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ORIGINAL ARTICLE

A spatial model for assessment of urban vulnerability in the light of the UN New Urban Agenda guidelines: case study of Assiut City, Egypt

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Abstract
Most cities in developing countries suffer environmental degradation caused by the growth of unplanned areas that sprawl in the cities. In the current paper, we attempted to integrate a set of selected UN-based urban indicators based on the New Urban Agenda (NUA) within a GIS framework to observe and assess some aspects of urban vulnerability among city districts based on deprivation. The vulnerability map for the districts in Assiut City was created through a spatial multicriteria evaluation model. Thirteen sub-indicators related to shelter, social environmental and economic situations have been assessed in the model using standardization, weighting and aggregation methods. Results revealed that: districts, namely, El Thaltha, El Owla, El Thania, and El Rabaa are most vulnerable in most scenarios, while districts, namely, El Sheyakha El Sabaa, and El Sadsa, El-Walidya El Qiblia and El-Hamra El Thania are among the least vulnerable zones. Results also revealed that vulnerable districts encompass the highest percentage of slums, highest density of population, highest rates for urban growth and poor connection to services. Eventually, we assume that the most vulnerable zones in the city are under the highest risk of airborne diseases including COVID-19 epidemic. Eventually, a subset of selected urban vulnerability indicators that could be triggering the spread of the pandemic was chosen for another spatial multcriteria model to delineate city zones under risk. The result revealed that expected high-risk areas exist in the south-west of the city and include El Thaltha, El Owla, El Thania and El Rabaa districts, while the least risk district is El-Walydia El-Qeblia. The applied methodology and its outputs could support decision makers in reviewing priorities, setting contingency plans, allocation of funds and raising resilience among the city districts.

Keywords Vulnerability · Urban environment · GIS · Multi-criteria decision analysis · Sustainability indicators · Models

Introduction

In developing world cities and towns, there are noticeable gaps in living conditions and in access to social and physical infrastructure. In these towns, problems may be concentrated and affect the quality of life of inhabitants. The reduction of city inequalities is mentioned as an important task for sustainable development on Agenda 21 (Mega 1995; Settlements 2001). Many cities however suffer from a crisis of information, undermining their ability to establish successful urban policy (Moor 2000). The effects of urban vulnerability can be measured and analyzed by categorizing regions according to their vulnerability level based on deprivation (poverty). Environmental degradation, poverty, lack of urban services, transport and inadequate shelter are among the main areas of concern. Deficiencies in infrastructure services are reflected obviously in the form of pollution, disease and economic stagnation (Flood 1997). Thus urban sustainability evaluation and related instruments, including indicators, are important to help policymakers determine *what measures are needed for urban sustainable development policies and initiatives.* In this context, the sustainable urban development issue was raised to include *urban vulnerability indicators* as a measuring instrument and in the implementation of policies to reduce these impacts' severity and frequency.

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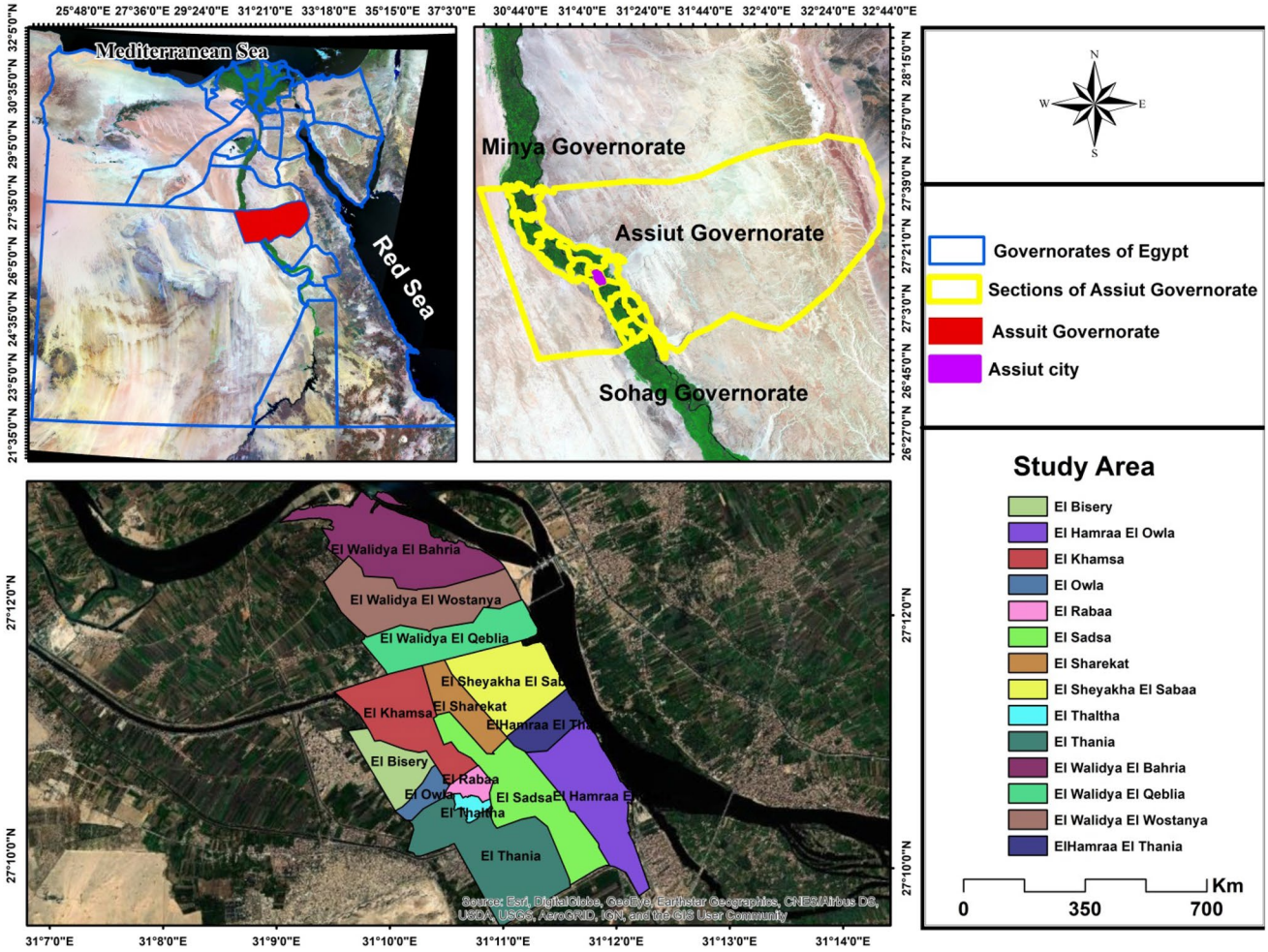


Fig. 1 Location of the study area

The New Urban Agenda (NUA) was endorsed by the United Nations General Assembly on 23 December 2016. It highlights linkages between sustainable urbanization and job creation, livelihood opportunities and improved quality of life. The NUA works as an accelerator of the Sustainable Development Goals (SDGs), particularly SDG 11- "Make cities and human settlements inclusive, safe, resilient and sustainable". Sustainable Development Goal 11 sets targets and defines indicators to measure progress and growth. NUA Vision is to promote safe, healthy, accessible affordable, resilient and sustainable cities and settlements to ensure prosperity and quality of life to all, and also to adopt disaster risk reduction and management. The core dimensions of the New Urban Agenda guidelines are: *Social sustainability*, *Economic sustainability*, *Environmental* and *Spatial sustainability*. Means of implementation are also addressed and include intervention mechanisms, hard measures for infrastructure and services, soft measures and technology and innovation. Intervention mechanisms are implemented

Table 1 Data sources

Data	Source
Assiut administrative boundary Pollution High-voltage pressure areas Road density Utilities	General Organization for Physical Planning (GOPP 2010, 2014)
Habitat quality Overcrowding Connection to services School enrollment Illiteracy rates Urban population growth Urban density Social status Quality of society Urban population growth Average price of residential	CAPMAS (2016)

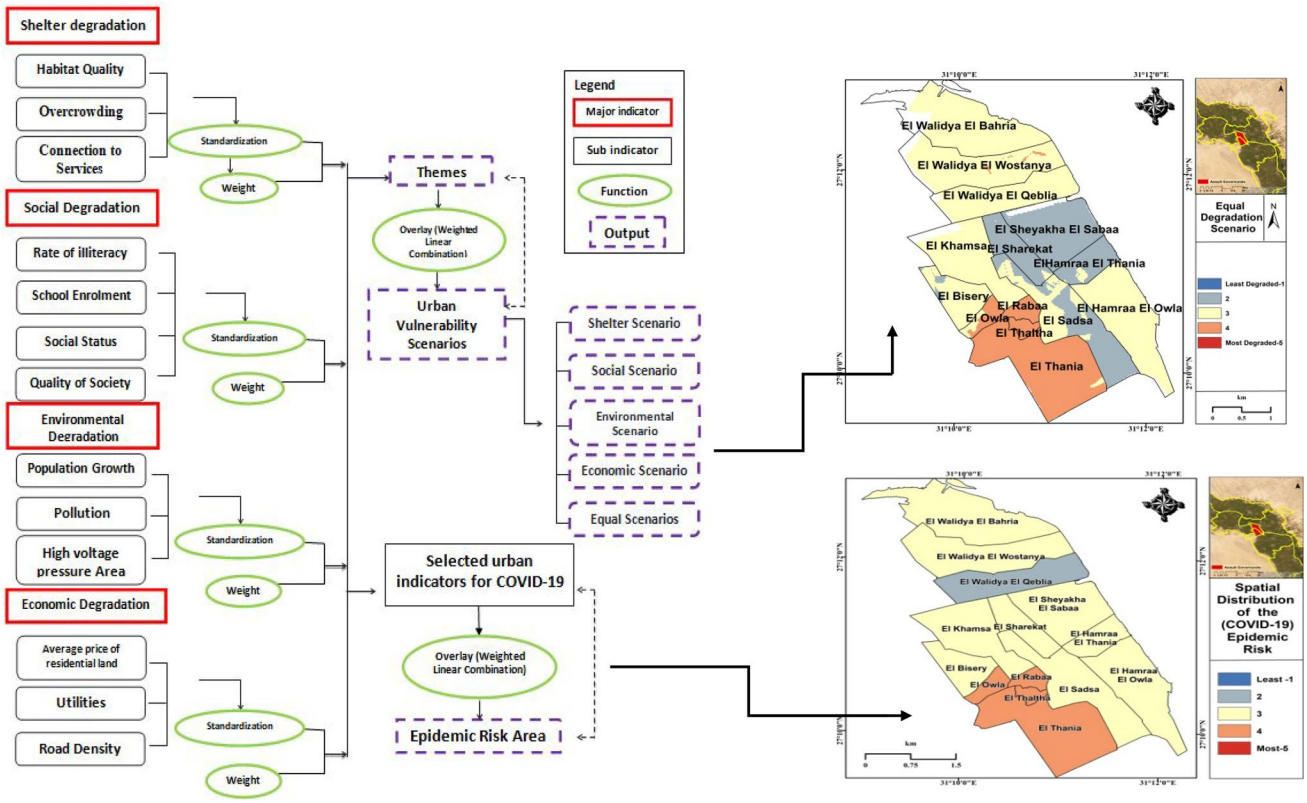


Fig. 2 A logical flowchart for the approach applied (indicators and dimensions are modified after UN Habitat)

through policies. Hard measures for infrastructure and services include transport and mobility, energy, solid waste and water and sanitation. Soft measures include culture, education, health and urban safety. Technology and innovation include technology, transportation, construction and building technology, mapping and spatial data (UN Habitat 2020).

Studying the urban environment has gained the attention of many researchers through several studies on different aspects. Priority areas are urban poverty alleviation and

Table 2 Selected UN-HABITAT's urban indicators

Major indicator	Sub-indicator			
Shelter indicator	(1) Habitat quality		(2) Overcrowding	(6) Connection to services (Poor services)
	Unsuitable habitat Quality of buildings Type of building use		Overcrowding Average size of the family	No sanitation No water networks No electricity networks Natural gas network
Social indicator	(10) Rate of illiteracy	(6) School enrolment	Social status	Quality of society
		Primary education ratio Secondary education ratio Higher education ratio	Single ratio Divorced ratio	Underage ratio Old age ratio
Environmental indicator	(11) Urban population growth		Pollution	High-voltage pressure areas
	Population growth Population density Vacant land ratio		Air pollution Soil pollution Noise Water pollution	
Economic indicator	(20) Average price of residential land		Utilities	Road density
			Roads	

how to face various challenges. Most common challenges include housing (Birch et al. 2016), infrastructure, Zeleza-Manda (2009); Luqman and Van Belle (2017) economic and social well-being and public health (APHRC 2014). Martı´nez (2009) combined the use of urban indicators and geographical information systems (GIS) as a diagnostic and observation tool to generate policy relevant information on the multidimensional aspects of spatial inequalities through a case study in Rosario, Argentina. Recently, researches address factors and indicators for measuring, evaluating and categorizing the different levels of quality of life using multicriteria techniques (Abd El-Karim and Awawdeh, 2020). Some researchers studied social geography in urban areas (Panagopoulos et al. 2016). Valencia et al. (2019) conducted a comparative transdisciplinary research project for adapting the sustainable development goals in seven cities on four continents. A study by Patel et al. (2017) focused on Cape Town's participation in piloting SDG 11. The Sustainable Development Goals (SDGs) aim at solving social, economic and environmental problems. The goals guarantee a safe life and promotes well-being for all. Agreements such as the UN Global Goals and the New Urban Agenda and current pressing problems such as the 2020 COVID-19 pandemic proves that it is impossible to tackle socio-ecological system issues without considering urban vulnerability models (Spiliotopoulou and Roseland 2020; Kumar et al. 2016; Saha et al. 2020). Shula et al. (2021) discussed the critical aspects of the COVID-19 for the achievement of the Sustainable Development Goals (SDGs).

In the current study, we attempted to integrate UN-based urban indicators within a GIS framework to create a model that describes and measures the aspects of urban vulnerability among the divisions (wards) of Assiut City. The methodology starts with the selection of appropriate urban indicators for assessment of potential environmental vulnerability of the city. The hypothesis is that the more environmental deterioration in the urban area, the more vulnerable the citizens are to environmental deterioration. In the second part, based on such results, we select some triggering factors related to public well-being. We use such factors to develop a spatial MCE model to delineate the most vulnerable wards under the higher risk of spreading COVID-19 among the wards.

Study area

Assiut City is situated in southern Cairo on the western side of the Nile River. It is one of the world's oldest towns, but mainly the new town dates back to 1800 A.D. It is the capital city of Assiut governorate in Upper Egypt. Assiut is the biggest city in Upper Egypt, located approximately 375 sq. km south of Cairo, and contains 14 districts (namely, Sheikhas) (Fig. 1). The governorate's total area is 25,926 square kilometers. The city is one of Upper Egypt's largest capitals, it has a population of total estimated population 400,000 inhabitants.

Methodological framework

The implementation of this analysis can be summarized into the following steps: (a) selection of the criteria to present the measuring indicators that diagnose the situation in the city. (b) The application of SMCE models: the first model is based on all the standardized criteria and the second model is based on a selected set of classified criteria. (c) Criteria weighting, after performing two different approaches regarding the criteria hierarchy (analytic hierarchy process in a GIS platform). (d) Aggregation functions were applied to create the thematic sub-models (types of urban environmental deprivation/ degradation) and the final overall urban vulnerability models in the environmental pillars (shelter,

Table 3 Selected UN-HABITAT's urban indicators for COVID-19 risk mapping

Major indicator	Sub-indicator		
Shelter degradation	Habitat quality	Overcrowding	Connection to services (poor services)
	Unsuitable habitat	Overcrowding	No sanitation
		Average household	No Water networks
			No electricity networks
			Natural gas network
Social degradation	Quality of society		
	Old age ratio		
Environmental degradation	Urban population growth	Pollution	
	Population density	Air pollution	
		Soil pollution	
		Noise	
		Water pollution	

Table 4 CI values for random matrices

Size of matrix	1	2	3	4	5	6	7	8	9	10
RI	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

Table 5 Fundamental scale of absolute numbers ranging from 1 to 9

1	Equal importance
3	Moderate importance of one over another
5	Essential or strong importance
7	Demonstrated importance
9	Extreme Importance
2, 4, 6, 8	Intermediate values
The reciprocals	For inverse comparison

social, economic and environmental scenarios). (e) Finally, selected indicators were used to model high-risk zones for the spread of COVID-19.

Different thematic maps from national agencies covering Assiut City at various levels have been obtained to model potential urban areas (city wards) of vulnerability in the following manner.

All maps were obtained in hard copies, scanned, geometrically rectified, digitized in ArcGIS10.3, and saved as feature classes in a geographic database for additional analyses (Table 1). A geographic database for the city was created using ESRI Arc Map (ESRI 2006). A logical flowchart for the methodology is shown in Fig. 2.

Identification of indicators

Determining indicators of urban vulnerability

Urban indicators are used to monitor problems in urban areas. However, they are mostly collected at global, national and city levels, but rarely disaggregated at district level. For city level, they are used to measure employment, health, and housing deprivations (Martı´nez 2009). The purpose behind monitoring urban vulnerability is to categorize and prioritize areas under risk. A selection of urban indicators that will be used to track vulnerabilities in urban areas is important to identify various urban problems and target vulnerability areas effectively. UN-HABITAT urban indicators were therefore chosen in four dimensions, matching the study area (Saule Junior and Cardoso 2004) as shown in Table 2.

An urban vulnerability model based on four main indicators has been developed. The first indicator, commonly known as the shelter indicator, refers to the shelter's aspects (with sub-indicators such as home value, overcrowding and service connectivity). The second indicator is a social indicator, which refers to the problems related to the social circumstances of citizens (sub-indicators are rate of illiteracy, school enrolment, social status and quality of society). The third is the environmental indicator that relates to the degradation caused by humans in the city environment (sub-indicators are pollution, high voltage pressure areas and urban population growth). Finally, the fourth indicator, named economic indicator, describes the city as one of the economic activity centers and the city's overall infrastructural conditions (sub-indicators are average price of residential land, utilities and road density). A total of 13 indicators and sub-indicators were established for the current analysis.

Urban vulnerability indicators and potential COVID-19 risk areas

In this section, we assume that the triggering factors governing the potential transmission of infectious diseases excel in zones suffering deteriorated environments in cities. In general, transmission of endemic diseases have been related to disadvantaged demographic, economic and environmental conditions and health conditions (Franco et al. 2020; Khalatbari-Soltani et al. 2020). The efficacy of the vaccine on infectious diseases has been strongly related to

Table 6 Standardization of factors of the environmental indicator

Vulnerability scale	Shelter degradation factors							
	Unsuitable habitat (%)	Governmental buildings (%)	Average size of the family (%)	Overcrowding	Water unconnected (%)	Sanitation unconnected (%)	Electricity unconnected (%)	Gas unconnected (%)
1	0–1.39	6.88–21	3–4.01	0–1.11	0–1.19	1–3.0	1–2	5.42–7.78
2	1.39–2.69	6.52–6.88	4.01–4.14	1.11–1.20	1.19–1.58	3.0–3.34	2–5	7.78–17.88
3	2.69–5.24	5.22–6.52	4.14–4.33	1.20–1.30	1.58–2.61	3.34–4.59	5–9	17.88–18.15
4	5.24–10.25	2.18–5.22	4.331–4.52	1.30–1.39	2.61–5.39	4.59–9.21	9–11	18.15–23.41
5	10.25–21	1.002–2.18	4.52–5	> 1.39	5.39–17	9.21–29	11–15	23.41–65

Table 7 Standardization of factors of the Social indicator

Vulnerability scale	Social degradation factors							
	Illiterate (%)	Primary education (%)	Secondary education (%)	Higher education (%)	Single (%)	Divorced (%)	Under age (%)	Old age (%)
1	5–10.24	19.39–23	42.72–46.0	29.48–49.0	26–28.62	0–0.72	5–15.24	3–6.09
2	10.24–14.22	16.73–19.39	42.29–42.72	21.41–29.48	28.62–29.34	0.72–0.77	15.24–16.42	6.09–7.06
3	14.22–18.13	14.87–16.73	41.38–42.29	15.52–21.41	29.34–32.67	0.77–0.96	16.42–17.11	7.06–7.61
4	18.13–24.99	13.57–14.87	39.05–41.38	11.22–15.52	32.67–35.18	0.96–1.19	17.11–18.29	7.61–9.00
5	24.99–44	11–13.57	27–39.05	4–11.22	35.18–38	1.19–1.5	18.29–21	9.00–15

Table 8 Standardization of factors of the Environmental indicator

Vulnerability scale	Environmental degradation factors							
	Population growth ratio	Population density (person/sq. meter)	Vacant land (%)	Distance to air pollution Sites (meter)	Distance to soil pollution Sites (meter)	Distance to noise sites (meter)	Distance to water pollution Sites (meter)	Distance to high voltage pressure (meter)
1	−9 to − 0.18	10–18.23	0.5–1.99	1383–2500	1208.30–2000	1545.26–3500	1960.9–3100	289–360
2	− 0.18–1.46	18.23–19.24	1.99–2.28	1103–1383	893.95–1208.30	1217.8–1545.2	1585.1–1960.9	207–289
3	1.46–3.12	19.24–23.89	2.28–3.31	783.6–1103.2	607.234–893.95	908.9–1217.8	1188.3–1585.1	126–207
4	3.12–4.77	23.89–45.36	3.31–7.12	397.6–783.6	334.40–607.23	548.8–908.9	766.8–1188.3	50–126
5	4.77–7	45.36–146	7.12–22.0	0–397.6	0–334.40	0–548.8	0–766.8	0–50

Table 9 Standardization of factors of the Economic indicator

Vulnerability scale	Economic degradation factors		
	Average price of residential land (L.E/sq. m.)	Road density (Km/sq.km)	Distance to utilities (Meter)
1	7371.89–13,000	0.012–0.015	1461.18–2352.91
2	4673.97–7371.89	0.015–0.019	965.95–1461.18
3	3101.25–4673.97	0.019–0.024	569.37–965.95
4	2184.44–3101.25	0.024–0.030	233.10–569.37
5	1400–2184.44	0.030–0.049	0–233.10

socioeconomic and demographic conditions (Bluhm and Pinkovskiy 2020). In particular, low population densities and the older age group (>=65 years) had a high proportion of deaths from H1N1 (Ponnambalam et al. 2012).. Moreover, population and density of the medical workers affected SARS positively (Fang et al. 2009). These results indicate that similar findings can be achieved for COVID-19 disease by analyzing urban vulnerability. Identifying potential social, economic, environmental and built environments is necessary for each step of the disease outbreak to effectively disrupt human transmission chains and avoid further propagation through appropriate measures (Khalatbari-Soltani et al. 2020). Urban vulnerability was not sufficiently considered in the previous studies, and thus needs to be explored to get comprehensive knowledge about the pandemic. Geographical information system (GIS) is an

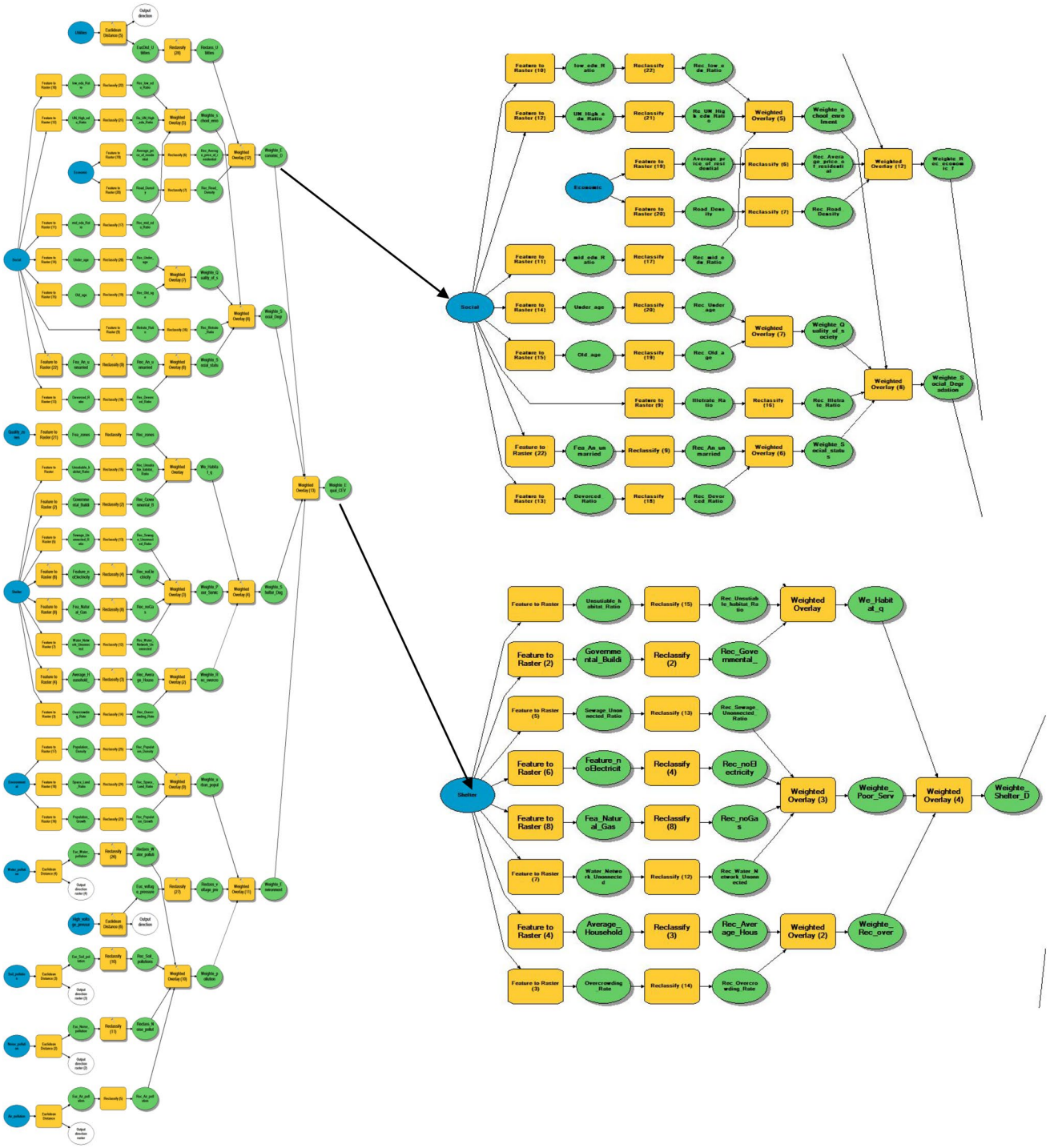


Fig. 3 Snapshot of the model indicators and scenarios

effective tool for managing a pandemic and improving the quality of healthcare by analyzing the spatial distribution of infectious diseases (Lovett et al. 2014; Mollalo et al. 2018, 2019). Consequently, some of the UN-HABITAT urban indicators related to vulnerability and could be triggering the spread of COVID-19 among citizens were identified. These

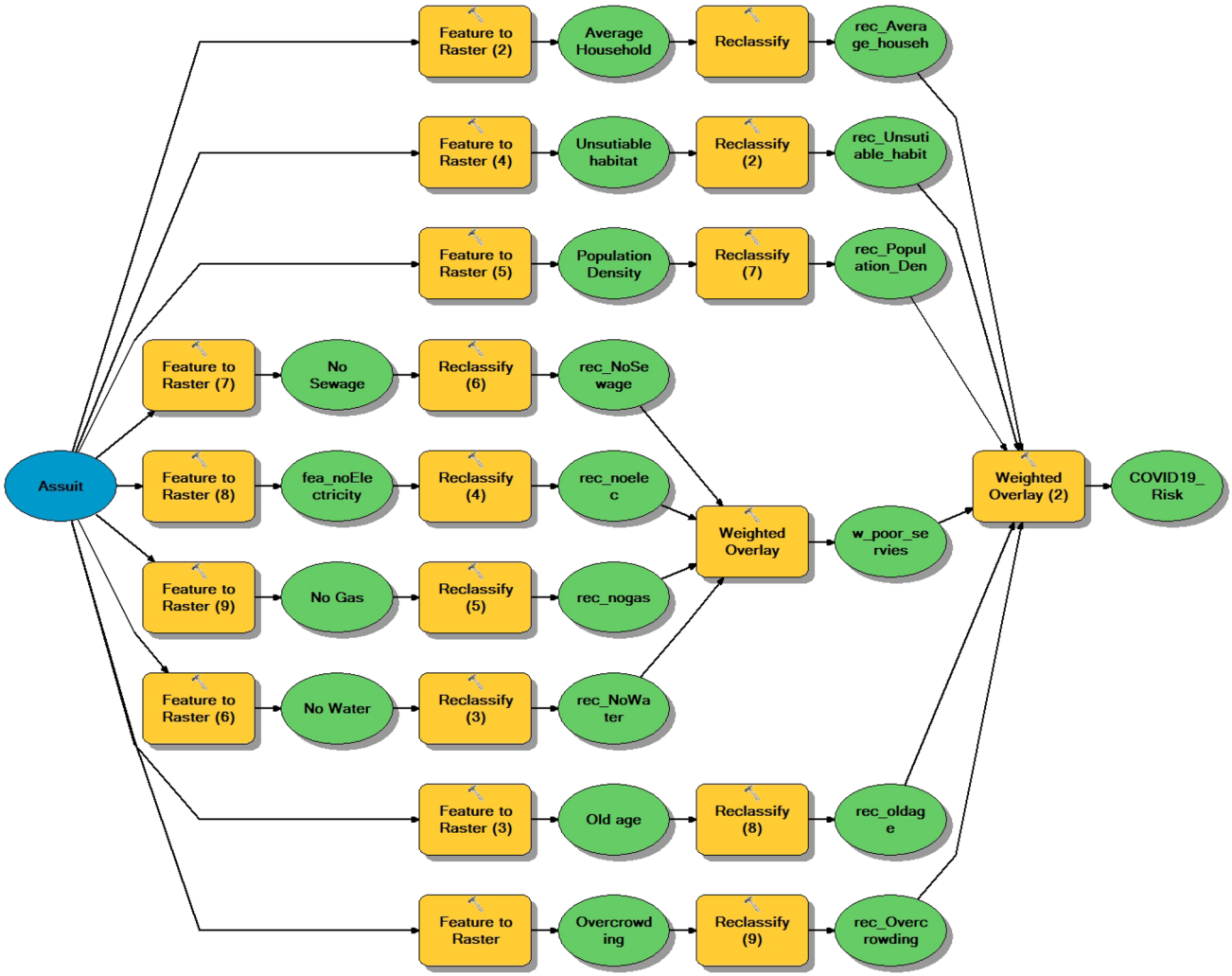


Fig. 4 Model of the spatial distribution of the epidemic risk

Table 10 Pairwise comparison weight matrix for economic indicator

Matrix		Average price of residential land	Utilities	Road Density	weight
		1	2	3	
Average price of residential land	1	**1**	3	1	46.38 %
Utilities	2	1/3	**1**	2	28.09 %
Road Density	3	1	1/2	**1**	25.52 %

were treated as contributing factors for the disease outbreaks shown in Table 3. A spatial model combined such factors to produce the COVID-19 potential risk areas index map.

AHP method to compute weights and priorities

The analytical hierarchy process (AHP) is a multicriterion decision method that uses hierarchical structures to present a problem by breaking it into factors and comparing them in

Table 11 Pairwise comparison weight matrix for environmental indicator

Matrix		Urban population	Pollution	High voltage pressure	weight
		1	2	3	
Urban population	1	**1**	1	3	42.86 %
Pollution	2	1	**1**	3	42.86 %
High voltage pressure	3	1/3	1/3	**1**	14.29 %

Table 12 Pairwise comparison weight matrix for shelter indicator

Matrix		Habitat Quality	Over crowding	Poor Services	weight
		1	2	3	
Habitat Quality	1	**1**	1/5	4	30.91 %
Overcrowding	2	5	**1**	1/5	33.27 %
Poor Services	3	1/4	5	**1**	35.82 %

pairs and then set a priority scale. Problems are divided into smaller and smaller components by a set of pairwise comparative assessments to demonstrate the relative strength of the influence of the hierarchical elements (Saaty 1997). The weights collected were analyzed using comparison matrices in Expert Choice (EC) software for support of the decision. When a series of criteria are compared, a square matrix with reciprocal characteristics is created. In reality, it is difficult to achieve complete consistency of the measurement. However, we have tests to determine the degree of consistency deviation. Each matrix can calculate the consistency index (CI) by the formula:

$$\mathrm{CI} = \frac{(yy\max - n)}{n-1}, \tag{1}$$

where n is the number of criteria being compared. For a reciprocal matrix, $\lambda\max \geq n$.

If the CI is divided by the random consistency number of the same size matrix, the consistency ratio (CR) will be obtained:

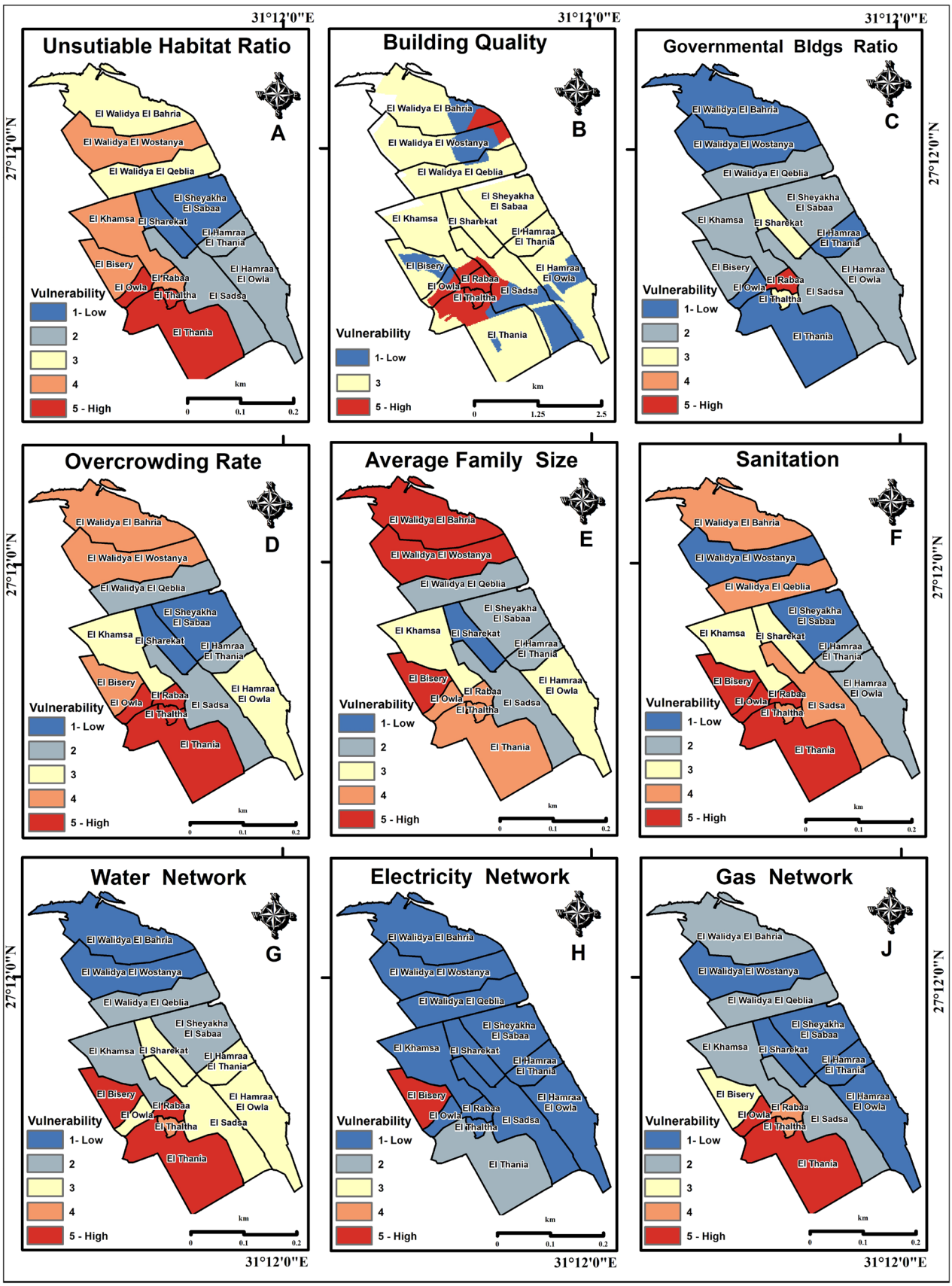
$$\mathrm{CR} = \frac{\mathrm{CI}}{\mathrm{CIR}} \tag{2}$$

where RI is the average value of CI values for random matrices using the Saaty scale (Table 4).

CR displays the degree of inconsistency permitted. Higher CR implies less consistent comparisons. Less CR means more consistent comparisons. CR = 0 implies a perfectly consistent result. If CR stands at 0.1 (10%), the findings are consistent and the final overall rate can be reached.

Table 13 Pairwise comparison weight matrix for social indicator

Matrix		Habitat Quality	Over crowding	Poor Services	Quality of Society	weight
		1	2	3	4	
Rate of Illiteracy	1	**1**	1/3	3	3	31.61 %
School Enrolment	2	3	**1**	1/2	1/4	23.59 %
Social Status	3	1/3	2	**1**	1/2	15.70 %
Quality of Society	4	1/3	4	2	**1**	29.55 %


Unsutiable Habitat Ratio
A
Building Quality
B
Governmental Bldgs Ratio
C
Overcrowding Rate
D
Average Family Size
E
Sanitation
F
Water Network
G
Electricity Network
H
Gas Network
J
31°12'0"E
27°12'0"N
El Walidya El Bahria
El Walidya El Wostanya
El Walidya El Qeblia
El Sheyakha
El Sabaa
El Khamsa
El Sharekat
El Hamraa
El Thania
El Bisery
El Rabaa
El Owla
El Thaltha
El Sadsa
El Hamraa
El Owla
El Thania
Vulnerability
1- Low
2
3
4
5 - High
km
0
0.1
0.2
1.25
2.5

◂**Fig. 5** Standardized factors maps for shelter degradation; **A** unsuitable habitat; **B** quality of buildings; **C** governmental buildings; **D** overcrowding; **E** average size of the family; **F** no sanitation.; **G** no water network; **H** no electricity network; **J** natural gas network

On the basis of Saaty (1980), to take the AHP decisions, the problem and decision need to be defined and criteria and sub-criteria established to generate alternative solutions must first be defined. The AHP hierarchy is then built through the development of comparative pairwise matrices, measurement of the eigenvalue λmax, the value of consistency index (CI) and the consistency ratio (CR). The relative preferences between two hierarchy elements are calculated in the matrix by the scale 1–9 (Saaty 1991) (see Table 5).

Integration of GIS–AHP to track urban vulnerability areas

After all relevant indicators have been identified, they were grouped according to their theme and relative assigned weights. The implementation of GIS capability and the integrated multicriteria spatial approach have significantly helped to render these combinations. These techniques allow the storage and testing of multidisciplinary data at different scales digitally (Burrough 1986). To reflect each criterion, a map layer was generated. Criteria attributes have different scales. Standardizing should be performed to perform the analysis through the transformation of attributes into a common suitability index for each element. This method of standardization refers to a number scale from 1 to 5, with (1) being the low-risk value and (5) being the high-risk value. All of the criteria layers were then aggregated and overlaid to produce maps of urban vulnerability area scenarios and spatial distribution of potential epidemic risk. Standardization of the sub-indicators map of each indicator is presented in Tables 6, 7, 8 and 9. The final models of the indicator scenarios and potential COVID-19 transmission risk zones are also shown in Figs. 3 and 4.

Results and discussion

The preliminary and final results of the spatial multicriteria evaluation SMCE models, and the final aggregated model are depicted in this section. The results include the standardization of the scale that was used to measure the indicators (factors) for each sub-model, the relative weights using the pairwise comparison and the aggregation. The final maps show the spatial distribution of vulnerability among the city districts. The vulnerability scenarios based on degradation of the situation (or rather deprivation) are depicted in the vulnerability maps. These include shelter, economic, social and environmental vulnerability. Finally, the predicted vulnerability map for spread of COVID-19 pandemic among the city districts is produced using a selected set of triggering indicators in an SMCE model.

Relative weight for the indicators using AHP

The pairwise comparison weight matrix of each indicator factor is presented in Tables 10, 11, 12 and 13.

Standardization maps

Standardized urban vulnerability indicators maps

Figure 5 shows the factor maps of the shelter degradation and spatial distribution of low- and high-risk zones based on each sub-indicator. Sub-indicators for social degradation are shown in Fig. 6, while the sub-indicators for environmental degradation are shown in Fig. 7. Finally, the sub-indicators for economic degradation are shown in Fig. 8.

Standardized COVID-19 risk area indicator map

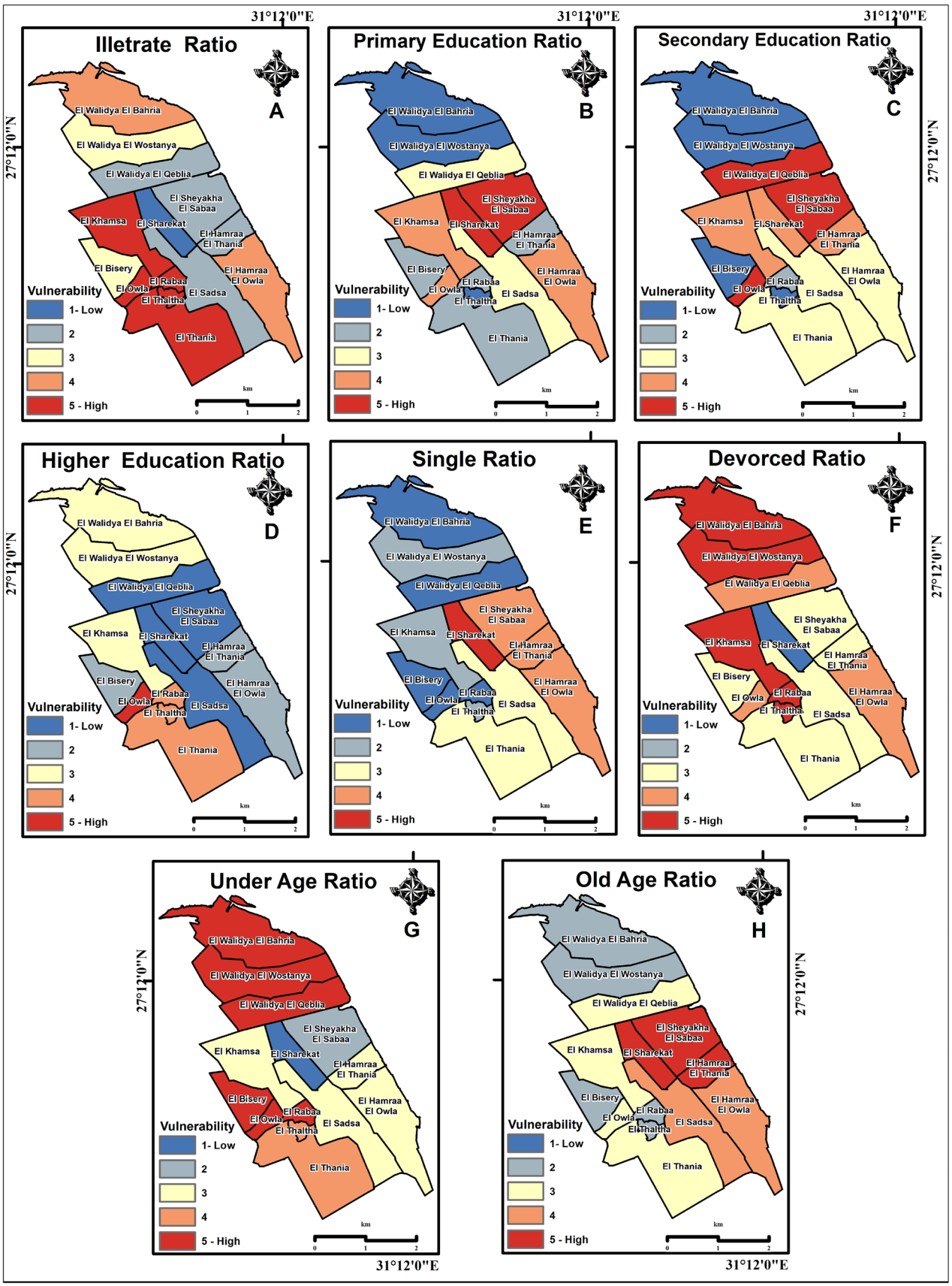
Figure 9 shows the spatial distribution of low- and high-risk zones of COVID-19 based on each urban vulnerability indicator.

Weighted combination maps

The final four combined urban vulnerability indicators result of the weighted linear combination aggregated vulnerability index maps for the four sub-models (shelter degradation, social degradation, environmental degradation and economic degradation maps) (Fig. 10).

Urban vulnerability scenarios

Five scenarios were examined by changing the priority weights combinations of the four sub-models using the weighted linear combination method Table 14. The operation of the weighted combination showed interesting results for each scenario. Using five categories for the vulnerability scale and switching the set of weights for the factors changed the trade-off between them. Decreasing the weight for a


31°12'0"E
27°12'0"N
Illetrate Ratio
A
Primary Education Ratio
B
Secondary Education Ratio
C
Higher Education Ratio
D
Single Ratio
E
Devorced Ratio
F
Under Age Ratio
G
Old Age Ratio
H
El Walidya El Bahria
El Walidya El Wostanya
El Walidya El Qeblia
El Sheyakha El Sabaa
El Khamsa
El Sharekat
El Hamraa El Thania
El Bisery
El Rabaa
El Owla
El Thaltha
El Sadsa
El Hamraa El Owla
El Thania
Vulnerability
1- Low
2
3
4
5 - High
km
0
1
2

◂**Fig. 6** Standardized factors maps for social poverty; **A** rate of illiteracy; **B** primary education ratio; **C** secondary education ratio; **D** higher education ratio; **E** single ratio; **F** divorced ratio.; **G** Underage ratio; **H** old age ratio

particular factor means prioritizing another one. Besides, the corresponding output results concerning the final high-risk site in each scenario was mapped and the areas were measured. Table 15.

All final output scenarios are clarified in Fig. 11.

These results show some significant findings that can be summarized as follows:

- In the shelter scenario, it is clear from the study that the most degraded areas are located in the south-west of the city including districts El Thaltha, El Owla, El Thania, El Rabaa and El-Bisery. The total area of such districts amounted to 2.71 sq. km equivalent to 16.88 percent. This vulnerability is caused by slums like Arab el-balad and Arbeen, poor connection to services and high ratio of overcrowding.
- The social scenario resulted in degraded zones in the west and south-west of the city. These include El Oula, El Thanya, El Thaltha and El Rabaa and El-Khamssa districts with a total area 2.71 sq. km equivalent to 16.88 percent. Vulnerability is mainly due to high ratio of illiteracy and underage ratio in addition to a relative high ratio of divorce.
- The environmental scenario result shows that the most vulnerable sites were found in the south-west of the city in El Owla, El Thania and El Rabaa, El-Sadsa, in the middle parts of El-Sheyakha El-Sabaa. In addition, a deprived zone exists in the north-eastern districts, namely El-Walydia El-Bahrya and El Walidya El-Wostanya. The total area is 2.13 sq km, equivalent to 13.26 percent. The main causes are related to humans activities such as pollution resources, high-voltage pressure areas, and the dense commercial and industrial activities.
- For the economic scenario, the most deprived zones were identified in the south-western district, namely El Thanya and in El-Thaltha. Despite having high road density and abundant utilities, the land price is quite low in such districts due to degraded, high-density buildings and roads, with no vacant lands to develop. On the contrary, it was observed that the northern districts El-Sadsa, El-Sabaa, El-Sharekat, El Hamraa El Thania have least economic vulnerability due to having higher land prices and abundance of utilities. The total degraded areas in such scenario amounted to 1.79 sq.km equivalent to 11.15 percentage.
- For the equal weights scenario, the most deprived zones are found in districts: El-Oula, El-Thanya, El Thaltha and El-Rabaa. The total degraded areas in such scenario amounted to 2.74 sq km, equivalent to 17.06 percentage.
- To have significant and brief rulings on the output results, the obtained worst site in each scenario should be examined and assessed based on the previously specified criteria. Nevertheless, such most vulnerable (worst) sites have to be represented in vulnerability index as hot spots or rather priority areas in need of upgrading programs and allocation of budgets.

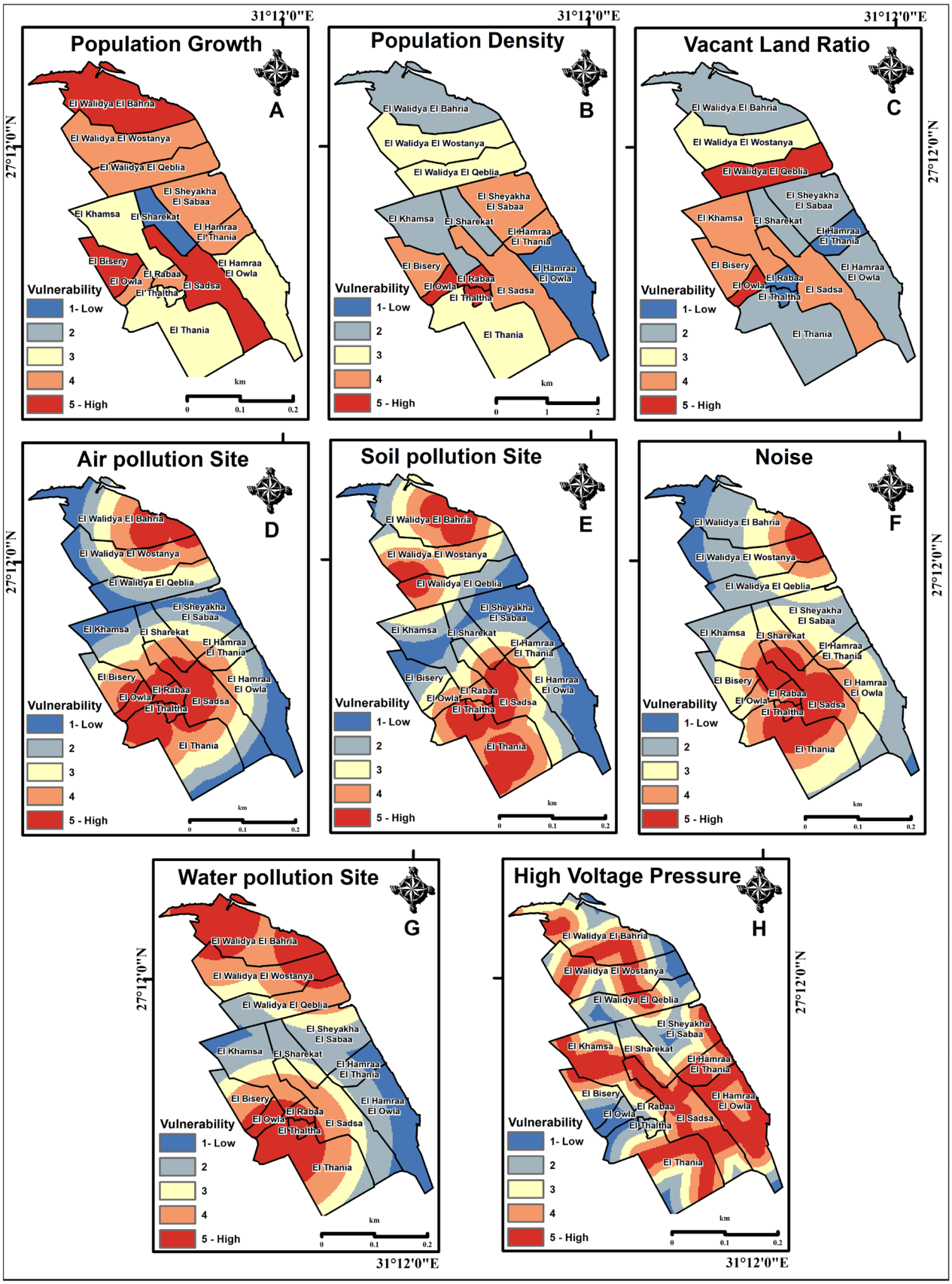
It is up to the decision maker to choose the most convenient scenario based on their priorities and sustainable development goals. Yet, from the authors' vision, the equal scenario is quite convenient because it takes into consideration the chosen indicators of sustainable urban development and treats the themes (urban, social, economic, or environmental) equally rather than focusing on either of them.

Spatial distribution of the epidemic risk

The study showed that based on our assumption, the relative high-risk areas of COVID-19 outbreak is located in the south-west of the city to include El Thaltha, El Owla, El Thania and El Rabaa districts. While the El Walidya El Qeblia district is the only low-risk area as shown as in Fig. 12.

The high-risk areas of the urban vulnerability scenarios were compared with assumed high-risk areas of COVID-19 outbreak. It was found that the the high-risk areas (highest vulnerability values) of equal senario are similar to high-risk areas of the epidemic potential transmission. We assume that the triggering factors of the high risk of transmission exist mostly in the most degraded zones of the city depicted in the environmental and shelter scenarios. for accuracy assessment, the authors tried to obtain statistics of the spread of the COVID-19 among Assiout City wards, but they were not available due to the lack of sufficient data and statistics on the cities' scale so far.

The results emphasize the importance of AHP, MCE and GIS in the reflection of spatial justice in utilities, infrastsructure, habitat quality and overall environmental quality in city planning. Such studies are quite difficult and costly when using traditional methods. They also unveil the urban degraded and vulnerable zones triggering the spread of epidemics.


Population Growth
A
Population Density
B
Vacant Land Ratio
C
Air pollution Site
D
Soil pollution Site
E
Noise
F
Water pollution Site
G
High Voltage Pressure
H
31°12'0"E
27°12'0"N
El Walidya El Bahria
El Walidya El Wostanya
El Walidya El Qeblia
El Sheyakha
El Sabaa
El Khamsa
El Sharekat
El Hamraa
El Thania
El Bisery
El Rabaa
El Owla
El Sadsa
El Thaltha
El Thania
Vulnerability
1- Low
2
3
4
5 - High
km

◂**Fig. 7** Standardized factors maps for environmental vulnerability; **A** population growth; **B** population density; **C** vacant land ratio; **D** air pollution; **E** soil pollution; **F** noise; **G** water pollution; **H** high-voltage pressure areas

Conclusion

In the current work, spatial models have been utilized in the assessment of the urban environment vulnerability among the districts of Asyiout City. Such vulnerability leads to a deprivation situation in the the three environmental pillars. The study attempts to conduct a diagnostic assessment for the overall urban environment and the factors that are assumed to trigger the spread of airborne diseases such as influenza and COVID-19.

The study showed that based on our assumption, the relative high-risk areas of COVID-19 outbreak is located in the south-west of the city to include El Thaltha , El Owla , El Thania and El Rabaa districts. While the El Walidya El Qeblia district is the only low-risk area. It was found that the the high-risk areas (highest vulnerability values) resulting from the equal weight senario model are similar to high-risk areas of the epidemic potential transmission. In such scenario, the environmental pillars (themes) are equally weighted (urban, social, economic, or environmental) rather than focusing on either of them.

The results of this study help us better understand intra-urban inequality and deprivation of services and basic infrastructure as well as the socioeconomic situation of the citizens. It explores their spatial distribtution among the districts through a combined tool (indeces and maps). This is especially useful for policymakers who need to conduct an assessment for a city based on sustainable development goals. Issues such as evaluation of inequality, poverty distribution , poor infrastructure and/or inadequate housing can be measured and mapped. The method can facilitate the prioritization and improvement plans/programs and could help decision makers in fund allocation . Results of the current research demonstrate that GIS-based indicators can be used to classify the worst areas with highest vulnerability among districts in a city. The authors hope that the current results would contribute to the management of the new epidemic

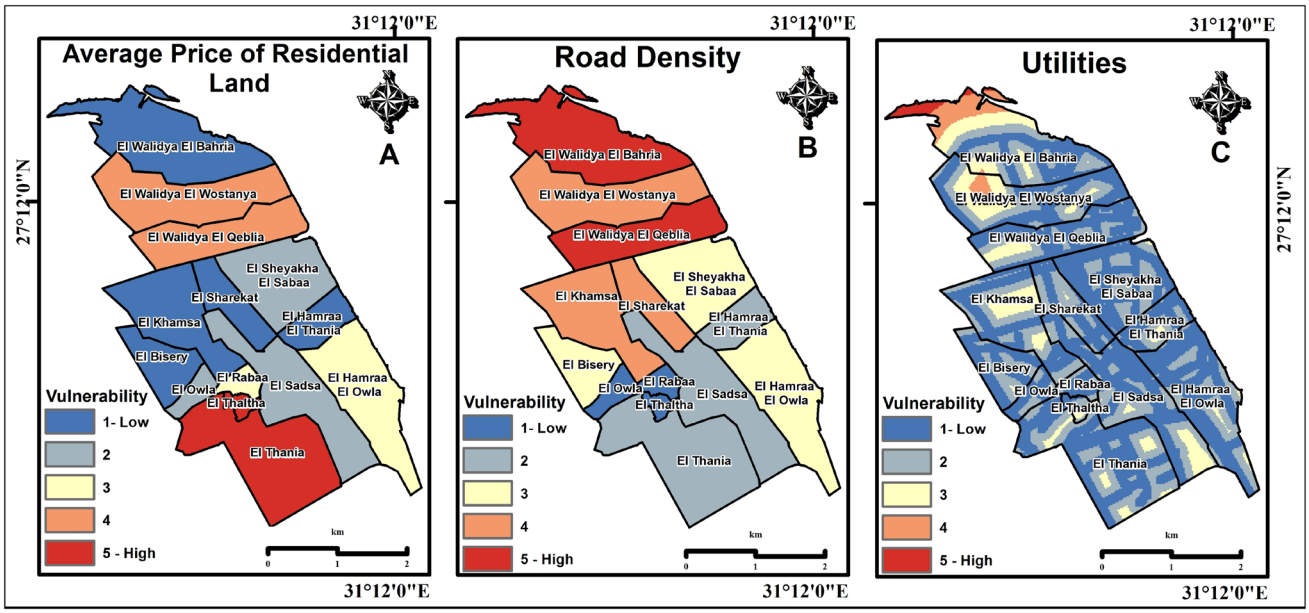
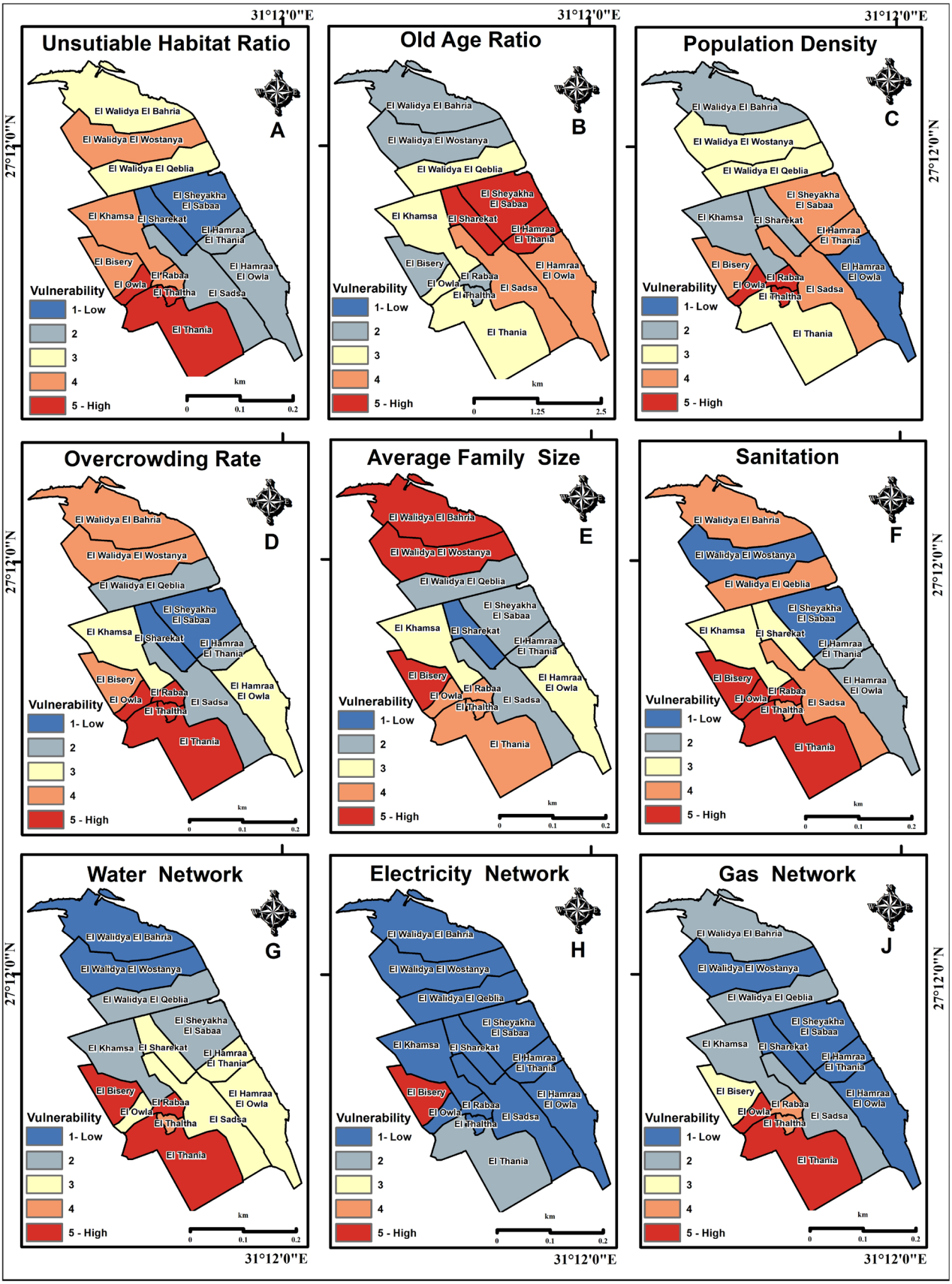


Fig. 8 Standardized factors maps for economic vulnerability; **A** average price of residential land; **B** road density; **C** utilities


Unsutiable Habitat Ratio
A
Old Age Ratio
B
Population Density
C
Overcrowding Rate
D
Average Family Size
E
Sanitation
F
Water Network
G
Electricity Network
H
Gas Network
J
31°12'0"E
27°12'0"N
El Walidya El Bahria
El Walidya El Wostanya
El Walidya El Qeblia
El Sheyakha
El Sabaa
El Khamsa
El Sharekat
El Hamraa
El Thania
El Bisery
El Rabaa
El Owla
El Thaltha
El Sadsa
El Hamraa
El Owla
El Thania
Vulnerability
1- Low
2
3
4
5 - High
km
0
0.1
0.2
1.25
2.5

◂**Fig. 9** Standardized factors maps for COVID-19; **A** unsuitable habitat; **B** old age ratio; **C** population density; **D** overcrowding; **E** average size of the family; **F** no sanitation; **G** no water network; **H** no electricity network; **J** natural gas network

outbreak and contingency plans for the citizens in Asyiout and for the overall improvement of the citizens' quality of life following the vision of the New Urban Agenda.

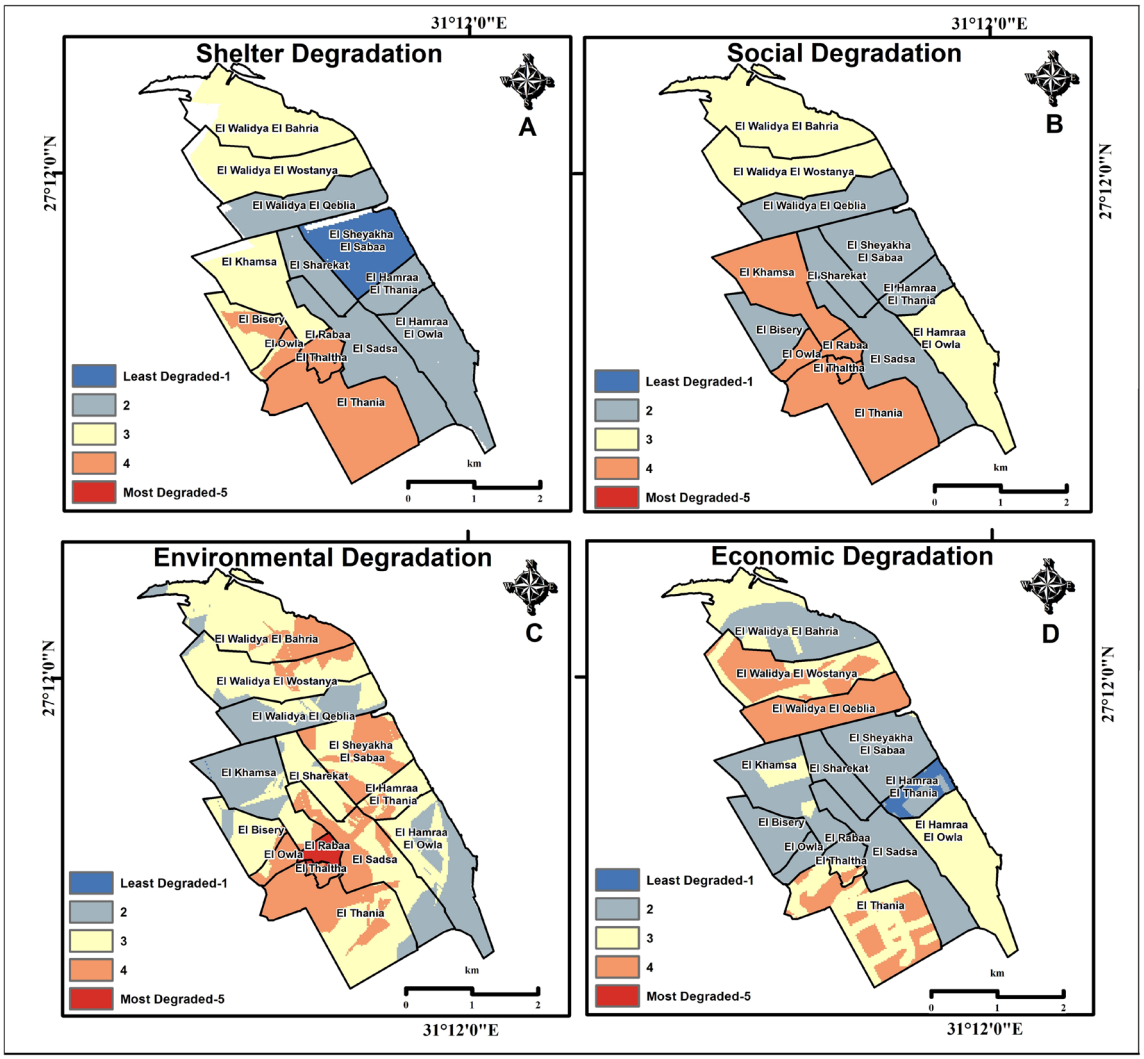


Fig. 10 Combined degraded situations (vulnerability) index maps result of the weighted linear combination for each of the four themes (sub-models)

Table 14 Assigned weights for multiple study scenarios

Indicators	Scenarios %			
	Shelter	Social	Environmental	Economic
Shelter	40	20	20	20
Social	20	40	20	20
Environmental	20	20	40	20
Economic	20	20	20	40
qual	25	25	25	25

Table 15 Urban vulnerability high-risk zones

Scenario	Area	
	Km^2	%
Shelter	2.71	16.88
Social	2.71	16.88
Environmental	2.13	13.26
Economic	1.79	11.15
Equal	2.74	17.06

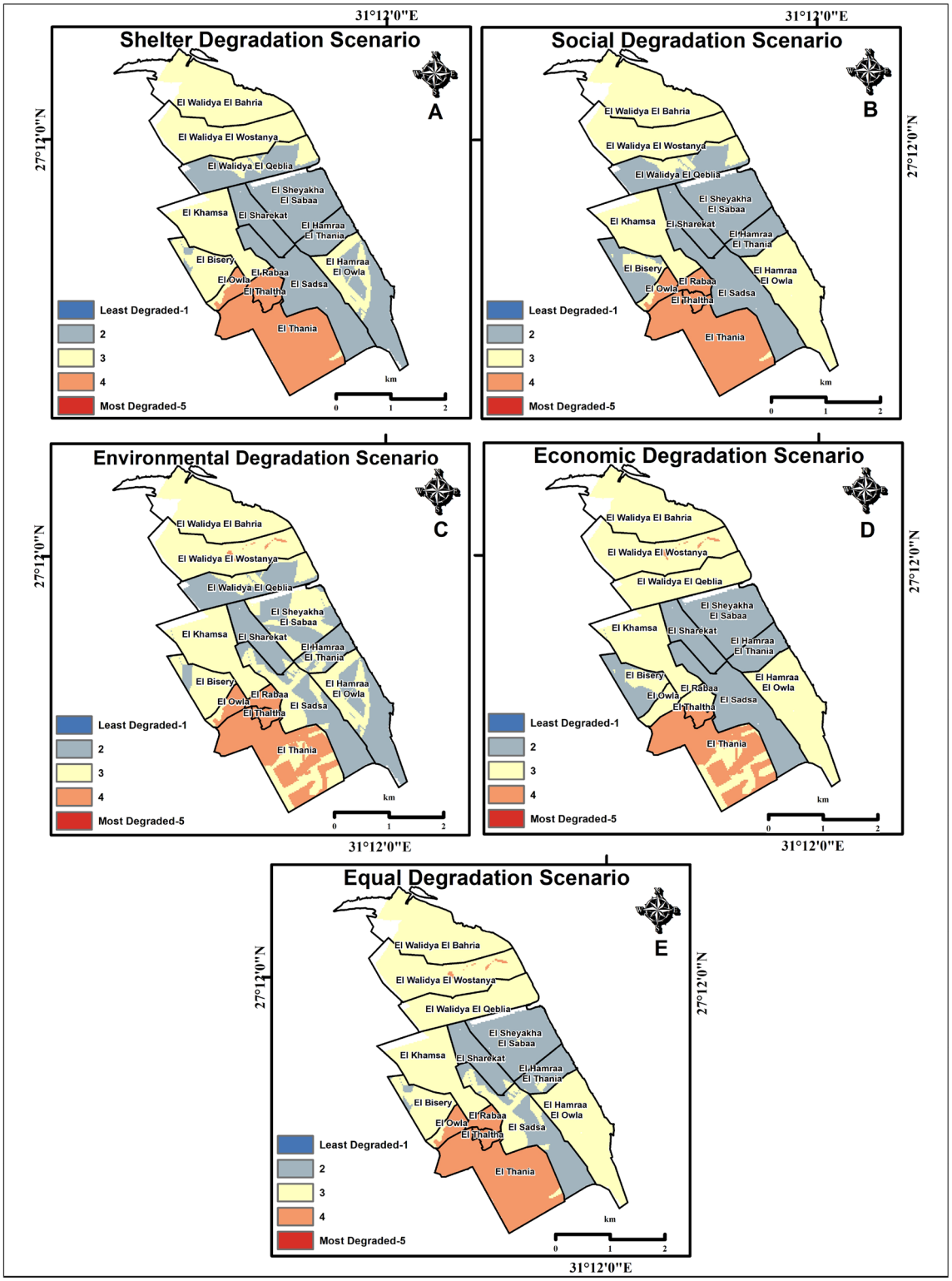


Fig. 11 Vulnerability index scenarios maps

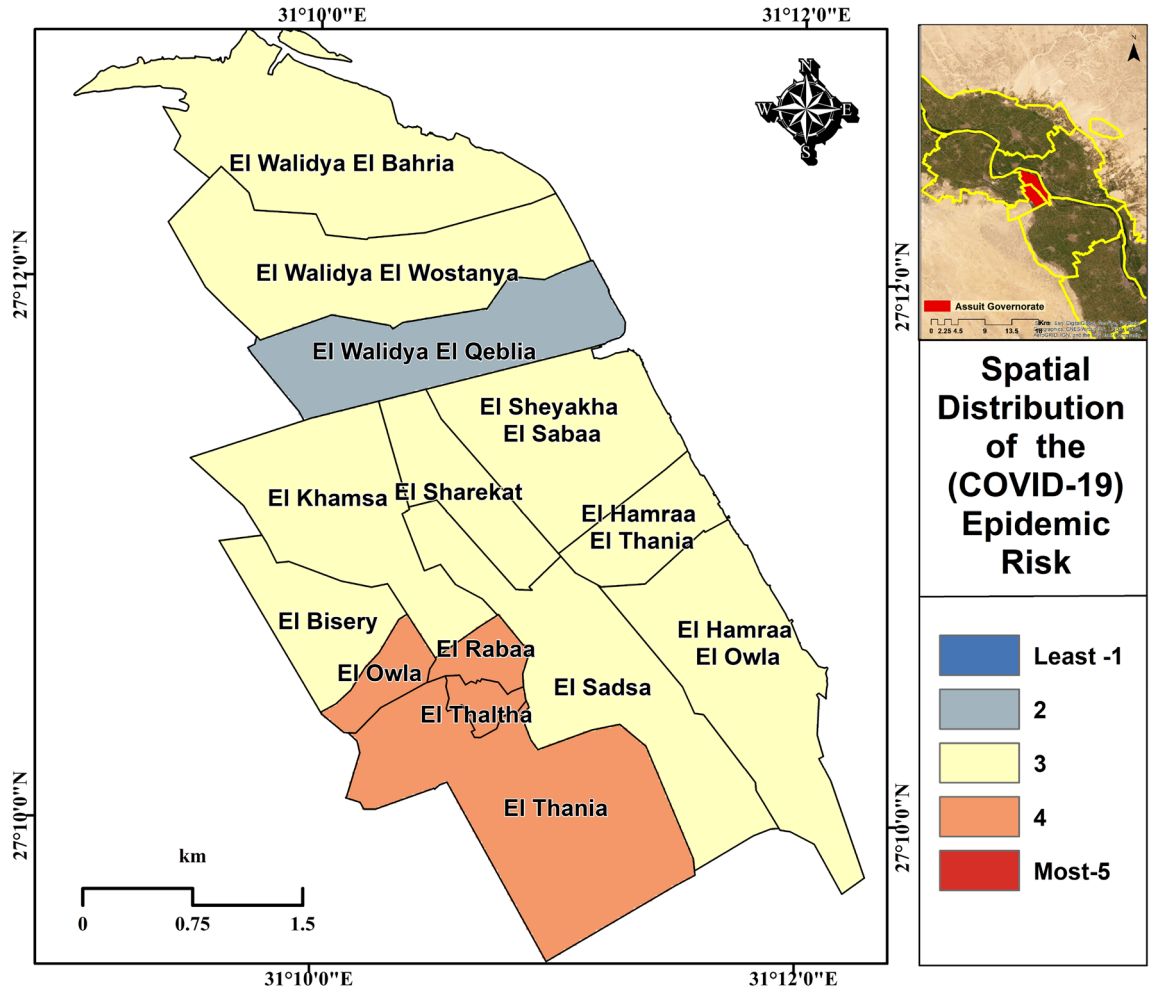


Fig. 12 Potential epidemic risk map

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