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RESEARCH PAPER

Key Determinants and Challenges of Sustainability in Cities of Punjab, Pakistan

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ABSTRACT

Cities' sustainability is a multifaceted challenge influenced by environmental, economic, infrastructural, and social factors. This study applies regression analysis to assess key sustainability determinants across six major cities in Punjab, Pakistan—Bahawalpur, Faisalabad, Lahore, Rawalpindi, Multan, and Sargodha. The results indicate that pollutants (PM2.5, PM10, NO_2, O3), water scarcity, and high crime rates hinder sustainability, while industrial expansion, infrastructure, and cultural institutions enhance resilience. Population and economic instability growth further complicate sustainability, proving that economic expansion alone is inadequate. Contrarily, pollution, water wastage, and rainfall variability cause major threat signifying the need for climate adaptation. Moreover, soaring crime rate in Bahawalpur and Sargodha weakens resilience, highlighting the crucial role of governance and law enforcement. Since sustainability is a context-specific concept, a one-size-fits-all approach is ineffective. This study suggests effective environmental policies, rigorous implementation of climate strategies, upgrading infrastructure, and enhancing security measures. A cross-functional approach constituting economic growth, environmental sustainability, and social well-being is essential for long-term resilience in Punjab's cities.

KEYWORDS Urban Sustainability, Socio-Eco Determinants, Environment Sustainability, Punjab, Pakistan

Introduction

All over the world, cities are expanding at fast pace, moved by population growth, industrialization, and economic activities (Pei, et al., 2025; Wang, et al., 2025) This swift urbanization causes significant challenges to sustainable development, making sustainability of cities a crucial area of research and policy formulation. City's sustainability is defined as the ability of a city to maintain a balance between economic growth, social well-being, and environmental conservation to ensure long-term prosperity for its inhabitants (Keith et al., 2023; Elmqvist et al., 2019). For a city, achieving sustainability is not just an aspirational objective but also a dire need, especially in the face of climate change, resource depletion, and socio-economic disparities (Díaz, et al., 2024; Mehryar et al., 2022). However, city sustainability is a complex mosaic of different dimensions that mainly involves environmental, social and economic dimensions (Huete-Alcocer et al., 2024).

In environment dimension, it marks the reduction of ecological footprints, the promotion of renewable energy, and the preservation of natural ecosystems within urban landscapes (Nketiah et al., 2024). In social domain, it aims to create inclusive, safe, and equitable communities that provide access to basic services such as education, healthcare, and housing (Pineo, 2022). Similarly, on economic front, city sustainability seeks to foster innovation, generate employment, and sustain economic growth without compromising future generations' needs (Anthony, 2024). Thus, urban sustainability is a multidimensional concept. This approach is particularly relevant to developing regions like Punjab, Pakistan, where cities are struggling with rapid population growth and environmental degradation. If unique dynamics of such cities are understood clearly, it can help foster sustainable development in them.

The sustainability of cities depends upon multiple factors, including governance, infrastructure, environmental stewardship, social equity, resource management and economic resilience (Zhang & Li, 2020). Infrastructure like energy efficient buildings, public transportation, and smart technologies, significantly contributes to reducing carbon footprints (Newman & Kenworthy, 2015). Moreover, efficient resource usage such as sustainable water consumption, waste treatment, and renewable energy ensures that cities can fulfill current and future demands without compromising ecological integrity (McDonnell & MacGregor, 2016). One more crucial determinant of urban sustainability is social equity that ensures affordable housing, access to education, and universal healthcare (Meerow et al., 2019). Environmental administration including green spaces, air quality control, and biodiversity conservation, is essential for maintaining urban resilience to climate-related disasters (McPhearson et al., 2016). Economic resilience is the ability of a city to combat and recover from economic shocks, is also crucial for sustainable urban development.

Urban sustainability has been studied extensively, but, most of the work is disproportionately concentrated in developed nations, often failing to notice the challenges faced by developing countries like Pakistan (Huang et al., 2022; Shen et al., 2021). The studies on Pakistan tend to focus on isolated aspects of sustainability, such as governance, infrastructure, or environmental policies (Ali & Bibi, 2023; Khan, et al., 2023; Ahmed, & Mustafa, 2022). One multidimensional study was conducted by Kousar & Anwar, (2025) for cities' ranking according to their sustainability status but which sustainability indicators affect how much across cities, remain largely unexplored (Ali et al., 2022; Javed & Khan, 2023). This study tries to fill these gaps by analyzing major sustainability determinants across big cities, offering a systematic and comparative assessment of cities' sustainability. The results will provide empirical insights to guide targeted urban policies, enabling policymakers and planners to develop sustainability strategies tailored to local contexts while aligning with global sustainable development goals

Literature Review

Cities' sustainability is a complicated issue influenced by economic, environmental, and social factors. Over the years, academics have revealed many aspects impacting sustainable urban development, adopting diverse approaches and analytical frameworks.

Among the pioneers, Hiremath et al., (2013) is the first pioneers to review indicator-based approach of urban sustainability, categorizing indicators into environmental, economic, and social dimensions. Later, the works of (Cohen, 2017; Dizdaroglu, 2017; Michalina, et al., 2021) signifies the need for adaptable indicators to effectively measure sustainable urban development, stressing their interdependence. The studies of (Guo et al., 2018; Yang et al., 2020; Chen & Zhang, 2021) enriched this literature by evaluating the role of awareness and perceptions of people in shaping sustainability concerns, underscoring balanced growth across sustainability dimensions and validating the need for data-driven assessments using the ELECTRE method respectively. Overall, these works signifies the importance of integrated frameworks to steer sustainable development. Yan et al. (2019) studied Chinese resource-based cities and found that economic diversification, environmental policies and innovation impact sustainability at different levels and context-specific policies are needed. Topal et al. (2020) did a systematic review and found that governance, technology and socio-economic factors are the key to urban sustainability and smart cities. They endorsed the concept about the interdisciplinary nature of sustainability. Zhan et al. (2018) used different approach and measured urban livability in China and found out that infrastructure, public services and environmental quality are the key factors. Xiao et al. (2022) expanded it by evaluating livability in underdeveloped regions and found that economic conditions and natural environment shape urban well-being. Wang et al. (2023) studied the relationship between economic development and livability and found that while economic growth increases infrastructure, it can also poses challenges of pollution and congestion. Overall, these studies revealed the interplay of economic and environmental factors in urban livability.

D'Acci (2024) further elaborated on this by looking at urban quality of life estimates and found out that economic conditions, infrastructure and social cohesion shape resident's well-being. Chen (2024) complemented this by discussing urban morphology and found out that spatial planning and city design influence daily life, mobility and social interactions. Talen (2024) introduced the concept of New Urbanism and advocated for mixed-use development, walkability and community-oriented spaces to enhance urban livability. Together, these studies provide a multidimensional perspective on urban sustainability and how planning, design and policy integration can make cities more resilient and livable.

In the neighboring countries, Narayanan et al. (2021) studied the sustainability-prosperity nexus in Indian cities and found out that governance, infrastructure and smart city initiatives are the key to long-term resilience. Liu et al. (2023) analyzed metro usage in Shenzhen and found out that public transport can reduce congestion and emissions and advocated transit-oriented development. Norouzian and Gheitarani (2024) examined urban flexibility in Hamadan, Iran and found out that governance, infrastructure adaptability and policy integration are the key to sustainability and resilience.Research on Pakistani cities' sustainability is scarce. Khan et al. (2021) studied urban resilience in Islamabad's informal settlements and found out socio-economic vulnerabilities. Ghalib et al. (2017) assessed sustainability in Punjab's cities and found out environmental, social and economic factors. Baig et al. (2019) looked at urban livability and found out governance and infrastructure are the key factors. Kousar and Anwar (2025) ranked Punjab's major cities based on sustainability indicators. Overall, these studies emphasize the need for inclusive urban planning and data-driven policies. Urban sustainability research is shifting towards empirical analysis and governance, public participation and technology-driven adaptability.

Material and Method

Study Area

This study examines six major cities—Lahore, Faisalabad, Rawalpindi, Multan, Sargodha, and Bahawalpur—selected for their economic significance, population density, and diverse challenges. They represent varying levels of development, infrastructure, and environmental conditions, making them ideal for analyzing urban sustainability across different contexts in Punjab, Pakistan.

Data

The data was collected for the years 2003–2022 from reliable secondary sources i.e Bureaus of statistics (Punjab development reports), Compendium of Environment Statistics, Open datasets and departments of respective utilities.

Indicator System

This study employed four key principles for selecting the most relevant indicators as depicted in Fig. 1.

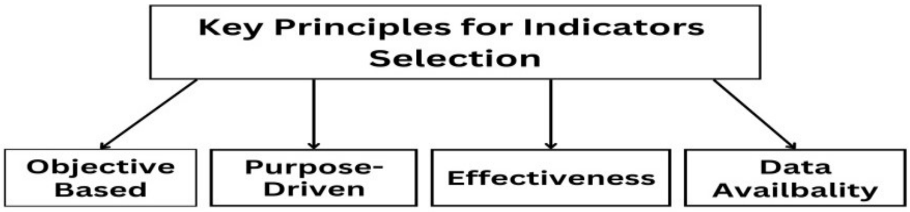

Figure 1: Showing key principals of most relevant indicators

Dependent Variable

Sustainability value of each city is the dependent variable for that city and rest of twenty one indicators/variables are independent variables. For getting sustainability value, this study uses methodology of Fang et al. (2021), where all indicators were divided into two major dimensions, one was quality of built environment in which all variables having positive impact of city's growth and development were included and the second was environmental pollution in which all variables having negative impact were gathered.

After Kaiser–Meyer–Olkin (KMO) test, data was standardized.

$$\mathrm{U(p/q)i}\,' = \frac{ui - \min(ui)}{\max(ui) - \min(ui)}$$

Where ui is the original data value of each indicator category i; min(ui) and max(ui), respectively and the standardized value is u(p/q)i.

And then weights (W(p/q)i) are calculated:

$$Wp/q_i = \frac{\lambda_{(\frac{p}{q})\mathrm{i}}}{\sum_{i=1}^{n/m} [\,\lambda_{(\frac{p}{q})\mathrm{i}}]}$$

Where, $\lambda_{(\frac{p}{q})\mathrm{i}}$ show the component score coefficient matrix and $\sum_{i=1}^{n/m} [\,\lambda \left(\frac{p}{q}\right) i]$ represents the sum of the component scores of each indicator category i of Qu or Pu calculated by the PCA method. The sum of the standardized value u(q)i 0 or W(p)i multiplied by the corresponding weight W(q)i or W(p)i is the comprehensive score (QUi or PUi) of each dimension for the urban sustainability assessment:

$$Q_{ui= w_{qi}\,.\,u_{qi}\,'} \quad ; \quad P_{Ui= W_{pi}\,.\,U_{pi}\,'}$$

And finally the sustainability formula is derived from the ratio of (Qu) and (Pu). Urban sustainability (Su) is calculated as:

$$Su = \frac{Qu}{Pu} = \frac{\sum_{i=1}^{n} QUi}{\sum_{i=1}^{n} \mathrm{PUi}}$$

Su is the dependent variable.

Table 1
sustainability values of each city

City	Bahawalpur	Faisalabad	Lahore	Rawalpindi	Multan	Sargodha
sustainability	1.199	1.184	0.764	0.678	0.976	0.911

Regression Analysis

A multiple linear regression model is employed to estimate the impact of the 21 indicators on the sustainability value of each city. The general form of the regression equation is as follows:

$$S_I = B_O + \sum_{j=1}^{21} B_J \, X_{IJ} + e_i$$

Where:

- S_I represents the sustainability value of city
- B_O is the intercept term
- B_J are the regression coefficients
- X_{IJ} represents the value of the indicator for city
- e_i is the error

Results and Discussion

For all cities, the variables were categorized into two groups. The first group represents the quality of the built environment, consisting of variables that positively contribute to various aspects of the city. In contrast, the second group includes variables that negatively affect the city's overall sustainability and development.

Bahawalpur

The regression model shows a strong correlation (R = 0.880) and explains 77.5% of sustainability variance (R^2 = 0.775) (Table 2). Only universities (β = 3.027, p = 0.012) and factories (β = 0.509, p = 0.015) have significant impacts. A one-unit increase in universities raises Bahawalpur's sustainability by three units, aligning with García-Aranda et al. (2024) and Romero & Molina (2017). Similarly, factory growth enhances sustainability, as noted by Juraschek et al. (2018). Other variables, including GDP, population, and employment, remain insignificant (p > 0.05). The model is overall significant (ANOVA p = 0.044).

Table 2
Regression Analysis for Built Environment Indicators of Bahawalpur

Variable	Coefficient (B)	Std. Error	Beta	t	Sig.
Constant	3.311	1.789	-	1.851	.097
GDP	0.955	2.391	0.610	0.400	.699
Population	6.439	3.915	2.511	1.645	.134
Factories	0.509	0.292	0.841	1.745	.015*
Employment	0.377	0.434	0.306	0.868	.408
Road Length	0.106	0.069	0.442	1.547	.156
Cultivation	-0.272	0.300	-0.316	-0.907	.388
Forests	-0.021	0.283	-0.051	-0.076	.941
Parks	-0.630	0.709	-0.835	-0.889	.397
Cinema	-0.350	0.323	-0.801	-1.084	.307
Universities	3.027	0.961	-4.073	-3.148	.012*

*Significant at the 0.05 level.

ANOVA

Model	Sum of Squares	Df	Mean Square	F	Sig.
Regression	0.471	10	0.047	3.102	.049b
Residual	0.137	9	0.015		
Total	0.608	19			

Model Summary

R	R Square	Std. Error of Estimate
0.880	0.775	0.12325

Regression Analysis for Environment Pressure of Bahawalpur

The model demonstrates a strong fit (R^2 = 0.981), explaining 98.1% of sustainability variance (Table 3). ANOVA confirms significance (F = 36.595, p < 0.001). Key predictors—$PM_{2.5}$ (β = -0.295, p = 0.001), PM_{10} (β = -0.717, p = 0.000), and Ozone (β = -0.635, p = 0.001)—show significant negative effects, aligning with research on air pollution's impact (Liu et al., 2024; Han et al., 2024). Water consumption (β = -1.679, p = 0.017) depletes resources (Sunny et al., 2024), while crime (β = -0.350, p = 0.042) harms sustainability (Mansourihanis et al., 2024). Rainfall (β = -0.243, p = 0.033) may contribute to urban flooding, but other variables lack statistical significance.

Table 3
Regression Analysis for Environment Pressure of Bahawalpur

Variable	Coefficients (Beta)	T	Sig.	Std. Error
Constant	-	12.468	0.000	0.220
Electricity	1.632	1.413	0.195	2.611
Water	-1.679	-2.995	0.017*	0.071
PM2.5	-0.295	-5.395	0.001**	0.011
NO2	-0.076	-0.845	0.423	0.044
PM10	-0.717	-8.049	0.000***	0.012
Ozone	-0.635	-5.043	0.001**	0.024
Rainfall	-0.243	-2.580	0.033	0.031
Temperature	-0.106	-1.194	0.267	0.069
Accidents	-0.186	-1.935	0.089	0.052
Crimes	-0.350	-2.421	0.042*	0.162
Density	-0.511	-0.327	0.752	42.926

*Significant at the 0.05 level.

ANOVA

Model	Sum of Squares	df	Mean Square	F	Sig.
Regression	0.596	11	0.054	36.595	0.000
Residual	0.012	8	0.001		
Total	0.608	19			

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	0.990	0.981	0.954	0.03848

Faisalabad

Regression Analysis for Built Environment Indicators of Faisalabad

The regression analysis reveals a moderately strong model (R = 0.852, R^2 = 0.725) as depicted in Table 4. Among the independent variables, Forests (B = 0.052, p = 0.043) exhibits a marginally positive relationship with sustainability, this result reiterates (Ramon, et al., 2023). while, universities (B = 0.176, p = 0.624) and employment (B = 0.070, p = 0.427), GDP (B = 0.181, p = 0.584) also indicate positive trends. Population (B = -

0.651, p = 0.456) show negative but insignificant impacts. The findings suggest that while environmental, economic and educational factors may contribute to sustainability, demographic pressures could counteract these effects. Given the lack of statistical significance

Table 4
Regression Analysis for Built Environment Indicators of Faisalabad

Variable	B	Std. Error	T	Sig.
Constant	1.108	1.566	0.708	.497
GDP	0.181	0.319	-0.568	.584
Population	-0.651	0.835	-0.779	.456
Factories	0.032	0.067	0.479	.643
Employment	0.070	0.084	0.832	.427
Road Length	-0.004	0.049	-0.072	.945
Cultivation	0.042	0.145	0.292	.777
Forests	0.052	0.027	1.970	.043*
Parks	0.042	0.203	0.208	.840
Cinema	0.017	0.023	0.738	.480
Universities	0.176	0.346	0.508	.624

*Significant at the 0.05 level.

ANOVA

Model	Sum of Squares	df	Mean Square	F	Sig.
Regression	0.182	10	0.018	2.376	.104b
Residual	0.069	9	0.008		
Total	0.252	19			

Model Summary

R	R Square	Adjusted R Square	Std. Error of Estimate
0.852	0.725	0.420	0.08764

Regression Analysis for Environmental Pressure of Faisalabad

Table 5
Regression Analysis for Environment Pressure of Faisalabad

Variable	Std. Error	(Beta)	T	Sig.
Constant	0.826	-	2.530	0.035
Electricity	0.182	0.710	0.874	0.407
Water	0.056	0.139	0.151	0.884
PM2.5	0.530	0.389	0.737	0.482
NO2	0.019	-0.500	-2.459	0.039*
PM10	0.064	-0.398	-0.842	0.424
Ozone	0.057	-0.561	-1.612	0.146
Rainfall	0.067	-0.157	-0.616	0.555
Temperature	0.083	0.144	0.532	0.609
Accidents	0.143	-0.179	-0.305	0.768
Crimes	0.248	-0.418	-0.645	0.537
Density	2.251	-0.618	-0.347	0.737

*Significant at the 0.05 level.

ANOVA

Model	Sum of Squares	df	Mean Square	F	Sig.
Regression	0.210	11	0.019	3.688	0.037
Residual	0.041	8	0.005		
Total	0.252	19			

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	0.914	0.835	0.609	0.07197

The regression analysis results indicate that among the various environmental factors examined, nitrogen dioxide (NO_2) exhibits a statistically significant negative impact on the sustainability ratio (β = -0.500, t = -2.459, p = 0.039) as depicted in Table 5. This finding aligns with previous research demonstrating the detrimental effects of NO_2 on urban sustainability. Larkin et al. (2017) developed a global land use regression model, revealing NO_2's widespread distribution and its harmful impact on public health and ecology. The model summary reveals a strong correlation (R = 0.914) and indicates that approximately 83.5% of the variance in the sustainability ratio is explained by the predictors included in the model (R^2 = 0.835).

Lahore

Regression Analysis for Built Environment Indicators of Lahore

Table 6
Regression Analysis for Built Environment Indicators of Lahore

Variable	B	Std. Error	T	Sig.
Constant	0.411	0.133	3.097	.011
GDP	0.026	0.015	1.691	.122
Population	-0.027	0.077	-0.351	.733
Factories	-0.006	0.017	-0.367	.721
Employment	0.049	0.040	1.229	.247
Road Length	-0.034	0.113	-0.302	.769
Cultivation	-0.294	0.110	-2.664	.024*
Parks	0.014	0.031	0.436	.672
Cinema	0.030	0.006	5.392	.000**
Universities	-0.012	0.017	-0.719	.489

*Significant at the 0.05 level.

ANOVA

Model	Sum of Squares	df	Mean Square	F	Sig.
Regression	0.189	9	0.021	125.628	.000**
Residual	0.002	10	0.000		
Total	0.191	19			

Model Summary

R	R Square	Adjusted R Square	Std. Error of Estimate
0.996	0.991	0.983	0.01293

**Significant at the 0.01 level.

The regression analysis demonstrates a strong predictive model (R = 0.996, R^2 = 0.991, Adjusted R^2 = 0.983) as depicted in Table 6. Among predictors, cinema (B = 0.030, p < 0.001) has a significant positive effect, suggesting that cultural infrastructure enhances sustainability in Lahore (Naheed & Shooshtarian, 2022). In contrast, cultivation (B = -0.294, p = 0.024) has a significant negative impact, implying that agricultural land use may contribute to difficulties of inhabitants. This revelation endorses Yu et al. (2025) findings that more cultivation can degrade environment. Other variables, including GDP, employment, population, factories, universities, road length, and parks, show no statistically significant impact, suggesting that their effects on sustainability may be context-dependent or influenced by external factors.

Regression Analysis for Environment Pressure of Lahore

The regression analysis confirms a highly significant model (F = 59.895, p = 0.000) with 98.8% variance explained (R^2 = 0.988), demonstrating its robustness as depicted in Table 7. Ozone (p = 0.009) and NO_2 (p = 0.052) show significant negative effects on Lahore's sustainability, aligning with studies on air pollution's environmental (Barnes et al., 2019; Sharma & Kapoor, 2020; Nasar-u-Minallah et al., 2024). PM_{10} and accidents have borderline significance (p = 0.063, p = 0.061), suggesting potential influence. Meanwhile, electricity, water, and temperature show non-significant effects, consistent with studies highlighting the indirect role of infrastructure (Seto et al., 2014; Barton, 2015).

Table 7
Regression Analysis for Environment Pressure of Lahore

Variable	Std. Error	Coefficients (Beta)	T	Sig.
Constant	0.506	-	0.057	0.956
Electricity	0.017	-0.202	-0.534	0.608
Water	0.095	0.546	1.452	0.185
PM2.5	0.253	0.140	0.873	0.408
NO_2	0.005	-0.110	-2.285	0.052*
PM10	0.007	-0.118	-2.160	0.063
Ozone	0.009	-0.193	-3.437	0.009**
Rainfall	0.009	-0.053	-0.989	0.352
Temperature	0.032	-0.004	-0.062	0.952
Accidents	0.011	-0.279	-2.174	0.061
Crimes	0.015	-0.104	-0.636	0.542
Density	0.040	0.308	0.507	0.626

*Significant at the 0.05 level.

ANOVA

Model	Sum of Squares	df	Mean Square	F	Sig.
Regression	0.188	11	0.017	59.895	0.000 **(Significant)**
Residual	0.002	8	0.000		
Total	0.191	19			

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	0.994	0.988	0.972	0.01691

**Significant at the 0.01 level.

Rawalpindi

Regression Analysis for Built Environment Indicators of Rawalpindi

Table 8
Regression Analysis for Built Environment Indicators of Rawalpindi

Variable	B	Std. Error	T	Sig.
Constant	-2.984	1.915	-1.559	0.153
GDP	-0.201	0.279	-0.719	0.190
Population	-0.321	0.847	-0.379	0.214
Factories	0.126	0.266	0.472	0.148
Employment	0.259	0.427	0.607	0.359
Road Length	1.041	0.481	2.163	0.059
Cultivated area	-0.082	0.091	-0.900	0.392
Forests	3.594	3.542	1.015	0.337
Parks	-0.325	0.153	-2.132	0.062
Cinema	-0.015	0.035	-0.440	0.270
Universities	0.252	0.339	0.742	0.177

*Significant at the 0.05 level.

ANOVA

Model	Sum of Squares	df	Mean Square	F	Sig.
Regression	0.056	10	0.006	1.969	0.161
Residual	0.026	9	0.003		
Total	0.081	19			

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	0.828	0.686	0.338	0.05323

Regression Analysis for Environment Pressure of Rawalpindi

The regression analysis shows a moderate predictive capability (R = 0.828, R^2 = 0.686, Adjusted R^2 = 0.338), explaining 68.6% of sustainability variation (Table 8). Road length (B = 1.041, p = 0.059) and parks (B = -0.325, p = 0.062) approach significance, suggesting infrastructure expansion may enhance Rawalpindi's sustainability (van Oorschot et al., 2024), while green space reduction could be detrimental (Lee & Kim, 2015). Other variables show limited direct impact, with cultivated area (B = -0.082, p = 0.392) indicating a potential but insignificant adverse effect.

Table 9
Regression Analysis for Environment Pressure of Rawalpindi

Variable	Std. Error	Coefficients (Beta)	T	Sig.
(Constant)	1.678	0.399		4.203
Electricity	0.049	0.059	0.924	0.828
Water	-0.053	0.019	-1.599	-2.705
PM2.5	-0.318	0.194	-0.217	-1.643
NO2	-0.032	0.007	-0.556	-4.377
PM10	-0.037	0.018	-0.282	-2.068
Ozone	-0.038	0.013	-0.929	-2.890
Rainfall	-0.016	0.007	-0.331	-2.393
Temperature	0.010	0.040	0.041	0.250
Accidents	-0.046	0.053	-0.256	-0.864
Crimes	-0.035	0.115	-0.180	-0.308
Density	-0.679	0.761	-0.589	-0.893

*Significant at the 0.05 level.

ANOVA

Model	Sum of Squares	df	Mean Square	F	Sig.
Regression	0.076	11	0.007	10.641	0.001
Residual	0.005	8	0.001		
Total	0.081	19			

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	0.967	0.936	0.848	0.02550

The regression analysis shows a strong model fit (R = 0.967, R^2 = 0.936), explaining 93.6% of sustainability variance as depicted in Table 9. Key predictors such as NO_2 (p = 0.002), PM10 (p = 0.072), and ozone (p = 0.020) exhibit significant negative effects on sustainability, aligning with previous research (Irankunda & Ozunu, 2024; Bilal et al., 2021). Water consumption (p = 0.027) reduces sustainability by increasing scarcity (Almulhim & Abubakar, 2024), while rainfall (p = 0.044) negatively impacts Rawalpindi, disrupting agriculture and causing floods (Elahi et al., 2024)

Multan

Regression Analysis for Built Environment Indicators of Multan

The regression analysis demonstrates a strong explanatory power (R = 0.939, R^2 = 0.882, Adjusted R^2 = 0.751), indicating that approximately 88.2% of the variation in the Sustainability Ratio is explained by the independent variables as depicted in Table 10. However, individual predictors exhibit varied significance levels. Factories (B = 1.212, p = 0.041) and GDP (B = 0.387, p = 0.049) reveal a relatively strong positive effect on Multan's sustainability reinforcing claims of (Mugano, 2024; Liu et al., 2014), though number of factories indirectly effect city's development. Other factors, such as Population (B = -1.102, p = 0.009) impact negatively on Multan's sustainability confirming existing literature on these variables (Girardet, 2019; Sodiq et al., 2019). Parks (B = -0.118, p = 0.685) also exhibit a negative impact, hinting at possible land-use trade-offs.

Table 10
Regression Analysis for Built Environment Indicators of Multan

Variable	B	Std. Error	t	Sig.
Constant	0.687	1.730	0.397	0.700
GDP	0.387	0.489	-0.791	0.049*
Population	-1.102	1.601	-0.688	0.009**
Factories	1.212	0.670	1.809	0.041*
Employment	0.046	0.192	0.237	0.818
Road Length	0.135	0.123	1.097	0.301
Cultivation	0.097	0.390	0.249	0.809
Forests	25.864	94.791	0.273	0.791
Parks	-0.118	0.281	-0.419	0.685
Cinema	0.002	0.054	0.044	0.966
Universities	0.139	0.336	0.415	0.688

*Significant at the 0.05 level.

ANOVA

Model	Sum of Squares	df	Mean Square	F	Sig.
Regression	0.356	10	0.036	6.743	0.004
Residual	0.048	9	0.005		
Total	0.404	19			

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	0.939	0.882	0.751	0.07270

Regression Analysis for Environment Pressure of Multan

Table 11
Regression Analysis for Environment Pressure of Multan

Variable	Std. Error	Coefficients (Beta)	t	Sig.
Constant	0.697	-	0.210	0.839
Electricity	8.187	-0.091	-0.081	0.938
Water	0.170	-1.347	-1.761	0.116
PM2.5	0.513	0.045	0.256	0.805
NO2	0.017	-0.263	-3.141	0.014*
PM10	0.044	-0.466	-2.979	0.018*
Ozone	0.033	-0.305	-1.703	0.127
Rainfall	0.050	-0.162	-1.446	0.186
Temperature	0.072	-0.142	-0.907	0.391
Accidents	0.133	-0.026	-0.129	0.900
Crimes	0.208	-0.035	-0.136	0.895
Density	2.282	1.907	1.582	0.152

*Significant at the 0.05 level.

ANOVA

Model	Sum of Squares	df	Mean Square	F	Sig.
1	0.388	11	0.035	17.625	0.000

Model Summary

R	R Square	Adjusted R Square	Std. Error of the Estimate
0.980	0.960	0.906	0.04473

The regression analysis indicates a significant model fit with a very high R-square value of 0.960 and an adjusted R-square of 0.906 as depicted in Table 11. The ANOVA test shows that the overall model is statistically significant ($F(11, 8) = 17.625$, $p < 0.001$), further confirming the robustness of the model. Among the predictors, NO_2 ($\beta = -0.263$, $p = 0.014$) and PM10 ($\beta = -0.466$, $p = 0.018$) have a statistically significant negative impact on sustainability, supporting findings from similar studies that link air pollution to environmental degradation (Gupta et al., 2019). In contrast, factors like Electricity ($\beta = -0.091$, $p = 0.938$) and Crimes ($\beta = -0.035$, $p = 0.895$) do not show significant effects, as also found in other studies where socio-economic variables had minimal impact (Graham & McCoy, 2024)).

Sargodha

Regression Analysis for Built Environment Indicators of Sargodha

Table 12
Regression Analysis for Built Environment Indicators of Multan

Variable	B	Std. Error	t	Sig.
Constant	1.041	0.793	1.314	0.218
GDP	1.113	1.458	0.763	0.463
Population	-3.061	7.485	-0.409	0.047*
Factories	0.088	0.082	1.076	0.030*
Employment	0.170	0.615	0.276	0.788
Road Length	0.012	0.017	0.698	0.501
Cultivation	-0.088	0.132	-0.663	0.522
Parks	0.048	0.215	0.221	0.829
Cinema	0.205	0.124	1.650	0.130
Universities	-0.010	0.306	-0.032	0.975

*Significant at the 0.05 level.

ANOVA

Model	Sum of Squares	df	Mean Square	F	Sig.
Regression	0.065	9	0.007	2.523	0.053
Residual	0.029	10	0.003		
Total	0.094	19			

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	0.833	0.694	0.419	0.05367

The regression analysis indicates a moderate explanatory power ($R = 0.833$, $R^2 = 0.694$, adjusted $R^2 = 0.419$) as depicted in Table 12. Among the independent variables, cinema ($B = 0.205$, $p = 0.130$) exhibits the strongest positive impact, although it remains statistically insignificant. Similarly, GDP ($B = 1.113$, $p = 0.463$) and factories ($B = 0.088$, $p = 0.03$) contribute positively (Abu-Rayash & Dincer, 2021) though GDP is not significant predictor here. Notably, universities ($B = -0.010$, $p = 0.975$) demonstrate no meaningful impact, suggesting that higher education institutions may not directly influence sustainability within the studied context.

Regression Analysis for Environment Pressure of Sargodha

The results indicate that several predictors significantly influence Sargodha's sustainability ratio, with NO_2, PM10, water consumption and crime rates showing notable negative impacts as depicted in Table 13. NO_2 ($\beta = -0.508$, $t = -2.606$, $p = 0.031$) negatively affects sustainability due to its harmful impact on air quality, while crime ($\beta = -2.063$, $t = -2.607$, $p = 0.031$) contributes to social and environmental stress, reducing sustainability. Conversely, population density ($\beta = 3.777$, $p = 0.044$) positively affects sustainability, aligning with Zhang & Sun (2021) on the benefits of efficient urban planning. Other variables, including temperature, rainfall, and water consumption, were not statistically significant. The regression model exhibits a strong fit ($R = 0.942$, $R^2 = 0.887$, adjusted $R^2 = 0.732$, $F = 5.713$, $p = 0.010$), explaining 88.7% of the variance in sustainability. These findings align with studies by Li et al. (2020) and Wang et al. (2019), reinforcing that pollution and crime hinder urban sustainability. The results emphasize the need for pollution control and urban safety measures to enhance long-term sustainability.

Table 13
Regression Analysis for Environment Pressure of Sargodha

Model	B(coefficients)	p	t
(Constant)	1.038	0.568	0.374
Electricity	0.776	1.423	1.667
Water	-0.071	0.666	-0.081
PM2.5	-0.398	0.155	-1.175
NO2	-0.508	0.031	-2.606
PM10	0.140	0.054	-0.473
Ozone	0.209	0.033	0.545
Rainfall	-0.029	0.022	-0.136
Temperature	-0.427	0.013	-1.325
Accidents	-1.330	0.124	-1.872
Crimes	-2.063	0.031	-2.607
Density	3.777	0.044	2.385

*Significant at the 0.05 level.

ANOVA

Model	Sum of Squares	df	Mean Square	F	Sig.
Regression	0.084	11	0.008	5.713	0.010
Residual	0.011	8	0.001		
Total	0.094	19			

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	**0.942**	**0.887**	**0.732**	**0.03647**

Discussion

Regression analysis of six major cities in Punjab highlights the complex mosaic of environmental, economic, infrastructural, and social factors in cities' sustainability. Major obstacles include air pollution, excessive water usage, and crime, while, infrastructure, industry, and cultural institutions steer resilience. The built environment is a key factor of sustainability, with universities and factories of Bahawalpur contributing positively, while industrial expansion in Multan and Sargodha boost economic stability (García-Aranda et al., 2024; Juraschek et al., 2018). However, economic indicators i.e GDP and employment exhibit inconsistent impact, revealing that economic growth alone is not a sufficient benchmark of urban sustainability. The findings also signifies the pressures of demographic expansion, as population growth in Faisalabad and Multan strains infrastructure and public services, reiterating concerns about urban congestion and declining livability (Sodiq et al., 2019).

Air pollution is one of the worst environmental problems in these cities; $PM_{2.5}$, PM_{10}, ozone, and NO_2 drastically lower sustainability, which is consistent with international studies on the negative ecological and health impacts of poor air quality (Zhao et al., 2023). In Bahawalpur and Rawalpindi, excessive water usage exacerbates resource scarcity (Zhu & Chang, 2020), while rainfall variability due to stark change in climate pattern in Rawalpindi disrupts urban systems through increased flooding and agricultural instability (Elahi et al., 2024). Additionally, Bahawalpur and Sargodha's crime rates erode societal resilience, underscoring the need of law enforcement and governance in maintaining sustainable urban settings.

Conclusion

The findings reveal that city sustainability in Punjab is influenced by a combination of environmental, economic, infrastructural, and social factors, while pollution, crime, and excessive resource consumption negatively affect sustainability. Universities, industrial expansion and cultural institutions boost resilience. However, the differences across cities suggest that sustainability policies must be tailored to local conditions rather than adopting a one-size-fits-all approach. Addressing these challenges requires an integrated policy framework that prioritizes environmental protection, sustainable urban planning, and social stability.

Recommendations

- Air Pollution Control: Stricter regulations, green spaces, and clean energy to reduce pollution.
- Water Management: Conservation policies and smart infrastructure to prevent overuse.
- Urban Planning: Mixed-use spaces, better transit, and controlled industrial growth for balance.
- Public Safety: Stronger law enforcement, community engagement, and surveillance to reduce crime.
- Green Infrastructure: Parks and urban forests to improve air quality and public health.
- Higher Education Investment: Expanding universities and research centers for innovation and resilience.
- Climate Adaptation: Flood management, better drainage, and climate-focused urban planning.

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