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Developing a Composite Adaptive Governance Index (AGI) for Egyptian Cities to Confront Climate Change Hazards

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ABSTRACT

Cities susceptible to climate change hazards need to adjust their economic, social, environmental, and urban capabilities, and they must strive to reduce existing risks and enhance government readiness for emergencies. According to reports from international institutions such as the Intergovernmental Panel on Climate Change (IPCC), the World Bank, and the Notre Dame Global Adaptation Initiative (ND-GAIN), countries should develop indexes matching the specificity of cities unique models. Accordingly, the research aims to develop a composite adaptive governance index (AGI) that fits the Egyptian cities exposed to different risks using a set of methods in applying the index; normalization techniques were based on the min-max method, and the normalized indicator scores were aggregated and weighted by the AHP method. Data analysis for 105 sub-indicators is collected to represent four main indexes (exposure, sensitivity, adaptive capacity, and governance). The online questionnaire was used to get suggestions from twenty experts in different fields. The concluded index was applied to nine cities; five of them are at risk of land submergence (Alexandria, Rashid, Burlus, Damietta, Port Said), three are at risk of flash floods (Aswan, Assiut, Sohag), and one is at risk of desertification and drought (ELKhargaa). The AGI shows positive values in one city, "Alexandria," while the rest have negative values. Assiut and Sohag are the worst due to their high level of poverty and low level of participation. The AGI value will rise in cities like Damietta and Port Said if more is done to improve crisis management techniques and governance efficacy.

KEYWORDS
Climate change, Egyptian cities, Vulnerability, Adaptive governance, Readiness, Hazards.

تطوير مؤشر الحوكمة التكيفية المركب للمدن المصرية لمواجهة مخاطر تغير المناخ

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ملخص البحث

تحتاج المدن المعرضة لمخاطر تغير المناخ إلى تعديل قدراتها الاقتصادية والاجتماعية والبيئية والحضرية، ويجب أن تسعى جاهدة للحد من المخاطر القائمة وتعزيز استعداد الحكومة لحالات الطوارئ. ووفقًا لتقارير من مؤسسات دولية مثل الهيئة الحكومية الدولية المعنية بتغير المناخ (IPCC)، والبنك الدولي، ومبادرة نوتردام العالمية للتكيف (ND-GAIN)، يجب على البلدان المختلفة تطوير مؤشرات تتناسب مع خصوصية نماذج المدن لديها. وعليه، يهدف البحث إلى تطوير مؤشر حوكمة تكيفية مركب (AGI) يناسب المدن المصرية المعرضة لمخاطر تغير المناخ المختلفة باستخدام مجموعة من الأساليب في تطبيق المؤشر وتم تجميع درجات المؤشرات الطبيعية ووزنها بطريقة AHP. حيث تم جمع تحليل البيانات لـ 105 مؤشرات فرعية لتمثيل أربعة مؤشرات رئيسية (التعرض والحساسية والقدرة على التكيف والحوكمة). تم استخدام الاستبيان

عبر الإنترنت للحصول على اقتراحات من عشرين خبيرًا في مجالات مختلفة. تم تطبيق المؤشر المستنتج على تسع مدن؛ خمس منها معرضة لخطر غرق الأراضي (الإسكندرية، رشيد، البرلس، دمياط، بورسعيد)، وثلاثة معرضة لخطر السيول والفيضانات المفاجئة (أسوان، أسيوط، سوهاج)، وواحدة معرضة لخطر التصحر والجفاف (الخارجة). أظهر المؤشر المركب AGI قيمًا إيجابية في مدينة واحدة، "الإسكندرية"، بينما سجلت بقية المدن قيم سلبية. أسيوط وسوهاج هما الأسوأ في قيم المؤشر بسبب ارتفاع مستوى الفقر وانخفاض مستوى المشاركة المجتمعية. ويلاحظ أن قيمة المؤشر المركب AGI يمكن أن تتحسن ارتفاعاً في مدن مثل دمياط وبورسعيد إذا تم بذل المزيد من الجهود لتحسين إدارة الأزمات وفعالية الحوكمة.

الكلمات المفتاحية: تغير المناخ، المدن المصرية، الضعف، الحوكمة التكيفية، الاستعداد، المخاطر.

INTRODUCTION

Observed and projected climate changes are a complex challenge among governments worldwide, with various vulnerability components impacting environmental, social, economic, and political disciplines (Bai et al., 2018). The level of vulnerability is changed directly with the effort given to adaptive governance; therefore, a system that is the most exposed need not be the most vulnerable (IPCC, 2014; Panday and Jha, 2012; Maiti et al., 2017). Adaptive governance needs to be improved to mitigate the negative consequences of climate change. In the meantime, these enhancements are required for future work (Oculi and Stephenson, 2018; Weiler et al., 2018). Achieving safe and sustainable development is imperative for sustainability goals, as the increasing effects of climate risks on cities, particularly those near the coast, present a significant obstacle for nations, such as the cities exposed to flooding in Egypt. Accordingly, it is necessary to strive for development by making societies more sustainable and cities more resilient. Acceptable responses to the changes differ from location to location and become more intricate in certain societies, resulting in heightened hazards and vulnerabilities and a deterioration in adaptability. This implies that they need to be dynamic, planned, and tailored to the specific needs of each nation. Therefore, to effectively implement long-term policy and reduce vulnerability, it is essential to identify the gaps first and the constraints facing governments (Buchir and Detzel, 2023). In light of this, the local government is continuously challenged to strike a balance between the need to make decisions that enable communities to adapt to impending environmental threats and the accomplishment of sustainable development objectives. Since the local governments of the cities are ill-equipped to handle climate change hazards (Da Silva et al., 2012), they depend on national measures and strategies. Egypt's Nationally Determined Contributions (ENDC) is a crucial policy document that outlines the goals and implementation of adaptation measures in many social and economic domains (UNFCCC, 2023). ENDC only applies at the national level and is missing at the city level. The composite index aims to deal with the Egyptian case and the privacy of data that may be very important in global measures but may not be available in the Egyptian case, especially at the city level. Consequently, this work is to suggest an explicit consideration of the governance component of the climatic vulnerability at the city level, using four primary components: adaptive capacity, exposure, sensitivity, and governance.

1. Literature Review

Governance is the process by which federal, regional, and local governments, with development partners, determine how to organize, fund, and oversee urban development (Avis, 2016; Qalqil, 2018). Effective governance systems are influenced by a variety of factors that differ depending on the unique characteristics of each region, including the ability to create and maintain public services, financial independence and

resource availability, full participation in decision-making, and others (UNDDR, 2017). According to Hutema et al. (2016), governance refers to institutional arrangements and policies based on the context of climate adaptation. It is the collective endeavor of national and international social actors to find cooperative ways to mitigate the adverse effects of climate change. Conversely, institutional arrangements for adaptation by the UNFCCC are a framework or method created by stakeholders at various levels to direct actions related to adaptation and vulnerability reduction (Worker, 2017). International organizations have provided alternative definitions of adaptive governance, including the Global Alliance for Resilience, Resilient Europe, and the Organization for Economic Cooperation and Development (OECD) (Table 1). Nonetheless, the majority of the definitions speak about the level of accountability, adaptation, transformation, and readiness of a city, neighborhood, house, organization, or business against potential risks or events (Figueiredo et al., 2018).

Table 1. The keywords of the "adaptive governance" definition

Organization	RE	PP	AR	BR	FP	FC
OECD	-	●	-	-	-	●
International Council for Local	-	-	-	-	-	●
United Nations Office for Disaster Risk	-	-	●	-	●	-
World Bank	●	-	-	●	-	-
100 Resilient Cities	-	-	●	●	-	-
Global Alliance for Resilience	-	-	-	-	●	-
IPCC	●	●	-	●	-	-

Note. RE: respond effectively; PP: proactiveness and participation; AR: absorption and reaction; BR: building resilience; FP: flexibility in pressures; FC: flexibility and capacity.

Source: based on IPCC, 2014; World Bank, n.d; Hall, 2014; Sharma-Wallace et al., 2018

The absence of performance monitoring systems with the capacity to modify policies in response to emergencies and unanticipated events might hinder the adoption of adaptive governance (Hall, 2014). Monitoring indicators are one of the most crucial tools used for this purpose since continuous performance monitoring requires an evaluation process to track the points where the system needs to improve and develop (Le and Chang, 2017). Therefore, it was necessary to review the following composite indexes:

The Intergovernmental Panel on Climate Change (IPCC) index used exposure, which refers to the extent and length of exposure to climate-related factors, such as a drought or shift in precipitation patterns (Thornes, 2002). The system's sensitivity refers to how much the exposure affects it, while its adaptive capacity describes how well it can tolerate or recover from the exposure (Ebi et al., 2006). The Livelihood Vulnerability Index (LVI) aims to give development organizations and policymakers a beneficial tool for understanding the social, health, and demographic aspects that influence climate vulnerability at the regional or local level. Its adaptability allows the overall composite index to identify potential areas for intervention (Hahn et al., 2009). The LVI looks at five different categories of household assets: financial, social, physical, natural, and human capital. The Multidimensional Vulnerability Index (MVI) focuses on a broad range of issues that have an impact on population well-being, such as livelihoods, water, health, social protection, and education. MVI was developed to investigate the intricate vulnerability of environmental, demographic, social, and economic change in rural, arid, mountainous, and Small Island Developing States (SIDS) areas (Guillaumont, 2024). The lack of data-driven information about which cities are more vulnerable than others provided by the MVI will make lagging cities less resilient to

diseases, economic shocks, natural disasters, and climate change (Badawy et al., 2022). The Notre Dame Global Adaptation Initiative Index (ND-GAIN) is a free, open-source index that measures current vulnerability to climate disruption. It assesses a country's susceptibility by considering its ecosystem services, infrastructure, food, water, health, and human habitat. Decision-makers in the business, NGO, government, and development sectors can use supporting data and information to make well-informed choices on capital projects, supplier chains, policy modifications, and community involvement. The ND-GAIN index divides the vulnerability measure into exposure, sensitivity, and adaptive capacity, and the readiness measure into economic, governance, and societal components (Chen et al., 2015).

Evaluating adaptive governance entails determining how well policies work, how resilient communities and ecosystems are, and the extent of reforms being implemented (Pandey et al., 2024). Adaptive governance opens the door to incorporating new systems in city planning that can facilitate cross-sectoral collaboration inside cities and integrate multiple hazards (Birkmann et al. 2014). This suggests that composite AGI can make local governments more capable of adjusting to and controlling the hazards associated with climate change through continuous assessment processes. Newly developed innovative methods and technologies have brought attention to how cities might deal with climate change and its potential repercussions (Saleh, 2020). Developing a composite AGI is considered one of many procedures that should be taken to ensure the implementation of adaptive governance. It is significant to work on building an index that includes the various dimensions that make up adaptive management in the face of climate change risks and the resulting disasters. The impact of management institutions, and specifically governance, on climate vulnerability has previously been discussed in previous research (Dasgupta et al., 2006; Pandey & Jha, 2012; Jubeh & Mimi, 2012; Kamh et al., 2016; ElGafy and Grigg, 2016; Le & Chang, 2017; Weiler et al., 2018). Most agreed with the IPCC Index that exposure is the main index to study in addition to the LVI and ND-GAIN indices about sensitivity and capacity. International studies focus on the national system without addressing the sub-national and local levels, in addition to the absence of means and tools that countries have to fulfill their responsibilities in the field of governance, especially at the level of local city administration. Recent research has sought to create a climate vulnerability index or assess the risk-resilience of cities by using governance as the main component of an index (Buchir and Detzel, 2023; Kim, B. et al., 2023). Therefore, the study aims to develop a composite index that includes more diverse measurement indicators: environmental and spatial dimensions of vulnerability, socio-economic sensitivity, and resilience through education, health, employment, infrastructure, and housing capacities, in addition to governance dimensions, stakeholder participation in decision-making, local government effectiveness, and crisis management strategies.

2. Study Area (Selecting Cities at Risk)

Egypt is distinguished by its location, which spans roughly 3,500 km along the coastlines of the Mediterranean and Red Seas, with hot, dry summers and mild winters, making the country mostly at risk from global climate change. Egypt's natural hazards risk level is summarized from 1900 to 2023 in Table 2. It demonstrates that the nation faces severe heat waves, water scarcity, and a high danger of river, urban, and coastal flooding (World Bank, 2023). In addition, Egypt ranks 104th on the ND-GAIN Index (Fig. 1). It is ranked the 93rd most vulnerable country and the 122nd most ready country. Egypt is positioned in the lower-left quadrant of the ND-GAIN matrix due to

its low readiness score and high vulnerability score, indicating a pressing need for investment and innovation to increase readiness (University of Notre Dame, 2023).

Table 2. Disaster type occurrence in Egypt between 1900-2023

Flood	14 (of which 6 recorded riverine floods, and 3 recorded flash floods)
Storm	8 (of which 6 recorded convective storms)
Extreme temperature	4 (of which 3 recorded heat waves, 1 recorded cold wave)
	Total deaths: 1 096. Total damages: 1.2 billion USD

Source: CRED, 2024; Seddeek, 2023

According to NASA (2024) and IPCC (2021), the estimations of future climate projections that will have a significant impact on urbanization, particularly in coastal areas, suggest that the increase could potentially reach 2.1°C to 3.5°C, and the UNDP report predicts that sea levels will rise by 20 to 50 cm as a result of the rapid melting of ice sheets due to high temperatures (Parry et al., 2007). By 2100, the Mediterranean Sea level is predicted to increase by 1.1 meters, and the infrastructure and buildings in local government areas and coastal areas will be most severely impacted (Elhamed, 2021; Wales et al., 2012). The Egyptian north coast, located on the Mediterranean Sea, is home to millions of people and has seen significant investments in the industrial, tourism, and agricultural sectors. It mainly affects the following five cities: Alexandria, Port Said, Damietta, Burllus, and Rashid; therefore, they were chosen as study areas (GOPP, 2024).

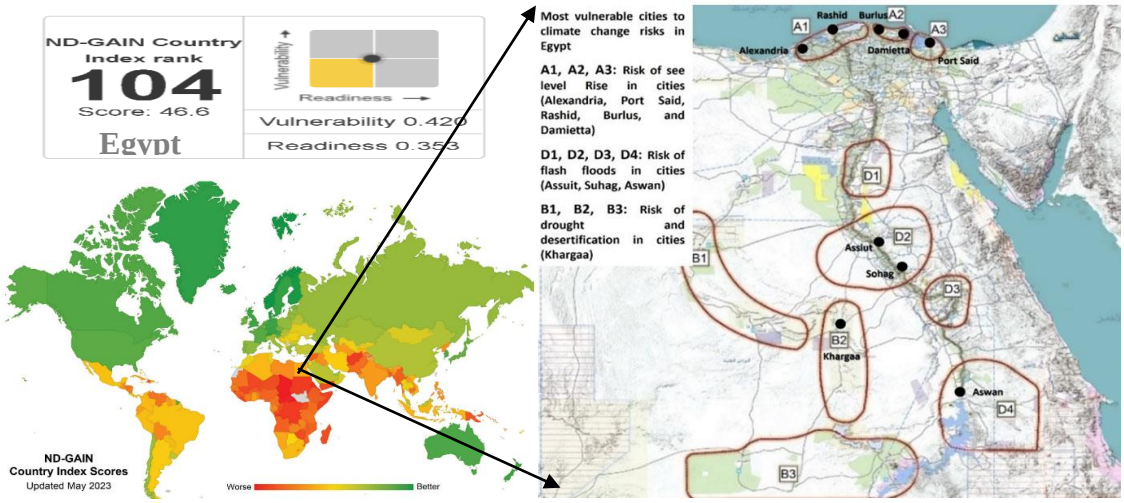

Figure (1): The ND-GAIN Index Egypt rank and Cities classified based on different climate change risks

Source: Univ of Notre Dame, 2023 and Authors depending on GOPP, 2024

In addition, the Nile Valley is one of the world's three most vulnerable hotspots to flash floods; recent examples of such hazards include the November 2021 floods in the Aswan Governorate caused by heavy rains. A total of 1,100 people (220 families) who lost their houses due to complete damage were hosted in 220 temporary residences run by the local authority of Aswan Governorate, while 4,685 people (937 families) refused to leave their partially damaged houses (ReliefWeb, 2021). In addition, flooding events occurred in 2017 and 2020 across Egypt, particularly in Sohag and Assiut governorates, which were also caused by heavy rains. The estimated number of affected people was 20,000 (4,000 families), with at least 40 people dead (ReliefWeb, 2020). Therefore, these three cities (Aswan, Sohag, and Assiut) were also chosen in addition to the five previous cities. A ninth city was also selected (see Fig. 1), which is the city of Kharga

(New Valley), as it is exposed to heat waves, desertification, water scarcity, and the encroachment of dunes on agricultural lands (GOPP, 2024).

3. Materials and Methods

There are seven steps to the process of this study (Fig. 2). The first step is the introduction with an explanation of the goal and the problem of the study, in addition to the review of earlier studies and indices linked to the hazards of climate change to get the essential dimensions and indicators to be measured to reach the perfect AGI composition. The second is exploring the study area to select cities at risk that will be tested. The third is about variable selection, and experts from different backgrounds use the online questionnaire method to give their opinions on the proposed indicators to measure and whether other indicators should be measured. The fourth step is to collect data. The Analytical Hierarchy Process (AHP) will be employed to pinpoint the essential components and indicators, adhering to pre-established standards; it will be the fifth step. The sixth step is structuring the AGI and calculating results through computed vulnerability and readiness scores using the ND-GAIN tool. The seventh and last step presents the findings in the context of nine Egyptian cities that are vulnerable to climate change risks and in light of data-driven decision-making.

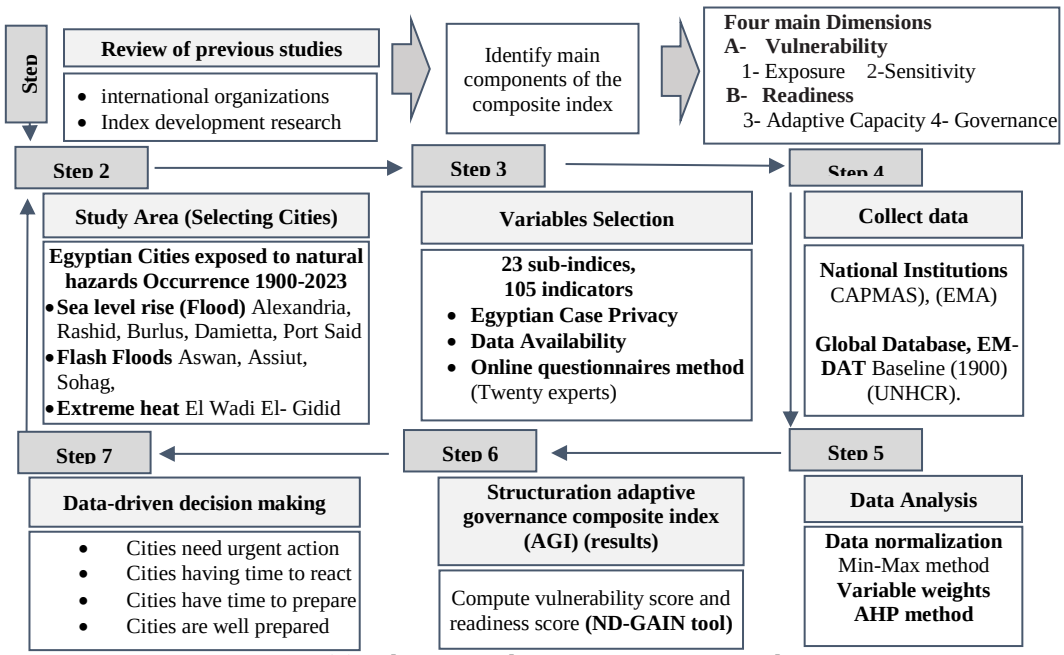

Figure (2): The research process. Source: Authors

3.1 Indicators Selection

In this study, the criteria for selecting indicators were as follows: First, since adaptation to external shocks and stresses leads to further development, governance, and adaptive capacity were identified as representative factors of urban resilience. However, vulnerability assessment through natural hazards, epidemics, air quality, and human-made disasters such as road accidents, occupational injuries, and solid waste, in addition to socio-economic vulnerability, factors of poverty, illiteracy, and marginalized groups. Second, indicators should reflect the specificity of the spatial, urban, natural, social, and administrative region characteristics and factors. Third, indicators were identified based on the availability of data that practitioners can easily collect and evaluate. Fourth, the aim was to develop an index that compares before and after the implementation of risk management projects, Such as environmental projects, infrastructure, social and economic protection projects, and sustainable urban planning.

Accordingly, the study defines the AGI by vulnerability status synthesis based on risk exposure and sensitivity to the negative impact of climate change, in addition to the system's readiness state based on its governance and adaptive capacity to leverage investments and convert them into adaptation actions. The AGI will point to cities that need urgent intervention according to negative values in hazards, vulnerability, and positive readiness values to confront hazards (see Table 3). AGI measures overall vulnerability by considering two essential indices (exposure and sensitivity) in addition to thirteen sub-indices, which are extreme heat, flood disasters, water quality and wastewater, air quality, epidemics, accidents, and work injuries, hazards, population demography, refugees, illiteracy, women's vulnerability, child vulnerability, elderly vulnerability, and poverty. The previous thirteen sub-indices will be detailed by measuring 60 indicators.

AGI measures overall readiness by considering two main indices (Adaptive Capacity and Governance) in addition to ten sub-indices, which are education, health, employment, housing, infrastructure, land cover, crisis management strategies, participation in decision-making, and government effectiveness. The previous ten sub-indices will be detailed by measuring 45 indicators (see Table 3). Twenty experts with a range of backgrounds and specialisations, including policymakers, academics, and practitioners, respond to the online questionnaire to choose the weights based on the relative relevance of each variable and to choose the indicators that comprise the composite index based on their influence. Based on the results of the questionnaire analysis. Of these, 15% were practitioners and engineering consultants, 15% were policymakers and executive bodies, and 70% were academics. Figure 3 illustrates the distribution of years of experience by category: over 20 years (55%), from 15 to 20 years (30%), and under 15 years (15%).

Figure (3): Field of expertise (left panel), and Years of experience (right panel)
Source: Authors

The consensus among the experts is that all the indicators are valid, sufficient in quantity, and encompass a range of aspects. Some have suggested raising some of the governance aspect's indicators, like population participating in activities, ability to express needs, number of local government registered volunteers, and number of outdoor community places, but they were left out since there isn't enough data to measure them. To gauge the degree of advancement made in the governance aspect of mitigating the dangers associated with climate change, some experts have also suggested that effort needs to be made to update these indicators and their findings regularly.

3.2 Collection of Data

First, exposure indicators were collected through the Egyptian Meteorological Authority (EMA, n.d), which includes temperature data, rainfall rates, and levels of gases affecting air quality. Data on flood risk levels was also collected through the World Bank's website on climate change.

Table 3. Major composite indices are detailed with sub-indices and indicators

Vulnerability				Readiness			
Exposure		**Sensitivity**		**Adaptive Capacity**		**Governance**	
E1- Extreme Heat (20%)		**S1-Poverty and Social Protection Programs (20%)**		**A1- Education (20%)**		**G1- Crisis Management Strategies (40%)**	
E1.1 MAX temperature	° C	S1.1National poverty line		A1.1 People with higher education		G1.1 Existence of local city strategies targets the reduction of impacts of floods	
E1.2 Intensity hot months over 40c	NO.	S1.2 Beneficiaries of Takaful	%	A1.2 Master's degree	%	G1.2 climate change adaptation plans	
E1.3 Average precipitation	mm	S1.3 Beneficiaries of Karama		A1.3 Ph.D. holders		G1.3 Existence of governmental disaster management structure	
E1.4 Days with rainfall (≥ 1.0 mm)	NO.	S1.4 Value outgoing Takaful &Karama	L.E	A1.4 Schools equipped for disabilities people		G1.4 Existence of flood early warning systems	YES /NO
E2- Flood Disasters (20%)		**S2-Count Refugees (10%)**		A1.5 Spent on vocational training	LE	G1.5 Existence of awareness campaigns for floods held by the government	
E2.1 Coastal flood	LEVEL	S2.1 Syrians		**A2- Health (20%)**		G1.6 Existence of evacuation centers in the strategic plan	
E2.2 Urban flood		S2.2 Sudanese	%	A2.1 Deliveries supervised by specialists	%	G1.7 Existence of the city's dependency on external supporters	
E2.3 River flood		S2.3 Other nationalities		A2.2 Mortality children under 5 years 1000 births		**G2- Government Effectiveness (30%)**	
E3- Water Quality & Wastewater (15%)		**S3- Population Demography (20%)**		A2.3 Neonatal mortality 1000 births	Rate	G2.1 Employed public administration, defense, social solidarity	
E3.1 Water samples not matching for production stations	%	S3.1 Population density		A2.4 Doctors per10,000 residents		G2.2 Employed social work	%
E3.2 Water samples not matching for distribution networks		S3.2 Marriage contracts		**A3- Employment (15%)**		G2.3 Employed administrative activities & support services	
E3.3 Sewage treatment		S3.3 Divorce cases	Rate	A3.1 Males unemployment		G2.4 Mobile Clinics	NO
E4- Air Quality (15%)		S3.4 Natural increase		A3.2 Females unemployment	%	**G3- Participation in Decision-Making (30%)**	
E4.1 PM 2.5	Microgram/m2	S3.5 Deaths		A3.3 Total unemployment		G3.1 Ability to access governmental information related to floods	(Y/N)
E4.2 PM 10		**S4- Illiteracy (15%)**		A3.4 Small businesses	NO	G3.2 Women's participation in the labor force	%
E4.3 NO2		S4.1 Males illiteracy	%	A3.5 Fund (Mil) L.E	L.E	G3.2 Population participating in activities	
E4.4 SO2		S4.2 Females illiteracy		A3.6 Job opportunities	NO	**3 sub-indices**	
E4.5 CO		S4.3 Total illiteracy		**A4- Housing (15%)**		**Total 14 indicator**	
E4.6 O3		**S5- Women's Vulnerability (15%)**		A4.1 Average size of household	Rate	**Source**: selected indicators by comprehensively reviewing previous studies based on **international programs:** United Nations, IPCC and INFORM Risk2024 OECD: Climate adaptation and resilience World Bank: Adaptive Social Protection: Building Resilience to Shocks**, In addition to the following research**: (Venkataswamy, S., et al., 2023), (Kim, B et al., 2023), (Buchir and Detzel, 2023), (Marzi, S et al., 2018), (Andrijevic, M et al., 2020).	
E5- Epidemic (10%)		S5.1 Women make decisions alone	%	A4.2 Overcrowding rate Person/ room			
E5.1 Typhoid fever		S5.2 Mothers who received pregnancy care before their last child		A4.3 Buildings requires demolition			
E5.2 Hepatitis (A)		S5.3 Girls aged 0-19 circumcised women		A4.4 Buildings need major renovation			
E5.3 Hepatitis (B)	%	S5.4 Women exposed to physical violence		A4.5 Residents of unsafe slum areas	%		
E5.4 Hepatitis (C)		**S6- Child Vulnerability (10%)**		A4.6 households that have a bathroom			
E5.5 Viral hepatitis		S6.1 Pop under15 years	%	**A5- Infrastructure (15%)**			
E5.6 Malaria		S6.2 Children exposed to corporal punishment		A5.1 Water connected			
E5.7 Deaths to admissions cases	Rate	S6.3 Children have All vaccinations		A5.2 Sanitary connected			
E6-Accidents & Work Injuries (10%)		S6.4 Child early development index		A5.3 Electric connected	%		
E6.1 Death road traffic accidents per 100,000	Rate	S6.5 Children suffering from anemia		A5.4 Gas connected			
E6.2 Work injuries		**S7- Elderly Vulnerability (10%)**		A5.5 Internet connection			
E6.3 ambulance cases for traffic accidents	%	S7.1 Pop +60 years	%	A5.6 Paved roads length	km		
E7-Hazardous Waste (10%)		S7.2 Elderly club hostels		**A6- Land Cover (15%)**			
E7.1 Generated hazardous waste	Ton / Year	S7.3 Elderly club existing		A6.1 Zoos and aquarium gardens area	Km 2		
E7.2 Amount of treated hazardous medical waste		S7.4 Elderly care foundations hostels	NO	A6.2 Botanical gardens and parks	NO		
E7.3 Waste from canals and drains	m3/ Year	S7.5 Elderly care foundations existing		A6.3 Botanical gardens and parks area	Km 2		
E7.4 Municipal wastes	Ton/ Day						
E7.5 Recycled Amount	%						
7 sub-indices		**7 sub-indices**		**6 sub-indices**			
Total 31 indicator		**Total 29 indicator**		**Total 31 indicator**			

Data related to water quality, sanitation, and municipal waste are from the Central Agency for Public Mobilisation and Statistics (CAPMAS), in addition to data on chronic and infectious diseases, road accidents, work injuries, and medical waste from the Egyptian Ministry of Health website. Secondly, sensitivity indicators were collected through the CAPMAS, which includes data on poverty, the Takaful & Karama "Solidarity and Dignity" program, illiteracy, and demographics, in addition to data on marginalized groups (women, elderly, and childhood), while refugee data was collected through the website of the United Nations High Commissioner for Refugees (UNHCR). Third, CAPMAS provides information on land coverage, employment and unemployment rates, infrastructure, education, health, and housing, as well as indicators of adaptive capacity. The list is supplemented with CAPMAS data on rates of participation in decision-making, employment rates within local administrations, governance indicators, and details on crisis management strategies drawn from local city administrations.

3.3 Data Normalization

Standardization took into consideration the functional relationship between indicators and adaptive capacity because each principal component consists of numerous diverse variables and different indicators measured on various scales (Mainali and Pricope, 2018). Two standardization techniques were used. Equation (1) has been used to standardize the following indicators, which are expected to have a direct relationship with adaptive capacities: higher education, good governance, developed infrastructure, adaptation strategies, etc. Equation (2) has been utilized to standardize the indicators that are expected to have an inverse relationship with adaptive capacities. These indicators include illiteracy, unemployment, marginalized groups (elderly people and women), the spread of epidemics, unplanned slum areas, etc.

$$index_{Sw} = \frac{Sw - Smin}{Smax - Smin} \qquad \text{Eq. 1}$$

$$index_{Sw} = 1 - \frac{Sw - Smin}{Smax - Smin} \qquad \text{Eq. 2}$$

Where Sw is the observed (average) value of the indicator, min and max are the minimum and maximum values of the indicator, respectively, and $index_{Sw}$ is the standardized value for the indicator (Kim, B et al., 2023).

3.4 Variable weights (AHP) method

The most popular approach for effective multi-criteria structuring and decision-making (MCDM) is AHP. A reciprocal pair matrix is created by comparing criteria and giving each relationship a relative priority weight based on a nine-point rating system (Saaty, 2006). As two criteria are compared at a time, this simplifies the problem. The primary eigenvector of the matrix yields the weights of the criteria following these comparisons. Experts were asked to complete the questionnaire by assigning weights to criteria on a nine-point scale derived from the comparison matrices. Following the questionnaire completion, the IDIRSI SELVA 17 software was used to create hierarchical conceptual models of the criteria. This process automatically produced a list of pairwise comparisons that were necessary to display the weights in the spreadsheet.

Table 4. Fundamental AHP judgment scale

Numerical rating	1	3	5	7	9
Verbal Judgement	Equal	Moderate	Strong	Very strong	Extreme

Source: Saaty, T.L. (2006).

3.5 (AGI) Index Structure

Once each indicator was standardized and weights were determined for each variable, the average value of the 23 components of the sub-indices was calculated using Equation (3) (Pandey and Jha, 2012).

$$(\mathrm{E1}) = \sum_{i=1}^{n} EW_i/n \qquad \text{Eq. 3}$$

Where E1 is one of the 23 sub-indices components of (AGI) index, W_i represents the indicators component of sub index E1 and n is the number of indicators. After values for each of the 23 sub-indice components were calculated, the four main dimensions; Exposure Index (EI), Sensitivity Index (SI), Adaptive capacity Index (AI) and Governance Index (GI) were obtained from the weighted average of the sub-indices as Equation (4,5,6,7) (Buchir and Detzel, 2023):

$$\text{Exposure Index (EI)} = \frac{(\mathrm{E1}*20)+(\mathrm{E2}*20)+(\mathrm{E3}*15)+(\mathrm{E4}*15)+(\mathrm{E5}*10)+(\mathrm{E6}*10)+(\mathrm{E7}*10)}{7*100} \qquad \text{Eq. 4}$$

$$\text{Sensitivity Index (SI)} = \frac{(\mathrm{S1}*20)+(\mathrm{S2}*10)+(\mathrm{S3}*20)+(\mathrm{S4}*15)+(\mathrm{S5}*15)+(\mathrm{S6}*10)+(\mathrm{S7}*10)}{7*100} \qquad \text{Eq. 5}$$

$$\text{Adaptive capacity Index (AI)} = \frac{(\mathrm{A1}*20)+(\mathrm{A2}*20)+(\mathrm{A3}*15)+(\mathrm{A4}*15)+(\mathrm{A5}*15)+(\mathrm{A6}*15)}{6*100} \qquad \text{Eq. 6}$$

$$\text{Governance Index (GI)} = \frac{(\mathrm{G1}*40)+(\mathrm{G2}*30)+(\mathrm{G3}*30)}{3*100} \qquad \text{Eq. 7}$$

It is now possible to calculate the level of vulnerability from the first and second dimensions, exposure and sensitivity, and the level of readiness from the third and fourth dimensions, adaptive capacity and governance, as in Equation (8,9) (Buchir and Detzel, 2023).

$$\text{Level of Vulnerability} = \frac{(\mathrm{EI})+(\mathrm{SI})}{2} \qquad \text{Eq. 8}$$

$$\text{Level of Readiness} = \frac{(\mathrm{AI})+(\mathrm{GI})}{2} \qquad \text{Eq. 9}$$

Finally, Adaptive Governance composite Index (AGI) is calculated, as in Equation (10) (Buchir and Detzel, 2023). $\text{Adaptive Governance composite Index (AGI)} = \text{level of Readiness} - \text{level of Vulnerability}$ Eq. 10

4. Results

Exposure is the first main indices, with 7 sub-indices, the value of each one ranging from the lowest 0.00 up to the highest 1.0. Considering the highest level of exposure, Sohag is at the highest rank of exposure, Rashid comes next at 0.92, Aswan and Alexandria scored 0.88, and Port Said is the lowest exposure city as it scored 0.63 (see Fig. 4 and Table 5).

Regarding the indices of sensitivity, Assuit and Sohag ranked highest, scoring 0.93 and 0.90, respectively. Port Said was the least sensitive city in the rank, scoring 0.27, which is better than Damietta, which scored 0.32, and Khargaa, which scored 0.36. Regarding Sohag and Assuit, women and child vulnerability are the highest scored values, and in Port Said, refugees scored zero and illiteracy 0.07 (see Fig. 4 and Table 5).

In terms of adaptive capacity, Alexandria ranked first, while Port Said ranked penultimate with scores of 0.69 and 0.39, respectively. Alexandria, as a metropolitan city, scored high values in indicators of land cover, housing, and infrastructure, in addition to education. Port Said scored the lowest value at 0.39, coming last after Khargaa, which scored 0.41. The governance sub-indices show Alexandria and Rashid

ranked first and second with the highest scores at 0.74 and 0.58, respectively, while Assuit and Sohag were the lowest-scoring cities with 0.16 and 0.19 in a row (see Fig. 5 and Table 5).

Table 5. The values of exposure, vulnerability, capacity, and governance accompanied AGI

	Alex	Behera (Rashid)	Kafr El-Sheikh (Burlus)	Damietta	Port Said	Assiut	Sohag	Aswan	Khargaa
Extreme Heat	0.1	0.4	0.34	0.1	0.1	0.72	0.86	0.98	0.86
Flood Disasters	1	1	0.88	0.75	0.75	0.44	0.5	0.5	0.19
Water Quality & Wastewater	0.22	0.49	0.5	0.3	0.67	0.53	1	0.57	0.53
Air Quality	0.82	0.43	0.45	0.51	0.55	0.39	0.46	0.23	0.47
Epidemic	0.25	0.24	0.61	0.29	0.16	0.34	0.24	0.16	0.09
Accidents & Work Injuries	0.81	0.3	0.14	0.42	0.26	0.24	0.14	0.18	0.1
Hazardous Waste	0.79	0.76	0.5	0.43	0.19	0.46	0.69	0.56	0.49
Exposure	**0.88**	**0.92**	**0.84**	**0.64**	**0.63**	**0.78**	**0.94**	**0.88**	**0.69**
Population Demography	0.92	0.31	0.36	0.55	0.61	0.43	0.42	0.28	0.32
Count Refugees	1	0.02	0.01	0.17	0	0.01	0.01	0.08	0
Illiteracy	0.3	0.92	0.72	0.36	0.07	1	0.83	0.28	0.08
Women's Vulnerability	0.28	0.36	0.4	0.15	0.27	0.69	0.87	0.59	0.53
Child Vulnerability	0.59	0.55	0.75	0.62	0.64	0.75	0.87	0.62	0.49
Elderly Vulnerability	0.68	0.05	0.26	0.14	0.66	0.14	0.06	0.05	0.12
Poverty and Social Protection Programs	0.2	0.55	0.54	0.1	0.01	0.76	0.67	0.36	0.25
Sensitivity	**0.53**	**0.69**	**0.66**	**0.32**	**0.27**	**0.93**	**0.9**	**0.5**	**0.36**
Vulnerability	**0.71**	**0.81**	**0.75**	**0.48**	**0.45**	**0.86**	**0.92**	**0.69**	**0.53**
Education	0.76	0.17	0.25	0.21	0.43	0.37	0.41	0.27	0.2
Health	0.42	0.54	0.72	0.74	0.59	0.28	0.43	0.49	0.61
Employment	0.4	0.65	0.68	0.38	0.01	0.75	0.93	0.4	0.45
Housing	0.79	0.69	0.78	0.72	0.66	0.65	0.45	0.57	0.44
infrastructure	0.78	0.63	0.73	0.92	0.36	0.4	0.54	0.53	0.53
Land Cover	1	0.17	0.03	0.04	0.28	0.12	0.29	0.13	0.23
Adaptive Capacity	**0.69**	**0.54**	**0.61**	**0.56**	**0.39**	**0.54**	**0.58**	**0.44**	**0.41**
Crisis Management Strategies	0.71	0.14	0.43	0.29	0.43	0	0.14	0.43	0.14
Participation in Decision-Making	0.75	0.85	0.46	0.64	0.75	0.09	0	0.39	0.83
Government Effectiveness	0.75	0.75	0.48	0.13	0.07	0.4	0.42	0.28	0.05
Governance	**0.74**	**0.58**	**0.46**	**0.35**	**0.42**	**0.16**	**0.19**	**0.37**	**0.34**
Readiness	**0.72**	**0.56**	**0.54**	**0.46**	**0.41**	**0.35**	**0.39**	**0.41**	**0.38**
AGI	**0.01**	**-0.25**	**-0.22**	**-0.03**	**-0.05**	**-0.51**	**-0.54**	**-0.29**	**-0.15**

Source: Authors

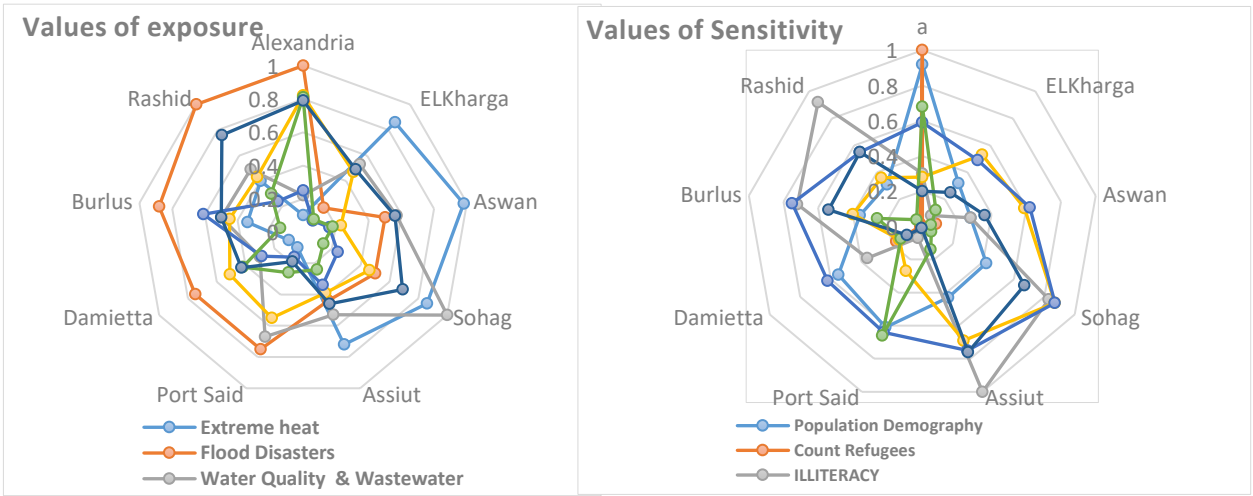

Figure (4): Values of exposure sub-indices (left panel) and values of sensitivity sub-indices (right panel). Source: Authors

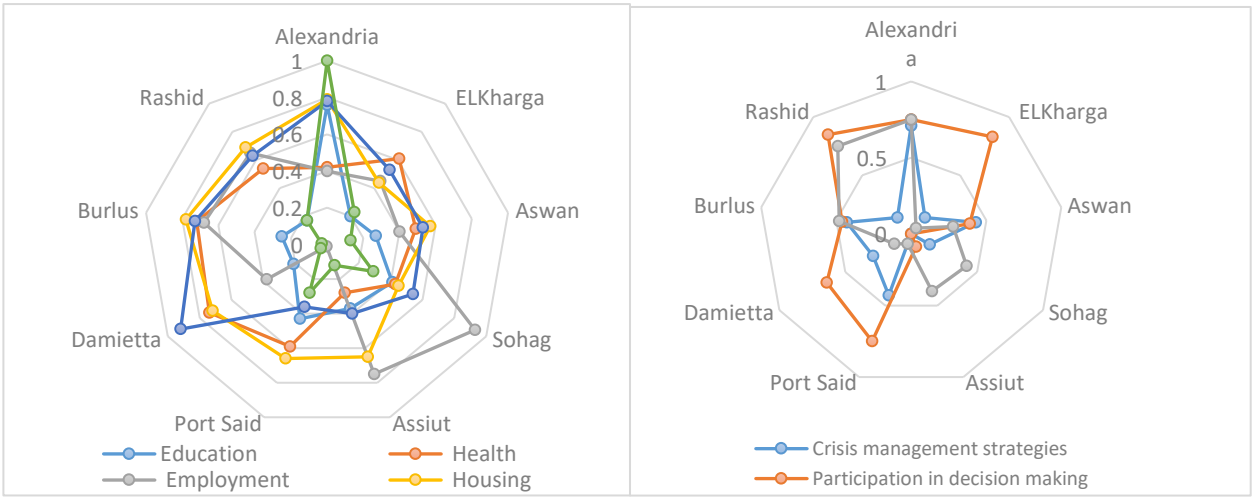

Figure (5): Adaptive capacity sub-indices values (left panel) and values of governance sub-indices (right panel).
Source: Authors

By using the values of exposure and sensitivity, vulnerability is taking place as a major index in addition to readiness, which accompanies the indices of adaptive capacity and governance. Figure 6 shows that Sohag and Assuit are the most vulnerable cities, while Port Said is the lowest. Alexandria is the readiest city, while Assuit and Sohag are the least ready cities.

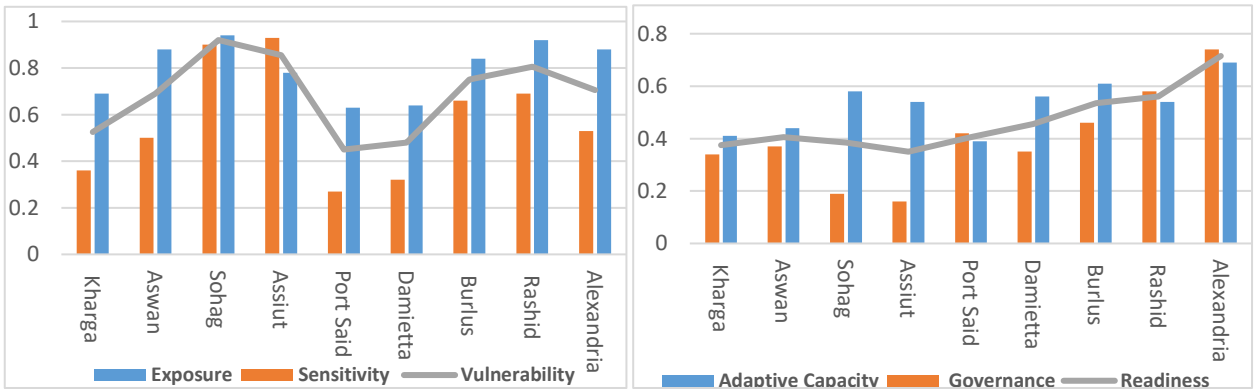

Figure (6): Values of exposure and sensitivity accompanied by vulnerability (left panel) and values of adaptive capacity and governance accompanied by readiness average (right panel).
Source: Authors

By comparing the values of vulnerability and readiness, vulnerability values are higher than readiness values. The only case against that is Alexandria, which makes it the only city with a positive value on the AGI (see Fig. 7), supporting a reasonable interpretation. Nevertheless, the city's government still needs to do a lot of work to improve its preparedness for handling the high value of risk vulnerability. Alexandria is a metropolitan area with several municipalities and tiers of government, giving it better capability and governance than other cities. The remaining cities' AGI values are negative, such as Assuit and Sohag, both in upper Egypt and noted for having low development indicators. In addition to having the highest level of poverty and the lowest level of participation in decision-making, this makes the government less ready and faces many challenges due to weak abilities. Cities like Damietta and Port Said, with more work on enhancing government effectiveness and crisis management strategies, will have a positive impact on the AGI value.

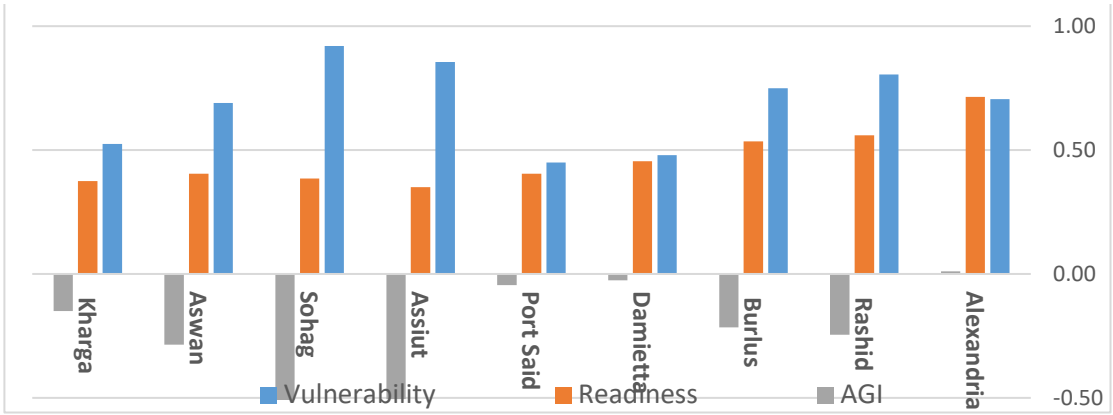

Figure (7): The values of city vulnerability and readiness, accompanied by AGI
Source: Authors

5. Discussion

Since cities are most vulnerable to climate change hazards, the AGI is an attempt to create a multidimensional composite index that suits Egyptian cities since each country needs a different model for adaptation. The development of the AGI depends more on the usage of a sufficient number of indicators to create reliable and applicable results compared to the other studies, especially in the area of governance and adaptive government. The indicators list was revised by twenty experts in various domains who only responded to the online questionnaire from 38 trials, but according to the data availability limitation, the suggested indicators could not be measured, such as population participating in activities, ability to express needs, number of local government registered volunteers, and number of outdoor community places, and were excluded from the final indicators list. The final 105 indicators were measured using the IPCC method to estimate missing data, and the AHP approach was used to aggregate and weight the normalized indicator scores. Normalization procedures were based on the min-max method to represent four primary indices (exposure, sensitivity, adaptive capability, and governance). Nine cities were involved in the test; three were vulnerable to flash floods, five to land submergence, and one to drought and desertification. Alexandria is the only city's AGI that displays positive values; the other cities' AGIs display negative values.

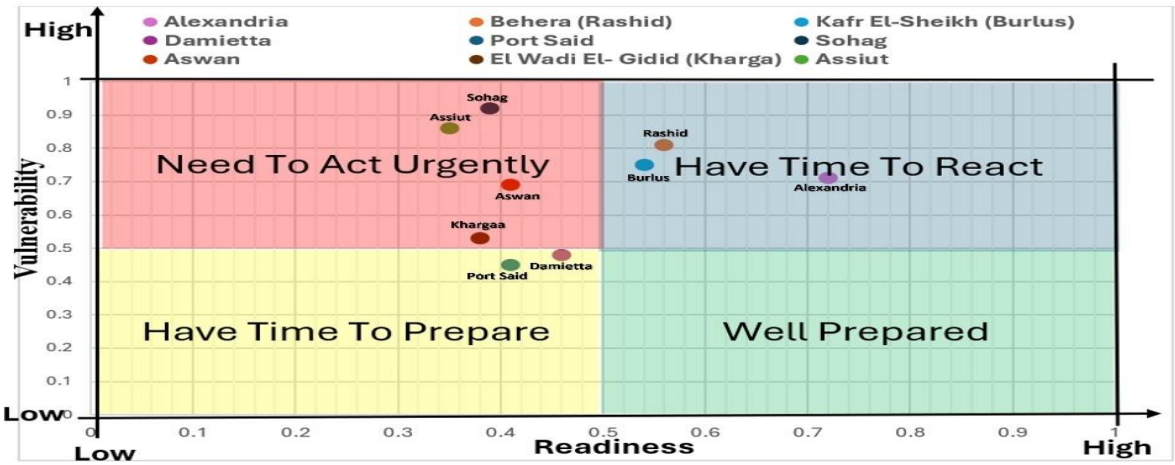

Figure (8): Combination of vulnerability and readiness to obtain the current status of cities in terms of reacting to the negative impact of climate change
Source: (adapted from Buchir and Detzel, 2023)

AGI could apply to many cities with different criteria and risks, as it can guide the authorities to take the proper procedures to confront the different hazards. Figure 8 shows the condition of the nine cities according to their recent levels of vulnerability and readiness. No city is well prepared, while Port Said and Damietta have time to prepare in addition to Alexandria, Rashid, and Burlus having time to react, but the cities of Sohag, Assuit, Khargaa, and Aswan need urgent action. This could help the government bodies and decision-makers take the needed interventions according to the measures that need improvement.

6. Conclusion

The study emphasizes the significance of data and monitoring in assessing climate vulnerability. A wide range of measures is essential to grasping the numerous dimensions of vulnerability (Guillaumont, 2024), and the absence of one measure or more may lead to a doubtful outcome in assessing climate vulnerability (Marzi, S. et al., 2018). It also showed that governance plays a role in identifying adaptation needs and managing institutions to improve policies and develop strategies that include climate change. In this regard, the launched in 2022 of the National Climate Change Strategy Egypt 2050. These are long-term national plans that seek to avoid the negative impacts of climate change and support the Sustainable Development Goals of 2030 (UNFCCC 2023). It improved Egypt's readiness score in the ND-GAIN index by seven places, from 129 in 2022 to 122 in 2023 (World Bank, 2023). The third objective of the strategy stipulates improving governance and management of climate change work by strengthening institutional, procedural, and legal arrangements such as the monitoring, reporting, and verification system, reforming sectoral policies necessary to accommodate the required interventions, and defining the roles and responsibilities of different stakeholders to achieve the strategic objectives. However, the mechanisms and means of implementing the national strategy at the local level still pose challenges, as confirmed by the study results, which revealed significant differences in governance indicators, especially between the North Coast and the South Valley cities. This highlights the importance of having a regular mechanism, such as the National Environmental Monitoring Program; this is also important for implementation at the local level. Accordingly, improving the approach to identifying indicators is essential for decision-makers and stakeholders. In addition, cooperation between different data producers to introduce qualitative measures that illustrate the effects of climate change response measures and projects and continuous monitoring to improve local governance strategies for cities is essential to obtaining a long-term vision for achieving climate resilience.

Abbreviations

Egypt's Nationally Determined Contributions (ENDC), The United Nations Development Programme (UNDP), Organisation for Economic Cooperation and Development (OECD), Intergovernmental Panel on Climate Change (IPCC), United Nations Framework Convention on Climate Change (UNFCCC), Livelihood vulnerability index (LVI), Multidimensional Vulnerability Index (MVI), The Notre Dame Global Adaptation Initiative (ND-GAIN), Small Island Developing States (SIDS), Egyptian Meteorological Authority (EMA), Central Agency for Public Mobilisation and Statistics (CAPMAS), United Nations High Commissioner for Refugees (UNHCR).

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