result indicates the necessity of reasonably expanding the number of heritage sites around the area.

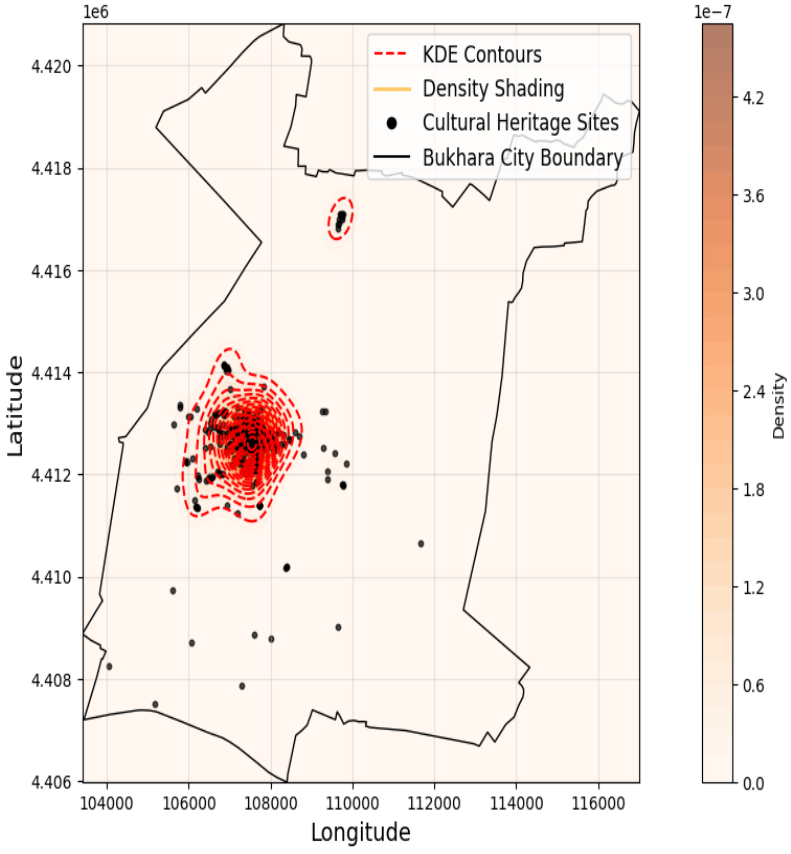

Figure 4. KDE Analysis of Bukhara City.

KDE analysis conducted for the Bukhara district (Figure 5) examined the distribution of 94 heritage sites. The results indicate that the heritage sites are concentrated in the western part of the district, demonstrating a one-sided distribution pattern. The density of heritage sites in this

region suggests that, as Bukhara city, most of the heritage concentration is clustered in a single area, particularly in the district's western part. Regarding tourism development through heritage, the areas enclosed within the red contour highlight the necessity of expanding infrastructure to support tourism activities. Additionally, identifying new heritage sites in the remaining areas should be considered to enhance tourist attraction potential and promote balanced tourism development across the district.

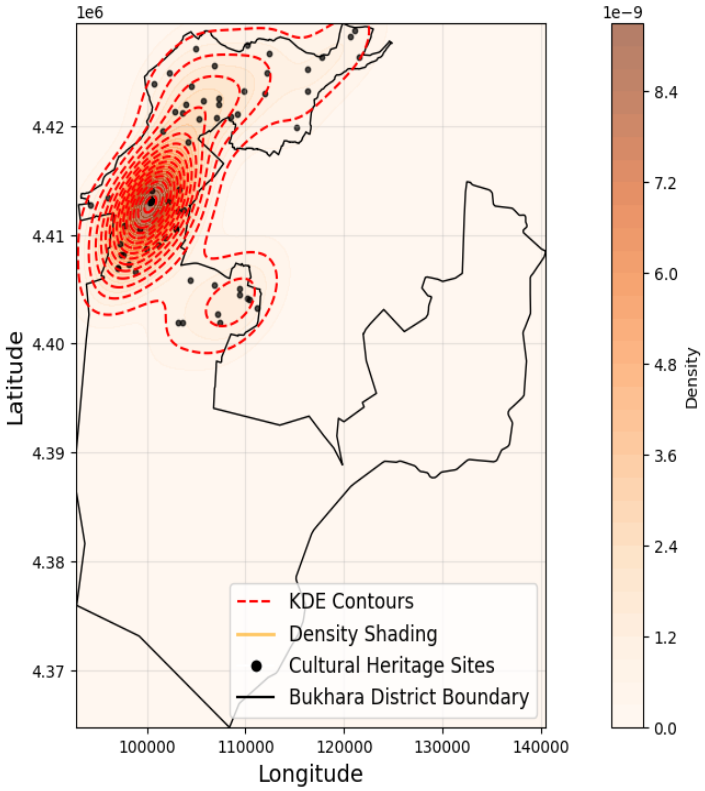

Figure 5. KDE Analysis of the Bukhara District.

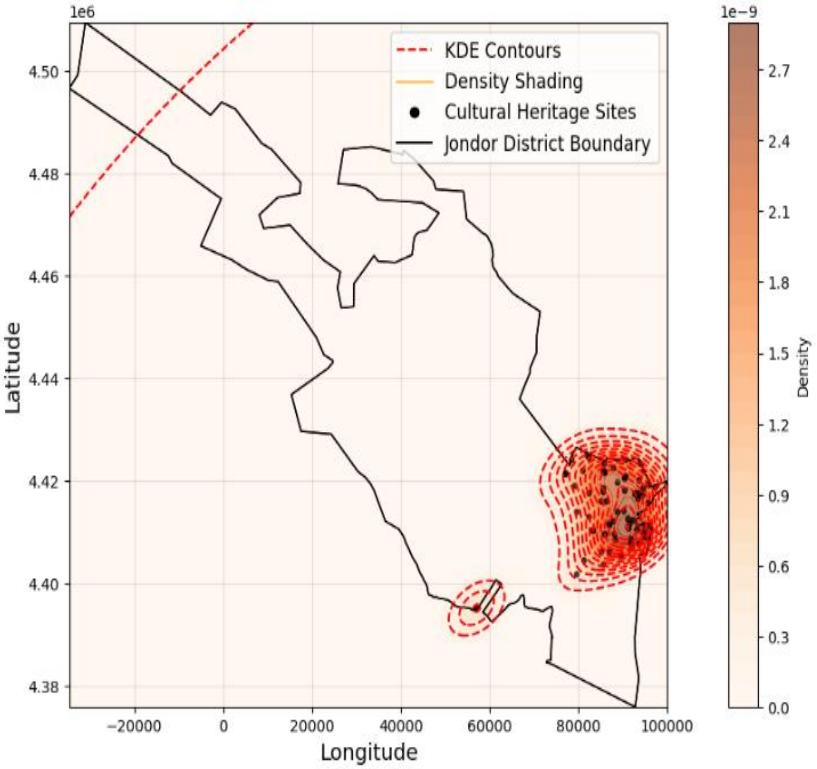

Figure 6. KDE Analysis of Jondor District.

The Jondor district (Figure 6) is one of the largest districts in the Bukhara region, extending from east to west. It contains 76 heritage sites. In the KDE analysis, the heritage sites have formed two distinct clusters. The majority of these sites are located in the eastern part, indicating that the main heritage concentration is limited to a single area. A significant portion of the district lacks heritage sites, highlighting an unequal distribution. However, the broad contour areas facilitate the development and management of tourism infrastructure by making planning and implementation more efficient.

The KDE analysis of Kagan district (Figure 7) shows that heritage sites are distributed over a wider area than the previously analyzed districts, and the KDE contour lines indicate a broader clustering and development potential relative to the district's territory. Kagan district contains a total of 63 heritage sites. The analysis identified that this district has significant potential due to its closeness to Bukhara International Airport and the presence of the railway station within the area. However, based on the existing analysis, expanding heritage preservation and utilizing tourism potential should be accompanied by infrastructure development to ensure effective management and sustainable growth.

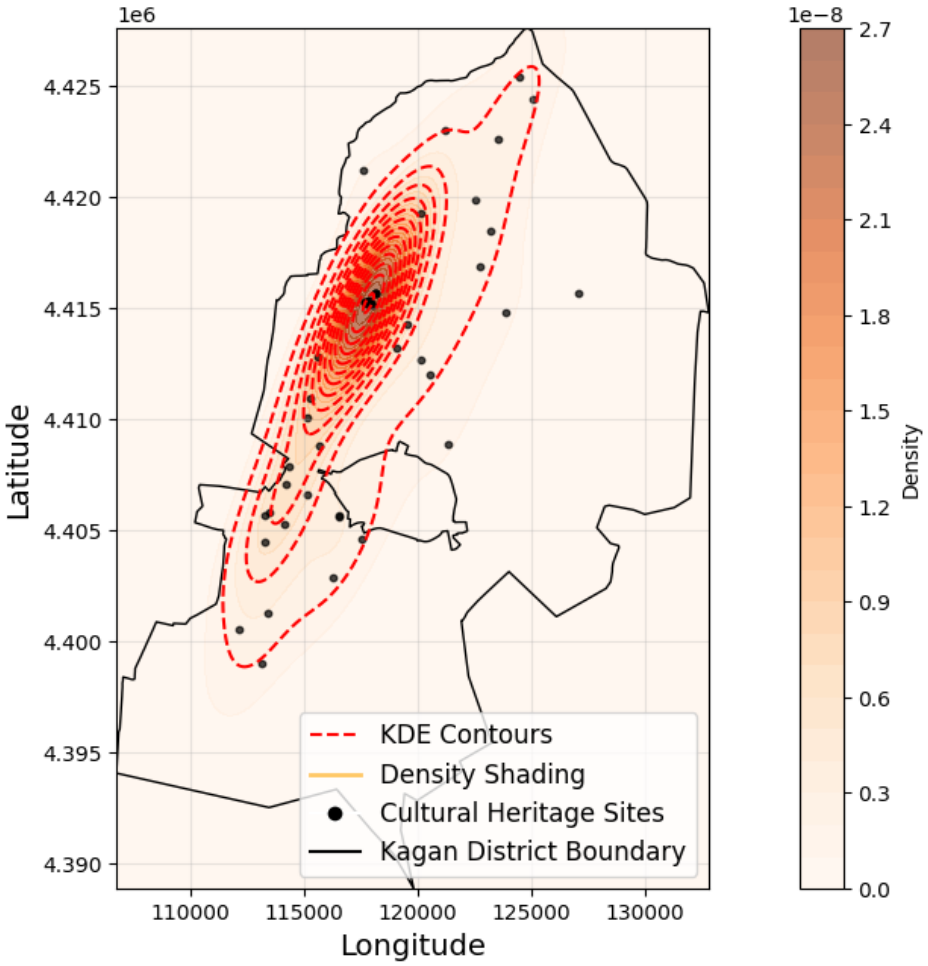

Figure 7. KDE Analysis of the Kagan District.

Vobkent district (Figure 8) contains 61 heritage sites evenly distributed across the area. As a result, the NNA analysis produced an R-value close to 1. While equal distribution increases the development potential of the district, it may also present challenges in cluster-based development and regional management. However, considering that the denser areas represent the district center, the KDE contour lines suggest the possibility of gradual expansion toward larger areas as a phased approach to the development.

Gijduvan district (Figure 9) contains a total of 50 heritage sites. These sites are concentrated in the southern part of the district, indicating a high degree of clustering in a single area. This situation supports the potential for developing cultural tourism in the southern part. In contrast, the absence of resources in the northern part suggests that there is a need for exploring opportunities for developing other types of tourism or increasing the number of heritage sites strategically and integrating them into tourism activities.

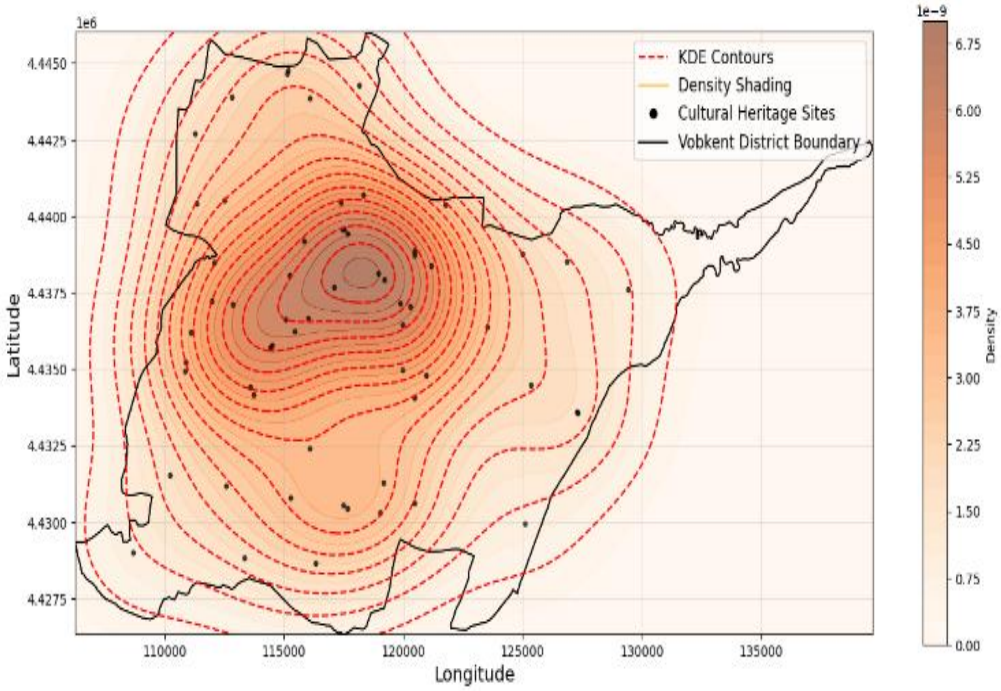

Figure 8. KDE Analysis of Vobkent district.

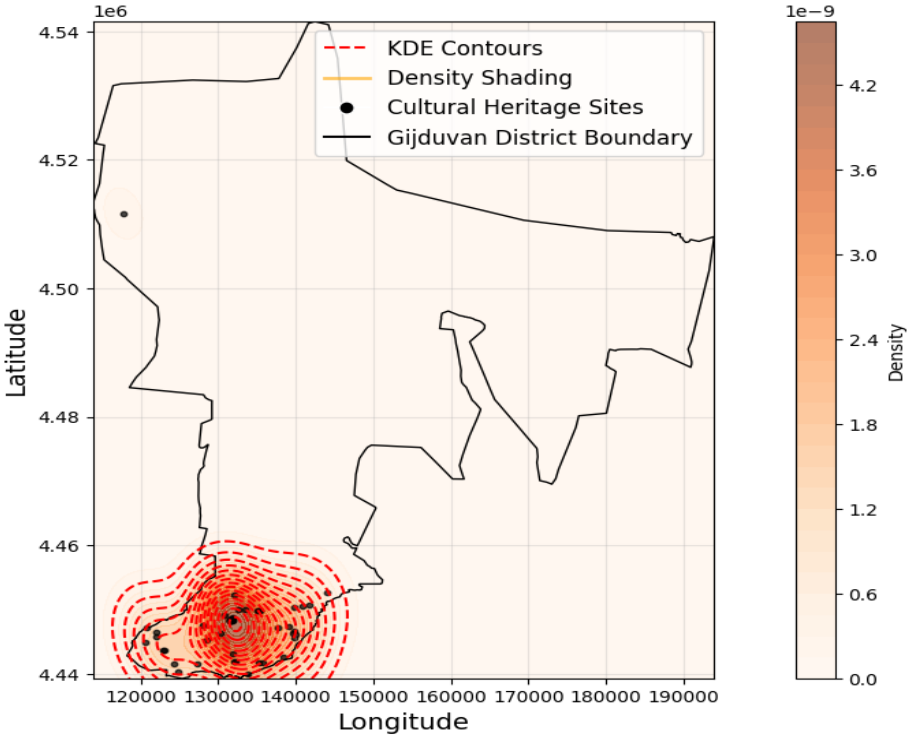

Figure 9. KDE Analysis of Gijduvan District.

Kagan city (Figure 10), as the administrative center of Kagan district (Figure 7), is the smallest area in the Bukhara region, containing 40 cultural heritage sites. The heritage sites are primarily concentrated in the central part of the city, forming a clustered distribution. As mentioned in the analysis of the Kagan district, the railway station is located in the city, and most tourists arrive through rail transport. Given this, Kagan city can serve as a transit heritage center for visitors traveling to see Bukhara's cultural heritage and other historical sites. The unequal distribution of heritage sites is also visible through KDE contours, highlighting the need for further heritage identification efforts in the eastern and western parts of the city.

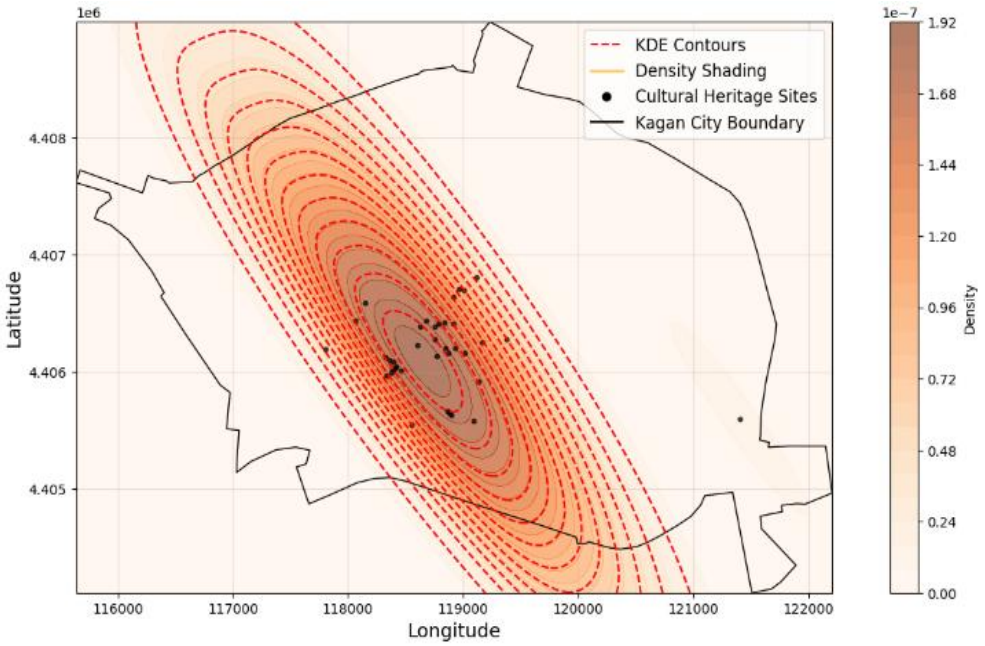

Figure 10. KDE Analysis of Kagan City.

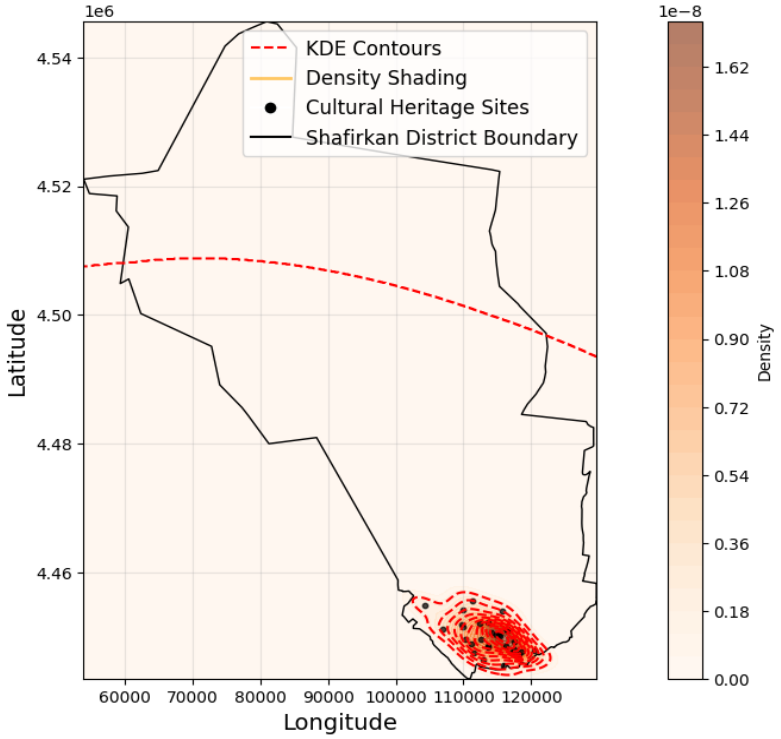

Figure 11. KDE Analysis of Shafirkan District.

Shafirkan district (Figure 11) has its heritage sites located in the southern part of the district. A large portion of the area lacks registered heritage sites. Given its 50 km distance from Bukhara, it necessitates development as either an independent tourism destination or an integrated part of other districts. A total of 31 heritage sites have been registered in the district. NNA analysis also indicated a random distribution, with $R = 1.009$, confirming the absence of clustering. Developing the district together with other district territories, identifying new heritage sites, and fully adapting the infrastructure would be appropriate.

The Romitan district (Figure 12) consists of three parts, with 29 registered heritage sites. All the sites are located in the eastern part of the district, while the other two parts lack heritage sites. According to the analysis, the distribution is partially clustered. This district has a well-developed domestic tourism sector, primarily attracting local visitors due to the presence of pilgrimage sites. The main issue is the deficiency of heritage sites in the other two areas, which suggests the

necessity of conducting scientific research to explore potential heritage sites and expand the existing register.

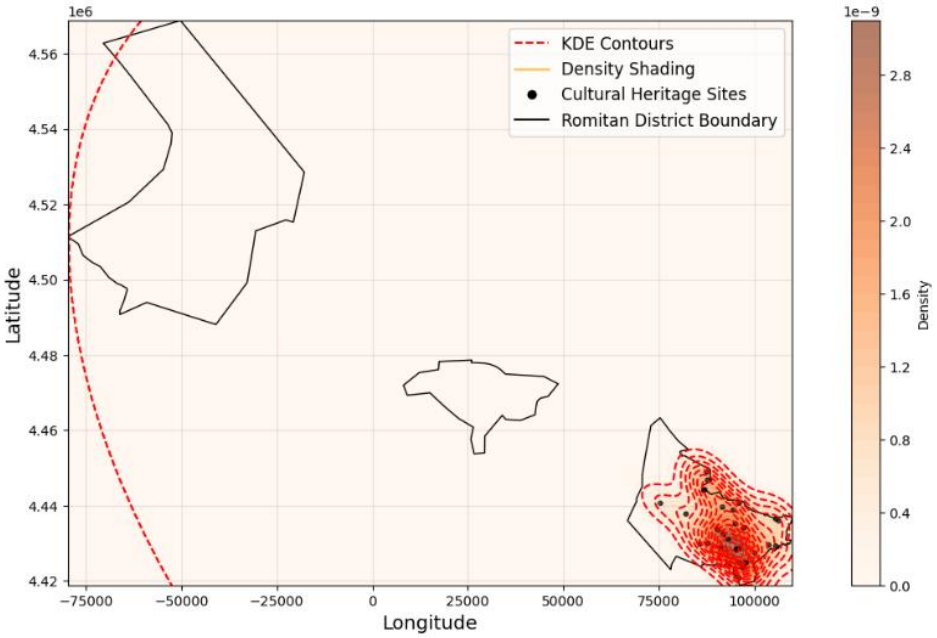

Figure 12. KDE Analysis of Romitan District.

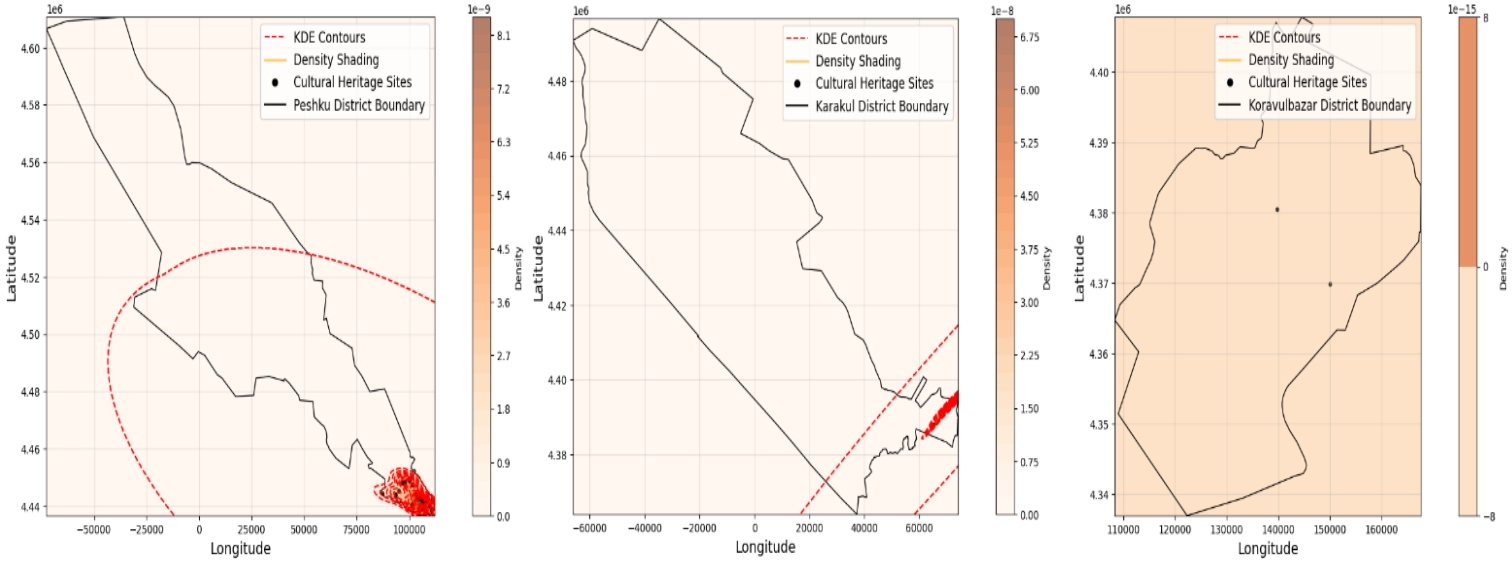

Figure 13. KDE Analysis of Peshku, Karakul, and Koravulbazar Districts.

The next three districts, Peshku, Karakul, and Koravulbazar (Figure 13), have the fewest heritage resources (with 25, 5, and 2 heritage sites, respectively). According to the analysis, the heritage sites in Karakul and Koravulbazar districts are dispersed and not clustered. Their joint development and infrastructure improvement present significant challenges. However, considering thematic opportunities, these districts can be developed in collaboration with other regions as part of a specialized grouping of heritage sites.

The results of the spatial analyses confirm the uneven distribution of heritage sites and their use in tourism, while clearly revealing concrete opportunities for the implementation of circular tourism strategies. Considering that over 80% of heritage sites are not used for tourism purposes and that the majority of active sites are concentrated in Bukhara city, circular tourism provides a practical foundation for balancing visitor flows and developing underutilized heritage areas. Through KDE and NNA results, high-density clusters and zones of scarcity are clearly identified, making it possible to design circular routes that connect both well-known and lesser-known sites. In this regard, circular tourism supports heritage preservation, sustainable development, and the diversification of tourism products, particularly in peripheral regions with potential for cultural, eco-, or community-based tourism.

4.4. Based on the Results of Bivariate Moran's I

Analysis to identify the spatial correlation between the number of cultural heritage sites and population density, a Bivariate Moran's I statistical analysis was conducted. This approach allowed for the exploration of the socio-spatial relationship between demographic factors and heritage resources. The spatial interaction between cultural heritage sites (first variable) and population density (second variable) across 13 districts of the Bukhara region was calculated using the GeoDa software (Figure 14).

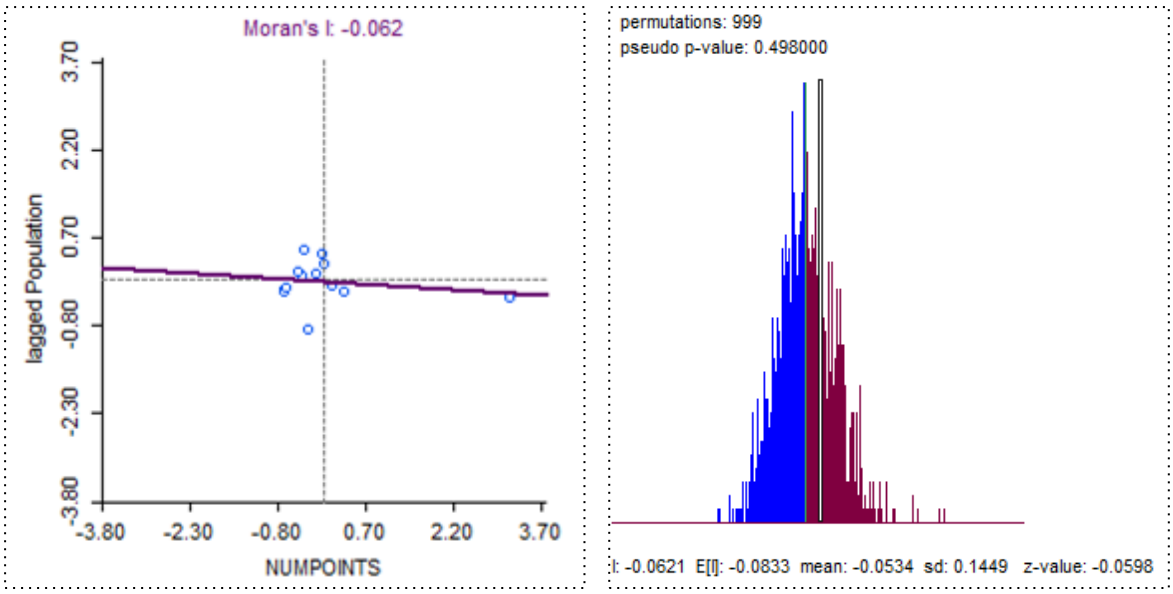

Figure 14. Bivariate Moran's I Analysis of Heritage Sites and Population Density.

The calculated Moran's I value is –0.0621, indicating a very weak negative spatial correlation. In other words, no statistically significant relationship exists between the number of cultural heritage sites and high population density areas. A z-value of –0.0598 and a p-value of 0.498 suggest that the result is not statistically significant. This implies that the spatial relationship is likely to be random.

In Moran's scatterplot, the points do not show a precise alignment along the diagonal but are dispersed around the center instead. The permutation histogram shows that the observed I value is close to the expected value (E[I]= -0.0833), indicating the weakness of the statistical signal.

The analysis shows no systematic or consistent pattern between the distribution of cultural heritage sites and the spatial distribution of the population in the Bukhara region. This suggests that there may be disparities in access to resources between districts. Furthermore, considering spatial inequality and demographic pressure, there is a need to adapt heritage utilization strategies to regional differences.

5. Discussion

Conducting spatial analyses has provided a clear understanding of the distribution of heritage sites across the districts of the Bukhara region and confirmed that heritage sites are unevenly distributed throughout the region. In particular, the eastern part of Bukhara has a high concentration of heritage sites, while large portions of the region remain unoccupied. Furthermore, the limited presence of heritage sites in three districts underscores the necessity for further scholarly investigation in these areas. Specifically, the Karakul district contains five heritage sites, the Koravulbazar district has two, while the Olot district does not have any registered heritage sites.

Despite the presence of 829 heritage sites in the Bukhara region, the study revealed that only 146 of them are actively using for tourism purposes, a fact also confirmed by the Bukhara Regional Department of Cultural Heritage (Figure 15). The heritage sites used in tourism account for 17.6% of the total, indicating significant potential for the further development of cultural heritage tourism.

The dynamic analysis of tourist arrivals to Bukhara from 2016 to 2024 reveals a significant increase in foreign and local visitors, especially since 2022 (Table 6). For instance, due to the pandemic, the number of international tourists visiting Bukhara dropped to just 13,300 in 2020,

whereas by 2024, this figure had exceeded 1.7 million. At the same time, the number of tourism-utilized sites has changed only slightly from 139 in 2020 to 146 in 2024. As a result, the number of tourists per site (i.e., tourism pressure) rose dramatically from 1,798 in 2020 to 39,351 in 2024.

These figures indicate an increasing load on tourism sites. Directing tourist flows to a relatively limited number of sites can lead to their rapid deterioration, declining service quality, and challenges in heritage conservation. From this perspective, the circular tourism approach becomes highly relevant. This approach seeks to redistribute the use of cultural heritage sites across regions, incorporate underutilized sites into tourism circuits, and diversify tourist flows to reduce pressure on highly visited locations.

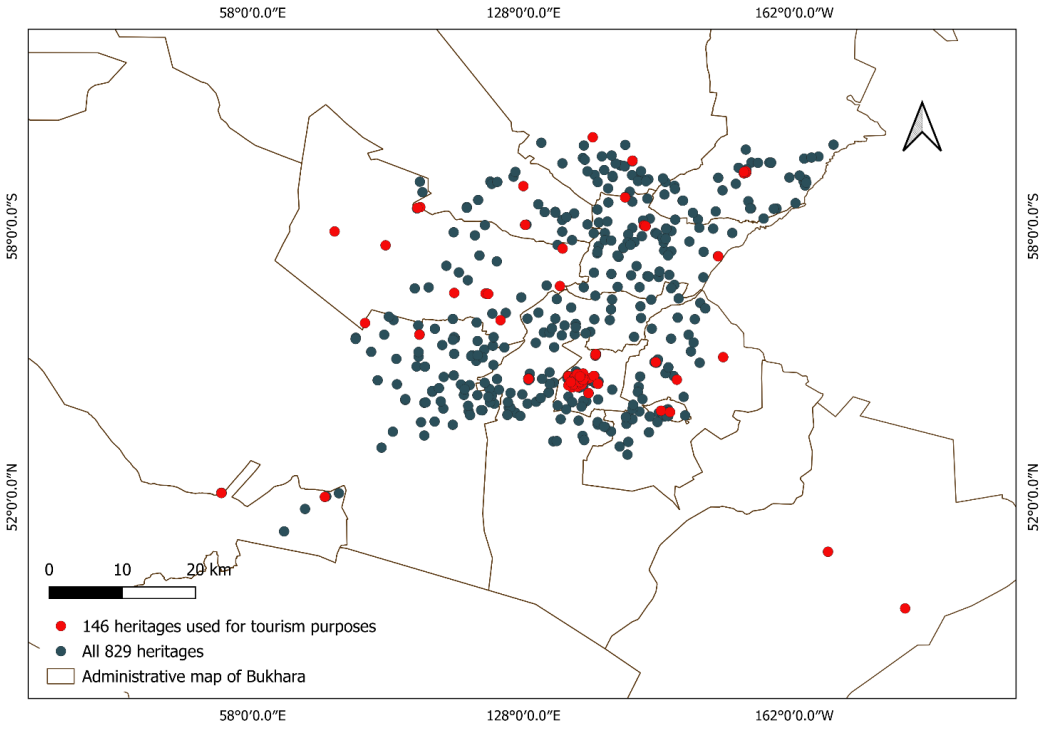

Figure 15. Cultural Heritage of the Bukhara Region and its Utilization in Tourism.

Thus, the analysis based on current statistical data demonstrates that the concentration of tourism pressure on a limited number of sites may negatively affect their long-term sustainability. This situation highlights the need to develop sustainable cultural heritage use strategies in the Bukhara region based on the principles of circular tourism.

Except for that, by classifying cultural heritage sites according to their types, an analysis was conducted to explore the spatial distribution and the variation in their tourism potential. As shown in Table 1, cultural heritage sites in the Bukhara region are categorized into seven main groups, with the most common being Defensive and administrative structures (315 heritage), Religious and spiritual sites (255 heritage), Residential and housing structures (131 heritage), and Social and public facilities (74 heritage).

Table 6. Dynamics of Tourist Arrivals and Usage of Cultural Heritage Sites in the Bukhara Region (2016–2024).

No	Indicator	Unit	2016	2017	2018	2019	2020	2021	2022	2023	2024
1	Total number of tourists visiting Bukhara	persons	827,700	1,179,900	2,512,000	3,640,900	249,900	2,265,300	3,514,200	4,877,000	5,745,200
2	Number of domestic tourists	persons	726,400	1,010,300	2,210,500	3,037,800	236,600	2,216,400	2,961,600	3,490,000	4,000,000
3	Number of international tourists	persons	101,300	169,600	301,500	603,100	13,300	48,900	552,600	1,387,000	1,745,200
4	Number of cultural heritage sites used for tourism purposes	units	95	105	105	123	139	139	139	139	146
5	Average number of tourists per heritage site (tourism pressure dynamics)	person	8,713	11,237	23,924	29,601	1,798	16,297	25,282	35,086	39,351

Spatial maps constructed for these four groups (Figure 16) revealed significant differences in location, density, and distribution patterns. For example, religious sites are predominantly concentrated in the central part of the historical city, while social and public facilities are more widely dispersed across broader geographic areas. Defensive and administrative structures are partially centralized despite exhibit clusters in peripheral areas. Although fewer in number, residential structures show a clustered distribution in certain districts.

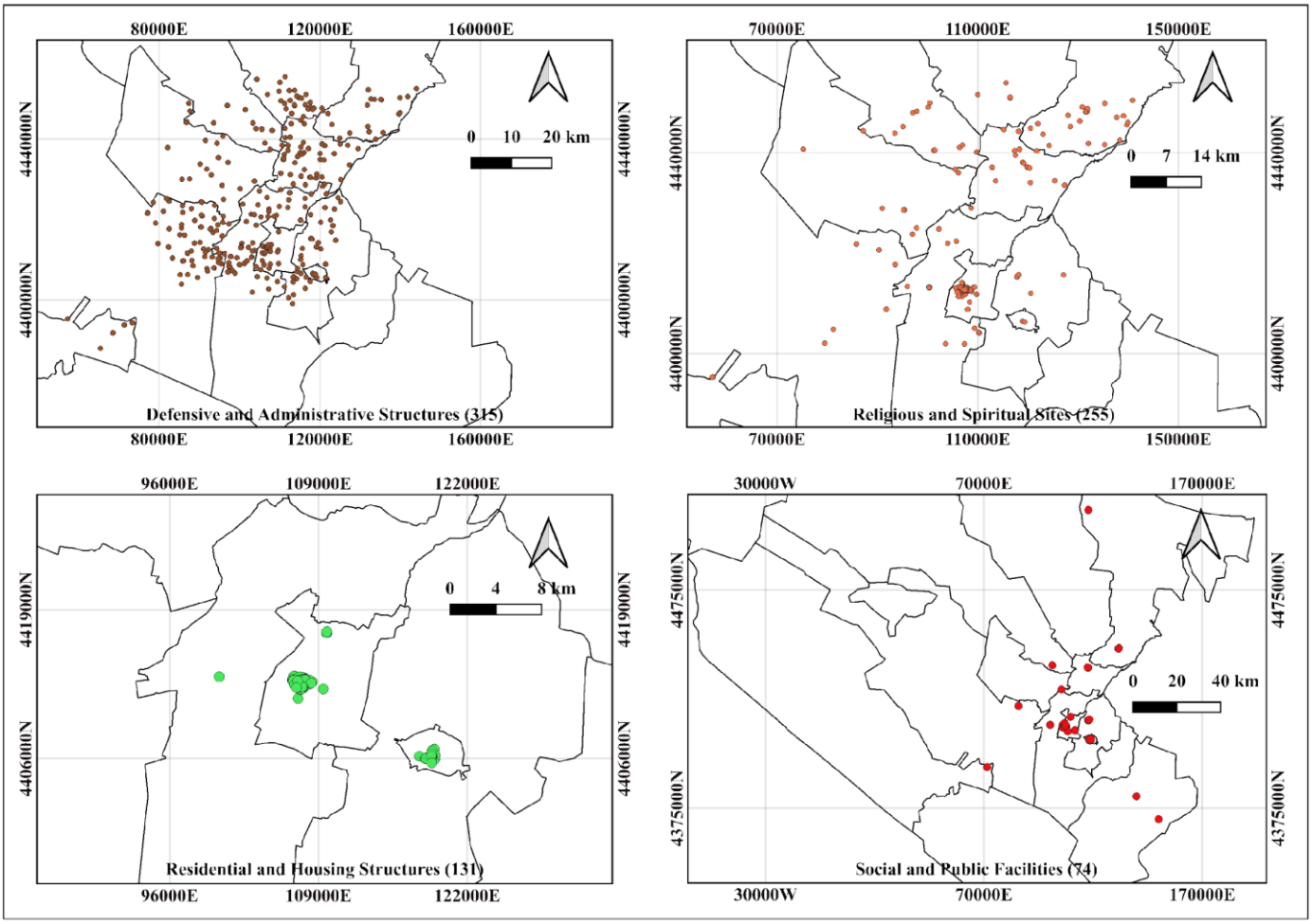

Figure 16. Spatial Distribution of the Four Main Heritage Site Categories in Bukhara Region.

These spatial variations directly influence each heritage group's degree of tourism adaptation, availability of supporting infrastructure, and accessibility for visitors. Consequently, it becomes evident which types of heritage sites are actively used in tourism and which remain underutilized.

Based on this approach, underused yet strategically located sites can be incorporated into circular tourism routes. For instance, social and public facilities located in peripheral areas, as well as nationally recognized but currently unexploited religious and administrative monuments, can be integrated into new itineraries through circular routes. Likewise, developing specialized tourism routes for each heritage group (e.g., "Administrative architecture trail," "Religious heritage route," "Historical residential street") offers an opportunity to diversify tourist flows, balance resource load distribution, and economically revitalize previously overlooked areas.

The study utilized NNA and KDE analyses to evaluate the spatial distribution of heritage sites, categorizing them as clustered, random, or dispersed. The findings indicate strong clustering in Bukhara city, where such high-density heritage site distribution enhances tourist accessibility but may also lead to overcrowding and excessive load on infrastructure. The analysis indicated that 108 out of the 146 heritage sites utilized for tourism (73.9%) are concentrated in Bukhara city.

Therefore, ensuring a more balanced distribution of visitors across the region is essential, as excessive concentration in a single area may result in social and environmental challenges for heritage sites. Additionally, attracting tourists to remote areas can help reduce the tourism burden on Bukhara city's heritage centers.

The clustered areas, including Bukhara district, Jondor district, Kagan district, Gijduvan district, Kagan city, and Peshku district, present strong potential for cultural tourism development. However, optimal development should be conducted within the potential contours identified in the KDE analysis. This approach will facilitate the development and management of tourism infrastructure while ensuring sustainable heritage conservation.

Vobkent district is unique among those heritage sites are evenly distributed. The heritage sites are denser in the central part of the district and become more dispersed towards the periphery. Developing heritage tourism across the district may present economic challenges due to infrastructure development costs. However, by selecting heritage sites based on their significance and attractiveness, it is possible to develop heritage tourism in a balanced manner. Similar patterns can be observed in Shafirkan, Romitan, Karakul, and Koravulbazar districts.

Indeed, the spatial distribution of cultural heritage sites in Bukhara region is directly influenced by natural geographical factors, historical development processes, and economic activities. Most cultural monuments are concentrated along the Zarafshon River, particularly in Bukhara and its surrounding districts. This sharp contrast is evident in the western and northern parts of the region, including Karakul, Romitan, Shafirkan, and Koravulbazar districts, where heritage sites are relatively dispersed. These regional differences are associated with natural resource availability, transportation networks, and historical development patterns.

Geographically, Bukhara region is located between the Zarafshon River valley and the Kyzylkum desert, with its eastern and central parts having favourable natural conditions for agriculture. These areas have historically had high population density, as irrigated farming has been well-developed. As a result, districts such as Bukhara, Vobkent, Gijduvon, and Kagan have a relatively high concentration of historical monuments. These areas have long-standing irrigation systems (Figure 17), which in turn facilitated the development of cultural and trade

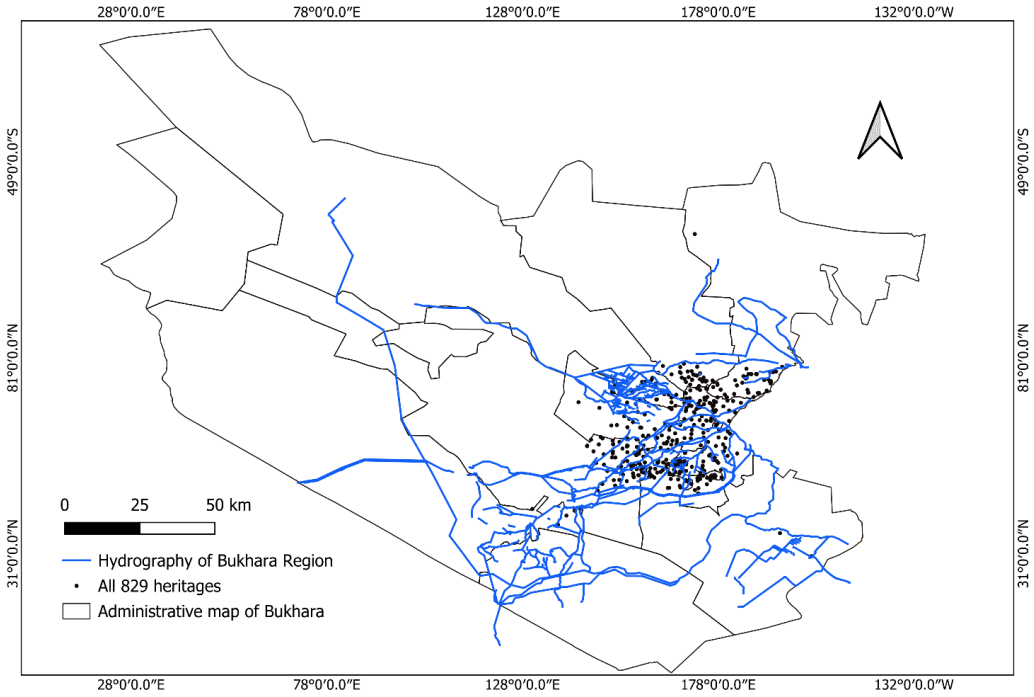

Figure 17. Hydrography Map of Bukhara Region.

It is worth mentioning that historically, the Bukhara region was one of the key branches of the Silk Road (Juraturgunov *et al.*, 2023), with its eastern part serving as a center for trade and economic activity. In particular, Jondor, Gijduvan, and Vobkent districts are home to historic caravanserais, madrasas, and mosques, highlighting the rich cultural heritage of these areas. In contrast, the northern and western parts of the region are characterized by desert landscapes, limited water resources, and their distance from major historical trade routes, resulting in a lower number of cultural heritage sites. Notably, Karakul and Koravulbazar districts have very few historical monuments, which is closely linked to their natural and climatic conditions.

Furthermore, from a historical perspective, Bukhara served as the political and cultural center of various states, including the Samanids, Karakhanids, Timurids, and the Bukhara Khanate and Emirate (Kilichov, 2023; Qaemmaqami, 2024). Over centuries, its central and eastern parts

evolved as more developed cultural and economic centers. In contrast, districts located in desert and semi-desert areas were historically home to nomadic populations, which explains the lower number of historical monuments in these regions.

Conducting the above-mentioned analyses provides a scientific basis for understanding the spatial distribution of heritage sites, assessing their utilization potential, and developing recommendations. Additionally, it is essential to consider certain limitations when conducting scientific research. During the study, KDE, NNA, and Gini index methods were applied for analysis. However, there are further possibilities for conducting different types of analyses, such as examining the historical periods, types, and current conditions of heritage sites. These aspects can serve as directions and foundations for future scientific research.

6. Conclusion

This study aimed to examine the geographical distribution and spatial characteristics of the registered architectural heritage sites in the Bukhara region to determine their clustering patterns and unique features. Based on this objective, 829 heritage sites registered under Resolution No. 846 of the Cabinet of Ministers of the Republic of Uzbekistan were analyzed. These 829 heritage sites were categorized based on their function and construction purpose, and their distribution was studied across the administrative divisions of the Bukhara region. The analyses were conducted using the Gini index, the Lorenz curve, the Nearest Neighbor Analysis, and the Kernel Density Estimation. The results complemented each other and provided a foundation for the following conclusions.

The spatial distribution of heritage sites across districts was found to be unequal. The analysis revealed that two districts contain more than 50% of all heritage sites, while the remaining ten districts contain less than 50%, confirming that heritage sites are predominantly concentrated in the eastern part of the Bukhara region, whereas they are highly dispersed in other areas. The spatial analysis further demonstrated that Bukhara city exhibits strong clustering, while Bukhara district, Jondor district, Kagan city, Gijduvan district, and Peshku district show clustering patterns. Meanwhile, Vobkent district has a near-random distribution, Shafirkon district a random distribution, Karakul district a slightly dispersed distribution, and Koravulbazar district a highly dispersed distribution.

Field research revealed that out of 829 heritage sites, only 146 are actively used for tourism, indicating significant untapped potential in cultural heritage tourism. Between 2020 and 2024, the number of international tourists grew from 13,300 to 1,745,200, and the total tourist count reached over 5.7 million, with domestic visitors. As a result, the number of tourists per cultural heritage site currently in use rose from 1,798 in 2020 to 39,351 in 2024, intensifying tourism pressure. Such a surge in visitation poses challenges to heritage preservation, diminishes the quality of visitor experience, and hinders the prospects for sustainable heritage use.

At the same time, the spatial distribution of heritage typologies revealed notable disparities among dominant categories such as religious (255), administrative (315), residential (131), and public sites (74). The development of distinct tourism products with thematic diversity based on each type or group, and the expansion of heritage utilization through a circular tourism approach, has become increasingly necessary. The Bivariate Moran's I analysis demonstrated no statistically significant correlation between population density and the spatial distribution of heritage sites ($I = -0.0621$, $p = 0.498$), indicating a mismatch between demographic centers and accessibility to heritage.

Based on these findings, it is essential to implement circular tourism strategies to ensure the long-term sustainability and equitable development of tourism. This includes diversifying tourism routes, activating underutilized but strategically located heritage assets, and promoting a more balanced integration of cultural resources into regional planning frameworks. Considering the spatial distribution of cultural heritage sites in the Bukhara region, it is essential to develop tourism development strategies. While the eastern part of the region currently attracts the main tourist flow, it is necessary to initiate some programs (plan, roadmap) aimed at enhancing the potential of historical sites in the western and northern parts. In this regard, diversifying tourism resources through the development of ecotourism, ethnographic tourism, and archaeological tourism in the desert and semi-desert areas of the region is of significant importance.

This study represents the first spatial analysis of Bukhara region's heritage and offers a valuable resource for organizations and researchers working in the fields of heritage and tourism. By applying advanced spatial methods not previously used in studies on Bukhara's heritage, it provides a strong foundation for conservation, utilization, development, and investment planning.

In line with the study's findings, the adoption of circular tourism principles is strongly recommended as a pathway toward more balanced and sustainable cultural tourism development. By integrating underutilized heritage assets into tourism circuits, promoting resource reuse, and redirecting visitor flows to peripheral districts, circular tourism can help reduce spatial inequalities while strengthening the local economy. The spatial analysis conducted in this research offers a solid empirical basis for designing such circular strategies, particularly in regions where cultural tourism remains underdeveloped. Future tourism development plans in Bukhara and other regions with similar contexts should consider circular tourism as a core framework to ensure inclusive, regenerative, and heritage-sensitive tourism systems.

Limitations: it is essential to acknowledge the limitations encountered during data collection. This study was based on the available official databases, which lacked several important indicators, such as visitor statistics for each heritage site, seasonal variations in tourism load, the condition of restorations, the level of local infrastructure, and the economic performance of tourism-utilized sites. Although these limitations narrowed the scope of the analysis, the study was still able to reveal the most pressing spatial issues based on the existing data. Future research could benefit from incorporating broader statistical datasets, including indicators related to tourism seasonality and infrastructure, thereby enabling a more in-depth and comprehensive understanding of the findings.

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Conflict of interest

All authors declare that they have no conflicts of interest.

Data availability

Data is available upon Request.

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