



## Proceedings of the Resilient Cities 2014 congress

### Session F2: Filling data gaps to address flooding in coastal cities

#### **Assessing resilience of the Nile Delta urban centers to sea level rise impacts**

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#### **Abstract:**

The Nile Delta in Egypt is considered to be one of the most vulnerable areas to climate change and associated sea level rise globally. Nile Delta coastal cities, with a high concentration of population, economic activities, infrastructure and services, are hotspots to such exposure. This paper assesses the resilience of cities in the Nile Delta coastal area to sea level rise impacts, focusing on inundation as one of the most significant physical impacts. The paper considers these cities within their hinterland context, rather than in isolation.

To assess the resilience of the Nile Delta's urban centers to sea level rise impacts, a composite resilience index is proposed. By integrating multiple physical and socioeconomic factors that determine urban resilience, this index highlights variations in resilience between the various urban centers. The varied levels of resilience demonstrated between urban centers in the Nile Delta are related to different levels of physical vulnerability and varied socioeconomic conditions.

#### **Keywords:**

Climate change, Sea level rise (SLR), City resilience, Nile Delta

## 1. City resilience: Concept and context

### 1.1 Concept

Human settlements are often concentrated in coastal areas due to potential economic benefits including for instance coastal tourism, marine trade, and concentration of natural resources. It is estimated that as much as 40% of the world's population lives within 100 km of the coast (SEDAC, Undated). The relatively high population density and concentration of economic activities in these areas have, however, created significant pressure, on coastal environments and ecosystems through pollution and over-exploitation of natural resources (Grenon & Batisse 1989; di Castri *et al.* 1990).

Coastal cities are exposed to compounding risks of climate change in general and sea level rise (SLR) in particular. Their resilience needs to be improved through low-regret measures such as enhancing population resilience through economic, human and social development actions. This can reduce potential damage from environmental hazards, e.g. SLR, while generating benefits to urban communities. This is especially true as rapid population growth and urbanization, as experienced in developing countries, may increase the exposure of communities and infrastructure to climate change impacts and SLR in particular.

Researchers and climate practitioners have made many attempts to define and identify the main elements of resilience in general and those of resilient cities in particular. For instance, the IPCC, in its Third Assessment report, defined resilience as the “amount of change a system can undergo without changing state” (IPCC, WGII, 2001, p. 943). A more detailed definition, provided by the AR5 of the IPCC defined resilience as “the capacity of a social-ecological system to cope with a hazardous event or disturbance, responding or reorganizing in ways that maintain its essential function, identity, and structure, while also maintaining the capacity for adaptation, learning, and transformation” (Arctic Council, 2013). Similarly, resilience is defined as “*the ability of a system to withstand or accommodate stresses and shocks such as climate impacts, while still maintaining its function*” (Dickson et al., 2012, p. 18).

### 1.2 City resilience: Conceptual framework

Urban centres consist of interdependent dynamic systems that involve infrastructure, housing, ecosystems, institutions and knowledge networks. In turn, the functioning of such systems are influenced by a wide range of interacting actors including civil society, households, private and public sectors (Dickson, et al, 2012). These urban systems perform functions, which provide goods and services to ensure the wellbeing of their citizens. Urban resilience, in this context, is thus associated with the resilience of both these systems and also the various actors involved.

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Correspondingly, resilience of cities, whereby cities are viewed as dynamic systems themselves, is concerned with the ability of such systems to support the provision and accessibility to services and functions essential for the wellbeing of all citizens, especially those lacking the means to buffer stresses (Dickson et al., 2012). Resilience in an urban context means the capacities of urban units to establish priorities and mobilize resources, as well as their ability to absorb the cumulative effects of outside shocks. A resilient system has key assets and functions distributed so that they are not all affected by a given event at any one time (locational diversity) and multiple ways of meeting a given need (functional diversity) (Dickson, et al, 2012).

Cities are not single entities, but rather they form part of a “system of cities” (Ernstson et al., 2010). We’d like to take this notion a step further by suggesting that:

1. Each city represents a dynamic system in which various components interact with each other within its boundary;
2. A group of cities in an area represent an interrelated network, with positive and/or negative influences; and
3. The city system and the network of cities are functioning within a much wider context that incorporates ecosystems and other economic activities supplying cities with needed resources. For instance, cities resilience would depend on the resilience and productivity of nearby agricultural land for ensuring continuous supply of foodstuff and raw materials to economic activities.

This means that the resilience of cities cannot be considered in a vacuum, but rather within the context they operate.

Below are some examples of how contextual factors influence city resilience:

- Lack of basic services coupled with overcrowded living conditions, typically prevalent in informal areas located in peripheral areas of cities; reduce further the resilience of the urban poor.
- Resilience is greatly influenced by the quality of urban governance and the level of infrastructure and services provided by the government (Prasad et al., 2009). The coverage of infrastructure and basic services is repeatedly employed to represent the quality of urban life. Rather, the quality of the provided infrastructure and services is more appropriate than the coverage proportions. Institutional governance, whether formal and/or informal, including participatory practices, may contribute to increased and/or decreased urban resilience.
- Resilience is also adversely affected by the deteriorating quality of the urban environment, due to pollution and overexploitation of natural resources.

Improving coastal cities’ resilience through low-regret measures are challenged by city officials and the urban poor who frequently suggest that challenges facing urban areas at present are difficult enough

without considering the uncertain risks associated with climate change (Hoornweg et al., 2011). This argument, however, ignores two aspects; on one hand that taking no action at present can limit the potential for adopting no-regret measures and also the potential co-benefits to urban population in general and the poor in particular, on the other.

## **2. The study area: Nile Delta coastal area**

Egypt in general and the Nile Delta in particular, have undergone rapid population growth and urbanization during the last five decades. Between 1947 and 2006, Egypt's population more than tripled from about 19 to 72 million. This trend was accompanied by continuous growth in the urban population during the same period, from 6.4 to 31 million people, representing 34% to 42.6% of Egypt's total population (CAPMAS, different Censuses).

The main urbanization trends involve Greater Cairo and Alexandria, which are dominating urban growth in absolute numbers. Also, the number and size of small to medium-sized cities is increasing. However, the reduction in the total number of cities over the period 1996-2006 is reportedly due to Census area re-definitions. Generally, the designation of urban areas in Egypt is more about administrative decisions rather than rates of urbanization (Figure 1).

The Nile Delta area, which is the most highly populated area in Egypt, is considered to be one of the most vulnerable areas to climate change and associated SLR. The Nile Delta coastal cities, with the concentration of population, economic activities and infrastructure and services, are hotspots to such exposure.

This paper intends to assess the resilience of cities in the Nile Delta coastal area to SLR impacts, focusing on inundation as one of the most profound physical impacts. In doing this, the paper does not deal with these cities as if they exist and function in a vacuum, but rather within their hinterland (context). Accordingly, in this paper, we focus on urban resilience at two levels: the first is at the city level and secondly the surrounding areas within which they exist.

The Nile Delta shoreline extends approximately 240 kilometers from Alexandria in the west to Port Said in the east and contains three coastal wetlands from east to west—Manzala, Burullus, and Idko—all with access to the sea (El Banna and Frihy 2009).

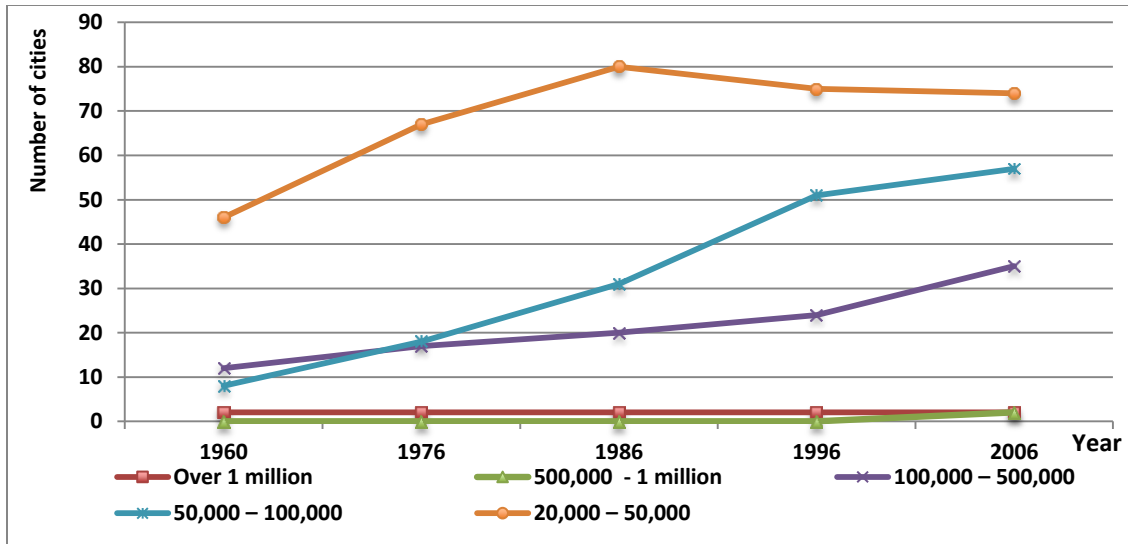


Figure 1: Evolution of Number of Egyptian Cities by Population Size (1960-2006)  
 Source: CAPMAS, 1978, CAPMAS, 1988, CAPMAS, 1998; CAPMAS, 2008

The coastal zone in the Nile Delta region has been experiencing land subsidence movement. Based on a review of studies, rates of subsidence of the Nile Delta during the Holocene Era varied widely along different parts of the northern sections of the Nile Delta, ranging between 0.5 and 4.5 mm/year (Stanley and Warne 1993; Stanley 1997). The highest rates of subsidence during the Holocene were experienced in Manzala Lake and around Damietta and Rosetta Nile branches promontories. Becker and Sultan, in a more recent study, reported similar results (Becker and Sultan 2009).

The Nile Delta coastal zone hosts 18 urban centers located in six different governorates namely Port Said, Damietta, Dakahlyia, Kafr El-Sheikh, Behaira, and Alexandria (Table 1). These urban centers cover an area of about 2879 square kilometers, numbered 6.4 million persons by the year 2006 (CAMPAS, 2008). The total built-up area of these urban centers is estimated to be as much as 631.74 km<sup>2</sup> (Figure 2).

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Table1: Total and built- areas of coastal urban centres

City	Governorate	Total Area (Km <sup>2</sup> )	Total Built-up Area (km <sup>2</sup> )
Alexandria	Alexandria	1491.97	353.06
New Burg EL Arab City		122.95	35.63
Damanhour	Behaira	16.31	13.66
Edku		89.02	52.85
Kafr El Dawar		28.87	7.33
Rosetta		49.68	4.62
Gamasa	Dakahlyia	14.02	5.84
Mansoura		27.47	13.85
Talkha		11.23	4.24
Damietta	Damietta	14.94	7.45
New Damietta		58.87	30.48
Ras El Barr		21.11	4.76
Baltim	Kafr El Sheikh	32.75	2.39
Bialla		39.78	4.68
Dessouk		7.89	4.68
Kafr EL Sheikh		19.83	10.26
Port Said	Port Said	832.23	59.65
Port Fouad		560.69	16.32
Total		2878.91	631.74

Source: Calculated by the authors using the developed GIS

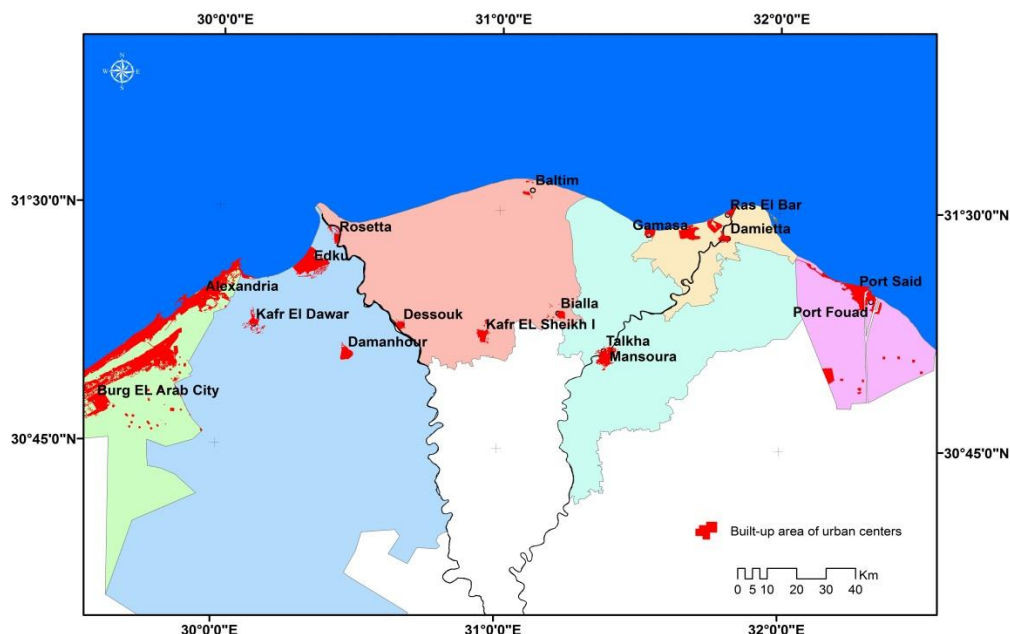


Figure 2: The built-up area of main urban centers in the Nile Delta coastal governorates  
 Source: Developed GIS by the authors

### 3. Methodology

Our assessment of urban resilience to SLR impacts in the Nile Delta coastal zone was conducted according to a three-step methodology:

*Step 1: Identifying underlying determinants of urban resilience:* This encompassed identifying, from the literature, various aspects associated with urban resilience. Thereafter we developed a list of relevant variables that could be employed to assess urban resilience in the Nile Delta coastal area. (Table 2).

Table 2: List of indicators and associated variables to determining urban resilience in the case of the Nile Delta Coastal zone

Aspect	Indicators	Variables
Physical aspects	Physical vulnerability to SLR inundation impacts	<ul style="list-style-type: none"> <li>• Built-up areas;</li> <li>• Infrastructure and services; and</li> <li>• Population susceptible to inundation</li> </ul>
Demographic aspects	Demographic conditions related to adaptive capacity	<ul style="list-style-type: none"> <li>• Household density;</li> <li>• Population growth rates; and</li> </ul>

		<ul style="list-style-type: none"> <li>• Demographic dependency ratio</li> </ul>
Socioeconomic aspects	Socioeconomic conditions related to adaptive capacity	<ul style="list-style-type: none"> <li>• Health status,</li> <li>• Education and income levels of the community; and</li> <li>• Unemployment rate</li> </ul>
Environmental aspects	Environmental quality Natural resources use	<ul style="list-style-type: none"> <li>• Air quality</li> <li>• Water quality</li> <li>• Soil quality</li> <li>• Exploitation of natural resources</li> </ul>
Institutional aspects	Institutional setup Governance	<ul style="list-style-type: none"> <li>• Formal and informal institutional settings;</li> <li>• Capabilities to mobilize various resources to deal with hazards, whether sudden or gradual.</li> </ul>

Step 2: Assessing physical vulnerability of Nile Delta coastal urban centers: This involved identifying the spatial extent of SLR impacts; in particular, inundations, using recent attempts to project rise in sea level at global levels and land subsidence of the Nile Delta area. This is then compared, using a developed Geographical Information System (GIS), to topographic layers in the system to identify areas susceptible to inundation by SLR.

Step 3: Assessing resilience of urban centers in the Nile Delta coastal areas: In order to turn the concept of resilience into a quantifiable term, attempts have been made to develop resilience indices. For instance, Institute of Government Services, Berkeley University (IGS) proposed a resilience index of Metropolitan areas resilience to future challenges, Meanwhile, FAO developed an index of resilience to food security, whereas Rose (2013) suggested an index of business recovery. None of these indices were intended to deal with environmental risks in general or climate change risks in particular (IGS, Undated; FAO, Undated; Rose, 2013).

In order to quantify urban resilience rather than conducting generic resilience assessment, in the case of the Nile Delta , a preliminary composite index was developed to integrate the different factors that determine resilience to SLR impacts. For that purpose the variables identified and estimated during previous steps (1 & 2) above are standardized and integrated into the composite index using an equal weighting scheme.

Assessing and quantifying resilience of these urban areas to SLR using the proposed composite index was constrained by the lack of socioeconomic and demographic data, especially at spatially disaggregated levels, from secondary information sources<sup>1</sup>. Additionally, assessment and integration of

<sup>1</sup> Similar concerns were voiced by other researchers, including for instance Small and Nicholls 2003



institutional aspects, though important in determining the level of city resilience, was constrained by not only the lack of data but also by being more or less uniform among various urban centers in the Nile Delta coastal zone.

Due to such a constraint, eight variables are integrated in the proposed composite index, including proportions of built-up area vulnerable to SLR, vulnerable population size, unemployment, demographic conditions (represented in demographic dependency ratio, annual population growth, and household density), human development index (HDI) (reflecting health, education, income levels in the community), environmental quality (represented in air quality parameters; the concentration of Lead (PB) and Total Suspended Particulates (TSP)), access to services (represented in average access to water, sewage and electricity) .

The above-mentioned variables, except for HDI, which is already standardized, were normalized using the following formula:

$$N_x = \frac{(X - X_{min})}{(X_{max} - X_{min})}$$

Where:

x = absolute value of the variable being normalized

N<sub>x</sub> = Normalized variable

X<sub>min</sub> = Minimum variable value

X<sub>max</sub> = Maximum variable value

This means that the resulting value of each standardized individual variable ranges between 0 and 1, thus describing relative variations of the considered variables within the urban centers.

Finally, the composite resilience index was calculated by combining the seven considered variable using an equal weight scheme (1/7) as follows:

$$R = \sum_{N_x=1}^{N_x=n} \left( N_x \frac{1}{n} \right)$$

Where:

R = Resilience index

N = Number of variables

N<sub>x</sub> = Normalized variable value

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We note that the developed composite resilience index is relative, which means that it mainly highlights variations in resilience levels between the urban centers. This is true also when considering different scenarios, which means that the value of the index cannot be compared across scenarios. The value of the index ranges between 0 and 1 reflecting highest and lowest level of resilience, respectively.

## **4. Results and discussion**

Based upon the above-mentioned methodology, the following presents the results of an assessment of physical vulnerability to inundation by SLR. The demographic, socioeconomic, environmental and institutional aspects associated with cities' resilience are also discussed.

### **4.1. Physical vulnerability aspects**

For the purpose of identifying areas susceptible to SLR, a GIS containing geo database was built for the study area. This consists of numerous feature classes (layers) representing various levels of administrative units and built-up areas in the coastal zone of the Nile Delta in addition to a raster surface representing topography (elevation).

To identify the physical impacts of SLR on urban areas in the coastal areas of the Nile Delta, recent projections of global rise in sea level up to the year 2100, were employed. They include three projections namely; 80 -200 cm (Pfeffer et al. 2008), 50 – 140 cm (Rahmstorf 2007) and 52 – 98 cm (IPCC, 2013)). The averages of these ranges, namely 140, 95 and 75 cm of SLR up to the year 2100 are employed to identify areas susceptible to inundation by SLR.

Since different parts of the Nile Delta have been experiencing varied land subsidence rate, ranging between 0.5 and 4.5 mm/year, they would be susceptible to different levels of relative SLR. Projected relative SLR for the coastal zone of the Nile Delta would range, up to the year 2100, between 145 – 185 cm; 100 – 145 cm, and 80 – 120 cm for the Pefeffer, Rahmstorf and IPCC RCP8.5, respectively. A raster layer was then developed to present relative rise in sea level and integrated into the system. These raster surfaces were employed to identify those areas vulnerable to inundation by SLR (Figure 3).

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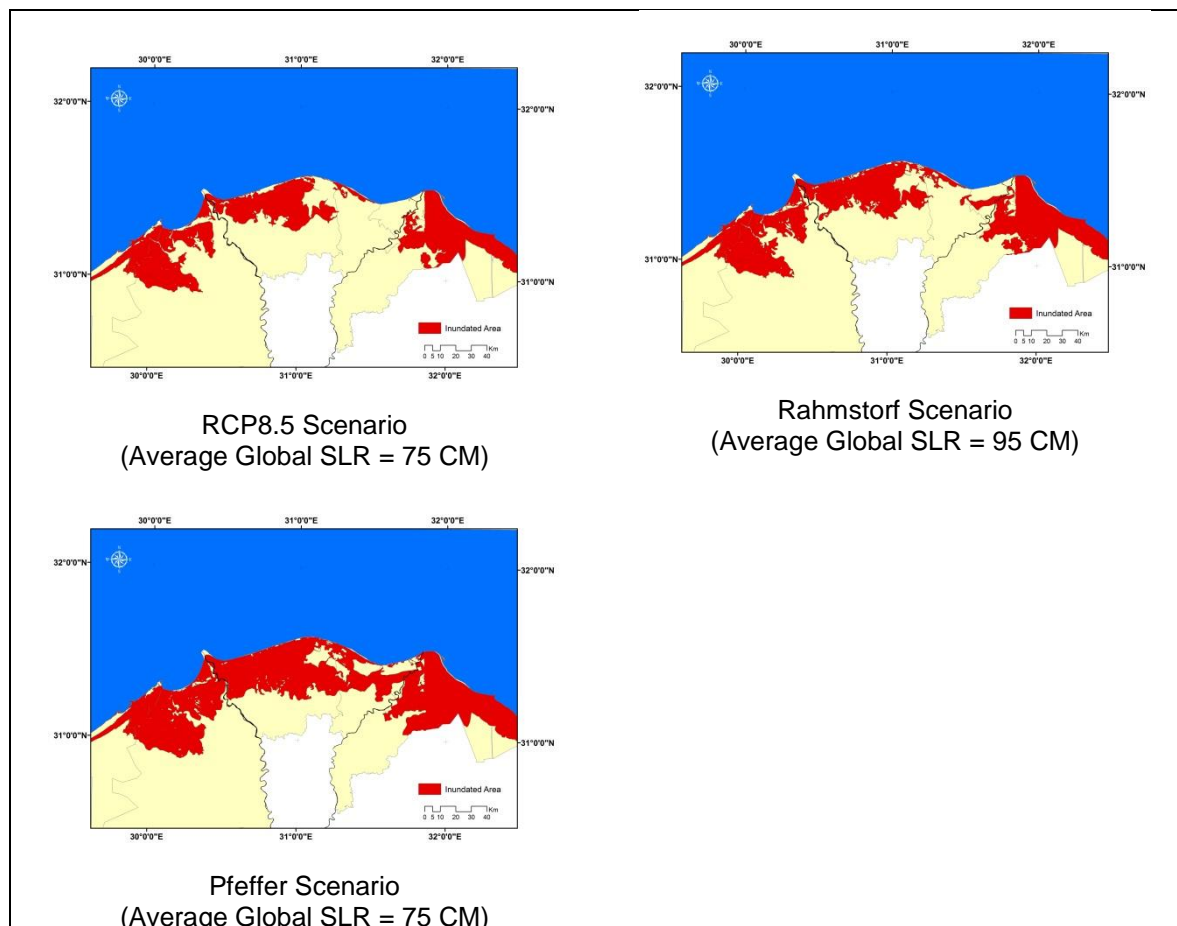


Figure 3: Areas Vulnerable to Inundated by SLR under different global SLR  
 Source: Calculated by the authors using the developed GIS

Out of the 18 urban centers existing in the Nile Delta coastal zone, findings show that 7 centers would not be impacted under considered SLR scenarios (Table 3). The remaining 11 urban centers would be, meanwhile, susceptible to different extents of inundation under the considered SLR scenarios. Accordingly, the analysis will focus on the eleven urban centres vulnerable to inundation by SLR.

Table 3: Built-up area vulnerable to inundation by SLR under different scenarios

City	Built-up Area susceptible to inundation by SLR					
	Pfeffer (140 cm SLR)		Rahmstorf (95 cm SLR)		IPCC AR5 RCP8.2 (75 cm SLR)	
	(Km <sup>2</sup> )	%	(Km <sup>2</sup> )	%	(Km <sup>2</sup> )	%
Alexandria	95.54	27.06	87.96	24.91	84.57	23.95
Edku	38.48	72.82	33.29	62.99	23.29	44.08
Kafr El Dawar	7.1	96.87	3.81	51.98	2.75	37.59

Rosetta	1.13	24.45	0.89	19.33	0.72	15.56
Gamasa	1.36	23.24	0.8	13.68	0.59	10.09
New Damietta	3.06	10.03	0.35	1.15	0.35	1.14
Ras El Barr	4.07	85.58	0.79	16.64	0.41	8.65
Baltim	2.38	99.57	2.04	85.34	0.67	27.98
Port Said	43.38	72.72	43.38	72.72	43.38	72.72
Port Fouad	16.29	99.82	14.06	86.18	13.9	85.19
Damietta	1.84	24.72	0.03	0.35	0	0
Total	212.79	38.53	187.37	33.93	170.63	30.90

The total built-up area of these 11 urban centers is 544.74 km<sup>2</sup>, which represents about 86.23% of total built-up area of urban centers in the Nile Delta coastal area. Total built-up areas susceptible to inundation by SLR in these 11 urban centers, ranged between 170.63 and 212.79 km<sup>2</sup>, representing 30.90% and 39.1% of their total built-up areas.

The spatial extent of SLR impacts differs widely among these urban centers. For instance, the proportions of inundated built-up areas in urban centers are found to be highest in the case of Port Fouad, ranging between 85.19% and 99.82% of its total built-up area under the Pfeffer and the IPCC AR5 RCP8.2 scenarios, respectively. The lowest built-up area susceptible to inundation was found to be Damietta, ranging between 10.03% and 0% of its total built-up area under the Pfeffer and the IPCC AR5 RCP8.2 scenarios, respectively. As would be expected, the magnitude of SLR impacts varied considerably for the same urban center under different SLR scenarios.

In order to estimate the population vulnerable to inundation by SLR, it was assumed that populations are evenly distributed over the built-up area of these urban centers. The total vulnerable population in the 11 urban centers ranged between 1.850 and 1.584 million people, accounting for 29.0% and 24.8% of total population.

It was found that Alexandria has the largest vulnerable population size of all urban centers studied (Table 4). Gamasa had, meanwhile, the smallest vulnerable population size under all SLR scenarios. Damietta, however, experienced the greatest variations under the three SLR scenarios, ranging between 58,300 and zero people, under Pfeffer and IPCC AR5 RCP8.2, respectively. Such variations can be attributed to the wide-ranging topography of the city and its surrounding areas.

Table 4: Vulnerable population size under different scenarios

City	Vulnerable population (thousand people)		
	Pfeffer (140 cm SLR)	Rahmstorf (95 cm SLR)	IPCC AR5 RCP8.2 (75 cm SLR)
Alexandria	1105	1017	978.00
Edku	71.00	61.00	42.83
Kafr El Dawar	110.46	59.28	42.87
Rosetta	16.86	13.33	10.73
Gamasa	0.48	0.28	0.21
Damietta	58.30	0.83	0
New Damietta	2.71	0.31	0.31
Ras El Barr	10.26	2.00	1.04
Baltim	40.03	34.30	11.25
Port Said	359.94	359.94	359.94
Port Fouad	75.53	65.21	64.46
Total	1849.96	1613.66	1584.48

It should be noted, meanwhile, that in some cases such as Port Said City, the spatial extent of vulnerable built-up areas and vulnerable population size did not differ under various SLR scenarios. This is mainly due to the spatial distribution of the built-up area, with about 75% of the built-up area being located in the northern low-lying land, which would be extremely vulnerable to inundation under even the lowest SLR scenario (IPCC AR5 RCP8.2 - 75 cm). The remaining sections of the built-up area (25%) are located southward in areas higher than the highest SLR scenario.

#### 4.2. Demographic aspects

The population size and built-up area of these urban centers varies widely, according to their historical development and functionality (Figure 4). In this respect, some urban centers such as Gamsa, Baltim and Ras-El-Barr are mono-functional, mainly serving as tourist resorts. Meanwhile, some other urban centers such as Alexandria and Port Said are multi-functional, as they host a number of economic activities such as industrial and commercial activities.

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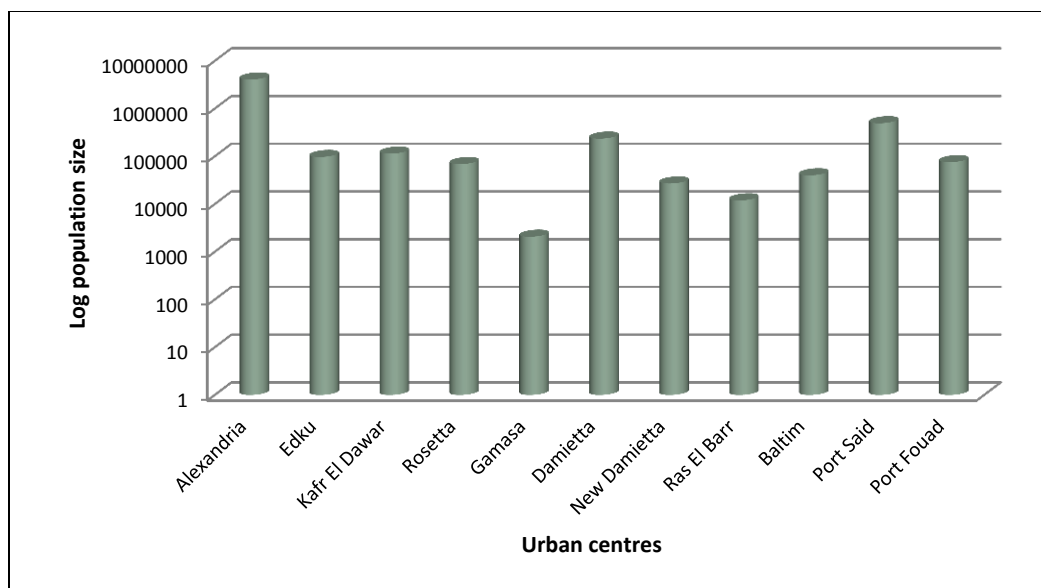


Figure 4: Log population size of urban centers in the coastal zone of the Nile Delta  
Source: CAPMAS, 2008

### 4.3. Socioeconomic aspects

The unemployment rate ranged between 9.76% in Baltim and 24.87% in Ras El Barr (CAPMAS, 2008). Also, the demographic dependency rate<sup>2</sup> varied between 70.3% in the case of Edku and 48.1% in the case of Port Said (UNDP, 2003) (Table 5).

Table 5: Socioeconomic conditions of urban centers in the coastal zone of the Nile Delta

City	Unemployment rate <sup>(1)</sup> (%)	Household Density <sup>(2)</sup> (Person/room)	Annual growth rate of population % <sup>(3)</sup>	HDI 2010 <sup>(4)</sup>	Demographic Dependency Ratio <sup>(5)</sup>
Alexandria	13.55	1.11	1.69	0.755	55.282
Edku	11.11	1.06	2.37	0.728	70.342
Kafr El Dawar	18.17	1.16	2.37	0.787	65.535
Rosetta	18.58	1.09	2.35	0.745	56.669
Gamasa	15.63	1.33	1.88	0.715	63.800
Damietta	15.12	1.01	2.35	0.788	52.375
New Damietta	16.71	1.13	2.37	0.745	67.666

<sup>2</sup> Demographic dependency ratio relates the number of children (0-14 years old) and older persons (65 years or over) to the working-age population (15-64 years old).

Ras El Barr	24.78	1.16	2.36	0.784	61.522
Baltim	9.76	1.03	2.38	0.753	62.448
Port Said	13.39	1.18	1.66	0.786	48.098
Port Fouad	9.90	1.23	1.66	0.813	54.674

Source:

<sup>(1)</sup> & <sup>(2)</sup> CAPMAS, 2008

<sup>(3)</sup> & <sup>(5)</sup> UNDP, 2003

<sup>(4)</sup> As HDI data in the UNDP 2010 was available at governorate level and HDI at locality level was only available in UNDP, 2003, HDI 2010 governorate level data was used to update HDI at locality level.

Alexandria, Damietta and Port Said are the main ports of Egypt, which indicate their importance to the national and local economies. Thus, the lack of resilience in these three cities to SLR may have far reaching implications to Egypt as a whole. This also applies to road networks to and from these cities, the accessibility of which may also reduce their resilience. Such different sizes and functionalities of urban centers imply their different scales, assets, socioeconomic conditions, capabilities and consequently different levels of resilience to SLR impacts.

Low-income and informal urban settlements in Egypt, as in most developing countries, tend to lack basic infrastructure and services, which is typically accompanied by overcrowded living conditions and poor housing quality. There are also positive externalities, despite the well-documented negative ones, associated with these settlements. These include, for instance, informal job opportunities and economic activities that represent a relatively significant proportion of the Egyptian economy. Additionally, these settlements provide the only opportunity of affordable shelter for low-income populations.

Finally, the overall density in cities reached on average 500 persons per hectare, but can exceed that in informal settlements to up to 2000 persons per hectare (World Bank, 2008). Some city areas and most informal settlements<sup>3</sup> lack integrated sanitation services.

#### 4.4. Environmental aspects

In the Nile Delta region, urban encroachment has led to significant loss of agricultural land, and it is estimated that one million acres of agricultural land has been lost between 1980 and 2004. If this trend continues, about half of Egypt's fertile agricultural land will be converted to informal settlements by 2025 (GTZ, 2004). The economic value of such lost agricultural land is enormous, particularly in a country where less than 4 percent of its total area is currently cultivated (Abdrabo and Hassaan, 1999). There is

<sup>3</sup> Informality may imply, in this respect, more than one meaning; it can mean substandard, illegal or disrespecting building laws and planning regulations (Khalifa, M, 2011).

also the adverse impact of coastal dynamics in terms of coastal erosion, which affects a number of sites along the Egyptian Mediterranean coast. Another significant issue of concern is high groundwater table levels as well as saltwater intrusion, which is expected to increase with SLR, causing significant adverse impacts on agricultural activities as well as built up areas in the coastal area of the Nile Delta.

Urban water and air quality continue to be adversely affected by the various activities undertaken within city boundaries, as well as in its hinterland. Still, attempts are being made to monitor and control by the Egyptian Environmental Affairs Agency (EEAA) 2011). Different cities, in this respect, are affected differently in terms of city functions, demographic conditions as well as dominant economic activities. For instance, air quality in Alexandria is adversely affected by traffic and traffic congestion as well as industrial activities, while water quality in Kafr-el-Sheikh is adversely affected drainage water as well as discharge of sewerage into water bodies.

#### **4.5. Institutional aspects**

The National Committee for Integrated Coastal Zone Management (NCICZM) was created in 2000 to develop a coastal zone management program for Egypt. The committee encompasses many different ministries, some social actors (e.g. NGOs) and has been chaired by the Ministry of Environment as an attempt to strengthen the horizontal integration necessary for integrated coastal zone management (ICZM) (Borhan et al., 2003).

Dysfunctional coastal governance systems can be characterized by a lack of vertical and horizontal integration that reveals gaps and conflicting positions between governing bodies (Tabet and Fanning, 2012). For instance, there are nine government bodies, in addition to eight coastal Mediterranean governorates, in charge of different aspects associated with coastal areas. The authority line in these government bodies is characterized by centralization and limited participatory practices, additionally, all leadership positions are appointed rather than being elected. This, in turn, directs loyalty to official leadership rather than the local population.

ICZM, though considered to be of utmost importance to the preservation of coastal areas, represents an issue of alarm for the Nile Delta coastal zone. The current institutional setting and coastal areas governance mechanisms involve limited institutional contribution to urban resilience in the Nile Delt For example, non-governmental organizations (NGOs) are stringently controlled by the Ministry of Social Affairs (MOSA), limits the possibilities for community mobilization and a more participatory approach to coastal area management (Tabelt and Fanning, 2012). Furthermore, an enormous body of legislation dealing with coastal areas is creating considerable overlap and conflict between different government bodies in charge of coastal areas management (Tarek, 2012).



In addition to a complicated institutional structure, the capacity is also limited. For example, despite availability of a wide range of possible alternatives to deal with the Nile Delta shoreline retreatment, the vulnerability of the Mediterranean coast to shoreline erosion has been dealt with through “hard” adaptation options such as the construction of breakwaters, dykes and jetties (Agrawala et al., 2004). Overlapping, duplication, and sometimes-contradictory decision making has negatively influenced the urban planning process in Egypt. These together with the prerequisite to acquire approval of several governmental bodies, usually leads to the delay of finalizing urban plans and enforcing them (World Bank, 2008)

As a result of an inefficient and ineffective institutional structure, in most cases the expansion of cities has involved the development of informal areas on the periphery of cities, where most basic infrastructure and services are lacking (UN-Habitat, 2003).

A National Committee for Crisis/Disaster Management and Disaster Risk Reduction was created to address the crises/disasters management in Egypt. Meanwhile, consultants at the Information and Decision Support Centre (IDSC) of the Cabinet of Ministers in Egypt developed a National Strategy for Adaptation to Climate Change and Disaster Risk Reduction for Egypt in 2011. The strategy, which is based on the findings of the first and second communication reports prepared within the framework of the UNFCCC (IDSC, 2011), adopted a sectorial approach in considering adaptation to climate change focusing on: coastal areas, water resources, agriculture, tourism, health, population, inhabitants, and roads. The strategy focused on resilience as it aimed at increasing the flexibility of the Egyptian community in dealing with impacts of climate change and enhancing the capacity to absorb and contain climate-related risks and disasters. However, these goals are quite generic with no clear focus on any specific assessment or objectives. Accordingly, the strategy provides a number of broad measures to achieve the above-mentioned goals, for instance it recommends enhancing community participation at all levels. Moreover, no operational plan for climate change at any of the cities in the Nile Delta was developed, as capacities needed for developing such operational plans are generally lacking.

#### **4.6. City resilience index**

The estimated resilience index, derived for urban areas susceptible to inundation by SLR in the Nile Delta coastal area, is shown in Table 6 and Figure 5. Ranking the eleven urban centers according to resilience index reveals that Port Said and Damietta cities had the lowest and highest resilience levels, respectively, under the three considered SLR scenarios. Port Said city has the lowest level of resilience with a resilience index value of 0.498, 0.495 and 0.473 under the three SLR scenarios of 75, 95 and 140 cm. It

is followed by Alexandria city with resilience index value of 0.450, 0.451 and 0.439 under the three scenarios respectively. Meanwhile, Damietta City seems to be highly resilient to inundation by SLR having a resilience index value of 0.167 under both 75 and 95 cm SLR scenarios and 0.194 under 140 cm SLR scenario.

Table 6: Resilience index of various urban centers under different scenarios

City	Resilience index		
	Pfeffer (140 cm SLR)	Rahmstorf (95 cm SLR)	IPCC AR5 RCP8.2 (75 cm SLR)
Alexandria	0.439	0.451	0.450
Edku	0.393	0.396	0.368
Kafr El Dawar	0.417	0.367	0.345
Rosetta	0.337	0.344	0.339
Gamasa	0.420	0.421	0.417
Damietta	0.194	0.167	0.167
New Damietta	0.277	0.278	0.279
Ras El Barr	0.392	0.310	0.298
Baltim	0.326	0.324	0.239
Port Said	0.473	0.495	0.498
Port Fouad	0.429	0.428	0.428
Average	0.372	0.362	0.348
Minimum	0.194	0.167	0.167
Maximum	0.473	0.495	0.498

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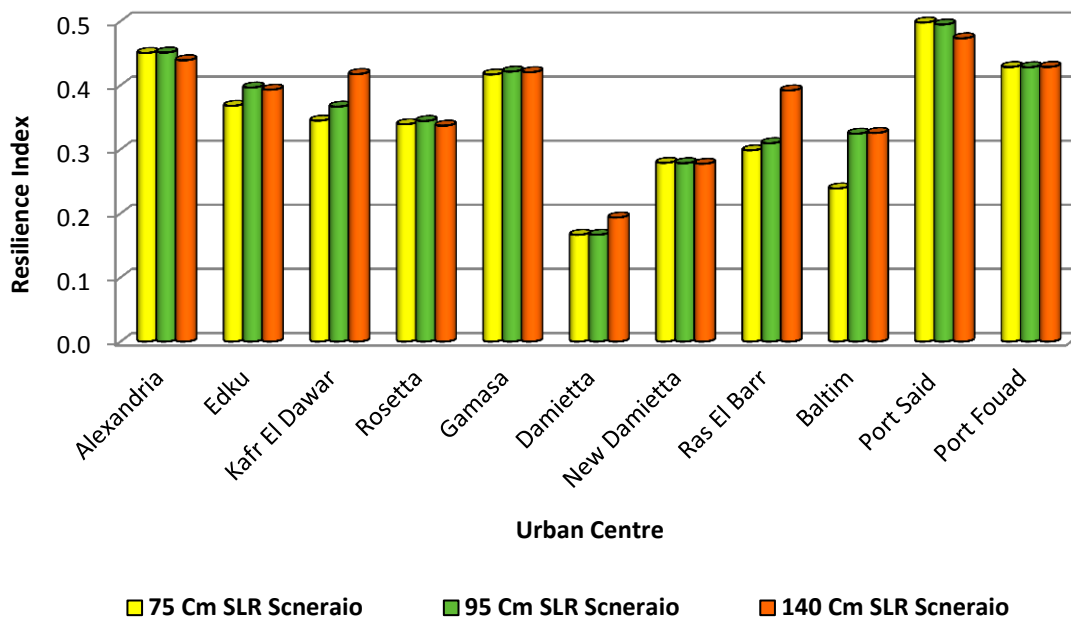


Figure 5: Resilience index of various urban centers in the Nile Delta coastal zone

The lowest level of resilience in the case of Port Said can be attributed to the large proportion of built-up area vulnerable to inundation by SLR and a relatively low coverage of infrastructure and services (Figure 6). While the low level of resilience in the case of Alexandria city can be explained by high proportions of population vulnerable to inundation by SLR.

Meanwhile, the highest level of resilience in the case of Damietta City can be justified by the low proportions of built-up area and population vulnerable to inundation by SLR, a relatively high HDI, high levels of access to basic services and infrastructure, and improved environmental and demographic conditions (Figure 6).

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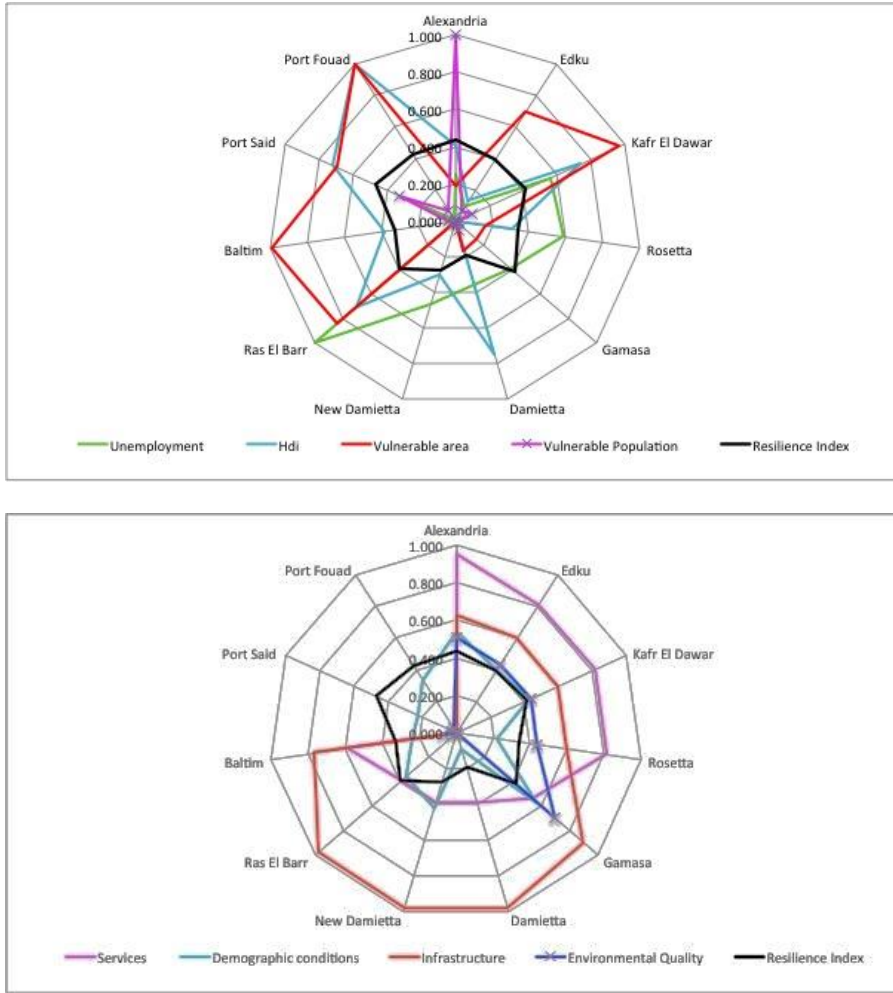


Figure 6: Contributing variables to resilience index of various urban centers in the Nile Delta coastal zone

Source: Developed by the authors

We suggest that the proposed index of city resilience could become a useful tool for researchers, policy and/or decision makers as well as municipal and city planners to identify urban hotspots that require action to improve their resilience. Moreover, such an index represents a viable alternative compared to qualitative assessments especially if the underlying deriving forces of resilience are taken into account. This, also, could provide an opportunity to adopt proactive planning actions, especially when considering low-regret measures to be implemented at city level.

Further research is needed to expand current work in terms of identifying and assessing the main factors contributing to lower resilience in the hotspots and examining the viability of implementing possible site-

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specific low-regret measures . This is especially true as this analysis and index estimation are undertaken at more disaggregated levels within urban areas, for instance in the case of Alexandria City.

Among different transferrable lessons, we note that city resilience cannot be assessed only through studying various city conditions, but must be considered within a wider context. Finally, it should be noted that the city resilience index can be applied in different places. The only factors that need to be considered when implementing the proposed city resilience index are: 1) the type of risk being assessed and 2) availability of disaggregated data and information of the variables representing the five aspects considered in this paper; namely physical vulnerability, demographic, socioeconomic, environmental, and institutional aspects.

#### **4. Conclusion**

The Nile Delta is considered to be one of the most vulnerable areas to SLR linked to current and projected climate change. Urban centers in the Nile Delta coastal zone are generally characterized by a concentration of population, economic activities, infrastructure and services. Egypt's rapid urbanization during the last five decades makes these urban centers more susceptible to the risk of inundation by SLR. This highlights the need for an in-depth assessment of the scale of the impacts as well as urban resilience.

Although there exists a number of research projects that consider the vulnerability of individual urban centers in the Nile delta coastal zone to inundation by SLR, no research work has been conducted to deal with the overall resilience of these urban centers.

Among the 18 urban centers in the Nile Delta coastal zone, the research found that 11 urban centers were affected by different scenarios of expected SLR. To assess the resilience of these urban centers to inundation by SLR, a composite resilience index was developed to integrate various physical and socioeconomic factors that determine urban resilience. The suggested index is a relative index highlighting variations in resilience between various urban centers.

The application of the resilience index showed that urban centers in the Nile Delta coastal zone reveal different levels of resilience to SLR impacts. It was found that the lowest level of resilience was recorded in the case of Alexandria, while Damietta was found to be highly resilient to inundation by SLR. Such varied resilience levels can be attributed to different magnitudes of physical vulnerability to inundation by SLR, which varied considerably among urban centers. Also, the socioeconomic conditions prevailing in urban communities contribute largely to their resilience.

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Concerning institutional aspects, though they were not incorporated in the developed resilience index, some action could be suggested to improve urban centers' resilience in light of current instructional setting and practices. This includes, for instance, awareness raising for policy and decision makers, increased participation and adoption of more proactive approaches towards climate change impacts.

Finally, more research is needed to assess resilience of these urban centers considering detailed data on existing infrastructure and service provision as well as poverty levels.

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