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The Resilience Performance Index, a Fuzzy Logic Approach to Assess Urban Resilience

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ABSTRACT

Urban resilience is recently a prominent issue due to rapid urbanization and increasing challenges and stressors affecting cities. Assessment of urban resilience is an essential step in enhancing resilience performance since regular assessment informs resilience action plans, determines areas of deficiencies, and provides spatial and temporal comparisons. However, resilience assessment is a complex process that requires intensive data and resources due to the multi-dimensional and dynamic nature of resilience, and the imprecision of resilience data. In this context, the research aims to develop The Resilience Performance Index (RPI), through setting a conceptual framework, defining relevant resilience indicators, and finally modelling resilience performance using *The Fuzzy Logic Approach*, aiming to combine resilience analysis with artificial intelligence (AI) tools and dynamic modelling methods. The RPI assesses both qualitative and quantitative resilience indicators obtained through records, census data or structured questionnaires. Indicators' values are modelled through a designed fuzzy logic system to obtain the resilience performance score. The developed index is applied on New Damietta city to inform resilience action plans in the Nile Delta region. The RPI addresses the complexity of resilience assessment and ambiguity of resilience data through an easy applicable, user friendly approach without the need for complex mathematical and statistical methods.

1. INTRODUCTION

Resilience can be defined as "the capacity of a certain system subjected to potential hazards or stresses to adapt, resist, or change in order to maintain its functions and structure, through learning from past experiences to inform future risk management measures" [1]. During the early stages of resilience research, most literature described resilience in terms of resisting shocks and mitigating impacts of disruptive events, however, recent researches regard resilience as "The ability to bounce forward" and not merely to resist shocks [2].

The study of natural hazards and disasters was first connected to resilience by Timmerman, who defined disaster resilience as "the capacity of a system, to absorb, adapt, and recover from negative impacts of disasters and other hazardous events". Accordingly, he pointed out two fundamental strategies to respond to potential disruptions; reliability and resilience [3], where reliability strategies consist of protective and defensive mechanisms against negative impacts of disasters, and resilience strategies indicate the capacity to absorb such disruptions and effectively recover. Reliability strategies are currently termed as "Risk management", and considered an inseparable component of resilience management strategies [4]. Current studies regard resilience as an alternative, more comprehensive paradigm of risk management, hence urging governments to regularly monitor and evaluate their resilience performance.

Although the basic fundamentals of resilience assessments seem similar, the process remains inherently contextual with no definite sets of indicators that can suit every location. Moreover, resilience levels vary throughout individual, community, or city levels, facing different hazards and stresses of different frequencies and magnitudes, across different spatial boundaries and temporal scales. Such dynamic nature of resilience requires a certain level of flexibility in the form of tailored sets of indicators, data collection tools, and computation and modelling methods.

The RPI is constructed according to the following systematic approach to address the complexity of resilience assessment:

- Setting a conceptual framework that acts as the theoretical basis for the index construction.
- Identification of the assessment spatial scale.
- Identification of resilience dimensions, relevant indicators and potential metrics.
- Data collection of primary data through structured questionnaires, and secondary data through census data.
- Determining the relative weights of resilience dimensions and individual indicators.
- Computation of indicators' values.
- The incorporation of artificial intelligence (AI) through the design of the resilience fuzzy logic model to model and simulate resilience performance.

2. LITERATURE REVIEW

The term 'Resilience' was originally derived from the word 'Resilio', a Latin word meaning "Bouncing back after disruptions" [5]. It was first presented through the field of physics to indicate the ability of an object subjected to an external force to recover after the force is no longer existent [6]. Later, 'Engineering Resilience' emerged to describe the physical system's ability to reach a state of stability or equilibrium after a certain disturbance [7]. Eventually, the concept extended to several fields and domains including ecology [8], psychology, social sciences, economics [9], industry [10], and organizational management [11].

The specific term of 'Urban Resilience' was introduced during The Annual Conference on Ecology in 2002 [12], in response to the emerging challenges arising in cities, such as rapid urbanization, climate change, natural disasters, health problems, pollution, political conflicts, along with other urban stressors [13]. Although, urban resilience is a relatively recent concept, it has gained the interest of researchers and practitioners worldwide [14], mainly focusing on the main features of resilient systems, resilience policies and practices [15], in addition to resilience assessment frameworks and indicators [16]. Nevertheless, researches and studies have not yet developed into a comprehensive understanding of resilience that covers the interdisciplinary notion of resilient cities and the overlapping fields of urban development, social sciences, ecology, infrastructure management and economics [17].

Among the wide array of urban resilience literature, the arguably largest two branches are *urban ecological* resilience and *disaster risk reduction* literature. The urban ecological literature regards cities as adaptive systems of urban ecosystems, simultaneously focusing on human and environmental systems [18, 19]. While the disaster reduction literature focuses on enhancing the resilience capacity of the cities' physical infrastructure and urban communities against natural and man-made hazards [20, 21].

A parallel growing paradigm is the *regional economic resilience*, which focusses on the shocks and stresses facing the city's economy and emphasizes on economic growth and diversity [22, 23].

2.1 Assessment of urban resilience

Generally speaking, assessment can be defined as "undergoing an intensive, systematic acquisition of information for the purpose of acquiring useful feedbacks concerning specific issues" [24]. In other words, assessment refers to the qualitative or quantitative evaluation of the state of a certain system. In urbanism, assessment is strongly connected to people's well-being and quality of life, in addition to conservation of natural ecosystems, making it an extremely important matter [25].

Resilience assessment is a complex issue due to various reasons; the fuzzy nature of resilience, resilience is a dynamic concept that changes over time and space, a city's resilience is only exposed through disruptive events, in addition to the interrelations between resilience factors and indicators.

Numerous attempts of resilience assessments have been adopted recently by governments, international organizations as the UN, NGO's, or academic institutions. Examples of such resilience assessments include: The City Disaster Resilience Scorecard [26], Resilience Capacity Index (RCI) [27], Climate Disaster Resilience Index (CDRI) [28], and PEOPLES Resilience Framework [29]. The majority of which focus on reducing vulnerability and building resilience capacity, through different strategies such as governance and institutional support, economic funds, raising community awareness, provision of basic services and accessibility of critical infrastructure, in addition to disaster mitigation measures and strategies However, most assessment methods have some gaps and limitations such as the tendency to focus on certain dimensions of resilience and specific hazards, thus overlooking the broad concept of resilience and its dynamic variations across temporal and contextual scales. In Figure 1, the conceptual framework of assessment followed to develop the Resilience Performance Index is illustrated.

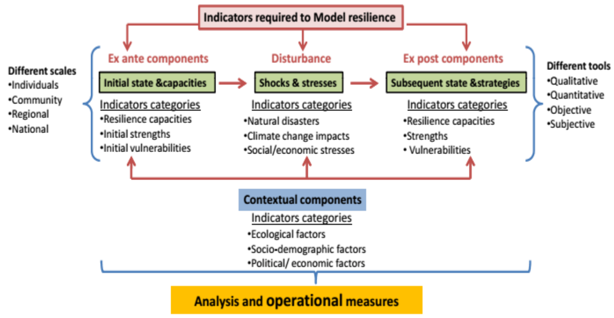


Figure 1. Proposed Resilience assessment framework

3. STUDY AREA

The Nile Delta is considered as one of the most densely populated areas in Egypt, contributing to the national economy through several industrial activities, in addition to its vast agricultural areas. However, the Nile Delta is expectedly prone to the inundation hazard of 31% of its total area in case of a 1m rise in sea level [30] as shown in Figure 2 [31].

Figure 2. Expected scenarios of sea level rise in the Nile Delta region

Figure 3. Satellite image of New Damietta city

New Damietta is one of the newly developed cities in the Nile Delta region, acting as an urban extension to the city of

Damietta. Figure 3 shows a satellite image of New Damietta city and the surrounding agricultural areas. The city is located on the Mediterranean cost with shores that extend to a length of 9 km, and its current population is 233.5 thousand. Its location is significantly important due to its proximity to the New Damietta Port, a major national development pillar, and its wide industrial, commercial, agricultural and touristic activities. The location of the city poses an expected threat arising from climate change, sea level rise and shoreline erosion, exacerbated by a 4.5 mm delta subsidence per year [32].

According to GIS mapping the city is facing an expected inundation hazard as illustrated in Figure 4.

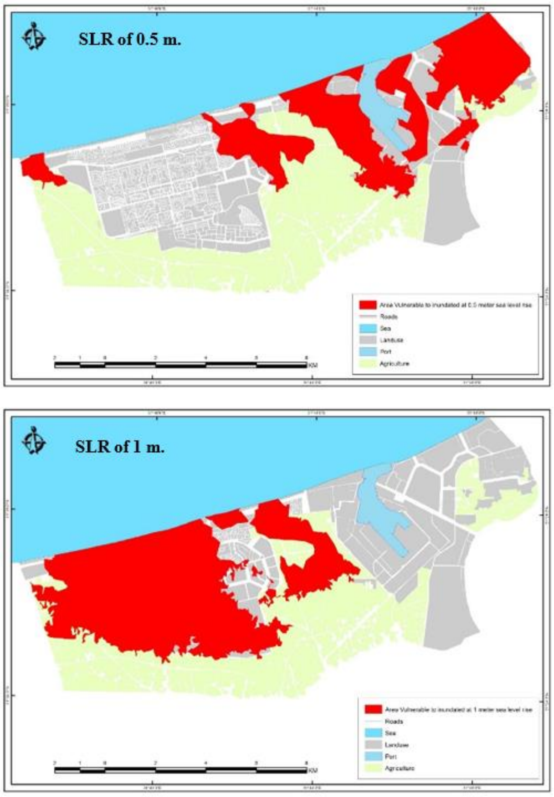


Figure 4. Expected inundated areas due to 0.5m, 1m sea level rise according to GIS mapping

4. MATERIALS AND METHODOLOGY

The development of a composite index for urban resilience assessment is a complex process, only attainable if individual indicators' data are precise and can be numerically quantified, which is practically unrealistic in most scenarios. Resilience assessment involves analyses of spatial data associated with urban, environmental, social, economic and institutional data. Such data is neither uniform nor precise [33]. Furthermore, resilience assessment includes verbal inputs from diverse participants with varying expertise, interests and backgrounds. This spatial ambiguity along with diverse human perceptions result in a certain degree of uncertainty [34]. Traditional Boolean assessment methods are based on the assumption that inputs are certain, precise and uniform crisp data, making such methods inappropriate to deal with the uncertainty and fuzziness of resilience data. In response to this dispute, the Fuzzy Logic Approach is proposed to model the input indicators' values of the RPI. Fuzzy Logic Systems are artificial intelligence (AI) tools that have two major advantages; modelling the vagueness and ambiguity inherent in linguistic information, and modelling the fuzziness of spatial data through defining fuzzy sets or categories where one value could simultaneously fit in. Therefore, FLSs can model imprecise quantitative or qualitative data inputs without the need for detailed descriptive mathematical formulae, normalization techniques, and complex aggregation methods [35].

4.1 Proposed indicators for RPI

Indicators are parameters proposed to describe the status of a system in regard to a certain concept [36]. They are considered the building blocks of any evaluation tool. Hence, they should be relevant, applicable, measurable, cost-effective and clearly interpreted [37]. Also, indicators must be as multidimensional and comprehensive as possible [38]. To construct the RPI, 44 indicators are proposed to assess the preparedness and capacity of an urban system to overcome potential vulnerabilities and enhance resilience capacity. The index is categorized into 4 main sub-indices; Natural & Environmental, Physical & Built environment, Social & Economic, and Governance & Institutional. Each sub-index consists of both quantitative and qualitative indicators which are further broken down into 57 metrics.

4.1.1 Natural & environmental sub-index

This dimension mainly focuses on the management and conservation of ecosystems and natural resources, and on mitigating the negative effects on the environment, as shown in Table 1.

Table 1. Natural and environmental sub-index

Sub-dimension	Code	Indicator	Description / Metric
Environmental management [39-42]	N1	Ecosystem management systems	Efficiency of monitoring / assessment systems for ecosystem services
	N2	Shore management policies	Efficiency of protection Strategies of shores against erosion
	N3	Natural resource management	Efficiency of natural resources management plans (conservation, reduced consumption levels, materials recycling.....etc.)
Hazard prediction [4, 39, 42-44]	N4	Hazard mapping	Efficiency of hazard mapping systems
	N5	Weather prediction	Efficiency of weather prediction, alert, and warning systems
Environmental quality [45-47]	N6.1	Pb ($\mu g/m^3$)	Degree of compliance of air pollutants average percentages with allowed limits
	N6.2	PM 10 ($\mu g/m^3$)	
	N6.3	T.S.P (μg/m3)	
1- Air quality	N6.4	SO_2 ($\mu g/m^3$)	
	N7.1	T.D.S (mg / l)	Degree of compliance of average percentages of water pollutants with allowed limits
	N7.2	BOD (mg / l)	
2- Water quality	N7.3	COD (mg / l)	
	N7.4	DO (mg / l)	

Table 2. Physical and built environment sub-index

Sub-dimension	Code	Indicator	Description / Metric
Basic infrastructure [4, 39, 40, 46, 47]	P1	Accessibility to electricity	% of population with access to electricity
	P2	Accessibility to potable water	% of population with potable water access
	P3	Accessibility to sanitation	% of population linked to sanitation networks
	P4	Water systems leakage	% of water lost during transmission
Accessibility to communication services [4, 40, 46]	P5.1	fixed phone lines	% of fixed phone lines subscribers
	P5.2	internet	% of internet users
Urban quality [40, 42]	P6	Informal / unsafe areas	% of population in informal or unsafe buildings
Urban mobility / street connectivity [4, 40, 45]	P7.1	Mass transportation (km/km^2)	Mass transportation network length /area of city
	P7.2	Land allocated to urban streets	% of land allocated to urban streets
Mixed use approach of development **[**40]	P8	Mixed use design approach	Degree of implementation of mixed use design approach
Green /Public spaces [40, 45]	P9.1	public / green spaces	% of public / green spaces in city
	P9.2	Green spaces/person	Area of green spaces per person (m^2 / person)
Urban population [40]	P10	Population density	No. of persons / km^2
Mitigation structures [4, 40, 42]	P11	Disaster defensive infrastructure	Efficiency of dams, breakwaters, drainage systems....
	P12	Waste management systems	Efficiency of waste management systems
	P13	Water management systems	Efficiency of desalination plants, rain water harvesting, reuse of treated domestic and grey water....)
Human well-being [4, 40, 43]	P14.1	Emergency facilities/1000 persons	No. of police stations, fire stations and ambulance facilities / 1000 persons
	P14.2	Area of security services	Area of security service per person (m^2 / person)
	P15.1	Average distance to hospitals	Average distance between hospitals and main settlements
	P15.2	Medical services area	Area of medical facilities per person (m^2 / person)
	P15.3	Physicians density	No. of physicians per 1000 person
	P15.4	Life expectancy	Life expectancy at birth (years)

Table 3. Social and economic sub-index

Sub-dimension	Code	Indicator	Description / Metric
Socio-economic development [4, 41, 43]	S1	Human Development Index (HDI)	Composite index of income, education & life expectancy
	S2	Old population dependency	% of old age population in relation to working population
	S3	Generation of new job opportunities	% of new jobs generated over a definite time period
Economic diversity [41, 46]	S4	Diversity of economy	Diversity of economic structures (industry - commerce- tourism- agriculture)
	S5	Diversity of work opportunities	Diverse work sectors
Individuals' socio-economic stability [4, 41]	S6	Unemployment rate	% of unemployed working force
	S7	Home ownership	% of people with home ownership
	S8	Car ownership	% of people who own cars
	S9	Social insurance	% of population under social insurance programs
	S10	Security/crime prevention services	City's efforts to secure citizens / properties
Social awareness [43, 44]	S11	Illiteracy rate	% of illiterate persons between 15 – 35 years
	S12	Social awareness	Degree of community awareness of potential hazards / resilience action plans
Shared social values [42, 43, 48]	S13	Civic engagement	Degree of public participation in through NGO's
	S14	Social cohesion	Shared values and collective community cohesion

Table 4. Governance and institutional sub-index

Sub-dimension	Code	Indicator	Description / Metric
Policies and regulations [4, 40, 42, 43, 45]	G1	Political leadership stability	Stable and strong political leadership
	G2	Decentralization policies	Decentralization of services and resources
	G3	Resilience fund allocations	Fund allocation for applying innovative technologies for risk assessment and mitigation systems
	G4	Law enforcement	Comprehensive legislative measures for climate change adaptation and risk mitigation
Resilience Strategies [40, 41, 43]	G5	Resilience strategic planning	Long term resilience planning strategies and visions
	G6	Disaster management plans	Disaster reduction and risk mitigation development plans
	G7	Environmental management	Environmental and climate change adaptation policies
	G8	Unsafe areas' management	Informal and unsafe areas management strategies

4.1.2 Physical & built environment sub-index

Physical and built environment indicators assess the state of the city's built environment and the extent to which it can tolerate and respond to disruptions and stresses without affecting its functionality. Physical indicators include accessibility to basic services, emergency response facilities, and land use. Physical indicators are listed in Table 2.

4.1.3 Social & economic sub-index

Social indicators describe the demographic features of the community such as levels of literacy, social cohesion, and community awareness. Whereas economic indicators assess the diversity and stability of the economy, as well its ability to draw investments, as shown in Table 3.

4.1.4 Governance and institutional sub-index

Strong governance and effective institutional support measures are essential for guiding and executing resilience strategies and action plans. The governance and institutional indicators mainly focus on the stability and institutional power of the governing structures of the city (See Table 4).

4.2 Determining the relative weights of the 4 main sub-indices of the RPI

The 4 resilience dimensions are logically unequally weighted. In order to assign their relative weights, the Budget Allocation Method (BAL) is used. BAL is an expert opinion based method where experts and stakeholders distribute a number of points (n), for example (100) points representing a certain budget among the 4 dimensions, so that the allocated points signify the relative weight of the sub-index in respect to the overall RPI [49, 50]. This step is attained through a questionnaire for urban planners, academics, and city officials. It is essentially important in the final model since the resulting weights signify the effect of each dimension on the final RPI score. Through the BAL, the relative significance of each sub-index is determined, as illustrated in the pie chart in Figure 5.

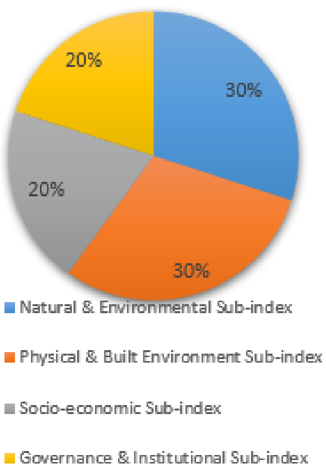


Figure 5. Relative significance weights of the 4 resilience sub-indices on the final RPI

4.3 Computation and weighting technique of individual indicators

Individual indicators' data is acquired in the form of primary data through a structured survey, or as secondary data from statistical reports, census data, or adapted metric calculations. The weighting scheme of the RPI follows the work of Alkire and Foster [51] to design a multi-dimensional index, based on the theoretical assumption that all indicators of resilience are interconnected and equally influential on the overall resilience score. Accordingly, the relative weight of each indicator is calculated using Eq. (1).

$$W = SDw * Iw \quad (1)$$

where: ***W** is the final weight of the indicator*.
SDw is the weight of the sub-dimension in respect to the main dimension.
Iw is the weight of the indicator in respect to its sub-dimension.

4.4 Modelling of RPI using the fuzzy logic approach

The individual RPI indicators are modelled using Fuzzy Logic Designer, an application developed by MATLAB, where their values are represented by 3 linguistic categories to indicate levels of resilience performances. A fuzzy logic system consists many steps, however the most important steps are fuzzification and defining the fuzzy rule base. Figure 6 illustrates the fuzzy logic assessment model used in this study.

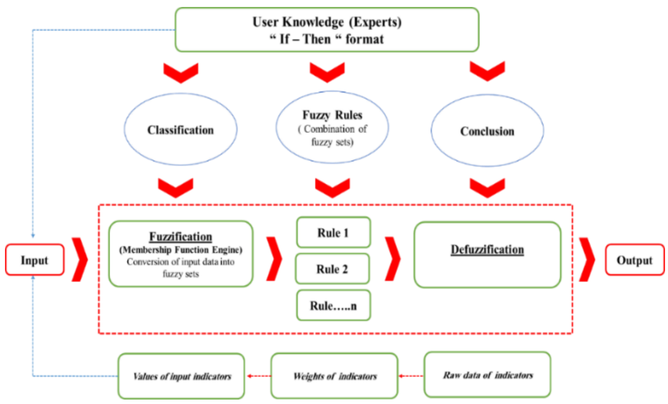
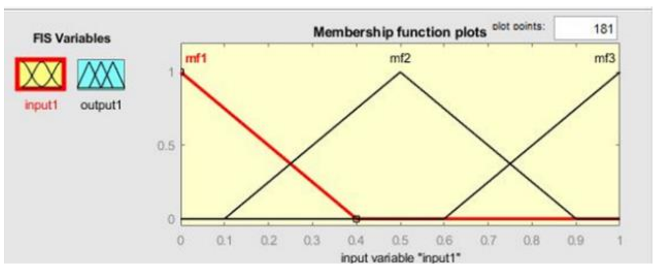


Figure 6. Fuzzy logic assessment model

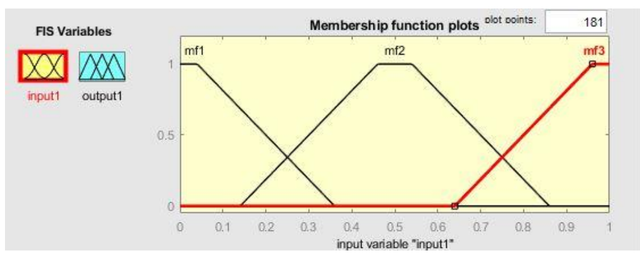
The basic steps for designing the RPI fuzzy logic model are listed below.

4.4.1 Fuzzification

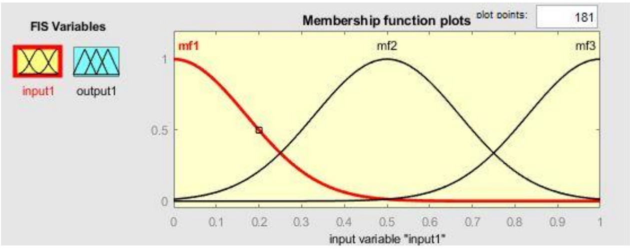
Fuzzification means transforming indicator values into homogeneous linguistic data sets called membership functions. MFs take many, forms as illustrated in Figure 7. The most common form is the triangular MF.



(a) Triangular MF



(b) Trapezoidal MF



(c) Gaussian MF

Figure 7. Forms of fuzzy logic MFs

In this study the MFs correspond to *Poor, Moderate*, and *Acceptable* resilience performances. The assigned MFs for RPI are shown in Table 5.

Table 5. Membership function ranges for the 4 resilience sub- indices and the overall RPI

Membership Functions' sets	Range
Poor	0-0.4
Moderate	0.3-0.7
Acceptable	0.6-1

4.4.2 Defining the Fuzzy Rule Base (FRB) for the RPI model

Defining the FRB employs empirical knowledge of experts and professionals and historical records to link inputs and outputs of fuzzy logic systems [52]. There are many types of FRB methods such as Mamdani's method, Suengo method, or Takagi-Suengo-Kang method. The most widely applied method is the Mamdani method [53], since it is a simple, easily interpreted method which depends on human reasoning in the form of simple if-then rules, where "If" stands for the "Predicate" whereas "Then" represents the "Conclusion" [35]. The FRB designed to link individual RPI indicators to their respective sub-indices consists of 3 rules for each indicator taking into consideration the weight of the indicator, for example:

- If Disaster management planning (G6) is Poor, then the Governance & institutional sub-index is Poor.
- If Disaster management planning (G6) is Moderate, then the Governance & institutional sub-index is Moderate.
- If Disaster management planning (G6) is Acceptable, then the Governance & institutional sub-index is Acceptable.

The FRB linking the 4 main resilience sub-indices to the overall RPI is further more complicated since there is a logical connection and overlapping relations between the 4 sub-indices and the final RPI proved through the applied BAL. The number of assigned rules used to build this FRB reached 175 rules. Examples of rules of the final FRB are listed below:

- If Natural & Environmental Sub-index is Poor and Physical & Built Environment Sub-index is Poor, then RPI is Poor.
- If Natural & Environmental Sub-index is Poor and Physical & Built Environment Sub-index is Moderate, then RPI is Moderate.
- If Natural & Environmental Sub-index is Poor and Physical & Built Environment Sub-index is Acceptable, then RPI is Moderate.

4.4.3 Defuzzification of fuzzy inputs

The final step in the FLS involves the defuzification process, where fuzzy inputs in the form of MFs and fuzzy rules are processed through AI techniques and aggregated to achieve an optimum crisp value that indicates the score of the sub-indices and the final index. The aggregation method used in this step is the 'centroid technique'.

4.4.4 Simulation of the RPI fuzzy logic model:

Once the RPI fuzzy logic model has been designed, it can be simulated using another MATLAB application called "Simulink", through which the designed RPI fuzzy logic model is embedded and actual input values of the study area are introduced as blocks or constants, to compute the score for each sub-index and finally the overall RPI score of the study area.

4.5 Computation of RPI indicators' values for New Damietta city

The values of the RPI input indicators for New Damietta city are based on quantitative data from governmental statistical reports, census data or GIS mapping, in addition to qualitative indicators values based on a structured survey questionnaire designed for experts, professionals, researchers and stakeholders. The proposed indicators, their membership function sets, and the corresponding values for New Damietta city are shown in Tables 6, 7, 8, and 9.

The indicators' values are then introduced into the designed Simulink model as individual blocks in the form of constant values which uses the embedded RPI fuzzy logic model to compute and aggregate these values into a final score for each of the 4 sub-indices. The resulting sub-indices' scores are then used as input values to compute the overall RPI of New Damietta. Figures 8, 9, 10, 11 and 12 illustrate the diagrams of the model showing the individual indicators' values, the sub-indices' scores and the overall RPI score.

Table 6. Natural and environmental sub-index for New Damietta city

Sub-dimension	Code	Indicator	W.	Poor	Moderate	Acceptable	IV.
Environmental management	N1	Ecosystem management systems	0.111	0-50%	40-80%	70-100%	59.23%
	N2	Shore management policies	0.111	0-50%	40-80%	70-100%	59.23%
	N3	Natural resource management	0.111	0-50%	40-80%	70-100%	57.31%
Hazard prediction	N4	Hazard mapping	0.167	0-50%	40-80%	70-100%	54.23%
	N5	Weather prediction	0.167	0-50%	40-80%	70-100%	70%
Environmental quality	N6.1	Pb ($\mu g/m^3$)	0.042	1.1-2/year	0.6-1.3/year	0-0.9/year	0.01
1- Air quality	N6.2	PM 10 ($\mu g/m^3$)	0.042	75-160/year	40-90/year	0-65/year	152
	N6.3	T.S.P ($\mu g/m^3$)	0.042	110-250/year	60-130/year	0-80/year	213
	N6.4	SO_2 ($\mu g/m^3$)	0.042	60-100/year	40-70/year	0-50/year	4
2- Water quality	N7.1	T.D.S (mg / l)	0.042	500-800/l	300-600	0-400	288
	N7.2	BOD (mg / l)	0.042	7-10	4-8	0-5	4.9
	N7.3	COD (mg / l)	0.042	12-20	7-15	0-10	11.8
	N7.4	DO (mg / l)	0.042	2.5-5	4-6	5.5-8	6.6

Table 7. Physical & built environment sub-index for New Damietta

Sub-dimension	Code	Indicator	W.	Poor	Moderate	Acceptable	IV.
Basic infrastructure	P1	Accessibility to electricity	0.05	0-50%	40-80%	70-100%	92.4%
	P2	Accessibility to potable water	0.05	0-50%	40-80%	70-100%	95.8%
	P3	Accessibility to sanitation	0.05	0-40%	30-70%	60-100%	91.9%
	P4	Water systems leakage	0.05	10-30%	4-15%	0-8%	19%
Communication services	P5.1	fixed phone lines subscribers	0.025	10-40%	30-60%	50-100%	64.47%
	P5.2	internet users	0.025	10-40%	30-60%	50-100%	64.9%
Urban quality	P6	Informal / unsafe areas	0.05	15-30%	7-20%	0-10%	4%
	P7.1	Mass transportation (km/km^2)	0.025	0-2	1.5-3	2.5-4	2.69
	P7.2	Land allocated to urban streets	0.025	0-10%	5-20%	15-40%	8.2%
	P8	Mixed use design approach	0.05	0-50%	40-80%	70-100%	70.4%
	P9.1	public / green spaces	0.025	0-50%	20-35%	30-45%	12.43%
	P9.2	Green spaces/person (m^2/person)	0.025	0-60	40-100	80-150	12.12
	P10	Population density (persons/km^2)	0.05	10 000-15 000	5000-11 000	0-6000	1175
Mitigation structures	P11	Disaster defensive infrastructure	0.083	0-50%	40-80%	70-100%	60.77%
	P12	Waste management systems	0.083	0-50%	40-80%	70-100%	58.82%
	P13	Water management systems	0.083	0-50%	40-80%	70-100%	58.85%
Human well-being	P14.1	Emergency facilities/1000 persons	0.0625	0-0.5	0.3-0.8	0.6-1	0.13
	P14.2	Area of security services (m^2/person)	0.0625	0-0.8	0.5-1.3	1.1-2	0.7
	P15.1	Average distance to hospitals	0.03125	12-20	7.5-15	0-10	15
	P15.2	Medical services area (m^2/person)	0.03125	0-0.7	0.5-1.3	1.1-2	0.78
	P15.3	Physicians / 1000 persons	0.03125	0-3	2-5	4-10	2.2
	P15.4	Life expectancy at birth (years)	0.03125	20-50	40-70	60-80	74

Table 8. Social and economic sub-index for New Damietta

Sub-dimension	Code	Indicator	W.	Poor	Moderate	Acceptable	IV.
Socio-economic development	S1	Human Development Index (HDI)	0.0667	0-0.55	0.5-0.8	0.75-1	0.8
	S2	% of old age population	0.0667	20-45%	5-25%	0-10%	6%
	S3	% of new jobs generated	0.0667	0-20%	10-40%	30-100%	47.9%
Economic diversity	S4	Diversity of economy	0.1	0-50%	40-80%	70-100%	74.62%
	S5	Diversity of work opportunities	0.1	0-50%	40-80%	70-100%	72.31%
Individuals' socio-economic stability	S6	Unemployment rate	0.04	15-30%	5-20%	0-10%	9.6%
	S7	Home ownership	0.04	0-40%	30-70%	60-100%	37%
	S8	Car ownership	0.04	0-30%	20-60%	50-100%	14.8%
	S9	Social insurance	0.04	0-40%	30-70%	60-100%	28.04%
	S10	Security/crime prevention services	0.04	0-50%	40-80%	70-100%	71.92%
Social awareness	S11	Illiteracy rate	0.1	15-100%	10-20%	0-15%	18.7%
	S12	Social awareness	0.1	0-50%	40-80%	70-100%	54.62%
Shared social values	S13	Civic engagement	0.1	0-50%	40-80%	70-100%	54.12%
	S14	Social cohesion	0.1	0-50%	40-80%	70-100%	69.62%

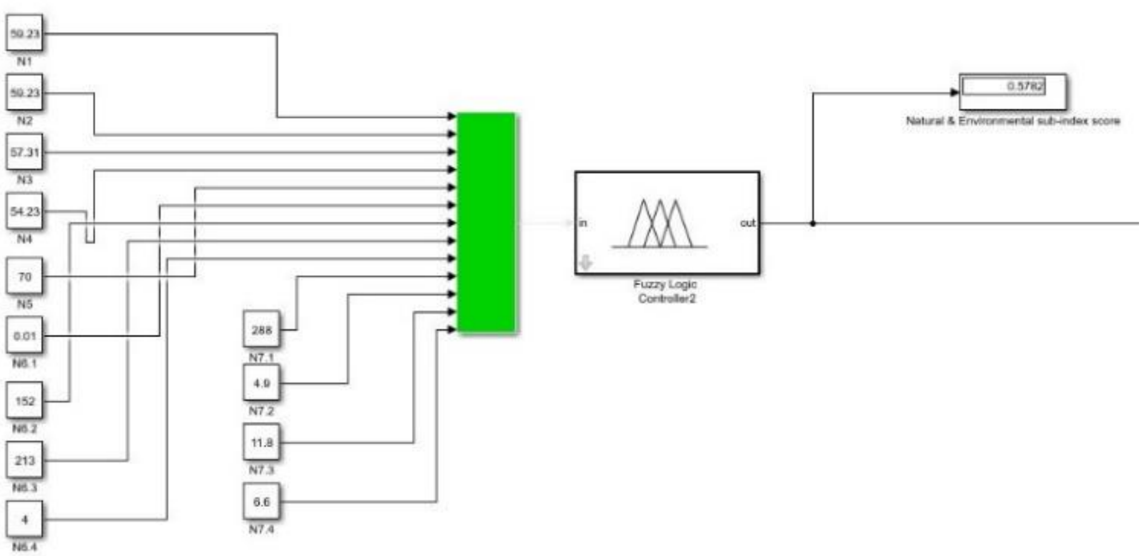


Figure 8. Natural and environmental sub-index model

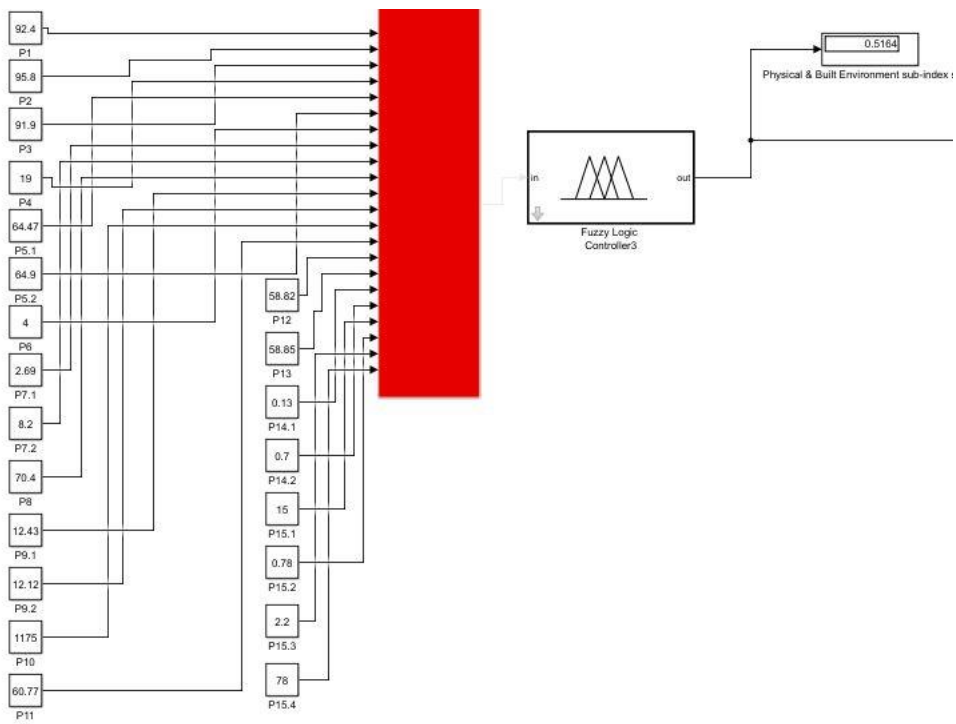


Figure 9. Physical and built environment sub-index model

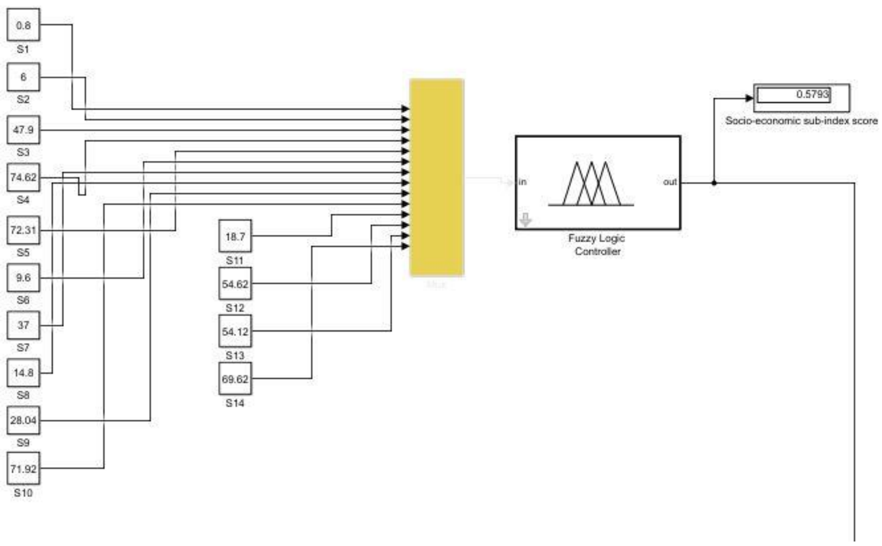


Figure 10. Socio-economic sub-index model

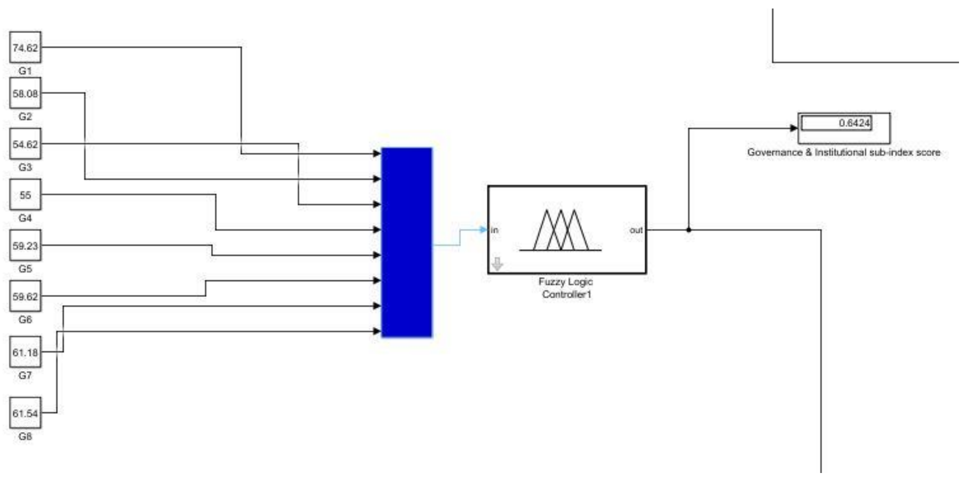


Figure 11. Governance and institutional sub-index model

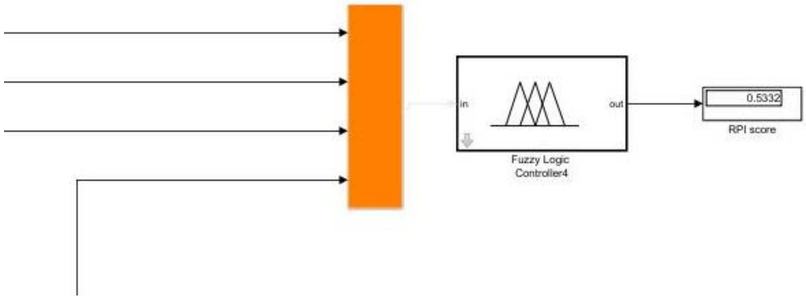


Figure 12. Final RPI model

Table 9. Governance and institutional sub-index for New Damietta

Sub-dimension	Code	Indicator	W.	Poor	Moderate	Acceptable	IV.
Policies and regulations	G1	Political leadership stability	0.125	0-50%	40-80%	70-100%	74.62%
	G2	Decentralization policies	0.125	0-50%	40-80%	70-100%	58.08%
	G3	Resilience fund allocations	0.125	0-50%	40-80%	70-100%	54.62%
	G4	Law enforcement	0.125	0-50%	40-80%	70-100%	55%
Resilience Strategies	G5	Resilience strategic planning	0.125	0-50%	40-80%	70-100%	59.23%
	G6	Disaster management plans	0.125	0-50%	40-80%	70-100%	59.62%
	G7	Environmental management	0.125	0-50%	40-80%	70-100%	61.18%
	G8	Unsafe areas' management	0.125	0-50%	40-80%	70-100%	61.54%

5. RESULTS

The modelling and simulation of the individual indictor values of New Damietta, using the designed fuzzy logic system and Simulink model resulted in the following scores shown in Table 10.

Table 10. Resilience sub-indices scores for New Damietta city

Index	Score	Evaluation
Natural & Environmental sub-index	0.5782	Moderate
Physical & Built Environment sub-index	0.5164	Moderate
Socio-economic sub-index	0.5793	Moderate
Governance & Institutional sub-index	0.6424	Acceptable
Overall RPI	**0.5332**	Moderate

The scores of the 4 resilience sub-indices in New Damietta city show moderate levels of Natural & Environmental resilience, Physical & Built environment resilience, Socio-economic resilience, and an acceptable level of resilience in the Governance & Institutional sub-index. The computed overall RPI score of New Damietta city is 0.5332, indicating a moderate level of overall resilience. The results require improvement measures in Natural & environmental, Physical & Built environment, and Socio-economic dimensions in order to enhance the resilience performance of the city.

6. CONCLUSIONS AND DISCUSSION

Current researches and resilience assessment practices have not yet developed into a single most appropriate practice. Existing assessment methods are mostly theoretical or conceptual frameworks, and only a few have been practically implemented. This is mostly because resilience measurements are complicated processes which require extensive data analysis, highly qualified skills, and large fund allocations. Such complicated requirements hinder regular and periodic resilience assessment and contradict with the dynamic notion of resilience. Apart from that, the multidisciplinary and fuzzy nature of resilience requires the employment of simulation and modelling techniques to easily compute and assess resilience. The proposed RPI addresses these complications through the use of Fuzzy Logic Designer, an AI tool developed by MATLAB to model and simulate the fuzzy and imprecise nature of resilience data without the necessity for complicated mathematical formulae, normalization and aggregation techniques.

The developed RPI model is an easy, applicable, flexible, and user friendly tool that allows for resilience assessment throughout numerous spatial and temporal scales. Since the capability of periodic and multi-contextual resilience assessment is considered a synonymic and inseparable function of resilience building in cities and urban systems, therefore the designed RPI model could be a useful tool in prioritizing and imposing resilience action plans and strategies, as well as guiding multi-dimensional decision making processes and addressing uncertainties.

The study offers a fundamental step towards the incorporation of AI tools in urban analyses, following the growing interest in smart technologies. The emerging roles of big data and the trending Internet of Things (IOT) paradigm, and cloud servers are considered the future research venue in resilience studies. Also, the use City Information Modeling (CIM) methods should be examined to simulate the impacts of potential hazards and stresses on urban settlements.

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NOMENCLATURE

BOD	Biochemical oxygen demand
COD	Chemical oxygen demand
DO	Dissolved oxygen
Pb	Lead
PM 10	Coarse particulate matter
SO_2	Sulfur dioxide
T.D.S	Total dissolved solids
T.S.P	Tri-sodium Phosphate