

Article

Urban Resilience Framework for Evaluating Jeddah's Capacity for Sustainability and Adaptation

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Abstract: Cities worldwide face crises like natural disasters, climate change, and infrastructure vulnerabilities, making urban resilience a critical priority. In Saudi Arabia, resilience strategies are being integrated into urban development, including Jeddah, which faces challenges such as flood risks and rapid urbanization. This study develops a framework to assess Jeddah's resilience, aligning with global initiatives like the SDGs and Saudi Vision 2030. Benchmarking against cities like Barcelona, Tokyo, and Dubai highlights adaptable strategies for Jeddah. The findings offer insights to enhance urban resilience, support sustainable urbanization, and inform policies for Jeddah and other cities globally.

Keywords: climate change; natural disaster; sustainability; urban resilience; resilience indicators

1. Introduction

1.1. Background

Urban resilience (UR) focuses on viewing cities as systems capable of building the capacity to withstand and recover from potential shocks while safeguarding their social, economic, and infrastructure systems [1]. Cities worldwide are facing various crises, including natural disasters, climate change, social challenges, and infrastructure vulnerabilities. Urban resilience has become a critical priority, highlighting a city's capacity to adapt, endure, and recover from these significant disruptions while maintaining its core functions and ensuring the well-being of its residents [2]. Urban resilience to climate change has become a fundamental component of today's sustainable urban development strategies, driven by the rising impacts of climate change and its harmful effect on cities. Issues such as rising temperatures, more frequent extreme weather events, and sea-level rise are affecting urban areas worldwide. The establishment of urban resilience as a key concept has grown and become increasingly urgent [3]. This study examines the current state of urban resilience in Jeddah, Saudi Arabia, by evaluating its performance across a set of indicators and proposing a localized framework tailored to the city's mobility, infrastructure, green spaces, environmental conditions, well-being, and emergency preparedness.

1.2. Objectives

1. To Develop a Comprehensive Framework: Create a structured framework that integrates criteria and indicators for assessing urban resilience that are adapted to Jeddah's unique context.
2. To Evaluate Jeddah's Current Resilience Status: Analyze the existing urban resilience measures in Jeddah to identify strengths and weaknesses in its capacity for sustainability and adaptation.



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3. To Benchmark Against Other Cities: Compare Jeddah's resilience indicators with those of other cities to highlight areas for improvement and best practices that can be adapted.
4. To Provide Policy Recommendations: Generate actionable recommendations for urban planners and policymakers aimed at enhancing Jeddah's resilience.

1.3. Research Questions

1. How can a structured framework be designed to effectively integrate criteria and indicators for assessing urban resilience in Jeddah's specific context?
2. What strengths and weaknesses can be identified in Jeddah's current capacity for sustainability and adaptation?
3. How do Jeddah's urban resilience indicators compare to other cities facing similar environmental and socioeconomic challenges?
4. What policy changes or initiatives can be proposed to improve Jeddah's urban resilience?

1.4. Significance

Worldwide, frameworks like the Sustainable Development Goals (SDG 11) highlight the importance of creating secure, resilient, and sustainable cities. This objective emphasizes the essential role of resilience in developing sustainable urban growth [4]. Moreover, the Resilient Cities Network (RCN) offers a complete framework for urban resilience planning, emphasizing key areas such as Health and Well-being, Economy and Society, Infrastructure and Environment, and Leadership and Planning. Meanwhile, through framework approach development, the RCN engages with city government officials to develop customized strategies to address specific urban challenges [5]. Within the Kingdom of Saudi Arabia, efforts are being made to incorporate resilience strategies into the development of its urban and suburban areas, while maintaining a balance between social, economic, and environmental considerations [6]. This study proposes a framework to assess Jeddah's urban resilience, addressing critical challenges such as flood risks, rapid urbanization, and climate adaptation needs. These findings align with global initiatives like the SDGs and the RCN while directly supporting Saudi Vision 2030, which emphasizes sustainable urbanization, economic diversification, and environmental stewardship by benchmarking Jeddah's resilience against global standards and identifying best-practice cities such as Barcelona, Tokyo, Copenhagen, New York, Semarang, Al-Madinah Al-Munawwarah, and Dubai. These cities were selected for their innovative approaches to urban resilience, offering adaptable strategies that can inform the development of a robust urban framework model for Jeddah.

2. Literature Review

2.1. What Is Urban Resilience?

The phrase "urban resilience" originates from the Latin word *resilio*, which means "to bounce back" [7]. In recent years, urban resilience has appeared as a fundamental policy in global discussions on sustainable urban development. UN-Habitat defines it as "the ability of any urban system, along with its inhabitants, to maintain continuity through various shocks and stresses while adapting positively and transforming toward sustainability [8]. It refers to the ability of an urban system, along with its socio-ecological and socio-technical networks across different spatial and temporal scales, to maintain or quickly restore essential functions when facing disturbances, adapt to change, and transform systems that limit future adaptive capacity [7]. Urban resilience is shaped not only by physical infrastructure but also by social vulnerability. Existing social, economic, and demographic factors influence a city's ability to recover, with risks increasing due

to income inequalities, limited healthcare access, and unstable housing. Resilience and vulnerability are not opposite but rather interconnected, where a city with high vulnerability can still enhance resilience through strong governance, community networks, and adaptive policies [9].

Likewise, the Resilient Cities Network defines urban resilience as “the capacity of individuals, communities, institutions, businesses, and systems within a city to survive, adapt, and grow no matter what kinds of chronic stresses and acute shocks they experience” [9]. By combining these definitions, urban resilience becomes a key element that integrates sustainability, adaptability, and durability, which establishes itself as an urgent approach in today’s urban planning strategies.

2.2. Criteria and Indicators

One of the main aspects of urban resilience studies is establishing effective methods for measurement [10]. Indicators are essential tools for assessing current conditions and enabling the development of better policies [11]. These indicators can essentially support the development of assessment tools to establish baseline conditions, allowing the evaluation of effectiveness and tracking progress toward community goals [12]. They serve as quantitative illustrations of specific components within a particular area. These indicators provide policymakers with critical information to evaluate effectiveness and implement necessary adjustments [11]. The selection of these indicators should be guided by key principles, including relevance to resilience objectives, measurability using available data, comparability across different urban contexts, and actionability to inform decision-making [13].

For example, New York City implemented 13 initiatives to enhance urban resilience in neighborhoods, buildings, infrastructure, and coastal defense as part of the One New York Strategy, aiming to mitigate the effects of climate change and other emerging threats. Consequently, key indicators were established, including preventing long-term disaster-related displacement by 2050, lowering the Social Vulnerability Index in communities, and reducing annual economic losses from climate-related hazards [14]. Similarly, in 2021, Barcelona launched the Climate Emergency Action Plan, aiming to position the city as a leader in sustainability. The plan addresses climate change by reducing emissions and enhancing resilience to its effects. It focuses on five key areas, including health and well-being, energy savings and generation, urban mobility, economy and consumption, and climate awareness. To achieve these goals, the plan outlines 18 strategic actions and incorporates 234 specific measures designed to improve the city’s climate resilience and sustainability [15].

3. Methodology

The study implements a structured methodological approach to ensure a clear and coherent research process. As illustrated in (Figure 1) the methodology is divided into six main steps, each building upon the previous one to support the study’s objective of evaluating urban resilience in Jeddah.

3.1. Literature Review on Urban Resilience

The research methodology began with an in-depth study of urban resilience, focusing on its aspects, significance, and measurable indicators. International frameworks and reports, such as the Resilient Cities Network (RCN), The City Resilience Program (CRP) of the World Bank, and Sustainable Development Goal 11 (SDG 11), were reviewed to establish a foundational understanding.

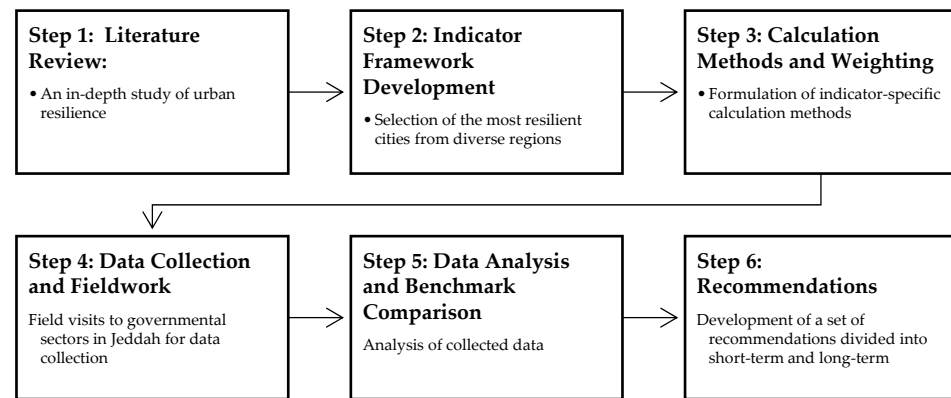


Figure 1. Research methodology roadmap.

3.2. Indicator Framework Development

A detailed analysis of the world's most resilient cities, selected from diverse regions, was conducted to study their criteria, strategies, and indicators for achieving resilience. Ten cities were initially reviewed: Copenhagen, Zurich, Paris, Barcelona, Tokyo, Semarang, Singapore, Al-Madinah Al-Munawwarah, Dubai, Doral, and New York. However, only seven cities—Copenhagen, Barcelona, Tokyo, Semarang, Dubai, Al-Madinah Al-Munawwarah, and New York were used to form the urban resilience framework due to the availability of data. The selection of these benchmark cities was guided by several key criteria, including the existence of comprehensive urban resilience strategies, relevant geographic or environmental challenges, similar urbanization dynamics, and the availability of resilience data and policy documentation. This selection ensured a balanced representation of cities across different contexts: two from Europe (Copenhagen, Barcelona), two from Asia (Tokyo, Semarang), one local city (Al-Madinah Al-Munawwarah), one from the Gulf region (Dubai), and one from the United States (New York). While these cities differ in climate, economy, and social environment, they provide a diverse perspective on building urban resilience policies that can support Jeddah's urban resilience strategies. Most of these cities are coastal—similar to Jeddah, which borders the Red Sea—enabling more relevant comparisons of challenges such as flood risks, storm surges, water management, and economic dependence on coastal industries. Through this analysis, both common and unique indicators were extracted from the benchmark cities to form the foundation of Jeddah's urban resilience framework. Common indicators identified across multiple case studies demonstrate universal applicability to resilience planning, including mobility, infrastructure, green spaces, environmental factors, well-being, and emergency preparedness.

For example, New York and Barcelona have implemented extensive public transport networks, influencing the inclusion of public transport spatial coverage as a key indicator in Jeddah's resilience framework [15,16]. Similarly, Copenhagen's focus on increasing green spaces and tree density served as a model for enhancing urban cooling and air quality, which is particularly relevant given Jeddah's climate and high temperatures. The framework incorporated flood management strategies based on Tokyo's flood mitigation and drainage systems, while Copenhagen's rainwater management approaches to address Jeddah's heat stress and water resource challenges [17,18]. For instance, Tokyo's flood mitigation system, including its underground floodwater diversion channels, influenced the decision to include stormwater drainage capacity as a significant indicator for Jeddah. Likewise, Semarang's success in integrating community-based resilience efforts led to the adoption of volunteerism as an indicator to enhance Jeddah's emergency preparedness [17,19].

Furthermore, locally and regionally, both Al-Madinah Al-Munawwarah and Dubai have earned the Platinum Certification of ISO 37120:2018 [20] from the World Council on City Data (WCCD), which is the highest international classification for urban data. This certification recognizes both cities' commitment to sustainable development, improved quality of life, urban performance measurement, and the utilization of high-quality urban data to support informed decision-making [20,21].

By the end of the case study analysis, common indicators were identified for their universal applicability, while unique indicators were integrated to ensure a comprehensive and robust urban resilience framework adapted to Jeddah's specific needs.

3.3. Calculation Methods and Weighting

3.3.1. Formulas and Calculations

Specific formulas and methodologies for evaluating the indicators were then identified from established references, including the SDG Indicators Metadata Repository, the New Urban Agenda (NUA) Monitoring Framework, and the City Prosperity Index Methodology and Metadata. Additional formulas were sourced from journal articles and reports related to urban resilience. These methodologies provided the computational foundation for assessing the selected indicators and guided the subsequent fieldwork.

Three formulas were used to calculate urban indicators to evaluate Jeddah's urban resilience. The primary data sources include Jeddah's population, which is 3,712,917, and its urban area, covering 1765 km². In cases where specific indicator values for Jeddah are unavailable, data from the broader Makkah province, with a total population of 7.7 million and a geographical area of 137,000 km², are used as a substitute. This ensures comprehensive and consistent analysis, even when local data are incomplete.

The first formula calculates the value of an indicator as a percentage of the total, enabling standardized comparisons across diverse criteria. Where X represents the observed value of the indicator, and $Total$ is the sum of all values under consideration. This approach normalizes data into percentages, facilitating comparative analysis (1).

$$\text{Indicators Value} = 100 \left(\frac{X}{Total} \right) \quad (1)$$

The second formula represents an indicator as a proportion of the total, scaled by 1000 for greater granularity. This is particularly useful when finer distinctions are required beyond percentages (2).

$$\text{Indicators Value} = 1000 \left(\frac{X}{Total} \right) \quad (2)$$

The third formula evaluates an indicator in relation to the total city or urban area, highlighting spatial distributions. It provides insights into population density or economic activity within the urban context (3).

$$\text{Indicators Value} = \left(\frac{X}{Total \text{ City Area or Urban Area}} \right) \quad (3)$$

Benchmark values were determined using the average performance of the seven selected case study cities to ensure that Jeddah's performance is measured against global resilience standards. Compliance levels were classified based on proportional differences from these benchmarks, providing a structured method for evaluating performance. This approach ensures clear differentiation between full compliance, substantial compliance, minimal compliance, and non-compliance, making the assessment transparent and comparable across indicators.

Indicators were scaled and subsequently classified into four categories. The directionality of the indicators was also considered, where a positive indicator (+) denotes that higher values are preferable, while a negative indicator (−) denotes that lower values are preferable. For positive indicators, performance levels were classified as follows: Full Compliance (FC) was achieved when performance reached 0.75 or more of the benchmark; Substantial Compliance (SC) corresponded to a performance range of 0.50 to 0.74 of the benchmark; Minimal Compliance (MC) was assigned when performance fell between 0.25 and 0.49 of the benchmark; and Non-Compliance (NC) was designated for performance levels below 0.25 of the benchmark.

For negative indicators, the classifications were defined as follows: Full Compliance (FC) was achieved when performance did not exceed 1.25 of the benchmark; Substantial Compliance (SC) corresponded to a performance range of 1.26 to 1.50 of the benchmark; Minimal Compliance (MC) applied to performance levels between 1.51 and 1.75 of the benchmark; and Non-Compliance (NC) was assigned when performance exceeded 1.75 of the benchmark.

3.3.2. Determination of Weight Value for Each Criterion and Indicator Using AHP

The Analytic Hierarchy Process (AHP), developed by Thomas L. Saaty [22], is among the most recognized and extensively utilized methods in Multiple Criteria Decision Making (MCDM). It enables users to systematically evaluate the relative importance of multiple criteria or alternatives within a given context. By structuring decision problems hierarchically, AHP facilitates pairwise comparisons of criteria and indicators based on expert judgment. These comparisons are performed using a numerical scale ranging from 1 to 9, after which the resulting data are arranged into matrices. Through matrix algebra computations, weights are derived to reflect the relative significance of each criterion and indicator within the established hierarchy. To ensure the reliability of the derived weights, AHP incorporates metrics for evaluating the consistency of judgments, such as the consistency ratio (CR). A CR value below 10% indicates an acceptable level of consistency, whereas values exceeding 10% signify inconsistent judgments that require re-evaluation [23].

In this study, the AHP method was applied to compute weights for criteria and indicators based on the judgments of an expert panel. Initially, pairwise comparisons were conducted by ten experts for the six main criteria comprising the urban resilience framework for Jeddah, allowing experts to assign relative weights to each criterion. The average weights provide a balanced view that accounts for the varying perspectives of all ten experts. All individual expert judgments had consistency ratios well below the 10% threshold (ranging from 0.44% to 2.60%), indicating that the pairwise comparisons were consistently applied, as presented in Table 1. Subsequently, the process was conducted for each criterion, encompassing its respective indicators, to determine the relative weights among indicators as presented in Table 2. An Excel template developed by Klaus D. Goepel [24] was utilized to perform these calculations. The resulting consistency ratio (CR) of individual expert judgments for the Mobility indicators ranged between 0.08% and 1.52%, for Infrastructure indicators between 0.65% and 2.98%, for Green Spaces indicators between 0.00% and 1.56%, for Environmental indicators between 2.14% and 2.94%, for Well-Being indicators between 0.57% and 2.58%, and for Emergency Preparedness indicators between 0.68% and 1.67%. These values indicate an acceptable degree of consistency in the pairwise comparisons and the resulting indicator weights.

Table 1. Summary of all expert weightings of main criteria of urban resilience framework for Jeddah using the AHP method.

Criteria	Exp 1	Exp 2	Exp 3	Exp 4	Exp 5	Exp 6	Exp 7	Exp 8	Exp 9	Exp 10	Average Weight	Rank
Mobility	0.09	0.07	0.07	0.08	0.22	0.18	0.16	0.11	0.06	0.32	0.14	4
Infrastructure	0.24	0.16	0.18	0.16	0.22	0.10	0.27	0.29	0.30	0.23	0.21	2
Green Spaces	0.05	0.09	0.12	0.19	0.07	0.07	0.09	0.13	0.13	0.08	0.10	5
Environmental	0.15	0.20	0.22	0.29	0.13	0.18	0.16	0.18	0.18	0.13	0.18	3
Well-Being	0.09	0.11	0.08	0.07	0.05	0.08	0.06	0.06	0.05	0.05	0.07	6
Emergency Preparedness	0.38	0.35	0.33	0.22	0.34	0.42	0.27	0.22	0.30	0.20	0.30	1
Consistency Ratio	1.48%	1.86%	1.73%	2.60%	0.89%	1.03%	0.44%	1.66%	1.90%	1.98%	-	

Table 2. Indicators of the urban resilience framework for Jeddah: Comparison with international benchmarks and weighting through the AHP method.

#	Criterion	Indicator	Measure	+/−	Jeddah	Benchmark (Average)	Compliance	Average Weight	Rank
1	Mobility	Journey Times	Average daily journey time per person (minutes).	−	44	31.43	SC	0.22	2
2		Public Transport Spatial Coverage	Ratio of area covered by public transport to the total area of a city (%).	+	23.99	88.33	MC	0.31	1
3		Private Transportation Accessibility	Ratio of private vehicle ownership to total population (%).	+	48.46	38.57	FC	0.16	3
4		Pedestrian Path	Ratio of pedestrian path length to total urban surface (%).	+	0.28	96.75	NC	0.08	5
5		Bike-lane Network	Ratio of bicycle lane length to total road length (%).	+	0.22	59.18%	NC	0.07	6
6		Street Density	Total length of streets per square kilometer of urban area (km/km ²).	+	8.89	12.50	SC	0.12	4
7		Electrical Charging Points	Number of EV charging points per square kilometer of urban area (km ²).	+	0.0102	3.45	NC	0.04	7
9	Infrastructure	Population Density	Number of people per square kilometer of urban area (people/km ²).	+	2104	6852.03	MC	0.04	6
10		Access to Electricity	Ratio of families connected to public electricity to the total number of families (%).	+	100	100	FC	0.22	2
11		Electrical Interruptions	Average number of customer-hours of interruptions experienced per customer (hours per customer).	−	0.00003	0.303	FC	0.08	4
12		Percentage of Sewage Treated	Ratio of sewage treated annually to the total sewage produced annually (%).	+	4.24 (Makkah region)	86.18	NC	0.19	3
13		Recycle and Reduce Waste for All Residents	Ratio of the volume of recycled waste to the total volume collected (%).	+	0.58	32.96	NC	0.07	5
14		Secure Adequate Clean Water Sources	Total volume of water distributed by the total population (m ³ /year per capita).	+	128.69	105.0	FC	0.40	1

Table 2. Cont.

#	Criterion	Indicator	Measure	+/−	Jeddah	Benchmark (Average)	Compliance	Average Weight	Rank
15	Green Space Green Spaces	Tree Density	Total number of trees relative to the total population (trees/person).	+	0.03	0.577 (Dubai: 1.73)	NC	0.16	4
16		Green Open Space	Ratio of a city's total green area to its total urban area (%).	+	0.13	21 (Dubai: 2.5)	NC	0.34	1
17		Public Parks	Ratio of parks available (Parks per 1000 people).	+	0.044	0.23 (Dubai: 0.062)	NC	0.25	3
18		Biodiversity	Ratio of the total area of land designated for natural protection or biodiversity within the city (%).	+	3.80 (Makkah region)	8.09	MC	0.26	2
19	Environmental	Wave Height	Highest recorded wave heights with the average rough wave height worldwide (meters).	−	3.31	2.5 (Rough)	SC	0.03	9
20		Sea Level Rise	Highest sea level recorded during extreme tides, storm surges, or annual peaks (millimeters per year).	−	5	3.3	MC	0.11	5
21		Sea Temperature	Average of the sea surface temperatures over a year (°F).	+	83.21	78.8	FC	0.06	8
22		Wind Max Speed	Average wind max speed over a year (km/h).	−	27	89 (Storm)	FC	0.02	10
23		PM2.5 across the city	Average concentration of particles in the air over a year ($\mu\text{g}/\text{m}^3$).	−	55.93	15	NC	0.20	1
24		PM10 across the city	Average concentration of particles in the air over a year ($\mu\text{g}/\text{m}^3$).	−	107.8	45	NC	0.15	3
26		NO ₂ across the city	Average concentration of nitrogen dioxide in the air over a year, measured in parts per billion (ppb).	−	34.15	13.29	NC	0.15	2
27		SO ₂ across the city	Average concentration of sulfur dioxide in the air over a year, measured in parts per billion (ppb).	−	6.29	15.27	FC	0.08	7
28		CO across the city	Average concentration of carbon monoxide in the air over a year, measured in parts per billion (ppb).	−	488	3490	FC	0.09	6
29		O ₃ across the city	Average concentration of ozone in the air over a year, measured in parts per billion (ppb).	−	44.04	50.96	FC	0.12	4
30	Well-being	Accessible Health Care for All Residences	Ratio of residents with health insurance to total population (%)	+	85.18 (Makkah Region)	95.38	FC	0.28	1
31		Patient Beds at Hospitals	Ratio of hospital beds to total population (per 1000 people)	+	2.25	4.75	MC	0.26	2
32		Hospital carried out disasters	Ratio of prepared hospitals and health centers to total facilities (%)	+	87.84	58.63	FC	0.25	3
33		Adequacy of services for the elderly	Ratio of senior care facilities to senior population (per 1000 seniors)	+	0.033	0.20	NC	0.07	5
34		Child to School	Ratio of child population to number of schools (children per school)	+	424.52	556.89	FC	0.10	4
35		Slum households	Ratio of people living in slums to total city population (%)	-	5.97	2.55	NC	0.05	6

Table 2. Cont.

#	Criterion	Indicator	Measure	+/−	Jeddah	Benchmark (Average)	Compliance	Average Weight	Rank
36	Emergency Preparedness	Stormwater Drainage Capacity	Total volume of rainwater runoff generated in an urban area (cubic meters/second).	+	41.65	85	MC	0.14	3
37		Emergency Shelters	Ratio of shelters to total population (%).	+	0.0056	0.01	MC	0.11	4
38		Ambulance center Density	Number of ambulance stations per square kilometer (stations/km ²).	+	0.011	0.047	NC	0.33	1
39		Civil Defense Centers	Ratio of civil defense center to total population (per 1000 people).	+	0.0054	0.15	NC	0.05	5
38		Siren Systems Density	Total number of sirens to total urban area (sirens/km ²).	+	0.164	2.05	NC	0.05	6
39		First-aid and emergency response	Ratio of transported patients and injured to the total number of emergency calls (%).	+	12.12 (Makkah region)	42	MC	0.32	2
40		Volunteerism	Ratio of city residents who volunteer to total city population (%)	+	0.041 (Makkah region)	26.82	NC	0.03	7

Terminology: Full Compliance (FC): Satisfies requirements of the Criterion/Standard. Substantial Compliance (SC): Satisfies most of the requirements of the Criterion/Standard. Minimal Compliance (MC): Lacks the strength of compliance with the Criterion. Non-Compliance (NC): Does not satisfy the requirements of the Criterion/Standard.

Referring to Table 1 and the analysis of average weights of the six main criteria comprising the urban resilience framework for Jeddah, the urban resilience criteria are prioritized as follows: (1) Emergency Preparedness (0.30) clearly emerges as the highest priority, suggesting that experts generally consider the ability to respond to and recover from disasters as the most critical aspect of urban resilience. (2) Infrastructure (0.21) ranks second, highlighting the importance of robust physical systems like transportation networks, utilities, and public facilities. (3) Environmental (0.18) takes third place, indicating significant importance placed on environmental quality, pollution management, and climate adaptation. (4) Mobility (0.14) ranks fourth, representing the value of efficient transportation systems and accessibility. (5) Green Spaces (0.10) places fifth, showing moderate importance given to parks, urban forests, and natural areas. (6) Well-Being (0.07) consistently ranks lowest among the criteria, though it is still recognized as a component of urban resilience.

3.4. Data Collection and Fieldwork

After finalizing the framework in the last quarter of 2024, fieldwork was conducted over a 3-month period, from November until January 2025, to gather data from various governmental sectors in Jeddah, such as the General Authority for Statistics, the National Center for Meteorology, the Ministry of Energy, Jeddah Municipality, the General Civil Defense, the Ministry of Education, the Ministry of Transport and Logistic Services, Metro Jeddah Company, and others relevant entities. During these visits, some interviews with government officials were also conducted to gain a deeper understanding of the indicators and collect information. Additional data and indicators were sourced from official government annual reports, the Kingdom of Saudi Arabia Open Data Platform, and official e-mail requests. In cases where data were unavailable, several methods were used to address missing values. Data from the Makkah region was utilized since Jeddah is part of this region, and certain datasets are only available at the regional level rather than the city level. This approach was applied to indicators such as the percentage of sewage treated, biodiversity shelters, accessible healthcare for all residents, first-aid and emergency response, and volunteerism. Furthermore, stakeholder interviews conducted during governmental

sector visits provided qualitative insights and supplementary data where gaps existed. Additionally, site visits and remote sensing tools such as Google Earth were used to verify spatial indicators related to infrastructure, mobility, and green spaces. However, some data were not accessible due to governmental confidentiality policies, limiting the ability to obtain certain datasets. When no suitable data sources were available, the indicator was excluded to maintain the study's analytical honesty. Like many other urban studies, data availability remains a challenge, particularly in city-level assessments. However, by utilizing multiple methods, this study ensures that the collected data remains robust and representative of Jeddah's urban resilience conditions. Future research could further improve data collection through remote sensing technologies, private-sector data sharing, and expanded stakeholder engagement.

3.5. Data Analysis and Benchmark Comparison

The collected indicators for Jeddah were then compared against the average benchmark values from the selected case studies. Descriptive statistical methods were used in comparison such as tables and radar charts. This comparison clarified Jeddah's standing for each indicator, highlighting strengths and identifying areas for improvement to the city's long-term urban resilience capacity.

3.6. Recommendations for Jeddah's Urban Resilience

Based on the analysis of Jeddah's urban resilience indicators, a list of recommendations was developed using strategies from the seven selected case studies. Each case study's indicators were reviewed, and the strategies yielding the most efficient results were adopted as recommendations. In addition to the case studies, some suggestions were gathered from international reports, such as those by the World Health Organization (WHO), to ensure a broader perspective. All recommended strategies were carefully evaluated to ensure they align with the unique conditions of Jeddah's urban fabric. The recommendations are divided into short-term and long-term strategies to ensure both immediate action and sustained resilience planning.

4. Study Area

4.1. Jeddah's Demographics, Geography, and Urban Challenges

Saudi Arabia has experienced one of the fastest urbanization rates globally. Since 1973, the country has witnessed substantial urban growth, mainly in major cities like Riyadh, Jeddah, Makkah, Madinah, and Dammam [13]. Jeddah was founded nearly 3000 years ago by a group of fishermen as a resting spot after their fishing settlement, which has played a significant role in Islam because of its significant location between the Islamic holy cities, Makkah and Madinah [25].

Jeddah is located on the western coast at the coordinates 21.54° N latitude and 39.7° E longitude. It is in the middle of the eastern Red Sea shoreline. The city is bordered to the east by the Tihama plains, a lowland region near the Hijaz mountains, and to the west by an offshore coral reef that runs to the coastline [15]. The city is characterized by a diverse topography, combining coastal plains, hills, and valleys [26]. The city's urban area is approximately 1765 km², while the total area reaches around 5460 km² [15]. The city's population has exceeded 3.4 million and is growing annually at approximately 2.5%. As a result, the city is undergoing significant urbanization, marked by rapid demographic expansion and spatial development (Figure 2) [16].

Jeddah experiences long, hot summers from May to September, with July being the hottest month (average lows of 27.2 °C and highs of 38.8 °C). Winters are short, lasting from December to March, with January as the coldest month (average lows of 18.3 °C and highs

of 28.3 °C) (Figure 3). The city has mild seasonal wind variations, with the windier period spanning December to September, peaking in June. Rainfall is infrequent, with November being the rainiest month, averaging 0.9 rainy days (Figure 4). The windy part of the year is from September 18th until December 25th, with average wind speeds of more than 14.8 km per hour. However, June is considered the windiest month of the year with an average wind speed of 16.7 km per hour (Figure 5) [27].

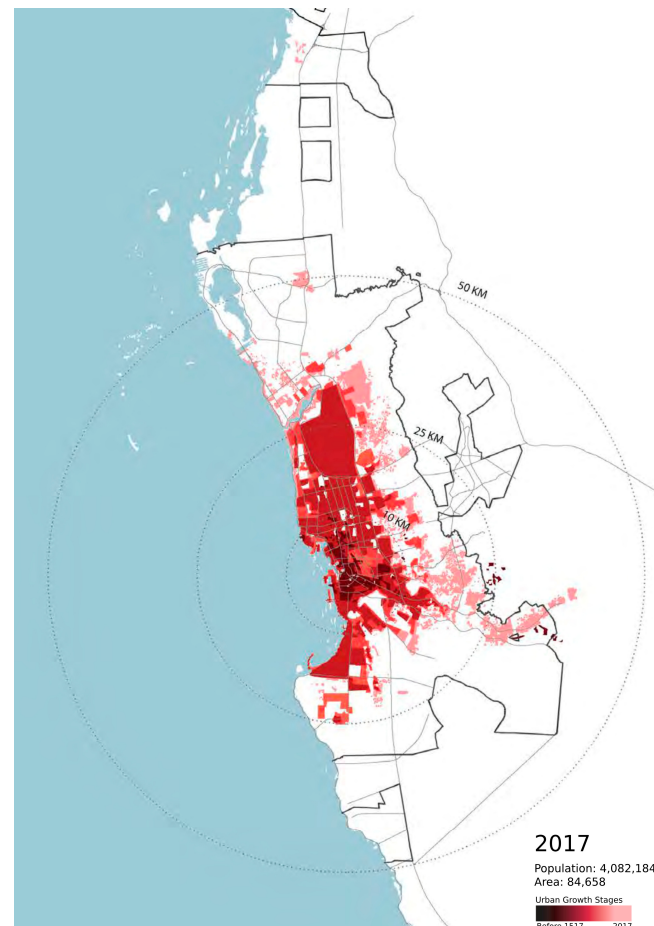


Figure 2. Jeddah's urban expansion over time (2017 Data) [28].

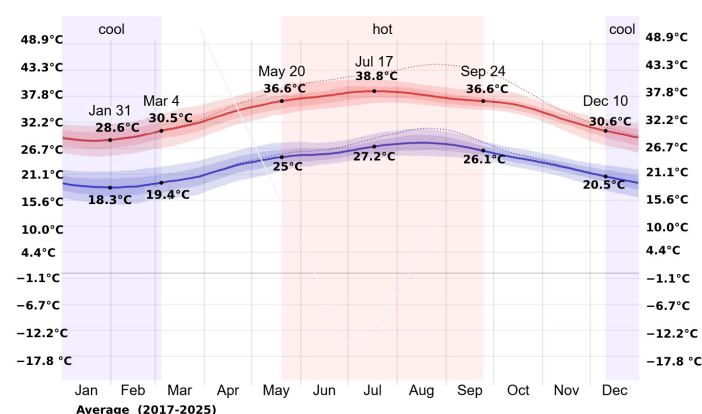


Figure 3. Jeddah temperatures daily average high (Red line) and low (Blue line) [27].

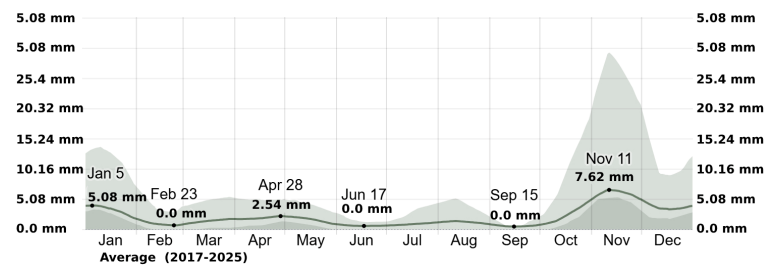


Figure 4. Jeddah average monthly rainfall [18].

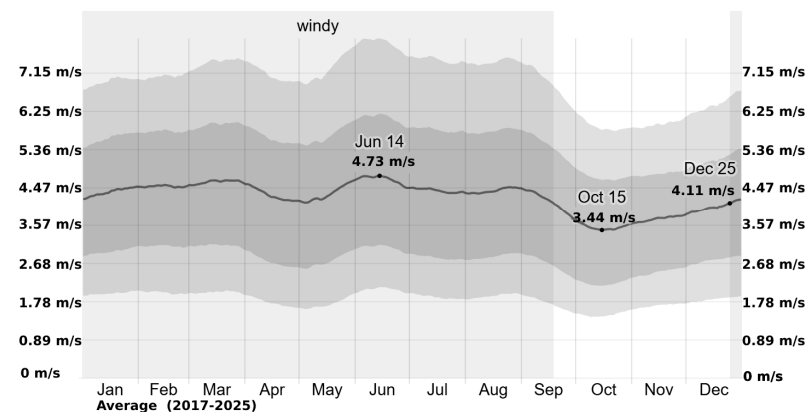


Figure 5. Jeddah average wind speed [18].

4.2. Major Flood Events in Jeddah: Historical Impacts and Challenges

The Red Sea Coast and its surrounding areas are considered among the most flood-prone regions globally, experiencing nearly all types of flooding and having a long history of climate-related hazards. In recent years, Saudi Arabia has experienced numerous flood events. Notable examples of destructive flash floods occurred in 1972, 1979, 1985, 2009, 2010, and 2011, emphasizing the severity of flash flooding over the past 50 years. On 25 November 2009, December 2010, and January 2011, Jeddah experienced significant flash floods caused by rainfall precipitation values of 83 mm to 111 mm, each lasting approximately three hours [29]. The three flood events resulted in the loss of 113 lives, left 350 people reported missing, and caused significant damage to infrastructure and property, including over 10,000 homes and 17,000 vehicles, with an estimated economic loss of around 3 billion dollars [30]. The rapid and often uncontrolled urban expansion in Jeddah has led to the development of neighborhoods in flood-prone areas, while the lack of a comprehensive drainage system across the city was a primary factor behind the severe rain-induced disasters that occurred between 2009 and 2011 [25].

In 2022, Jeddah witnessed its heaviest rainfall, with 179 mm falling over nearly six hours. The downpour affected both urban and rural areas, leading to the closing of major roads. In its aftermath, parts of the city experienced power outages and interruptions to the water supply [21].

5. Final Results

Data Analysis

This study compared various indicators to international benchmarks to evaluate the performance of key systems in Jeddah, specifically urban resilience. The results reveal that Jeddah requires significant improvements across most indicators to strengthen its resilience as a city. Out of the initial 85 indicators derived from international frameworks and resilient city case studies, only 50 were identified as relevant to Jeddah's unique climatic,

environmental, and urban characteristics. Among these, data were successfully collected for 40 indicators, while the remaining indicators were deemed inapplicable or excluded due to data limitations. The benchmark cities selected for comparison, such as New York (USA), Barcelona (Spain), Copenhagen (Denmark), Tokyo (Japan), Semarang (Indonesia), Al-Madinah Al-Munawwarah (Saudi Arabia), and Dubai (United Arab Emirates) were carefully chosen based on their relevance to Jeddah's urban challenges and resilience strategies. Table 2 provides a comprehensive comparison of these indicators and their corresponding benchmark values, and (Figures 6–11) demonstrate the comparison results of the Jeddah Urban Resilience Framework in a radar chart, evaluated on a scale of 10.

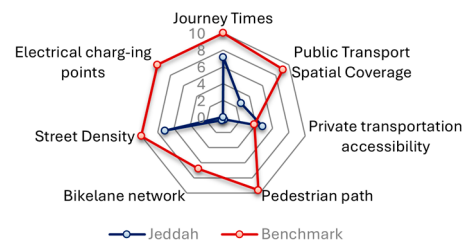


Figure 6. Mobility: Jeddah vs. benchmark.

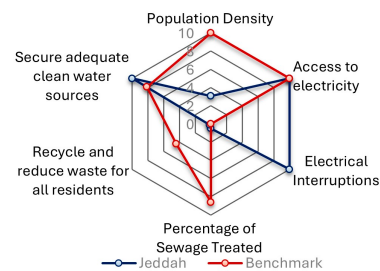


Figure 7. Infrastructure: Jeddah vs. benchmark.

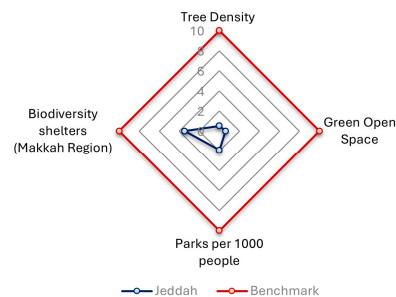


Figure 8. Green space: Jeddah vs. benchmark.

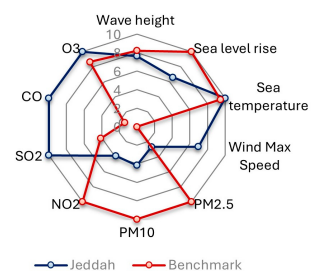


Figure 9. Environment: Jeddah vs. benchmark.

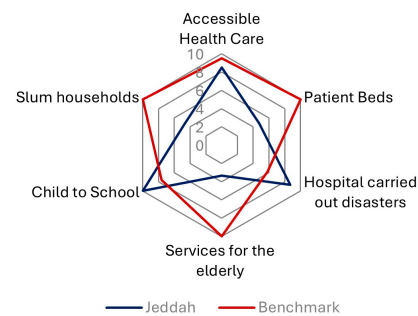


Figure 10. Well-being: Jeddah vs. benchmark.

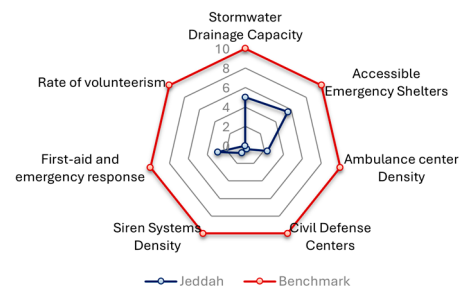


Figure 11. Emergency preparedness: Jeddah vs. benchmark.

6. Discussion

The results of the Urban Resilience Framework for Jeddah, along with its comparison to international benchmarks in Table 2, reveal a clear distinction between strong performance areas and weak indicators requiring urgent improvement. Jeddah performs strongly in fundamental infrastructure indicators such as access to electricity (100%) and secure adequate clean water sources, demonstrating the city's success in delivering essential services. These areas represent a foundational level of resilience. Additionally, under the well-being criterion, Jeddah recorded favorable results in healthcare accessibility and hospital disaster readiness, with 85.18% of residents having health insurance and nearly 88% of hospitals equipped to handle emergencies.

In contrast, the mobility criterion reveals significant shortcomings. Although private vehicle ownership is high, public transportation coverage is severely limited, serving only 23.99% of the urban area—well below the 88.33% average among benchmark cities. Moreover, pedestrian and bicycle infrastructure are nearly absent. As a result, the city relies heavily on private cars, leading to increased congestion and emissions, especially affecting residents without access to personal vehicles.

Environmental and green space indicators highlight some of the most critical gaps in resilience. Tree density in Jeddah is only 0.03 trees per person, which is far below that of the benchmark, which is 0.58. Additionally, green space in Jeddah comprises just 0.13% of the urban area, significantly lower than Dubai's 2.5% [31–33]. Consequently, the city faces severe challenges related to air quality, with most air quality indicators exceeding safe thresholds. The limited vegetation, dependence on private vehicles, and industrial activity are major contributors to environmental degradation.

In this context, addressing Jeddah's environmental challenges is not only essential for local resilience but also aligns with broader national goals, particularly Saudi Vision 2030 and the Green Saudi Initiative (SGI). This initiative supports the Kingdom's ambition to achieve net-zero emissions by 2060 through the adoption of a circular carbon economy and by accelerating the transition to a green economy. SGI aims to achieve three key goals: reducing carbon emissions, planting trees across the Kingdom, and protecting terrestrial and marine ecosystems [34]. Enhancing urban greenery and reducing emissions in cities

like Jeddah is crucial to supporting Saudi Arabia's long-term environmental sustainability, in line with SGI.

Emergency preparedness is another area requiring immediate improvement. While some progress has been made, particularly in providing emergency shelters, the city's stormwater drainage capacity remains insufficient, which poses a significant risk of flooding during heavy rainfall. Additionally, the density of ambulance stations, civil defense centers, and siren systems is inadequate for the city's growing population. Volunteerism rates are also extremely low, well below international averages.

In summary, Jeddah's urban resilience shows the ability to meet basic service demands; however, it must urgently evolve to address more complex urban challenges and natural disaster risks. Drawing on the experiences and strategies of the selected benchmark cities will be essential in enhancing Jeddah's ability to adapt to urban, environmental, and climatic pressures.

7. Recommendations

Based on the findings from the analysis of urban resilience indicators, this section provides actionable strategies to address identified challenges and enhance Jeddah's resilience that are gathered from seven case studies—New York, Copenhagen, Tokyo, Barcelona, Semarang, Al-Madinah Al-Munawwarah, and Dubai along with other international reports to apply these recommendations to guide policymakers in implementing targeted and effective interventions. The recommendations presented are classified into short-term (1–3 years) and long-term (4+ years) strategies based on urgency, feasibility, required resources, and potential for immediate or lasting impacts. Short-term measures focus on immediate urban challenges, offering rapid improvements using existing technologies or infrastructures. In contrast, long-term strategies involve comprehensive planning, substantial investments, and structural transformations to ensure sustainable and resilient urban development in Jeddah.

7.1. Mobility

7.1.1. Short Term

- Optimize transport routes and utilize intelligent traffic management systems to reduce journey times.
 - i. Implementation: Introduce AI-driven traffic flow management and optimize road signal timing to reduce congestion.
 - ii. Feasibility: High feasibility due to available traffic data and existing smart mobility infrastructure.
 - iii. Expected Impact: Reduced journey times, lower emissions, and improved traffic efficiency.
- Promote electric vehicles (EVs) and expand the network of EV charging stations.
 - i. Implementation: Provide incentives for EV adoption and integrate charging stations in residential and commercial areas.
 - ii. Feasibility: Moderate—It requires government incentives and private-sector engagement.
 - iii. Expected Impact: Lower air pollution and reduced reliance on fossil fuels.

7.1.2. Long Term

- Improve and expand public transport networks with low-emission electric buses and high-capacity rail systems.

- i. Implementation: Invest in metro and BRT (Bus Rapid Transit) systems, particularly in underserved areas.
 - ii. Feasibility: Moderate to high—It requires significant policy and funding commitment.
 - iii. Expected Impact: Increased mobility options, reduced congestion, and improved urban air quality.
- Reduce vehicle emissions across the city by transitioning fleets to low-emission vehicles.
 - i. Implementation: Enforce emission regulations, provide incentives for fleet electrification, and introduce low-emission zones.
 - ii. Feasibility: Moderate—It requires gradual policy enforcement and infrastructure development.
 - iii. Expected Impact: Decreased air pollution improved public health, and alignment with global sustainability goals.
- Expand the city's bike lane network and introduce bike-sharing systems.
 - i. Implementation: Construct safe, dedicated bike lanes and integrate public bike-sharing.
 - ii. Feasibility: Moderate—It requires urban space allocation.
 - iii. Expected Impact: Increased non-motorized transport usage, reduced emissions, and healthier urban lifestyles.
- Build wide, safe, and shaded pedestrian paths throughout the city, incorporating green corridors to balance urban density.
 - i. Implementation: Retrofit pedestrian infrastructure with shading elements and tree-lined walkways.
 - ii. Feasibility: High—It requires integration into urban planning policies.
 - iii. Expected Impact: Improved walkability, urban cooling, and enhanced accessibility.
- Redesign major corridors to improve safety and prevent serious crashes.
 - i. Implementation: Apply urban street design best practices such as traffic calming, improved intersections, and pedestrian-friendly layouts.
 - ii. Feasibility: Moderate—It requires detailed traffic studies and phased implementation.
 - iii. Expected Impact: Reduced traffic fatalities and improved pedestrian safety.

7.2. Infrastructure

7.2.1. Short Term

- Attract investment through zoning and incentives.
 - i. Implementation: Introduce zoning regulations and financial incentives to encourage sustainable infrastructure investments through public–private partnerships.
 - ii. Feasibility: High feasibility—It is supported by existing urban planning frameworks and Vision 2030.
 - iii. Impact: Increased sustainable development projects, economic growth, and improved infrastructure resilience.
- Establish free public Wi-Fi networks.
 - i. Implementation: Set up Wi-Fi hotspots in public parks, transportation hubs, and high-density areas.
 - ii. Feasibility: Highly feasible—Minimal technological and financial barriers.
 - iii. Impact: Improved digital accessibility and increased public safety through enhanced communication channels.

- Rainwater harvesting incentives.
 - i. Implementation: Offer incentives, guidelines, and technical assistance to promote household rainwater harvesting.
 - ii. Feasibility: Feasible—It is easy to implement at household levels with moderate investment.
 - iii. Impact: Reduced urban flooding and improved local water resource management.
- Redundancy systems for backup power.
 - i. Implementation: Adopt renewable energy storage solutions, such as solar battery storage, in critical infrastructure like hospitals and emergency centers. Encourage private sector adoption of distributed energy storage.
 - ii. Feasibility: High—Proven renewable technologies are available for immediate integration.
 - iii. Impact: Minimized service disruptions, enhanced energy security, and improved emergency resilience through sustainable backup power solutions.

7.2.2. Long Term

- Incorporate green building standards.
 - i. Implementation: Mandate green building codes and provide support for sustainable building practices.
 - ii. Feasibility: Moderate—It requires comprehensive legislative support.
 - iii. Impact: Long-term reduction in energy consumption and improvement in urban sustainability.
- Execute green infrastructure for stormwater management.
 - i. Implementation: Develop rain gardens and integrated smart stormwater systems citywide.
 - ii. Feasibility: High—It has proven effectiveness internationally.
 - iii. Expected Impact: Significant reduction in flooding risks and improved urban environmental quality.

7.3. Green Spaces

7.3.1. Short Term

- Promote community gardens and urban farms.
 - i. Implementation: Convert vacant land for community farming; provide technical support.
 - ii. Feasibility: Highly feasible—It requires minimal initial investment.
 - iii. Expected Impact: Enhanced community engagement, food security, and improved urban environment.
- Create and promote farmers' markets with local producers.
 - i. Implementation: Establish designated spaces for farmers' markets in urban areas, provide logistical support, and implement policies that prioritize local producers.
 - ii. Feasibility: High—It requires municipal coordination and policy support but is achievable with community and business involvement.
 - iii. Impact: Increased access to fresh, local food, support for small-scale farmers, and promotion of sustainable food systems.
- Reduce urban light pollution.
 - i. Implementation: Introduce lighting standards for buildings.
 - ii. Feasibility: Very feasible with minimal infrastructure changes.

- iii. Impact: Improved ecological health and urban livability.

7.3.2. Long Term

- Develop continuous green corridors.
 - i. Implementation: Systematic planting and maintenance of trees, and creation of interconnected parks.
 - ii. Feasibility: Moderate—It requires coordinated planning and sustained funding.
 - iii. Expected Impact: Significant improvement in biodiversity, urban cooling, and residents' quality of life.
- Green the city's streets, parks, and open spaces through Parks without Borders.
 - i. Implementation: Expand urban greening by planting trees, creating shaded walkways, and making parks more accessible through open design, fostering community interaction and environmental benefits.
 - ii. Feasibility: High—It can be integrated into existing urban planning policies with moderate investment.
 - iii. Impact: Improved urban cooling, enhanced walkability, increased biodiversity, and stronger community engagement.

7.4. Environmental

7.4.1. Short Term

- Strengthen coastal ecosystem protection.
 - i. Implementation: Establish zoning and specific protective regulations for beaches.
 - ii. Feasibility: High feasibility—It can be enforced through existing environmental frameworks.
 - iii. Expected Impact: Enhanced coastal biodiversity and sustainability.
- Improve waste and sewage management.
 - i. Implementation: Upgrade waste collection methods and sewage infrastructure.
 - ii. Feasibility: Moderate to high; infrastructure investments are necessary.
 - iii. Expected Impact: Reduced pollution and improved public health.
- Enhance food waste and recycling systems for sustainability.
 - i. Implementation: Mandate food service establishments to separate food waste for composting, improve curbside recycling by shifting from dual-stream to single-stream collection, and support the development of markets for recycled materials.
 - ii. Feasibility: High—It can be implemented through regulatory measures and public-private partnerships.
 - iii. Impact: Increased waste diversion from landfills, enhanced recycling efficiency, and strengthened circular economy practices.

7.4.2. Long Term

- Enhance coastal marine biodiversity.
 - i. Implementation: Deploy artificial reefs to restore marine habitats and conduct climate impact studies on sea temperature, water quality, and biodiversity to guide conservation efforts.
 - ii. Feasibility: Moderate—It requires collaboration with marine researchers and environmental agencies.

- iii. Impact: Strengthened marine ecosystems, improved biodiversity, and enhanced coastal resilience to climate change.
- Conduct district-specific climate change analyses.
 - i. Implementation: Develop localized risk assessments using climate data and urban mapping.
 - ii. Feasibility: High—It can be integrated into existing urban planning and resilience policies with the government.
 - iii. Impact: Enhances disaster preparedness and targeted adaptation strategies.
- Promote renewable energy and green job creation.
 - i. Implementation: Encourage renewable energy projects (solar/wind) and support employment in climate-related sectors.
 - ii. Feasibility: High—It aligns with national renewable energy goal and economic diversification efforts.
 - iii. Impact: Decreased emissions, energy efficiency, and enhanced climate resilience.
- Implement large-scale organic waste composting.
 - i. Implementation: Establish community composting and industrial composting facilities.
 - ii. Feasibility: Moderate—It requires public acceptance and infrastructure.
 - iii. Expected Impact: Reduced waste, enhanced soil quality, and sustainable waste management.

7.5. Well-Being

7.5.1. Short Term

- Establish Family Justice Centers and health clinics.
 - i. Implementation: Set up community-based family support and primary health-care facilities.
 - ii. Feasibility: Highly feasible—It provides strong social benefits.
 - iii. Expected Impact: Improved healthcare access and enhanced family and community resilience.
- Create health clinics in areas with primary care shortages.
 - i. Implementation: Establish primary care clinics in underserved areas, prioritizing districts with limited healthcare facilities.
 - ii. Feasibility: High—It requires government and private sector collaboration
 - iii. Impact: Improved healthcare accessibility, reduced strain on major hospitals, and better health outcomes for vulnerable populations.
- Provide opportunities for physical activity for residents.
 - i. Implementation: Develop accessible parks and recreation areas with adaptive equipment, walking paths, and community fitness programs.
 - ii. Feasibility: High—It aligns with public health goals and urban planning initiatives, requiring moderate investment and policy support.
 - iii. Impact: Improved public health, social inclusion, and community well-being, reducing sedentary lifestyles and promoting accessibility for people with disabilities.
- Protect schools with environmental and road safety measures.
 - i. Implementation: Introduce traffic calming measures, designated pedestrian crossings, and shaded walkways around schools to enhance student safety and accessibility. Incorporate heat-resistant materials and green infrastructure in school design to improve environmental conditions.

- ii. Feasibility: High—It can be integrated into existing urban planning and transportation policies with moderate investment.
- iii. Impact: Improved student safety, reduced traffic-related accidents, and enhanced learning environments through better climate resilience.

7.5.2. Long Term

- Localized healthcare and senior care services.
 - i. Implementation: Integrate healthcare facilities within neighborhoods, increasing accessibility.
 - ii. Feasibility: Feasible—Moderate investment with substantial social benefits.
 - iii. Expected Impact: Improved healthcare accessibility and quality, especially for vulnerable populations.
- Improve Localized Healthcare Access.
 - i. Implementation: Establish satellite clinics and decentralized health centers within residential areas to reduce reliance on central hospital campuses.
 - ii. Feasibility: High—It can be integrated into existing healthcare policies with moderate investment.
 - iii. Impact: Enhanced accessibility to healthcare, reduced patient travel time, and improved health outcomes for underserved communities.
- Enable crime prevention through environmental design (CPTED)
 - i. Implementation: Integrate CPTED principles into urban planning by improving street lighting, maintaining green spaces, and optimizing urban layouts to enhance visibility and security.
 - ii. Feasibility: High—It can be implemented through existing urban planning initiatives with minimal infrastructure adjustments.
 - iii. Impact: Reduced crime rates improved public safety perception, and enhanced neighborhood livability.

7.6. Emergency Preparedness

7.6.1. Short Term

- Identify areas where high water levels will first penetrate.
 - i. Implementation: Conduct hydrological studies and flood mapping to identify vulnerable zones where high-water levels are likely to penetrate first. Utilize GIS technology and historical flood data to create a risk assessment model.
 - ii. Feasibility: High—It can be integrated into existing disaster preparedness frameworks with government and academic collaboration.
 - iii. Impact: Improved flood response efficiency minimized property damage, and enhanced community resilience against extreme weather events.
- Enhance disaster communication and public awareness.
 - i. Implementation: Establish an integrated early warning system using SMS alerts, mobile apps, and public announcements. Install clearly marked evacuation routes and emergency shelter signs in high-risk areas. Conduct participatory disaster mapping by engaging local communities in risk identification and preparedness drills.
 - ii. Feasibility: High—It requires coordination between government agencies and telecom providers but builds on existing technologies.
 - iii. Impact: Faster emergency response increased public awareness, and reduced casualties and property damage during disasters.

- Community-based disaster preparedness groups.
 - i. Implementation: Form localized disaster-preparedness groups in high-risk sub-districts. Train residents on risk assessment, first aid, evacuation procedures, and emergency response in collaboration with civil defense and local authorities.
 - ii. Feasibility: High—It requires community engagement and structured training but is cost-effective and can leverage existing civil defense resources.
 - iii. Impact: Increased local resilience, faster response times, and reduced reliance on external emergency services during crises.
- Emergency relief and medical transportation routes.
 - i. Implementation: Identify and designate critical emergency relief and medical transport routes, ensuring uninterrupted access to hospitals, shelters, and supply distribution points. Integrate GIS-based mapping and real-time traffic management to optimize emergency response times.
 - ii. Feasibility: High—Requires coordination with transportation and emergency management authorities but is logistically feasible with existing infrastructure.
 - iii. Impact: Faster medical response times, improved disaster relief efficiency, and reduced casualties during emergencies.

7.6.2. Long Term

- Strengthen structural and coastal resilience.
 - i. Implementation: Implement resilient coastal infrastructure, reinforce buildings to withstand extreme events, and ensure that all homes meet earthquake resistance standards.
 - ii. Feasibility: Moderate—It requires considerable funding and planning.
 - iii. Expected Impact: Reduced vulnerability to flooding, storms, and earthquakes, enhancing safety and long-term structural durability.
- Allocate land for future flood protection infrastructure.
 - i. Implementation: Designate and preserve land for critical flood protection infrastructure, such as dikes, locks, and retention basins, ensuring future adaptability to extreme weather conditions.
 - ii. Feasibility: Moderate— It requires urban planning integration and proactive land-use policies.
 - iii. Impact: Prevents urban encroachment on essential flood mitigation zones, ensuring long-term flood resilience and minimizing future infrastructure costs.
- Evaluate and adapt buildings for flood resilience.
 - i. Implementation: Assess existing structures to identify those at high flood risk, determining whether they should be demolished, repurposed, or relocated. Prioritize the protection of critical infrastructure such as hospitals, schools, and emergency response centers.
 - ii. Feasibility: Moderate—It requires detailed flood risk assessments and collaboration with urban planners and policymakers.
 - iii. Impact: Enhances urban resilience by reducing exposure to flooding, ensuring the safety of essential buildings, and improving long-term disaster preparedness.

8. Conclusions

This study identified critical gaps and opportunities in Jeddah's urban resilience across multiple indicators. Key findings highlight the need to enhance mobility, improve infrastructure, expand green spaces, address environmental challenges, promote well-being,

and strengthen emergency preparedness. These criteria represent significant opportunities to create a more resilient urban environment that addresses the needs of both current and future populations.

Despite these contributions, the study has some limitations, such as restrictions on specific government data due to security and confidentiality policies, including crime and car accident rates. Additionally, some datasets were only accessible at the regional rather than the city level, limiting city-specific insights. Although international case studies offered valuable benchmarks, the effectiveness of these strategies in Jeddah may vary due to differences in local economics, climate, social structures, and governance systems. Furthermore, many of the world's leading urban resilience cities did not share their frameworks or data, which limited our ability to analyze their strategies, leading to their exclusion from the study.

Future research should focus on gathering more detailed city-level data, assessing the long-term effects of resilience strategies, and utilizing advanced GIS tools to evaluate their impact.

Urban resilience is not just a local priority but a global imperative. As cities like Jeddah confront increasing environmental, social, and infrastructural challenges, adopting innovative and sustainable practices becomes essential. The insights from this study can guide the development of improved urban resilience strategies and inform decision-making policies for Jeddah and other cities striving to strengthen their resilience frameworks.

While this framework is tailored to Jeddah's unique climatic, socio-economic, and urban conditions, its methodological approach can be adapted to other cities with different characteristics. By adjusting indicator selection, weighting criteria, and benchmarking strategies, this framework provides a flexible model that can be customized to suit cities with varying environmental, infrastructural, and governance contexts. Future research could explore its applicability to rapidly growing cities in arid regions or those facing distinct resilience challenges, ensuring a broader impact on urban sustainability and planning.

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