Climate change vulnerability index and multi-criteria ranking approach for assessing the vulnerability to climate change: case study Egypt

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Abstract: As a cross-cutting issue, climate change is increasingly recognized as an important factor in development-oriented planning and decision-making. Assessing vulnerability to climate change at different scales is therefore an essential step in the assembly of baseline information to support policy development and strategic planning. Climate change is critical event that will affect people at the local scale. Thus, to plan adaptation strategies, it is essential to identify and rank the vulnerable areas to apply climate adaptation actions on priority basis. This study demonstrates how to use a climate change vulnerability index and multi-criteria analysis to rank the vulnerability to climate change at local scale. It was applied to the governorates in Egypt, where there are many concerns regarding the impact of climate change. The assessment was carried out by overlaying climate risk, exposure, sensitivity and adaptive capacity following the vulnerability assessment framework of the IPCC. The key indicators of the climate change vulnerability index and their weights were determined by applying the Delphi process. Based on amalgamation of the results, the Egyptian governorates were ranked according their vulnerability to climate change for targeting adaptation planning and decision making.

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1. Introduction

The development of national strategy requires assessment of climatic factors and how changes in them will affect decisions for mitigation and adaptation. Vulnerability to climate change is a cross-cutting issue that should be considered in development strategies at various levels [UNDP 2010].

Vulnerability, or the degree to which a system is exposure to, or unable to cope with, adverse effects of climate variability and extremes is a function of the character, magnitude, and rate of climate variation, as well as the system's sensitivity and adaptive capacity [IPCC 2001, Yusuf and Francisco 2009]. The exposure to climate change is defined as the nature and degree to which a system is exposed to significant climatic variations, and sensitivity is defined as the degree to which a system is affected by climate-related stimuli. Adaptive capacity is defined as the ability of a system to adjust to climate change [NAPA 2010, IPCC 2007, IPCC 2001].

Assessment of the vulnerability to climate change requires a clear conceptual framework and is essential to develop relevant adaptation policies [Jun et al. 2013]. Climate change vulnerability must consider how the environment, society, and economy at different scales will be affected as well as the adaptive capacity. Assessing vulnerability is therefore a necessary prerequisite to developing low-emission climate-resilient plans and strategies.

Vulnerability assessment depends on the scale of analysis and most adaptive responses will be made at the local level by resource managers, municipal planners, and individuals. Thus, vulnerability assessment at the local scale becomes important because of the biophysical differences of locations and the socio-economic contextual differences.

Development of methodologies to assess climate change vulnerability has concentrated on a composite index (Brooks et al., 2005; Moss et al. 20001; UNDP, 2010). These approaches are useful to help the national agencies create a standard to determine the priority of support for adaptation. Example, researchers applied Climate change Vulnerability Index (CVI) to mapping and ranking the vulnerability to climate change at the national and local levels [Yusuf and Francisco 2009, NAPA 2010]. Actually, vulnerability assessment is closely related to multi-criteria decision-making (MCDM) problems since it applies a spatial ranking to hazards. Using MCDM, the ranking of vulnerability scores can be used to prioritize climate-change adaptation plans by analysis of changes to achieve certain objectives[Chung S. and Lee S., 2009].

Climate change is recognized as a particularly-significant risk factor in Egypt. As noted by Egypt's

Second National Communication to the UNFCCC, "Egypt is one of the most vulnerable countries to the potential impacts and risks of climate change" [EEAA 2010]. Many studies have reported on the potential impact of climate change on Egypt [Mostafa et al. 2016, Ahmedel ta. 2014, Smith et al 2014, Abdrabo and Hassaan, 2014, Ouda 2013, EEAA 2011, El Raey 2010, El-Gafy 2009, Conway et al., 2004]. Out of its belief in the significance of climate change and its potential impact, Egypt was among the countries of the international community which took part in most of the studies, research, conferences, seminars, and meetings addressing this phenomenon [IDSC 2011]. The Egyptian government through the national ministries and authorities developed adaptation strategies to climate changes [IDSC 2011, Nour El-Din 2013, EEAA 2011, McCarl et al. 2015]. Egypt consists of 27 governorates that located in different agro-climatic zones. Therefore, when achieving strategies to climate change, priorities should be determined. Ranking of vulnerability scores can be translated into prioritizing climate-change adaptation plans.

This study ranks the Egyptian governorates according to their vulnerability to climate change. Climate change vulnerability index (CVI) and multi-criteria analysis approaches were applied to achieve the objective of the current research. The main objective of this study is to offer decision makers with an approach to determine the priority in achieving the climate-change adaptation strategies in the Egyptian governorates. This approach can be implemented by other countries with similar governance patterns and climatic situations.

2. Climate Change Vulnerability Index

Vulnerability is defined by the IPCC as the combination of sensitivity to climatic variations, the probability of adverse climate change, and adaptive capacity. For each of these components of vulnerability, formal indices can be constructed and combined [UN 2014]. CVI provides decision makers and researchers with an approach to identify location where risks may be relatively high. It can be used as a numerical basis for ranking locations by potential vulnerability to climate change [NAPA 2010, UNDP 2010].

CVI is a composite index that consists of three components that are exposure, sensitivity, and adaptation capacity. Exposure (E) refers to a variety of climate-related stimuli such as a rise in sea level, temperature changes, precipitation changes, heat waves, heavy rainstorms, and climatic droughts. Sensitivity (S) is the degree to which a system is modified or affected by perturbations. Adaptive capacity (AC) is the ability of a system to accommodate environmental hazards or policy changes and to expand the range of variability with which it can cope (Yusuf and Francisco 2009, NAPA 2010). Mathematically CVI can be defined as follows:

CVI=f (exposure, sensitivity, adaptive capacity).

3. Research Approach

The study uses the CVI and multi-criteria analysis in the following steps to identify the Egyptian governorates that are most vulnerable to climate change (Figure 1):

i) Applying the Delphi process to determine the indicators of the CVI considering the exposure-sensitivity-adaptive capacity.

ii) Assigning weighted values to the indicators using results of surveys of experts in the Delphi process.

iii) Collecting and preparing data for the selected indicators.

iv) Standardizing the indicators.

v) Comparing two MCDM methods to aggregate the CVI. The two methods are the Weighted Sum Method (WSM) and Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS).

vi) Selecting a MCDM method and quantifying climate vulnerability by applying it.

vii) Ranking the governorates according their vulnerability to climate change.

viii) Developing climate change vulnerability maps (ArcGIS 9.3 was utilized).

ix) Determine the most vulnerable governorate to climate change.

2.1. Determination of CVI indicators and their weights

Each of the CVI components (exposure, sensitivity, and adaptive capacity components) includes a set of indicators. The Delphi technique is applied to select these indicators and assign weights to each indicator according to its importance. The Delphi technique is based on a structured process for collecting and analyzing knowledge from a group of experts by means of a series of questionnaires (Hsu and Sandford 2007). The questionnaires are returned to the respondents, who are able to modify their responses sequentially. The indicators rejected by at least 50% of the respondents were removed. The weights of the key indicators were determined after the third round of the Delphi survey (the process is being repeated until the mean value of the i+1st circle does not show a slight deviation from the mean values of weight obtained in i^{th} circle). Afterward, the average weights for each indicator were taken.

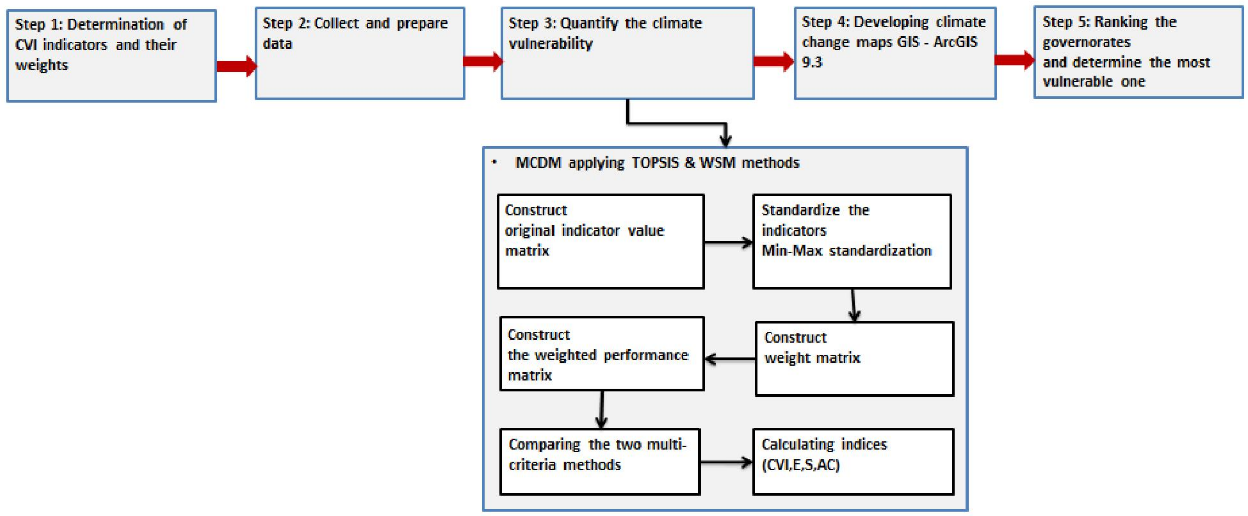

Figure 1: Methodological framework.

2.2 Quantify the vulnerability of the Egyptian governorates to climate change

Multi-criteria ranking approach was applied to quantify the climate vulnerability of the Egyptian governorates. Multi-criteria approaches are applied to determine management alternatives for complex resource systems [Mahmoud and Garcia 2000]. The current study started by comparing two well-known multi-criteria methods that are WSM and TOPSIS. This comparison was carried out to select the best one for ranking the Egyptian governorates according to their vulnerability to climate change. WSM is a simple multi-criteria method that reduces the amount of information by aggregating weighted standardized scores of alternatives [Fishburn 1967]. TOPSIS determines a solution with the shortest distance from the ideal solution and the farthest distance from the negative-ideal solution [Hwang and Yoon 1981]. To apply the WSM and TOPSIS methods, the following process were carried out:

i) Construct original indicators matrix (X) and weight matrix (W) as illustrated in Equations (1) and (2).

$$X = (\boldsymbol{x_{ij}}) = \begin{bmatrix} \boldsymbol{x_{11} x_{12} x_{13} \dots x_{1n}} \\ \boldsymbol{x_{21} x_{22} x_{23} \dots x_{2n}} \\ \dots \dots . \dots \dots . \dots \\ \boldsymbol{x_{m1} x_{m2} x_{m3} \dots x_{mn}} \end{bmatrix} \qquad \textbf{(1)}$$

$$\boldsymbol{W = (w_i)_n = [w_{11} w_{12} w_{13} \dots w_{1n}]}$$

$$0 \le w_i \le 1 \text{ and } \textstyle\sum_i^n w_i = 1 \qquad \textbf{(2)}$$

Where, $\boldsymbol{i}$ is the number of Egyptian governorates (i=1,2,..,m) and $\boldsymbol{j}$ is the number of CVI indicators$(\boldsymbol{x_{ij}})$ ((j= 1,2,…,n).

ii) Transform various attribute dimensions into non-dimensional attributes which allows for a direct comparison among the attributes. The normalized performance matrix R is constructed by computing the normalized value $\boldsymbol{r_{ij}}$of indicator$(\boldsymbol{x_{ij}})$ as follows:

$$\boldsymbol{r_{ij}} = \frac{\boldsymbol{x_{ij} - Min_i\,(x_{ij})}}{\boldsymbol{Max_i(x_{ij}) - Min_i\,(x_{ij})}} \qquad \textbf{(3)}$$

$$\boldsymbol{r_{ij}} = \frac{\boldsymbol{Max_i(x_{ij}) - x_{ij}}}{\boldsymbol{Max_i(x_{ij}) - Min_i\,(x_{ij})}} \qquad \textbf{(4)}$$

$$\boldsymbol{R = (r_{ij})_{mn}} \qquad \textbf{(5)}$$

Equation 3 is used when the $\boldsymbol{Min\,(x_j)}$ of the parameter is the most vulnerability value and $\boldsymbol{Max\,(x_j)}$ is the least vulnerability value, where Equation 4 is used for the opposite situation.

iii) Construct the weighted performance matrix A by multiplying R by its associated weights W

$$\boldsymbol{A = R \times W = (a_{ij})_{mn}} \qquad \textbf{(6)}$$

iv) Rank the governorates according to their vulnerability to climate change.

The final CVI for each governorate applying WSM$\boldsymbol{CVI_{i-WSM}}$ is calculated utilizing equation 7.

$$\boldsymbol{CVI_{i-WSM} = \textstyle\sum_{j=1}^{j=n} a_{ij}} \qquad \textbf{(7)}$$

The final CVI for each governorate applying TOPSIS ($\boldsymbol{CVI_{i-TOPSIS}}$) is calculated utilizing equations 8 to11by the following steps.

Determine the PIS($\boldsymbol{a_j^+}$ – the maximum of weighted normalized values)and NIS ($\boldsymbol{a_j^-}$ – the minimum of weighted normalized values) as follows:

$$\boldsymbol{a_j^+ = Max_i(a_{ij})} \qquad \textbf{(8)}$$

$$\boldsymbol{a_j^- = Min_i(a_{ij})} \qquad \textbf{(9)}$$

Calculate the Euclidean distances of each alternative from PIS and NIS as follows:

$$\boldsymbol{d_i^+} = \sqrt{\textstyle\sum_{j=1}^{n} (a_{ij} - a_j^+)^2} \qquad \textbf{(10)}$$

$$\boldsymbol{d_i^-} = \sqrt{\textstyle\sum_{j=1}^{n} (a_{ij} - a_j^-)^2} \qquad \textbf{(11)}$$

Calculate the relative closeness $\boldsymbol{RCi}$ for each governorate with respect to PIS and NIS, and rank the governorates according to RCi. The larger value is the most vulnerable governorate to climate change.

$$CVI_{i-TOPSIS} = RC_i = \frac{d_i^-}{d_i^+ + d_i^-} \quad (12)$$

3 Results And Discussions

3.1 Quantify the climate vulnerability

3.1.1 Original indicators matrix (selected CVI indicators)

After a series of discussions with researchers and decision makers, 20 key indicators were identified to quantify the vulnerability (3 exposure, 8 sensitivity, and 9 for adaptation capacity). The indicators rejected by at least 50% of the respondents were removed. The final exposure-sensitivity-adaptive capacity indicators of CVI (20 indicators) are illustrated in Figure 2.

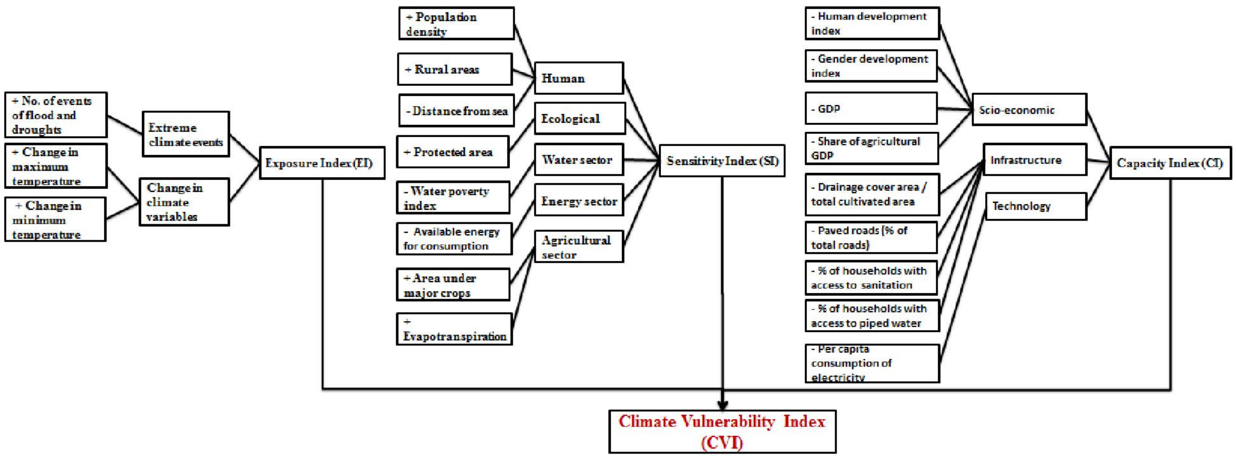

Figure 2: a final Exposure-sensitivity-adaptive capacity indicator of the vulnerability index, (+) indicates that the higher the value the higher the vulnerability to climate change and the (-) is the opposite.

3.1.2 Weighted matrix of CVI indicators

The weights of the CVI indicators were determined as illustrated in section 2.1. The weights of 20 indicators of sensitivity, exposure and capacity components from six experts and their mean, standard deviation, and coefficient of variation are illustrated in Table 1.

3.1.3 Normalized and weighted performance matrix

The normalized performance matrix of the indicators of exposure, sensitivity and capacity components were constructed applying equation 3 to 5. The weighted performance matrix for each component was constructed applying equation 6. The weighted normalized performance matrix of the sensitivity index, as an example, is shown in Table 2.

3.1.4 Comparison between the two MCDM methods (WSM and TOPSIS)

The sensitivity indices (SI) of each governorate were determined applying the WSM and TOPSIS methods to be taken as a guide to compare between the methods. Equation 7 was applied to determine final SI applying WSM. For determine final SI applying **TOPSIS,** distances from FPIS, FNIS, and the relative closeness (***RC***) were calculated applying equations 8 to 12, as shown in Table 3.

Analysis of the results showed that the two methods give the governorates the same rank of sensitivity, as shown in Table 4. Based on this result WSM was selected for calculating the final climate vulnerability index and its component (exposure, sensitivity, and capacity indices) due to its simplicity.

3.2 Climate vulnerability assessment

3.2.2 Exposure index

The exposure index of each Egyptian governorate was determined as shown in Figure 3. The governorates were ranked according to their exposure to climate change as presented in Table 5. This ranking is given to the governorates base on the combination exposure index that has three components (events flash flood, change in maximum temperature, and change in minimum temperature). Ranking the Egyptian governorates according to their the exposure index illustrated that the most exposed governorates to climate change are the North and south Sinai governorates as shown in Figure 3 and Table 5. North Sinai governorate shows higher exposure potential in terms of events of flash flood and change in maximum temperature. South Sinai governorate shows higher exposure potential in terms of events of flash flood and change in minimum temperature the less exposure governorate to climate change is Al – Minagovernorate.

Table 1: Weight of the climate vulnerability index's indicators according to the Expert view point and their mean, stander deviation, and coefficient of variation

Components	Category	Indicator (ID)	Indicator	Weight according to the Expert view point DM1	DM 2	DM 3	DM 4	DM5	DM6	Mean	SD	Coeff. of variation
Exposure (E)	Extreme climate events	E1	No. of events of flash flood	0.40	0.50	0.40	0.50	0.50	0.50	0.47	0.05	0.11
	Change in Climate variables	E2	Change in maximum temperature	0.30	0.25	0.35	0.35	0.30	0.30	0.31	0.04	0.12
		E3	Change in minimum temperature	0.30	0.25	0.25	0.25	0.20	0.20	0.24	0.04	0.16
Sensitivity (S)	Human	S1	Population density	0.20	0.17	0.15	0.12	0.15	0.16	0.16	0.03	0.17
		S2	Rural population	0.10	0.08	0.08	0.13	0.13	0.10	0.10	0.02	0.22
		S3	Distance from sea	0.30	0.35	0.40	0.35	0.30	0.35	0.34	0.02	0.16
	Ecology	S4	Protected area coverage	0.04	0.03	0.07	0.04	0.06	0.05	0.05	0.01	0.30
	Agricultural	S5	Area under major crops	0.09	0.10	0.10	0.12	0.10	0.09	0.10	0.01	0.11
		S6	Evapotranspiration	0.08	0.09	0.07	0.07	0.07	0.08	0.08	0.01	0.15
	Water	S7	Water poverty index	0.13	0.10	0.08	0.10	0.11	0.10	0.10	0.03	0.17
	Energy	S8	Available energy	0.06	0.08	0.05	0.07	0.08	0.07	0.07	0.02	0.02
Capacity (C)	Scio-economic	C1	Human development index	0.20	0.17	0.15	0.18	0.20	0.20	0.18	0.02	0.11
		C2	Gender development index	0.05	0.08	0.06	0.08	0.05	0.10	0.07	0.02	0.29
		C3	GDP	0.15	0.13	0.15	0.13	0.15	0.11	0.14	0.02	0.12
		C4	Share of agricultural GDP	0.10	0.08	0.08	0.11	0.07	0.07	0.09	0.02	0.19
	Infrastructure	C5	Drainage cover area / total cultivated area	0.10	0.10	0.20	0.10	0.15	0.08	0.12	0.04	0.37
		C6	Length of unpaved roads	0.10	0.13	0.05	0.10	0.06	0.08	0.09	0.03	0.34
		C7	% of households with access to sanitation	0.10	0.10	0.10	0.10	0.10	0.08	0.10	0.01	0.08
		C8	% of households with access to piped water	0.10	0.11	0.11	0.10	0.12	0.15	0.12	0.02	0.16
	Technology	C9	Per capita consumption of electricity	0.10	0.10	0.10	0.10	0.10	0.13	0.10	0.10	0.10

Table 2: The weighted normalized performance matrix of the sensitivity index

Governorate	**Population density**	**Rural population**	**Distance from sea**	**Protected area coverage**	**Area under major crops**	**Evapotranspiration**	**Water poverty index**	**Available energy for consumption**
Beheira	0.004	0.097	0.342	0.000	0.100	0.002	0.07	0.05
Kafr el - Sheikh	0.003	0.051	0.342	0.010	0.064	0.000	0.07	0.06
Gharbia	0.008	0.070	0.311	0.000	0.043	0.004	0.06	0.06
Dakahlia	0.005	0.090	0.342	0.000	0.074	0.005	0.06	0.05
Sharqia	0.004	0.103	0.314	0.000	0.099	0.017	0.07	0.05
Dumyat	0.006	0.017	0.342	0.000	0.012	0.000	0.04	0.03
Monufia	0.005	0.066	0.301	0.000	0.044	0.008	0.08	0.07
Qalyubia	0.017	0.059	0.280	0.000	0.020	0.014	0.06	0.06
Alexandria	0.009	0.001	0.342	0.000	0.020	0.003	0.05	0.04
Ismailia	0.001	0.013	0.316	0.000	0.042	0.019	0.05	0.04
Al - Suwayyis	0.000	0.000	0.342	0.000	0.004	0.023	0.01	0.04
Port Said	0.002	0.000	0.342	0.010	0.010	0.009	0.05	0.02
Cairo	0.158	0.000	0.270	0.019	0.001	0.022	0.00	0.04
Giza	0.020	0.065	0.260	0.010	0.002	0.025	0.03	0.05
BaniSwaif	0.006	0.045	0.232	0.010	0.033	0.038	0.10	0.07
Al - Minya	0.007	0.086	0.188	0.000	0.058	0.042	0.10	0.07
Al - Fayoum	0.005	0.050	0.232	0.019	0.051	0.038	0.09	0.06
Asyut	0.008	0.065	0.120	0.010	0.039	0.046	0.09	0.06
Suhaj	0.008	0.075	0.085	0.000	0.035	0.043	0.09	0.07
Qina	0.008	0.051	0.068	0.000	0.042	0.046	0.08	0.06
Luxor	0.005	0.015	0.051	0.000	0.005	0.070	0.07	0.05
Aswan	0.004	0.017	0.000	0.019	0.021	0.070	0.05	0.05
North sinai	0.000	0.002	0.342	0.019	0.019	0.001	0.07	0.05
South sainai	0.000	0.002	0.342	0.048	0.001	0.041	0.07	0.02
Matroh	0.001	0.003	0.342	0.019	0.040	0.005	0.07	0.00
Newvally	0.001	0.002	0.171	0.029	0.032	0.077	0.07	0.02
Red sea	0.004	0.000	0.342	0.019	0.000	0.041	0.07	0.00

Table 3: Distances from FPIS and FNIS and resulting RC and vulnerability ranking for Egyptian governorates applying TOPSIS.

Governorate	Population density	Rural population	Distance from sea	Protected area coverage	Area under major crops	Evapotranspiration	Water poverty index	Available energy for consumption	d+	Population density	Rural population	Distance from sea	Protected area coverage	Area under major crops	Evapotranspiration	Water poverty index	Available energy for consumption	d-	RC
Beheira	0.154	0.006	0.000	0.048	0.000	0.075	0.029	0.020	0.333	0.004	0.097	0.342	0.000	0.100	0.002	0.075	0.048	0.667	0.67
Kafr el - Sheikh	0.155	0.052	0.000	0.039	0.036	0.077	0.032	0.007	0.398	0.003	0.051	0.342	0.010	0.064	0.000	0.071	0.062	0.602	0.60
Gharbia	0.150	0.033	0.031	0.048	0.057	0.072	0.042	0.006	0.440	0.008	0.070	0.311	0.000	0.043	0.004	0.062	0.062	0.560	0.56
Dakahlia	0.153	0.013	0.000	0.048	0.026	0.072	0.048	0.023	0.383	0.005	0.090	0.342	0.000	0.074	0.005	0.055	0.046	0.617	0.62
Sharqia	0.154	0.000	0.027	0.048	0.001	0.059	0.029	0.015	0.334	0.004	0.103	0.314	0.000	0.099	0.017	0.074	0.053	0.666	0.67
Dumyat	0.152	0.086	0.000	0.048	0.088	0.076	0.061	0.041	0.554	0.006	0.017	0.342	0.000	0.012	0.000	0.042	0.027	0.446	0.45
Monufia	0.153	0.038	0.041	0.048	0.056	0.069	0.024	0.000	0.430	0.005	0.066	0.301	0.000	0.044	0.008	0.079	0.068	0.570	0.57
Qalyubia	0.142	0.044	0.062	0.048	0.080	0.063	0.039	0.003	0.481	0.017	0.059	0.280	0.000	0.020	0.014	0.064	0.065	0.519	0.52
Alexandria	0.149	0.102	0.000	0.048	0.080	0.074	0.055	0.030	0.539	0.009	0.001	0.342	0.000	0.020	0.003	0.048	0.039	0.461	0.46
Ismailia	0.158	0.090	0.026	0.048	0.058	0.058	0.057	0.027	0.521	0.001	0.013	0.316	0.000	0.042	0.019	0.046	0.042	0.479	0.48
Al - Suwayyis	0.158	0.103	0.000	0.048	0.096	0.054	0.090	0.025	0.574	0.000	0.000	0.342	0.000	0.004	0.023	0.013	0.044	0.426	0.43
Port Said	0.157	0.103	0.000	0.039	0.090	0.068	0.049	0.050	0.556	0.002	0.000	0.342	0.010	0.010	0.009	0.055	0.018	0.444	0.44
Cairo	0.000	0.103	0.072	0.029	0.099	0.055	0.103	0.031	0.493	0.158	0.000	0.270	0.019	0.001	0.022	0.000	0.037	0.507	0.51
Giza	0.138	0.038	0.082	0.039	0.098	0.051	0.069	0.016	0.531	0.020	0.065	0.260	0.010	0.002	0.025	0.035	0.052	0.469	0.47
BaniSwaif	0.152	0.058	0.109	0.039	0.067	0.039	0.006	0.001	0.471	0.006	0.045	0.232	0.010	0.033	0.038	0.097	0.067	0.529	0.53
Al - Minya	0.152	0.017	0.154	0.048	0.042	0.035	0.000	0.001	0.448	0.007	0.086	0.188	0.000	0.058	0.042	0.103	0.067	0.552	0.55
Al - Fayoum	0.153	0.053	0.109	0.029	0.049	0.038	0.016	0.006	0.452	0.005	0.050	0.232	0.019	0.051	0.038	0.088	0.063	0.548	0.55
Asyut	0.150	0.039	0.222	0.039	0.061	0.031	0.014	0.010	0.566	0.008	0.065	0.120	0.010	0.039	0.046	0.089	0.058	0.434	0.43
Suhaj	0.150	0.028	0.256	0.048	0.065	0.034	0.012	0.002	0.595	0.008	0.075	0.085	0.000	0.035	0.043	0.091	0.066	0.405	0.40
Qina	0.151	0.053	0.273	0.048	0.058	0.031	0.023	0.003	0.640	0.008	0.051	0.068	0.000	0.042	0.046	0.080	0.065	0.360	0.36
Luxor	0.153	0.088	0.290	0.048	0.095	0.007	0.029	0.018	0.728	0.005	0.015	0.051	0.000	0.005	0.070	0.074	0.051	0.272	0.27
Aswan	0.154	0.086	0.342	0.029	0.079	0.007	0.050	0.018	0.764	0.004	0.017	0.000	0.019	0.021	0.070	0.053	0.050	0.236	0.24
North sinai	0.158	0.102	0.000	0.029	0.081	0.076	0.029	0.015	0.490	0.000	0.002	0.342	0.019	0.019	0.001	0.074	0.054	0.510	0.51
South sainai	0.158	0.102	0.000	0.000	0.099	0.036	0.029	0.049	0.473	0.000	0.002	0.342	0.048	0.001	0.041	0.074	0.019	0.527	0.53
Matroh	0.158	0.101	0.000	0.029	0.060	0.071	0.029	0.065	0.513	0.001	0.003	0.342	0.019	0.040	0.005	0.074	0.004	0.487	0.49
Newvally	0.158	0.101	0.171	0.019	0.068	0.000	0.029	0.051	0.598	0.001	0.002	0.171	0.029	0.032	0.077	0.074	0.017	0.402	0.40
Red sea	0.154	0.103	0.000	0.029	0.100	0.036	0.029	0.068	0.520	0.004	0.000	0.342	0.019	0.000	0.041	0.074	0.000	0.480	0.48

Table 4: Sensitivity index applying the two MCDM methods

Governorate	Sensitivity index		Rank	
	WSM	TOPSIS	WSM	TOPISS
Beheira	0.67	0.67	1	1
Sharqia	0.67	0.67	2	2
Dakahlia	0.62	0.62	3	3
Kafr el - Sheikh	0.60	0.60	4	4
Monufia	0.57	0.57	5	5
Gharbia	0.56	0.56	6	6
Al - Minya	0.55	0.55	7	7
Al - Fayoum	0.55	0.55	8	8
BaniSwaif	0.53	0.53	9	9
South sainai	0.53	0.53	10	10
Qalyubia	0.52	0.52	11	11
North sinai	0.51	0.51	12	12
Cairo	0.51	0.51	13	13
Matroh	0.49	0.49	14	14
Red sea	0.48	0.48	15	15
Ismailia	0.48	0.48	16	16
Giza	0.47	0.47	17	17
Alexandria	0.46	0.46	18	18
Dumyat	0.45	0.45	19	19
Port Said	0.44	0.44	20	20
Asyut	0.43	0.43	21	21
Al - Suwayyis	0.43	0.43	22	22
Suhaj	0.40	0.40	23	23
Newvally	0.40	0.40	24	24
Qina	0.36	0.36	25	25
Luxor	0.27	0.27	26	26
Aswan	0.24	0.24	27	27

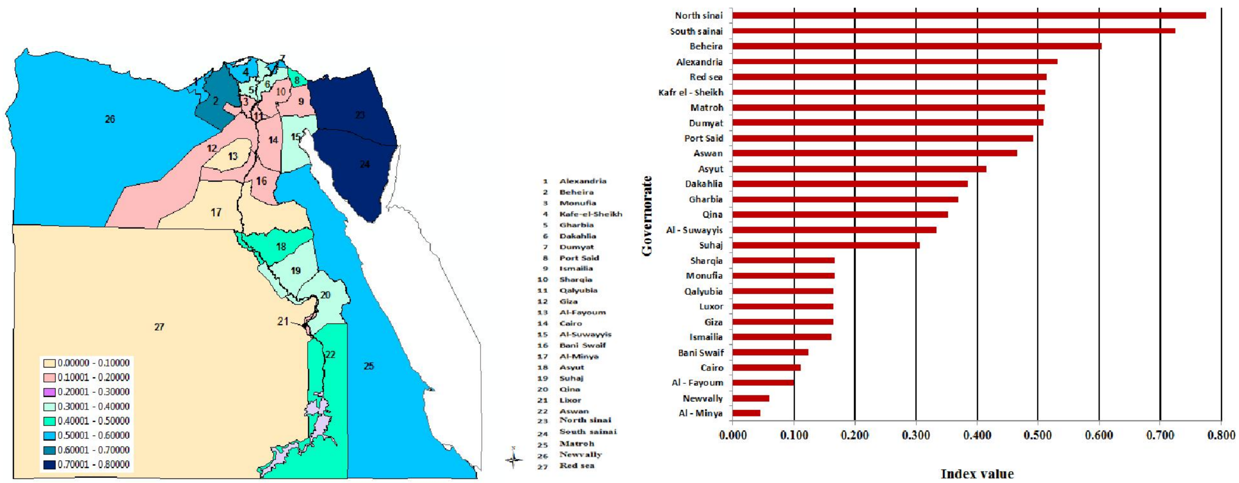

Figure 3: Exposure index of the Egyptian governorate

Table 5: Rank of the exposure index and its indicators

Governorate	Extreme climate events	Change in Climate variables		Exposure index
	No. of events of flash flood	Change in maximum temperature	Change in minimum temperature	
North Sinai	1	1	26	1
South Sinai	1	13	1	2
Beheira	1	24	2	3
Alexandria	1	7	12	4
Red sea	1	3	21	5
Kafr el - Sheikh	1	11	16	6
Matroh	1	27	12	7
Dumyat	1	12	17	8
Port Said	1	17	23	9
Aswan	10	4	4	10
Asyut	10	21	14	11
Dakahlia	12	10	22	12
Gharbia	14	5	6	13
Qina	13	21	18	14
Al - Suwayyis	14	26	11	15
Suhaj	14	21	18	16
Sharqia	19	20	3	17
Monufia	19	18	5	18
Qalyubia	19	13	10	19
Luxor	17	25	18	20
Giza	19	16	7	21
Ismailia	17	19	24	22
BaniSwaif	24	8	8	23
Cairo	19	15	25	24
Al - Fayoum	25	9	9	25
Newvally	27	2	15	26
Al - Minya	25	6	27	27

[*] **The governorate ofrank (1) - is the most vulnerable governorate**

3.2.3 Sensitivity index

The sensitivity index of each Egyptian governorate was determined as shown as shown in Figure 4. The governorates were ranked according to their sensitivity to climate change as presented in Table 6. This ranking is given to the governorates based on the combination sensitive index. The most sensitive governorates to climate change are Behera and Sarkia governorates as shown in Figure 4 and Table 6. The sensitive index considers five categories, as shown in Table 3. The five categories are human, ecology, agricultural, water, and energy. Behera governorate shows higher sensitivity potential in terms of distance to the sea and area under major crops. Sarkia governorate shows higher sensitivity potential in terms of rural population and area under major crops. The least sensitive governorate to climate change is Aswan governorate.

3.2.4 Adaptation capacity index

The adaptation capacity index of each Egyptian governorate was determined as shown as shown in Figure 5. Adaptation capacity is defined as the ability of the system to adjust to climate change. The adaptation capacity index in this study is based on socio-economic, infrastructure, and technology factors. The least governorate in its adaptation capacity to climate change is Matrouh governorates as shown in Figure 5. The governorates were ranked according to their adaptation capacity to climate change as presented in Table 7. Matrouh governorate shows low adaptation capacity in terms of drainage cover area / total cultivated area and % of households with access to water. The highest governorate in its adaptation capacity to climate change is Dumyat governorate.

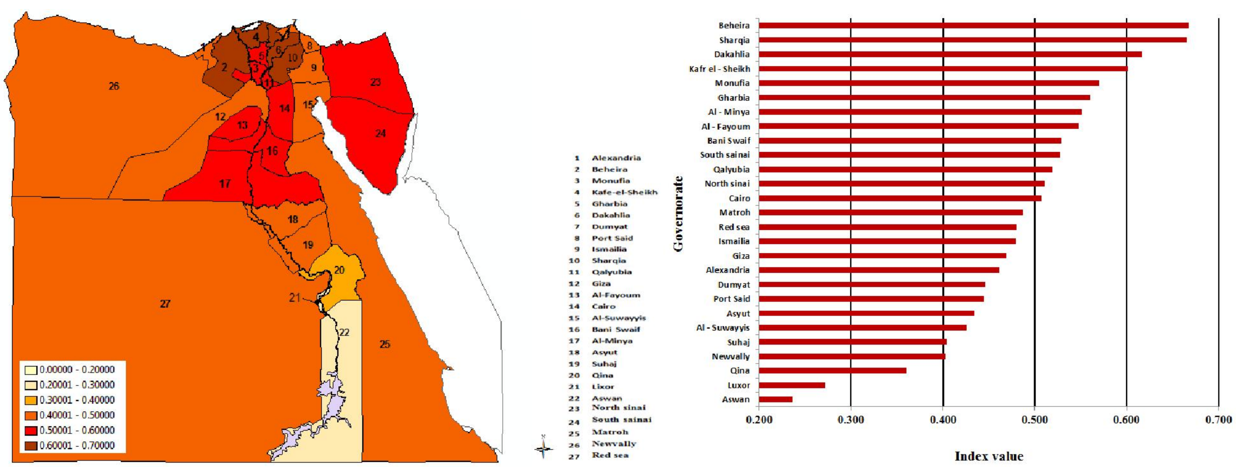

Figure 4: Sensitivity index of the Egyptian governorate

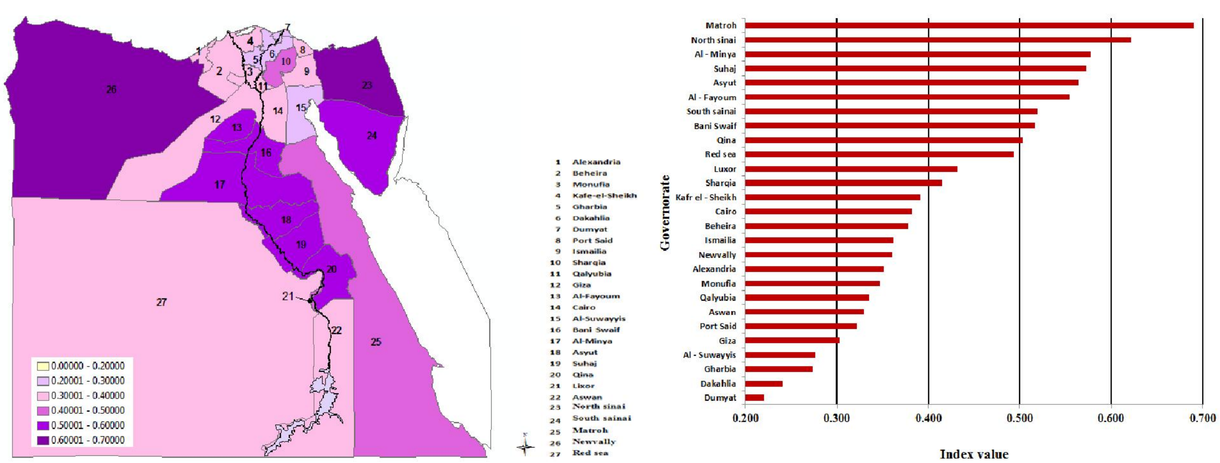

Figure 5: Adaptation capacity index of the Egyptian governorate

Table 6: Rank of the sensitivity index and its indicators*

Governorate	Human			Ecology	Agricultural		Water	Energy	Sensitivity Index WSM
	Population density	Rural population	Distance from sea	Protected area coverage	Area under major crops	Evapotran spiration	Water poverty index	Available energy for consumption	
Beheira	18	2	1	14	1	24	8	16	1
Sharqia	17	1	13	14	2	16	9	12	2
Dakahlia	12	3	1	14	3	21	19	17	3
Kafr el - Sheikh	20	11	1	9	4	27	16	9	4
Monufia	14	7	15	14	7	19	7	1	5
Gharbia	7	6	14	14	8	22	18	8	6
Al - Minya	9	4	21	14	5	7	1	2	7
Al - Fayoum	13	13	19	3	6	10	5	7	8
BaniSwaif	10	14	19	9	14	11	2	3	9
South Sinai	27	21	1	1	25	8	10	23	10
Qalyubia	3	10	16	14	17	17	17	5	11
North Sinai	25	22	1	3	19	25	10	11	12
Cairo	1	25	17	3	26	14	27	21	13
Matroh	23	19	1	3	11	20	10	26	14
Red sea	19	24	1	3	27	8	10	27	15
Ismailia	22	18	12	14	10	15	23	19	16
Giza	2	8	18	9	24	12	25	13	17
Alexandria	4	23	1	14	18	23	22	20	18
Dumyat	11	16	1	14	20	26	24	22	19
Port Said	21	25	1	9	21	18	20	24	20
Asyut	6	9	23	9	12	5	4	10	21
Al - Suwayyis	26	25	1	14	23	13	26	18	22
Suhaj	5	5	24	14	13	6	3	4	23
Newvally	24	20	22	2	15	1	10	25	24
Qina	8	12	25	14	9	4	6	5	25
Luxor	15	17	26	14	22	2	10	14	26
Aswan	16	15	27	3	16	2	21	15	27

* **The governorate ofrank (1) - is the most vulnerable governorate**

3.2.1 Climate vulnerability index

The three components (exposure, sensitivity and capacity) of the vulnerability index were integrated as explained in the methodology section for the construction of the final index. Equal weights were given to the three components. Analysis of the final Climate vulnerability index shown that the Egyptian governorates that are most vulnerable to climate change is North Sinai, as shown in Figure 6. North Sinai governorate could be considered very vulnerable to climate change followed by South Sinai, Matrogh, Behera, and Kafer el-sheikh governorates. The less vulnerable governorate to climate change is New valley governorate.

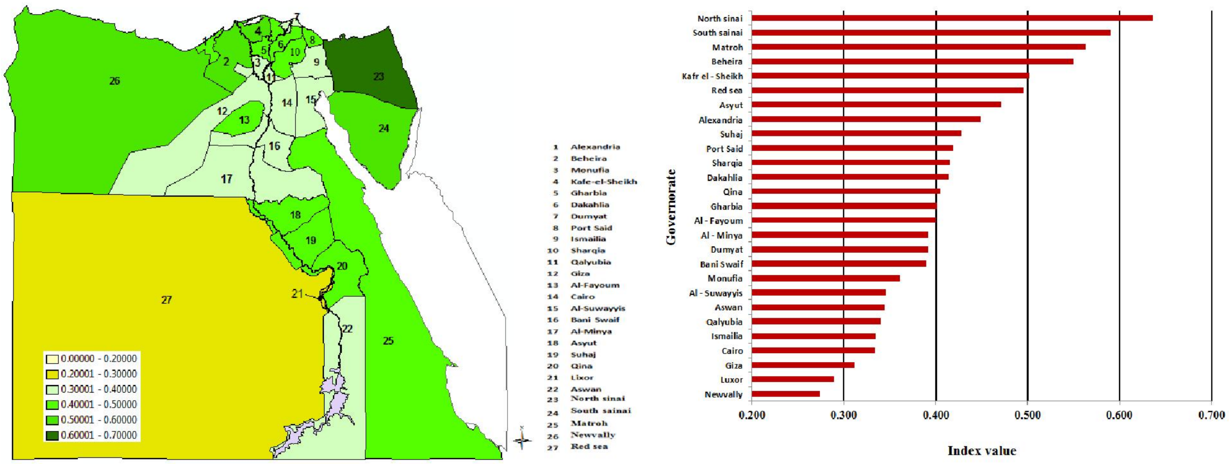

Figure 6: Climate change vulnerability index of the Egyptian governorate

Table 7: Rank of the adaptation capacity index and its indicators

Governorate	Scio-economic				Infrastructure				Technology	Capacity index
	Human development index	Gender development index	GDP	Share of agricultural GDP	drainage cover area / total cultivated area	Paved roads (% of total roads)	% of households with access to sanitation	% of households with access to water	Per capita consumption of electricity	
Matroh	9	2	7	17	1	6	7	1	20	1
North Sinai	19	1	5	9	1	2	12	4	8	2
Al - Minya	2	3	2	23	19	18	3	3	3	3
Suhaj	4	9	6	15	13	8	5	10	6	4
Asyut	3	6	4	16	14	19	2	13	2	5
Al - Fayoum	1	5	1	22	15	12	9	18	1	6
South Sinai	25	4	9	3	1	15	21	2	12	7
BaniSwaif	6	6	3	14	26	16	4	9	4	8
Qina	4	10	11	19	17	24	1	7	5	9
Red sea	23	6	9	1	1	26	12	4	24	10
Luxor	14	13	20	6	1	20	15	20	13	11
Sharqia	10	13	14	26	22	1	11	8	10	12
Kafr el - Sheikh	7	18	12	24	27	5	6	17	7	13
Cairo	11	21	19	2	1	17	26	23	25	14
Beheira	8	13	8	27	20	23	10	6	9	15
Ismailia	20	21	22	18	11	4	17	19	17	16
Newvally	27	11	13	13	1	9	19	21	15	17
Alexandria	22	21	23	10	1	3	23	24	26	18
Monufia	17	13	16	21	21	11	8	12	16	19
Qalyubia	13	19	15	11	24	10	18	15	22	20
Aswan	12	12	21	12	16	25	14	22	11	21
Port Said	26	21	25	7	10	7	24	11	19	22
Giza	16	13	26	4	12	21	27	25	27	23
Al - Suwayyis	24	21	27	5	1	13	25	27	23	24
Gharbia	18	21	18	20	23	22	16	16	18	25
Dakahlia	15	19	17	25	25	14	22	14	14	26
Dumyat	21	27	24	8	18	27	20	26	21	27

4 Conclusion

The research showed how vulnerability can be expressed to the governorate level in GIS maps by use of multi-criteria analysis and Climate Change Vulnerability Index approaches. This enables the analyst to identify and rank the governorates according to vulnerability to climate change.

The study compared two MCDM methods and demonstrated that they assign the governorates the same rank of vulnerability to climate change. Based on this result the Weighted Sum Method was selected to calculate the climate vulnerability index and its components (exposure, sensitivity, and capacity). Some 20 exposure-sensitivity-adaptive capacity indicators of CVI and their weights were then determined after a series of discussions with researchers and decision makers.

After ranking twenty-seven governorates according to their vulnerability the results showed that the North Sinai governorate is most vulnerable to climate change followed by the South Sinai, Behera and Matrogh governorates. The least vulnerable governorate to climate change is New Valley.

In terms of the components of the index, the results showed that the most exposed governorates to climate change are North and South Sinai governorates and the least-exposed is the Al - Mina governorate. The governorates most sensitive to climate change are Behera and Sarkia while the least sensitive is Aswan governorate. The governorate with least adaptation capacity to climate change is the Matrouh governorate while the governorate with highest adaptation capacity is Dumyat.

Given the importance of vulnerability analysis to Egyptian national policy, the outcome of this study can be useful to target financial resources towards adaptation measures in Egypt, and the same approaches may be useful in similar locations. More research is needed to compare different multi-criteria methods such as the fuzzy multi-criteria approach to study vulnerability to climate change in greater detail.

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