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Do School-Site Distribution and School-Building Quality Align with Urban Quality of Life?

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Abstract

This exploratory ecological study examines associations between school-site distribution, school-building quality, population per school building, and urban quality-of-life (QoL) rank standing across eight Saudi cities. The cross-sectional analysis used 4,637 unique surveyed school buildings and 4,085 valid geocoded sites. School-site pattern was assessed using a Clark–Evans-style nearest-neighbor ratio (NNR), while mean building quality and population per declared public-school building were examined as additional city-level indicators. Exact Spearman permutation tests, Holm adjustment for the three pre-specified hypotheses, OLS sensitivity models, influence diagnostics, and leave-one-city-out cross-validation were used. NNR showed a nominal positive association with QoL standing (ρ=0.738, p=0.0458), but this was not supported after Holm correction (p=0.1375). Building quality (ρ=0.119, p=0.793) and population per school (ρ=0.405, p=0.3268) were not supported. The joint model had poor cross-validated performance (Q^2=−0.549). NNR was also entangled with site density and convex-hull extent, and the Oxford functional-urban-area boundaries do not necessarily coincide with the administrative/project boundaries of the school data. An illustrative association-based model contrast of +2.70 standing points had a 95% CI of −2.45 to +7.84. The findings are hypothesis-generating rather than causal or predictive and require validation using consistent geographic boundaries, edge-corrected spatial measures, school-age demand, and effective capacity.

Keywords: quality of life; school infrastructure; spatial equity; educational facilities; nearest-neighbor analysis; Saudi cities; urban planning; school-site distribution.

1- Introduction

Urban quality of life is a multidimensional concept that reflects the extent to which urban environments provide residents with adequate social, economic, environmental, and public services. In contemporary urban planning, quality of life is increasingly linked to the availability, accessibility, and quality of essential urban facilities.

In the Saudi context, education is recognized as one of the important dimensions of urban quality of life, alongside housing, health, transportation, infrastructure, employment, and social well-being (Al-Qawasmi et al et al., 2021).

Schools represent an important component of urban social infrastructure because their role extends beyond the provision of educational services. Well-integrated schools can contribute to social interaction, community cohesion, inclusion, and neighborhood resilience. Recent research has emphasized that schools can function as multifunctional community assets when their design, accessibility, and relationship with surrounding urban spaces are appropriately considered (Binabid & Anteet, 2026).

In addition to location and distribution, the physical quality of school buildings represents another important dimension of educational infrastructure. School facilities influence the physical learning environment and may affect students' comfort, safety, health, attendance, and educational experiences. Therefore, evaluating school infrastructure requires attention not only to the geographical distribution of facilities but also to their physical condition and functional quality. Recent research further emphasizes that improving the accessibility and quality of schools simultaneously can provide a more comprehensive understanding of educational equity and urban service provision (Pizzol et al., 2021). Population pressure also represents an important factor in evaluating educational provision.

Within the Saudi urban context, rapid urban development and differences in population size, spatial structure, and service provision create an important opportunity to examine whether variations in school distribution and school infrastructure are associated with differences in urban quality of life. The availability of comparable city-level quality-of-life data and school-facility information provides a basis for conducting an exploratory comparative analysis across selected Saudi cities.

Therefore, examining the relationship between school-site distribution, school-building quality, population pressure, and urban quality of life can provide a broader perspective on the role of educational infrastructure in urban development. The present study addresses this issue through a comparative analysis of eight Saudi cities, focusing on whether differences in school spatial regularity, building quality, and population per school building are associated with differences in urban quality of life.

1.1 Study Problem

Although previous research has addressed school accessibility, educational infrastructure, and urban development from different perspectives, limited evidence directly examines whether the spatial regularity of school distribution is associated with differences in urban quality of life across Saudi cities. Moreover, the potential roles of school-building quality and population pressure have not been examined simultaneously within the same analytical framework. Accordingly, the central problem of this study is the limited empirical understanding of the relationship between the spatial characteristics of school infrastructure and urban quality of life. The study therefore focuses on three related dimensions: the regularity of school distribution, the quality of school buildings, and population per school building.

1.2 Significance of the Study

The significance of this study is both theoretical and practical. Theoretically, it contributes to the discussion of urban quality of life by examining educational infrastructure as a spatial component of urban development. Practically, the findings may provide useful evidence for education and urban-planning authorities when evaluating the distribution and adequacy of school facilities.

The study also contributes by distinguishing between the quantity, spatial distribution, physical quality, and population pressure associated with schools rather than treating the number of schools as the sole indicator of educational provision.

1.3 Study Objectives

The study aims to: -

1-Examine the relationship between the spatial regularity of school distribution and urban quality of life.

2-Examine the relationship between school-building quality and urban quality of life.

3-Examine the relationship between population per school building and urban quality of life.

4-Provide an exploratory planning scenario that considers the joint contribution of the examined school-related indicators.

5-Generate evidence that can support future spatial and longitudinal research on educational infrastructure and urban quality of life.

1.4 Study Hypotheses

The study tests the following hypotheses: -

H1: Greater spatial regularity in school distribution is positively associated with higher urban quality of life.

H2: Higher school-building quality is positively associated with higher urban quality of life.

H3: Higher population per school building is negatively associated with urban quality of life.

1.5 Study Questions

The study seeks to answer the following questions: -

1-Is the spatial regularity of school distribution associated with urban quality of life?

2-Is school-building quality associated with urban quality of life?

3-Is population per school building associated with urban quality of life?

4-To what extent do the examined school-related indicators jointly provide an exploratory explanation of differences in urban quality of life?

1.6 Study Population

The analytical study population consists of eight Saudi cities included in the 2025 Oxford Economics quality-of-life ranking and for which comparable school-facility data were available: Jeddah, Dammam, Taif, Riyadh, Khamis Mushait, Makkah, Madinah, and Hofuf/Al-Ahsa.

1.7 Study Delimitations

Temporal delimitation: The study uses quality-of-life data for 2025, with a 2022 population basis and the available school-facility data.

Spatial delimitation: The study focuses on the eight selected Saudi cities.

Thematic delimitation: The study examines the exploratory relationship between school distribution, school-building quality, population pressure, and urban quality of life.

1.8 Previous Studies

1-Binabid and Anteet (2026), Schools as Social Infrastructure and Their Contribution to Urban Quality of Life. The study examined schools as social infrastructure and their role in urban quality of life. It found that integrating schools into urban areas enhances social inclusion, community interaction, and well-being. Relation to the current study: It supports the view that school infrastructure contributes to urban quality of life, while the current study quantitatively examines this relationship across Saudi cities.

2-Abdelhamed and Zid (2025), School Design and Building-Quality Criteria in Egypt and Saudi Arabia. The study evaluated school design and building quality, focusing on safety, sustainability, energy efficiency, and learning environments. Relation to the current study: It supports the building-quality dimension examined in the current study and its potential relationship with urban quality of life.

3-Hwang (2024), Elementary School Accessibility and Spatial Equity. The study examined school accessibility and spatial equity, highlighting the importance of appropriate school locations for equitable educational services. Relation to the current study: It supports the focus on school distribution and spatial regularity as key aspects of urban planning and service equity.

4-Han et al. (2023), A Spatial Accessibility Framework for School Location and Coverage. The study developed a spatial accessibility framework to improve school location and coverage and promote educational equity. Relation to the current study: It emphasizes the importance of school location and accessibility, while the current study examines their relationship with urban quality of life.

*** Synthesis of Previous Studies**

Recent studies demonstrate that school infrastructure should be evaluated not only by the number of schools but also by their spatial distribution, accessibility, physical quality, and relationship to urban conditions. However, limited research has examined these dimensions simultaneously in relation to urban quality of life, particularly in Saudi cities. The current study addresses this gap by examining school-site distribution, building quality, and population pressure and their association with urban quality of life across eight Saudi cities.

2- Conceptual background and hypotheses

2.1 Urban quality of life as a multidimensional outcome

QoL combines objective and subjective domains. Sen's capability perspective locates wellbeing in substantive freedoms and opportunities, while social-indicator research stresses that economic and subjective measures capture different aspects of a good life (Sen, 1999; Diener & Suh, 1997). City indices operationalize this broad concept for comparison, but their contents and weights determine what they can support. The Oxford Economics Global Cities Index assesses 1,000 urban economies across Economics, Human Capital, Quality of Life, Environment, and Governance. Its QoL category covers income equality, income per person, housing expenditure, life expectancy, crime, and recreation and cultural sites (Oxford Economics, 2025). Public-school facilities are not a direct QoL-category indicator, which reduces mechanical overlap with the school variables used here.

The published Oxford ranking is valuable for consistent comparative positioning, but a rank is ordinal. A difference of 20 rank positions does not necessarily represent the same latent QoL difference at every point in the distribution. Accordingly, this paper treats rank-based results as primary and uses a higher-is-better rank-standing transformation only to improve interpretation and express model-based scenarios. No claim is made that this transformation recovers Oxford's proprietary cardinal category score.

2.2 Schools as spatially distributed social infrastructure

Accessibility research defines access as the ease with which people can reach opportunities or services, combining land use, transport, temporal, and individual components (Geurs & van Wee, 2004). For schools, spatial inequity can emerge when facility placement, residential pattern, and transport do not align. Talen (2001) demonstrated the importance of measuring elementary-school access as a question of community and spatial equity, and Moreno-Monroy, Lovelace, and Ramos (2018) showed how school location and public transport can jointly reproduce educational inequality.

Facility counts alone cannot reveal whether schools are clustered, peripheral, or evenly spaced. A city with many schools can still contain large service gaps. Conversely, a spatially dispersed governorate may show long nearest-neighbor distances because it contains remote settlements rather than because it has an equitable school network. This study therefore uses the Clark–Evans nearest-neighbor ratio as a parsimonious point-pattern indicator and accompanies it with alternative regularity and extent diagnostics (Clark & Evans, 1954; Diggle, 2013). The measure captures the pattern among observed school sites; it is not a student-level travel-time accessibility metric.

2.3 School-building quality as an independent dimension

The school building is a physical and social environment, not merely a container for instruction. Research has linked aspects of classroom design, ventilation, thermal conditions, maintenance, and overall building condition to learning, attendance, health, and school climate (Mendell & Heath, 2005; Uline & Tschannen-Moran, 2008; Haverinen-Shaughnessy et al., 2011; Barrett et al., 2015; Maxwell, 2016). Quasi-experimental evidence from school construction also suggests that infrastructure investment can affect educational and neighborhood outcomes, although the magnitude and pathway depend on context (Neilson & Zimmerman, 2014).

These findings justify retaining physical quality as a conceptually independent input. They do not imply that an average city-level building score must correlate with a broad metropolitan QoL rank. Aggregation can obscure within-city inequalities, a restricted score range can weaken detection, and building quality may affect pupils directly while contributing only indirectly to a composite urban outcome. A null city-level relationship would therefore not mean that school condition is unimportant.

2.4 Population pressure, agglomeration, and confounding

Population per school is a transparent service-pressure ratio: higher values indicate more residents per declared public-school building. In a within-region allocation analysis, high pressure can identify under-provision. Across cities, however, the ratio can be confounded by density, age structure, household composition, commuting, private-school substitution, building capacity, and metropolitan productivity. A large, attractive city can obtain a favorable QoL rank while operating under intense school demand. For this reason, the expected negative association is tested rather than assumed.

2.5 Hypotheses

H1 (primary): Higher school-site distribution evenness is associated with better Oxford QoL rank standing.

H2: Higher mean school-building quality is associated with better Oxford QoL rank standing.

H3: Lower population per school building is associated with better Oxford QoL rank standing.

The hypotheses concern city-level association. They do not assert that changing a school indicator would, by itself, cause a change in the Oxford ranking.

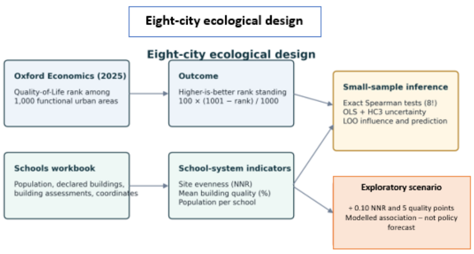

Figure 1. Analytical framework linking the published Oxford QoL rank and the Schools.xlsx workbook to three school-system dimensions, small-sample inference, and an explicitly exploratory planning scenario.

3- Materials and methods

3.1 Study design and units of analysis

The study is a cross-sectional ecological analysis with cities as the unit of observation. Inclusion required a Saudi city to appear in the 2025 Oxford Economics Global Cities Index ranking and to have a unique matching QoL rank, population total, declared number of school buildings, and facility-level school records in the Schools.xlsx workbook. Exactly eight cities met these conditions: Jeddah, Dammam, Taif, Riyadh, Khamis Mushait, Makkah, Madinah, and Al Hofuf, linked to Al-Ahsa school records. The design intentionally excludes all other Saudi regions, governorates, and cities from estimation.

The substantive school scope follows the dissertation protocol: public basic education at elementary, intermediate, and secondary levels. Private and international schools, kindergarten, higher education, specialized training institutions, and non-Ministry institutions are outside the intended scope. The workbook records public-school units operating in government-owned, rented, partnership, and other facility arrangements; these facility arrangements were not treated as private education.

Table 1. Data sources and analytical roles

Source	Reference year	Analytical scale	Variables used	Role
Oxford Economics Global Cities Index	2025	1,000 FUAs	QoL category rank	Outcome

Source	Reference year	Analytical scale	Variables used	Role
Schools.xlsx	Project extract	17,008 school-unit rows	Buildings, quality, coordinates, scope	Predictors
Saudi population basis	2022	Matched city/governorate	Population totals	P/S denominator
Derived eight-city dataset	This study	8 cities	NNR, regularity, deduplicated quality	Inference

Note. FUA = functional urban area; P/S = population per declared public-school building.

3.2 Data sources

The outcome source is the Oxford Economics Global Cities Index 2025 report. Oxford evaluates the world's 1,000 largest urban economies and publishes overall and category ranks. The attached ranking table provides QoL category ranks for the eight cities but not the underlying raw QoL category scores. The study therefore uses the rank itself and a transparent transformation of it.

The explanatory source is Schools.xlsx, a 17,008-row facility workbook containing assessment-report identifiers, school-unit attributes, city and governorate fields, population, declared building counts, a supplied building-quality percentage, coordinates, an in/out scope flag, and physical-condition fields. The eight linked units contained 5,502 school-unit rows. Because multiple school units can share a physical facility, the assessment-report identifier (Arabic field:) was used as the building-level key. This produced 4,637 unique surveyed buildings, of which 4,588 had a non-missing building-quality score. A total of 4,085 unique in-scope facilities had valid coordinates for point-pattern analysis.

Population and declared school-building totals were read from city-governorate invariant fields in the workbook. The population values correspond to the 2022 population basis used in the supporting project context and are attributed to Saudi census statistics (General Authority for Statistics, 2022). Across the eight units, the workbook recorded 19.83 million residents and 5,495 declared school buildings.

3.3 City crosswalk and geographic harmonization

City names were harmonized explicitly: Oxford Jeddah to workbook Jiddah; Dammam to Al-Dammam; Taif to Al-Taif; Riyadh to Al-Riyad; Khamis Mushait to Khamis Mushait; Mecca to Makkah al-Mukarramah; Madinah to Al-Madinah al-Munawwarah; and Al Hofuf to Al-Ahsa. Province was included in every match to prevent name collision.

Oxford's international city framework is based on functional urban areas, whereas the school workbook is aligned to administrative and project study units. These geographies are not guaranteed to coincide. The crosswalk therefore permits exploratory matching but does not establish geographic equivalence. A definitive analysis would require identical, independently defined geographic boundaries for both school indicators and QoL. Given the present mismatch, the study is interpreted as a tightly constrained exploratory ecological analysis.

3.4 Outcome construction

Let r_i denote the Oxford QoL category rank of city i among 1,000 cities, where rank 1 is best. The higher-is-better rank standing S_i was defined as:

$$S_i = 100 \times (1001 - r_i) / 1000$$

The transformation maps rank 1 to 100 and rank 1,000 to 0.1. It is affine and preserves all rank ordering. It does not create cardinal QoL information. Exact Spearman tests therefore remain the primary evidence, and OLS on S_i is used only for interpretable association-based effect scaling.

3.5 School-system indicators

Population pressure per school (P/S) was taken from the workbook and verified as population divided by the declared number of public-school buildings: -

$$(P/S)_i = P_i / B_i$$

where P_i is the population of the linked unit and B_i is the declared building count. The natural logarithm of P/S was used in OLS sensitivity models because the ratio was right-skewed.

Building quality was the workbook's supplied composite percentage (field: Building quality %). Its internal weighting formula was not available in the source data. He attachments, so the study treats it as an operational facility-condition score rather than redefining its construct. Shared-building duplicates were removed using the assessment-report identifier. The primary quality indicator is the unweighted mean among unique in-scope buildings with a score. Sensitivity measures used all unique surveyed buildings, the median, the share below 40%, and urban-only unique buildings.

School-site distribution evenness was measured among unique in-scope geocoded sites. Longitude and latitude were projected locally to kilometers using a city-centered equirectangular approximation. For each site, the distance to its nearest other site was calculated. Let $\bar{d}_o$ be the observed mean nearest-neighbor distance, n the site count, and A the convex-hull area. Under complete spatial randomness, the expected mean distance is $\bar{d}_e = 0.5/\sqrt{(n/A)}$. The Clark–Evans-style nearest-neighbor ratio is: -

$$NNR_i = \bar{d}_o / \bar{d}_e$$

The Clark–Evans-style NNR was calculated using the convex hull of observed sites. No edge correction was applied, so the statistic is sensitive to boundary definition and peripheral sites. Because site density showed the same rank association as NNR and convex-hull area was strongly associated with QoL standing, NNR cannot be interpreted as isolating the effect of spatial distribution. Density, extent, and alternative nearest-neighbor measures are therefore treated as sensitivity diagnostics rather than independent confirmation of a distribution effect.

3.6 Statistical analysis

The three focal hypotheses (H1–H3) were treated as the pre-specified primary inferential family and Holm-adjusted. Additional tests of alternative regularity measures, density, convex-hull area, regression coefficients, model fit, and sensitivity diagnostics were treated as exploratory. The exhaustive permutation test is exact conditional on exchangeability of the outcome ranks across the eight city labels. This assumption is strong because the cities differ in scale, geography, and socioeconomic context; therefore, the permutation results support within-sample exploratory inference only and should not be generalized as population-level causal evidence.

For effect scaling, OLS models regressed QoL standing on standardized indicators. The primary one-predictor model included site NNR. The joint model included standardized NNR and standardized in-scope mean building quality: -

$$S_i = \alpha + \beta_D\, z(NNR_i) + \beta Q\, z(Q_i) + \varepsilon_i$$

Classical standard errors and HC3 heteroskedasticity-consistent standard errors were reported. HC3 is useful as a finite-sample sensitivity check, but robust standard errors do not solve omitted-variable bias or model misspecification (MacKinnon & White, 1985; Long & Ervin, 2000). Exact outcome-label permutation tests were also calculated for the joint model R^2 and individual coefficients.

Influence and predictive fragility were assessed by refitting the primary joint model after omitting each city and by leave-one-city-out cross-validation. Q^2 was calculated relative to prediction by the sample mean; negative Q^2 indicates that cross-validated predictions were worse than the mean-only benchmark. With two predictors and eight cities, these diagnostics are more informative than relying on in-sample R^2 alone.

All computations used double-precision arithmetic. Missing quality scores were excluded from the relevant facility-level mean; no city-level outcome or focal predictor was imputed. Statistical tests were two-sided. Exact p-values are reported to four decimals and should be interpreted with effect size, uncertainty, multiplicity, and design limitations rather than against a binary threshold.

3.7 Planning scenario

The joint raw-scale OLS coefficients were used to construct an illustrative association-based model contrast: +0.10 NNR and +5 percentage points in mean building quality. This is a mathematical comparison within the fitted sample, not an intervention scenario, causal forecast, expected gain, or investment appraisal.

$$\Delta S = 0.10\ \hat{\beta}_D + 5\ \hat{\beta}_Q$$

The scenario increments were selected for interpretability, not because they represent a costed intervention. A 95% confidence interval was calculated from the joint coefficient covariance matrix. Because the data are cross-sectional and ecological, ΔS is an association-based model contrast, not a causal forecast, guaranteed improvement, or promise of movement in a future Oxford ranking.

4- Results

4.1 City profiles and data coverage

Oxford QoL ranks ranged from 381 for Jeddah to 480 for Al Hofuf, corresponding to standing values from 62.0 to 52.1. Dammam had the highest site-evenness NNR (0.519), while Al Hofuf/Al-Ahsa had the lowest (0.096). Mean in-scope building quality ranged from 35.47% in Taif to 44.48% in Jeddah. Population pressure varied from 1,866 residents per school in Khamis Mushait to 5,871 in Jeddah.

Unique-building survey coverage ranged from 76.8% in Taif and Madinah to 89.2% in Riyadh. In aggregate, 4,637 unique facilities were surveyed against 5,495 declared buildings, a weighted coverage of 84.4%; 98.9% of unique surveyed facilities had a quality score. These coverage levels support city-level description but allow non-response bias if unsurveyed buildings systematically differ from surveyed buildings.

Table 2. Eight-city analytical profile

City	QoL rank	Standing	Population (m)	Buildings	P/S	NNR	Quality (%)
Jeddah	381	62.0	4.67	795	5,871	0.277	44.5

City	QoL rank	Standing	Population (m)	Buildings	P/S	NNR	Quality (%)
Dammam	394	60.7	1.37	361	3,787	0.519	41.1
Taif	425	57.6	1.15	539	2,137	0.238	35.5
Riyadh	427	57.4	6.99	1,690	4,137	0.327	42.7
Khamis Mushait	433	56.8	0.66	352	1,866	0.241	38.8
Mecca	459	54.2	2.12	523	4,052	0.257	39.4
Madinah	465	53.6	1.52	617	2,467	0.189	42.5
Al Hofuf/Al-Ahsa	480	52.1	1.36	618	2,193	0.096	42.0

Note. Standing = 100 × (1001 − rank)/1000. Quality is the mean among unique in-scope scored buildings.

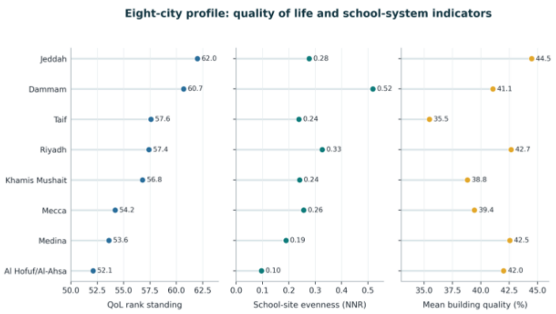

Figure 2. Eight-city values for Oxford QoL rank standing, school-site evenness, and mean in-scope building quality. Cities are ordered by QoL standing.

4.2 Focal rank associations

H1 received nominal support. QoL standing and site-evenness NNR had an exact Spearman correlation of ρ = 0.7381 (p = 0.0458). Thus, the observed rank alignment was stronger than 95.4% of the exhaustive two-sided permutation distribution. When the three focal hypotheses were treated as one family, however, the Holm-adjusted p-value was 0.1375. The result is therefore best described as a positive nominal association with multiplicity sensitivity, not definitive confirmation.

H2 was not supported. Mean in-scope building quality had only a weak positive rank association with QoL standing (ρ = 0.1190; exact p = 0.7930). The all-building mean produced a weak negative association (ρ = −0.1667; p = 0.7033), and alternative quality aggregations did not reveal a stable city-level pattern.

H3 was also not supported. Population per school correlated positively, not negatively, with QoL standing (ρ = 0.4048; exact p = 0.3268). This counter-theoretical direction indicates that the cross-city P/S ratio is entangled with urban scale and agglomeration. It should not be interpreted as evidence that higher pressure improves QoL.

Table 3. Exact Spearman tests for the three focal hypotheses

Test	Indicator	ρ	Exact p	Holm p	Interpretation
H1	Site evenness (NNR)	0.738	0.0458	0.1375	Positive nominal signal; multiplicity-sensitive

Test	Indicator	ρ	Exact p	Holm p	Interpretation
H2	In-scope building quality	0.119	0.7930	0.7930	Not supported
H3	Population per school	0.405	0.3268	0.6537	Not supported; direction opposite expectation

Note. Each exact p-value enumerates all 40,320 permutations. Holm p-values control family-wise error across H1–H3.

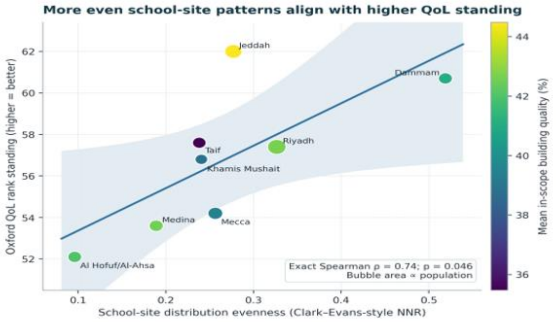

Figure 3. Primary association between school-site distribution evenness and Oxford QoL rank standing. The line and shaded band are the simple OLS fitted mean and classical 95% mean-response interval; inference is based primarily on the exact Spearman test. Bubble area is proportional to population and colour shows mean in-scope building quality. Nominal exact p = 0.0458; Holm-adjusted p = 0.1375 across three focal tests.

4.3 Regression estimates and predictive performance

In the simple standardized OLS model, a one-standard-deviation increase in NNR corresponded to 2.49 QoL standing points (95% classical CI 0.14 to 4.85), with R^2 = 0.529 and adjusted R^2 = 0.450. The classical p-value was 0.0410, but the HC3 p-value was 0.1305, demonstrating sensitivity to leverage and finite-sample uncertainty.

In the joint model, the NNR coefficient was 2.48 standing points per standard deviation (classical p = 0.0630; HC3 p = 0.1527; exact coefficient-permutation p = 0.0352). The building-quality coefficient was 0.37 points per standard deviation (classical p = 0.7336; HC3 p = 0.8652; exact coefficient-permutation p = 0.8045). The model R^2 was 0.540, but adjusted R^2 fell to 0.357 and the exact permutation p-value for model R^2 was 0.1424.

Cross-validated performance was poor: leave-one-city-out RMSE was 3.99 standing points and Q^2 was −0.549. This means that, for held-out cities, the two-predictor model performed worse than predicting the eight-city mean. The model is therefore explanatory and exploratory within the observed sample, not a validated prediction tool.

Table 4. Standardized OLS association estimates

Model	Predictor	β	Classical 95% CI	p	HC3 p	Exact coef. p
Simple	z(NNR)	2.49	[0.14, 4.85]	0.0410	0.1305	—
Joint	z(NNR)	2.48	[-0.20, 5.15]	0.0630	0.1527	0.0352

Model	Predictor	β	Classical 95% CI	p	HC3 p	Exact coef. p
Joint	z(Quality)	0.37	[-2.30, 3.05]	0.7336	0.8652	0.8045

Note. Simple model $R^2 = 0.529$; joint $R^2 = 0.540$, adjusted $R^2 = 0.357$, exact model p = 0.1424, LOOCV Q^2 = -0.549.

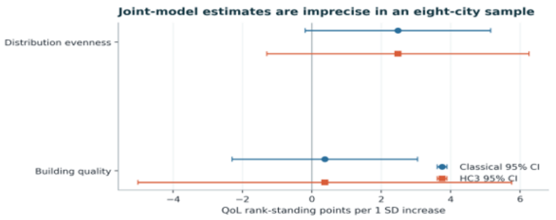

Figure 4. Standardized coefficients from the joint model with classical and HC3 95% confidence intervals. Both intervals are wide; HC3 uncertainty is particularly important in the eight-city design.

4.4 Influence and spatial-metric sensitivity

The positive direction of the NNR relationship was not created by a single city. When each city was omitted in turn, the Spearman correlation between NNR and QoL standing remained positive, ranging from 0.607 to 0.857. In joint-model refits, the standardized NNR coefficient also remained positive. In contrast, the quality coefficient changed sign across omissions, confirming its instability.

Alternative nearest-neighbor regularity, defined as 1/(1 + CV), correlated positively with QoL standing (ρ = 0.8095; exact p = 0.0218), whereas the nearest-neighbor Gini result was weaker (ρ = −0.5476; p = 0.1710). This supports the broad interpretation that more homogeneous school-site spacing aligns with better QoL standing.

The sensitivity analysis also reveals a major geographic caution. Site density had the same rank association as NNR (ρ = 0.7381; p = 0.0458), and convex-hull area correlated inversely with QoL standing (ρ = −0.8095; p = 0.0218). Consequently, part of the apparent site-pattern signal may reflect the spatial extent of the linked administrative unit—especially large Al-Ahsa and Madinah extents—rather than distribution alone. This finding reinforces the functional-urban-area versus governorate boundary limitation and prevents treating NNR as a pure accessibility measure.

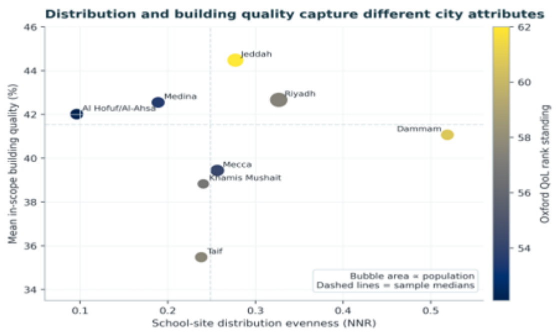

Figure 5. Joint distribution–quality plane. Bubble area is proportional to population, color indicates QoL standing, and dashed lines mark sample medians. The figure illustrates that site pattern and assessed building condition are empirically distinct dimensions.

4.5 Exploratory improvement scenario

The raw joint model estimated 20.34 QoL standing points per 1.0 increase in NNR and 0.133 points per one percentage-point increase in mean building quality. Applying the pre-defined scenario gave a distribution component of +2.03 points for +0.10 NNR and a quality component of +0.66 points for +5 quality points. Their combined point estimate was +2.70 standing points.

Relative to the eight-city mean standing of 56.8, +2.70 equals 4.75%. Because one standing point corresponds mechanically to ten rank positions under the rank transformation, the point estimate is equivalent to a mechanical rank-standing translation, not an expected future rank gain. The 95% confidence interval was −2.45 to +7.84 standing points, however, and therefore includes no gain and a negative change. The interval, the null quality relationship, and the poor cross-validation all preclude describing +2.70 as a proven effect.

Table 5. Exploratory joint improvement scenario

Component	Model contrast	Standing-point estimate	95% CI	Interpretation
Distribution	+0.10 NNR	2.03	[-0.16, 4.23]	Association component
Building quality	+5 percentage points	0.66	[-4.08, 5.40]	Not independently supported
Combined	Both changes	2.70	[-2.45, 7.84]	mechanical standing translation; CI crosses zero

Note. Confidence intervals are classical joint-model intervals. Values are association-based contrasts, not causal forecasts.

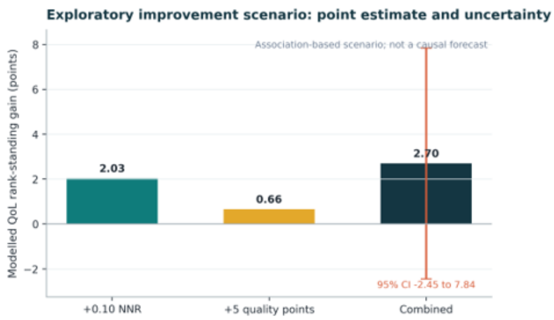

Figure 6. Decomposition of the exploratory joint scenario. The combined 95% confidence interval crosses zero. The values are model-based associations and not causal forecasts.

5- Discussion

5.1 Principal findings

Among the eight Saudi cities, school-site evenness was the only school-system dimension that showed a positive nominal rank association with the Oxford QoL outcome. The direction remained positive after omitting any single city and under an alternative nearest-neighbor regularity measure. This provides a defensible empirical signal that the spatial pattern of school sites may align with broader urban conditions associated with QoL.

The evidence is nevertheless weaker than a simple $p < 0.05$ reading would suggest. The association did not survive Holm correction across three focal tests, the HC3 p-value in the simple OLS model exceeded 0.05, the joint model was not significant as a whole under exact permutation, and cross-validated prediction was poor. In addition, NNR was entangled with site density and convex-hull extent. The most accurate conclusion is therefore "promising, boundary-sensitive association," not "proven effect."

5.2 Why spatial pattern may matter more than counts

The contrast between NNR and population per school is substantively informative. P/S compresses a city to two totals and cannot reveal internal location. NNR uses facility coordinates and distinguishes concentrated from relatively even patterns. Spatial accessibility theory predicts that opportunity depends on the arrangement of people, destinations, and transport, not only on aggregate supply (Geurs & van Wee, 2004). The results are consistent with that theory, although the study lacks population grids, road-network travel times, school capacity, and pupil origins needed to measure access directly.

For policy, this distinction means that "build more schools" and "place schools better" are not equivalent. Additional facilities can lower P/S without improving access if they reinforce existing clusters. Conversely, reallocating programs, catchments, transport support, or shared use can improve effective access without changing the citywide building count. The present analysis can identify candidate cities for deeper diagnosis but cannot prescribe exact sites.

5.3 Interpreting the null building-quality result

The absence of a city-level association between mean building quality and QoL standing should not be read as evidence that safe, healthy schools do not matter. The broader literature identifies plausible pathways from facility condition to attendance, learning, health, and school climate (Durán-Narucki, 2008; Uline & Tschannen-Moran, 2008; Barrett et al., 2015; Maxwell, 2016). The current outcome is a broad urban rank whose indicators do not directly include school condition, and the analysis averages thousands of heterogeneous buildings into one city mean.

Several factors may attenuate the relationship. The eight city means occupy a relatively narrow band; unsurvey buildings may not be random; the supplied quality score's internal weighting is unavailable; a mean can hide deprived neighborhoods; and facility benefits may emerge only after time lags or through pupil-level outcomes. Building condition may also be a necessary baseline standard rather than a differentiator of metropolitan QoL. A future study should retain building quality as an independent dimension while using building-level, neighborhood-level, and longitudinal outcomes.
quality of life.

5.4 Why population per school did not behave as expected

The positive, non-significant relationship between P/S and QoL is a warning against causal interpretation of cross-city service ratios. Jeddah and Riyadh combine large populations, strong urban economies, and high school pressure. Their favorable QoL standing can reflect income, employment, amenities, and health despite pressure on education infrastructure. Age structure and private-school enrolment can also alter the relevant public-school demand denominator. Population is not pupil demand, and a building count is not capacity.

Within a governorate or over time, P/S can remain a useful planning diagnostic. Across heterogeneous cities, it needs adjustment for school-age population, enrolment, classroom capacity, shift operation, urban density, commuting, and alternative provision. The present result therefore rejects the assumption that P/S alone demonstrates how school provision affects QoL.

5.5 Translating the scenario responsibly

The policy-relevant question is how much QoL might improve if both distribution and building quality improve. The transparent point estimate is +2.70 rank-standing points for +0.10 NNR and +5 quality points: +2.03 from distribution and +0.66 from quality. This equals 4.75% of the sample mean and approximately 27 rank places under the affine rank transformation.

Three qualifications are essential. First, the 95% interval ranges from −2.45 to +7.84, so the data are compatible with no improvement. Second, the component attributed to quality is not independently supported by the bivariate or joint tests. Third, the Oxford rank itself depends on how all 1,000 cities change; a local improvement does not guarantee the same future rank movement. The estimate is best used to define a testable planning target for a prospective evaluation, not to justify a benefit claim in an investment appraisal.

5.6 Implications for Saudi urban and education planning

The findings support an integrated workflow rather than a single national coefficient. Cities with low spatial regularity should first be examined using pupil-weighted network access, catchments, travel time, capacity, and land availability. Building interventions should be prioritized using safety, health, maintenance, and utilization criteria even where the city mean is not associated with QoL. Population pressure should be calculated with school-age population and effective capacity rather than total population alone.

A decision dashboard could therefore retain three separate axes: (1) accessibility and distribution, (2) physical quality and safety, and (3) capacity pressure. Combining them only after validation avoids allowing a strong value on one dimension to conceal weakness on another. It also aligns with SDG 4.a's concern for safe, inclusive learning environments and with Vision 2030's emphasis on loveable cities.

The eight-city comparison suggests where deeper work may be most useful, not which city "performs best" overall. Al Hofuf/Al-Ahsa and Madinah require boundary-resolved accessibility analysis because their administrative spatial extents strongly affect point-pattern metrics. Taif's lower mean building-quality score warrants building-level condition review. Jeddah combines the highest QoL standing and building quality with the highest P/S, illustrating why aggregate indicators need joint interpretation.

6- Strengths and limitations

This study has several strengths. It enforces the requested eight-city scope; reconciles city names explicitly; distinguishes ranks from raw scores; deduplicates shared school buildings; uses thousands of geocoded facility records; separates distribution, quality, and pressure; conducts exhaustive rather than asymptotic rank tests; reports multiplicity, HC3, influence, and cross-validation sensitivity; and translates coefficients into a scenario without hiding uncertainty.

The limitations are substantial. Eight observations offer low power, unstable regression estimates, and no credible basis for a complex multivariable causal model. The design is ecological, so city-level relationships cannot be assigned to pupils, households, or neighborhoods (Robinson, 1950). It is cross-sectional and temporally mismatched: school and population conditions are linked to a 2025 QoL rank without a panel demonstrating sequence. Omitted variables—including income, density, transport, school-age share, enrolment, capacity, private provision, municipal investment, and governance—can confound all coefficients.

Geography is another central limitation. Oxford functional urban areas and the workbook's governorate-aligned study units do not necessarily share boundaries. Convex-hull NNR is sensitive to peripheral sites and does not include an edge correction. All observed NNRs are below 1, indicating clustering relative to complete spatial randomness, but the appropriate benchmark for schools is not necessarily randomness. Schools respond to settlement pattern, zoning, topography, and road networks. A more even point pattern is not automatically more equitable if residents are unevenly distributed.

The supplied building-quality score is operationally useful but incompletely documented. Its item weights, inter-rater reliability, assessment dates, and external validation were unavailable. It should therefore receive limited inferential weight until the measurement instrument is documented and independently validated.

Finally, Oxford publishes QoL category ranks in the attached table rather than underlying raw category scores. Rank standing improves readability but remains ordinal information. Scenario rank-place equivalents are mathematical translations, not predicted future positions, because other cities' performance and Oxford's methodology can change.

7- Future Research Agenda

Future research should first resolve the geographic mismatch by using identical, independently defined boundaries for QoL and school data, with edge-corrected spatial statistics. It should compare NNR, density, extent, accessibility, and population-weighted travel-time measures before attributing meaning to distribution. Larger samples should permit adjustment for urban scale, density, income, school-age population, enrollment, and effective capacity. Longitudinal or quasi-experimental designs are needed to assess temporal ordering and causal mechanisms. The building-quality instrument should also be documented and externally validated. Until these steps are completed, the present findings should be treated as hypothesis-generating rather than predictive or investment-guiding.

8- Conclusion

Across eight Saudi cities, school-site evenness showed a positive nominal association with Oxford QoL rank standing ($\rho=0.738$, $p=0.0458$), but this association was not supported after Holm correction and was sensitive to geographic extent and site density. School-building quality and population per school building were not supported as city-level associations with QoL standing. The joint regression had poor cross-validated performance ($Q^2=-0.549$), and the illustrative +2.70 standing-point model contrast had a 95% CI spanning −2.45 to +7.84. These findings do not support causal or predictive claims. The study is best regarded as hypothesis-generating and as a basis for future analyses using matched geographic boundaries, edge-corrected spatial measures, school-age demand, effective capacity, and longitudinal designs.

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