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Coastal public realms and housing livability in Saudi cities: developing a comprehensive waterfront development index (CWDI) for Jeddah

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Introduction: Urban waterfronts in Gulf cities are strategic public assets crucial for environmental risk management and enhancing the livability of surrounding residential and national housing areas, yet most existing urban evaluation indices are city-wide and lack the sensitivity required for hot–arid coastal environments. This study responds by developing a context-specific performance metric to evaluate coastal public realms and examine how waterfront performance can be conceptually linked to housing-community welfare, while acknowledging that household-level housing outcomes are not directly measured in this study.

Methods: We developed and applied a novel Comprehensive Waterfront Development Index (CWDI) tailored to Jeddah, Saudi Arabia, to evaluate coastal public realms across sustainability, resilience, and cultural and social integration dimensions aligned with Vision 2030. The CWDI uses a mixed-methods design that integrates global urban evaluation frameworks (Tier 1 indicators) with context-specific indicators reflecting Jeddah's climate and culture (Tier 2 indicators). Dimension weights were calibrated using the Analytic Hierarchy Process (AHP) with input from residents, business operators, and planning professionals. The index was applied to three major waterfront zones, North Corniche, Central Waterfront, and the Historic Waterfront (Al Balad), using a combination of field surveys (n = 312), spatial datasets, and administrative records.

Results: Findings reveal a "two-speed" waterfront: newly redeveloped zones perform relatively well in Public Spaces and Amenities (3.5/5) and Accessibility (3.1/5), offering improved spatial amenities for adjacent housing communities. However, Resilience and Climate Adaptation (2.1/5) and Environmental Sustainability (2.7/5) are the weakest dimensions, with low scores for solar adoption, cooling infrastructure, and flood risk mitigation. The historic Al Balad waterfront consistently underperforms, exposing heritage communities to environmental risks and poor public-space provision.

Discussion: The analysis demonstrates that while public investment has successfully enhanced amenities in new zones, critical resilience and environmental gaps remain, particularly impacting vulnerable and historic communities. The study makes three key contributions: (i) it offers a transferable, waterfront-specific, stakeholder-informed index suitable for hot–arid Gulf cities; (ii) it empirically examines the spatial interface between coastal public realm quality and social housing livability; and (iii) it provides

actionable policy recommendations for integrating CWDI scoring into municipal governance and the planning of future coastal housing projects to drive performance toward Vision 2030 goals.

KEYWORDS

comprehensive waterfront development index (CWDI), jeddah, Saudi vision 2030, social housing, urban resilience, urbansustainability

1 Introduction

1.1 Waterfronts, housing livability, and resilience in gulf coastal cities

Across the world, urban waterfronts have become focal points of regeneration, climate adaptation, and public-realm investment. Formerly industrial or port-dominated zones are increasingly reimagined as mixed-use, accessible, and resilient urban fronts that support economic diversification, environmental restoration, and social cohesion (Beatley, 2014a; Barbero and Timpe, 2025; Tommarchi, 2025). These coastal public realms can also shape everyday experiences for surrounding neighborhoods, including lower-income and social-housing districts, by offering recreational space, opportunities for social interaction, and, in some contexts, relatively cooler microclimates compared with those of inland urban areas.

In Saudi Arabia, Vision 2030 and associated programs have elevated quality of life, environmental sustainability, and housing provision as national priorities, including large-scale national and social housing schemes. Coastal cities such as Jeddah occupy a central position within this agenda due to their combined port functions, tourism economy, heritage assets, and rapidly expanding residential areas. The Jeddah waterfront is among the Kingdom's most prominent public-facing spaces, connecting diverse user groups, residents, visitors, and households across income levels, within a shared public realm that influences perceived livability and environmental comfort (Zaki and Hegazy, 2023).

Despite this strategic role, evaluation tools for Gulf waterfronts remain limited. Many widely used sustainability and livability indices operate at the city scale and therefore struggle to capture fine-grained differences across waterfront segments or to capture how coastal public-realm performance may relate to adjacent housing areas. For social and national housing in coastal settings, this is a critical blind spot: housing-community livability and resilience may be shaped not only by housing conditions, but also by the accessibility, comfort, and safety of regional public assets such as waterfronts.

1.2 Social and national housing, public open space, and coastal context

Gulf countries have invested heavily in national and social housing programs, which have often featured low-density suburban layouts and car-dependent mobility (Alawadi et al., 2024; Arif and Aldosary, 2023). Recent policy shifts increasingly emphasize more compact, mixed-use, and environmentally sustainable forms, alongside improved access to public open space and amenities. In coastal cities such as Jeddah, Dammam, and Jubail, waterfronts can function as regional "lungs" and social condensers, providing public space that many housing developments, particularly older or lower-income neighborhoods, lack internally (Mostafa and Alshahrani, 2024).

In this context, coastal public realms are not isolated leisure landscapes; they function as critical shared infrastructure for housing quality of life. They offer outdoor thermal-relief spaces in hot–humid climates; everyday recreation and walking/cycling environments for households who may not have private amenities; opportunities for social integration among diverse income and nationality groups; and a visible interface between housing policy, tourism, and heritage-led development.

In the Saudi context, these dynamics are inseparable from the rapid expansion of national and social housing programs, which increasingly structure the city's residential geography and everyday mobility. Many beneficiaries of these schemes, as well as lower–middle-income households in older districts, rely on regional public assets such as the Jeddah waterfront to compensate for limited private and neighborhood-level amenities. The performance of the coastal public realm in terms of accessibility, outdoor thermal comfort, safety, cultural inclusiveness, and climate resilience can therefore be understood as a contextual factor that shapes the conditions for housing livability and social equity in the city. However, existing tools for evaluating social and national housing in the Gulf rarely consider how well adjacent or connected waterfronts function as shared infrastructure for these communities, leaving a critical gap at the interface of housing policy, public-space design, and coastal risk management.

1.3 Research gap and aim

Several composite indices, such as the Sustainable Cities Index (SCI), LEED for Neighborhood Development (LEED-ND), and the Global Liveability Index (GLI), offer structured approaches to assessing urban sustainability and livability (Arcadis, 2022; U.S. Green Building Council, 2016; Economist Intelligence Unit, 2023). They cover critical areas such as mobility, the environment, the economy, and social services. However, when applied to Gulf coastal cities, three limitations are evident:

1. **Scale and coastal specificity:** These frameworks are predominantly city-wide and are not designed to evaluate waterfront segments or marine–coastal interfaces and associated climate risks.
2. **Climatic and governance sensitivity:** Many indicators and thresholds are calibrated for temperate contexts, with limited sensitivity to hot–arid/hot–humid conditions, high solar exposure, and Gulf institutional and cultural practices.
3. **Weighting and contextual differentiation:** Most indices rely on fixed or proprietary weighting schemes and rarely distinguish between globally comparable indicators and locally specific priorities derived from stakeholders.

Consequently, municipal planners and housing authorities in Saudi Arabia lack a practical, context-sensitive index for evaluating waterfronts in terms of their relationship to broader livability and resilience concerns associated with social and national housing. In this context, this study aims to develop and apply a context-specific evaluation framework, the Comprehensive Waterfront Development Index (CWDI), to assess the sustainability, resilience, and social inclusiveness of Jeddah's waterfront as a strategic public asset for surrounding housing and social-housing communities.

1.4 Objectives and contributions

To achieve this aim, the study pursues the following objectives:

1. Review and synthesize global urban sustainability and livability frameworks relevant to waterfront development.
2. Identify and adapt evaluation dimensions and indicators suitable for Jeddah's coastal and housing-related context.
3. Calibrate and weigh the index using multi-stakeholder input through the Analytic Hierarchy Process (AHP).
4. Apply the CWDI to three key waterfront zones in Jeddah using mixed methods and compare the results against international best practices.
5. Derive planning and policy recommendations for integrating CWDI into waterfront governance and into the design and management of coastal public realms serving national and social housing in Gulf cities.

The study contributes by:

- Proposing a waterfront-specific, two-tier index that distinguishes between globally comparable and Saudi/Gulf-specific indicators.
- Demonstrating a stakeholder-informed weighting approach that embeds local values and housing-related priorities.
- Providing a diagnostic and strategic tool that can be used by municipal authorities, housing agencies, and planners to help inform investments and regulatory reforms in coastal public realms.

2 Literature review

2.1 Evolution of urban waterfront development

Historically, waterfronts were engines of industrial growth, maritime trade, and logistics, but also sources of environmental degradation and physical separation between cities and their water bodies (Breen and Rigby, 1994; Hoyle, 2000; Sairinen and Kumpulainen, 2006; Desfor and Laidley, 2011; Benabbou et al., 2022; Wu and Liu, 2023). From the mid-twentieth century onwards, deindustrialization and port relocation triggered widespread waterfront decline, with many sites becoming underused or derelict. In response, cities such as Baltimore, London, and Barcelona pioneered waterfront regeneration, repositioning these areas as mixed-use, pedestrian-oriented quarters with strong real estate, tourism, and cultural functions.

Contemporary scholarship frames waterfronts as socio-ecological systems that deliver ecosystem services (flood regulation, microclimate moderation, biodiversity corridors) and social and health benefits (Pelling, 2010; Turner et al., 2016). This has led to calls for integrating coastal management, landscape ecology, and climate resilience into waterfront planning (IPCC, 2022).

At the same time, critical perspectives warn that regeneration can produce exclusionary enclaves, displace low-income communities, and limit access for ordinary residents (Bruttomesso, 2001; Pistone, 2025). Equitable access, participatory governance, and cultural representation are therefore considered essential for socially just waterfront development.

In sum, waterfront transformations today must reconcile economic revitalization, environmental stewardship, and social inclusion. For Gulf cities, this implies not only high-profile tourism and leisure projects but also attention to how waterfronts support everyday life for nearby housing neighborhoods, including national and social housing.

2.2 Social housing, public realm, and coastal environments

In the Gulf region, social and national housing policies have traditionally prioritized plot-based, low-density housing forms, often on the urban periphery. This model has contributed to car dependency, limited walkability, and uneven access to high-quality public spaces (Alawadi et al., 2024; Dahy et al., 2024; Patel et al., 2025).

Recent policy reforms under Saudi Vision 2030 and similar national agendas in other Gulf states emphasize improved housing quality, compact and mixed-use development, and better integration of public spaces and mobility networks (Klingmann, 2022; Alansari and Alkhaled, 2023; Arif and Aldosary, 2023; Aloshan et al., 2024; Refaat et al., 2024; Abdallah et al., 2025).

In coastal cities, the interface between housing and waterfronts is critical. Well-designed coastal public spaces can provide accessible recreational and social environments for residents of nearby housing, including lower-income groups; enhance perceived livability and mental health, especially when internal neighborhood amenities are limited; and serve as part of a climate adaptation strategy, offering cooling corridors, vegetated buffers, and flood risk mitigation features that benefit both the public realm and adjacent housing.

However, there is still a scarcity of operational tools that link waterfront performance directly to housing and social-housing outcomes, especially in hot–arid Gulf contexts where outdoor thermal comfort and resilience are critical.

2.3 Urban evaluation frameworks and their limitations for arid waterfronts

Several global frameworks quantify urban sustainability and livability:

TABLE 1 Comparative analysis of selected urban sustainability and livability frameworks.

Framework	Core dimensions	Key indicators (illustrative)	Weighting methodology	Relevance to gulf coastal cities and housing contexts
Sustainable cities index (SCI) (arcadis)	People (social), planet (environmental), profit (economic)	Public transport access, healthcare, green space provision, income inequality, energy use, GHG emissions	Proprietary weighted scoring based on arcadis' global urban benchmarking model	High relevance for providing a macro-level sustainability lens, but it lacks coastal/marine indicators and does not explicitly consider waterfronts as shared infrastructure supporting national and social housing neighborhoods
LEED for neighborhood development (LEED-ND) (USGBC)	Smart location & linkage; neighborhood pattern & design; green infrastructure & buildings	Walkability, connectivity, water efficiency, brownfield redevelopment, energy performance, integration of public spaces	Points-based system with fixed thresholds; aggregate score determines certification level	Strong applicability to build form, public-realm quality, and green infrastructure; however, temperate-climate assumptions and north american standards require adaptation for hot–humid coastal environments and for waterfronts serving lower-income and social-housing communities
Global liveability index (GLI) (EIU)	Stability; healthcare; culture & environment; education; infrastructure	Safety, healthcare access, climate comfort, cultural availability, transport and utilities, and education quality	Weighted scoring based on expert panels and global datasets; updated regularly across 140+ cities	Useful for high-level livability benchmarking but lacks spatial resolution, coastal/climate-resilience indicators, and explicit attention to distributional issues affecting residents of lower-income or social-housing districts that depend on regional public assets such as waterfronts

- The Sustainable Cities Index (SCI), developed by Arcadis, structures city performance under three pillars, People, Planet, and Profit, covering aspects such as transport, green space, economic stability, and social equity (Arcadis, 2022).
- LEED for Neighborhood Development (LEED-ND) provides a rating system for smart location, neighborhood pattern and design, and green infrastructure/buildings, widely used in planning walkable, mixed-use, and ecologically responsible neighborhoods (U.S. Green Building Council, 2016).
- The Global Liveability Index (GLI), produced by the Economist Intelligence Unit, benchmarks cities across stability, healthcare, culture and environment, education, and infrastructure (Economist Intelligence Unit, 2023).

Table 1 provides a comparative overview of these three frameworks, examining their core dimensions, key indicators, scoring methodologies, and relevance to arid waterfront environments.

While influential, these frameworks are not tailored to coastal, hot–arid environments (Pizzo, 2015; Lucas et al., 2016; Angelidou, 2017). SCI and GLI operate at the city scale, with limited attention to coastal edges, marine ecosystems, and climate–water interactions. Furthermore, LEED-ND offers strong guidance on the built environment but assumes temperate climatic norms and vegetation standards that require adaptation in arid/hot–humid settings.

Finally, many indices rely on top-down weighting schemes that underrepresent local stakeholder priorities and governance realities. These limitations motivate the development of a waterfront-focused index that combines good global practice with indicators and weights grounded in Gulf environmental and institutional contexts.

2.4 Learning from international waterfront best practices

To inform index design, this study draws qualitative lessons from three internationally recognized waterfront cases:

- **Sydney** (Darling Harbor, Barangaroo): Characterized by strong public–private partnerships, transit integration, and climate-resilient coastal infrastructure.
- **Vancouver** (False Creek, Granville Island): Known for community-led planning, ecological zoning, green infrastructure, and integration of affordable housing.
- **Barcelona** (Olympic Port, Forum Area): Demonstrating event-led regeneration, adaptive reuse of industrial land, and activation of beaches and cultural spaces.

These cases were selected based on demonstrated success in sustainable waterfront regeneration and integrated governance; availability of documented performance data that can be mapped onto the CWDI dimensions; and the presence of coastal climate stressors (flooding, stormwater, urban heat), even if climatic conditions differ from those in Jeddah.

Gulf cities such as Dubai, Doha, and Muscat are more similar to Jeddah in terms of climate and culture. However, their detailed

TABLE 2 Global best practices comparison.

City	Key features of waterfront development	Link to CWDI dimensions and housing/ Neighborhood livability
Sydney (darling harbor, barangaroo)	Strong public–private partnerships; integrated transit and pedestrian planning; high-quality public spaces and cultural venues; climate-resilient coastal infrastructure	**Accessibility:** Excellent pedestrian–transit integration improves access for surrounding residential and high-density housing areas. **Public spaces & amenities:** Mixed-use, activated public realm. **Economic vitality:** Strong tourism and service clusters. **Resilience & climate adaptation:** Flood protection and landscaped edges that reduce risk for adjacent neighborhoods
Vancouver (false creek, granville island)	Community-led planning and environmental zoning; integration of affordable housing; extensive green infrastructure and low-carbon energy; human-scale, walkable environment	**Environmental sustainability:** Green–blue infrastructure and ecological zoning. **Cultural & social integration:** Heritage reuse and strong community stewardship. **Accessibility:** Continuous public access to the water for nearby housing districts. **Economic vitality:** Support for local and eco-oriented economies, benefitting mixed-income residents
Barcelona (olympic port, forum area)	Post-event regeneration of industrial waterfront; redeveloped public beaches and cultural spaces; maritime economy and tourism infrastructure; adaptive reuse of industrial land	**Cultural & social integration:** Public art, cultural programming, and civic identity. **Public spaces & amenities:** Active beaches and coastal promenades. **Economic vitality:** Tourism–maritime synergy. **Accessibility:** Coastal walkways and multimodal connections that serve surrounding dense residential areas

The bold values refer to the name of each dimensions.

waterfront performance data is less standardized and often embedded in non-public master plans (Almheiri et al., 2024). For this reason, the present study uses Sydney, Vancouver, and Barcelona as governance and design benchmarks, while concluding that CWDI can be adapted to Gulf waterfronts and coastal housing-led projects.

The case study selection was informed by literature on global waterfront planning and policy innovation (Aelbrecht and Arefi, 2024; Amrousi et al., 2024; Benabbou et al., 2022; Huang et al., 2022; Tommarchi, 2025; Üzümcüoğlu and Polay, 2023; Zaman et al., 2024). To ensure comprehensive comparative value, five thematic selection criteria were used:

- **Environmental comparability**: Each city addresses climate stressors such as urban heat, coastal flooding, or stormwater runoff through context-sensitive interventions.
- **Integrated infrastructure**: Green-blue infrastructure, coastal protection systems, and energy-efficient design are standard features across all three cases.
- **Governance and policy innovation**: The cases reflect successful cross-sectoral coordination and inclusive urban governance.
- **Community participation and land-use diversity**: Emphasis on mixed-use development and public engagement supports social integration and vibrant waterfronts.
- **Scalability and transferability**: The policy tools, design strategies, and governance models demonstrated in these cities are adaptable to Jeddah's institutional and ecological context.

To extract actionable lessons, a framework-based analysis assessed key practices, policies, and design features across the six CWDI dimensions in each city: Accessibility, Environmental Sustainability, Economic Vitality, Public Spaces and Amenities, Cultural and Social Integration, and Resilience and Climate Adaptation. Lessons were categorized thematically, facilitating benchmarking and comparison. Results are in Table 2. Connecting global practices to local planning, this section provides an empirical basis for a waterfront index, filling a gap in the literature on Middle Eastern coastal urbanism and positioning the CWDI as a regionally relevant contribution.

3 Materials and methods

3.1 Research design and CWDI conceptual framework

The Comprehensive Waterfront Development Index (CWDI) is designed to capture the multi-dimensional performance of urban waterfronts as socio-ecological public realms that support housing livability and resilience. The conceptual framework integrates:

- **Coastal urbanism and blue urbanism** (waterfronts as interfaces of land, water, and climate risk) (Beatley, 2014b; Huang et al., 2022; IPCC, 2022; Chen and Ma, 2023; Toomey et al., 2023; Üzümcüoğlu and Polay, 2024; Zaman et al., 2024)
- **Urban regeneration and public-space theory** (waterfronts as catalysts for mixed-use development and social life) (Breen and Rigby, 1994; Sairinen and Kumpulainen, 2006; Desfor and Laidley, 2011; Gehl, 2020; Toomey et al., 2021; Dubinina et al., 2022; Wu and Liu, 2023; Tommarchi, 2025).
- **Resilience and climate adaptation frameworks** (flood risk management, heat mitigation, and ecosystem-based approaches) (Pelling, 2010; Sharifi and Yamagata, 2020; Ciampa et al., 2021; UNEP, 2021; Crupi, 2022; IPCC, 2022; Baumeister, 2023; Burda and Nyka, 2023; Pistone, 2025; Thomas et al., 2024).

Methodologically, the study follows four sequential phases:

1. **Framework review and dimension screening**: reviewing SCI, LEED-ND, GLI, and waterfront literature to derive candidate dimensions.

2. **Indicator development and two-tier structuring**: selecting and classifying indicators into globally core comparable (Tier 1) and Jeddah-specific (Tier 2).
3. **Stakeholder-based weighting**: eliciting dimension weights via the AHP process.
4. **Application to Jeddah**: scoring three waterfront zones, triangulating survey responses with spatial, environmental, and administrative data, and benchmarking against international cases.

3.2 Dimension selection

Based on thematic convergence across global indices and local relevance screening, six headline dimensions were selected:

1. **Accessibility** (transport connections, walkability, universal design).
2. **Public Spaces and Amenities** (parks, recreation, services).
3. **Economic Vitality** (business diversity, tourism, employment).
4. **Environmental Sustainability** (green-blue infrastructure, resource efficiency).
5. **Cultural and Social Integration** (heritage, social inclusion, public art).
6. **Resilience and Climate Adaptation** (flood protection, heat mitigation, emergency preparedness).

At an earlier stage, additional candidate dimensions (governance, mobility integration, and ecosystem services) were examined. However, they were incorporated into the six final dimensions to avoid over-fragmentation and maintain usability for municipal practitioners. Governance-related indicators are embedded primarily in Public Spaces and Amenities and Cultural and Social Integration; mobility integration in Accessibility; and ecosystem services in Environmental Sustainability and Resilience and Climate Adaptation. This consolidation follows recommendations in recent coastal/blue-urbanism guidance and waterfront evaluation work (UN-Habitat, 2020; UNEP, 2021; Zaman et al., 2024; Gonzalez-Pardo et al., 2025).

3.3 Indicator development and two-tier structure

An initial pool of 64 indicators was compiled from SCI, LEED-ND, GLI, waterfront literature, and Saudi/Vision 2030 policy documents. Indicators were screened using three criteria:

- Relevance to hot–arid coastal urbanism and waterfront–housing linkages.
- Data availability through official sources, remote sensing, or field surveys.
- Stakeholder priority, based on expert workshops with planners, municipal staff, and community representatives.

This process yielded 42 indicators, organized into a two-tier structure:

- **Tier 1 (Core)**: 25 indicators that are broadly applicable to waterfronts in diverse cities (e.g., pedestrian continuity, public transit access, green space *per capita*, business diversity).
- **Tier 2 (Context-Specific)**: 17 indicators tailored to Jeddah and Gulf coastal contexts (e.g., shading coverage, cooling infrastructure, heritage-site integration, religious/traditional space provision, heat island mitigation, stormwater reuse).

The complete list of indicators, including their classification and measurement metrics, is provided in Appendix A (Supplementary Table A1).

3.4 Weighting scheme and CWDI formula

3.4.1 AHP-based dimension weighting

Dimension weights were derived using the Analytic Hierarchy Process (AHP). Three stakeholder groups were surveyed:

- **Residents** (n = 93) live in districts that commonly use the waterfront.
- **Business and tourism operators** (n = 27) active along the waterfront.
- **Planning professionals and academics** (n = 18) with expertise in urban/coastal planning.

Each respondent completed pairwise comparisons of the six CWDI dimensions. Individual matrices were checked for internal consistency; responses with a consistency ratio (CR) above 0.10 were not used individually but were combined into group-level geometric means to retain stakeholder representation. Group-level CR values were below 0.08. It is important to note that the AHP method relies on structured expert judgment and internal consistency of comparisons rather than statistical representativeness of the sample; therefore, the resulting weights reflect the priorities of the selected stakeholder groups rather than statistically generalized population estimates. To avoid dominance of any numerically larger group, the final dimension weights were obtained through a two-step aggregation:

1. Compute a weight vector for each stakeholder group using the geometric mean of their pairwise comparisons.
2. Average the three group vectors with equal weight (1/3 each), rather than weighing by sample size.

Table 3 reports on the resulting weights. Resilience and Climate Adaptation (20.8%) and Public Spaces and Amenities (19.4%) emerge as the top-priority dimensions, followed by Economic Vitality (16.2%) and Accessibility (16.1%). Cultural and social integration and environmental sustainability, while slightly lower, still constitute significant shares.

3.4.2 Indicator weighting within dimensions

Within each dimension, indicators were assigned relative weights through expert workshops with planners and academics. Overlapping or low-impact indicators were merged or dropped to maintain parsimony. Within each dimension, weights sum to 1.0, ensuring that each dimension score is a weighted average of its indicators.

TABLE 3 CWDI scores by indicator for Jeddah's waterfront, with key observations and primary stakeholder relevance.

Dimension	Indicator	Score (0–5)	Summary of key observations	Main stakeholder relevance
Accessibility	Pedestrian network continuity	3.0	Walkability is moderate; continuous promenades in newer sections, but gaps and interruptions near older segments and Al balad	Residents, housing authorities
	Bicycle lane coverage	2.5	Inconsistent bicycle lane coverage; some new sections have lanes, but networks are fragmented	Residents, policymakers
	Universal accessibility compliance	3.8	Approx. 37% of facilities meet universal design standards; older segments lag behind	Residents (including disabled users), policymakers
	Public transit access	3.2	Bus routes exist near most waterfront segments, but service frequency and shade at stops are limited	Residents, businesses
	Signage and wayfinding	2.9	Basic signage present; limited multilingual information and scarce digital or real-time guidance	Residents, tourists
	Shaded walkways	2.3	Shade coverage is limited; many key pedestrian stretches remain exposed to direct sun in summer	Residents, housing communities
	Parking and drop-off zones	3.1	Parking is moderately available but poorly organized at peak times; there is a limited designated drop-off for families and disabled users	Residents, businesses
	Normalized accessibility score	**3.1**		
Public spaces and amenities	Public restroom availability	3.6	Restrooms are available and relatively well-maintained in newer zones; historic and older areas remain underserved	Residents, tourists
	Café and commercial node density	3.9	High density of cafés and commercial nodes in north corniche; sparser offer in some segments	Residents, businesses
	Nighttime safety	3.0	Lighting improved in many sections, but residents report dark spots and insufficient policing in others	Residents, businesses
	Park and green area accessibility	3.5	Parks and green pockets exist but remain unevenly distributed along the waterfront	Residents, families
	Recreational infrastructure	3.3	Playgrounds, sports courts, and exercise equipment are present but vary in quality and coverage	Residents, youth
	Cleanliness and maintenance	3.0	Cleanliness is moderate; waste bins are present but irregularly placed and sometimes overflowing at peak times	Residents, municipal services
	Event hosting capacity	2.8	Limited permanent infrastructure for events; temporary structures are often used during festivals	Policymakers, event organizers
	Normalized public spaces & amenities score	**3.5**		
Economic vitality	Tourism revenue per capita	3.2	Tourism revenue is strong in northern zones and obhur but weaker near Al balad waterfront	Businesses, tourism authorities
	Local business diversity index	2.8	Commercial mix is concentrated around certain hubs; inland segments and historic areas have less diverse offerings	Businesses, municipal planners
	Street vendor regulation score	2.7	Informal vendors are present but weakly regulated; issues of congestion and hygiene persist in peak seasons	Businesses, policymakers
	Property value appreciation	3.5	Property values have been appreciated significantly in redeveloped waterfront sectors, less so in older districts	Investors, housing authorities
	Investment in waterfront projects	2.9	Investment patterns show strong focus on flagship areas, with gaps in secondary and historic segments	Policymakers, private sector
	Nighttime economy index	2.6	Activities taper off after late evening; underutilized potential for family-oriented and youth activities at night	Businesses, residents
	Job creation rate	3.0	Job creation tied to tourism and services is moderate and often seasonal	Businesses, labour authorities
	Normalized economic vitality score	**2.9**		

(*Continued*)

TABLE 3 Continued

Dimension	Indicator	Score (0–5)	Summary of key observations	Main stakeholder relevance
Environmental sustainability	Green space per capita	2.5	Green areas are expanding in new projects but remain limited overall; tree canopy coverage is still modest	Residents, policymakers
	Solar panel usage rate	1.2	Only around 4% of waterfront buildings use rooftop PV; limited adoption of on-site renewables	Policymakers, businesses
	Stormwater management systems	2.4	Basic drainage and retention basins present; some low-lying zones remain vulnerable to heavy-rain events	Policymakers, JSDP
	Air quality index	3.3	Generally acceptable, with seasonal dust events and traffic-related peaks	Residents, health authorities
	Waste separation facilities	2.1	Few recycling points; sorting is not systematic across waterfront facilities	Residents, municipal services
	Use of sustainable materials	2.7	Use of eco-materials in recent projects; older segments retain conventional materials and surfaces	Policymakers, designers
	Energy efficiency of buildings	2.9	Limited number of LEED or equivalent certified buildings; energy retrofits are still emerging	Policymakers, developers
	Normalized environmental sustainability score	**2.7**		
Cultural & social integration	Cultural programming frequency	2.3	Regular events occur in peak seasons but less in off-peak months; limited continuity in cultural calendar	Residents, ministry of culture
	Heritage site integration	2.9	Heritage elements near Al balad are visible but not fully integrated into waterfront narratives and routes	Policymakers, heritage authorities
	Youth-oriented facilities	3.1	Sports and play areas exist but are insufficient for growing populations	Youth, housing communities
	Public art installations	3.4	Several public art pieces are present, though not always contextually linked to local culture	Residents, tourists
	Community participation mechanisms	2.6	Limited structured opportunities for community input into waterfront design and management	Residents, NGOs
	Diversity and inclusion events	2.7	Some inclusive events exist, but representation of different groups and neighborhoods is still limited	Residents, municipalities
	Religious and traditional space allocation	3.0	Basic provision for prayer and traditional gathering spaces in selected nodes	Residents, religious affairs
	Normalized cultural & social integration score	**2.8**		
Resilience & climate adaptation	Flood risk mitigation index	2.0	High-risk coastal and low-lying zones still face flood and drainage challenges during extreme rainfall	Policymakers, businesses, housing authorities
	Emergency response infrastructure	2.2	Emergency access and response systems exist but are not fully coordinated or well signposted	Civil defense, residents
	Heat island mitigation features	2.1	Limited shading, reflective surfaces, and cooling landscapes; many paved areas intensify heat stress	Residents, health authorities
	Climate-adaptive design standards	2.3	Climate-responsive design principles are referenced in policy, but implementation on the ground remains partial	Policymakers, designers
	Cooling infrastructure coverage	1.8	Very few water-based, misting, or mechanical cooling installations in public spaces	Residents, tourists
	Disaster evacuation planning	2.6	Evacuation plans exist on paper but lack clear signage, drills, and public communication	Residents, civil defense
	Water reuse and recycling	2.0	Stormwater and greywater reuse systems are largely absent in existing waterfront infrastructure	Policymakers, utilities
	Normalized resilience & climate adaptation score	**2.1**		

The bold values refer to the normalized score.

3.4.3 Aggregation formula

The CWDI uses a three-level aggregation. First, indicator scores (s_{ij}) are assigned to the indicator j within dimension i on a 0–5 scale based on calibrated thresholds. Second, dimension scores S_i are computed as weighted averages of indicator scores:

$$S_i = \sum_{j=1}^{n_i} w_{ij}\ s_{ij}$$

where w_{ij} is the normalized weight of the indicator j in dimension i, and n_i is the number of indicators in the dimension i.

Finally, the overall CWDI score for a waterfront zone is computed as:

$$CWDI = \sum_{i=1}^{6} W_i\ S_i$$

where W_i is the AHP-derived weight of the dimension i, and $\sum_i W_i = 1.0$. Dimension scores are reported on a 0–5 scale, and the overall CWDI can be expressed either on a 0–5 scale or rescaled to 0–100 for communication.

3.5 Scoring system and thresholds

Each indicator is scored on a 0–5 ordinal scale:

- **0** – indicator absent or severely deficient.
- **3** – meets minimum standard or acceptable performance level.
- **5** – exemplary performance, aligned with best-practice benchmarks.

Thresholds were established based on a literature review and local policy targets, with detailed justifications provided in Appendix A (Supplementary Table A2). For Tier 2 indicators, thresholds were calibrated to Jeddah's context, for example: minimum and exemplary shading levels for walkways considering local solar exposure; flood risk mitigation standards incorporating Jeddah's stormwater drainage program; and cooling infrastructure benchmarks reflecting local design practices.

3.6 Data collection

3.6.1 Perception surveys and stakeholder groups

Primary data collection took place between December 2024 and June 2025 through structured questionnaires administered on-site and online. Four stakeholder groups were surveyed regarding perceptions and experiences, using a purposive nonprobability sampling strategy. This approach was selected to ensure that respondents, particularly for the AHP weighting, possessed the specific local experience or technical expertise required to evaluate complex urban criteria, which a random sample might fail to capture. The groups included:

- Residents (n = 140)
- Tourists and visitors (n = 72)
- Business operators (n = 65)
- Public-sector officials (n = 35)

While this purposive approach was essential for capturing informed perspectives on waterfront performance, it is acknowledged that certain user groups, such as elderly residents, informal workers, or those with limited mobility, may be underrepresented in the sample. These sampling constraints are addressed in the limitations section (Section 5.5).

These data were used to support qualitative interpretation of CWDI scores and cross-validate objectively measured indicators (e.g., perceptions of heat vs. spatial/environmental data; feelings of safety vs. crime/surveillance data). The AHP weighting survey used a subset of respondents (the three groups described in Section 3.4.1) selected for their familiarity with planning and waterfront issues.

3.6.2 Objective datasets and triangulation

Indicator scores were triangulated using multiple sources (presented in Appendix B). Subjective perceptions and objective data were jointly used to assign final indicator scores. For example, low perceived safety at night had to be corroborated by poor lighting coverage or limited surveillance infrastructure before assigning low scores.

3.7 Benchmarking and transferability

To situate Jeddah's performance, CWDI dimension scores were qualitatively compared with documented policies, designs, and performance indicators from Sydney, Vancouver, and Barcelona, and the thematic categories were aligned with the CWDI dimensions (Accessibility, Public Spaces, Economic Vitality, Environmental Sustainability, Cultural/Social Integration, Resilience). The CWDI was also designed with digital implementation in mind. Tier 1 indicators can be populated from existing datasets and GIS layers, while Tier 2 indicators require limited field inputs. This structure facilitates replication in other Saudi and Gulf coastal cities and adaptation to coastal social-housing projects, where open space and waterfront interfaces must be systematically evaluated.

4 Case study: Applying the CWDI to Jeddah's waterfront

4.1 Study area and spatial boundaries

Jeddah's waterfront along the Red Sea is a linear, heterogeneous zone combining formal promenades, beaches, marinas, commercial clusters, and historic urban fabric. For this study, the waterfront was divided into three zones within a 1.5 km inland buffer, defined and validated in consultation with Jeddah Municipality (see Figure 1):

1. **North Corniche**–primarily recreational and hospitality-oriented, with new promenades, parks, and mixed-use developments.
2. **Central Waterfront**–the most intensively used public realm, with high pedestrian volumes and diverse users from across the city.
3. **Historic Waterfront (Al Balad)** – adjacent to the UNESCO-listed historic core, characterized by older building stock, mixed land uses, and socioeconomically diverse communities.

The waterfront serves residents from multiple housing types: established neighborhoods, newer national housing projects

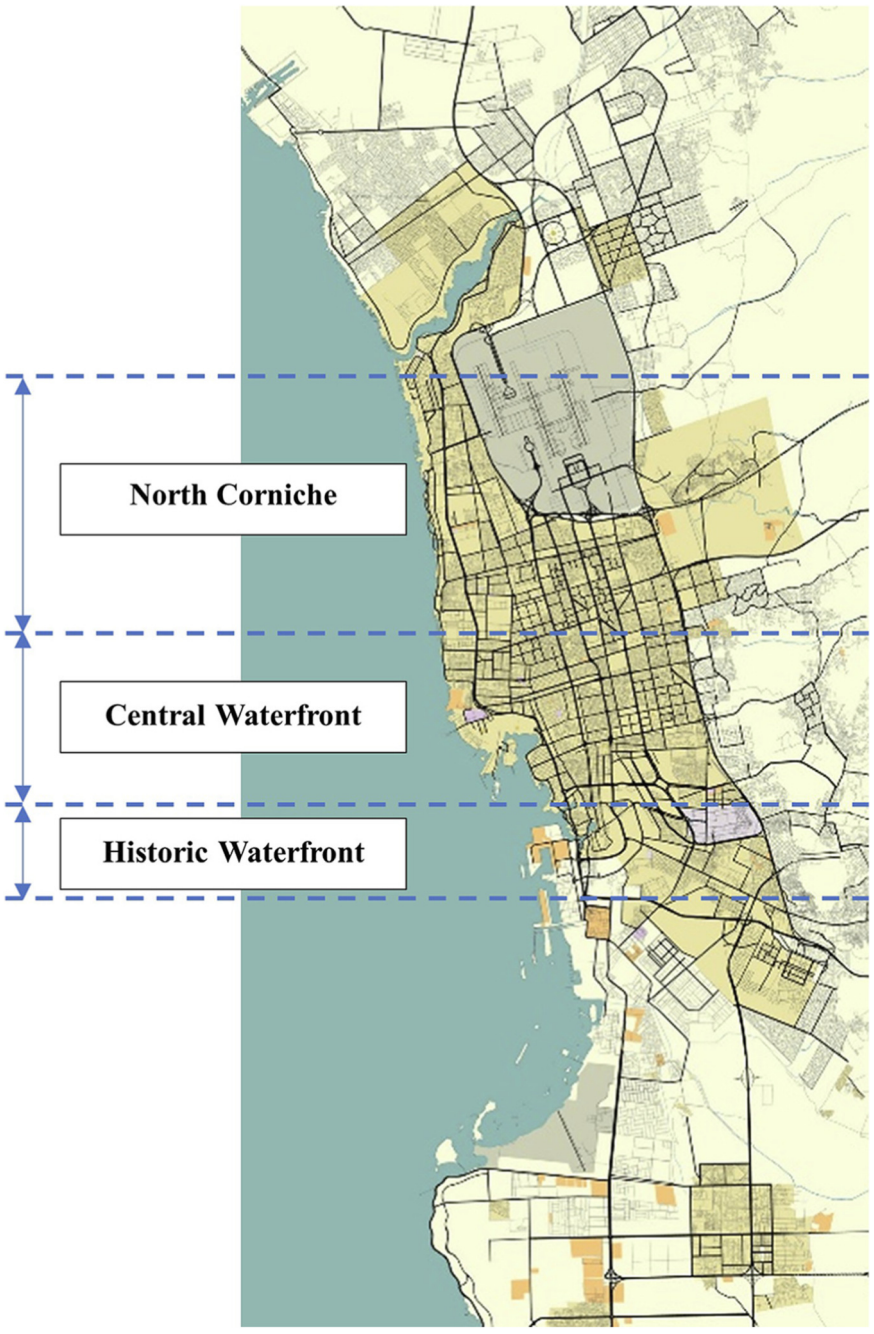

FIGURE 1
Map of Jeddah showing the three waterfront zones and their relationship to surrounding residential and national housing areas.

connected via arterials, and older mixed-income districts near Al Balad. The CWDI, therefore, provides insight not only into spatial quality but also into how coastal public spaces support or constrain housing-related quality of life.

4.2 CWDI scores across dimensions

CWDI indicator scores for Jeddah's waterfront, along with brief observations and stakeholder relevance, are presented in Table 4. Dimension-level normalized scores are calculated using the weighting procedure described in Section 3.4.

At the dimension level, Jeddah's waterfront shows a differentiated performance profile (Figure 2; Table 3). As illustrated in Figure 2, Public Spaces and Amenities scores highest (3.5/5), reflecting visible investments in promenades, parks, and recreational facilities, particularly in the North Corniche and Central Waterfront. Accessibility performs moderately (3.1/5), ranking second in the dimension score profile shown in Figure 2: while pedestrian paths and basic transit access are present, network continuity for cycling, shaded pedestrian comfort, and universal-design consistency remain uneven across segments. Economic Vitality is also moderate (2.9/5), positioned mid-range in

TABLE 4 Final weights of CWDI dimensions based on stakeholder input (AHP aggregated scores).

CWDI dimension	Residents (n = 93)	Business/Tourism (n = 27)	Professionals/Academics (n = 18)	Aggregated final weight (%)
Accessibility	18.2%	14.7%	15.5%	16.1
Public spaces and amenities	20.5%	18.1%	19.7%	19.4
Economic vitality	13.4%	23.2%	12.1%	16.2
Environmental sustainability	14.6%	11.3%	13.9%	13.3
Cultural and social integration	15.7%	10.5%	16.3%	14.2
Resilience and climate adaptation	17.6%	22.2%	22.5%	20.8
Total	**100%**	**100%**	**100%**	**100**

The bold values refer to the total percentage.

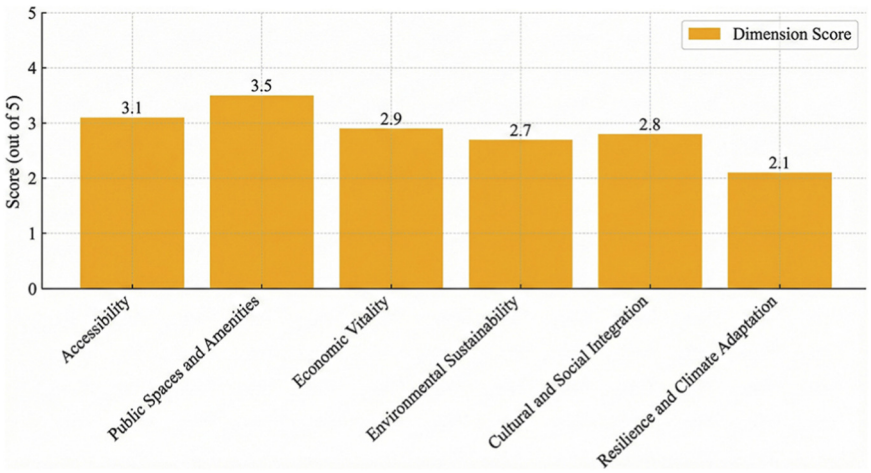

FIGURE 2
CWDI dimension scores for Jeddah's waterfront across the three assessed zones. Normalized dimension scores (0–5) summarize comparative performance across Accessibility, Public Spaces and Amenities, Economic Vitality, Environmental Sustainability, Cultural and Social Integration, and Resilience and Climate Adaptation. Higher values indicate stronger performance relative to the CWDI thresholds; lower values indicate priority gaps for targeted intervention (see Table 3 for indicator-level drivers; Table 4 for dimension weights).

Figure 2, supported by tourism activity and property value appreciation in some areas, yet with uneven benefits across zones and persistent informality pressures in parts of the waterfront economy.

Lower scores are concentrated in Environmental Sustainability (2.7/5) and Cultural and Social Integration (2.8/5), forming the second tier of dimensions in Figure 2, indicating gaps in systematic recycling/waste separation, renewable-energy uptake, heritage-route integration, and continuity of inclusive cultural programming. The weakest dimension is Resilience and Climate Adaptation (2.1/5), visibly trailing other dimensions in Figure 2, driven by limited flood risk mitigation capacity, weak cooling provisions in outdoor spaces, and partial implementation of climate-adaptive design standards, especially in older waterfront segments.

The detailed indicator-level performance underlying these dimension scores is presented in Table 4, which provides the specific scores and observations for each of the 42 indicators across the three waterfront zones.

Overall, the results indicate a waterfront that is highly upgraded in visible amenity terms yet comparatively underprepared in resilience and environmental systems (see Table 3). These gaps are particularly relevant for waterfront segments that serve, or are adjacent to, older and more vulnerable housing communities, where public-realm performance may shape day-to-day comfort and perceived livability pressures.

4.3 Stakeholder value perspectives

The AHP-derived weights indicate distinct yet overlapping stakeholder priorities across the CWDI dimensions (Figure 3; Table 4). As shown in Figure 3, residents (and, in the broader perception survey, frequent waterfront users/visitors) place the

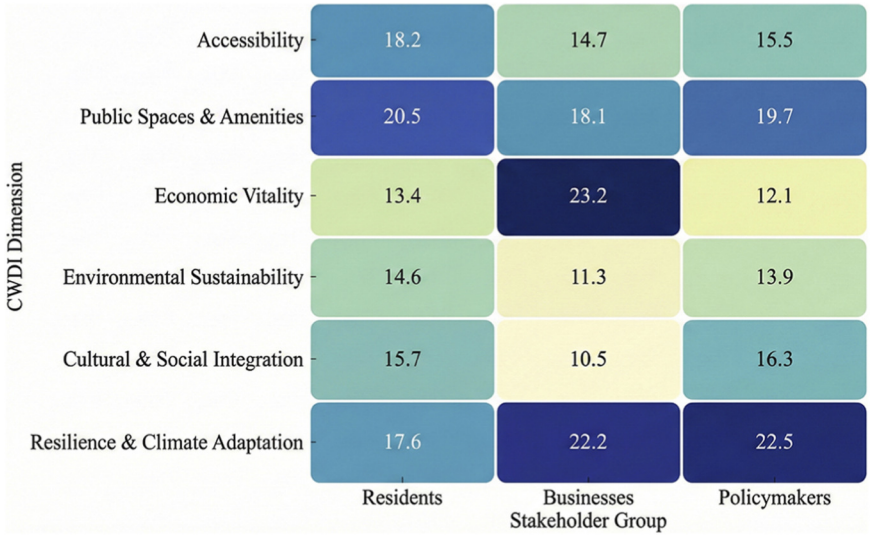

FIGURE 3
Stakeholder priorities across CWDI dimensions derived from the AHP weighting process. Dimension weights illustrate how residents, business/tourism operators, and planning professionals/academics prioritize CWDI dimensions. The figure highlights convergence around Resilience and Climate Adaptation and Public Spaces and Amenities, alongside differences in emphasis across groups (see Table 3 for full weights and aggregation procedure).

greatest emphasis on Public Spaces, and Accessibility, with these two dimensions receiving the highest weightings from this group, reflecting immediate concerns about comfort, safety, and day-to-day usability. In this context, lower scores for shaded pedestrian comfort and outdoor cooling provisions are especially consequential in Jeddah's climate and are likely to constrain the duration and timing of waterfront use for many households, including lower- and middle-income groups.

Business and tourism operators place higher emphasis on Economic Vitality and Resilience and Climate Adaptation, a pattern clearly visible in Figure 3, where these dimensions exceed the group-average weights, reflecting the view that reliable services and climate-ready infrastructure are important for sustaining investment confidence, operational continuity, and employment generation along the waterfront. Planning professionals and academics prioritize Resilience and Climate Adaptation and Cultural and Social Integration, with Figure 3 showing these dimensions receiving their highest weights from this professional group, aligning these concerns with longer-term strategic objectives associated with Vision 2030, including resilient urban development and culturally grounded place-making.

Despite variation in emphasis across the three stakeholder groups visualized in Figure 3, Resilience and Climate Adaptation and Public Spaces and Amenities appear in the top tier across groups, indicating a convergence that may support consensus-driven prioritization (see Table 4). Importantly, interventions that strengthen resilience, such as flood risk reduction measures, shade, and cooling corridors, and green–blue infrastructure, are expected to improve public-space comfort and functionality and may also contribute to perceived livability benefits for communities that depend on the waterfront as shared urban infrastructure.

Taken together, the dimension scores visualized in Figure 2, the stakeholder priorities illustrated in Figure 3, and the detailed indicator performance documented in Table 4 provide a comprehensive diagnostic basis for understanding how Jeddah's waterfront currently functions as shared infrastructure for surrounding housing communities, and where targeted interventions could yield the greatest improvements in livability and equity.

4.4 Housing and social-housing implications along the waterfront

Although the CWDI does not directly score individual housing projects, the spatial analysis highlights several critical implications for national and social housing near or connected to the waterfront:

- **Spatial inequality in heritage zones:** Households in older districts and heritage areas near Al Balad appear disproportionately exposed to lower public-space quality and higher environmental risk compared to those near the North Corniche, potentially reinforcing spatial inequality.
- **Accessibility barriers for new housing:** Residents of newer housing areas who depend on car trips to reach the waterfront are likely constrained by limited public transit frequency and weak micro-mobility infrastructure, which presents a barrier to equitable access.
- **Thermal relief deficits:** The observed scarcity of cooling infrastructure, shading, and green-blue buffers limits the waterfront's capacity to provide necessary thermal relief for households living in surrounding compact, hard-surfaced neighborhoods.

In short, the findings suggest that current waterfront performance only partially realizes its potential as an extension of the housing and social-housing quality-of-life system in Jeddah.

5 Discussion

5.1 Key findings: a "two-speed" waterfront and spatial justice

The CWDI results indicate a "two-speed" performance profile for the waterfront (Figure 2; Table 4). On the one hand, newly developed zones, particularly in the North Corniche, score relatively higher in Public Spaces and Amenities and feature upgraded promenades, parks, and commercially active nodes aligned with Vision 2030-oriented public-realm investment. On the other hand, multiple indicators point to comparatively weaker performance in older and heritage-adjacent segments, most notably near Al Balad, where amenity provision, resilience readiness, and cultural and social integration appear less consistently embedded in the waterfront experience.

This duality has implications for spatial justice, as waterfront quality is unevenly distributed along the coastal edge. Communities living in or near heritage and lower-income districts may be less likely to benefit from upgraded waterfront segments, and the conditions in those areas may correspond with greater exposure to heat and flood-related stressors, with limited resilience measures and outdoor comfort provisions. These findings do not establish causal housing impacts, but they suggest that uneven public-realm performance can shape the accessibility, comfort, and risk environment experienced by housing communities that rely on the waterfront as shared infrastructure.

5.2 Comparison with international waterfronts

Benchmarking against Sydney, Vancouver, and Barcelona is used here to interpret likely institutional and design gaps, rather than to propose direct replication of specific interventions. Three contrasts are particularly salient:

- **Governance**: benchmark cities often have dedicated waterfront authorities, performance-based zoning, and negotiated community benefits that align private development with public goals. Jeddah's waterfront is managed through fragmented institutional arrangements, limiting coherence and long-term stewardship.
- **Resilience mainstreaming**: in Sydney and Barcelona, climate adaptation measures are integrated into codes and infrastructure investments; Vancouver leverages ecological planning and biodiversity corridors. Jeddah has policy narratives around resilience but limited implementation, as reflected in low scores for flood mitigation, cooling features, and water reuse.
- **Inclusivity and community participation**: Vancouver and Barcelona explicitly incorporate community participation and heritage programming into waterfront design and governance. Jeddah's weaker scores in cultural programming, participation mechanisms, and youth facilities indicate a more top-down approach with limited co-production.

These differences suggest that improving Jeddah's CWDI performance is less about copying specific design features and more about building institutional and regulatory capacity to enforce resilient, inclusive standards along the coastal edge.

5.3 Implications for sustainable and resilient social housing in gulf coastal cities

For Gulf social and national housing agendas, the CWDI serves as a diagnostic lens to support screening and prioritization, a tool for identifying hotspots and guiding attention, not a prescription for engineering solutions. It does not replace detailed hydrologic, engineering, environmental, or socio-economic assessments, but it can help structure where and why deeper analysis and investment are most needed.

1. **Waterfronts as shared housing infrastructure**: Coastal public realms can be conceptualized as extensions of housing environments, especially where neighborhoods lack internal public-space and thermal-comfort provisions. CWDI dimensions such as accessibility, outdoor comfort proxies (e.g., shading and cooling indicators), and cultural integration are therefore relevant to how housing communities experience livability in coastal cities.
2. **Prioritizing resilience investments where housing is vulnerable**: CWDI scoring can help flag waterfront segments adjacent to older building stock, heritage districts, or lower-income communities where resilience deficits may be most consequential, effectively highlighting priority areas for further investigation. In such contexts, once flagged by the CWDI diagnostic, more detailed site-level assessments would be needed to determine appropriate interventions, such as flood risk reduction, shade networks, cooling corridors, and green–blue buffers, which are likely to yield high public value by improving comfort and lowering exposure to climate stressors.
3. **Guiding the location and design of new social housing**: When new coastal housing schemes are planned, CWDI-led assessments can inform the development of minimum standards for public-realm accessibility, cooling infrastructure, and cultural programming by highlighting performance gaps in existing waterfront areas. These diagnostic insights can then be translated into design requirements through conventional planning and engineering processes, as well as requirements for integrating social housing residents into waterfront amenities and mobility networks.
4. **Scaling CWDI to neighborhood-level open spaces**: The two-tier structure enables adaptation of the CWDI approach to internal open spaces within social-housing neighborhoods: Tier 1 provides a shared core of comparable indicators, while Tier 2 can be tailored to local microclimate and sociocultural needs (e.g., shaded courtyards, family-oriented spaces, culturally appropriate gathering areas).

In all these applications, the CWDI is intended to function as a strategic diagnostic, a tool to direct attention, resources, and regulatory focus toward areas and dimensions where performance lags. The translation of diagnostic findings into site-specific engineering, design, and investment decisions necessarily requires deeper technical analysis, community engagement, and feasibility assessment that lie beyond the scope of the index itself.

5.4 Theoretical and methodological contributions

This study advances scholarship on coastal urbanism and urban performance indices in three ways:

1. **Contextualized waterfront index:** The CWDI demonstrates an approach for adapting global evaluation frameworks into a waterfront-specific index that can be tailored to hot–arid Gulf coastal environments by integrating resilience, environmental performance, and cultural and social dimensions in a structured way.
2. **Stakeholder-calibrated weighting:** The use of AHP across multiple stakeholder groups embeds local priorities into the weighting structure and increases transparency relative to indices that rely solely on proprietary or expert-only weighting schemes.
3. **Perceptual–empirical triangulation:** Combining perception data with spatial and administrative datasets provides a more policy-relevant diagnostic picture than relying on a single data type, while also enabling cross-checking of subjective experiences against observable conditions.

5.5 Limitations and future research

Several limitations should be acknowledged to ensure a transparent interpretation of the findings and to guide future refinement of the tool.

5.5.1 Methodological limitations

First, both the perception surveys and the AHP weighting process relied on non-probability purposive sampling. This approach was deliberately chosen to ensure that respondents possessed specific local experience or technical expertise required to evaluate complex waterfront criteria, a requirement that random sampling could not guarantee. However, while this strategy was necessary to capture specific stakeholder diversity across different waterfront zones, it does not yield statistically representative estimates of the entire Jeddah population. The sample sizes, particularly for the AHP expert groups (residents n = 93, business operators n = 27, planning professionals n = 18), are modest and reflect the difficulty of recruiting respondents with the requisite specialized knowledge. Consequently, while the priorities expressed offer valuable insights into stakeholder perspectives, they should not be interpreted as statistically generalizable to the broader population of Jeddah residents or to all business operators and professionals in the city. The reported priorities, particularly those derived from the smaller expert AHP subsamples, should be interpreted as indicative patterns among active users and professionals rather than definitive population parameters. Second, despite the use of consistency checks, the AHP participant pool remains modest and may underrepresent certain user groups, such as elderly residents or informal workers, a gap that future studies could address through targeted oversampling or mixed-method engagement strategies.

5.5.2 Indicator and temporal limitations

Regarding the index structure, several Tier 2 indicators (e.g., shading walkways, community participation mechanisms) involve expert judgment. While triangulation with spatial observations and administrative records was employed to minimize bias, a degree of subjectivity remains in these context-specific scores. Furthermore, the assessment represents a single time-slice; it cannot fully capture seasonal variations in outdoor comfort (e.g., peak summer heat intensity) or the rapid physical changes resulting from ongoing redevelopment projects. Additionally, the comprehensive 42-indicator structure, while designed for diagnostic precision, requires substantial institutional capacity for data collection and maintenance. This burden may be particularly challenging for smaller municipalities or cities with limited technical staff and data infrastructure, potentially limiting the index's applicability in such contexts. Future applications of the CWDI could consider streamlining the indicator set or developing a modular version that allows users to select a core subset of indicators depending on available resources and specific policy priorities, without compromising the index's overall diagnostic value.

5.5.3 Generalizability and scope

Geographically, the analysis is limited to one city and three specific waterfront zones. The transferability of the CWDI, specifically the Tier 2 indicators, to other Saudi or Gulf coastal cities with different governance structures and microclimates requires further empirical testing. Finally, regarding the link to housing, the study conceptualizes how waterfront performance supports community livability and equity, but it does not directly quantify household-level outcomes. The association between CWDI scores and specific metrics, such as resident health, energy burden, or property values, remains inferential rather than empirically demonstrated in this study.

5.5.4 Future research directions

To address these gaps and advance the field of coastal urbanism in the Gulf, future research should:

- **Test Transferability:** Apply the CWDI (with adapted Tier 2 indicators) to a second Gulf coastal city (e.g., Dammam, Jubail, or Manama) to validate the framework's adaptability.
- **Longitudinal Monitoring:** Conduct seasonal assessments to track performance dynamics over time, potentially integrating the CWDI with urban digital twins or GIS dashboards for real-time scenario testing.
- **Empirical Housing Linkages:** Integrate CWDI scores with longitudinal socio-economic and health datasets to empirically measure the causal impact of waterfront interventions on adjacent housing communities.
- **Refine Scoring Protocols:** Develop more explicit measurement rubrics for Tier 2 indicators (e.g., automated

shade calculation via remote sensing) to further reduce subjectivity.

- **Develop Streamlined Versions:** Create modular or streamlined versions of the CWDI tailored to the capacity constraints of smaller municipalities, enabling broader adoption while maintaining core diagnostic functionality.

6 Conclusion

This paper developed and applied a Comprehensive Waterfront Development Index (CWDI) for Jeddah, Saudi Arabia, conceptualizing the waterfront as a strategic public realm that supports the sustainability and resilience of surrounding residential and social-housing communities. The index combines global frameworks with a two-tier indicator structure and stakeholder-calibrated weights and is operationalized through mixed methods and international benchmarking.

The results reveal a waterfront that is physically upgraded yet environmentally fragile and spatially unequal. New segments provide attractive public spaces and reasonable accessibility, but resilience and environmental sustainability lag behind, particularly in the historic Al Balad waterfront area, where vulnerable communities are concentrated. These findings underscore the need for integrated, equity-oriented planning that aligns coastal redevelopment, resilience infrastructure, and social-housing policies.

By making waterfront performance measurable and comparable, the CWDI offers municipal planners, housing agencies, and policymakers a practical tool to:

- Diagnose strengths and gaps along the coastal edge.
- Prioritize resilience and inclusivity investments where they most benefit housing communities.
- Embed transparent performance thresholds into regulatory and incentive frameworks.
- Scale the approach to other Saudi and Gulf coastal cities and to neighborhood-level open spaces in social housing developments.

For social and national housing agendas in Saudi Arabia and the wider Arabian Gulf, the CWDI offers more than a diagnosis of iconic coastal projects: it provides a practical lens for assessing how waterfronts perform as extensions of housing environments and as shared public infrastructure for diverse, often vulnerable, resident groups. By applying CWDI criteria to coastal social-housing projects and to neighborhoods functionally linked to the waterfront, planners and housing authorities can embed minimum standards for outdoor comfort, equitable access, cultural programming, and climate resilience from the outset. In this way, the framework can support a new generation of Gulf housing policies in which the design and governance of coastal public realms are explicitly aligned with the livability, inclusion, and long-term safety of residents, rather than treated as separate tourism or real-estate concerns.

Ultimately, the CWDI is proposed not as a static scorecard but as an adaptive framework that can evolve with new data, changing climate risks, and shifting societal priorities. Its application in Jeddah represents an initial step toward more evidence-based, inclusive, and climate-responsive coastal and housing development under Vision 2030 and the broader sustainable development agenda.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary Material, further inquiries can be directed to the corresponding author.

Author contributions

IH: Conceptualization, Investigation, Methodology, Project administration, Supervision, Writing – review and editing. AI: Data curation, Formal Analysis, Investigation, Methodology, Resources, Validation, Writing – original draft.

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Conflict of interest

The author(s) declared that this work was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fbuil.2026.1750109/full#supplementary-material

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