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Assessment of Urban Resilience through the Development of an Urban Resilience Assessment Model (Resilience Performance Index)

Arch.Rasha Mahmoud Gaber[1], Prof. Mohamed Hussein Abd El-Kader[2], Prof. Ehab Mahmoud Okba[3]

[1]*Department of Architecture, Faculty of Engineering, MTI University, Cairo, Egypt.*

[2]*Department of Architecture, Faculty of Engineering, Cairo University, Egypt.*

[3]*Department of Architecture, Faculty of Engineering, Fayoum University, Egypt.*

Abstract

Modern cities and urban settlements are principally composed of complex networks. However, these networks are continually subjected to extreme threats such as disruptive events either due to climate change impacts or other man-made accumulated stresses, which makes them more and more vulnerable. Resilient systems involve being able to predict, adapt to, respond to, and recover from such disruptive events.

Cities, worldwide have initiated different tools and frameworks to assess their urban resilience against different shocks and stresses. The process of assessing urban resilience involves complimentary functions of urban risk analysis and resilience capacities. In such process, risk analysis adopts a bottom-up approach while resilience capacity assessment follows a top-down approach.

The main aim of this paper is to propose a methodology for designing a resilience assessment model that integrates different dimensions of urban resilience (Natural, physical, social, economic, and institutional), taking into consideration the current contextual state, the expected threats, and the main associated stakeholders.

Keywords: Assessment, hazards, indicators, resilience, resilience modelling.

I. INTRODUCTION

The assessment of urban resilience is considered a relatively complex process due to the dynamic nature of resilience as well as the cross interactions between different resilience dimensions. Moreover, resilience varies across different spatial and temporal scales.

There have been many attempts to assess urban resilience either by international initiatives such as the UNISDR, or by governments, or non- governmental organization, or through research and academic institutions. Generally speaking, most of the adopted frameworks focus on methods of reducing vulnerability and enhancing the resilience capacity through different factors including economic assets, governance and institutional support, community connectivity and knowledge, access to critical infrastructure services, risk analysis and disaster mitigation plans. However, these assessment frameworks mostly share a common limitation which is the tendency to focus on a specific type of hazard and only some dimensions of resilience not taking into consideration the broad view of the concept of resilience. A comprehensive assessment of resilience involves the integration of contextual factors, potential shocks/stresses, along with adopted mitigation measures and strategies across different spatial and temporal scales. The resilience assessment framework model to be adopted in this study is shown in Figure 1.

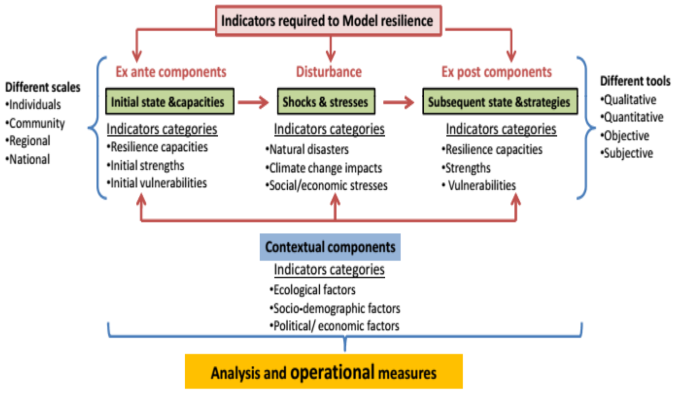

Fig. 1: Resilience Framework Model
Source: author based on data available in Constas M.,et al.(2014)

II. PURPOSE FOR DEVELOPING RESELENCE PERFORMANCE INDEX:

The main purposes for the development of the Resilience performance Index may be defined as follows:

- Assessing the initial resilience status and base-line conditions of a certain community to inform resilience action plans.
- Evaluating the efficiency of resilience strategies and interventions in enhancing the resilience performance.

- Informing strategic decision making and prioritization of interventions and resource allocation according to the vulnerability assessment.
- Measuring relative progress in addressing assigned urban, environmental, and socio-economic goals.

III. STEPS FOR DEVELOPING RESILIECE PERFORMANCE INDEX:

In order to develop the Resilience Performance Index, a series of informative steps must be followed as listed below:

III.I. Defining potential hazards and risks:

Risk can be defined as the probability of a serious disruption of the main functions of an urban community resulting in human, resources and economic losses, as well as negative environmental impacts [1]. Therefore, risk is interrelated to hazards and vulnerability, as expressed by the following equation:

$$Risk = Hazard * Vulnerability$$

Risk can arise due to climatic hazards such as droughts, heat/cold waves, sea level rise, and wind storms (Table:1), or non-climatic hazards such as volcanoes and earth-quakes (Table:2). It is worth mentioning, that although both climatic and non-climatic hazards are generally referred to as natural hazards, the human trigger of such hazards cannot be ignored. Other man-made hazards include violence attacks, crime, industrial hazards, and traffic accidents.

Another type of hazard that cannot be neglected is what is so called secondary hazard, which is a hazard that occurs due to a former natural hazard. For example, a fire arising from drought or lightening, or landslides due to heavy rain, or disease spread due to floods, as in Figure 2. The severity of the impact of the secondary hazard may sometimes exceed that of the primary hazard. Therefore, a multi-hazard approach must be adopted to inform better risk management [2].

Fig. 2: Deadly garbage slide in Manila post heavy rainfall (2011).

Photo Credit: EPA, retrieved from: http://gulfnews.com/news/world/philippines/eight -killed-six-missing-astyphoon-ravages-north-1.858354

Vulnerability, on the other hand, is the degree to which a certain urban context is susceptible to negative effects of hazards. It is therefore related to the existing characteristics and current conditions of the urban area subjected to one or more type of hazard. It depends on factors such as location, population density, quality of built physical environment, as well as the existence and efficiency of mechanisms for disaster response and mitigation [3].

Conceptually vulnerability can be assessed according to 3 main dynamic approaches:

- First, the threshold approach: through hazard scenarios' simulation integrated with socio-economic impacts, in addition to demographic factors.
- Second, pre-existing state approach: through simulation of urban and population growth as well as development scenarios.
- And finally, the outcome approach, which observes vulnerability in terms of adopted action plans and adaptation scenarios coupled with population growth projections and socio-economic impacts [4].

In sum, the existence of the hazard does not necessarily imply that it will turn into a disaster, there are 4 factors that transform a hazard into a disaster:

- The type, frequency, intensity, magnitude, and time duration of current or future hazards.
- The sensitivity of the location to current and future hazards deterring it from dealing with it such as the existing conditions of the location.
- The functionality and efficiency of the public and private sector entities in charge of responding to hazards.
- The functionality and efficiency of the public and private sector entities responsible for recovery action plans [2]

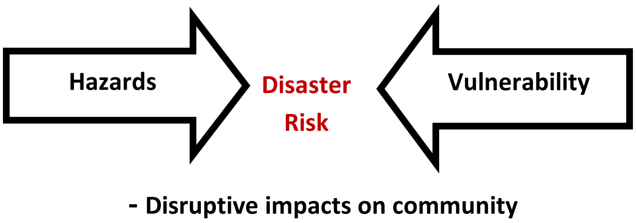

Figure 3: Illustration of the relation between hazard, vulnerability, and disaster risk
Source: Author

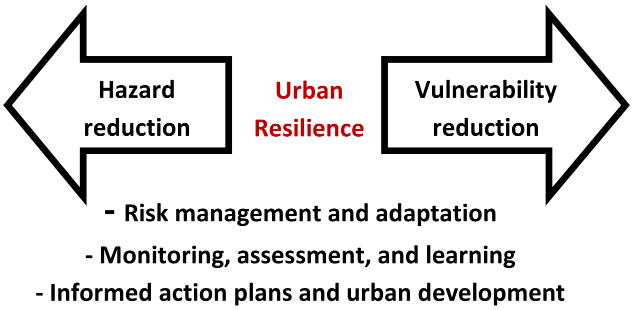

Figure 4: Illustration of the concept of urban resilience
Source: Author

Table 1: Types of Climatic Hazards

Hazard types	Triggering factors and effects	Related measurements	Required assessment data	Disaster management tools
Drought	Drought is related to a number of issues including climate change effects such as rising temperatures and less rainfall. It is also a factor of human behavior as with increasing heat island effect and irresponsible use of water resources. -Drought is a major cause of migration to cities resulting in more pressure on critical services and infrastructure as well as increase in dwellers of hazardous areas.	Food supply and water availability per capita	-Precipitation levels - Surface temperatures - Stored water volumes - capacity of reservoirs	-Water management - Harvesting of rain water. - Reduce intensive irrigation agriculture - Ground water recharge - Avoid deforestation
Floods, tidal floods, sea level rise	-Climate change has caused a noticeable increase in sea level rise and precipitation levels, which poses risk to coastal zones, river banks, and deltas. -Sea level rise may cause loss of urbanized land in coastal zones currently populated by 2.8 billion people (40% of the world's population). Moreover, flash floods and heavy rains cause pressure on drainage systems that are sometimes blocked or inadequate, also concrete surfaces and reduction in open spaces exacerbate the effect of heavy rain.	-Frequency and intensity of floods. -Wave height - Water column horizontal pressure.	Topography (DEM), historical rain fall measurements, tidal measurements, bathymetry, patterns of drainage, percentage of built-up area and physical assets, land use.	-Coastal zone management plans. - Structural flood management measures (Excess water channelization, dams…) -Regulations of land use.
Thunderstorms and strong winds	-Strong winds can occur in the form of cyclones, typhoons, or hurricanes as a result of climate change factors. In addition, the urban layout of the city may contribute to increasing wind speeds due to a phenomenon known as ' wind tunnel effect '. - In some cases strong winds are accompanied by heavy rain fall or thunder storms triggering secondary hazards in the form of landslide, floods, or fires.	-Maximum speed and radius of wind. - Water column central pressure. - Height of waves.	-Topography (DEM), Patterns of drainage systems, bathymetry, historical rain fall measurements, land use	-Coastal zone management plans. - Building regulations and codes for strong winds. - Warning and evacuation plans.

Source: Author based on data from Wamsler 2014, IPCC 2007a and UNISDR 2010a

Table 2: Types of Non-climatic Hazards

Hazard types	Triggering factors and effects	Related measurements	Required assessment data	Disaster management tools
Earthquakes	- Cities lying on what is so called earthquake belts are highly at risk due to the destructive effects of earthquakes. - Although earthquakes are mainly a geological hazard, recent researches indicate that they are often triggered by the phenomena of frost melting making them in some way a climate related hazard.	-Richter scale measurements.	Soil, seismic and geological mapping	- Seismic building codes and regulations. - Land use zoning according to soil stability mapping.
Tsunamis	-Tsunamis are a geological hazard that can occur due to many factors which include volcanic eruptions either on land or under water, earthquakes that occur underwater, or landslides. -Tsunamis represent a major hazard to tsunami-prone coastal zones especially the costs of both the Indian and Pacific oceans	Height of waves	Coastal zones topography, bathymetry, flood resisting infrastructure.	Coastal zone management plans, evacuation plans.

Table 2: continued...

Volcanoes	-During the past, volcanic areas have attracted urban settlements due to the richness of the soils and the flatness of the lands surrounding them. Eventually, these areas have developed into large urban centers exposing their inhabitants to the risk of flowing volcanic mud and lava.	Degree of volcano explosiveness and flow of lava.	- Proximity of people and assets to volcanoes. - Topography	-Reallocating of physical assets and populations far from potential lava flow paths. - Structural lava blocking measures.
Fire hazard	- Fires can stem from many reasons including high temperatures, earthquakes, windstorms, industrial or domestic accidents especially in high density built environments. -Rapid urban growth and the use of building materials that are not fire-resistant increase fire risk.	- Elevated temperatures.	Wind intensity and speed, topography, land use.	-Codes and regulations for fire resistance. - Suitable roads for fire trucks accessibility.
Landslides	- Land slides can be regarded as a primary hazard caused by locating urban settlements on unstable slopes formed from landfills, reduced vegetation, or waste disposal areas, or as a secondary hazard following earthquakes, flooding, or heavy rain.	Mass movements and slope failure,	Geological and Topographical data (DEM), land use and land cover.	- Structural responsive measures (retaining walls). - Reconfiguration of population in land-slide prone areas. - Building codes and zoning regulations for buildings in land-slide prone areas.

Source: Author based on data from Wamsler 2014, IPCC 2007a and UNISDR 2010a

III.II. Identifying potential stakeholders:

The process of identifying the concerned stakeholders is an essential step in the development of the Resilience Performance Index. The defined stakeholders are then classified according to their level of power or authority and their interest in enhancing the resilience performance. The concerned stakeholders include:

- Governmental sector: local governmental authorities and administrative entities.
- Public/Private sector: public and private development companies, public financial institutions, banks, private companies, business investors, academic institutions.
- Non- governmental organizations working on mitigating vulnerabilities and enhancing community resilience.

III.III. Data Collection tools:

Different data collection methods should be adopted; either primary data or secondary data, through:

1. Qualitative Data:

Attained through in depth interviews with different stakeholders such as: government officials, members of public and private sectors, different non-governmental organizations.

2. Quantitative Data:

In the form of calculated results of a set of questionnaires among different stakeholders and community members regarding various dimensions of resilience, potential risks and stresses, governance and institutional support systems, along with values of measurable indicators.

III.IV. Selection of indicators:

Indicators are considered as the fundamental building blocks of any resilience assessment tool. Indicators, therefore, should be as comprehensive and multidimensional as possible, they also should be simply applicable, scalable, and updatable [5].

A set of indicators are selected in accordance to the potential hazard and stresses and the initial state of the urban context. A quantitative analysis is then used to assess the Resilience performance Index using a mathematical method of calculating the values of individual indicators.

According to various literature, the construction of an index can depend on different mathematical methods based on the summation of its components. In order to use a straight summation method, the units have to be normalized into a standard unit to allow their addition and averaging to reach a representative score or rank. In such case, this average value is called a composite index. The different components of the index are then added depending on varying or equal weights assigned for each component [6]. For this study, an equal weighing method is preferred.

In the following section a list of indicators would be proposed to develop the *Resilience Performance Index*. The deducted indicators are categorized into 5 main dimensions namely: Natural & Environmental, physical & built environment, social and cultural, economic, and governance and institutions. It might also be useful to adopt a matrix approach that relates the different indicators to the different phases of resilience actions which are: understand risk, prepare, absorb, respond, and bounce back/transform. This step is considered fundamentally essential in determining the appropriate stage of the proposed interventions.

1. Natural & Environmental indicators:

This set of indicators is mainly centred on the conservation of ecosystem services and the availability and quality of natural resources. Measures adopted to conserve and manage natural resources, protect ecosystems, and reduce negative impacts on the environment are regarded as important features of resilience.

Table 3: Proposed Natural and Environmental resilience indicators:

Code	Indicator
N1	Availability of monitoring and assessment systems for ecosystem services
N2	Employing local materials and natural resources
N3	Access to natural resources (energy resources, water, food.....etc.)
N4	Reduction of pollution levels of natural environment
N5	Quality of natural resources (air quality, water quality......etc.)
N6	Availability and protection of natural wetlands
N7	Protection of shores against erosion
N8	Availability of natural resources management plans (conservation, reduced consumption levels, materials recycling.....etc.)
N9	Hazard mapping systems
N10	Weather prediction, alert, and warning systems

2. Physical and built environment indicators:

The city's physical features and the built environment play a significant role in determining its resilience status. The degree to which the built environment of the city can tolerate disruptive events and continue to function effectively is dependent on a variety of indicators, as listed below. Factors like land use, building condition, and critical infrastructure facilities are prominent resilience indicators.

Table 4: Proposed physical and built environment resilience indicators:

Code	Indicator
P1	Efficient critical infrastructure services
P2	Accessibility to basic needs(shelter, energy, water, health, and education ...)
P3	Monitoring and maintenance of critical infrastructure
P4	Emergency communication systems
P5	Information Communication Technology (ICT) systems
P6	Percentage of unsafe building locations
P7	Percentage of impervious surfaces
P8	Connectivity of public transportation
P9	Street connectivity
P10	Mixed use approach of development
P11	Percentage of public spaces
P12	Percentage of green areas
P13	Passive design techniques
P14	Building density
P15	Building conditions
P16	Percentage of green infrastructure versus grey infrastructure
P17	Disaster defensive infrastructure (dams, breakwaters, drainage systems....)
P18	Waste management systems
P19	Water management systems (desalination plants, rain water harvesting, reuse of treated domestic and grey water....)
P20	Fire detection and extinguishing systems
P21	Security and surveillance systems

Table 4. continued..

3. Social and cultural indicators:

According to resilience literature social and cultural assets of the community can significantly affect its resilience. The demographic composition of the community, literacy levels, civic participation, community cohesion, and awareness levels, must be equally considered as natural and physical aspects of resilience, since they imply the behaviour of the community before, during, and after disruptive events.

Table 5: Proposed social and cultural resilience indicators:

Code	Indicator
S1	Accessibility to health facilities
S2	Security and crime prevention services
S3	Diverse segregation of populations
S4	Degree of social equity (Gender and minority)
S5	Percentage of risk awareness
S6	Percentage of single family structures
S7	Percentage of extended family structures
S8	Community cohesion and social interaction
S9	Percentage of civic engagement
S10	Diversity of work opportunities
S11	Shared values and collective memories

4. Economic indicators:

Economic resilience of a certain community depends on the stability and diversity of its economic structures, as well as the capacity of the available job opportunities to support different population groups.

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Financial business plans, insurance facilities, and various public and private funding entities are essential tools to achieve economic stability.

The ability to attract investments and ensure resourcefulness, and robustness of development plans is one of the main characteristics of an economic resilient community.

Table 6: Proposed economic resilience indicators:

Code	Indicator
E1	Unemployment rate
E2	Income rates
E3	Percentage of home ownership
E4	Percentage of car ownership
E5	Demographic structure of working population
E6	Public and private savings
E7	Insurance facilities
E8	Diversity of economic structure
E9	Income / prices stability
E10	Percentage micro enterprises and small businesses

5. Governance and Institutional indicators:

Effective governance and institutional support are necessary for ensuring implementation of resilience action plans. Considering the complex and dynamic nature of resilience and the interrelations between different stressors and dimensions of resilience, indicators of strong leadership and institutional backup are essentially important to evaluate the resilience performance of a community.

Table 7: Proposed governance and institutions resilience indicators:

Code	Indicator
G1	Long term planning strategies and visions
G2	Stable and strong political leadership
G3	Decentralization of services and resources
G4	Transparency and anti-corruption measures
G5	Multi-stakeholders and community integration in decision making
G6	Comprehensive resource management strategies
G7	Disaster reduction and risk mitigation development policies
G8	Environmental and climate change adaptation policies
G9	Fund allocation for applying innovative technologies for risk assessment and mitigation systems
G10	Fund allocation for disaster reduction research
G11	Informal and unsafe areas management strategies
G12	Comprehensive legislative measures for climate change adaptation and risk mitigation
G13	Law enforcement measures
G14	Tax reductions and financial incentives for employing disaster mitigation measures.

III.V. Reporting and visualization of results:

Visualization of results is a considerably vital step in order to allow an easier interpretation of results to inform future action plans, as well as to indicate temporal changes in resilience performance and to instigate comparisons among different locations. Graphical visualization methods used include radar diagrams and Micro-soft excel sheets.

III.VI. Comparative analysis:

The comparative analysis approach is used to investigate points of similarities and differences among different case studies, thus contributing to inductive theory building. This can be attained through the cross-sectional comparison of different cities, groups, or individuals at the same point in time [7].

The comparative analysis is to be applied on different case-studies pointing out their areas of strengths and weaknesses regarding the resilience performance, therefore, determining possible ways to enhance factors of strengths or eliminate factors of weaknesses.

IV. RESILIENCE PERFORMANCE INDEX:

In conclusion to the previous section a *Resilience Assessment Model* is proposed to transform the different components of resilience assessment into measurable values for a model that can be developed into a simple software tool to assess urban resilience. As in Figure 5 the model consists of 5 main successive sectors. Each sector combines a number of the resilience assessment components addressed above. In the following section each of the 5 sectors would be broken down into its main processes and associated indicators.

1. Current Scenario Modelling:

This step involves all contextual data and is mainly illustrated in the form of spatial maps of the following inputs:

- City Boundaries.
- Land uses.
- Basic Infrastructure Services. (Road networks- bridges / tunnels- water supply- sanitation / sewage networks)
- Critical Infrastructure (Government offices- police / fire station- major hospitals)
- Environmentally sensitive areas (coastal zones- protectorates- water bodies….)
- Physical / urban profile: potential unsafe areas either naturally or due to human activities (unsafe slopes- flood plains- areas with poor building conditions and infrastructure…..)
- Social profile: population density- vulnerable populations- single / extended family structures….)
- Economic profile: industrial / commercial activities- farming / fishing areas- touristic sites- cultural / heritage sites…)

2. Risk analysis:

The hazard analysis is an essential step that involves spatial mapping of potential risks through;

- Hazard maps based on detailed analysis of sources, frequencies and magnitudes of past or predicted hazards either climatic or non-climatic hazards.
- Using strategic master plans of the city to determine the potential urban growth and future development to identify high risk areas that might arise in the future.

3. Damage Impact analysis:

Overlay urban, social, and hazard profiles to determine potential damage either in terms of number of fatalities or in terms of economic losses due to damage in infrastructure or public and private assets, using a GIS platform.

4. Resilience Performance Evaluation:

This essential step is centred on visualization and comparison of risk, vulnerability and resilience measures through:

- Spatial visualization of risk maps and damage impacts.
- What if scenarios and comparisons between costs of damage, number of fatalities and cost of resilience measures.

5: Reporting Resilience Capacity:

This step involves the reporting and interpretation of the key elements of resilience assessment through delivering and communication of the findings and conclusion of the assessment process according to the assigned purpose. The reporting process involves a spatially clear illustration of the values of the index components [8]. It can also be paired with methods of spatial interrogation of the index or sophisticated graphs of index outputs [9].However, since resilience assessments are also directed to support decision making and action policies, reporting should include narrative constructed interpretations for different audiences [10].

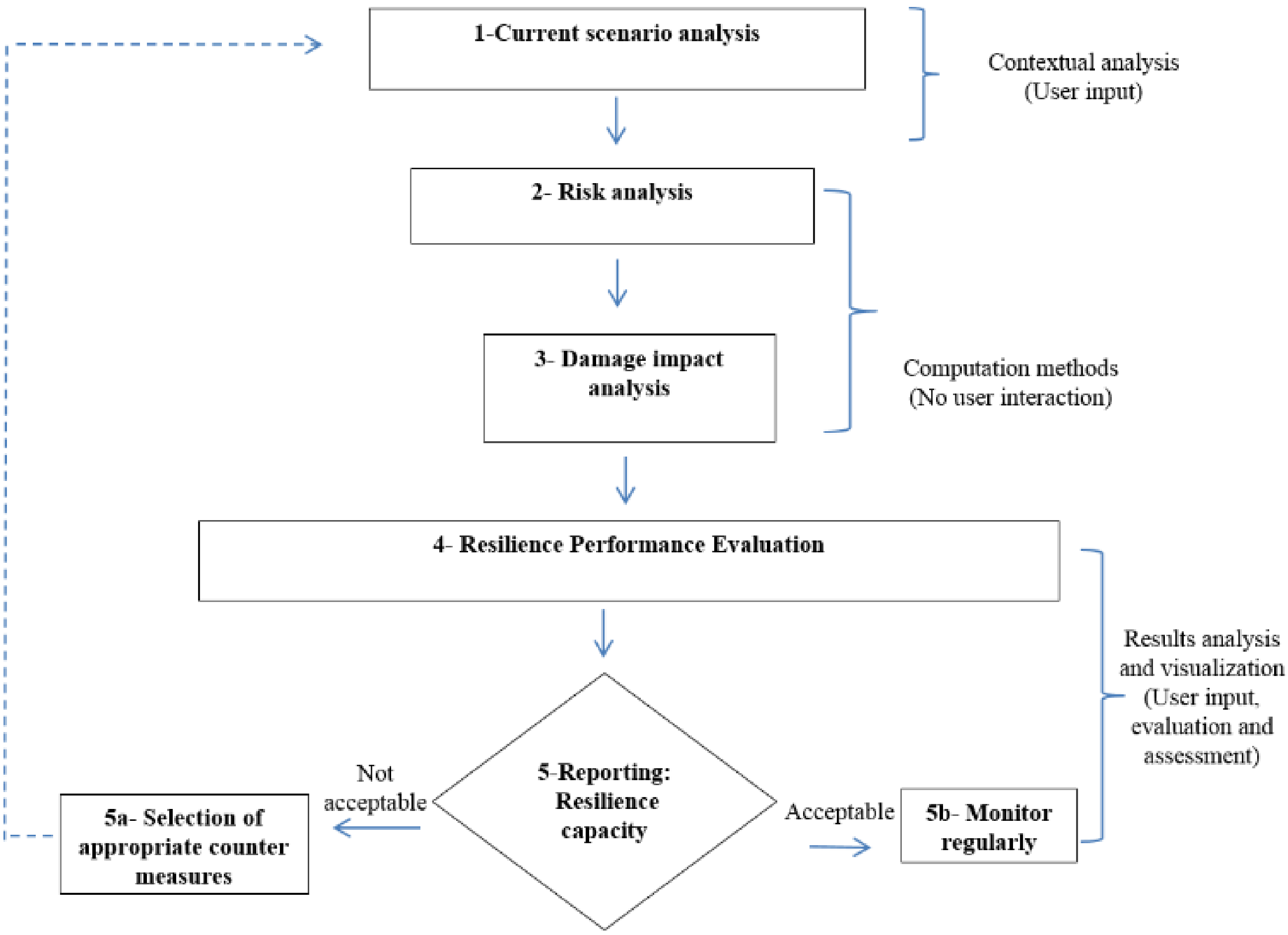

Figure 5: Resilience Assessment Model
Source: Author

The outcome of this essential step determines the resilience capacity of the urban area assigned for assessment. Two scenarios are expected:

a- If the evaluation and interpretation of resilience elements shows an accepted resilience capacity, then monitoring procedures are to be performed regularly to ensure the continuity of resilience performance.

b- If the evaluation shows increasing vulnerability factors and unaccepted resilience capacity, more measures to reduce vulnerability and more efficient resilience strategies should be introduced to the system.

V. CONCLUSION AND RECOMMENDATIONS

A resilience assessment framework should be comprehensive in order to :

- Address multiple resilience dimensions.
- Consider the interactions and connections between various scales ranging from districts and neighbourhoods to cities.
- Accounts for changes that occur across time scales.
- Attempts to develop appropriate measures for different factors of resilience aiming to address uncertainties and transform resilience into a more tangible concept.
- Ensure the involvement and participation of various stakeholders.
- Determine the basic measures and actions that can be applied to enhance the systems resilience performance.
- Act as an ex-ante system to support decision- makers and planners in identifying areas of greater vulnerabilities and prioritize action plans and resource allocation.
- Act as an ex-post system to help local authorities and governments to assess the efficiency of the resilience measures that have been undertaken.
- Employ a combination of bottom-up as well as top-down approaches, since bottom-up approaches are needed to ensure that the indicators are reliable and comply with the context and the community perception, whereas top-down approaches are needed to ensure data standardization and comparison.
- The results of resilience assessment using a certain tool has to be effectively delivered and communicated in a suitable manner to different stakeholders and community members to inform future action plans and improvements.

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