Sea level rise impacts on Egyptian Mediterranean coast (case study of Alexandria)

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The global warming from the greenhouse effect will raise sea level due to expanding ocean water, melting mountain glaciers, and causing ice sheets to thaw or slide into the oceans. Such a rise would flood deltas, coral atoll islands, and other coastal lowlands, erode beaches, aggravate coastal flooding, and intimidate water quality in estuaries and aquifers. Alexandria city is considered at risk from the effects of any sea level rise resulting from climate change and global warming. This research predicts the values of Alexandria shoreline displacement in the coming twenty and fifty years due to sea level rise at the area of study which extends 1.5 km long from Sidi Bisher to Bir Masouad. This study shows that the flooded lost areas at Alexandria beaches at the study area is expected to be 4 m width in year 2027 and 10 m width in year 2057 for each meter long. The cost of loss these areas is expected to be L.E 9700 / m^2 in year 2027 and L.E. 290000 / m^2 in year 2057. Because of the decrease of the beach width, Alexandria's summer visitors are expected to be reduced by 14% in year 2027 and 37% in year 2057. It is recommended to study a strategy plan to protect Alexandria coastline, from the impacts of sea level rise and introduce a complete study on different techniques to reduce these impacts. The Environmental Impact Assessment studies should be implemented before the construction of any projects along Alexandria coastline.

نظرا للتغيرات المناخية العالمية و ظاهرة الانحباس الحرارى والتى ينتج عنها زيادة منسوب سطح مياه البحار والمحيطات ولا سيما البحار شبه المغلقة مثل البحر المتوسط ونظرا لما تعرضت مدينة الإسكندرية من مهاجمة الأمواج بضراوة فى مواسم الشتاء السابقة كأحد النتائج للظاهرة سالفة الذكر مما أدى إلى انهيار أجزاء من سور الكورنيش بمنطقة المندرة ووصول مياه ورمال البحر إلى نهر طريق الكورنيش فى النوات فقد كانت هناك ضرورة لدراسة تأثير الارتفاع المتوقع لمنسوب سطح مياه البحر علي شاطيء مدينة الإسكندرية وما قد ينتج من تناقص مساحة شواطئها. وقد تمت تلك الدراسة فى المنطقة المحصورة بين سيدي بشر وبير مسعود بطول 1.5 كم من خلال دراسة عدد ستة قطاعات عرضية وعمل رفع مساحي لها وبفرض أن الزيادة المتوقعة لمنسوب سطح مياه البحر علي شاطيء مدينة الإسكندرية هي 10.4 سم و 26 سم في أعوام 2027 و2057 علي الترتيب فقد تبين أن المساحة المتوقعة التي سوف تغمرها مياه البحر نتيجة ارتفاع منسوب سطح مياه البحر بمنطقة الدراسة هي 4 م^2/م.ط و 10 م^2/م.ط في أعوام 2027 و2057 علي الترتيب وهذا الأرتفاع سوف ينتج عنه فقدان لمساحة من شواطيء الإسكندرية بمبلغ 9700 جنيه/ م^2 و290000 جنيه/ م^2 في أعوام 2027 و 2057 علي الترتيب، وتم تقدير القيمة الإيجارية المفقودة نتيجة إرتفاع منسوب سطح مياه البحر بمنطقة الدراسة وهي 60 ، 4950 مليون جنيه مصري في أعوام 2027 و 2057 علي الترتيب مع توقع انخفاض في عدد المصطافين بمقدار حوالي 14% و37% في منطقة الدراسة في هذه السنوات علي الترتيب مما سوف ينتج عنه تأثير سلبي علي دخل السياحة للمدينة، وقد أوصت الدراسة بأستخدام الشعب المرجانية الصناعية لحماية المنشأت الساحلية حيث أن لها تأثير بيئي ضعيف، مع ضرورة عمل دراسات لبحث تأثير ارتفاع منسوب سطح مياه البحر علي أي مشروع ساحلي قبل تنفيذه .

Keywords: Sea level rise, Shoreline displacement, Alexandria coastline, Shore erosion, Flooding

1. Introduction

The earth has a natural greenhouse effect which keeps it much warmer that it would be without an atmosphere. Greenhouse gases in the atmosphere trap infrared heat energy trying to escape back to space. In doing so, they raise the temperature of the lower atmosphere and the Earth's surface in contact with it. During the last 200 years, mankind has been releasing substantial quantities of extra greenhouse gases to the atmosphere, through the burning of fossil fuels and deforestation. These extra gases are trapping more heat in the atmosphere. This climatic trend is known as global warming. The latter part of the 20th century has seen an increase in the Earth's average temperature of 0.6 C° which is expected to have further increase in the 21st century.

Sea-level rise is the most fundamental challenge of global warming that urban settlements face, and it will tend to increase because of the on-going influx of people and economic assets into the coastal zones. At risk are entire parts of coastal cities and their infrastructure, beaches subject to erosion, river floors in estuarine zones subject to sedimentation, and wetlands and tidal flats subject to flooding. Groundwater is at risk of increasing stalinization, and coastal aquifers at risk of decreasing, affecting fresh water supply and peri-urban agriculture [1].

Egypt is potentially one of the countries most at risk from the effects of climate change. It is located in an arid - to semi-arid zone. The inhabited area of the country constitutes only 4% of the total area of the country (1 million km^2), and the rest is desert. Its only source of water, the Nile River, provides more than 95% of all water available to the country.

The coastal zones of Egypt extend for more than 3500 km and are the home of more than 40% of the population. Most of these people live in and around a number of very important and highly populated industrial and commercial cities: Alexandria, Port Said, Damietta, Rosetta and Suez. A 50 cm sea-level rise on Egypt's coastal zones would affect 2 million people and 214000 jobs, and cause land and real estate losses worth US$ 35 billion [2].

Alexandria city is one of the oldest cities on the Mediterranean coast, and is an important tourist, industrial and economic centre. The city has a waterfront that extends for 60 km, from Abu-Qir Bay in the east to Sidi Krier in the west and includes a number of beaches and harbours. Alexandria's beaches are the main summer resort of the country, and its harbours are the most important import/export link between Egypt and Europe. About 40% of all Egyptian industry is located within the governorate of Alexandria. As a result of its high population density and industrial pollution, environmental problems have affected a large sector of the community in the area [3].

During the last few years, Alexandria coastline suffered from many erosion and flooding problems. In wintersj of 2003 to 2006, many surge storms strike Alexandria coastline and cause large amount of flooding and sand transport. It is expected that these kinds of storms will increase at the coming years due to the phenomenon of sea level rise and also due to the large amount of rock and sand that had been filled into the sea during development of Kornish road in the last few years.

The objective of this research is to study the impacts of climate changes on Alexandria city. Field surveying for different vertical sections on Alexandria coastline from Montaza east to Bahri west are illustrated. Prediction of Alexandria shoreline displacements during the next 20 and 50 years and their impact on Egyptian economy are introduced.

2. Climate change

The United Nations Framework Convention on Climate Change [1] defines climate change as "a change of climate which can be attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods". The Earth's climate changes when the amount of energy stored by the climate system is varied. The most significant changes occur when the global energy balance between incoming energy from the sun and outgoing heat from the earth is upset. There are number of natural mechanisms that can upset this balance, for example fluctuations in the earth's orbit, variations in ocean circulation and changes in the composition of the earth's atmosphere. In recent times, the latter has been evident as a consequence not of natural processes but of man-made pollution, through emissions of greenhouse gases [1]. By altering the global energy balance, such mechanisms "force" the climate to be changed. Consequently, scientists call them "climate forcing" mechanisms.

Greenhouse gases include any gas in the atmosphere that is capable, as a result of its particular molecular structure, of absorbing infrared radiation or heat. They are called greenhouse gases because they behave like glass in a greenhouse gas, allowing sunlight to pass through but trapping the heat formed and preventing it from escaping, there by causing a rise in temperature. Natural greenhouse gases include water vapour or moisture, carbon dioxide, methane, nitrous oxide and even ozone, which is more commonly associated with the ozone layer and ultraviolet radiation. The amounts of all these gases in the atmosphere are now being increased as a result of man-made processes, such as fossil fuel burning and deforestation. The atmospheric concentration of carbon dioxide, for example, has increased by 30% since the 18th century, whilst levels of methane have more than doubled. Water vapour, whilst not directly released by man-made processes in substantial quantities, may be increasing as a result of climate feedback effects [4].

Fig. 1 illustrates the rise in atmospheric carbon dioxide from year 1744 to 1992. Note that the increase in carbon dioxide's concentration in the atmosphere has been exponential during the period examined. An extrapolation into the immediate future would suggest continued increases [5].

Without the natural greenhouse effect, the Earth's average temperature would be -18C° instead of the current 15C° [6], it raise the temperature of the lower atmosphere and the earth's surface. The latter part of the 20th century has seen the increase in the Earth's average temperature of 0.6 C°. Projections of further increase in the 21st Century vary considerably, between a minimum of 1.4 C° and a maximum of 5.8 C° as shown in fig. 2 depending on the level of stabilization of carbon emissions, the pace of de-carbonization of the global economy, and the patterns of demographic and economic development. Such increases represent a dramatic shift with regard to the natural variability of the planet's mean temperature, which has remained within 0.5 C° over the last 1000 years [7].

3. Impacts of climate change

The Intergovernmental Panel on Climate Change, IPCC, [8] provides an update of the existing knowledge and the integration of field studies, results of modelling simulations, and other information available on the projected impacts of climate change on urban areas. According to the IPCC reports [8] and [9], the main threats to the urban population and to the physical assets of developing cities that will impact them with more or less intensity based on the actual climate changes that will unfold are the following ones [7]:

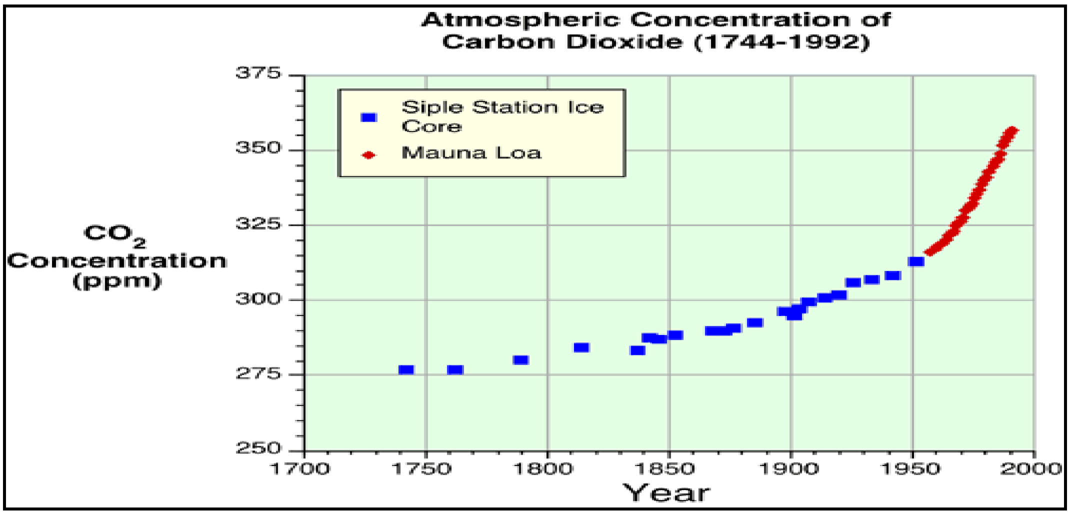

Fig. 1. The atmospheric concentration of carbon dioxide from year 1744 to year 1992 [5].

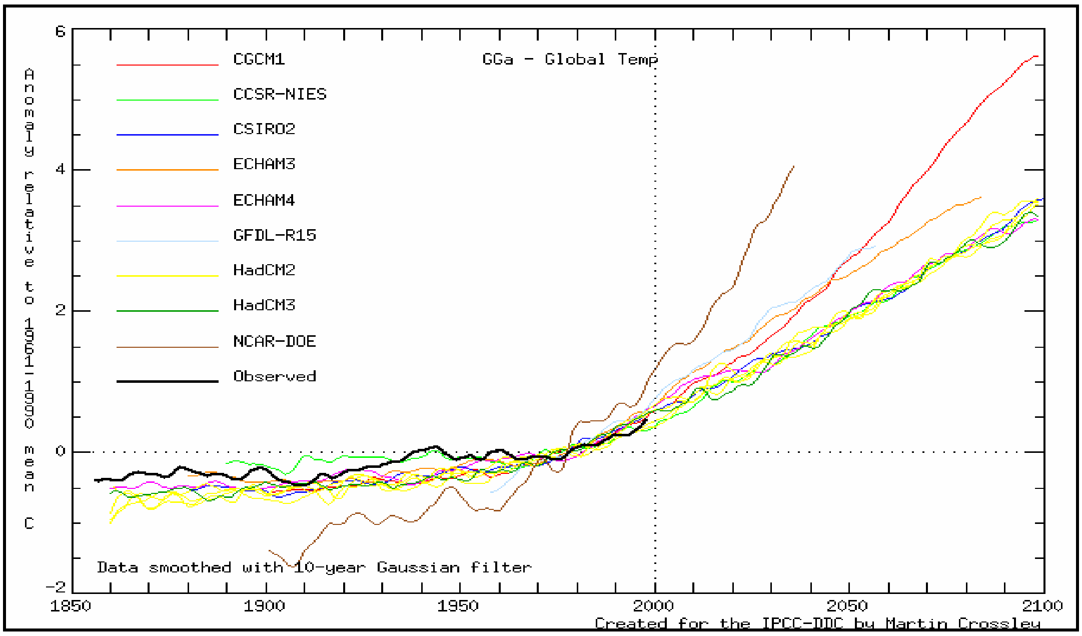

Fig. 2. Global Mean Temperature, 2000-2100 Projections from different models [7].

• *Tropical cyclones*: Increasingly frequent and intense tropical and extra-tropical cyclones will likely cause severe wind damage and storm surges which, compounded with the sea-level rise, are expected to become a severe problem for low-lying coastal regions and cities, with particular risks for ports and other coastal infrastructure.

• *Flooding and land-slides*: the expected increase in the scale, intensity and frequency of the rainfall regimes in most developing countries will likely strain severely or overwhelm the storm-drainage systems of many urban centers. It will likely cause periodic flooding of low-lying areas as well as landslides and mud-slips of the geologically unstable slopes, often subject to informal settlements; cities built next to rivers or on reclaimed lands in river-bed planes will be prone to additional inundations.

• *Water quality and shortage*: Floods of the urban areas will likely damage water treatment works and flood wells, pit latrines and septic tanks; sewage treatment systems and solid waste disposal areas will likely be equally affected, contaminating water supplies. Where overall rainfall will decrease, droughts will likely compromise the replenishment of the water tables and thus the normal sources of water supply for the urban areas.

• *Heat and cold waves*: Intense episodes of thermal variability will likely severely strain urban systems, by representing an environmental health risk for the more vulnerable segments of the population, imposing extraordinary consumptions of energy for heating and air conditioning where available, and disrupting ordinary urban activities.

• *Sea-level rise*: This is the most fundamental challenge of global warming that urban settlements face, and it will tend to increase because of the on-going influx of people and economic assets into the coastal zones. Coastal cities and their infrastructures and beaches subject to erosion, river floods in estuarine zones subject to sedimentation, and wetlands and tidal flats subject to flooding. Groundwater is at risk of increasing salinization, and coastal aquifers at risk of decreasing, affecting fresh water supply and peri-urban agriculture. The indirect impacts of such climatic threats are of course much wider. They include environmental health problems due to the expected changes in geographic ranges and incidence of vector-borne and infectious diseases, allergic and respiratory disorders, nutritional disorders related to climate-related food shortages, as well as the physical damages and institutional strains imposed on the health care system. Where the impacts will be felt, urban economic activities will be likely affected by the physical damages caused to infrastructure, services and businesses, with repercussions on overall productivity, trade, tourism and on the provision of public services.

4. Causes of sea water level rise and its expected values in the coming century

Much of the rise in sea level has been due to the rise in global temperature associated with the global warming of the past century. This type of sea level rise is known as ecstatic sea level rise. As the global temperature increases, the ocean water expands. This is also known as thermal expansion of the ocean water. A thermal expansion has contributed 2 to 7 cm to the total sea-level rise over the past century has been estimated by [8]. In addition, as global temperatures rise, mountain glaciers melt. The IPCC estimates that 2 to 5 cm of the total sea-level rise over the last century has been due to the melting of glaciers. All over the world, scientists have documented the retreat of mountain glaciers, including the rocky mountains of North America, the Alps of Europe, and the Himalayas of Asia [10].

Groundwater depletion is another factor as the removal of water from aquifers for irrigation and other purposes exceeds rates of recharge in many parts of the world. This water evaporates into the atmosphere, or contributes to runoff eventually reaching the sea. Estimates place current rates of sea-level rise due to this effect at 0.07 - 0.38 mm per year [8]. Another factor contributing to the rise in sea level is the movement of the land. Because the continents are dynamic and float on the Earth's mantle, the continents exhibit their own movements over long time periods as shown in fig. 3. So, if a continent or portion of a continent is rising, the ocean water at the continent's coast will appear to fall with respect to the motion of the land. Likewise, if a continent or portion of a continent is sinking, the sea level at the coast will appear to rise. This effect is known as relative sea level rise, a continent can be rising as a result of a retreating ice sheet from a previous ice age. As the earth warms after an ice age and the weight of the ice is removed, the continent rebounds or rises higher in the mantel. This is currently occurring on the Norwegian Sea coast of Norway as a result of the retreat of the ice from the last ice age. On this coast, sea level is falling, not rising.

IPCC [8] as estimated that the global average sea level has risen from 0.10 to 0.25 meters in the past century. However, sea level is affected by many factors, including local ones, so sea level change at any single location may be a rise, a fall, or no change at all. Furthermore, IPCC [8] mentioned that sea level will rise from 0.20 to 0.86 meters by the year 2100. In other words, sea level rise will not only continue into the next century, but will continue at an accelerated rate [9]. The range of sea level rise is 0.13 to 0.94 meters as predicts by [8]. The Third Assessment Report of Working Group I of the IPCC builds upon past assessments and incorporates new results from the past five years of research on climate change. Many hundreds of scientists from many countries participated in its preparation and review. The global sea level for the next century is projected to rise by 0.09 to 0.88 meters based on data shown in fig. 3 [11]. As an average for these three reports the expected sea level rise will range from 0.485 to 0.535 meters with average value 0.52 meters for the next century. This average value is used in this study to predict the impacts of sea level rise at Alexandria beaches.

5. Effect of sea water level rises on Egyptian coast and Alexandria City

Egypt’s Nile delta with its coastal front on the Mediterranean is considered vulnerable to the impacts of climate change. In addition to expected rise in sea-level, shoreline erosion, stresses on fisheries and saltwater intrusion in groundwater create major challenges. These factors also produce stressful effects on water and agricultural resources, tourism and human settlements. Fragile and unique ecosystems such as the mangrove stands in

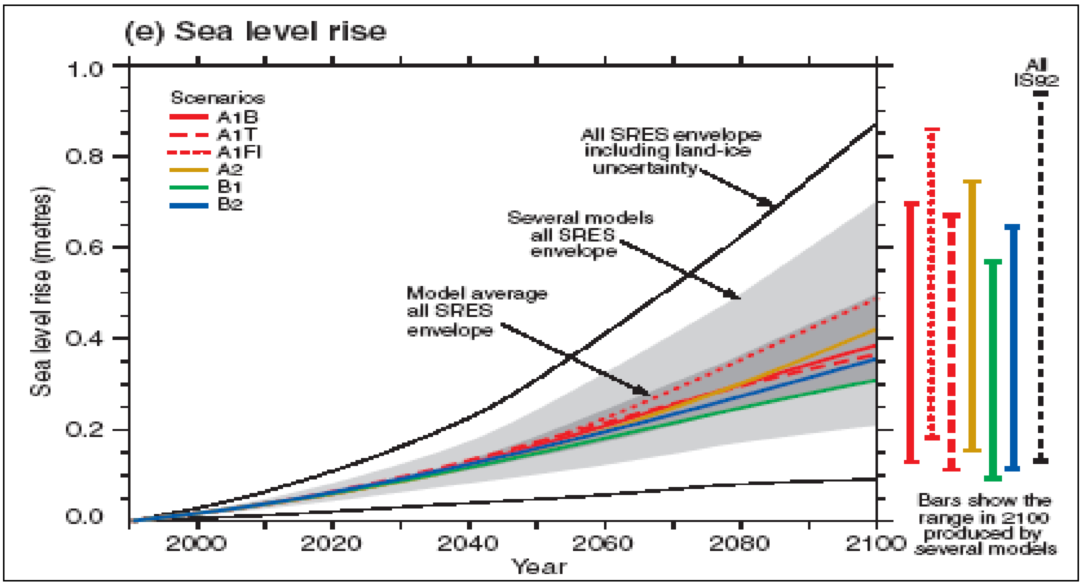

Fig. 3. Predicting sea water level rise using different models [11].

the Red Sea, which stabilize shorelines and provide a habitat for many species, may also be threatened. The northern Egyptian lakes, which constitute about 25% of the total Mediterranean wet lands and produce about 60% of the fish products, are also highly vulnerable to the impacts of climate change. Since the lakes are relatively shallow, climate change can lead to an increase in water temperature, which could result in changes in the lake ecosystems as well as changes in yield [2]. The potential impacts of climate change on coastal resources are ranked as most serious. Sea levels are already rising in the Nile delta due to a combination of factors including coastal sub-reduction and reduced sediment loads due to the construction of the High Aswan Dam upstream. Climate change induced sea-level rise only reinforces this trend. In addition to this high biophysical exposure to the risk of sea level rise, Egypt's social sensitivity to sea level rise is particularly high. As much of Egypt's infrastructure and development is along the low coastal lands, and the fertile Nile delta also constitutes the prime agricultural land in Egypt. The loss of this land due to coastal inundation or to saline intrusion will therefore have a direct impact on agriculture, which in turn is critical to Egypt's economy. Fig. 4 provides a view on the most vulnerable Egyptian cities; Alexandria, Rosetta, Port Said, and coastal zones and how it can impact by 0.5 and 1 meter sea level rise [12].

Alexandria city is located to the west of the Rosetta branch of the Nile and is famous for its beaches, historic and archaeological sites. It has a population of about four million and hosts the largest harbour in the country as well as roughly 40% of the Egyptian industrial activities. During summer, the city attracts over a million tourists. The extension of the city to the south is impeded by the existence of a large water body “Maryut Lake”. Water level in Maryut Lake is kept at 2.8 m below sea level through continuous pumping of water into the Mediterranean. Alexandria old city is safe from direct effects of sea-level rise, as it is located at 12 meters above sea-level. However, the port area and newer suburbs have been built on low land with the aid of flood defences, and are at direct risk. Low marshes and lagoons that surround the city could be lost or seriously contaminated with salt water due to sea-level rise. Ultimately, the city could become a peninsula, surrounded by the Mediterranean, only reached by bridges and causeways [7].

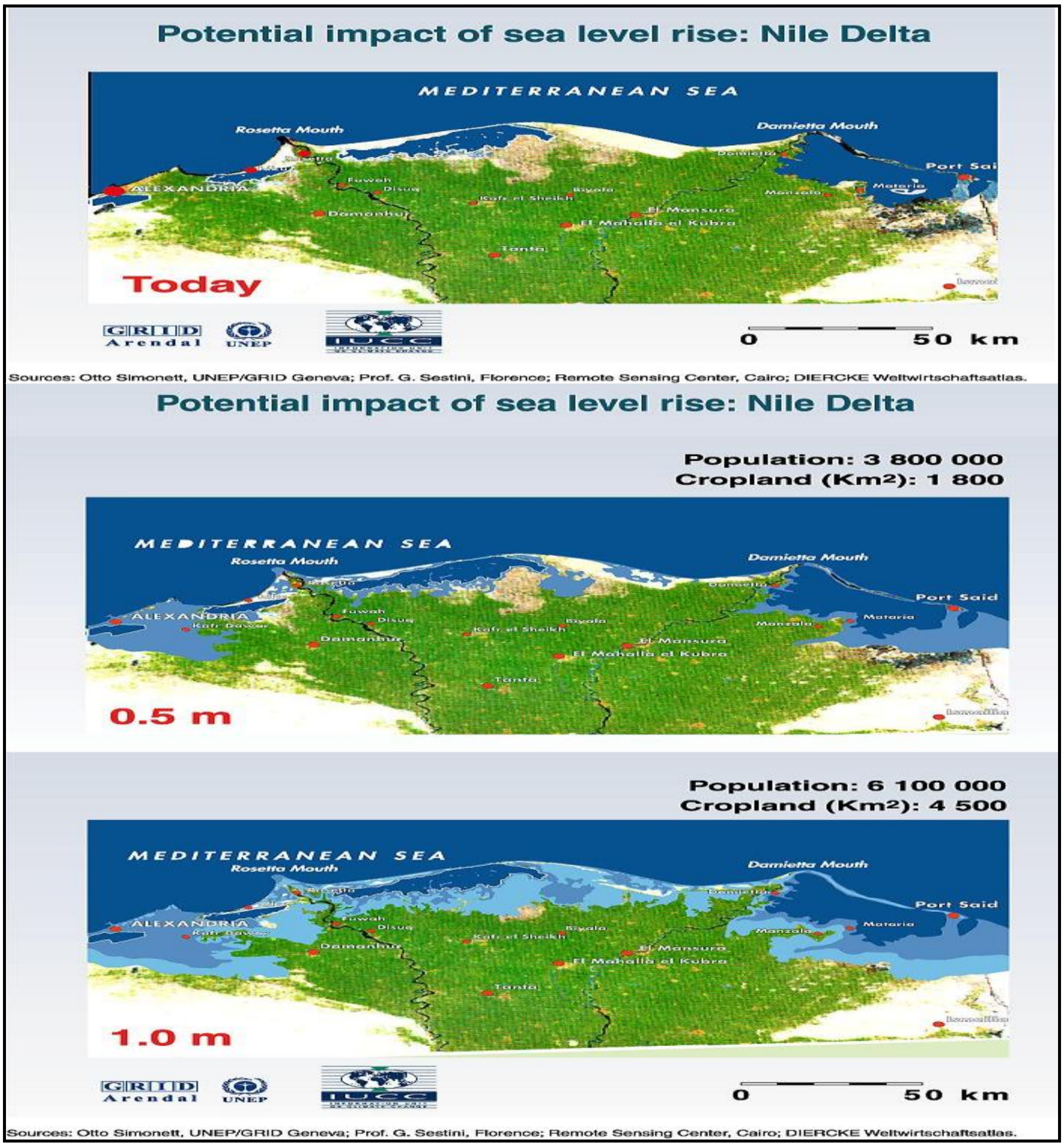

Fig. 4. Coastal inundation in the Nile delta under sea level rise (current; 0.5m; 1.0m) [12].

A Geographic Information System (GIS) using the ARC/INFO environment to assess the impacts of sea level rise (SLR) at Alexandria was applied by [3]. A number of scenarios were assumed over the century (0.25, 0.5 and 1.0 m). The percentage of the population and land use areas at risk for each scenario level were identified and quantified by the GIS analysis as shown in Table 1. The first column shows the percentage of each sector that is currently located at an elevation below sea level. However, these locations are protected from inundation, either naturally or through hard structures. If sea level rises by 0.25, 0.5, and 1.0 respectively, the other columns of the table show the percentages of sectors that will be inundated, since they cannot be protected by current structures. Analyses of the results indicate that for a sea level rise of 0.5m about 30% of the city area will be lost due to inundation. Over 1.5 million people will also have to be relocated. Other expected losses include 195,000 jobs as well as land, properties and revenues in the range of $30 billion. These are based upon extrapolation of current national statistics, and are only intended as order of magnitude estimates.

Another study to predict the impacts of sea level rise at Alexandria was carried by [2]. A scenario of sea level rise of 0.5, 1.0, and 2.0 m, over the next century was assumed. Analysis of the GIS data for the three scenarios indicates the capability of the technique to map vulnerable areas and to quantitatively assess vulnerable sectors in each area. Table 2 presents gross percentage loss for each scenario of sea level rise. It illustrates that, if no protection action is taken, the agricultural sector will be the most severely impacted (a loss of over 90 %), followed by the industrial sector (loss of 65 %), and the tourism sector (loss of 55 %) due to a sea level rise of 0.5 m.

Table 1
Percentages of the population and the areas of different land use currently below sea level and at different levels of elevation (m) for the city of Alexandria [3]

Sector	Below sea level	0.25 m	0.5 m	1.0 m
(% of areas affected)				
Population	45	60	67	76
Beaches	1.3	11	47.8	64
Residential	26.2	27.5	39.3	52
Industrial	53.9	56.1	65.9	72.2
Services	45.1	55.2	75.9	82.2
Tourism	28	31	49	62
Restricted Area	20	21	25	27
Urban	38	44	56	67
Vegetation	55	59	63	75
Wetland	47	49	58	98
Bare Soil	15	24	29	31

Table 2
Percentage of potential loss of areas, population and land use due to sea level rise at Alexandria Governorate [2]

Elevation	SLR 0.5 m	SLR 1.0 m	SLR 2.0 m
Area	51	62	76
Population	50	64	79
Agriculture	93	95	100
Industry	65	70	90
Residential	45	50	75
Municipal services	30	50	70
Commercial areas	20	25	35
Community facility	15	20	30
Archaeological sites	48	55	70

Estimation of the socio-economic impact due to loss of land and jobs is possible using employment statistics relevant to each sector and taking future growth rates into consideration. Results of the impact on population and loss of employment are shown in table 3.

6. Prediction of Alexandria shoreline displacement due to sea level rise at 2027 and 2057

To predict the effect of estimated sea level rise at Alexandria coastline, a programme of field investigations has been planned and applied in this study by the researchers. The levels and horizontal dimensions of twenty cross sections along Alexandria coastline from Mandra in the east to Bahri in the west with 16.3 km long have been measured during June 2006. The longitudinal distance between the twenty sections ranges from 0.28 to 1.2 km with beach widths range from 0.0 to 40.0 meters.

Table 3
Population expected to be displaced and loss of employment due to sea level rise at Alexandria Governorate [2]

Year		2000 (SLR=5cm)	2010 (SLR=18cm)	2030 (SLR=30cm)	2050 (SLR=50cm)
Area at risk (km2)		32	144	190	317
Population to be displaced (Thousands)		57	252	545	1,512
	Agriculture	0,336	1,370	3,205	8,812
Loss of Employment	Tourism	1,359	5,737	12,323	33,919
	Industry	5,754	25,400	54,936	151,200
Total loss of employment		7,449	32,509	70,465	195,443

From a preliminary analysis of the data received from the field investigation, an area of study from Sidi Bisher to Bir Masud has been chosen. This includes six cross sections from the twenty sections have been measured as shown in fig. 5. Reasons for choosing this area are related to its high density with summer visitors and its small beach width. Moreover, this area does not have any off-shore protection structures.

A bathymetric map for the area of study shown in fig. 6 [13]. Location of six section are plotted on the map as shown in fig .6. One example of the cross sections at Sidi Besher beach is presented in fig. 7.

An average sea level rise value equal to 0.52 cm per year as stated in details at section 4 was assumed to predict the expected total sea level rise during the coming twenty and fifty years. The estimated values of sea water level rise in years 2027 and 2057 and its relationship to shoreline are shown in fig. 10. In order to estimate the area loss of the sandy beach at the area of study after twenty and fifty years, the expected mean sea level is assigned at the six cross sections as shown in fig. 8.

For the area of study, the shoreline displacements have been calculated for one meter long of the beach for year 2027 and 2057. The calculated displacements for the six sections after twenty and fifty years are shown in tables 4 and 5 respectively.

Results presented in tables 4 and 5 indicate that Alexandria beaches, at the area of study, will lose four meters width for each meter long during the coming twenty years and ten meters width for each meter long during the coming fifty years. These estimated values of area loss and shoreline displacement are presented in fig. 9.

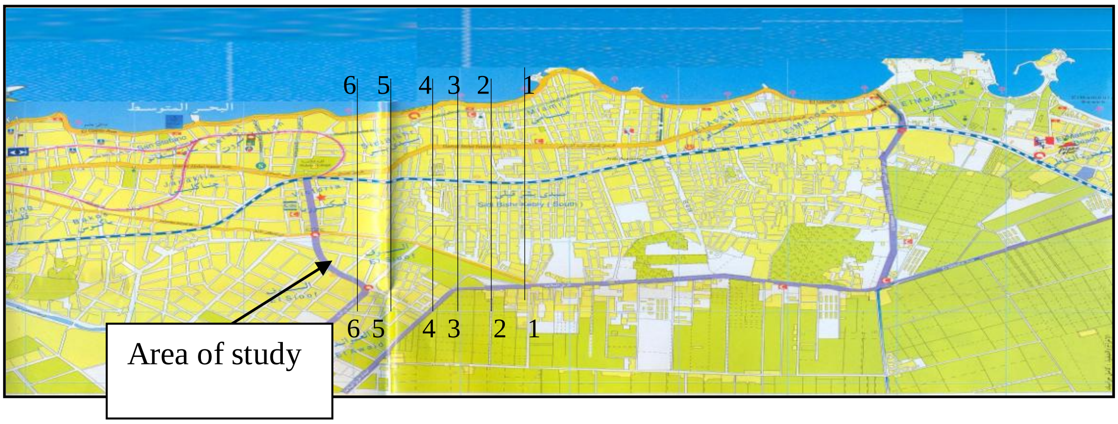

Fig. 5.six cross the area of study.

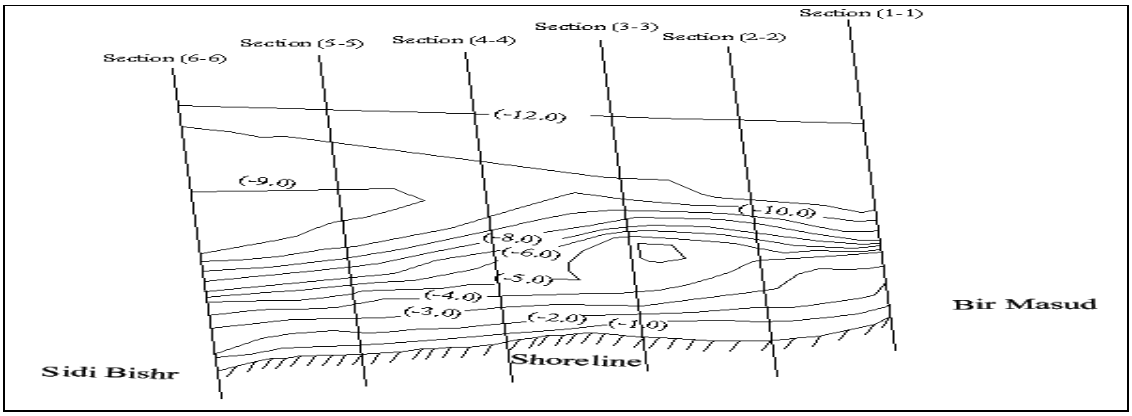

Fig. 6. Bathymetric map shows the area of study [13].

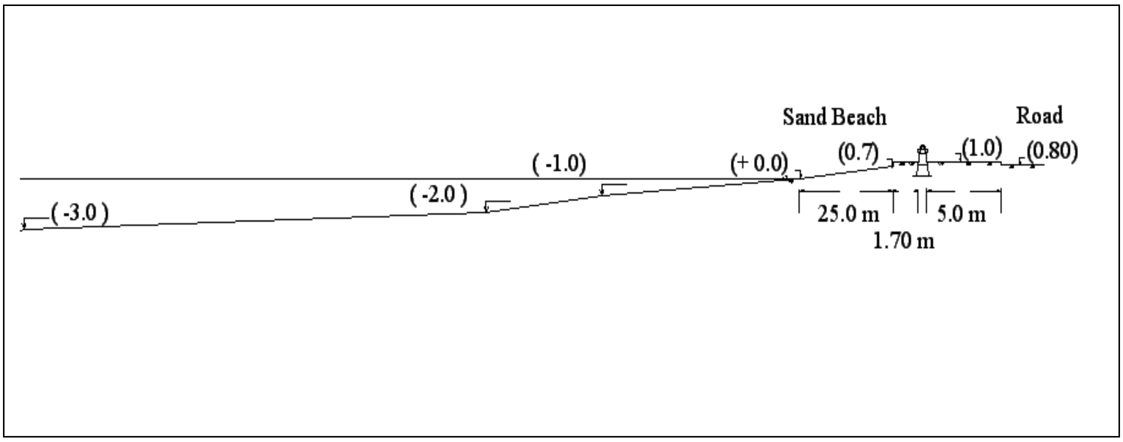

Fig. 7. Details of cross s(6-6) at Sidi Basher beach.

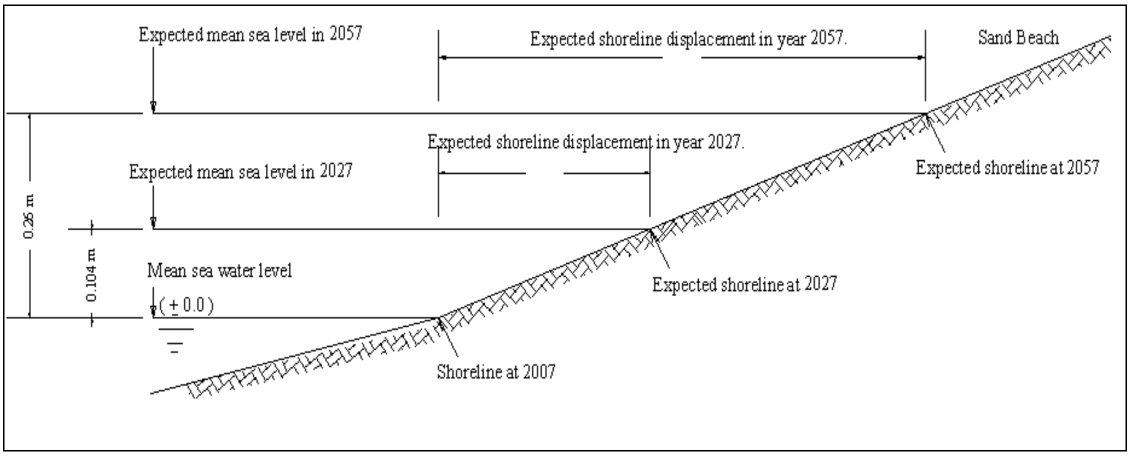

Fig. 8. Sketch explains the current mean sea level and the expected sea levels at years 2027 and 2057 for s(5-5).

Table 4
Calculations of shoreline displacement for one meter long in year 2027

Section no.	Shoreline displacement (m)	Average shoreline displacement (m)	Intersection distance (m)	Average loss areas (m^2)
1-1	2.08			
		4.16	335	1394
2-2	6.24			
		5.20	315	1638
3-3	4.16			
		3.81	330	1257
4-4	3.46			
		3.29	355	1168
5-5	3.12			
		3.42	370	1266
6-6	3.71			
Total loss area in year 2027(m^2)				6723
Shoreline displacement in 2027 for one meter long (m)				4.0

Table 5
Calculations of shoreline displacement for one meter long in year 2057

Section No.	Shoreline displacement (m)	Average shoreline displacement (m)	Intersection distance (m)	Average loss areas (m^2)
1-1	5.20			
		10.40	335	3484
2-2	15.60			
		13.00	315	4095
3-3	10.40			
		9.53	330	3145
4-4	8.66			
		8.97	355	3184
5-5	9.28			
		8.54	370	3160
6-6	7.80			
Total loss area in year 2057(m^2)				17068
Shoreline displacement in 2027 for one meter long (m)				10.0

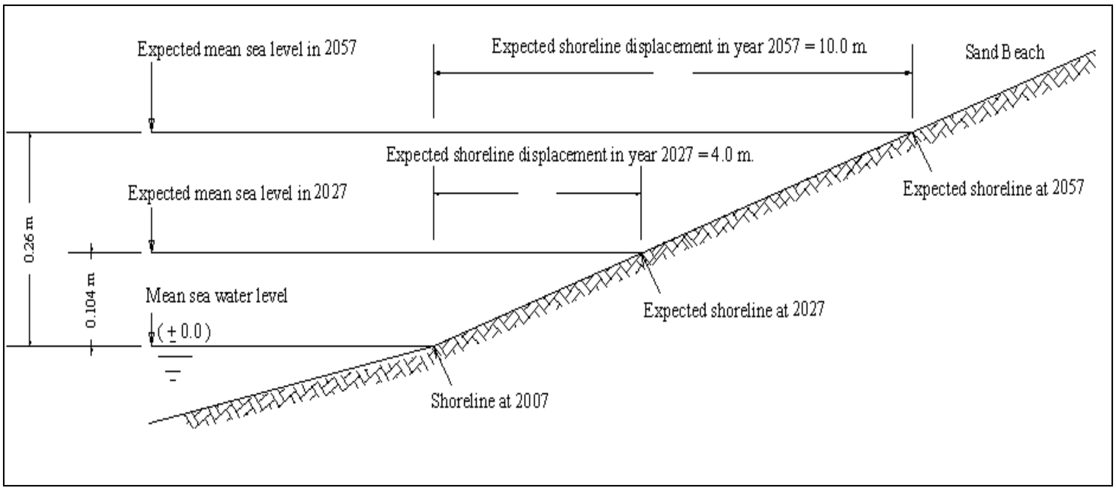

Fig. 9. The expected shoreline displacement at year 2027 and 2057 at the area of study.

The following eq. of [14] was applied to estimate the cost of one meter square at the area of study after twenty and fifty years,

$$FV_N = PV\,(1+i)^N\,, \qquad (1)$$

in which:

FV_N is the future value (L.E.).
PV is the present value (L.E), assumed equal to L.E. 1000 per meter square.
i is the interest rate (%), assumed equal to 12 %.
N is the number of years.

The calculated price is L.E 9,700 per meter square in year 2027 and L.E. 290,000 per meter in year 2057 using the previous equation. The estimated total cost of lost areas due to sea level rise in the study area are nearly expected to be L.E 60 million and L.E 4950 million in years 2027 and 2057, respectively. Another effect for the loss of these valuable areas is the number of Alexandria's summer visitors. It is expected that Alexandria's summer visitors will be decreased by 14% in year 2027 and 37% in year 2057 at the area of study.

7. Conclusions

Alexandria city is one of the important tourists, industrial and economic centre, its beaches are the main summer resort of the country, and its harbours are the most important import/export link between Egypt and other countries. Alexandria faces many problems along its coastline like beach erosion and flooding. In winter of 2003 to 2006, many surge storms strike Alexandria coastline cause large amount of water flooding and sand movements. It is expected that these kinds of storms will be increased at the coming years due to the phenomena of sea level rise. The objective of this research is to highlights the impacts of sea level rise on Alexandria coastline. The prediction of Alexandria shoreline displacement during the next 20 and 50 years was presented and discussed. Based on the present study, the following main conclusions can be summarized.

The flooded lost area in Alexandria coastline is expected to be 4 m^2 for each meter long if sea level rise equals 10 cm in year 2027 and 10 m^2 for each meter long if sea level rise equals 26 cm in year 2057. The estimated cost of lost lands due to sea level rise , for the area between Sidi Bisher to Bir Masouad are expected to be 9700 L.E./m^2 and 290000 L.E./m^2 in years 2027 and 2057, respectively.

The estimated total cost of lost areas due to sea level rise in the study area are nearly expected to be L.E 60 million and L.E 4950 billion in years 2027 and 2057, respectively.
Alexandria summer visitors are expected to decrease by 14% and 37% in years 2027 and 2057 respectively, which in turn affect the city economy.

For the future researches it is recommended to use soft coastal structures such as artificial reefs in the protection of Alexandria coastal zones from erosion and flooding. The soft structures have low environmental impact, low cost and give good views for summer visitors than hard structures. Also, a strategy plan for Alexandria coastline development should be studied and implemented. This plan should includes the impacts of sea level rise and introduce a complete study on different techniques to reduce these impacts.

References

[1] United Nations Environment Programme (UNEP): "An Introduction to Man-Made Climate Change", United Nations Environment Programme Information Unit for Climate Change (IUCC), Fact Sheet 1, Nairobi, Kenya (1990).

[2] S. Agrawala, A. Moehner, M. El Raey, D. Conway, M. Van Aalst, M. Marca Hagenstad and J. Smith, "Development and Climate Change in Egypt: Focus on Coastal Resources and the Nile", Environment Directorate Environment Policy Committee, Working Party on Global and Structural Policies, Working Party on Development Co-Operation and Environment (2004).

[3] M. El Raey, "Vulnerability Assessment of the Coastal Zone of the Nile Delta of Egypt to the Impacts of Sea Level Rise", In: Ocean and Coastal Management, Vol. 37, pp. 29-40 (1997).

[4] J.G. Titus, "Greenhouse Effect, Sea Level Rise, and Land Use", Originally Published in Land Use Policy, April, Vol. 7, Issue 2, pp. 138-53 (1990).

[5] M. Pidwirny, "Fundamental of Physical Geography", Physical Geography Net, University of British, Okanagan, Columbia, USA (2006).

[6] Canada's Third National Report on Climate Change Actions to Meet Commitments Under the United Nations Framework Convention on Climate Change, Canada, ISBN 0-660-18694-2 (2001).

[7] A.G. Bigio, "Cities and Climate Change", Senior Urban Specialist, This Work was Initiated as a Background Paper for the Forthcoming World Development, as Part of the Urban Environment Thematic Group Activities for FY02, Tudur, 1 March (2002).

[8] IPCC "Third Assessment Report: Climate Change 2001", the Latest Report of the Intergovernmental Panel on Climate Change (IPCC), Cambridge University Press, Cambridge, UK (2001).

[9] IPCC "The Regional Impacts of Climate Change", An Assessment of Vulnerability Special Report of IPCC Working Group II

Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, p. 517 (1999).
[10] J.G. Titus and R.A. PARK, "Greenhouse Effect and Sea Level Rise: The Cost of Holding Back the Sea", Originally in Coastal Management, Vol. 19, pp. 171-204 (1991).
[11] Policymakers "A Report of Working Group I of the Intergovernmental Panel on Climate Change (IPCC)", Summary for Policymakers (2001).
[12] United Nations Environment Programme (UNEP) "Potential Impact of Climate Change", United Nations Environment Programme Information Unit for Climate Change (IUCC) (2003).
[13] Coastal Research Institute Ministry of Water Resource and Irrigation, Alexandria, Egypt (2006).
[14] E.F. Brigham and J.F. Houston, "Fundamentals of Financial Management", South-Western, A division of Thomson Learning, 9th Edition, Harcourt Brace, ISBN: 0030314615, United States of America, p. 959 (2000).

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