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Regional Resilience: A Systematic Analysis of Egyptian Medium-Sized Cities

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Abstract This study develops a structured framework for measuring regional resilience in Egypt's medium-sized city regions, focusing on economic, environmental, and social vulnerabilities. Using the 4Rs model -Risks, Resistance, Robustness, and Recoverability- the research constructs a composite index using socio-economic, infrastructural, and institutional indicators. Analysing 37 city regions across 17 Egyptian governorates reveals significant resilience disparities. Governorate capitals and well-connected city regions demonstrate stronger resilience due to more robust economic bases and governance structures. In contrast, peripheral regions face high vulnerability due to weak institutional capacity and limited economic diversification. The results highlight a critical imbalance between resistance and recoverability, while some regions recover quickly, they remain susceptible to recurrent disruptions. The measurement model and classification framework aim to support policymakers in identifying at-risk areas and potential regional growth centres, enabling more effective resilience strategies. By embedding resilience thinking into urban and regional planning, the findings contribute to a more adaptive and sustainable regional development approach for Egypt's medium-sized city regions.

Keywords: Medium-Sized Cities, Regional Development, Regional Resilience, Regional Resilience Measurement, Resilience Framework.

1 Introduction

In the face of economic crises, natural disasters, and epidemics, there is growing scholarly interest in understanding the unpredictability of local and regional responses to such shocks. Moreover, how regions react to such challenges indicates their economic resilience. Recently, the concept of regional resilience has gained significant attention across multiple disciplines, including economics [1-2], economic geography [3-4], and regional sciences [5-6].

Many scholars have emphasised the necessity of formalising the "regional resilience" concept within the literature, stimulating discussions surrounding its definition and the quantitative measures essential for evaluating it. This paper aims to contribute to this critical discussion by putting the main common or agreed-upon concepts in an applied formula that combines the different viewpoints of regional resilience to reach a measuring index that can be considered a comprehensive and aggregated tool for measuring regional resilience at the level of city regions.

Resilience is a multifaceted concept that has evolved across various fields, where the term is derived from the Latin word resilire, meaning "to spring back" or "to rebound" [7]. It initially emerged in physics to describe a material's capacity to resist external shocks. After that, the concept gained ecological relevance in the 1960s, primarily through ecologist Crawford Stanley Holling, who differentiated resilience from stability within ecological systems [8]. Over time, resilience expanded into psychology, economics, geography, and urban planning, each adapting the term to its unique contexts [7]. An evolutionary approach to resilience has gained prominence

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in economic geography, challenging the equilibrist thinking in engineering and ecological interpretations. This approach recognises the inevitability of structural change, viewing resilience as the capacity for reorganisation within existing industries or adaptation through shifts to new economic activities [9].

Empirical studies on regional economies' responses to shocks often focus on whether regions are resilient and seek to identify determinants of resilience [10]. Such studies employ a deterministic approach, classifying resilience types before measuring regional resilience against the predefined concepts.

In the regional resilience literature, scholars consider macro-economic performance as a main stress factor, while urban resilience studies focus on the mega cities and urban regions on their micro-meso levels (community/city scales) [11]. Urban and regional resilience research on small and medium-sized cities is not as common as mega cities despite their development potentials and the risk and challenges they face [12] This is particularly true in the Egyptian urban context, where medium-sized cities face several challenges requiring regional resilience to ensure sustainable development. These cities face natural disasters, including floods and earthquakes, which pose significant risks to the built environment and human lives [13]. Furthermore, weak institutional frameworks, limited resource access, and low levels of social capital make these cities particularly vulnerable to economic downturns and other external shocks [14]. To address these challenges, it is essential to understand the factors contributing to regional resilience in Egyptian medium-sized cities and their regions.

This research aims to contribute to the academic discourse on the regional resilience of medium-sized cities within the Egyptian regional system. It will provide a comprehensive analysis of the key factors contributing to regional resilience in medium-sized cities in Egypt, focusing on economic development, infrastructure, social capital, disaster preparedness, and governance. By identifying these factors, the study will offer a comprehensive understanding of the complex dynamics of regional resilience, thereby providing a solid foundation for developing policy interventions that can promote sustainable development in Egypt's medium-sized cities.

2 Background

2.1 Regional Resilience

The concept of regional resilience has gained considerable attention during the economic crises of the last few decades, helping to clarify its implications while emphasising the lack of agreement on its definition. In economic geography, many researchers question the traditional engineering and equilibrium perspectives of resilience, which define it as a return to stability after external shocks. Instead, many scholars advocate for an evolutionary perspective on regional resilience, focusing on regions' long-term adaptability and capacity to restructure their socio-economic systems following change [15]. Meerow et al. [16] identify five conceptual frameworks and tensions in defining resilience, particularly emphasising the concept of equilibrium. These frameworks are: (1) equilibrium vs. non-equilibrium resilience; (2) positive vs. neutral (or negative) conceptualisations of resilience; (3) mechanisms of system change (i.e., persistence, transitional, or transformative); (4) adaptation vs. general adaptability; and (5) timescale of action.

Within the resilience literature, scholars have examined three primary perspectives on equilibrium: single-state equilibrium (engineering resilience), multiple-state equilibrium (ecological resilience), and dynamic non-equilibrium (evolutionary resilience) [17-19]. The resilience concepts based on their equilibrium perspectives are described below.

2.1.1 Engineering Resilience

Engineering resilience, often associated with single-state equilibrium, refers to a system's ability to return to its previous state following a disturbance [19]. This concept is widely employed in resilience studies across disciplines such as disaster management, psychology, and economics. Within this framework, resilience is primarily understood as the capacity for restoration and maintaining a consistent, stable state. The defining characteristics of engineering resilience include the following [16]:

1. It assumes that the regional economy returns to its pre-shock state of equilibrium after experiencing a disturbance.
2. It is particularly applicable for analysing macroeconomic fluctuations and large-scale emergencies.
3. It typically involves low-intensity impacts.

This perspective has been described as a 'backwards into the future' approach, which is subject to critique. For instance, Martin and Sunley [4] argue that the pre-shock structures of a region may not always be desirable, as they may fail to provide full employment, adequate income levels, or ecological and social sustainability. Furthermore,

conceptualising resilience merely as “bouncing back” neglects the possibility that recovering from shocks may also involve the emergence of new developmental paths [20].

2.1.2 Ecological Resilience

Ecological resilience, associated with the concept of multiple-state equilibrium, suggests that systems can exist in different stable states [19]. Unlike engineering resilience, this perspective indicates that when faced with a disturbance, systems may shift from one stability domain to another rather than merely returning to their original state [16, 18]. This approach emphasises the potential for fundamental change and adaptation in response to challenges. The main characteristics of ecological resilience include the following [9, 16, 21]:

1. It is grounded in the idea that a shock can push a region into a new equilibrium state or initiate a different developmental trajectory
2. It is particularly suited for analysing macroeconomic fluctuations and large-scale emergencies.
3. It typically involves the impacts of short-term exposure.

2.1.3 Evolutionary Resilience

Some researchers argue that initial economic and structural strategies alone are insufficient for fostering long-term regional growth. Instead, an "evolutionary" or "adaptive" approach has been proposed, which integrates short-term and long-term strategies for sustainable development [22]. This approach draws on complex adaptive systems theory and urban systems theory, conceptualising cities and regions as interconnected systems shaped by internal dynamics and external forces. A key innovation within this framework is the distinction between "sustaining" (adaptation) and "developing" (adaptability) within complex systems [17, 23-24].

Evolutionary resilience emphasises the non-linear and dynamic nature of regional systems, recognising their capacity for both positive and negative transformations in response to unpredictable changes. The approach aims to foster flexible and responsive strategies that enhance regional development in complex and volatile environments [25].

The primary characteristics of evolutionary resilience include the following [7, 15]:

1. It assumes that regional economies are never in a state of equilibrium but instead engage in a continuous process of renewal and adaptation.
2. It highlights the capacity for renewal and transformation in response to structural changes and profound macroeconomic fluctuations.
3. It involves profound and long-term impacts, such as those associated with grand societal challenges like climate change.

The concept of evolutionary resilience acknowledges the potential for crises to catalyse the emergence of new industrial paths through the destruction of outdated paths [15, 24-26]. However, this perspective adopts a ‘neutral’ stance on crisis-induced transformation, offering limited guidance on the desirable direction of change. As Trippl et al. [20] note, it provides little insight into which types of new economic activities or reorientations of existing industrial paths would be most advantageous for regional development.

2.1.4 Transformative Resilience

The concept of transformative resilience has emerged in the economic geography literature as a novel perspective on regional resilience. This approach defines resilience as the capacity of a system to undergo significant transformation in response to shocks, enabling it to transition to a new, sustainable path characterised by more productive and equitable use of physical, human, and environmental resources [27].

Transformative resilience often entails substantial changes, such as regionalising global supply chains, fostering environmentally sustainable tourism, advancing transitions in socio-technical systems (e.g., energy, mobility, food, or housing), pursuing post-growth initiatives, and adopting new institutional and behavioural practices. These transformations aim to address pressing global challenges while fostering sustainable regional development [20]. However, the concept requires further theoretical clarification and empirical research to establish its applicability in developmental fields. Transformative resilience must be refined to account for practical implementation and measurable outcomes in diverse contexts to serve as an explicit regional policy framework [27].

As illustrated in **Fig. 1**, we can conclude that the differences between the four concepts of resilience are the dynamic properties and the conceptualisation of the system; where Engineering Resilience adopts the single equilibrium view of a system, Ecological Resilience is a multiple equilibria approach, Evolutionary Resilience emphasizes non-linear dynamics and adaptive capacities beyond equilibrium, finally Transformative Resilience represents a

transition into a new, sustainable path using transformative capacities.

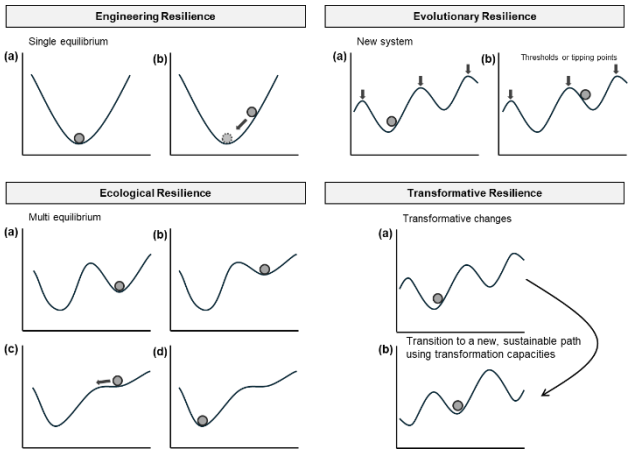

Fig. 1 The difference between the four concepts of resilience [27-28]

2.1.5 Regional resilience and urban systems

Contemporary research on urban and regional resilience often adopts a centralised approach, primarily focusing on isolated cities or regions without accounting for the broader dynamics of regional urban systems [22].

In their meta-analysis of urban and regional resilience discourses, Leitner et al. [29] observed a clear distinction in focus. Urban studies scholars predominantly examine resilience at the local scale, addressing shocks that arise from bottom-up processes. Conversely, research on regional resilience emphasises meso- and macro-level dynamics, considering top-down shocks such as economic recessions, international trade restrictions, and global crises [24, 30]. Unlike urban resilience, which often neglects intercity interactions, regional resilience situates regions as embedded systems within broader macroeconomic processes [11]. This divergence highlights the need to integrate urban and regional resilience frameworks to create a unified approach to understanding resilience across multiple scales.

Such an integrated approach would consider cities and city regions as fundamental units for measuring regional resilience, positioning these urban entities as integral components of broader regional systems. This perspective recognises that cities are embedded within regions, which are, in turn, connected to macroeconomic changes at national and global levels [21, 31]. By aligning urban and regional resilience strategies, scholars and policymakers can adopt holistic frameworks that support regional development and better address systemic challenges.

2.2 Medium-Sized Cities

According to many scholars, medium-sized cities are essential to regional development and play a crucial role in achieving sustainable development goals (SDGs) at the local level [12, 32-33].

Despite their importance, Birkmann et al. [12] emphasise that the small and medium-sized cities and their regions often remain underrepresented in academic and policy discourse, particularly within the context of regional resilience. While existing studies have extensively discussed the resilience of primate cities and large urban centres, limited attention has been given to small and medium-sized cities, which are often more vulnerable and exhibit rapid growth, especially in Africa and Asia [32].

The vulnerabilities of small and medium-sized cities are frequently underestimated in comparison to those of megacities due to four primary reasons: limited data availability, insufficient political power, inadequate personnel, and scarce resources. Knowledge about the past and potential future impacts of extreme events - such as fatalities, economic losses, and livelihood disruptions- on cities of varying sizes remains particularly limited in developing countries [12].

Many empirical studies conclude that medium-sized cities play a supportive role in enhancing regional resilience [22, 25, 34]. However, during specific crises, rural areas and suburban centres may emerge as the primary contributors to regional resilience, especially in situations involving natural resources and environmental challenges [10]. To effectively study the regional resilience of medium-sized cities, it is essential to view the city and its surrounding region as a unified development unit.

2.2.1 Reclassifying Egyptian medium-sized cities

The issue of regional resilience is particularly relevant to the Egyptian urban and regional context. Rapid urbanisation and economic growth have introduced new challenges for local communities, mainly medium-sized and small cities, which are often overshadowed by the focus on larger metropolitan areas [35].

According to the National Urban Policy [36], medium-sized cities are those with populations ranging from 100,000 to 250,000 inhabitants. These cities have the potential to act as anti-magnetic growth poles, driving future urban development in Egypt. However, they currently face significant functional and productive development capacities, exacerbating structural and hierarchical imbalances of the Egyptian urban system.

Despite their developmental potential, including access to natural resources and a significant population base, medium-sized cities in Egypt often lack robust economic drivers, such as economic growth and diversity, and a strong industrial base [33]. This deficiency emphasises the need to understand their roles better and highlights the ineffective integration of these cities within the broader urban system.

To address these challenges, medium-sized cities can be reclassified into sub-categories based on their intermediary roles to nominate the most capable cities and city regions to strengthen their regions' developmental capacities while enhancing their resilience against shocks and risks. Such classifications should consider the integration of these cities across various spatial scales, from their interactions with neighbouring primate cities to their influence on small rural settlements within their peripheral spheres.

Accordingly, a comprehensive classification framework for medium-sized cities should incorporate key characteristics such as population size, urban infrastructure, economic and social assets, and the effectiveness of local governance. These elements are essential for accurately assessing the medium-sized cities' regional resilience capacities and understanding their potential roles within the urban and regional systems.

2.3 Measuring Regional Resilience: components and phases

The measurement of regional resilience has been a central concern in academic research and literature [6, 10, 20, 27-38]. Over the past decade, numerous empirical studies have attempted to develop holistic indices to evaluate regional resilience across various spatial scales [25, 27, 34, 39-41].

A pioneering contribution to measuring regional resilience was Martin's [23] analytical framework, which conceptualised resilience as a dynamic process comprising multiple phases. Martin introduced the concept of Resistance, which he measured using a sensitivity index (SI) that compares regional employment trends to the national employment levels. This straightforward index provides a foundational tool for exploratory analysis, offering insights into the initial resilience of regions based on employment data.

While employment-based indicators are helpful for initial analysis, they alone are insufficient to capture the multidimensional nature of resilience. Therefore, a more comprehensive understanding requires integrating additional indicators to reflect resilience as a dynamic and complicated process. Combining various determinants of resilience into a unified index allows for a broader and more detailed assessment [4].

An increasingly popular and relatively independent approach to measuring and evaluating regional resilience is the construction of comprehensive composite indicators and indices. These tools allow for comparing territorial performance such as countries, regions, cities, or city regions and are widely recognised as valuable instruments in policy analysis and public communication. Moreover, Composite indicators and indices (CIs) are extensively used to benchmark the mutual and relative progress of territories across various policy domains [42]. However, their primary role should be viewed as initiating discussions and stimulating public interest rather than providing definitive conclusions.

Most regional resilience indicators, measurements, and interpretations have been developed based on studies conducted in Europe and the United States, often in response to the global financial crisis of 2008. Therefore, while these indicators offer valuable insights, their applicability may vary across the different spatial contexts and types of territories [43]. As a result, research on regional resilience must consider the distinctive characteristics of specific regions or countries and their distinct spatial urban system.

2.4 The 4 Rs model

This paper introduces a model for examining and evaluating the resilience of medium-sized cities and city regions. The model addresses two fundamental questions: (1) how effectively these regions can resist and survive various risks and shocks, and (2) how quickly they can recover from such events?

As **Fig. 2** indicates, the process of regional resilience can provide such an index by tracking the regional growth trajectory from before the shock occurs until the city-region recovers from its effects and integrating the determinants of the regional resilience process -as introduced by Martin and Sunley [4]- into two general groups and four sub-categories, with two categories in each group.

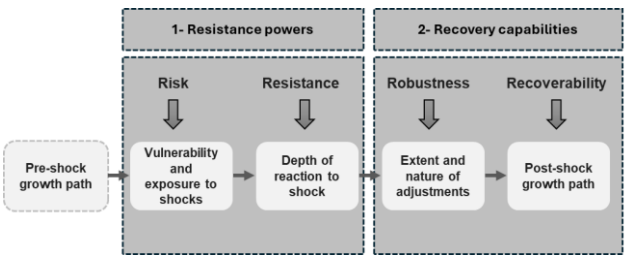

Fig. 2 Determinants of Regional Resilience [4]

Drawing on five decades of resilience research, this study proposes four distinct phases or stages of regional resilience, based on the definitions of the "4 Rs", as follows:

2.4.1 R1: Risks

The First phase focuses on assessing whether cities and their regions are prepared to face hazards and shocks, as well as their vulnerability to such events. Therefore, the risks phase encompasses the vulnerabilities arising from insufficient urban infrastructure, which plays a critical role in the region's ability to survive external shocks. This is particularly relevant in rural areas, where inadequate infrastructure increases their vulnerability [22]. This urban infrastructure includes access to clean water, proper sewage systems, adequate housing, food security, and stable income sources.

2.4.2 R2: Resistance

The second phase evaluates the current and potential capabilities of these regions to withstand risks. Accordingly, Resistance represents the depth and strength of the regions' reactions to shocks, focusing on general economic indicators. The ability of a region to endure stress is critical to maintaining its stability during crises [9].

2.4.3 R3: Robustness

The third phase examines the adaptability and responsiveness of city regions to hazards. Thus, Robustness reflects the extent and nature of adjustments required to adapt to, confront, and respond to shocks. This stage relies heavily on the strength of social networks and the availability of public facilities, both of which are integral to the regional response to external pressures [18, 30].

2.4.4 R4: Recoverability

The final phase assesses the region's ability to recover and restore its functions after experiencing shocks. In other words, Recoverability involves evaluating whether regions possess the necessary resources to explore new growth paths. This phase emphasises the role of knowledge networks and technical human resources in driving recovery and fostering sustainable development [26, 43].

3 Methods

This study adopts the methodological approach outlined by Nardo et al. [44], which is widely utilised in constructing composite indicators across various regional and resilience-related empirical studies [2, 27]. The methodology has been tailored to align with the objectives of the resilience index proposed in this paper, following these key steps:

1. Selecting an appropriate spatial scale of analysis: by determining the spatial scale that aligns with the study's focus on medium-sized cities and their surrounding regions.
2. Selecting indicators: through identifying relevant indicators that accurately reflect the dimensions of resilience, including risks, resistance, robustness, and recoverability.
3. Normalising and Weighting data: standardising data to ensure comparability across indicators with different units or scales and weighting data by assigning appropriate weights to indicators and aggregating them to construct the composite resilience index.

3.1 Selecting Spatial Scale and Sample

City regions were selected as the spatial unit of analysis due to their suitability for the research's objectives. They represent the smallest spatial unit with centralised statistical data and are the least administrative units with normative competencies. Moreover, city regions act as a crucial connecting point between urban, local, and regional systems. This selection enables the construction of a broadly applicable index while ensuring a representative sample of the Egyptian urban system.

To define medium-sized cities, this research followed the criteria of NUP 2024 [36], which categorises medium-sized cities as those with urban populations ranging from 100,000 to 250,000. Accordingly, 39 medium-sized cities were identified across 17 governorates in Egypt. These are all the cities in the population category of the medium-sized cities in 2017.

Furthermore, new urban settlements, such as the 10th of Ramadan and Al Obour cities, were excluded from the sample due to their distinct characteristics and typically do not possess what can be described as city regions, thus the final scope of study includes 37 city regions; these settlements differ significantly regarding historical economic development trajectories, regional roles, and spatial connections. Table 1 details the economic, socio-demographic and urban characteristics used in regional resilience empirical studies [9, 25, 34, 37, 43, 45-50].

3.2 Selecting indicators

Empirical studies on urban and regional resilience predominantly focused on the development and application of frameworks, indicators, or models, which serve to

investigate the concepts of resilience [51]. A review of multiple empirical studies on regional resilience [9, 25, 34, 37, 43, 45] and indices developed by regional and international agencies concerned with regional and urban development [46- 50] revealed that indicators commonly used to measure regional resilience can be categorised into four main groups: economic, social, institutional, and environmental. These categories encompass the multidimensional aspects of resilience, reflecting the complexity of urban and regional systems.

As shown in **Table 1**, the indicators have been organised into the most common sectoral components. Additionally, potential indicators relevant to the context of Egyptian medium-sized city regions are highlighted. These are the publicly available data on the level of city regions, ensuring applicability to the specific urban and regional systems under study. Economic indicators are the most frequently utilised measures of regional resilience because the field of regional resilience has its roots in economic geography [4]. This emphasis reflects the strong association between economic performance and a region's capacity to withstand and recover from external shocks.

Table 1 Components and measurements of regional resilience* [9, 25, 34, 37, 43, 45-50]

Economic components	
General Economy	GDP per capita
	Gini index
	Economic growth rate
	Unemployment rate
	Dependency Ratio
Innovation	New economic establishments
	Patent applications
	Share of higher education in the workforce
Economic diversity	Economic diversification coefficient
	Primary economic sectors employment
	Reliance on individual companies
	Emergency financial planning and financing

Social Components	
Participation and inclusion	Using participatory planning approaches
	Participants in government projects
	Participants in community activities
Access to services	Educational and health services coverage
	Literacy rate
	Social protection services coverage and access
	Food security (agriculture and agro-industries)
Social Security and Equality	Aid plans to the unemployed, and the poor
	Income security for the elderly and disabled.
	Insurance coverage percentage
	Education dropout rate
	Minimum wage for one hour of work
	Females' employment rate
Quality of Life	Life expectancy at birth
	Holders of higher education qualifications
	Households' income and expenditure rate

Institutional components (administrative)	
Risk readiness	Risk planning, evacuation and emergency plans
	Plans for economic recovery and recovery
	Security and emergency services, civil defense and ambulance
	Communicable disease system
Risk Exposure	Population at risk
	Population in high-risk areas

Environmental and infrastructure components	
Built Environment	Percentage of unplanned areas and slums
	Households living in informal housing
	Population with easy access to public transport and infrastructure networks
Natural environment	Safe and unsafe waste disposal methods
	Loss of agricultural and natural land
	Estimated average exposure to air pollution
	Number of protected natural areas
	Renewable energy sources

* Potential available indicators in the context of Egyptian medium-sized city regions are highlighted in red colour

As elaborated in the background section of this research, the measuring indicators were categorised into four categories i.e. (Risk, Resistance, Robustness, Recoverability), furthermore, each pair of these categories forms a resilience characteristics group (or a sub-index) as illustrated in **Table2**, where:

- "Risk category" includes indicators related to basic vulnerability of the city region to risks, such as (urban infrastructure, Housing, and dependency),
- "Resistance category" includes employment and population indicators, which support the region's ability to resist the shocks.
- "Robustness category" includes social inclusion and insurance indicators which ensure that all region's population are secured and can participate in the economy.
- "Recoverability category" includes education and knowledge indicators which enables the revolutionary resilience in the face of uncertainties.

Risk and Resistance categories form the first resilience sub-index (Resistance to shocks), while Robustness and Recoverability categories form the second resilience sub-index (Recovery capabilities).

The public census data of Egypt were utilised to construct the regional resilience measurement model for medium-sized city regions in Egypt [52]. Various scholars have widely adopted this approach in regional resilience studies [45].

Table 2 Selected indicators of regional resilience

1- Resistance to shocks	
Risk	**Resistance**
• Access to appropriate infrastructure (clean water, sanitation, and electricity) • Dependency Ratio • Housing status (type of dwelling and crowding rate)	• Employment rate • Employment in non-primary sectors • Population size (and population growth rate)
2- Recovery capabilities	
Robustness	**Recoverability**
• Females' employment rate • Insurance coverage percentage	• Literacy rate • Holders of higher education qualifications • Education dropout rate

Basically, only data available for the urban and rural settlements of the city regions, as reported in the 2017 census, were included in the analysis. In addition, the 2006 census data were employed solely to calculate the population growth rate.

3.3. Normalising and weighting data

The final regional resilience index comprises two sub-indices i.e. (Resistance to shocks, and Recovery capabilities), each measured by five to six indicators, as illustrated in **Table 2**. To aggregate these indicators into a

single sub-index, each indicator was normalised to a scale of 0 to 1 using the min-max transformation equation [33, 53].

Equation 1 min–max transformation

$$indicator = (real\ value - min)/(max - min)$$

Furthermore, the indicators were aggregated into sub-indices based on their positive or negative influence on regional resilience. Indicators contributing positively to resilience were standardized and aggregated differently from those with negative impacts to ensure their effects were appropriately weighted, negative indicators were transformed using the invers normalization approach, applying the formula (1 - normalized value) to ensure alignment with positive indicators before aggregation.

Since the relative influence of each indicator on resilience was unknown due to the absence of established weighting criteria [34, 42], an equal weighting approach was adopted for the aggregation process. This method, commonly used in composite indices, ensures that no single indicator disproportionately influences the overall resilience assessment, maintaining neutrality in the aggregation process [34]. A comparative framework for evaluating city regions' resistance to shocks and recovery capabilities is used to categorise city regions according to their performance in these two sub-indices into one of four quadrants, providing insights into their resilience profiles as in **Fig. 3** [4, 25].

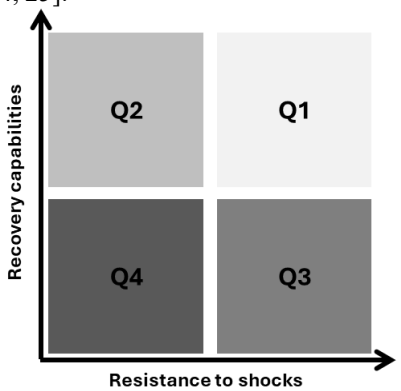

Fig. 3 Regional resilience index structure [4, 25]

Where the city regions in:
Q1 are most resilient,
Q2 are vulnerable city regions but fastest to recover,
Q3 are resistant city regions but slowest to recover,
Q4 are non-resilient city regions.

4 Results

The 4Rs model was applied to 37 Egyptian medium-sized city regions, revealing a strong correlation between resistance to shocks and recovery capabilities. To systematically classify these city regions, a threshold of 0.5 in both sub-indices was used as a dividing line to distinguish between the best- and worst-performing city regions. The findings indicate a concerning trend, as the majority of the studied city regions demonstrate low resilience, illustrated in Table 3; 62.2% (23 city regions) fall into the non-resilient category (Q4), highlighting the widespread vulnerability of medium-sized city regions in Egypt.

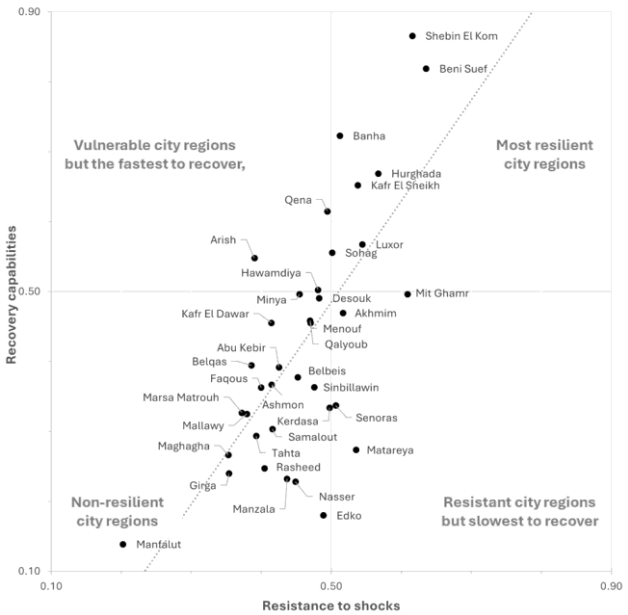

Fig. 4 Classification of Egyptian medium-sized city regions

This classification suggests that nearly two-thirds of the studied city regions lack either adequate resistance to shocks or effective recovery mechanisms, or in many cases, both, as in **Fig. 4**.

Notably, the classification results reveal that all seven of the most resilient city regions (Q1) are governorate capitals, with Shebin El Kom and Beni Suef emerging as the most resilient. This resilience is primarily attributed to their strong recovery capabilities, driven by diversified economic bases, well-developed infrastructure, and strong governance structures. These factors enhance their ability to absorb shocks and recover efficiently. Despite these city regions' remarkable recovery performance, their resistance scores remain moderate, with the highest recorded resistance value at 0.64 (Beni Suef). In contrast, the maximum recovery score reaches 0.87, indicating that

while these cities can recover quickly from shocks, they remain vulnerable to recurrent disruptions and risks from one aspect or another.

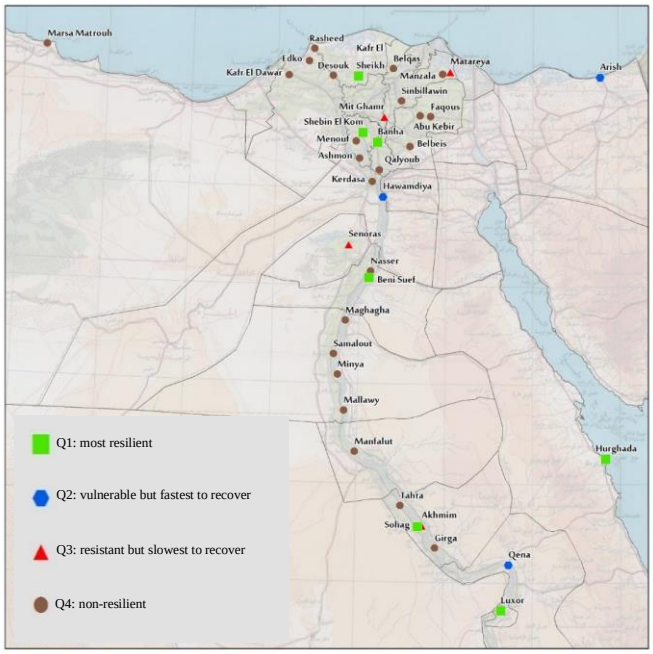

Fig. 5 Classification of the Egyptian middle-sized city regions based on the 4Rs model

Further analysis of the model highlights distinct spatial patterns in resilience distribution, as shown in **Fig. 5**.

City regions located within the range of major urban areas, such as Banha and Shebin El Kom, tend to demonstrate moderate resilience, balancing resistance and recoverability. These city regions benefit from industrial hubs, diversified economic bases and relatively developed infrastructure. Conversely, peripheral city regions like Marsa Matrouh and Manfalut exhibit significantly lower resilience scores, largely due to limited economic diversification, a reliance on agriculture or single-sector economies, and weaker institutional capacities, for all these reasons that hinder their ability to withstand and recover from disruptions.

Table 3 Distribution of Egyptian medium-sized city regions based on the 4Rs model

Classification of medium-sized city regions	Number of city regions	Percentage %
Q1: Most resilient	7	18.9%
Q2: Vulnerable but fastest to recover	3	8.1%
Q3: Resistant but slowest to recover	4	10.8%
Q4: Non-resilient	23	62.2%
total	37	100.0%

Moreover, the detailed results show significant variability in resistance to shocks across different city regions. The highest resistance score recorded is 0.64 (Beni Suef), while the lowest is 0.10 (Samalout). This disparity indicates considerable variation in economic structures and governance effectiveness across different regions. A key understanding from this variation is that city regions with higher resistance tend to have well-established industrial or commercial sectors. In contrast, those with lower resistance scores rely predominantly on vulnerable primary economies such as agriculture.

Robustness indicators reveal inconsistencies in adaptation strategies across city regions. Hurghada, despite its relatively high recovery score (0.67), exhibits a robustness score of only 0.39, suggesting an over-reliance on tourism and limited economic alternatives. This underscores the importance of economic diversification as a key factor in long-term resilience.

The classification of city regions, as presented in **Fig. 5**, highlights that a significant proportion of city regions fall within the “vulnerable but fast to recover” quadrant (Q2). Such regions as Minya, Qalyoub, and Menouf demonstrate relatively rapid recovery capabilities but struggle with low initial shock resistance. This suggests that while these city regions possess short-term recovery mechanisms, they suffer from structural weaknesses that leave them exposed to future disruptions, requiring policy interventions to enhance long-term resistance.

On the other hand, at the lower end of the classification, the least resilient city regions (Q4) include Manfalut, Edko, Nasser, and Manzala. These city regions suffer from both weak resistance and inadequate recovery capabilities, making them particularly vulnerable to economic and environmental shocks. With recovery scores as low as 0.14**,** these city regions lack the necessary infrastructure, economic diversity, and institutional frameworks to recover effectively from shocks. Without immediate intervention, these areas will face the risk of long-term socio-economic decline, increasing poverty rates, and reduced investment attractiveness.

5 Discussion

The results of this study highlight significant disparities in resilience among medium-sized city regions, revealing a distinct spatial pattern that aligns with governance structures, economic diversification, and infrastructure capacity. These results align with the previous research on urban and regional resilience, emphasising the role of

institutional capacity, economic diversity and infrastructure in shaping a region's ability to withstand or recover from external shocks [28, 42].

A key observation from this study is the dominance of governorate capitals in the high-resilience category, which reflects the crucial role of administrative functions and institutional capacity in enhancing regional resilience. As noted by Di Caro [25], regional resilience is strongly influenced by structured governance, enhanced service provision, and economic diversification, which collectively support their resistance to shocks and expedite their recovery processes. However, while administrative status provides an advantage, it is not sufficient on its own to ensure resilience. City regions that lack robust infrastructure and economic foundations remain vulnerable, regardless of their governance structure [42].

In addition, the findings point out the urgent need for targeted interventions in peripheral city regions, especially those with weak economic bases and inadequate infrastructure. The gap in resistance scores between high- and low-performing regions indicates the absence of necessary economic and governance structures to withstand external shocks. This supports the argument made by Aswegen et al. [22], who emphasise the importance of inclusive regional planning in strengthening resilience. Moreover, integrating peripheral cities into broader economic and infrastructural networks can enhance their resilience through better connectivity, resource allocation, and institutional support.

An interpretation of the findings reveals the divergence between resistance and recoverability among city regions. Some cities show strong short-term recovery abilities, yet their underlying vulnerabilities leave them exposed to future disruptions. This indicates that resilience is not just about bouncing back from shocks but requires ongoing economic and social investments. This confirms the existing evidence in various studies about the relation between resistance and recoverability in regional resilience [30, 51]. For instance, tourism-driven regions like Hurghada demonstrate high recovery scores but low robustness scores, exposing the risks of over-reliance on a single economic sector. This finding supports previous work by Cowell 2013, who argues that economic diversification is essential for sustaining resilience beyond immediate recovery [39].

Another crucial finding is the role of infrastructure in mediating resilience. City regions with more advanced infrastructural networks tend to exhibit greater robustness and recoverability, confirming previous research on the link between urban systems and resilience capacity [12, 22, 54]. This suggests that investments in infrastructure should be a cornerstone of resilience-building strategies. However, infrastructure development must be aligned with broader socio-economic planning to ensure equitable access, long-term sustainability, and regional balance.

6 Conclusions

This study provides a comprehensive and structured approach to assessing regional resilience in Egypt's medium-sized city regions, utilising the 4Rs model to evaluate their resistance to shocks and recovery capabilities. The findings reveal significant disparities in resilience levels, with a clear spatial pattern linked to infrastructure development, governance structures, and economic diversification. Governorate capitals, such as Shebin El Kom and Beni Suef, exhibited the highest resilience due to strong governance frameworks, diversified economic bases, and well-developed infrastructure. Conversely, peripheral city regions, including Manfalut, Edko, and Nasser, are characterised by low resistance and slow recovery, highlighting their vulnerability to economic and environmental disruptions.

A key conclusion from this study is the imbalance between resistance and recoverability in several city regions. While some regions recover quickly from shocks, they remain structurally vulnerable due to over-reliance on specific industries, such as tourism or agriculture. This highlights the need for resilience strategies that extend beyond recovery efforts and focus on long-term economic adaptability, governance strengthening, and infrastructure enhancement. Additionally, the disparity in infrastructure development emphasises the importance of prioritising investments in weaker city regions to reduce regional inequalities and promote sustainable development.

Future research should integrate qualitative assessments, such as case studies and stakeholder interviews, with quantitative resilience metrics that could provide deeper insights into the social, institutional and economic dynamics that shape regional resilience.

In conclusion, the proposed classification model can guide regional policies by identifying at-risk regions and creating tailored interventions to boost adaptive capacities. Incorporating resilience metrics into development strategies ensures that all city regions -regardless of their economic and spatial positioning- are equipped to withstand future uncertainties and disruptions.

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