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Vulnerability Assessment of the Impact of Sea Level Rise and Land Subsidence on North Nile Delta Region

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Abstract: A survey of the detailed quantitative assessment of the vulnerability of the Nile Delta coast of Egypt to the impacts of SLR and land subsidence is presented. Remote sensing, GIS and modeling techniques are used together with ground-based surveys to assess vulnerability of the most important economic and historic centers along the coast, the Governorates of Alexandria, Beheira, Kafr El-Sheikh and Damietta. The technique has also readily applicable to other vulnerable areas of the coastal zone of Egypt such as the governorate of Suez, Port Said and Matruh for future planning. The results indicated that, the Mediterranean coastal governorates are ranked as low- moderate and high vulnerable to the SLR. Also, in these governorates alone, over 4 million people will have abandon their homes, 0.5 million jobs and tourism income may also be lost due to SLR. The loss of the world famous historic, cultural and archeological sites is unaccountable. The severe land-use interference and the large population involved and conflicting requirements for the development makes it necessary to use decision- support systems based on GIS for future development and planning of these areas. Short-term adaptation measures are also necessary in the frame of the no regrets policy, involving beach nourishment, sand dune fixation, upgrading awareness and building institutional capability in the integrated coastal zone management are highly recommended.

Key words: Land subsidence · North Nile Delta · Sea level rise

INTRODUCTION

The study area lies at the northern part of Nile Delta and is bounding to the east by the Suez Canal, to the north by the Mediterranean Sea, to the west by the Burg El-Arab and to the south by the Ismailia Canal (Fig. 1). It extends for about 240 km from Alexandria (west) to Port Said (east), between Latitudes 30° 0` to 32°10` E and Longitudes 31° 20` to 32° 0` N. This area is characterized by arid to semi-arid climate (i.e. long dry summer and short temperate winter with rainfall period from October to March). The vulnerability of various resources of Egypt to the impacts of climate change has been recognized since a long time. In particular, qualitative vulnerability assessment of water resources, agricultural resources and coastal zone resources have been investigated thoroughly. The Pcoastal zone of Egypt in particular, is most vulnerable to the impacts of climate change and sink under sea water, not only because of the impact of sea level rise and land subsidence, but also because of the impacts on water, agriculture, tourism resources and human settlements. The study area, has adequate information about the geology, structure and geomorphology [1-4], however very few studies deal with vulnerability assessment of the impact of sea level rise [5, 6,7] and no study evaluated the risk degree of both sea level rise and land subsidence in addition to other environment anthropogenic criteria.

The aims of the present study are to identify the potential risks of SLR impacts along Egypt's Mediterranean coastal area; to determine the effect of increasing rate of the Nile Delta subsidence due to removal of oil, gas, water from the inland delta's underlying sediments and subsurface faulting; survey the

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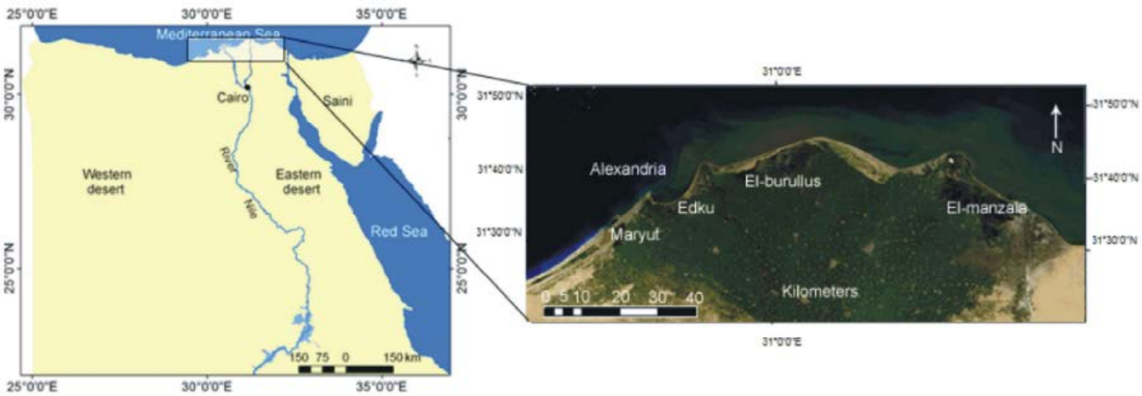

Fig. 1: Location map of study area

results of detailed quantitative assessment of the vulnerability of important governorate of Egypt to the Mediterranean Sea namely Alexandria, Beheira, Damietta and Kafr El- Sheikh governorate and assess potential impacts on each governorate and to evaluate economic losses using remote sensing (RS) and Geographic Information System (GIS) and modelling techniques together with ground-based surveys.

Geomorphology: Several authors have treated the physiographic units of the eastern Nile Delta, among them [8, 9, 10]. It is already known that the landscapes of the area was greatly affected by the tectonics of the Nile Delta region as well as by the climatic changes, which affected the area throughout the successive wet and dry Pleistocene period. These units are beach, coastal flat, coastal dunes, sabkhas, lagoon, saltpans, marshes and fish farms.

Beach and Coastal Flat: The north-western coastal area is characterized by the presence of consolidated Pleistocene carbonate ridges (Fig. 2a) that are laterally oriented from Alexandria to the Sallum plateau. These ridges progressively increase in elevation from about 10 m along the coast to 100 m with some 40 km inland [11]. They are the primary source of the beaches and seabed sediments of this region [12]. The beaches range from zero to 1 m in elevation and the natural lagoons and depressions-wetlands of this region are vulnerable area to the SLR. The morphology of the northern Nile Delta region vary from low-lying (<1.0 m below MSL) to high land (20 m height) associated with zones of intermediate elevation.

Coastal Dunes: A wide field of active longitudinal or "serif" dunes, 15-30 m height and parallel to the shoreline backs the beach identified west of Gamasa drain by UNESCO/ UNDP [13] and Frihy [14]. Another barchans dune belt fronts the arcuate bulge of the central-Delta region between El-Burullus and Kitchener drain (Fig. 2b). Field observations indicate that part of these dunes has been excavated for the roads and urban construction. The dunes remaining extend toward the south in the form of elongated sand bodies, 1.1-1.4 km long, more or less straight or serrated, with their long axes lying parallel to the prevailing N and NW wind. Dune degradation is widespread and leads to hazardous consequences for coastal buildings and the nearby international highway [3].

Sabkhas: Salt marshes cover considerable areas in the Middle East region with altitudes ranging from (- 300) m below sea level to almost (200) m above sea level. In Egypt, these occur along the Red Sea coastal belt in south Sinai, east of the Eastern Desert and in the vicinity of lakes in the Mediterranean part [15, 16]. The Mediterranean salt marshes are found in the vicinity of Bardawil, Manzala, Maryut and Burullus lakes occurring along the coast of Mediterranean Sea. These are generally oligotrophic [16] (Fig. 2c).

Lagoons: The broad beaches of the Delta are backed partially by dunes, cultivated land and urban centres coastal wetlands forming natural lagoons and reclaimed fish farms. Four brackish coastal lagoons (Idku, El-Burullus, Maryut and El Manzala) are separated from the sea by sandy barriers breached by artificial inlets (Fig. 2de). The sandy barriers are low-lying and very narrow that presently subjected to erosion and subsidence as a result of the large human activities, it suffers from a number of major problems including population pressure, interference of land use, pollution, water logging and lack of institutional capabilities for integrated management.

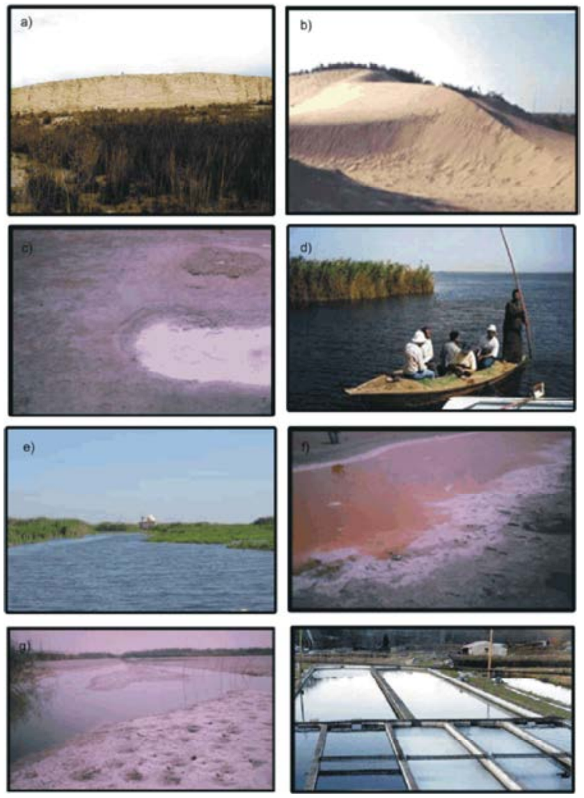

Fig. 2: Photographs showing the physiographic units in study area include: a) the carbonate ridges in Abu Qir (Burj Al Arab); b) the coalesced sand dunes forming Y-junction, Idku town; c) the sabkhas; d, e) El Manzala and Idku lagoon; f) Saltpans; g) Marshes; h) Fish farms.

Saltpans: Characteristic features of the El Manzala lagoon are saltpans. A vast area 3×2 km^2 has been devoted to sea salt extraction in the north-western part of El Manzala lagoon with in this area a system of tanks containing sea water in various stages of evaporation is used for salt production. Limited sea salt extraction was carried out in the area wherever the inshore profile has a shallow enough gradient or wherever marshes could be adapted, but it is now a highly organized and efficient industry (Fig. 2f).

Marshes: These marshes are important wild life habitat, serving as breeding grounds for a wide variety of animal life. They provide vital food and habitat for clams, crabs and juvenile fish, as well as offering shelter and nesting sites for several species of migratory waterfowl. Presently, human activities have reduced the area of marshes to about 96%; parts of marshes have been reclaimed for agriculture or modified to fish farms (Fig. 2g).

Fish Farms: Recently, fish farming instead of traditional agriculture has been seen as a way to increase agricultural profits from saline affected land. Concerns, however, have been raised that fish farming may increase the salinity problems. In the salinity affected soils of the El-Salam canal project area in Egypt, farmers are giving up traditional farming for fish farming due to possibilities to increase their profits. The government, however, supports traditional agriculture in order to increase national income and secure food. The total of fish farms is 258051Acre according to Ministry of Water Resources and Irrigation [17] (Fig. 2h).

Geology and Tectonic Setting: The exposed rocks in study area are mainly sedimentary and ranging in age from Pleistocene to Recent (Fig. 3). The following is a brief description of each lithological unit. The exposure of these old deltaic deposits is subjected to intensive erosion where an areal desert pavement is developed on the surface.

Quaternary Deposits: In the area of study, the Holocene deposits are widespread. They are represented by a variety of unconsolidated deposits (surficial deposits), which are differentiated into: beach deposits, young deltaic, young fluviomarine and Wadi deposits. Beach deposits predominate the area between Damietta and Port Foad. These deposits are composed of loose fine to medium quartz sand. They attain a thickness reaching 5m. Young deltaic deposits are wide spread in the northern and western sides of study area. These deposits are composed of Nile silt, fine sand and clay. They attain a thickness reaching 10 m. Young fluviomarine deposits are dominated the surface of northern plain and the southern fringes of El Manzala lake. They are composed of dark clays and silt clays with sand lenses, gypsum and salt crystals. They have a maximum thickness of 10 m. Wadi deposits occur in the courses of the large Wadis. These deposits are composed of calcareous and ferruginous loamy sand, mixed with pebble and rock fragments. They have a thickness of about 2m.

Nile Silt: Nile silt represents the evolution of five river regimes; three of them were formed through the Quaternary; the Protonile (Q_1), the Prenile (Q_2) and the Neonile (Q_3). The Protonile, which is the earliest of the Pleistocene rivers, was a highly competent river which carried gravel - size sediments. The Prenile is a vigorous river and has formed the marine cross - bedded sand.

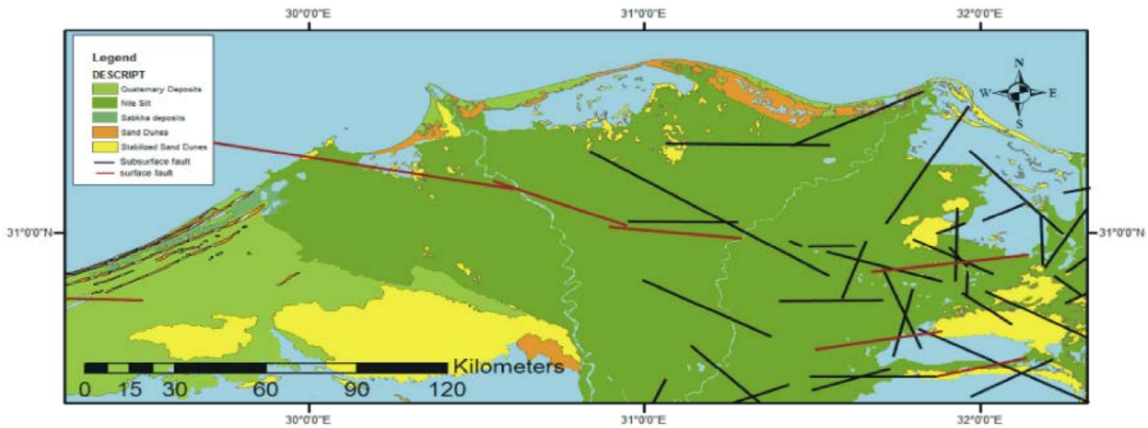

Fig. 3: Geologic map of the study area (modified after, Zaid [10])

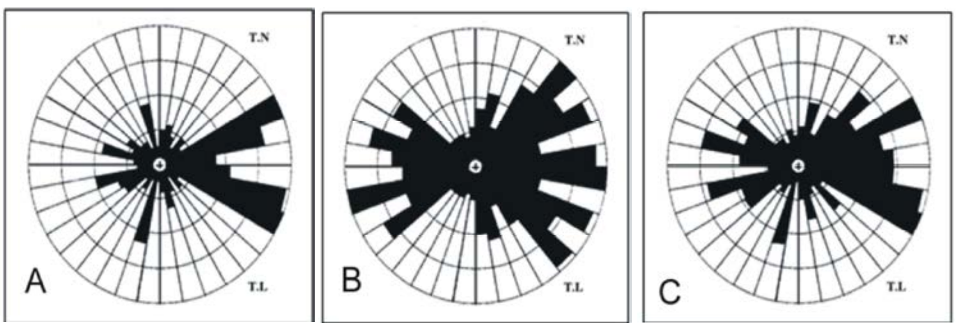

Fig. 4: Rose diagram of major tectonic trends interpreted from; A- subsurface tectonic faults, B- surface tectonic faults and C- regional Faulting.

Due to the disturbance of the Red Sea, a capture of Atbara River and Blue Nile was produced. The Neonile occurs as a result of flow of Atbara River and Blue Nile across the elevated Nubian massif.

Sabkhas Deposits: Sabkhas appear on the surface in El Ballah and Serw areas. They are formed of nearly pure gypsum, occasionally alternating with clay bands. They have a maximum thickness of 4m.

Quaternary Sand Dune: Old eolian deposits forming Turtle back-like features are scattered irregularly on the cultivated land and are particularly crowded in the northern eastern part and south of El Manzala Lake. These deposits are composed of loose fine to medium sand with a thickness of 8 m. Recent eolian sands accumulate at El Khanka and El Salhiya Plain. These deposits are composed of loose fine to coarse quartz sand with a variable thickness.

Tectonic Setting

Surface Faulting: An active major belt of Neogene normal fault trends, W to E, clearly defines the Mediterranean coast of Egypt from Sallum to Rafah. The study area is underlain by Pleistocene carbonate rocks and stiff mud of lagoon faces. Major fault lines (Abu Qir, Rashid fault lines, Qattara-Eratosthenes, Suez-Cairo Alexandria) are active structures in this sector. The lower Deltaic plain of the Nile Delta is underlain by Holocene sediment (pro-Delta fluvial marine mud). These Holocene sediments are underlain by late Pleistocene alluvial sands [18]. The thickness of the Holocene faces ranges from 50 m at Port Said (relatively highly subsided) and tends to decrease or be nearly absent westward below the Alexandria coastal plain. A series of major fault lines are documented in the Delta region [19]. Associating with these faults are the earthquakes epicentres [20], (Fig. 3).

Subsurface Faulting: The fault system interpreted from analyses of the bouguer gravity, aeromagnetic and basement tectonic maps exhibits different direction and lengths as reflected by the amplitudes and gradients associated with their anomalies [10]. The overlaying between the two layers of surface and subsurface faults show that, there are seven rejuvenated subsurface faults, which are extended to the surface and affecting the

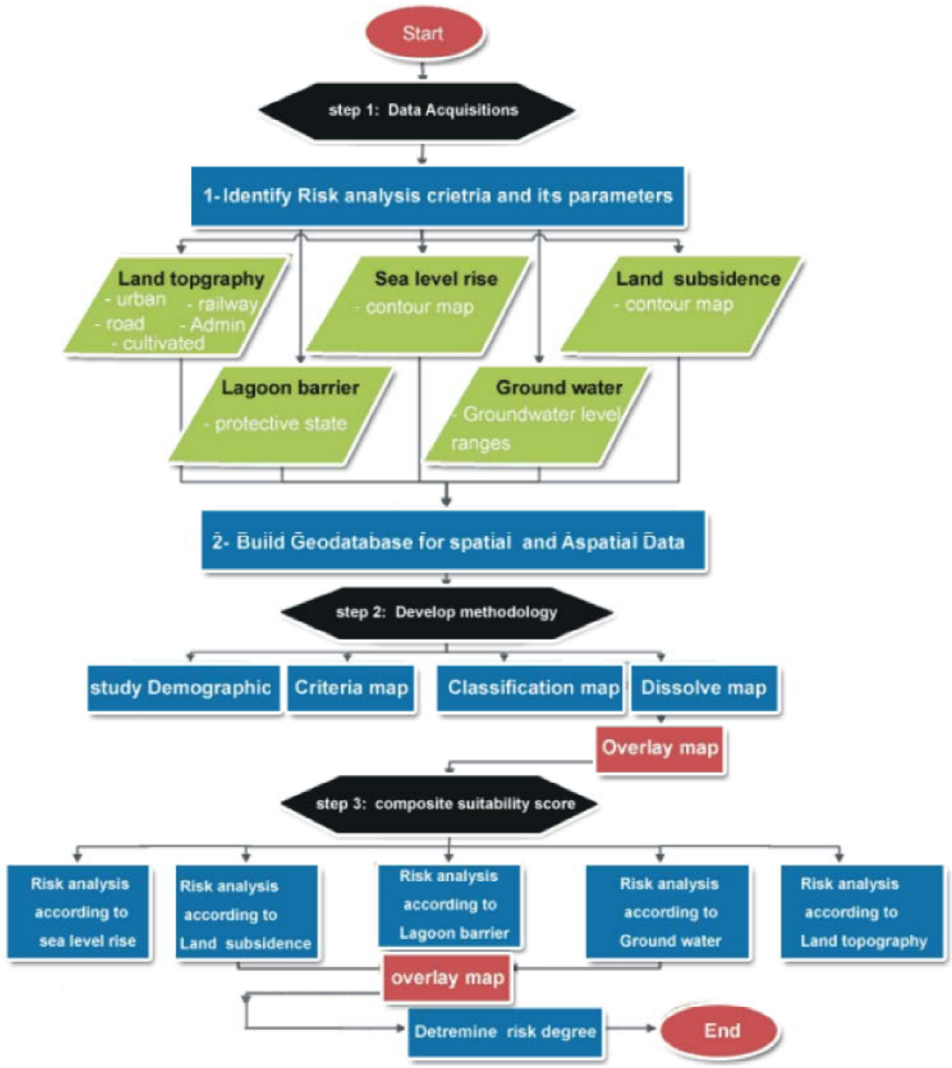

Fig. 5: Flow chart showing the workflow diagram

Tertiary rocks. These faults consider the strongest faults in study area (Fig. 3). The calculated parameters of the surface and subsurface faults interpreted from visual interpretations of TM and borehole data. It shows the presence of 46 faults trends representing the directions; ENE- WSW, NE- SW, NW- SE, WNW- ESE, E - W and N-S in a decreasing order of predominance (Fig. 4), which are consistent with the important tectonic directions previously detected by Youssef [21], Halsey and Gardner [22] and Meshref [23]. This horizontal compressive force may have created, the two conjugate shear fractures; NE (Aqaba) and NW (Suez) trends. These tectonic trends show relative strength in northern Egypt with lesser magnitude than the southern portion of Egypt and explain well the tectonic framework and the tectonic history of the area.

MATERIALS AND METHODS

The study area is included in (4) Land sat (TM) (175-38, 175-39, 176-38 and 176-39) (year 1990). The remote sensing (RS) and Geographic Information System (GIS) and modelling techniques were applied (Fig. 5):

- Starting with raw data to the form of digital format for the study area on computer compatible tapes (CCTs).
- Different image processing techniques were executed in order to improve the information content and make it more readily available for efficient visual and digital interpretation.
- The digital mosaic of land sat images and topographic maps of scale 1: 50,000 have been produced for the study area using arc map (9.3).

- Based on visual and digital interpretation of the produced mosaics, land use/land cover, infrastructures, consequently irrigation and drainage canals were out lined on a map and have been calculated and listed in tables.
- Geology, structure and morphology of the study area were delineated and mapped by visual and digital interpretation of the land sat (TM) images.
- Different coastal areas that have subjected to sea level rise (water cover) have been assessed.

RESULTS

Criteria: There are five criteria control the risk degree of north Nile Delta, Egypt. These criteria include: sea level rise, local subsidence, land topography, coastal protection and ground water level.

Sea Level Rise: According to United Nations Intergovernmental Panel on Climate Change [24, 25] reports, the two principal causes for the rise of sea level in the past 100 years have been: a) The thermal expansion of ocean waters b) The melting of glaciers (mostly continental), both generated by the greenhouse effect. Most researchers consider the first factor to be a more significant contributor to SLR; however others, such as Miller *et al.* [26], Jones *et al.* [27], consider mass increase to play a larger role than thermal expansion. SLR in the Mediterranean over the 20th century has been quite similar to the average global SLR of 0.5-2.5 mm/year [28]. This trend however has not been consistent throughout the century. There are two distinctly different sea level trends. The first extends from the end of the 19th century to 1960, when sea level in the Mediterranean rose by rates just somewhat higher than the overall trend. From 1961 to the end of the 20th century, no change in sea level occurred in the Mediterranean. The mean global SLR estimated by various researchers for the past 100 years, as summarized by Brochier and Ramieri [29], is about 1-2.5 mm/year. Church *et al.* [30] computed a global 1.8±0.3mm/year rise for 1950-2000. No significant increase in the rate of SLR has occurred over that period of time. Cabanes *et al.* [31], Cazenave *et al.* [32] showed a global mean SLR, observed by Topex/Poseid on between 1993 and 2000, to be 2.5±0.2 mm/year. Between the years 1961 and 2003, the global SLR at an average rate of 1.8 mm/year and between the years 1993 and 2003, this rate was higher, averaging approximately 3.1 mm/year [33]. According to IPCC [33], sea levels will rise by between 18 and 59 cm by the end of the 21st century. In recent years (December 2003, 2010 and January 2011), major storms strike the Mediterranean coastline of Egypt. These storms produced during a short period a surge up to about one meter above the MSL [7, 34]. The SLR in the Mediterranean over the 20th century has been quite similar to the average global SLR of 0.5-2.5 mm/year [28]. According to the maximum global Mediterranean SLR of Micha and Michal [28], the predicated Mediterranean SLR during 2050 and 2100 has been calculated for the Nile Delta region (Table 1 and Fig. 6).

Land Subsidence: The modern Nile Delta is the major agricultural production area for Egypt and was formed from sediments supplied by at least 10 distinct distributaries channels throughout the Holocene, with an average elevation around a meter above the mean sea level [35]. The subsidence of the northern 30 km of the Delta is a topic of major concern to the Egyptian population and government. Ongoing subsidence rates in the north Nile Delta were estimated using persistent scattered radar interferometers techniques [35]. The highest rates is 8mm/yr (twice average Holocene rates) correlate with the distribution of the youngest deposition, with older depositional centres while subsiding at slower rates is of 2-6 mm/yr. Diverse subsidence rates were determined using different techniques in the Nile Delta: 3.98 mm/year [36], 4-5 mm/year [37] and 2 to 8 mm/year [38]. According to the maximum subsidence rate of Nile Delta of Becker and Sultan [38], the predicated subsidence rate during 2050 and 2100 has been calculated for the Nile Delta region (Table 2 and Fig. 7). A scenario of maximum global of sea-level rise (2.5mm) of Micha and Michal [28] over the next century is assumed, taking land subsidence (8.0 mm yr^{-1}) of Micha and Michal [38] into consideration.

Land Topography: Land topographic is an important factor in land use decision-making and is crucial to the sea level rise threatened areas. Also it is an important factor in selecting the land suitable for urban settlement. The study area is nearly flat and of low elevation, that reaches zero above sea level in several sites. This is clear in the digital elevation model (DEM) (Fig. 8). The result image shows that the study area has low elevation. It ranges between zero and 5 meters (Fig. 8). The study revealed that during floods of Mediterranean Sea water, the water would flow mostly to the west direction from El Manzala and/ or El-Burullus towards Idku Lake (Fig. 9). These means that the most extensive impacted areas are towards the northwest (e.g. Alexandria, Matruh).

Table 1: The predicted of sea level rise during the years 2010 -2100 according to Micha and Michal [28]

Year	Projections of SLR (mm)	Projections of SLR (cm)
2010	0 mm (present case)	0 cm (present case)
2010-2050	100 mm	10cm
2050-2100	125 mm	12.5cm

Table 2: The predicted of land subsidence according to Becker and Sultan [38].

Year	Land Subsidence (mm)	Land Subsidence (cm)
2010	0 mm Present case	0 cm Present case
2010-2050	320 mm	32 cm
2050-2100	400 mm	40 cm

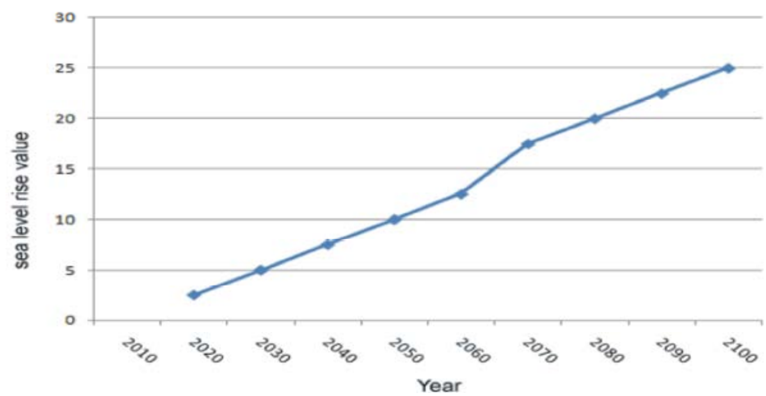

Fig. 6: The predicted values of the sea level rise (cm)

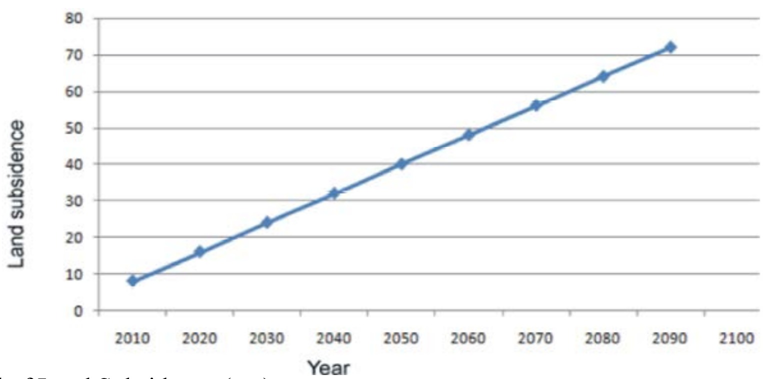

Fig. 7: The predicted of Land Subsidence (cm)

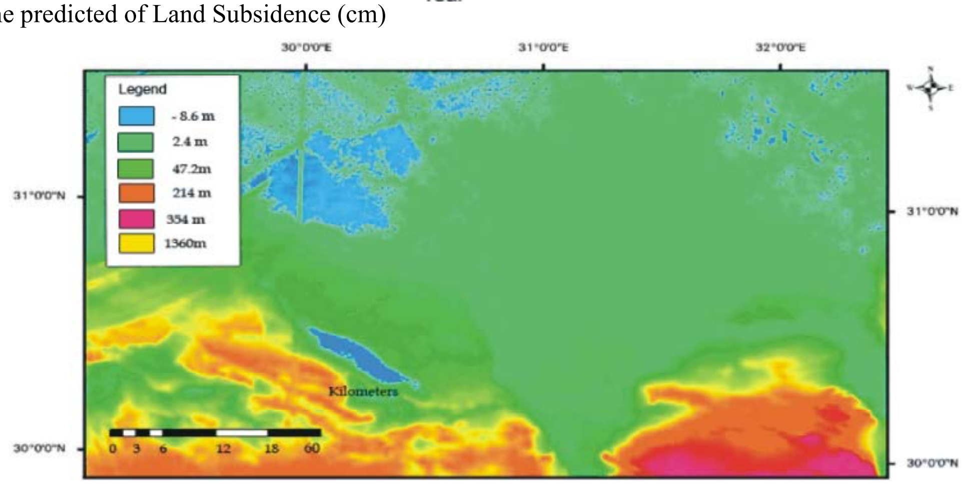

Fig. 8: Digital Elevation Model (DEM) of the northern Nile Delta, Egypt

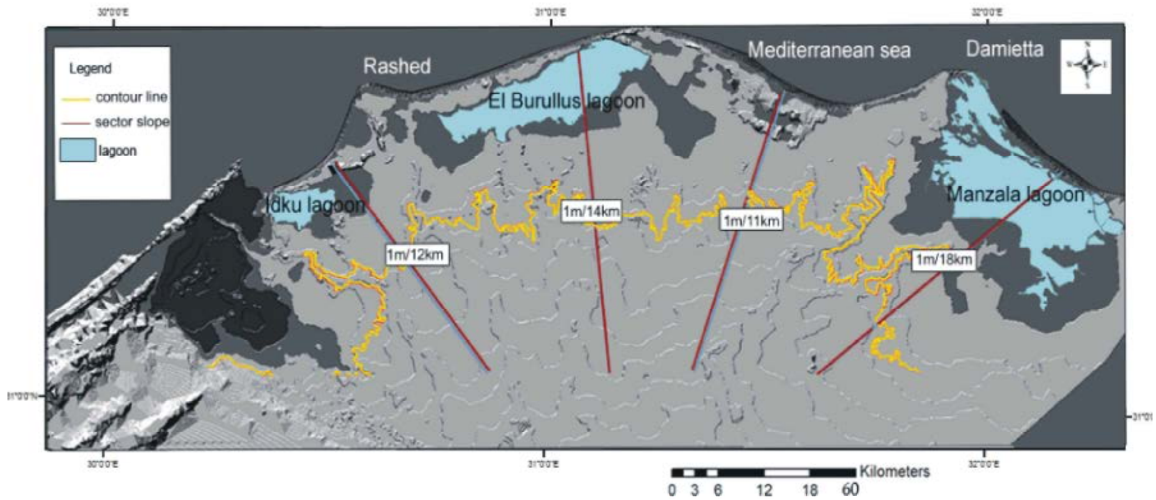

Fig. 9: Aspect module of the northern Nile Delta represents the slop direction

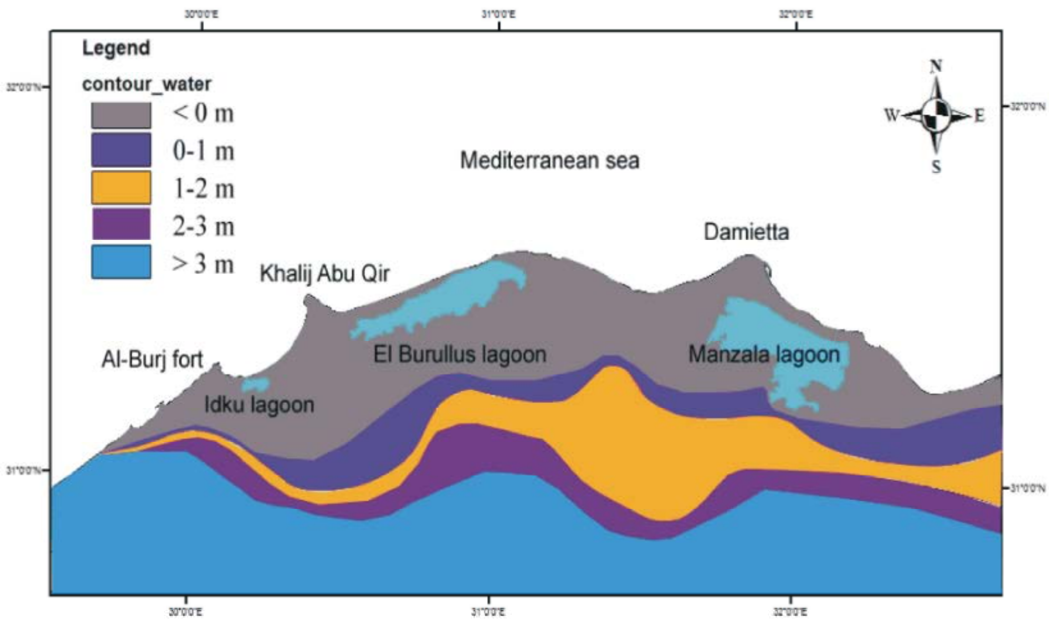

Fig. 10: Groundwater level range in study area

Ground Water Level: The groundwater level ranges between 0 m and less than 1m for most of study area (Fig. 10), which means that any excess of water will cause large danger on land. Sea level rise will allow to water to be moved towards land. Sea level rise on saturated land increase the total run off (flooding potentiality) and decrease the chance of downward infiltration recharge probability. In the central and southern portions of the flood plain, the downward leakage towards the Quaternary aquifer ranges between 0.25 and 0.8 mm/day, depending on the soil type, irrigation and drainage practices. In the desert areas, relatively high leakage rates are observed for basin, furrow and sprinkler irrigation (1.0-1.5 mm/day) with much lower rates for drip and central pivot irrigation (0.1-0.5 mm/day). Discharge of groundwater takes place through four processes: outflow into the drainage system, direct abstraction, evapotranspiration and inter-aquifer flow of groundwater. In 1985 the annual abstraction for both drinking water and irrigation was 460 million cubic meters and increased to 635 million cubic meters in 1997. Due to increase in desert fringes reclamation in the western Nile Delta region in the end of 19^{th}, the abstraction from groundwater increased dramatically to 1370 million cubic meters. This continuous discharge of groundwater, oil and gas increase the subsidence rate.

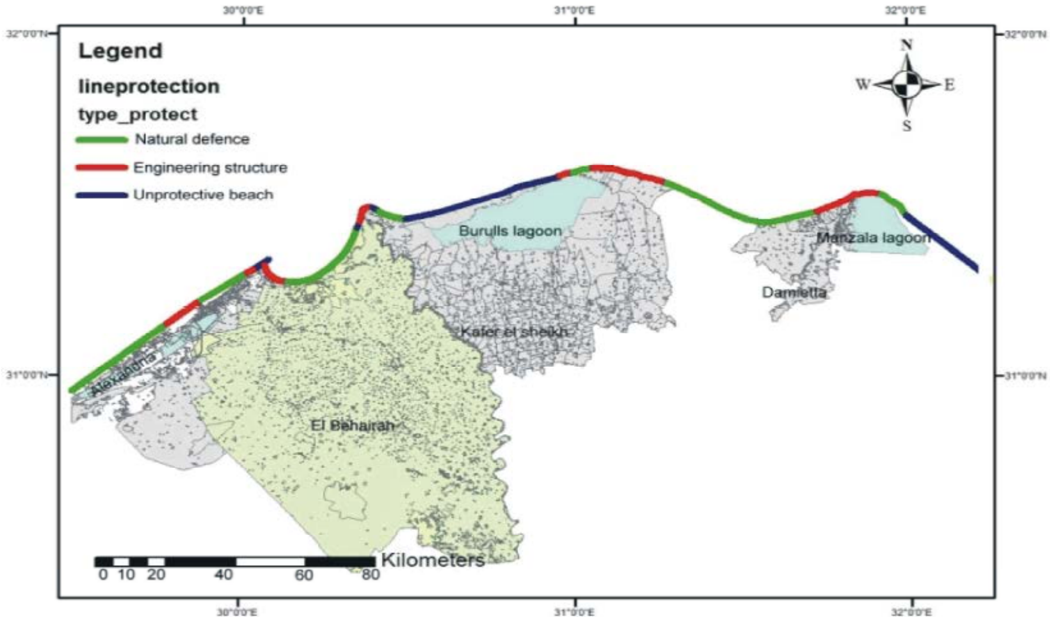

Fig. 11: The lower coastal plain of the Delta showing different protective conditions

Table 3: Detail of GIS input data

GIS	Data description	Data Source
	Land topography:	
Layer 1	Admin	Landsat 4 , Bands 7, 4, 2 Topographic map 1:50,000 scale
Layer 2	Shyakha	
Layer 3	Cultivated area	
Layer 4	Lakes	
Layer 5	Urban	
Layer 6	Irrigation	
Layer 7	Railways	
Layer 8	Roads	
Layer 9	Contour	
Layer 10	Elevation point	
Layer 11	Bridges	
Layer 12	Utilities	
Layer 13	Coastal protection: Line protection	Landsat 4 , Bands 7, 4, 2 Topographic map 1:50,000 scale
Layer 14	Ground water level: Ground water contour	Landsat 4 , Bands 7, 4, 2 Topographic map 1:50,000 scale
Layer 15	Geology maps: Fracture line and faults	Landsat 4 , Bands 7, 4, 2 Topographic map 1:50,000 scale

Coastal Protection: The coastal plain of the north Nile Delta is subdivided into three regions [6]. The first are the regions protected by engineer structure, the second one are the regions protected by natural defense, where the last regions are not protected (i.e. they haven't both natural and engineer defense). The later regions will be the opens, where the water will flow towards the land during sea level rise (see blue color, Fig. 11).

Risk Weight: Vulnerability assessment and ranking vulnerability is defined as "The degree to which a system is susceptible to, or unable to overcome with adverse effects of SLR, land subsidence and other studied criteria. Vulnerability is a function of the character, magnitude and the rate of climate variation to which a system is exposed, its sensitivity and its adaptive capacity" [25]. To detect the risk degree of each criterion, there are fifteen spatial data layers of input for overlaying in ArcGIS9.3 with GIS extension modules; Image Analysis and Spatial Analyst. Some details of input data are shown in Table 3. The actual weight for each criterion has been evaluated and total risks for the investigated governorate have been calculated. The author gives all parameters the same weight [10]. This weight refer to the effect of each parameter on the four studied governorates where helps to detect the total risk degree of each studied sites.

Table 4: Risk analysis of studied governorate due to land topography and risk degree.

Classes		Risk weight	Risk %	Risk degree
1	>3 cm	0	0%	Safe
2	3cm-1cm	0.5	0%-25%	Safe - low risk
3	1-50cm	1.0	25%-50%	Low risk-moderate risk
4	50-25 cm	1.5	50%-75%	Moderate risk-high risk
5	25-<0 cm	2.0	75-100%	High risk- very high risk

Table 5: Risk analysis of studied governorate due to SLR and risk degree

Classes		Risk weight	Risk %	Risk degree
1	0 cm	0	0%	Safe
2	0cm- 5 cm	0.5	0%-25%	Safe - low risk
3	>5 cm -<10cm	1.0	25%-50%	Low risk-moderate risk
4	>10<12 cm	1.5	50%-75%	Moderate risk-high risk
5	>12->22 cm	2.0	75%-100%	High risk- very high risk

Table 6: Risk analysis of studied governorate due to land subsidence and risk degree

Classes		Risk weight	Risk %	Risk degree
1	0	0	0%	Safe
2	>0-<30cm	0.5	>0-25%	safe - low risk
3	>30-42 cm	1.0	25-50%	low risk-moderate risk
4	42-72 cm	1.5	50%-75%	moderate risk-high risk
5	>72 cm	2.0	50-100%	high risk- very high risk

Table 7: Risk analysis of studied governorate due to ground water level and risk degree

Classes		Risk weight	Risk %	Risk degree
1	>3cm	0	0%	Safe
2	2-3cm	0.5	>0-25%	Safe - low risk
3	1-2 cm	1	25-50%	Low risk-moderate risk
4	<0-1cm	1.5	50%-75%	Moderate risk-high risk
5	0 cm	2	50-100%	High risk- very high risk

Table 8: Risk analysis of studied governorate due to coastal protection and risk degree

Classes		Risk weight	Risk %	Risk degree
1	Natural protect	0	0%	Safe to low risk
2	Engineering protect	1	>0-50%	Moderate risk
3	UN protected	2	50-100%	High to very high risk

Generally, the authors have been classified the studied criteria into five classes, expect the coastal protection criteria classified into three classes only. Each class has definite weight and they give a risk degree for each class (Tables 4-8). Sea level rise is the more extensive criteria with land subsidence that control the total risk weight of the study area. Groundwater, land topography and coastal protection criteria are also significant in calculating the total risk weight.

Case Studies: This part discusses the effect of the studied criteria on four coastal governorates (e.g. Damietta, Alexandria, Beheira and Kafr El-Sheikh) as case studies.

Alexandria Governorate: Alexandria Governorate is located to the west of the Rashid branch of the River Nile and is famous for its beaches, historic and archaeological sites. It is the eighth largest governorate in Egypt with a population of about 4.699,980 million.

Table 9: Total loss in land use/ land cover with different SLR and land subsidence at Alexandria governorate

Sector	SLR<0	SLR=10	SLR=22	L.S= 32	L.S=72
Population	22.44	57.12	5.44	83	83
Railway (km)	101981.5	149725.4	22373.067	274079.967	274079.967
Urban (km^2)	13.2	33.6	3.2	50	50
Cultivated (km^2)	764.6	22.2	1.2	788	788
Admin (km^2)	1019.1	1482.7	650.3	3152.1	3152.1
Irrigation (km)	337886.6	54169.29	3373.883	395429.773	395429.773

Table 10: Total loss in land use/ land cover of Al - Behairah Governorate with different SLR and land subsidence.

Sector	SLR<0	SLR=10	SLR=22	L.S =32	L.S =72
Population	8.95	6.25	7.1	8.51	1.8
Railway (km)	363412.735	168994.64	168994.64	168994.6	146665.2
Urban (km^2)	17.9	12.5	14.2	17.02	3.6
Cultivated (km^2)	1960641.2	5695.3	11382.6	11386.2	28420.8
Road (km)	1824583.345	529845.57	677448.162	817750.2	735627.36
Admin (km^2)	186933.9	3875.9	4458.3	4458.3	6151.12
Irrigation (km)	3392919.5	868983.94	1002957.079	1175013.9	873334.52

Table 11: Total loss in land use/ land covers of Kafr El Sheikh Governorate with different SLR and land subsidence

Sector	SLR=10	SLR=22	L.S =32	L.S =72
Population	1.28	2	1.44	1.36
Urban (km^2)	1.6	2.5	1.8	1.7
Cultivated (km^2)	158828.9	14191.9	14191.3	14183.9
Road (km)	2523186.61	385591.0	449039.6	444808.9
Admin (km^2)	16350.02	3211.6	3211.6	3345.34
Irrigation (km)	1770787.7	382324.26	474360.0	508640.003

Table 12: Total loss in land use/ land covers of at Damietta Governorate at different SLR and land subsidence.

Sector	SLR=10	SLR=22	L.S =32	L.S =72
Population	22	22	22	22
Urban (km^2)	1.2	1.2	1.2	1.2
Cultivated (km^2)	19584.2	19584.2	19584.2	19584.2
Road (km)	209453.03	209453.03	209453.03	209453.03
Admin (km^2)	1.2	1.2	1.2	1.2
Irrigation (km)	172011.40	172011.40	172011.40	172011.40

Table 13: Risk weight and risk degree of study area

Governorates Criteria	Land topography	Sea level rise	Land subsidence	Ground water	Coastal protection	Total average	Total risk
Alexandria	2	2	2	2	1	65-90%	Very high
Beheira	1	1.0	1.0	1.0	1.5	35-60%	Moderate to high
Kafr El- Sheikh	1.5	1.0	1.0	2	1.5	45-70%	Moderate to high
Damietta	0.5	0.5	0.5	2	1.5	25-50%	Low to moderate

It hosts the largest harbour in the country and about 40% of the Egyptian industrial activities. The risk analyses of Alexandria Governorate revealed that large parts of the area (>50% of total area) are subject to sink under sea water (e.g., Al-Amereya, Al-Montazah, Ar-Raml, Bab Sharqi, Karmouz, Moharam Bek, Sidi Gaber) by the year 2100 (Fig. 12 and Table 9) [39].

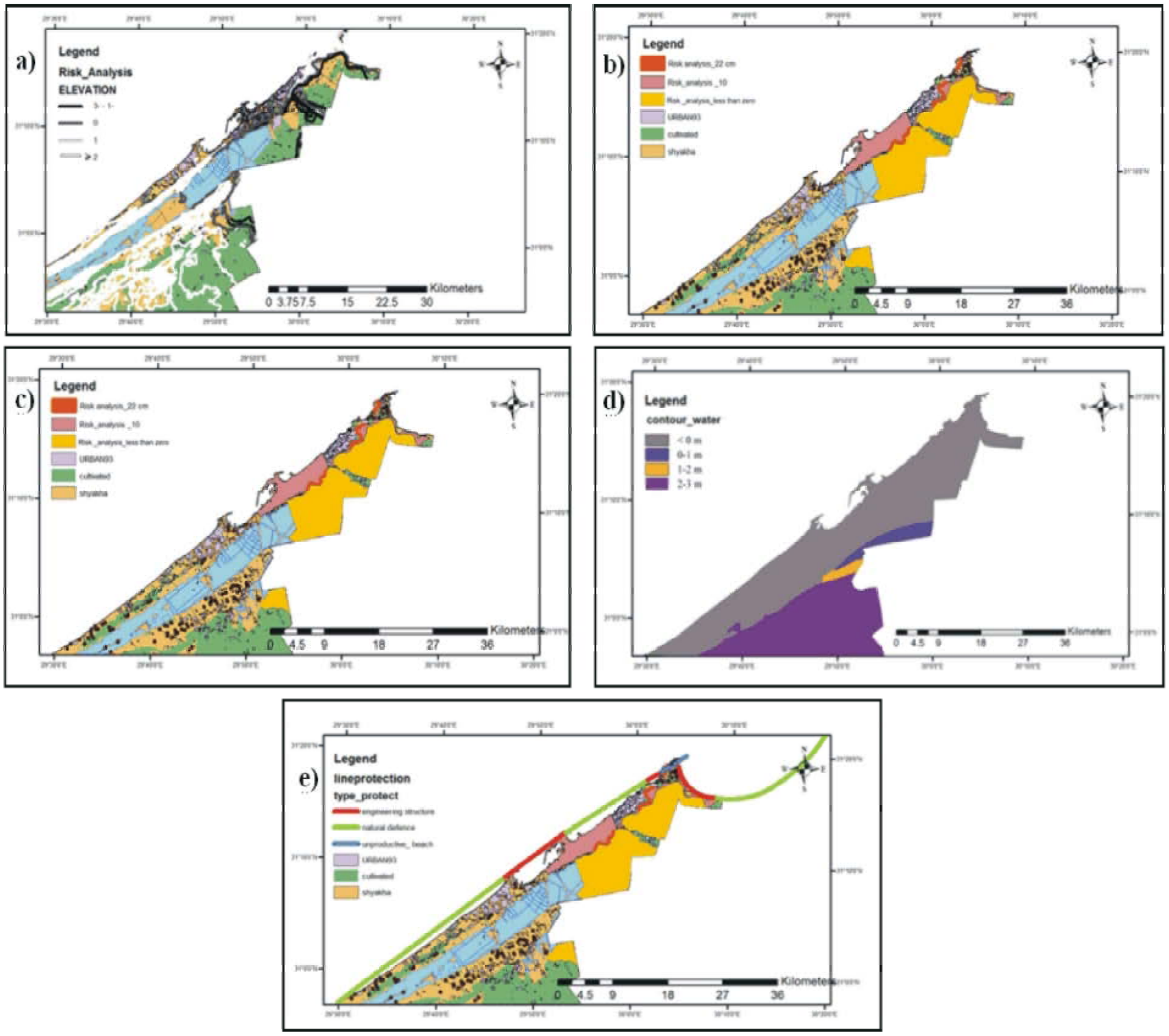

Fig. 12: Risk degree of Alexandria Governorate due to the studied criteria: a) land topography; b) sea level rise; c) land subsidence; d) ground water level and e) coastal protection criteria

Beheira Governorate: Beheira Governorate is located to the west of the Rashid branch of the River Nile and is famous for its historic and archaeological sites. It is the Fifth largest city in Egypt with a population of about 5,623,926 million [39]. The risk analyses of Beheira Governorate indicate that its northern parts (40% of total area) are subject to sink under sea water (e.g. Kafr El-Dawar, Abu Al-Matamir and Abu-Homos by the year 2100 (Fig. 13 and Table 10).

Kafr El-Sheikh Governorate: Kafr El-Sheikh Governorate is located on the Mediterranean Sea coast to the east of Damietta branch of the River Nile. In addition to its strategic position, Lake El Burullus, the largest of Nile Delta lakes is located in the governorate. It is the thirteenth largest governorate in Egypt with a population of about 3,118176 million [39]. The spatial analysis of Kafr El Sheik Governorate indicates that its northern eastern parts (10-15% of total area) are subject to sink under sea water by the year 2100 (e.g. Burullus, Al-Hamul, Metobas, Fowa, Biyala and Sisalim) (Fig. 14 and Table 11).

Damietta Governorate: Damietta Governorate is located on the Mediterranean Sea to the west of Damietta branch of the River Nile. In addition to its strategic position, it is

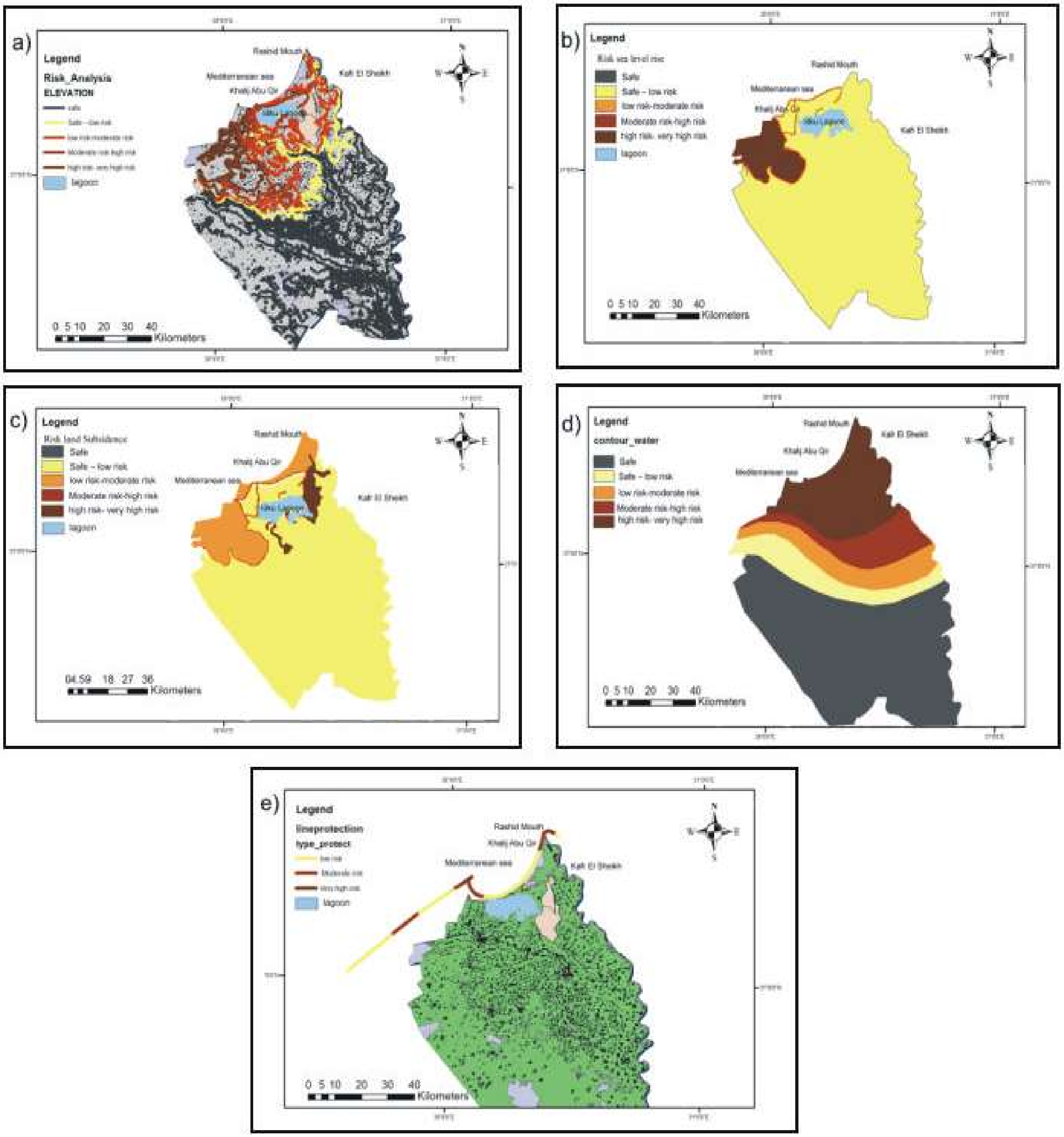

Fig. 13: Risk degree of Al Behairah Governorate due to studies criteria: a) land topography; b) sea level rise; c) land subsidence; d) ground water level and e) coastal protection criteria

the second largest tourist and trade centre of Egypt on the Mediterranean. Lake El Manzala, the largest of Nile delta lakes is located just to the east of the governorate. The GIS spatial analysis of Damietta Governorate indicate that most of study area are safe to low risk, however, very few parts (1- 2% of total area) of this governorate are subject to covered by sea water (e.g. Awlad Hamam, Al-Awadiyyah, Al-Hasaniyyah and Ar-Rahamnah) at the end of 21th century (Fig. 15 and Table 12).

Total Risk: Geostatistical analysis using ArcGIS 9.3 of the four studied governorates indicated that large parts of these coastal governorates subject to lost and buried under sea water (Table 13). The study revealed that the risk degree is moderate to high for Beheira, low to moderate for Damietta Governorate and very high for Alexandria Governorate (Table 13, Fig. 16). Field study shows that SLR is the more extensive criterion affecting the northern Nile Delta region. For examples, the rise of

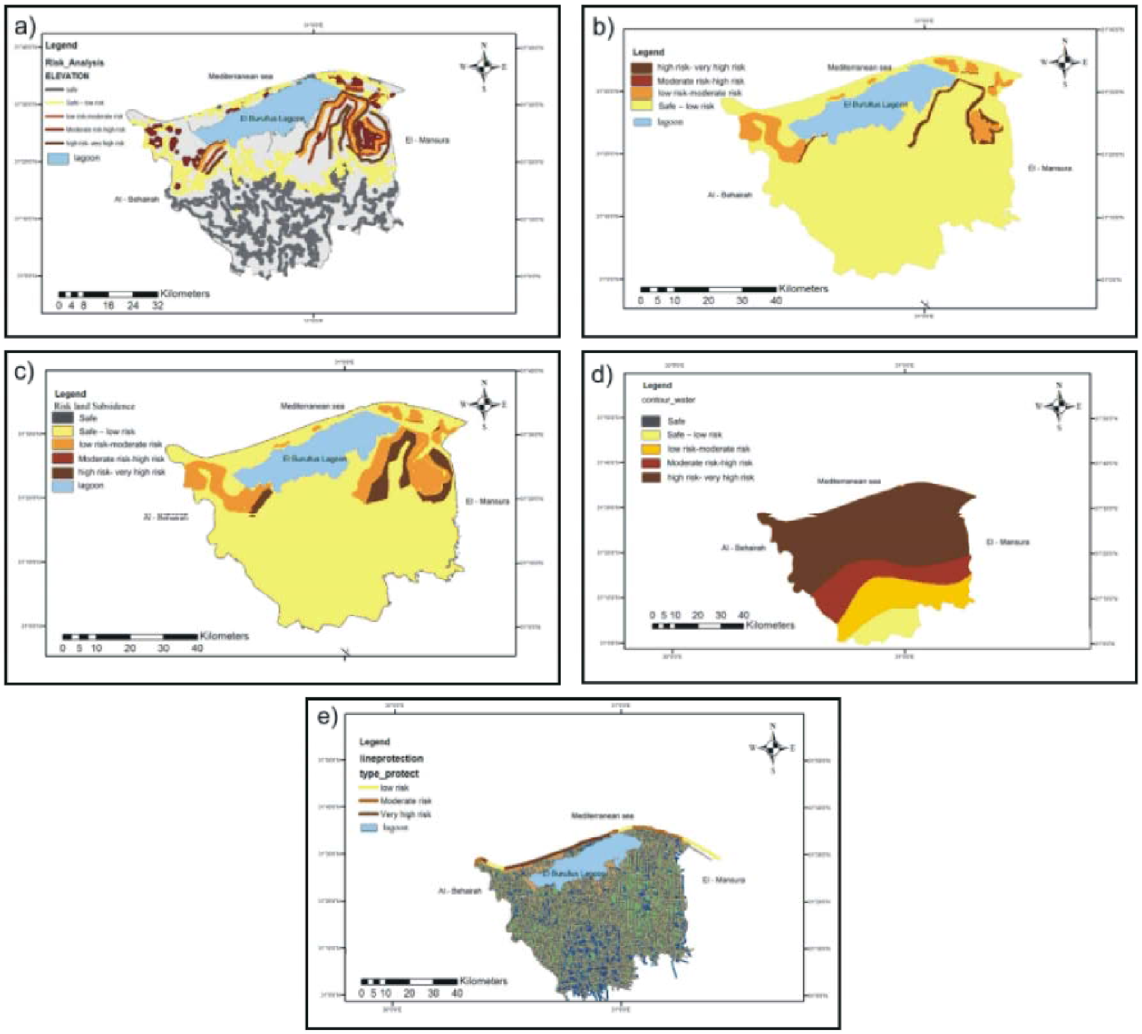

Fig. 14: Risk degree of Kafr El Sheikh Governorate due to studies criteria: a) land topography; b) sea level rise; c) land subsidence; d) ground water level and e) coastal protection criteria

Sea level leads to death of palm trees in Rashid (Fig. 17a) and increases the chemical weathering of historical archaeological sites (Fig. 17b). In addition to, the ground water table level instability increases the distortion and inclination of building and infrastructure (Fig. 17c).

CONCLUSIONS AND RECOMMENDATIONS

The coastal zone of Nile Delta is presently under going extensive change caused by natural and anthropogenic influences. Natural factors affecting changes of the Nile Delta coast including sediment supply, coastal process, tectonic activities, climatic changes and SLR. Application of five-stage vulnerability assessment methodology using remote sensing, GIS and modelling techniques, have enabled a quantitative assessment of the risks of each sector and each district of four important governorates of Egypt on the Mediterranean coast of the Nile Delta due to SLR and land subsidence. Spatial and geostatistical analyses indicate high vulnerability and severe economic losses. This vulnerability have been increased at the end of 20th century, especially after the construction of High Dam and cut off of Nile sediments. The study indicates that coastal zone mostly subject to buried under seawater by end of 21st century. The study also indicate that the risk degree of studied governorates range between low - moderate to high risk, which may result in population displacement of about 4 million, loss of jobs of about 0.5 million and tourism income may also be lost due to SLR.

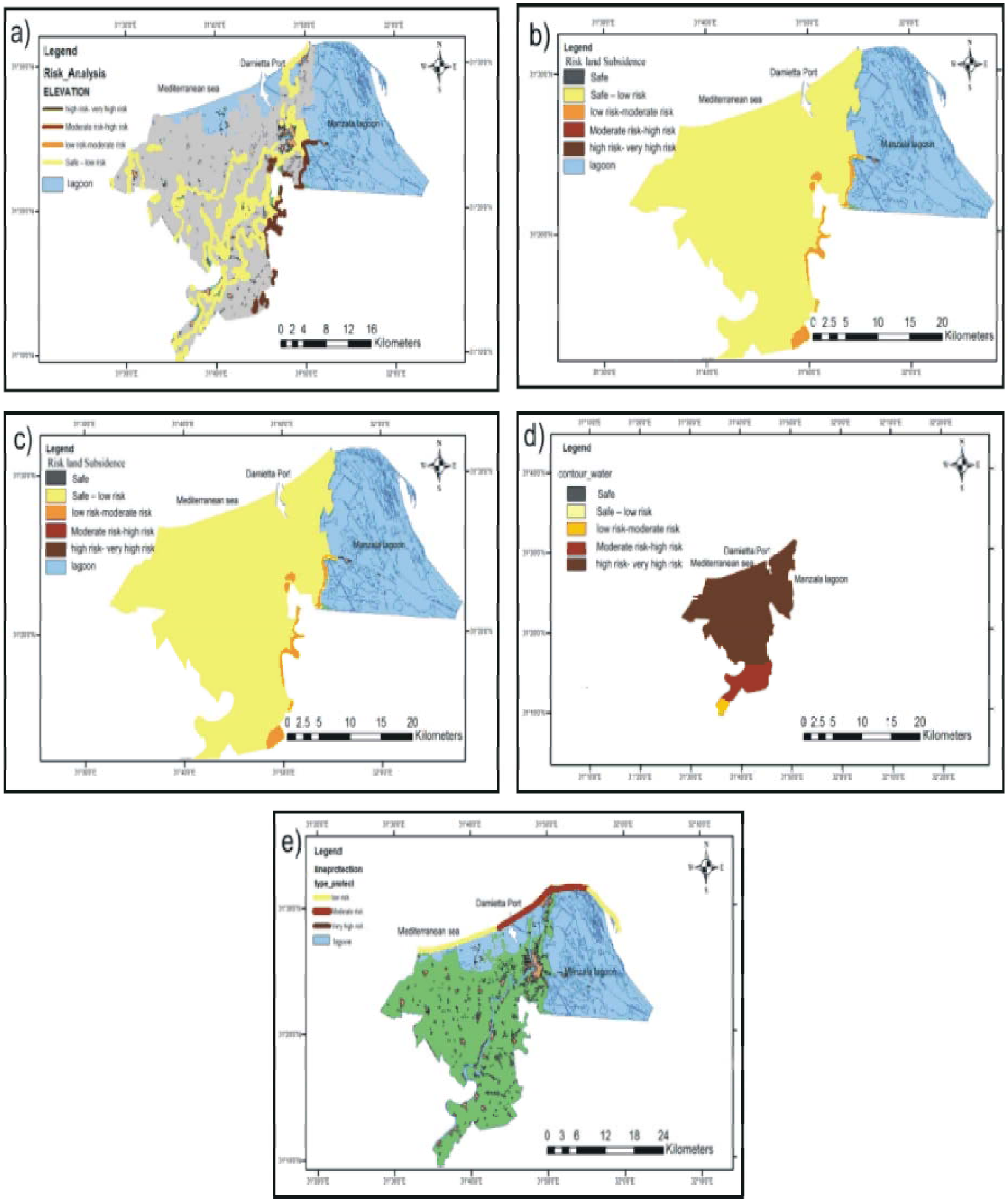

Fig. 15: Risk degree of Damietta Governorate due to studies criteria: a) land topography; b) sea level rise; c) land subsidence; d) ground water level and e) coastal protection criteria.

The study recommended using decision- support systems based on GIS for future sustainable development and planning of the coastal area in Egypt. Short-term adaptation measures are also necessary in the frame of the no regrets policy. These involving beach nourishment, sand dune fixation, upgrading awareness and building institutional capability in the integrated coastal zone management are highly recommended.

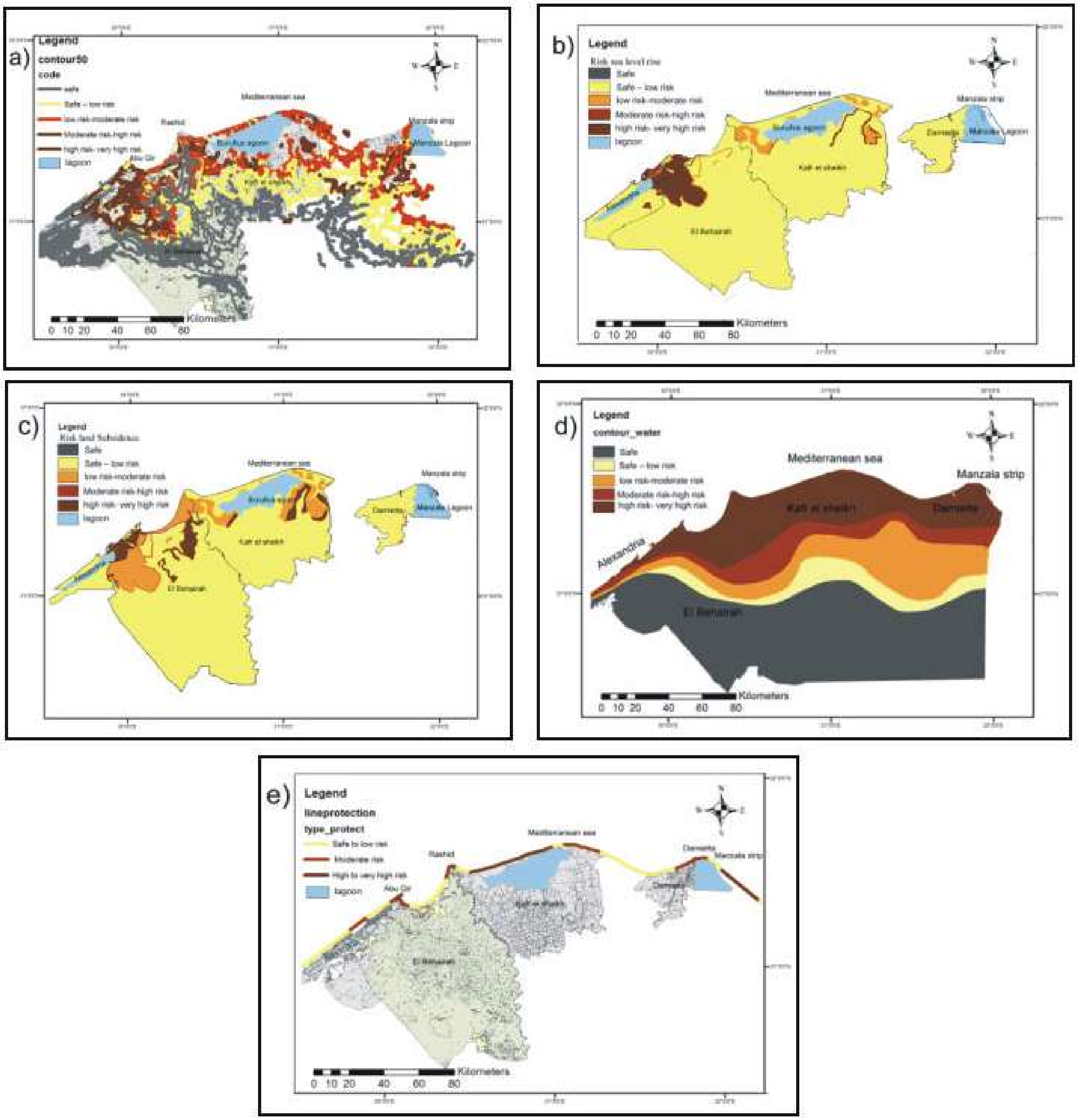

Fig. 16: Total risk degree of studied governorates due to the studied criteria a) land topography; b) sea level rise; c) coast protection; d) groundwater level; e) land subsidence

Fig. 17: The effect of rise of Mediterranean Sea and groundwater levels on study area; a) death of palm trees in Rashid; b) chemical weathering on the floor of Rashid Bay Citadel; C) distraction and inclination of building.

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