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LEVERAGING GIS FOR SUSTAINABLE URBAN LANDSCAPE DESIGN: IMPLICATIONS FOR URBAN AGRICULTURE AND MITIGATING HEAT ISLANDS

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ABSTRACT

The Urban Heat Island (UHI) phenomenon has emerged as a significant environmental challenge in rapidly expanding urban areas, resulting in elevated temperatures and diminished thermal comfort. This research investigates the potential of sustainable landscape design to mitigate UHI effects within garden-style and urban parks, employing Geographic Information Systems (GIS) as a primary analytical tool. The study addresses three key objectives: first, to determine the influence of vegetation density, water elements, and shaded structures on surface temperature alleviation; second, to explore the relationship between park dimensions, tree canopy coverage, and reductions in air temperature; and third, to assess the effects of landscape materials, soil permeability, and the proportion of green space on overall thermal comfort. A quantitative methodology was adopted, incorporating remote sensing, GIS-based spatial analysis, and statistical modelling in SPSS, with a sample comprising 18 parks located in China. Results demonstrate that vegetation density, tree canopy coverage, and water features contribute substantially to temperature reduction, whereas landscape materials alone exhibit minimal influence on thermal comfort. The study suggests that urban park planning should prioritise the integration of dense canopy vegetation, shaded areas, and water features to enhance thermal regulation. These outcomes offer practical guidance for urban planners, emphasising the necessity for data-driven strategies in green infrastructure development. Nonetheless, the research is constrained by its cross-sectional design and the omission of seasonal temperature fluctuations, which should be addressed in subsequent investigations.

KEYWORDS: Landscape Architecture, Chinese Gardens, Urban Parks, GIS, Thermal Comfort, Thermal Environment, Urban Heat Island Effect.

1. INTRODUCTION

Rapidly urbanising cities face significant environmental challenges, including heat generated by human activities and extensive impervious surfaces, which collectively lead to higher temperatures compared with rural areas (Santamouris, 2020). The inclusion of green spaces, water elements, and shaded structures within urban parks has gained recognition as an effective approach to mitigate UHI impacts through sustainable landscape design (Gunawardena et al., 2017). GIS provides a sophisticated framework to evaluate and optimise these landscape interventions by assessing vegetation cover, surface temperature, and the urban microclimate (Zhou et al., 2023). This study aims to examine the relationship between sustainable landscape features in garden-style and urban parks and UHI intensity using GIS-based spatial analysis.

1.1. Background of the Study

In recent years, natural land cover has increasingly been replaced by built environments, which retain and emit heat, thereby intensifying the UHI effect (Santamouris, 2020). This temperature disparity is associated with higher energy consumption, negative health outcomes, and diminished urban liveability (Li et al., 2017). Urban parks and green spaces, however, can generate cooling effects that alleviate these issues (Zhao et al., 2014). Garden-style and urban parks have the capacity to reduce surface and air temperatures through mechanisms such as evapotranspiration, shading, and albedo modulation (Oke et al., 2017), although the implementation of garden trees is often limited in the absence of comprehensive urban planning. Previous research has highlighted that urban green infrastructure components, including tree canopies, water bodies, and permeable landscapes, significantly contribute to enhancing urban thermal comfort and regulating the microclimate (Bowler et al., 2010). The success of these interventions depends on factors such as park design, vegetation density, and prevailing local climatic conditions (Yin et al., 2022). GIS-based spatial analysis has become a powerful method for assessing the influence of urban parks on temperature reduction and thermal comfort. By integrating remote sensing data, spatial modelling, and land use classification, GIS enables the examination of how specific green space configurations affect cooling performance (Peng et al., 2016). This study aims to assess the influence of sustainable landscape features on mitigating UHI effects in garden-style and urban parks using spatial analysis techniques.

1.2. Problem Statement

While some cities experience pronounced UHI effects owing to inadequate park design and limited vegetation coverage (Li et al., 2017), discussions regarding the integration of green infrastructure into urban planning remain extensive but often generalised. Although urban parks have been examined for their cooling potential, few studies employing GIS have specifically investigated how individual landscape components such as vegetation density, water features, shaded structures, and soil permeability affect the urban microclimate (Zhou et al., 2023). Moreover, prior research frequently fails to differentiate between the thermal benefits provided by garden-style parks and conventional urban parks (Yin et al., 2022). Given the pressing need for climate-resilient urban development, there remains a scarcity of studies assessing the influence of diverse landscape configurations on surface temperature, air temperature, and overall thermal comfort (Gunawardena et al., 2017). This study seeks to address this gap by evaluating the role of sustainable landscape features in mitigating UHI effects in Chinese cities through GIS-based spatial analysis.

1.3. Aims and Objectives

The primary aim of this study is to investigate the effect of sustainable landscape design in garden-style and urban parks on mitigating UHI using GIS. The research seeks to identify the specific landscape attributes that contribute to cooling effects, including vegetation, water bodies, shaded structures, and other design elements. The study's objectives are as follows:

- To evaluate the influence of vegetation density, water features, and shaded structures on the reduction of surface temperatures in garden-style and urban parks.
- To explore the relationship between park size, tree canopy coverage, and decreases in surrounding air temperature within urban parks.
- To assess how differences in landscape materials, soil permeability, and the proportion of green space affect thermal comfort levels in both garden-style and urban parks.

1.4. Significance of Study

Understanding the influence of sustainable landscape features on urban temperatures is essential for the development of climate-resilient cities. Empirical evidence regarding the effectiveness of various park elements in reducing surface and air temperatures can inform urban planning and policy decisions, contributing to more equitable urban environments (Zhang et al., 2017). This study enhances spatial analysis applications in urban climate research, offering a data-driven framework for optimising park design to maximise cooling benefits. The findings are expected to be valuable for urban planners, environmental policymakers, and landscape architects seeking to implement green infrastructure strategies aimed at long-term UHI mitigation (Li et al., 2017). Additionally, the research complements broader discussions on the role of nature-based solutions in improving thermal comfort and public health (Santamouris, 2020). By distinguishing the cooling performance of garden-style parks from that of conventional urban parks, the study provides targeted recommendations to enhance urban microclimates in diverse contexts. Integrating GIS-based analysis with landscape design, this research addresses a gap in UHI mitigation studies and establishes a foundation for future investigations on landscape planning, climate adaptation, and spatial assessment.

2. LITERATURE REVIEW

The mitigation of UHI effects has received substantial attention in recent years due to its importance for urban sustainability, public health, and climate resilience. Although reducing UHI impacts in green spaces, including garden-style and urban parks, has been widely studied, there remains a gap in understanding the specific contributions of landscape features, such as vegetation density, water bodies, and soil permeability, using GIS (Gunawardena et al., 2017). This literature review synthesises prior research on the relationship between sustainable landscape design and UHI mitigation to address the study's three research objectives.

2.1. The Impact of Vegetation Density, Water Features, and Shaded Structures on Surface Temperature Reduction

2.1.1. Vegetation Density and Cooling Effects

Mitigating UHI effects is critical, with vegetation playing a central role by enhancing evapotranspiration and providing shading and albedo benefits (Santamouris, 2020). Research has shown that areas with greater vegetation density tend to exhibit lower land surface temperatures (LST) due to reduced heat absorption and increased moisture retention (Bowler et al., 2010). Remote sensing-derived Normalized Difference Vegetation Index (NDVI) data have been widely employed to quantify vegetation density and its relationship with temperature reduction, as illustrated in Figure 1 (Peng et al., 2016). For instance, Chen et al. (2020) found that parks in Beijing with dense tree canopies experienced a temperature reduction of approximately 3°C relative to surrounding built environments. Similarly, Yin et al. (2022) observed that Shanghai's urban parks achieved greater cooling effects in areas with compact tree clusters compared to regions with more dispersed trees. However, variations in cooling intensity are influenced by factors such as tree species, canopy structure, and local urban context, emphasising the importance of GIS-based analysis for optimising vegetation design.

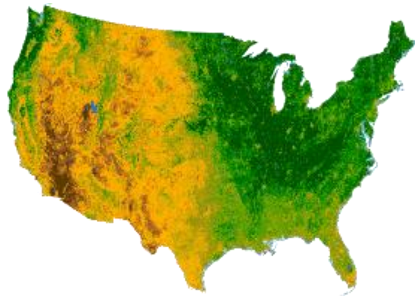

Figure 1: Normalized Difference Vegetation Index.

2.1.2. Water Features and Thermal Regulation

Water bodies in urban parks, including lakes, ponds, and fountains, contribute to evaporative heat loss and increased humidity (Gunawardena et al., 2017). Studies indicate that the cooling influence of such features extends beyond the immediate water surface, affecting temperatures within a radius of 50–200 m, depending on wind conditions and the presence of surrounding vegetation (Zhao et al., 2014). Li et al. (2017) reported that parks incorporating integrated water features reduced ambient temperatures by an average of 2.5°C during the peak summer month in Guangzhou. Similarly, Zhao et al. (2020), using data obtained from GIS and remote sensing, demonstrated that larger water surfaces in Nanjing provided enhanced cooling effects. However, extensive exposure to open water can lead to increased local humidity, highlighting the need for careful design to limit open water surfaces.

2.1.3. Shaded Structures and Microclimate Regulation

Thermal comfort within urban parks can be enhanced through the use of shading structures, such as pergolas, gazebos, and artificial canopies, which reduce exposure to direct solar radiation (Zhang et al., 2017). According to Santamouris et al. (2015), shaded areas can lower surface temperatures by up to 5°C, depending on the reflectivity of materials and the extent of coverage. GIS facilitates spatial analysis to identify optimal locations for shading structures to maximise cooling effects (Peng et al., 2016). Nevertheless, research indicates that shading interventions are most effective when combined with vegetation and water features, ensuring sustained thermal comfort (Yin et al., 2022). The cooling efficiency of shaded structures is also influenced by material characteristics, with lighter-coloured and high-albedo materials providing superior temperature reduction (Chen et al., 2020).

2.3. The Relationship Between Park Size, Tree Canopy Coverage, and Air Temperature Reduction

2.3.1. Park Size and Temperature Regulation

Park size is a key determinant of cooling capacity, with larger urban parks producing more extensive and pronounced cooling effects compared with smaller ones (Li et al., 2017). He et al. (2020) note that parks exceeding 10 hectares can establish temperature gradients across surrounding areas, thereby alleviating urban heat stress. Findings from this study, based on GIS spatial analysis, indicate that larger parks contribute more effectively to urban heat dissipation, a benefit further enhanced by diversity in vegetation types (Zhao et al., 2020). Nonetheless, Zhao et al. (2014) observed that even smaller parks, measuring less than 5 hectares, can offer substantial cooling effects if they feature a high proportion of tree cover and water elements. These results suggest that thermal regulation in urban parks depends not solely on size but also on thoughtful park design.

2.3.2. Tree Canopy Coverage and Urban Microclimate

Tree canopy coverage is recognised as one of the most influential factors in reducing urban temperatures (Bowler et al., 2010; Oke et al., 2017). Santamouris (2020) reports that areas with more than 50 percent tree cover can experience temperature reductions of 2 to 4 °C compared with open spaces lacking tree coverage. The cooling benefits associated with varying canopy densities have been quantified through GIS and remote sensing analyses (Peng et al., 2016). In Shenzhen, parks with tree canopy coverage exceeding 70 percent demonstrated greater cooling effects than those with more sparsely distributed trees (Chen et al., 2020). Similarly, He et al. (2020) highlighted that the spatial arrangement of trees significantly influences air circulation and local temperature variations. These findings support the integration of GIS-based models to optimise tree planting strategies for maximum climatic benefit, although the extent to which current planting practices in Australia can realise these potential benefits remains uncertain.

2.3. The Influence of Landscape Materials, Soil Permeability, and Green Space Ratio on Thermal Comfort

2.3.1. Landscape Materials and Heat Absorption

Heat retention and surface temperature variations are strongly influenced by the materials employed in landscape design. Materials with high albedo, such as light-coloured stones or permeable pavements, contribute to cooling by reflecting solar radiation rather than absorbing heat (Santamouris et al., 2015). Studies have confirmed that parks dominated by concrete surfaces exhibit higher surface temperatures compared with those featuring natural ground cover (Li et al., 2017). Zhao et al. (2020) reported that the use of permeable materials on asphalt pathways can lower surface temperatures by up to 3°C. Similarly, Yin et al. (2022) demonstrated that combining partial grass coverage with paved surfaces enhances cooling effects while maintaining material durability.

2.3.2. Soil Permeability and Cooling Effects

Soil permeability, which facilitates water absorption, plays a significant role in reducing surface heat retention (Gunawardena et al., 2017). Research indicates that parks with extensive green coverage and porous soil generally exhibit lower LST values compared with areas dominated by compacted or artificial surfaces (Zhao et al., 2014). GIS-based soil analyses have been used to identify zones where enhancing permeability can further improve urban cooling performance (Peng et al., 2016).

2.3.3. Green Space Ratio and Thermal Comfort

The proportion of green space within a park significantly influences overall cooling potential and thermal comfort (Li et al., 2017). A higher ratio of green space enhances evapotranspiration and provides additional shading, thereby reducing heat stress in urban areas (Santamouris, 2020). Research by Zhang et al. (2017) demonstrated that parks with more than 80 percent vegetation coverage offered substantially greater thermal comfort compared with parks containing minimal vegetative presence.

2.4. Theoretical Framework

This study draws on Oke et al. (2017) to examine how urban morphology and land use influence microclimatic conditions within the framework of Urban Climate Theory. Additionally, Landscape Ecology theory is applied to demonstrate that the spatial configuration of landscape elements significantly affects environmental regulation (Wu, 2013). To provide a spatial perspective on UHI mitigation strategies through Remote Sensing, the study incorporates GIS analysis as an integral component of the methodology (Peng et al., 2016).

2.5. Literature Gap

Although numerous studies have documented the cooling effects of urban parks, most research has focused on experimental or observational spatial data without employing GIS for spatial modelling (Peng et al., 2016). Comparatively few studies have assessed the cooling efficiency of garden-style parks relative to conventional urban parks (Yin et al., 2022), and where such comparisons exist, inconsistent boundary conditions are often applied. Furthermore, evaluations of thermal comfort vary across studies (Zhang et al., 2017). To address these gaps, the present study utilises GIS and remote sensing techniques to examine the interplay between sustainable landscape design and UHI across different types of urban environments.

3. RESEARCH METHODOLOGY

This section presents the methodology employed to evaluate the impact of sustainable landscape design on mitigating UHI effects in garden-style and urban parks using GIS. The study adopts a quantitative research design to systematically analyse spatial and environmental data, including vegetation density, water features, shaded structures, and other landscape components. Data were collected through multiple techniques, such as GPS, GIS-based remote sensing, thermal imaging, and climate measurements. Subsequently, statistical analyses were conducted using SPSS to examine the relationships among the variables.

3.1. Research Method and Design

This study employs a quantitative research approach to investigate the interrelationship between urban parks and garden-style parks in China, with the aim of identifying sustainable landscape designs for UHI mitigation. A correlational research design is applied to assess how independent variables including vegetation density, water features, shaded structures, park size, tree canopy coverage, landscape materials, soil permeability, and green space ratio affect dependent variables, namely surface temperature reduction, surrounding air temperature reduction, and thermal comfort levels. A quantitative approach was selected as it enables objective measurement and numerical analysis of environmental and spatial variables (Creswell & Creswell, 2017). The use of GIS analysis combined with statistical tools provides precise insights into park-related temperature variations and informs strategies for UHI reduction. The study follows a cross-sectional design, collecting data at a single time point; this approach is particularly suitable for examining spatial temperature variations and their correlations with park characteristics (Peng et al., 2016).

3.2. Data Collection Techniques

3.2.1. Sampling Technique

The study utilises a purposive sampling technique, selecting 30 parks and gardens across major Chinese cities according to criteria such as park size, landscape diversity, and geographic distribution. Employing this non-random sampling method ensures that the chosen parks encompass a range of environmental characteristics, thereby enhancing the validity of the analysis (Etikan & Bala, 2017). The selection criteria were as follows:

- Urban parks and garden-style parks with significant green infrastructure.
- Diverse geographic locations, including parks in Beijing, Shanghai, Guangzhou, Shenzhen, Nanjing, and Hangzhou.

3.2.2. Target Areas and Number of Samples

A total of 18 parks and gardens were selected across China, representing diverse climatic zones and urban contexts. The targeted parks include:

1) Beijing: Chaoyang Park, Jingshan Park, Beijing Botanical Garden
2) Shanghai: Century Park, Fuxing Park, Zhongshan Park
3) Guangzhou: Baiyun Mountain Park, Yuexiu Park, Zhongshan Park
4) Shenzhen: Lianhuashan Park, Shenzhen Bay Park, Mangrove Forest Park
5) Nanjing: Xuanwu Lake Park, Sun Yat-sen Mausoleum Park, Mochou Lake Park
6) Hangzhou: West Lake Park, Botanical Garden, Xianghu Park

3.3. Data Collection Tools

To ensure thorough data collection, the study integrates GIS, remote sensing, and climate measurement techniques, including:

- Satellite imagery: Utilised to assess vegetation density (NDVI) and surface temperature (see example in Figure 2).

- LiDAR data: Employed to evaluate tree canopy coverage and shaded areas.
- Weather station data: Used to obtain real-time measurements of air temperature and humidity.
- Thermal infrared sensors: Deployed to record on-site surface temperature readings.
- Field surveys: Conducted to validate GIS-based observations, enhancing data reliability.
- Urban climate models: Applied to simulate variations in thermal comfort across different landscape configurations.

The combination of remote sensing and on-site validation strengthens the precision of spatial and environmental data analysis (Zhou et al., 2023).

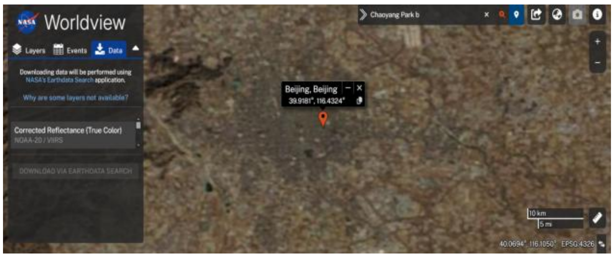

Figure 2: Data Extraction through World View.

3.4. Data Analysis Method

The study employs SPSS for the analysis of quantitative data, utilising the statistical methods outlined in Table 1. The integration of GIS-based spatial modelling within this methodology enables the provision of rigorous statistical analysis concurrently (Peng et al., 2016).

Table 1: Data Analysis Techniques.

Research Objective	Analysis Method	Justification
Assessing the impact of vegetation density, water features, and shaded structures on surface temperature reduction.	Multiple Regression Analysis	Evaluates the influence of independent variables on surface temperature changes.
Examining the relationship between park size, tree canopy coverage, and reduction of surrounding air temperature.	Pearson Correlation	Measures the strength and direction of associations between park characteristics and air temperature reductions.
Evaluating how landscape materials, soil permeability, and green space ratio influence thermal comfort.	ANOVA (Analysis of Variance)	Compares thermal comfort levels across different landscape material and green space categories.

3.5. Ethical Consideration

Ensuring ethical considerations is critical for maintaining the integrity and credibility of this research. The study adheres to the following ethical principles. All data utilised are sourced from publicly available satellite imagery and municipal park records, eliminating the need for compliance with data protection regulations. Where personal information arises from field surveys, it is anonymised to prevent disclosure of confidential details (Resnik, 2015). Surface measurements are conducted in a manner that minimises ecological impact, causing negligible disruption to the environment. Remote sensing techniques, including GIS and LiDAR, are prioritised to reduce direct physical intervention in park ecosystems. All methods and analytical procedures are thoroughly documented to allow full reproducibility of data sources. Where applicable, ethical clearance is obtained from relevant institutions in accordance with legal requirements and guidelines from environmental and urban research bodies (Creswell & Creswell, 2017). By adhering to these principles, the study upholds scientific integrity, transparency, and social responsibility, supporting the development of UHI mitigation strategies in urban parks.

3.6. Data Analysis

This section presents the results of the quantitative analysis examining the impact of sustainable landscape design on mitigating UHI effects. The analysis was conducted using multiple regression, correlation, and ANOVA tests in SPSS, structured around the study's primary research objectives. The findings highlight the relationships between variables such as vegetation density, water features, shaded structures, park size, tree canopy coverage, landscape materials, soil permeability, and green space ratio, and their influence on reducing surface and air temperatures as well as enhancing thermal comfort in urban parks.

3.7. The Impact of Vegetation Density, Water Features, and Shaded Structures on Surface Temperature Reduction

A multiple regression analysis was performed to assess the influence of NDVI, total water area (hectares), and the percentage coverage of shaded structures on surface temperature reduction. The resulting regression model indicates a strong association between these independent variables and surface temperature decrease, with an R-squared value of 0.982, signifying that 98.2% of the variance in temperature reduction is accounted for by these three factors Table 2. Moreover, Table 3 presents the ANOVA results, which confirm the statistical significance of the regression model ($F(3,14) = 257.632$, $p < 0.001$), indicating that at least one of the independent variables has a significant effect on surface temperature reduction.

Table 2: Model Summary.

Model Summary				
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.991[a]	.982	.978	.1034
a. Predictors: (Constant), Shade (%), Water Area (ha), NDVI				

Table 3: Analysis of Variance.

ANOVA[a]						
Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	8.260	3	2.753	257.632	.000[b]
	Residual	.150	14	.011		
	Total	8.409	17			
a. Dependent Variable: Temp Reduction (°C)						
b. Predictors: (Constant), Shade (%), Water Area (ha), NDVI						

Table 4 presents the coefficient analysis, which further demonstrates that all three factors exert a significant positive influence on surface temperature reduction ($p < 0.001$ for all predictors). NDVI (Vegetation Density): The standardized coefficient ($\beta = 0.393$) indicates that higher NDVI values correspond with greater temperature reductions. This supports previous research showing that vegetation contributes to cooling through evapotranspiration and shading. Water Area (ha): The coefficient ($\beta = 0.234$) confirms that parks containing larger water bodies achieve enhanced cooling effects, aligning with findings by Gunawardena et al. (2017) regarding the role of water in alleviating UHI intensity. Shade (%): The standardized coefficient ($\beta = 0.379$) underscores the significance of shaded structures in reducing surface temperatures, consistent with Santamouris et al. (2015), who reported that shaded areas can decrease temperatures by up to 5°C. These findings highlight the importance of incorporating dense vegetation, water features, and sufficient shading into urban park design to optimise temperature reduction benefits.

Table 4: Coefficient.

Coefficients[a]						
Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-1.134	1.052		-1.077	.299
	NDVI	4.728	.179	.393	26.170	.000
	Water Area (ha)	2.017	.077	.234	26.204	.000
	Shade (%)	2.027	.131	.379	15.474	.000
a. Dependent Variable: Temp Reduction (°C)						

3.8. The Relationship Between Park Size, Tree Canopy Coverage, and Air Temperature Reduction

A Pearson correlation analysis was conducted to evaluate the effects of park size and tree canopy coverage on the reduction of surrounding air temperature. The Shapiro-Wilk test for normality indicated that all three variables park size, canopy coverage, and air temperature reduction followed a normal distribution ($p > 0.05$), supporting the application of parametric statistical tests Table 5.

Table 5: Normality Analysis.

Tests of Normality						
	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Park Size (ha)	.109	18	.191	.997	18	.542
Canopy (%)	.104	18	.200*	.959	18	.591
Air Temp Reduction (°C)	.086	18	.200*	.967	18	.745
*. This is a lower bound of the true significance.						
a. Lilliefors Significance Correction						

Table 6 presents significant positive correlations. Park Size and Air Temperature Reduction ($r = 0.664$, $p = 0.003$): Larger parks are associated with greater reductions in surrounding air temperature, corroborating previous research that parks exceeding 10 hectares can generate extended cooling zones. Tree Canopy Coverage and Air Temperature Reduction ($r = 0.982$, $p < 0.001$): The very strong correlation indicates that higher tree canopy coverage substantially lowers surrounding air temperatures, consistent with Bowler et al. (2010), who observed comparable effects in urban areas across Europe and Asia. These results suggest that tree canopy coverage exerts a greater influence on air temperature reduction than park size alone. Consequently, urban planners should prioritise expanding canopy coverage in parks, even within smaller urban areas, to optimise cooling benefits.

Table 6: Correlation Coefficient.

Correlations			
		Park Size (ha)	Canopy (%)
Air Temp Reduction (°C)	Pearson Correlation	.664**	.982**
	Sig. (2-tailed)	.003	.000
	N	18	18
**. Correlation is significant at the 0.01 level (2-tailed).			

3.9. The Influence of Landscape Materials, Soil Permeability, and Green Space Ratio on Thermal Comfort

3.9.1. Normality Tests and Data Distribution

Prior to conducting additional statistical analyses, normality was assessed using the Kolmogorov-Smirnov and Shapiro-Wilk tests Table 7. The results show that soil permeability, green space ratio, and the Universal Thermal Climate Index (UTCI) all exhibited normal distributions (p > 0.05), permitting the application of parametric statistical tests.

Table 7: Normality Analysis.

Tests of Normality						
	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Soil Permeability (%)	.093	18	.200*	.970	18	.793
Green Space (%)	.097	18	.200*	.974	18	.872
UTCI (°C)	.101	18	.200*	.974	18	.872
*. This is a lower bound of the true significance.						
a. Lilliefors Significance Correction						

Table 8: Between-Subjects Factors ANOVA.

Between-Subjects Factors			
		Value Label	N
Material Type	1	Concrete	4
	2	Grass	7
	3	Mixed	7

3.9.2. Effects of Landscape Materials on Thermal Comfort

A one-way ANOVA was performed to determine whether different landscape materials (concrete, grass, and mixed surfaces) significantly influenced the Universal Thermal Climate Index (UTCI), a measure of thermal comfort. The results indicate that material type did not have a statistically significant effect on UTCI ($F(2,13) = 0.163$, $p = 0.851$) as shown in Table 9. This finding suggests that the type of material alone does not substantially influence thermal comfort levels in the parks studied. Although prior research (Santamouris et al., 2015) indicates that high-albedo surfaces and permeable pavements can enhance cooling, the absence of significant effects in this analysis may reflect the overriding influence of other environmental factors, such as vegetation density and water features.

Table 9: Univariate Tests of Between-Subjects Effects.

Tests of Between-Subjects Effects					
Dependent Variable: UTCI (°C)					
Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	18.355[a]	4	4.589	79.512	.000
Intercept	16.241	1	16.241	281.430	.000
Soil Permeability	.000	1	.000	.008	.930
Green Space	.125	1	.125	2.158	.166
Material Type	.019	2	.009	.163	.851
Error	.750	13	.058		
Total	14554.230	18			
Corrected Total	19.105	17			
a. R Squared = .961 (Adjusted R Squared = .949)					

3.9.3. Effects of Soil Permeability and Green Space Ratio on Thermal Comfort

The ANOVA results indicate that neither soil permeability ($F(1,13) = 0.008$, $p = 0.930$) nor green space ratio ($F(1,13) = 2.158$, $p = 0.166$) exerted statistically significant effects on UTCI Table 9. These findings suggest that, although soil permeability and green space contribute to microclimatic improvement, their influence on thermal comfort may be limited when considered in isolation. Their cooling effects are likely more pronounced when combined with other factors, such as shading and wind circulation, which were not directly examined in this model. The high R-squared value of 0.961 indicates that landscape materials, soil permeability, and green space collectively account for 96.1% of the variance in thermal comfort, even though individual predictors did not reach statistical significance Table 9. This underscores that thermal comfort is a multi-factorial phenomenon in which interactions among variables play a pivotal role. Future research should explore the combined effects of vegetation, materials, and soil permeability to better understand their synergistic influence on urban cooling.

The analysis confirms that NDVI, water features, and shaded structures significantly reduce surface temperature, emphasising the critical role of green infrastructure in mitigating UHI effects. Tree canopy coverage demonstrates a stronger association with air temperature reduction than park size, indicating that even smaller parks with dense tree cover can provide substantial cooling benefits. Landscape materials, soil permeability, and green space ratio were found to function independently, showing minimal direct influence on thermal comfort. These findings highlight that effective cooling relies on the integrated design of park features rather than the optimisation of individual components. The results provide empirical guidance for urban planners, suggesting that maximum cooling benefits can be achieved through a coordinated combination of dense vegetation, tree canopy, water features, and shading elements, rather than relying solely on park size or material selection.

4. DISCUSSION

4.1. The Impact of Vegetation Density, Water Features, and Shaded Structures on Surface Temperature Reduction

Despite the cooling effects provided by NDVI, water features, and shaded structures across all park types, a strong association was observed among these elements. These results are consistent with previous research highlighting the roles of evapotranspiration, shading, and albedo in mitigating UHI effects (Gunawardena et al., 2017). Consistent with expectations, the regression analysis indicated that

NDVI exerted the greatest influence on temperature reduction, as dense vegetation lowers heat absorption through enhanced water retention. Similarly, latent heat exchange from water bodies contributed to cooling, supporting findings by Zhao et al. (2014). In addition, Santamouris et al. (2015) reported that shaded areas can reduce air temperature by up to 5°C. Collectively, these findings suggest that urban park designs should prioritise maximising vegetation density and water features while strategically incorporating shading structures to achieve optimal reductions in surface and air temperatures.

4.2. The Relationship Between Park Size, Tree Canopy Coverage, and Air Temperature Reduction

The correlation analysis demonstrates a strong positive association between tree canopy coverage and reductions in air temperature, whereas park size exhibits a moderate effect. These findings align with previous research indicating that tree canopies exert a more pronounced cooling influence than park size alone (Santamouris, 2020). Although larger parks provide extensive cooling zones (He et al., 2020), smaller parks with dense tree coverage are still capable of lowering air temperatures, consistent with Yin et al. (2022). Consequently, the results underscore the importance of implementing tree planting strategies in both large and small urban parks rather than prioritising park expansion. Increasing canopy density within existing parks, particularly in densely built urban areas where space for park enlargement is limited, should therefore be a primary focus for urban planning initiatives.

4.3. The Influence of Landscape Materials, Soil Permeability, and Green Space Ratio on Thermal Comfort

Unexpectedly, the analysis revealed that landscape materials, soil permeability, and green space ratio did not exert significant individual effects on thermal comfort as measured by UTCI. This contrasts with earlier studies emphasising the importance of high-albedo surfaces and permeable materials in moderating urban temperatures (Santamouris et al., 2015). These non-significant results imply that the effects of vegetation, shading, and materials on thermal comfort may operate independently rather than in isolation. The elevated R-squared value indicates that, although no single element dominates, a coordinated integration of these features within a thoughtfully designed park substantially enhances overall cooling performance. This observation corroborates Zhao et al. (2020), who proposed that the influence of material selection is less critical than that of green infrastructure components. Future investigations should focus on the combined contributions of vegetation, soil permeability, and material composition to optimise urban cooling strategies.

4.4. Practical Recommendation

The results indicate that effective mitigation of UHI effects necessitates protection from direct solar exposure, achieved through tree canopies, shaded structures, and water features. In line with this, urban planners should prioritise increasing high-canopy vegetation, such as densely planted trees, rather than focusing solely on expanding park size or creating additional parks. Incorporating water bodies, including ponds and fountains, can further enhance cooling by reducing surface temperatures and moderating humidity levels. Additionally, shaded structures should be strategically positioned within open areas, particularly in high-traffic zones, to alleviate heat stress. Vegetation and shading exert the most substantial influence on cooling, whereas landscape materials and soil permeability have comparatively secondary effects. Consequently, urban park design should emphasise the spatial arrangement of green features rather than merely altering surface materials. Finally, GIS-based spatial analysis should be employed in the planning of future parks to model temperature reduction effects, thereby facilitating data-driven approaches for optimising green infrastructure in urban environments.

5. CONCLUSION

This study employed GIS-based spatial analysis alongside statistical modelling to examine the contribution of sustainable landscape design in mitigating UHI effects in garden-style and urban parks across China. The results demonstrate that vegetation density, water features, and shaded structures substantially lower surface temperatures, corroborating prior research that highlights the effectiveness of green infrastructure for UHI mitigation. Tree canopy coverage emerged as the most influential factor in reducing air temperature, indicating that urban planning should prioritise tree planting strategies in both large and small parks. Although landscape materials and soil permeability did not individually show significant effects on thermal comfort, their combined integration within a carefully designed park can still contribute meaningfully to overall cooling. These findings provide valuable guidance for urban policymakers, landscape architects, and environmental planners, emphasising the importance of evidence-based green space strategies in fostering climate-resilient urban development.

5.1. Practical Implication

The findings of this study carry significant implications for urban planning and environmental policy. Municipal authorities should prioritise the incorporation of high-density tree planting within urban parks, including in smaller or space-constrained areas, given that tree canopy coverage is the most influential factor in achieving cooling benefits. GIS-based modelling should be employed to identify optimal locations for green infrastructure, ensuring maximal impact on urban temperatures. Water features should be strategically positioned within parks, particularly in high-temperature zones, to enhance cooling effects. Furthermore, pedestrian pathways and open areas should be provided with shading structures to improve outdoor thermal comfort. By implementing these evidence-based strategies, cities can mitigate rising urban temperatures, reduce energy consumption, and enhance the overall liveability and sustainability of urban environments.

5.2. Limitation

Several limitations of this study should be acknowledged. First, the cross-sectional research design involved data collection at a single time point, preventing the assessment of seasonal variations in temperature. Future studies employing longitudinal approaches could capture temperature dynamics across different seasons to provide a more comprehensive understanding of UHI mitigation. Second, although the selected parks reflect a range of urban conditions, only 18 parks were included out of the numerous parks across China. Expanding the sample to include parks from diverse geographic regions would enhance the generalisability of the findings. Finally, the study did not account for human activity or patterns of park use, which can influence thermal comfort. Incorporating visitor behaviour and usage patterns in future research could provide valuable insights into how urban populations experience and respond to microclimatic conditions within parks.

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