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Assessing the Urban Quality of Life Using Remote Sensing and Socioeconomic Data: A Case Study of Islamabad City

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Abstract

Continuous evaluation of the quality of life of a population holds significant importance as it enables planners, social workers, and government organizations engaged in the provision of human services to gain awareness of areas that require attention. This research investigates the interplay between urbanization and quality of life in Islamabad, Pakistan, utilizing a novel approach that integrates remote sensing data (Landsat-8) with socioeconomic indicators such as population density, household income, and college graduates. Results show that the level of vegetation greenness and the extent of urban land use within a particular area are significant indicators of the quality of life. A higher level of greenness and a lower percentage of urban land use are associated with a higher quality of life. However, densely populated and high land surface temperature areas show a decline in greenness and urban quality of life. The findings of this study offer valuable insights for urban planners and policymakers toward a more sustainable and liveable city by addressing the challenges of population density, green space availability, surface temperature, and socioeconomic disparities.

Keywords: Geospatial analysis, Remote sensing, Population density, Multi-criteria analysis, Urban Quality of Life

1. Introduction

The issue of sustainable cities and urban ecosystems has become a significant focal point for urban planners, policymakers, and residents (Jensen et al., 2004). In 2012, Pakistan's urban population was 37%, highlighting the country's rapid urbanization pace (Jensen et al., 2004). Liu et al. (2021) project that in 2030, Pakistan's population distribution will reach an equilibrium, with equal proportions residing in rural and urban areas. This projected equilibrium necessitates critically evaluating the challenges and opportunities associated with such a demographic shift.

Urbanization, the process of population growth in cities and towns, has a complex and multifaceted impact on the environment. While it offers

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undeniable benefits regarding economic development, job creation, and access to essential services (Sapena et al., 2021), it poses significant challenges to land use, resource consumption, and environmental degradation. One of the primary concerns associated with urbanization is the escalation in land demand. As cities expand, they encroach upon natural habitats, degrading grasslands, forests, and croplands. Despite the potential environmental consequences, urbanization continues to be an influential force in promoting economic development. Concentrating businesses and industries in cities creates job opportunities and stimulates technological advancements. Moreover, cities serve as vital nodes for crucial public services such as education, healthcare, and transportation, thereby enhancing the well-being of inhabitants (Avtar et al., 2020). This improvement in living standards is typically accompanied by increased migration from rural areas, accelerating urban expansion.

Nevertheless, the advantages of urbanization are not uniformly dispersed. As cities proliferate, they may accentuate existing social and economic disparities, disadvantaging populations within urban settings (Liu et al., 2021). Furthermore, the influx of people into urban areas can lead to challenges, including traffic congestion, air pollution, and industrial emissions, which have adverse effects on public health and environmental conditions (Butt et al., 2012). One of the primary concerns planners and municipal authorities face now is the attainment of a harmonious equilibrium between economic and social progress. This entails addressing the issues of poverty reduction, fostering and sustaining income and employment prospects, and striving to establish communities that are more sustainable and peaceful. Nevertheless, the process of urbanization gives rise to other environmental challenges, including but not limited to industrial emissions, transportation congestion, and pollution (Butt et al., 2012).

The unanticipated expansion of urban areas has detrimental effects on the physical and social aspects of cities, as Shao et al. (2021) noted. One of the primary negative consequences of urban expansion is the reduction in vegetation coverage and the subsequent increase in impervious surfaces. The modifications brought about by urbanization significantly impact the hydrologic cycle, resulting in diminished infiltration and evapotranspiration rates. These changes also lead to alterations in atmospheric and surface temperature regimes, which in turn place stress on both water and energy resource management systems, as well as solid waste disposal infrastructure (Franco & Macdonald, 2018; Ghaffarian et al., 2018; Shan et al., 2019; Shaw & Das, 2018; Wiatkowska et al., 2021).

Urban environmental quality is a multifaceted parameter that exhibits spatial and temporal variability. It arises from various ecological factors, such as urban heat islands (UHI), the distribution of green spaces, the density and configuration of buildings, and air and water quality. Additionally, it is influenced by socioeconomic factors, which can either enhance or diminish the quality of life (Zafar et al., 2023).

Using remotely sensed data is advantageous in analyzing urban environments due to its inherent capacity to provide valuable information about urban sprawl, land cover, impervious surfaces, and surface temperature. This data can be effectively employed to monitor and assess changes in these variables over time across different spatial and temporal scales (Zhong et al., 2023; Levering et al., 2021). The utilization of urban environmental quality data (Thiyagarajan et al., 2020) derived from remote sensing techniques capturing environmental and ecological information (Aslanov et al., 2021; Gupta et al., 2020; Salata et al., 2020) in conjunction with socioeconomic indicators, is highly advantageous for informing decision-making and policy formulation on urban phenomena (Wang et al., 2021). The comprehension of diverse environmental conditions within the administrative divisions of urban areas enables the prioritization of engagement in regions characterized by more significant environmental conflicts (Musse et al., 2018). Additionally, it facilitates the implementation of sophisticated zoning, among the several techniques employed by urban planners to regulate the fundamental attributes of urban areas (Li & Weng, 2007).In their study, Afsar et al. (2021) employed Landsat-7 imagery and socioeconomic data to calculate the quality-of-life indices for Karachi, a major metropolis in Pakistan. These indices were derived at the level of Union Councils, which are administrative-spatial units within the city. The study's findings clearly showcased the efficacy of utilising Index raster techniques to assess and delineate the quality of life. In their study, Chen et al. (2000) employed geographic information systems (GIS) and remote sensing techniques to analyze urban expansion. In their research, Prakash et al. (2016) employed a multi-criteria approach to visualize and evaluate India's quality of life. The environmental quality in Toronto was assessed by Faisal and Shaker (2017) using principal component analysis (PCA) and geographic information system (GIS) methodologies.

Most approaches for evaluating quality of life encompass multivariate methodologies, with principal component analysis being a prominent methodology (Nguyen et al., 2019). Additional methods involve assigning weights to scores based on their level of importance to derive a comprehensive final score (Dimitrov et al., 2018; Frick & Tervooren, 2019; Fu et al., 2019; Mesquita et al., 2022; Shaw & Das, 2018), as well as superimposing values using the vector map of each indicator obtained from a geographic information system.

This research project leverages remote sensing technology, specifically satellite imagery, to analyze Islamabad City extensively, combining spatial and spectral data. Previous studies have highlighted the importance of green spaces within urban environments, which diverse horticultural areas, recreational facilities, and tree cover characterize. To quantify the extent of these vegetative features, our investigation employs a vegetation index calculated using multi-spectral data (specifically the red and infrared bands). To further elaborate on the integration of socioeconomic factors and environmental indicators within our proposed framework for assessing urban areas' liveability, we have incorporated additional metrics beyond greenery percentage. Specifically, we have included Population Density, Household Income, Education Level, and Poverty Rates as key socioeconomic variables contributing to the overall Quality Index. Moreover, we have integrated environmental indicators into the computational process by leveraging Land Surface Temperature (LST) data derived from the Thermal Band of the Landsat-8 satellite. This multifaceted approach allows for a more comprehensive evaluation of an area's liveability, considering both social and ecological aspects.

2. Materials and Methods

2.1 Study Area

The Pakistani government federally administers Islamabad (Capital city of Pakistan) as part of the Islamabad Capital Territory. It is located at 33°41′35″N 73°03′50″E and has various elevations between 457 and 610 meters above sea level. As per Butt et al. (2012), the total land area of Islamabad amounts to approximately 906.5 square kilometers, while the specified green area extends over an additional 3626 square kilometers, featuring the presence of the Margalla Hills in the northern and northeastern sectors. The regional climate can be classified as a tropical/subtropical mountain monsoon regime, marked by an average annual temperature of 20.9°C and a yearly rainfall of 1323.4 millimeters in lower-lying areas. According to Liu et al. (2021), the area's indigenous vegetation includes tropical evergreen broad-leaf forests below 900 meters, while subtropical evergreen coniferous and deciduous broad-leaf forests are observed at higher elevations. Islamabad is divided into five zones, as shown in Figure 1, with Zone III primarily designated as the Margalla Hill National Park.

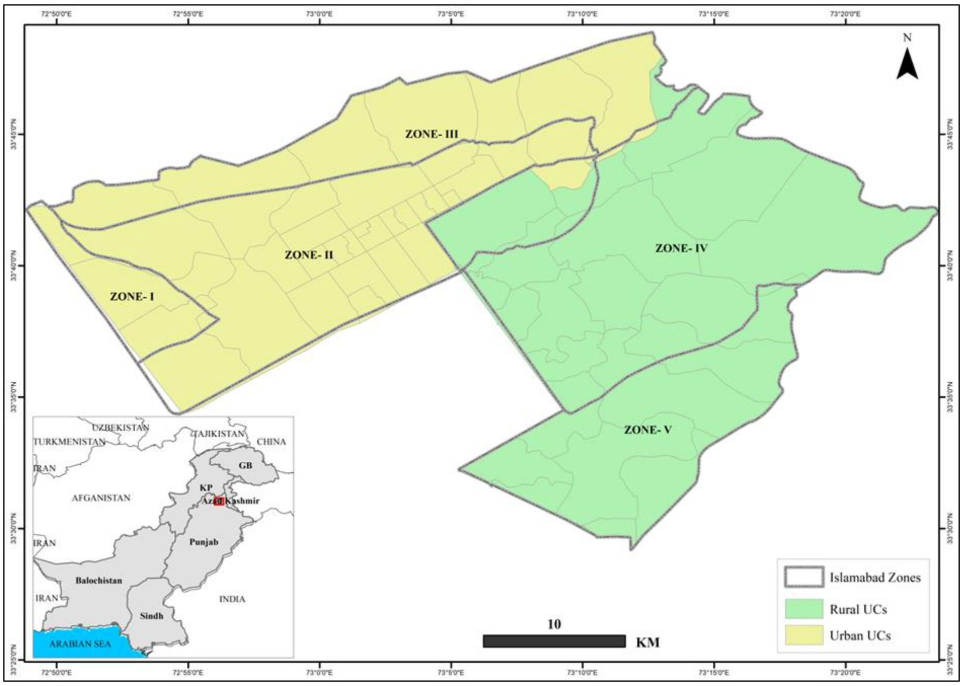

Figure 1: Location map of Islamabad (Capital Development Authority)

2.2 Datasets

This research employed a mixed methods approach, integrating remote sensing data with socioeconomic indicators to assess the urban quality of life.

2.2.1 Remote Sensing Data Acquisition and pre-processing

Multispectral satellite imagery from Landsat-8 was acquired for the study area. On April 26th, 2014, a clear satellite image of Islamabad was selected due to its favorable timing during the early summer season, which marks the vegetation's peak growth and maturation stage. To ensure accurate analysis, the acquired Landsat-8 data underwent rigorous radiometric corrections before being geographically referenced utilizing the Universal Transverse Mercator (UTM) projection based on the World Geodetic System (WGS-84) datum for zone 43°N. Images were pre-processed for atmospheric correction and radiometric calibration. Various land use/land cover maps were generated using supervised classification algorithms. Normalized Difference Vegetation Index (NDVI) was calculated to assess vegetation cover distribution. Land Surface Temperature (LST) was derived from the thermal band of Landsat-8.

Land use land cover (LULC) classification: In this study, we employed remote sensing technology to extract land use/land cover classes from a

Landsat image utilizing supervised classification. Specifically, we used a maximum likelihood classifier to categorize the image into five land use/land cover types: water bodies, forests, built-up areas, agricultural lands, bare lands, and other vegetative covers. The resulting classified image is depicted in Figure 2 below.

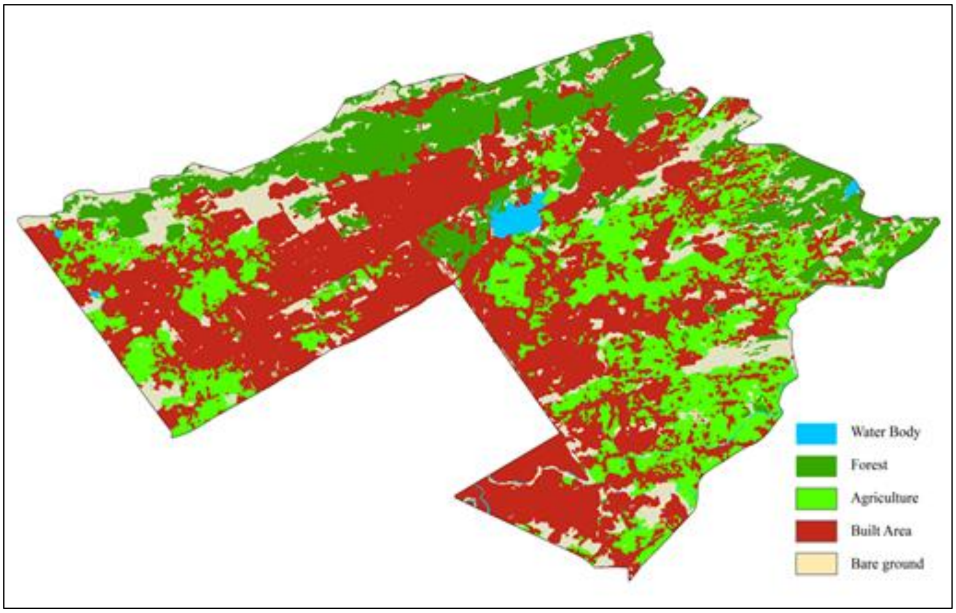

Figure 2: LULC classes developed by authors in 2014

Normalized Difference Vegetation Index (NDVI) as Green Areas*:* The normalized difference vegetation index (NDVI) is a prominent indicator of the presence of vegetation in the environment (Bannari et al. 1995). The NDVI index has a range of 1 to +1. A higher NDVI index score suggests more vegetation on the ground. Generally, a negative NDVI index value denotes non-green areas such as barren, sea, river, and built-up areas, and a positive value represents green areas (Abdullah et al. 2019). Furthermore, the NDVI value can be utilized to determine the health of plant/vegetation communities. This is due to the expectation that healthy plants/vegetation communities will have greater NDVI values than unhealthy plants. We implemented an innovative approach that integrates a threshold-based methodology with the Normalized Difference Vegetation Index (NDVI) derived from Landsat satellite imagery suggested by Liu et al. (2021). This allowed for delineating green patches and their subsequent visualization in Figure 3.

The NDVI is calculated as in Equation (1) and (2).

$$NDVI = (NIR - R) / (NIR + R) \qquad (1)$$

$$\text{NDVI} = (\text{Band 5} - \text{Band 4}) / (\text{Band 5} + \text{Band 4}) \qquad (2)$$

where NIR [Band 5] and R [Band 4] represent the near-infrared and the red band of Landsat 8 image product, respectively.

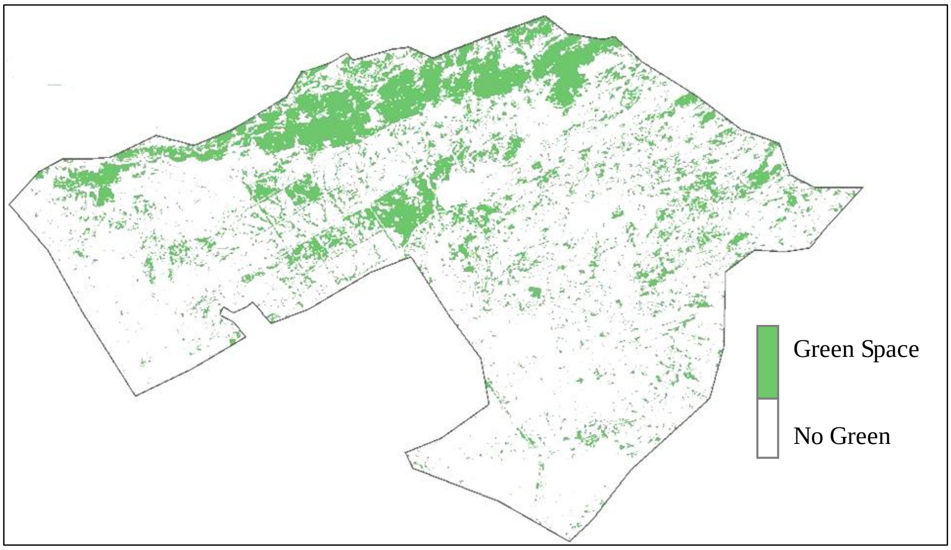

Figure 3: Green areas map of Islamabad in 2014

Surface Temperature: In their suite of offerings, the United States Geological Survey's Earth Resources Observation and Science (EROS) Centre provides users with standardized digital numbers (DN) representing multi-spectral imagery acquired through the Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS) aboard Landsat 8. These DN values have been formatted as 16-bit unsigned integers for convenient use. To facilitate accurate representation of the Top of Atmosphere (TOA) reflectance or radiance, these values can be revised using radiometric rescaling coefficients supplied within the accompanying metadata file. This process begins with converting TIRS band data into TOA spectral radiance employing the provided radiance rescaling factors in the metadata file.

$$L_\lambda = M_L Q_{cal} + A_L \qquad (3)$$

Where:

L_λ = TOA spectral radiance (Watts/(m2*srad*μm))

M_L = Band-specific multiplicative rescaling factor from the metadata

A_L = Band-specific additive rescaling factor from the metadata

Qcal = Quantized and calibrated standard product pixel values (DN)

TIRS band data can be converted from spectral radiance to brightness temperature using the thermal constants provided in the metadata file:

$$T = \frac{K_2}{ln\left(\frac{K_1}{L_\lambda}+1\right)} \quad (4)$$

Where:

T = At-satellite brightness temperature (K)

L_λ = TOA spectral radiance (Watts/(m2*srad*µm))

K_1 = Band-specific thermal conversion constant from the metadata

K_2 = Band-specific thermal conversion constant from the metadata

2.2.2 Socioeconomic Data

Socioeconomic data i.e., population density, income levels, educational attainment, and poverty rates, were collected from the Pakistan Bureau of Statistics. This data was normalized and standardized to ensure compatibility with remote sensing data. The selection of relevant socioeconomic indicators was guided by previously established standards as outlined in scholarly literature (Smith, 1973; Weber and Hirsch, 1992; Lo and Faber, 1997). Specifically, these indicators included population density, housing density, household income, percentage of individuals holding higher educational attainment, and percentage of households living beneath the poverty threshold.

Quality of Life: This study investigates the quality of life within urban areas through a novel approach that combines diverse data sources and utilizes a weighted overlay analysis within a Geographic Information System (GIS) framework. The research leverages satellite imagery to acquire data on built-up areas, surface temperature, and green spaces, which are then aggregated to the sector level using administrative boundaries. This spatial data is then integrated with socioeconomic data on population, income, education, and housing density collected at the sector level, enabling a comprehensive understanding of the various factors influencing quality of life.

Seven key variables were selected for the evaluation: percentage of green area, surface temperature, built-up area, population density, average household income, housing density, and rate of college-educated individuals. Each variable was assigned a weight based on its relative importance in assessing overall quality of life, considering expert opinion and relevant literature. Subsequently, the weighted overlay analysis was employed to integrate these diverse datasets and generate a quality-of-life map classified into seven distinct classes, representing varying levels of quality of life across the urban landscape.

This approach offers several significant advantages for assessing urban quality of life. Firstly, it facilitates the seamless integration of spatial and socioeconomic data, providing a more comprehensive and multifaceted perspective on urban environments. Secondly, the weighted overlay analysis allows prioritizing factors based on their specific importance within a given context, ensuring a tailored assessment process (Table 1). Finally, the resulting quality-of-life map provides a valuable visual representation of spatial variations, enabling targeted interventions and informed decision-making for urban development initiatives.

Table 1: Description of variables classes, weights and source

S. No	Variable	Classes	Weights	Source
1	Built up area	Below10%	7	Extracted from landsat-8 image
		10% - 20%	6	
		20% - 40%	5	
		40% - 60%	4	
		60% - 80%	3	
		80% - 90%	2	
		Above 90%	1	
2	Green area	Below10%	1	Extracted from landsat-8 image
		10% - 20%	2	
		20% - 40%	3	
		40% - 60%	4	
		60% - 80%	5	
		80% - 90%	6	
		Above 90%	7	
3	Building Density	Below 1000	7	Acquired from local authority
		1000-5000	6	Survey report
		5000-7000	5	
		7000-10000	4	
		10000-15000	3	
		15000-20000	2	
		Above 20000	1	
4	Surface	Below 280K	7	Extracted from landsat-8
	Temperature	280K-285K	6	thermal data
		285K-290K	5	
		290K-295K	4	

		295K-300K	3	
		300K-310K	2	
		Above 310K	1	
5	Income	Below 10,000 PKR/month	1	From Pakistan Bureau of Statistics
		10,000-25,000 PKR/month	2	
		25,000-50,000 PKR/month	3	
		50,000-100,000 PKR/month	4	
		100,000-200,000	5	
		PKR/month	6	
		200,000-300,000	7	
		PKR/month		
		Above 300,000 PKR/month		
6	College Graduates	Below 100	1	From Pakistan Bureau of Statistics
		100-200	2	
		200-300	3	
		300-400	4	
		400-500	5	
		500-600	6	
		Above 600	7	
7	Population Density	Below 1000 P/Km^2	7	From land scan data
		1,000-10,000 P/Km^2	6	
		10,000-20,000 P/Km^2	5	
		20,000-30,000 P/Km^2	4	
		30,000-40,000 P/Km^2	3	
		40,000-50,000 P/Km^2	2	
		Above 50,000	1	

3. Results and Discussion

The study's findings raise concerns about the current urban environmental quality in Islamabad. The unacceptable quality of life rating for 69% of the city necessitates immediate action from environmental agencies and urban management authorities. This underscores the importance of prioritizing environmental protection and implementing sustainable development policies.

3.1 Socioeconomic and Environmental Correlations

The analysis revealed a strong correlation between the environmental and socioeconomic circumstances of different communities within Islamabad. This interconnectedness emphasizes the need for a holistic approach to urban planning that addresses both environmental and social challenges comprehensively.

3.2 Green Space Availability

Open and green spaces within urban environments are crucial in enhancing quality of life. Green spaces within urban areas are instrumental in attaining environmental quality goals and fostering sustainable local development (Liu et al., 2021). This study highlights the crucial role of both accessibility and quality of green spaces when evaluating urban residential environments. By analyzing the correlation between NDVI values and self-reported well-being measures among city residents, the authors showcase the positive impact of proximity to green areas on mental health and life satisfaction. The relationship between urban green space availability and resident well-being has garnered increasing attention in recent years. This study highlights the importance of ensuring the availability of green spaces near residential areas. These spaces contribute significantly to promoting a healthy lifestyle and mitigating the negative impacts of urbanization. Quantitative analyses assessing the extent of green spaces per city block or per capita resident can help identify and prioritize areas needing urban planning and revitalization across different parts of a city (Sapena et al., 2021).

3.3 Rapid Population Growth

Islamabad City has experienced rapid population growth in recent years, driven by migration from rural areas and smaller towns. This influx places significant strain on the city's existing resources and infrastructure. The study's findings point towards a need for sustainable urban planning strategies that can accommodate a growing population while protecting the environment and ensuring quality of life for all residents.

3.4 Population Density and Quality of Life

The study confirms the well-established inverse relationship between population density and quality of life. In densely populated areas, access to resources and amenities can become limited, leading to a decline in quality of life. This reinforces the need for balanced urban development strategies, including creating satellite towns and decentralizing services.

3.5 Surface Temperature as an Indicator

The study employed surface temperature data to indicate the urban heat island effect. The observed inverse relationship between temperature and quality of life emphasizes the need for strategies to combat the urban heat island effect. Implementing green infrastructure, promoting urban cooling techniques, and reducing reliance on fossil fuels are crucial steps towards creating a cooler and more liveable city.

The findings of this study offer valuable insights for urban planners and policymakers in Islamabad City. By addressing the challenges of population density, green space availability, surface temperature, and socioeconomic disparities, the city can strive towards a more sustainable and liveable future for its residents. Implementing informed urban planning strategies, prioritizing environmental protection, and promoting equitable access to resources and amenities are essential steps toward creating a thriving urban environment for all.

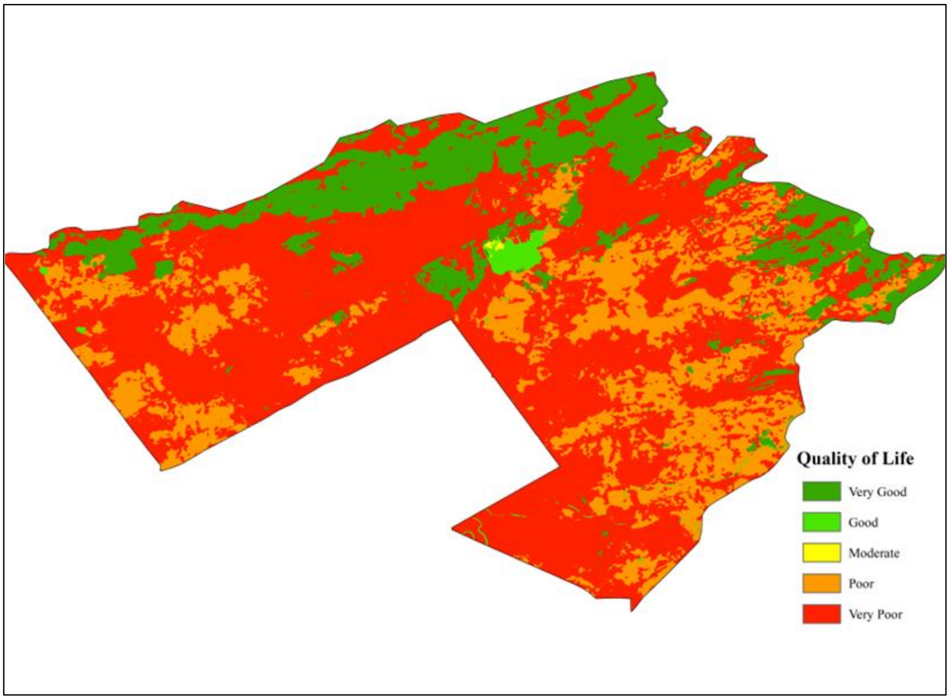

Figure 4: Quality of life map developed based on weight scores.

Incorporating verdant and publicly accessible outdoor areas into cityscapes is vital for optimizing inhabitants' well-being. This investigation underscores the significance of providing nearby residential areas with adequate amounts of green space, as it has been demonstrated that these environments serve as potent facilitators of physical activity and stress reduction, thereby counteracting the harmful consequences of urbanization on human health.

4. Conclusions

This study employed a novel approach to assess urban quality of life in Islamabad City, Pakistan, by integrating remote sensing data with socioeconomic indicators. The analysis revealed significant disparities in quality of life across the city, with 69% experiencing unacceptable levels based on the established criteria.

A strong positive correlation exists between built-up area and housing density, indicating a decline in quality of life with increasing density, particularly evident in the city's core sectors. The study raises significant concerns about the current state of Islamabad's urban environmental quality, with 69% receiving an unacceptable rating. This necessitates immediate action to prioritize environmental protection and implement sustainable development policies. A strong interconnectedness exists between the environmental and socioeconomic conditions of different communities within Islamabad, emphasizing the need for a holistic approach to urban planning. Open and green spaces are crucial in enhancing urban quality of life, and their availability near residential areas is critical. Rapid population growth driven by migration significantly strains the city's resources and infrastructure, highlighting the need for sustainable urban planning strategies to accommodate future growth while protecting the environment and ensuring quality of life. The well-established inverse relationship between population density and quality of life was confirmed, reinforcing the need for balanced development strategies. Surface temperature data served as an indicator of the urban heat island effect, and the observed negative correlation between temperature and quality of life underscores the need for strategies to combat this phenomenon.

The research results provide significant implications for urban planners and policymakers in Islamabad City, highlighting the need to address pressing issues related to population density, accessibility to green spaces, ambient temperatures, and socioeconomic disparity if they are to create a more resilient and habitable environment for its inhabitants.

Further research is required to explore the complex relationships between various factors impacting urban quality of life. This can include Investigating the effectiveness of specific interventions and policies, developing dynamic models to predict future scenarios, Incorporating additional data on factors such as air quality and noise pollution, and expanding the study to other cities to compare and contrast findings.

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