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Multi-Criteria Risk analysis of Al-Behairah Governorate, North Nile Delta, Egypt

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Abstract: The quantitative assessment of the vulnerability of the Nile Delta coast of Egypt to the impacts of SLR and land subsidence is presented the answer for the following questions; analysing the risks, ranking the vulnerability and suggesting adaptation measures. Determine the social and biophysical vulnerability demonstrates the asymmetrical impacts of the SLR on the Mediterranean coast of Egypt, select areas at risk in Al Behairah governorate. Geographic information system (GIS) and Remote sensing (RS) techniques is powerful tool for handling and organized spatial information that can help to assess the ranges of vulnerability ranking for the study area. Geostatistical analysis using ArcGIS 9.3 of the studied governorate indicated that large parts of their coastal areas subject to be lost and buried under sea water by the year 2100. The study revealed that the risk degree is moderate to high (35-60%). Field study shows that SLR is the more extensive criterion affecting the northern Nile Delta region. For examples, the rise of Sea level leads to death of palm trees in Rashid and increases the chemical weathering of historical archaeological sites. In addition to, the ground water table level instability increases the distortion and inclination of building and infrastructure.

Key words: Risk analysis · Al-Behairah · North Nile Delta

INTRODUCTION

The study area is located in the western Nile delta, Egypt and is situated between Latitudes 30° 36` 40`` and 31° 19` 35`` N and longitudes 30° and 30° 51` 26`` E (Fig. 1). It is the fifth largest city in Egypt, covers an area of 4084 km^2. The area under investigation characterized by many archaeological sites such as (King Farouk Castle, Gardens Aqueduct Edfina, etc.....). Al-Behairah governorate is located mainly in low-lying coastal region which subject it to many environmental impacts such as Sea level rise (SLR), coastal erosion, loss of coastal wetlands and impacts on biodiversity [1]. This impact may cause the distraction of many economic, social and biologic systems. The aims of the present study are to determine and assess the different geo-environmental hazard criteria affecting on Al-Behairah governorate and trying to mitigate its risk using Remote Sensing (RS) and Geographic Information System (GIS) techniques.

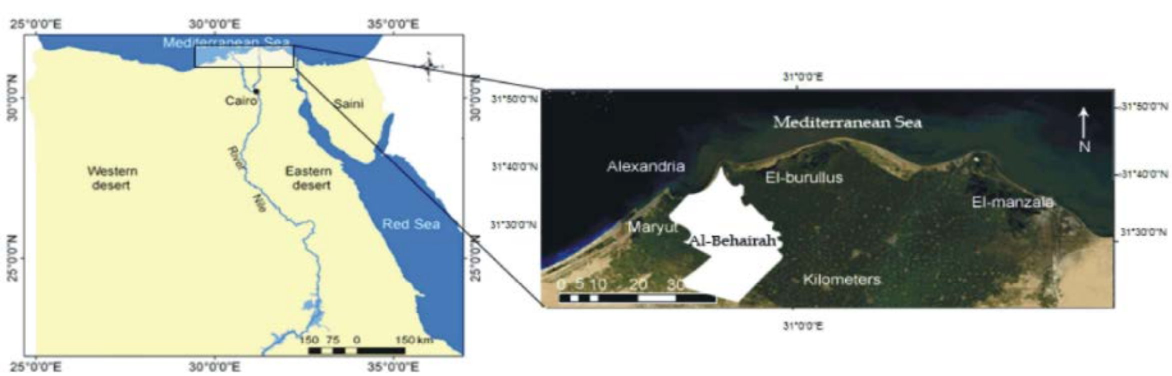

Fig. 1: Location map of study area

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MATERIALS AND METHODS

The study area is included in four Landsat Thematic Mapper (TM). The RS, GIS and modelling techniques were applied (Fig. 2):

- Remote sensing techniques include visual and digital interpretation of Land sat TM image (bands 7, 4, 2).
- Identify different natural and cultural criteria and its parameters (Land topography, Sea level rise, Land subsidence, Ground water, Coast protection).
- Spatial analysis for different criteria.
- Risk analysis, risk weight and risk degree.

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

Sea Level Rise: According to Brochier and Ramieri [2], the mean global SLR is about 1-2.5 mm/year for the past 100 years. Church *et al.* [3] computed a global 1.8±0.3mm/year rise for 1950-2000. The SLR that recorded between 1950 and 2000 is about 2.5±0.2 mm/year [4, 5], while this value increases to 3.1 mm/year [6]. SLR in the Mediterranean over the 20th century has been quite similar to the average global SLR of 0.5-2.5 mm/year [7]. According to the maximum global Mediterranean SLR of Micha and Michal [7], the predicated Mediterranean SLR during 2010 and 2100 has been calculated for the Nile Delta region (Table 1, Fig. 3).

Land Topography: Land use/land cover of Al-Behairah governorate (Fig. 4) was delineated using the digital elevation model (DEM) of landsat TM image and topographic map scale 1:50000. Generally, the study area is nearly flat and range in elevation between -3 m to >2m above the mean sea level (Fig. 5). The study area inclined towards the north direction, this well clear in the digital elevation model (DEM) and aspect model (Figs. 6 and 7).

Land Subsidence: Many researchers have been delated with land subsidence (LS) rate in Nile Delta region using different techniques. Stanley and Goodfriend [8] suggested 3.98 mm/year rate, Stanley and Toscano [9] indicated a 4-5 mm/year, while Becker and Sultan [10] suggested rate as 2 to 8 mm/year. According to the maximum subsidence rate of Nile Delta [10], the predicated subsidence rate during 2010-2100 has been calculated for the Nile Delta region (Table 2). A scenario of maximum global of sea-level rise (2.5 mm) [7] over the next century is assumed, taking land subsidence (8.0 mm yr^{-1}) [10] into consideration.

Table 1: The predicted values of sea level rise (cm) during the years 2010 -2100 according to Micha and Michal [7]

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

Table 2: The predicted of land subsidence (cm) according to Becker and Sultan [10]

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

Ground Water Level: The groundwater level in area under investigation (0-□1m, Fig. 8), not allow to any excess of precipitated water to be infiltrated to Nile Delta, this may lead to decrease the chance of downward infiltration recharge and increase the flood's potentiality. Due to the soil type, irrigation and drainage practices, the downward infiltration rate to the Quaternary aquifer range between 0.25 and 0.8 mm/day. There are four processes controlling the groundwater discharge. These processes are outflow into the drainage system, direct abstraction, evapotranspiration and inter-aquifer flow of groundwater. From 1985-1997 the annual abstraction of ground water increased from 460*10^{6} to 635*10^{6} m^{3}. This continuous discharge of groundwater, oil and gas increase the subsidence rate.

Coastal Protection: The coastal plain of Al-Behairah governorate extends to more than 33 km along the Mediterranean Sea. The study indicated that most Al-Behairah Governorate is protect by natural and cultural defence (>90%). However the UN protected plain extends to 2 km at al Burj Rashid sector. This plain will play the open, where the water passes to cover the land (Fig. 9).

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 [6]. To detect the risk degree of each criterion, there are fourteen spatial data layers of input for overlaying in ArcGIS9.3 with GIS extension modules;

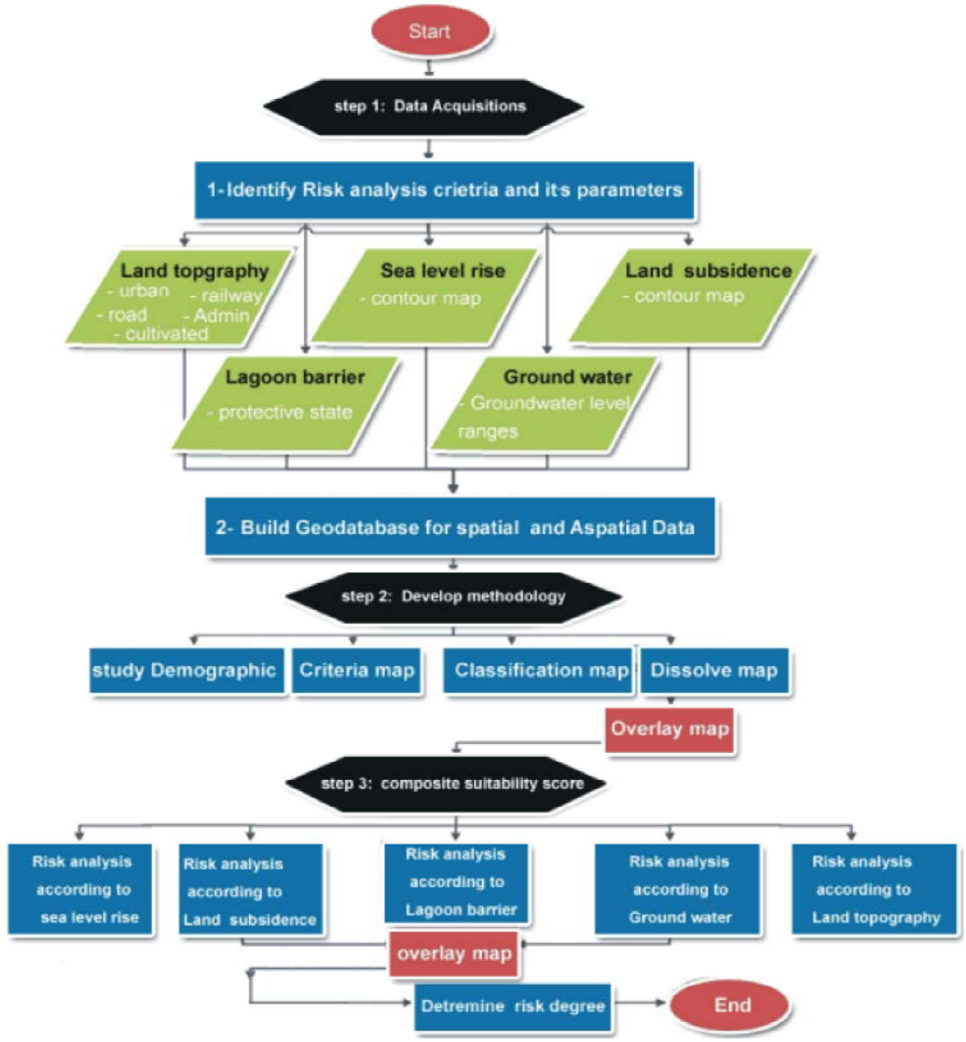

Fig. 2: Flow chart showing the workflow diagram

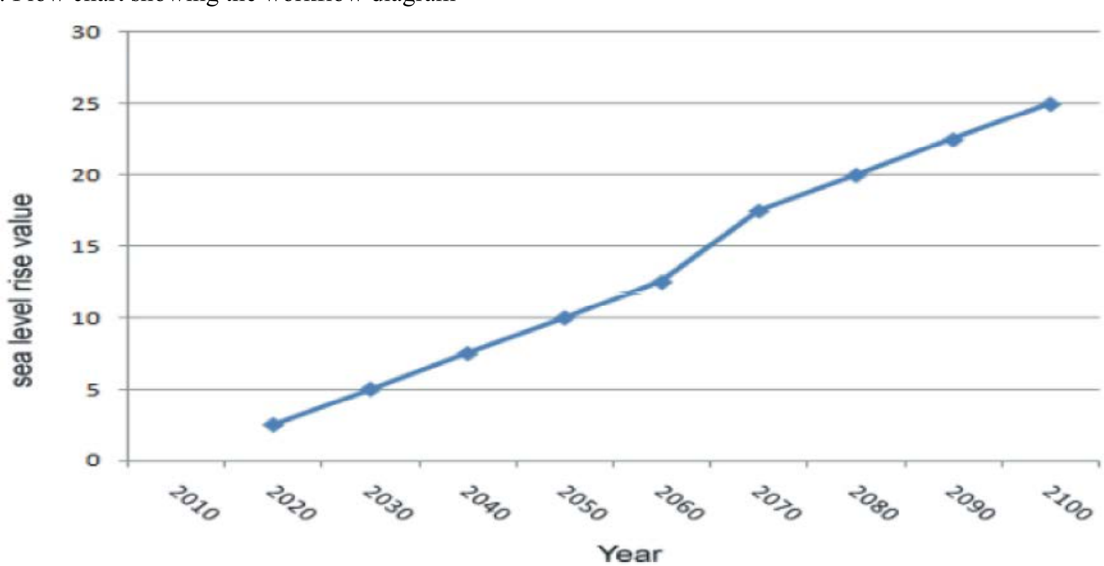

Fig. 3: The predicted values of the sea level rise (cm)

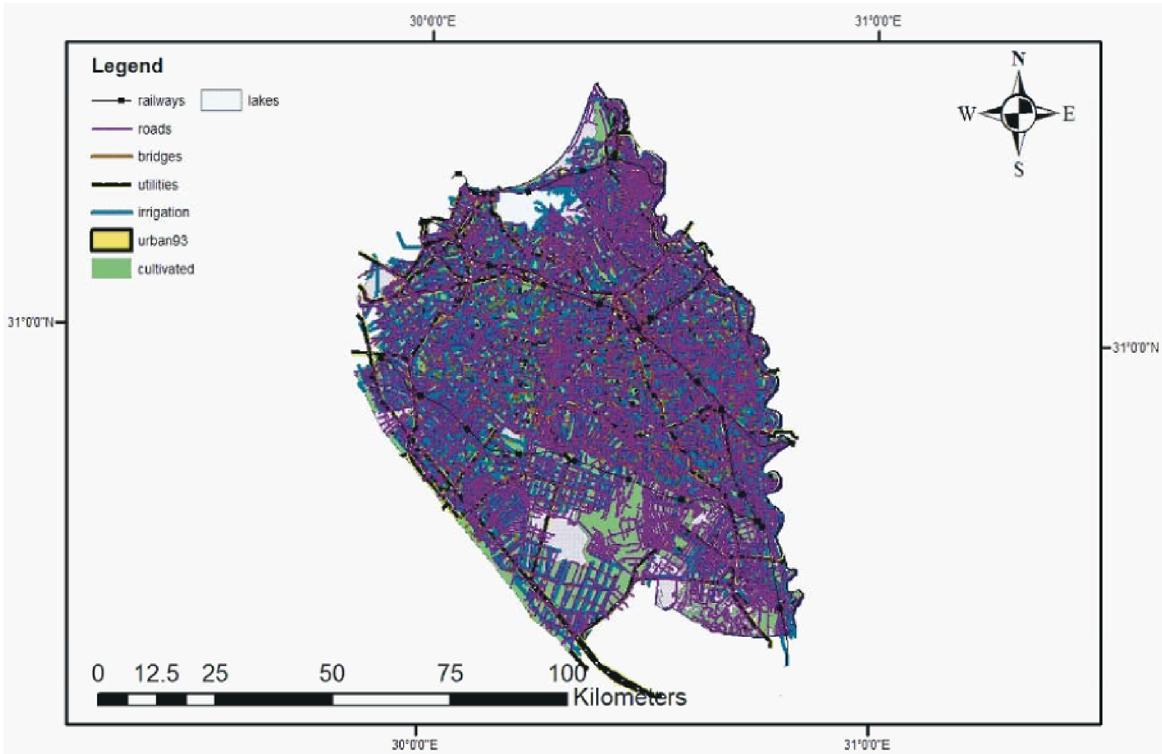

Fig. 4: Land use/ land cover classes of Al - Behairah governorate

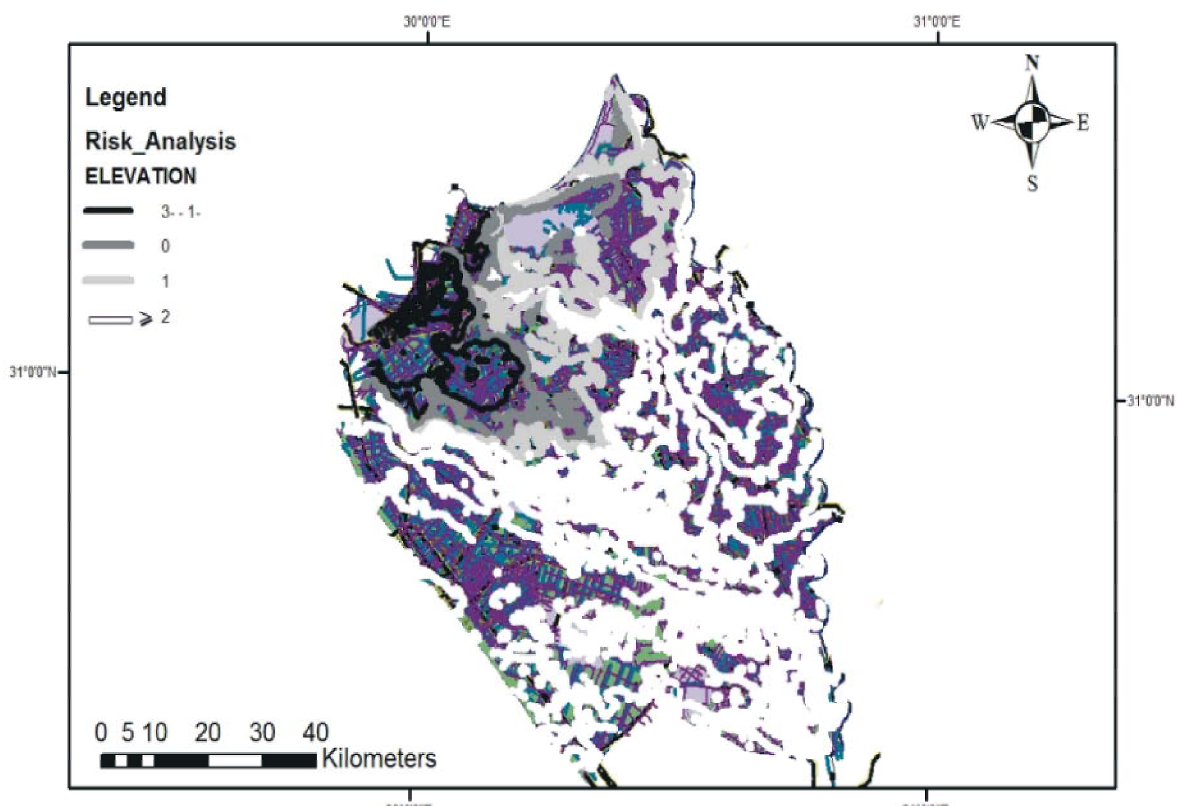

Fig. 5: Risk analysis due to land topography for Al - Behairah governorate

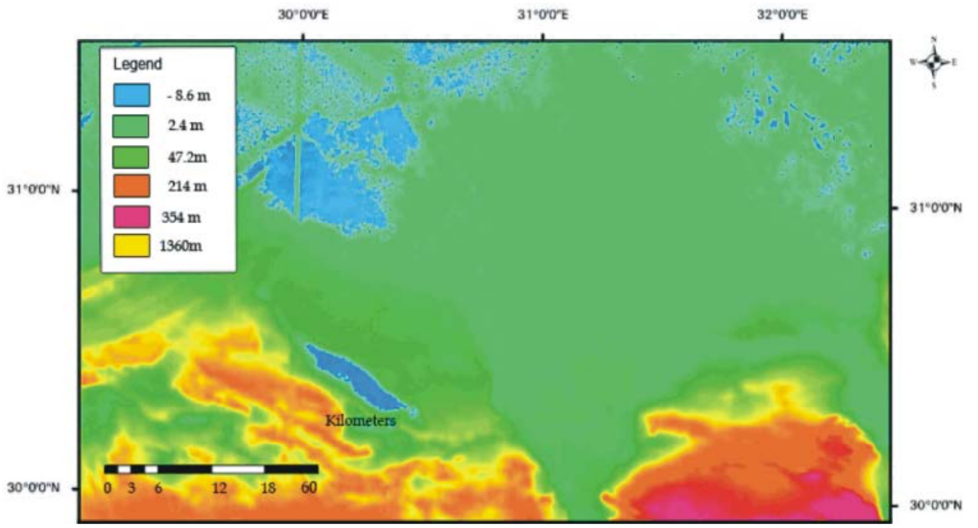

Fig. 6: Digital elevation model (DEM) of the northern Nile Delta, Egypt

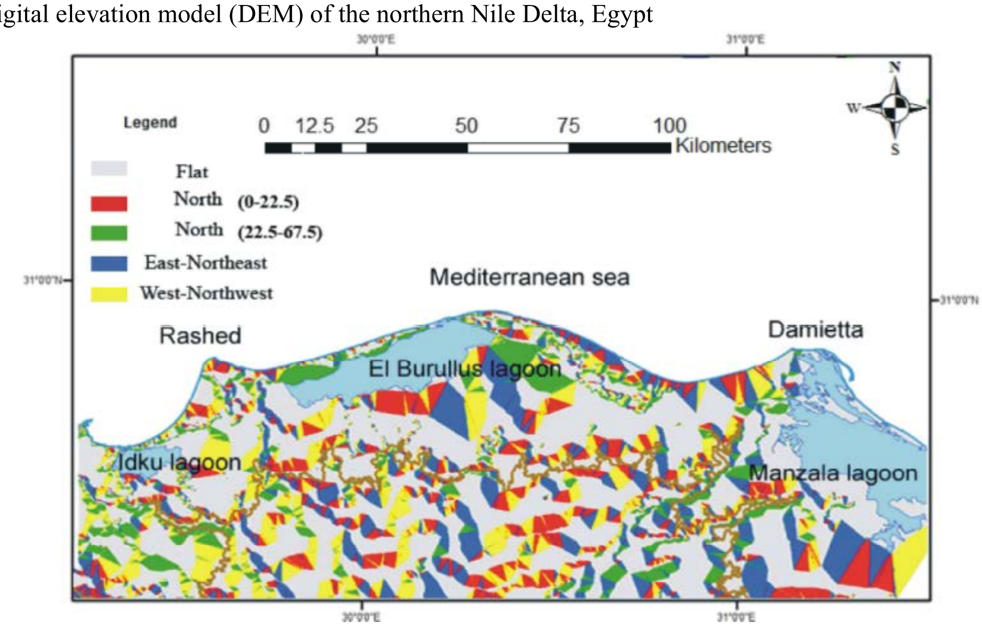

Fig. 7: Aspect module of the study area represents the slop direction

Table 3: Detail of GIS input data

GIS	Data Description	Data source
	Land topography:	Landsat 4, bands 7, 4, 2 and topographic map, scale 1:50,000
Layer 1	Admin	
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 and topographic map, scale 1:50,000
Layer 14	Ground water level: Ground water contour	Bands 7, 4, 2 and topographic map, scale 1:50,000

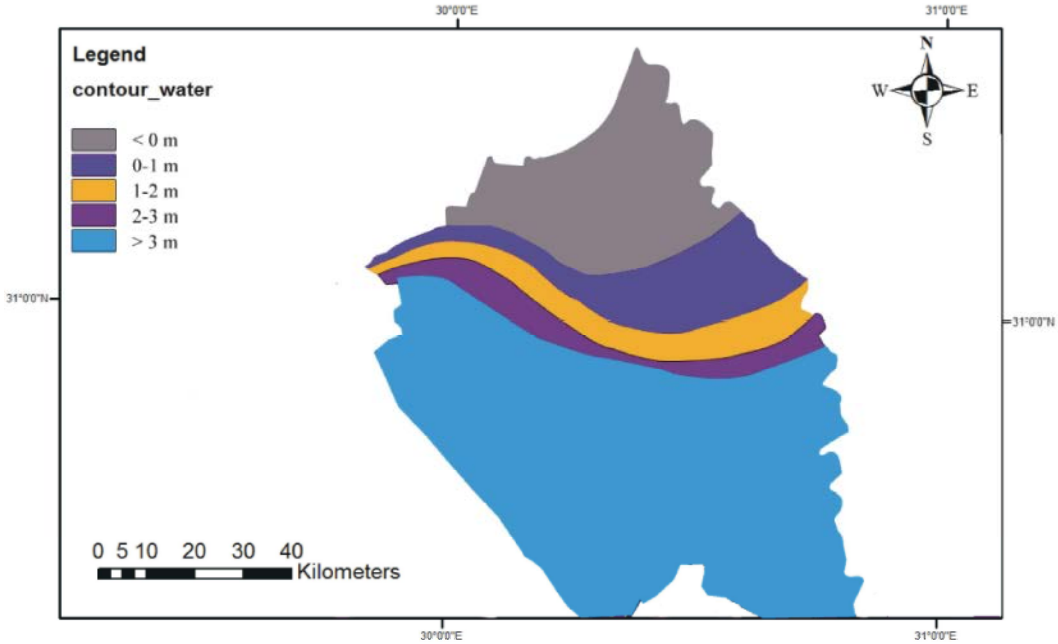

Fig. 8: Groundwater level range in study area

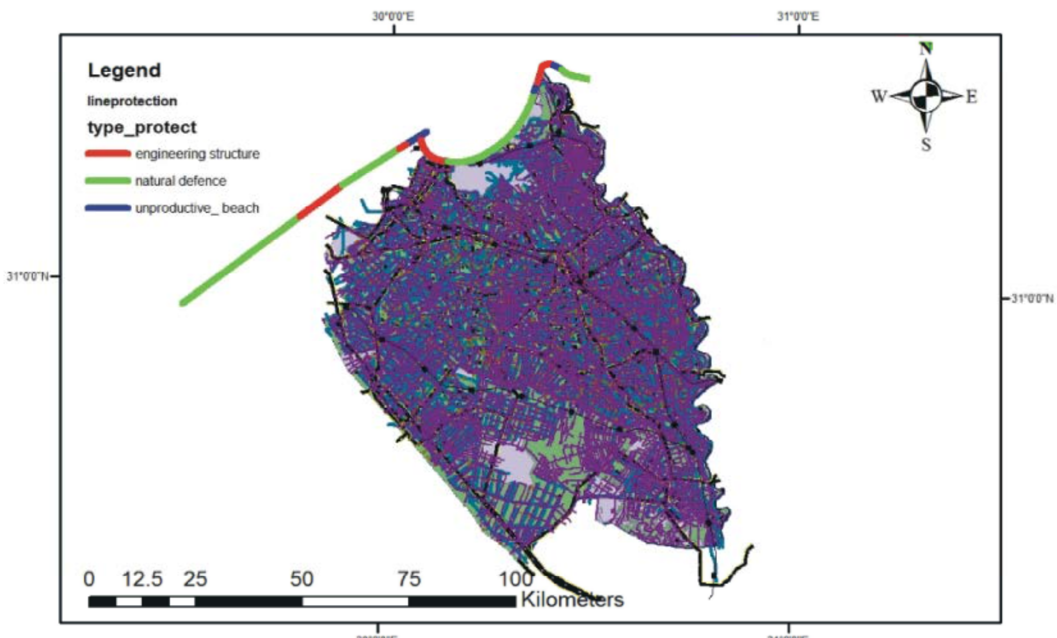

Fig. 9: The lower Mediterranean coastal plain showing different protective conditions

(Image Analysis and Spatial Analyst). Some details of input data are shown in Table 3. The author detects five criteria that mainly control the risk degree of study area. Who gives a same weight for each criterion [11]. The actual weight for investigated criteria has been calculated due to their effect on study area, the total actual weights for studied criteria will indicate the risk percent. 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. They give a risk degree for each class (Tables 4, 5, 6, 7 and 8). The study indicated that 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.

Table 4: Risk analysis of Al-Behairah governorate due to land topography and risk degree

No	Class	Risk weight	Risk %	Risk degree
1	>3 m	0	0	Safe
2	3 m-1m	0.5	0 - 25	Safe - low risk
3	1-50 cm	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 - very high risk

Table 5: Risk analysis of Al-Behairah governorate due to SLR and risk degree

No	Class	Risk weight	Risk %	Risk degree
1	0 cm	0	0	Safe
2	0 cm - 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 - very high risk

Table 6: Risk analysis of Al-Behairah governorate due to land subsidence and risk degree

No	Class	Risk weight	Risk %	Risk degree
1	0	0	0	Safe
2	>0 - <30 cm	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 - very high risk

Table 7: Risk analysis of Al-Behairah governorate due to ground water level and risk degree

No	Class	Risk weight	Risk %	Risk degree
1	>3m	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	0m	2	50 - 100	High risk- very high risk

Table 8: Risk analysis of Al-Behairah governorate due to coastal protection and risk degree

No	Class	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

RESULTS

This part presents the answer for the following questions; analyzing the risks, ranking the vulnerability and suggesting adaptation measures to mitigate the impact of the SLR along the Mediterranean coast of Egypt. Determine the social and biophysical vulnerability demonstrates the asymmetrical impacts of the SLR on the Mediterranean coast of Egypt, select areas at risk in Al-Behairah governorate. Sea level rise criteria used to detect the area that may expose to cover by seawater at the present case (2010) and during the present century (from 2013-2050 and from 2050-2100) (Figs. 10 and 11). Land subsidence is due to initiation of deep seated faults and continues discharge of groundwater, oil and gas. This continues subsidence with sea level rise will expose many sectors of Al-Behairah governorate to sink in the next few years. GIS technique used to detect these sectors (Figs 12 and 13). At the northern part of Al - Behairah governorate, the ground water level ranges between zero to less than 1m expect few areas. This level subject governorate for incoming sea level risk (Fig. 8). Total area exposed to ground water risk 1194.0 km^2. Figure 14 shows that all studied criteria have an effect on the future

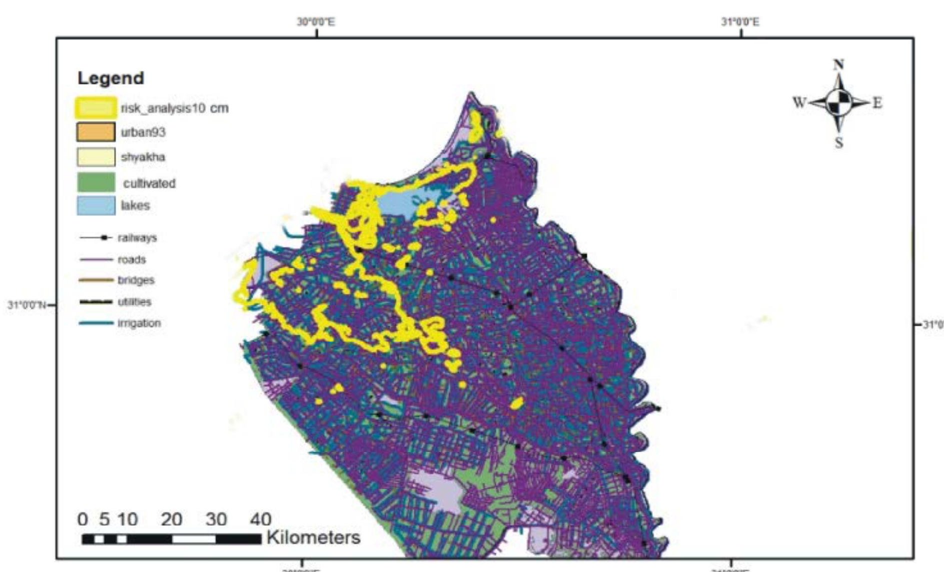

Fig. 10: Estimation of expected loss resulting from 10 cm rise in sea level at Al - Behairah governorate (2010)

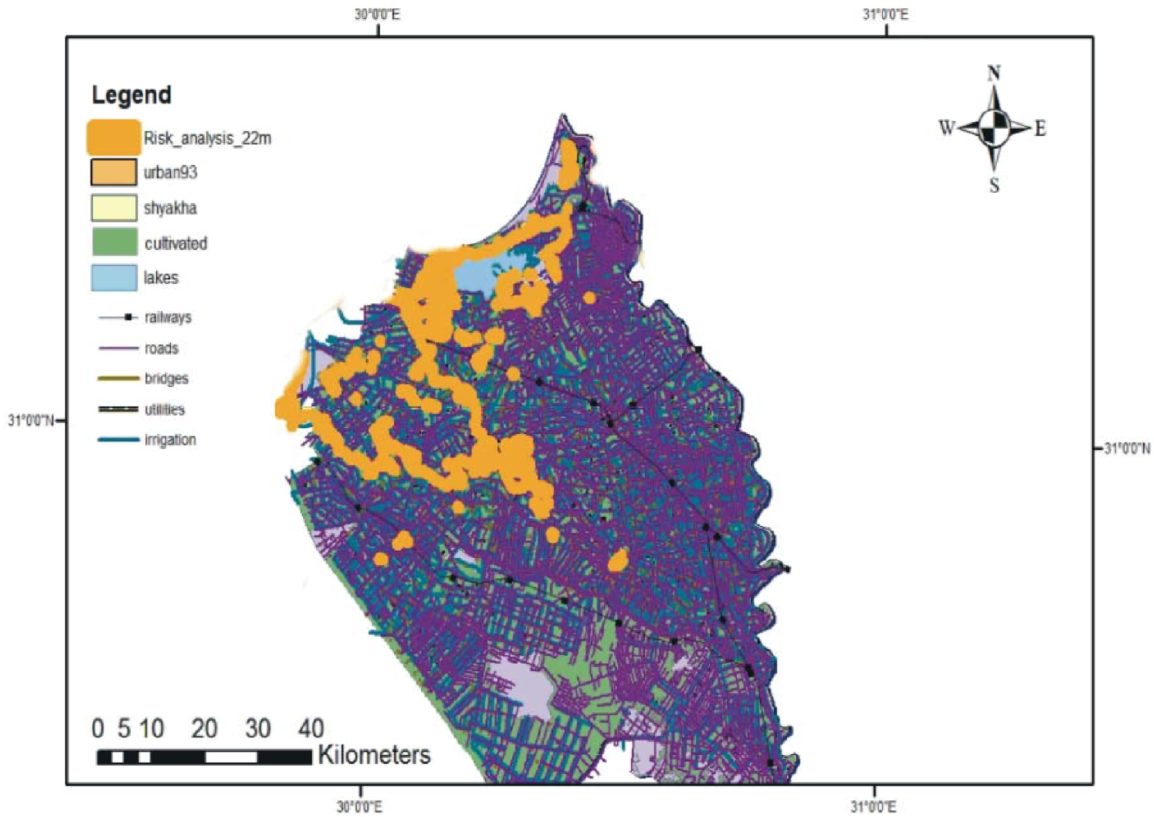

Fig. 11: Estimation of expected loss resulting from 22.5 cm rise in sea level at Al -Behairah governorate (2050)

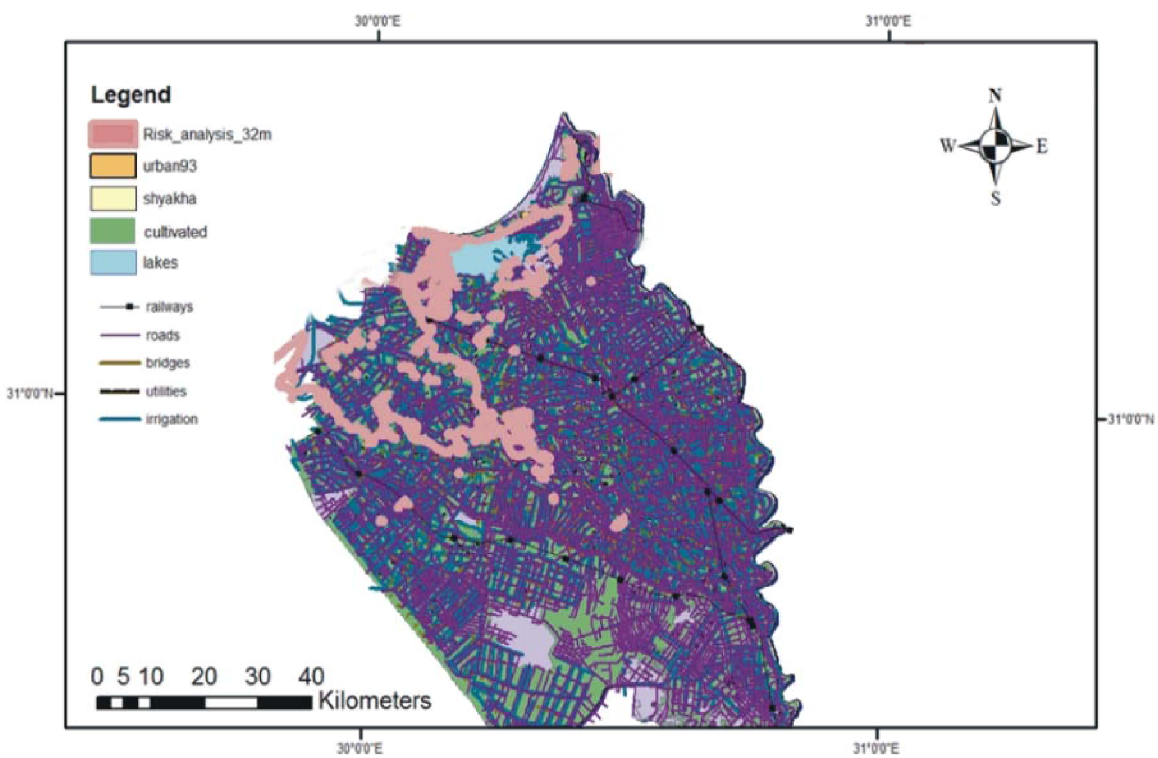

Fig. 12: Estimation of expected loss resulting from 32 cm land subsidence at Al -Behairah governorate (2050)

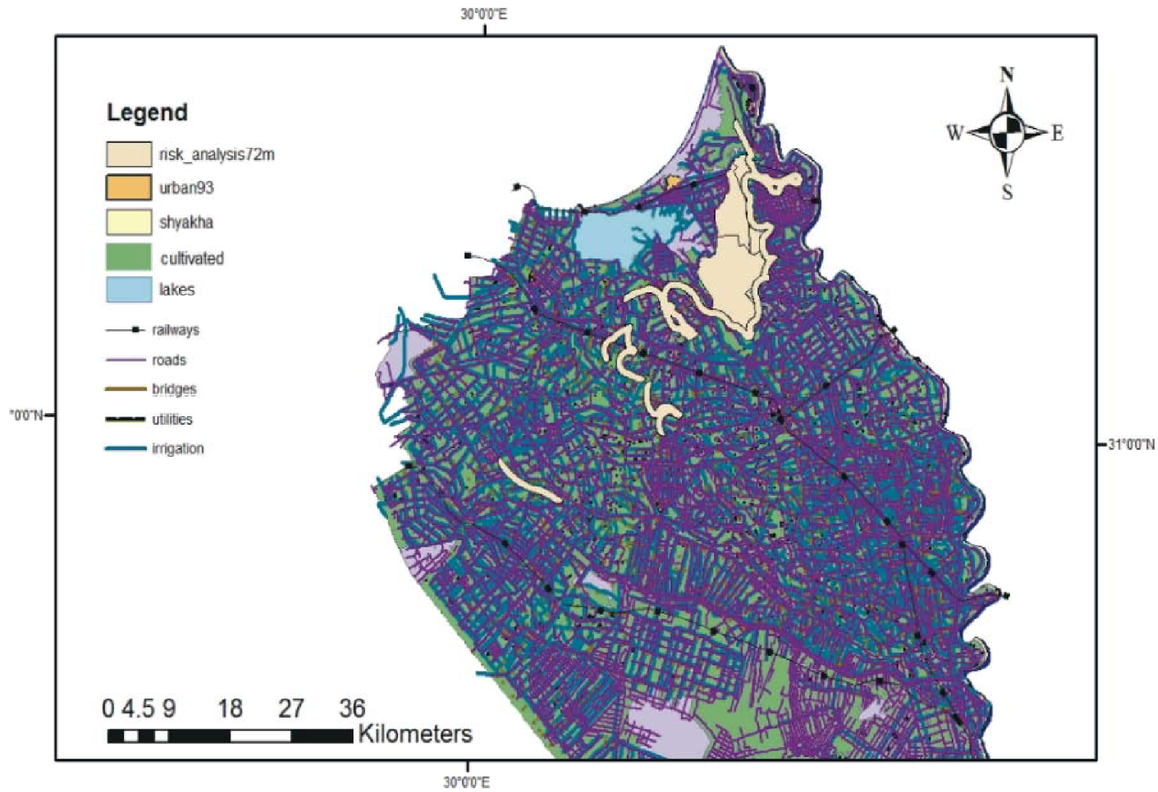

Fig. 13: Estimation of expected loss resulting from 72cm land subsidence at Al -Behairah governorate (2100)

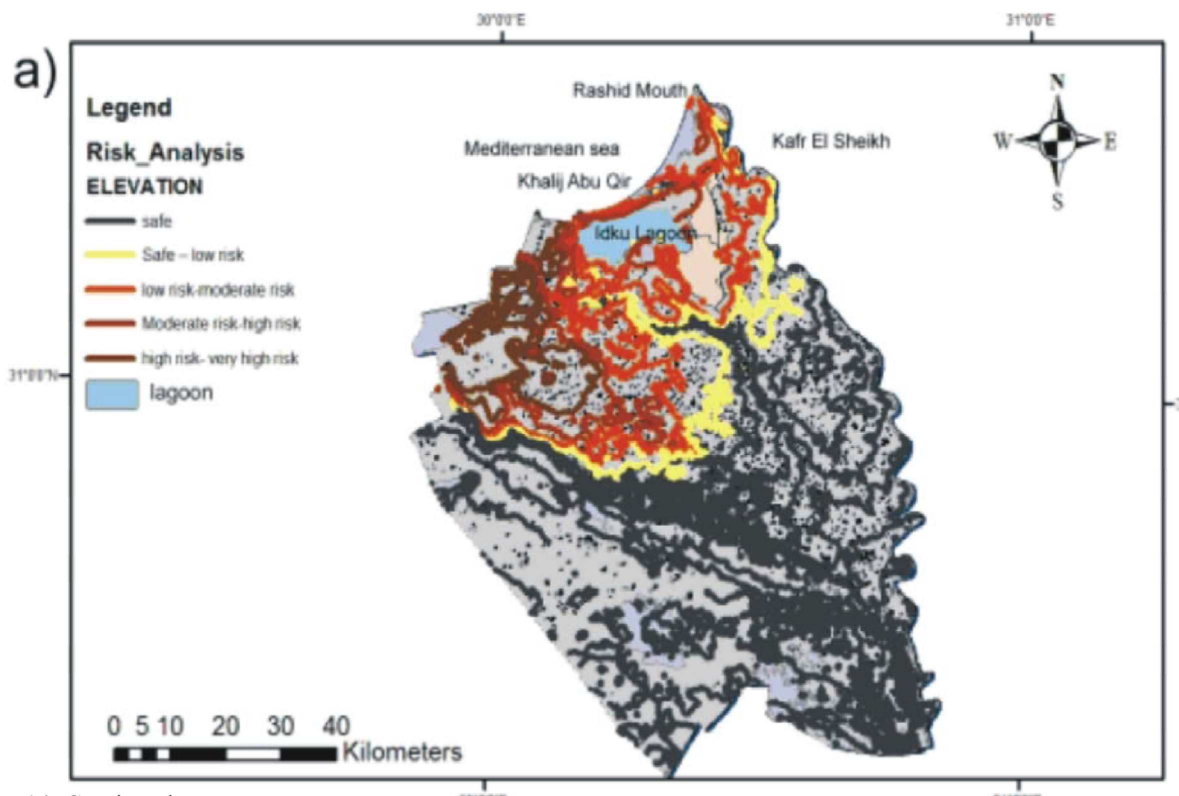

Fig. 14: Continued

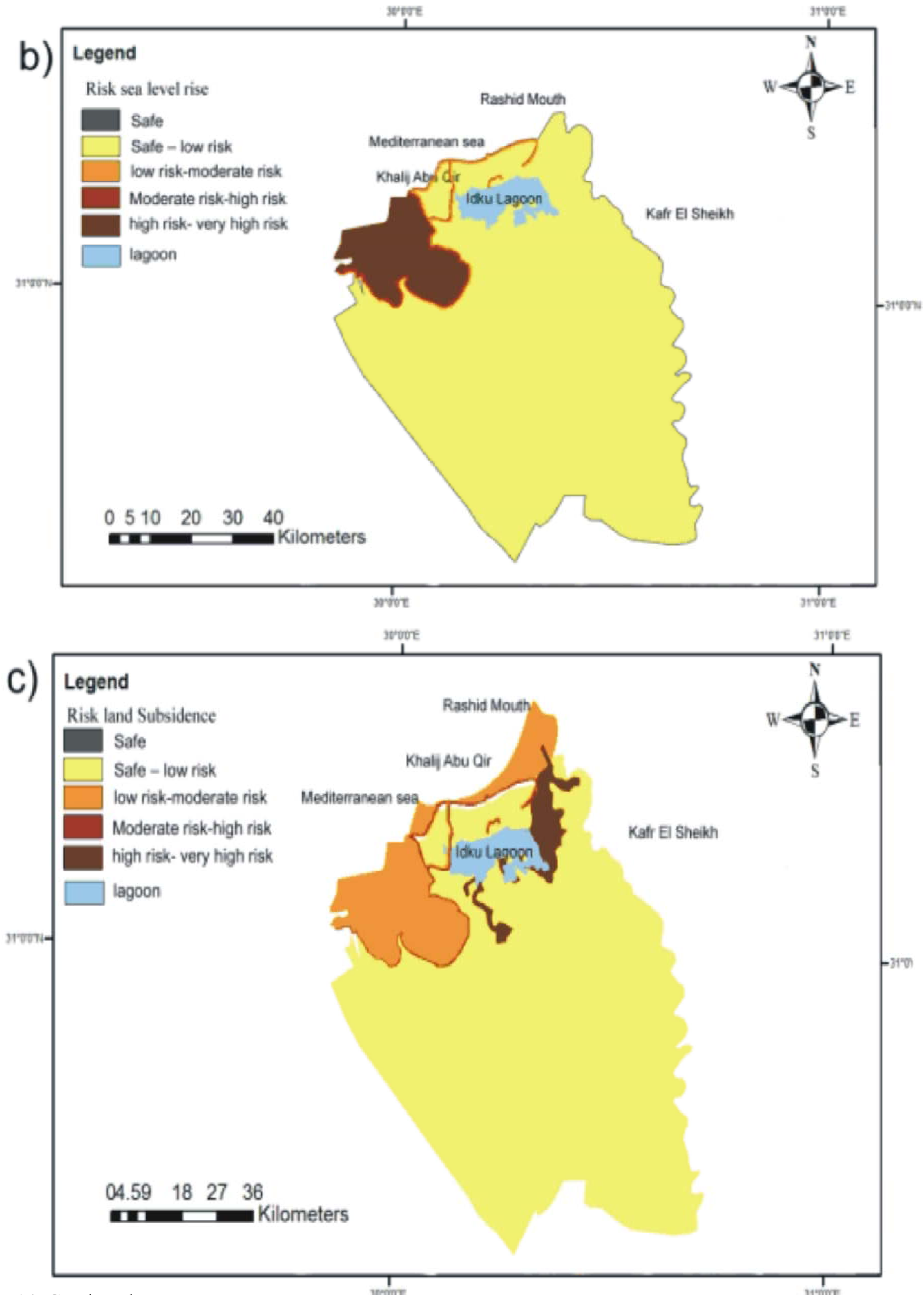

Fig. 14: Continued

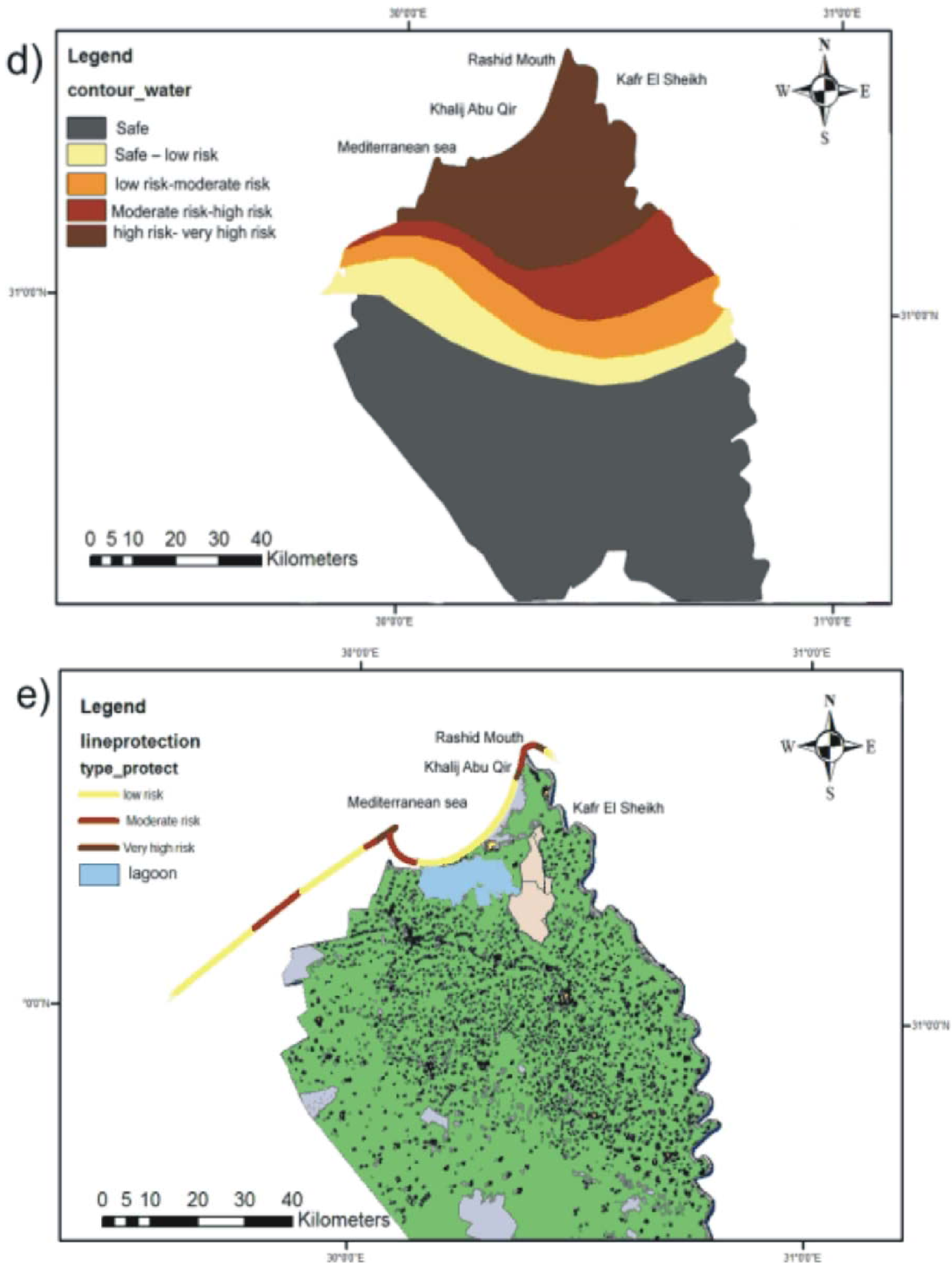

Fig. 14: Total risk degree of Al -Behairah governorates due to a) land topography; b) sea level rise; c) coast protection; d) groundwater level; e) land subsidence

Fig. 15: Photographs of Al-Behairah Governorate showing the areas that subject to sink under sea water during the period (2010-2100): a) Al Beherah; b) Rached; c) Edco; d) Damanhour; e) Kafr Al Dawar; f) Dlyngat.

Table 9: Total loss in land use/ land cover of Al - Behairah Governorate with different SLR and land subsidence

Sector	SLR<0	SLR=10	SLR=102	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 10: Risk weight and risk degree of study area

Criteria							
Governorates	Land topography	Sea level rise	Land subsidence	Ground water	Coastal	Total	Total Risk
Al - Behairah	1.0	1.0	1.0	1.0	1.5	35-60%	Moderate. to High

sustainable development of study area. However, the study indicated that the Sea level rise is the more extensive criteria that control the total risk degree of studied governorate.

Total Risk: Geostatistical analysis using ArcGIS 9.3 of the Al- Behairah governorate indicated that large parts of their coastal sectors subject to lost and buried under sea water (Table 9) by the end of the present century. The study revealed that the risk degree is moderate to high for Al Behairah (Table 10 and Fig. 15).

CONCLUSION AND RECOMMENDATIONS

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 Al-Behairah important Governorate Western Nile Delta due to SLR, land subsidence, coast protection, groundwater level. The risk analyses of Al Behairah Governorate indicate that its northern parts (about 40% of total area) are subject to sink under sea water (e.g. Kafr Al-Dawar, Abu Al-Matamir and Abu-homos) by the year 2100. Spatial and geostatistical analyses indicate high vulnerability and severe economic losses. This vulnerability have been increased at the end of 20^{th} 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 21^{th} centuery. The study also indicate that the risk degree of studied governorate range between moderate to high risk, which may result in population displacement of about 4 million, loss of jobs of about 2 million and tourism income may also be lost. 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.

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