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DIFFERENT METHODS USED FOR PROTECTING COASTS FROM SEA LEVEL RISE CAUSED BY CLIMATE CHANGE

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Abstract

The global mean surface temperature is projected to increase about 1-3.5 C by the year 2100 caused in sea level rising by about 15-95 cm. Low gradient coastal landforms most susceptible to inundation include deltas, estuaries, beaches and barrier islands, and coral reefs. Without serious adaptation measures, millions of people will be displaced from their homes. In addition, the loss of productive land will have serious implications on job opportunities, food availability and population movement. In this paper, the current status of many countries in the world affected by rising sea levels is presented. Also, the methods and strategies that can be used to cope with the expected sea level rising are discussed briefly such as nourishment, barriers, coastal armoring,

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managed retreat, an application of the integrated coastal zone management, floatable developments, etc. Finally, the current situation in Egypt and its vulnerability to sea level rise are presented.

1. Introduction

1.1. Background

Climate change is considered as one of the hottest global environmental problems facing the world community that threatens development to proceed in a sustainable manner. Since 1992, the Earth Summit in Rio de Janeiro, where the United Nations Framework Convention on climate change (UNFCCC) was opened for signature, till now, the world community still strives to reach common position on several issues to achieve ultimate objective of the convention. The ultimate objective of the convention is to stabilize Green House Gases (GHG) concentration in the atmosphere at a limit that prevents dangerous interference with climate system.

Human activities are increasing the concentration of the green house gas (GHG) which tends to warm up the atmosphere in some regions, and aerosols, which tend to cool the atmosphere. Based on the different scenarios of the projection of the GHG and aerosols, the global mean surface temperature is projected to increase about 1-3.5 C by the year 2100. The projected associated increase in sea level is about 15-95 cm. Serious changes have been identified, including an increase in some regions in the incidence of extreme high temperature events, floods and droughts. The most likely affected sectors by the climate change are; water resources, coastal zones, agriculture, rangeland and livestock, human health, human settlements, energy, forest, bio-diversity: species, communities and ecosystems and fisheries (IPCC [18]).

1.2. Problem identification

Sea level changes are caused by several natural phenomenon; the three primary contributing ones are: ocean thermal expansion, glacial melt from Greenland and Antarctica, in addition to a smaller contribution from other ice sheets, and change in terrestrial storage. Among those, ocean thermal expansion has been expected to be the dominating factor behind the rise in sea level. However, new data on rates of deglaciation in Greenland and Antarctica suggest greater significance for glacial melt, and a possible revision of the upper-bound estimate for sea level rise (SLR) in this century (Dasgupta et al. [2]).

It is predicted that, with global warming, global average sea levels may rise by between 7 and 36 cm by the 2050 s, by between 9 and 69 cm by the 2080 s and 30-80 cm by 2100. The majority of this change will occur due to the expansion of the warmer ocean water. Since the Greenland and Antarctic ice sheets contain enough water to raise the sea level by almost 70 m, people will be directly affected by rising sea levels in several ways. As seas rise many areas of the coasts will be submerged, with increasingly severe and frequent storms and wave damage, shoreline retreat will be accelerated. In addition, expected disastrous flooding events caused by severe climate events such as heavy flooding, high tides, windstorms in combination with higher seas (Dasgupta et al. [2]).

1.3. Main objectives

The main objectives of this article review can be summarized as follows:

1. Shedding light on current status of many countries in the world affected by rising sea levels.
2. Discussing methods and strategies that can be used to cope with expected sea level rising.
3. Presenting the different types of sea dicks as widely used methods to protect the coasts from sea level rise.
4. Shedding light on the current situation in Egypt.

2. Literature Review

The impacts of Sea Level Rise (SLR) will not be globally uniform, because of local variations in vertical crystal movements, topography, wave climatology, long shore currents, and storm frequencies. Low gradient coastal landforms most susceptible to inundation include deltas, estuaries, beaches and barrier islands, and coral reefs. Regions at risk include the Low Countries of Europe, eastern England, the Nile delta in Egypt, the Ganges-Brahmaputra, Irrawaddy, and Chao Phraya deltas of south-eastern Asia, eastern Sumatra, and Borneo. In the United States, the mid-Atlantic coastal plain, the Florida Everglades, and the Mississippi delta will be particularly vulnerable. Developing countries are certainly identified mainly at risk. The consequences of SLR for population location and infrastructure planning in developing countries should definitely be reviewed by the developing world (Elsharkawy et al. [11]).

2.1. Previous works for Egypt

Fanos et al. [12] presented a brief review of the major existing coastal problems along the Nile Delta coast in Egypt. They provided a general description for all the protection works along the Nile Delta coast such as Maadia outlet Jetties, Rosetta promontory sea walls, Burg El-Burullus Sea Wall and Mohamed Ali sea wall.

El-Raey et al. [9] carried out an assessment of the impact of sea level rise on the city of Port Said, Egypt using remote sensing and GIS techniques. They used Bruun's method to estimate the horizontal retreat, due to three scenarios of sea level rise (0.5, 0.75 and 1.25 m SLR). They presented a long-term land subsidence based on mean annual sea levels at Alexandria (44 years) and Port Said (50 years). They suggested that protection measures must be carried out with emphasis on building breakwaters along the most vulnerable shoreline area.

El-Raey et al. [10] carried out an assessment of the vulnerability and expected socio-economic losses over Alexandria and Port Said in Egypt. They summarized coastal protection works along the Nile Delta coast with a discussion of the lifetime of the structure. They also discussed the impact of sea level rise on these structures. They found that if no action is taken, then an area of about 30% of Alexandria will be lost due to inundation. Almost 2 million people will have to abandon their homeland; 195,000 jobs will be lost and an economic loss of over $3.5 billion is expected over the next century. At Port Said, they found that the economic loss is over $2.0 billion for 0.50 m SLR and may exceed $4.4 billion for 1.25 m SLR.

Frihy [15] carried out a degree of vulnerability analysis to locate which sectors need to be assessed and adapted to possible sea level rise (SLR) for the Nile delta-Alexandria region of Egypt. He presented a long-term sea level rise based on mean annual sea levels measured by tide gauges located at Alexandria, Burullus and Port Said. He found that the values of relative sea level rise for Alexandria, Burullus and Port Said were 1.6, 1.0 and 2.2 mm/year, respectively. He concluded that not all of the coastal zones of the Nile delta are vulnerable to accelerated sea level rise at the same level. Finally, he categorized the Nile delta-Alexandria coast into 30% vulnerable areas, 55% invulnerable areas and 15% artificially protected coastal stretches.

El-Gindy et al. [7] used the time series of the available hourly sea level data collected during the periods 1982-1983 and 2000-2001 at two locations at Rosetta promontory, Egypt. This is to study the main features of sea level, tides and surge variations in this region. They found that the annual Main Sea Level (MSL) at the Estuary station was about 30 cm, while at the sea station, it was 12 cm above the zero level of the Survey Authority.

Frihy et al. [16] presented a comparison of relative sea level trends estimated from annual tide-gauge records at different coastal cities in Egypt (Alexandria, Abu Qir, Rosetta, Burullus, Damietta and Port Said). They found that an overall upward trend of relative sea level fluctuates between 1.8 and 4.9 mm/year.

2.2. Previous works around the world

Kelvin and Fernando [21] discussed the effect of global warming and groundwater extraction on relative sea level rises in *Philippine*. They presented the sea level rise records and the groundwater use at Manila from 1902-2000. They found that the sea level rise of 1 to 3 mm/year is due to global warming. The principal reason for this rise was that excessive groundwater extraction which lowering the land surface by several centimeters to more than a decimeter per year. They suggested to spent money on preventing the land subsidence by reducing groundwater pumping and moderating population growth and land use.

Karaca and Nicholls [20] presented the sea level data for selected locations around the Black Sea at *Turkey* from 1935 to 2000 (Sevastapol, Varna, Constantza, Batumi, Tuapse and Poti). They found that the capital loss of a 1 m rise in sea level could be about 6% of current Gross National Product (GNP), whereas simple protection/adaptation could cost 10% of current GNP.

Pruszak and Zawadzka [25] analyzed current and predicted influences of accelerated sea level rise on the *Polish* coast. They divided the Polish coast into three areas according to coastal and socio-economic characteristics. Then, they considered two scenarios of accelerated sea level rise ((i) 30 cm/100 year and (ii) 100 cm/100 year). They carried out an analysis of the threats of land loss and flood risk. Also, they assessed the economic and social costs for losses.

Sterr [28] carried out the vulnerability assessments in *Germany* at three scales: (i) The national level, i.e., for all coastal areas lying below 5 m (Baltic Sea Coast) and 10 m (North Sea Coast), (ii) The regional level for the coastal state of Schleswig-Holstein, and (iii) The local level for selected communities within this state. He found that an accelerated sea level rise of 1 m would put more than 300,000 people at risk in the coastal cities and communities. Also, the economic values endangered by flooding and erosion would amount to more than 300 billion US$ (based on 1995 values).

Baric et al. [1] presented sea level measurements at five points on the east Adriatic coast in *Croatia* over the last 40 years indicate different sea level trends. They studied the effects of 20 and 86 cm sea level rises on this coastal area. They found that the sea level varied from a rise between +0.53 and +0.96 mm/year to a decrease between –0.50 and –0.82 mm/year. Also, they found that coastal areas appear to have a low vulnerability to changes in sea level. However, some important sites would be seriously endangered.

They suggested preparing the long-term national adaptation strategies to sea level rise and plans of actions, and monitoring of the consequences of sea level rise.

Ferreira et al. [14] presented monthly mean sea level data at Cascais and Lagos in *Portugal*. They concluded that the specific adaptation policies for accelerated sea level rise impacts do not presently exist. However, existing laws can be used to prevent and/or reduce socio-economic impacts if they are strictly applied. Also, a strong commitment to coastal management by Portuguese authorities is therefore necessary in order to prevent and minimize future implications of accelerated sea level rise.

Lebbe et al. [23] described the physical characteristics of the coasts in the *Belgium* and a qualitative interpretation of its vulnerability. They presented the mean sea level in Oostende for the period 1930-2000. In addition, they discussed *Belgian* coastal defense structures and their effectiveness. They found that low-lying polders are the most vulnerable to sea level rise.

De la Vega-Leinert and Nicholls [3] presented historical relative sea level rise in *Great Britain* during the twentieth century for five selected stations with the longest-spanning records. They concluded that coastal management is embracing sea level rise and climate change as one of the long-term issues that must be addressed, while recently no statutory guidelines are encouraging decision makers and actors alike to promote integrated coastal zone management. Hence, preparations for adaptation to sea level rise are more advanced than in most European coastal countries. They recommended that new coastal defenses consider an allowance for accelerated sea level rise and they also prepared strategic shoreline management plans, which include proposals for managed retreat in flood-prone areas with low levels of development, and allowing continued erosion of retreating cliffs.

Fenger et al. [13] presented long-term sea level variations during the period 1890 to 1996 at five locations in *Denmark* (Aarhus, Esbjerg, Gedser, Hornbæk and Copenhagen). They found that the estimated relative sea level will increase by 33-46 cm within the next 100 years.

3. Methods for Managing Sea Level Rise

There are many strategies were used and adapted to face the sea level rising in the different countries of the world. In this chapter, the most of these strategies are listed and described briefly. In addition, some examples, the advantages and disadvantages of each strategy are presented.

3.1. Soft construction techniques

A beach is the perfect defense against wave action and, if a beach is poor, then one option may be to undertake beach nourishment. This basically involves adding large quantities of material to a beach in order to build it up. The material added will need to be very similar to the material naturally found on the beach and will probably come from remote sources. Offshore dredging can provide a good source of suitable material for beach nourishment schemes or alternatively the sediment can be obtained from land based quarries. Sand dune stabilization is a coastal management technique for preventing erosion. Sand dunes trap sand and beach material washed and blown up, the rate of erosion is slowed and an effective flood barrier is created. Sand dunes may be stabilized through the planting of vegetation. Vegetation encourages dune growth by trapping and stabilizing blown sand.

3.1.1. Examples

- A good example is Miami Beach, Florida, *USA*, which was re-nourished in 1979 by a joint Corps of Engineers - City/County government project costing $52 million. The capitalized annual cost is about $4 million and the project has lasted more than 20 years without the need to re-nourish the beach.
- In *Australia*, there is a variety of coastal dune landforms. They range from relatively small shore-parallel fore dunes that sit immediately behind the beach, tens of meters wide and a few meters thick.

3.1.2. Advantages

- It has no negative effect on the fishermen, farmers and artificial workers near the beach.

- Forming new beaches for tourism and thus creates more employment.
- It has no adverse effects on farmers or the artificial workers near the beach.
- Costs for this option are low compared to installing protecting structures or to changes in land use.
- Sand dunes stabilization is economical, environmentally friendly, and is not regarded as unattractive.

3.1.3. Disadvantages

- It is required the large quantities of sand.
- This process must be continuous and periodic.
- This way is not used for beaches subjected to high waves and current. If waves are high, then the most of the nourishment sand lost.

3.2. Barriers

The barrier is a large dam, gate, or lock or a series of them. The main function of it is managing the tidal flows and the probable sea level rise in and out of the bays and harbors. The barrier could be fixed in place and allows managed flow through a portal for water exchange, tidal function and navigation. Alternatively, it could be temporarily deployed just to head off the worst flooding during a storm surge.

3.2.1. Examples

- Oosterscheldekering Barrier, *Netherlands*: Constructed between the islands Schouwen-Duiveland and Noord-Beveland to protect the Netherlands from flooding. The dam is based on 65 concrete pillars with 62 steel doors, each 42 meters wide.
- Thames Barrier, *England*: A series of river gates, it was built in the 1970s to protect vulnerable London from storm surges. In 1990, the

Thames Barrier closed once or twice a year on average, while in 2003, it closed 14 times. It is expected to be useful only for another 50 years because of sea level rise.

- Venice MOSE, *Italy*: About 80 mobile barriers in the lagoon of Venice that will lie on the sea floor but inflate during high tides. It is expected to be completed in 2012 and to operate as much as 100 times a year.

3.2.2. Advantages

- Protect a large area of land with high efficiency.
- Used against storm surge and sea level rise.
- Do not impede navigation.

3.2.3. Disadvantages

- Barriers are expensive to construct.
- Effecting on the protected area's salinity, sedimentation, wetlands, wildlife and endangered species.
- Effecting on sedimentation, likely making parts of the protected area shallower, while increasing coastal erosion.
- It may not work due to technical problems.

3.3. Coastal armoring

The coastal armoring is a linear protection, such as levees and sea walls that fix the shoreline in its current place. Linear protection is today's most widely used tool for protecting both development and wetlands along the ocean coastline. It takes different forms depending on the kind of coastline needing protection. The most hardened form, engineered concrete sea walls and bulkheads, protects the shore from strong wave action. Earthen levees or dikes protect low-lying land, often from river flooding, and sea level rising. They also can be raised with sand bags in an emergency. The different types of armoring and beach stabilization structures are discussed briefly in Table 1.

3.3.1. Examples

- Hondsbossche-Zeewering, *Netherlands*, is a 5.5 km long sea dike between the villages of Camperduin and Petten.
- Afsluitdijk, *Netherlands*, is a major causeway in the *Netherlands*, constructed between 1927 and 1933 and running from Den Oever on Wieringen in North Holland province, to the village of Zurich (mun. Wûnseradiel) in Friesland province, over a length of 32 km and a width of 90 m, at an initial height of 7.25 m above sea level.
- Ocean Beach, San Francisco, California, *USA*, at the Pacific Ocean, is fixed in place by both a massive sea wall, and Dikes.

3.3.2. Advantages

- Armoring is the oldest flood protection tool. It is familiar and behaves predictably.
- It can be used in combination with other strategies to protect existing development from rising water.
- It can be used against both storm surge and baseline sea level rise.

3.3.3. Disadvantages

- It is a short-term solution. It can be engineered only to accommodate a certain storm size or rise in sea level.
- It also requires costly annual maintenance.
- An unusually large storm event can also cause it to rupture.
- Hard shoreline protection is not as effective as natural shorelines at dissipating the energy from waves and tides.
- Armored shorelines tend to be more vulnerable to erosion, and to increase erosion of nearby beaches.
- Giving people a false sense of security and encouraging development in areas that are vulnerable to flooding.

3.4. Elevated development

It is raising the height of land or existing development and protecting it with coastal armoring. Also, elevation of land can be used to protect infrastructure such as airports, roads or railways near the shoreline.

3.4.1. Examples

- Elevated houses in Treasure Island, San Francisco, *USA*, the government elevates the building pad for the island's proposed developed area and concentrate development there.
- Elevated houses in New Orleans, Louisiana, *USA*, New Orleans actually requires new or rehabilitated housing in levee-protected areas. These houses are elevated either 3 feet above grade, or to the base flood elevation, whichever is higher.

3.4.2. Advantages

- Allowing structures to be built upon an encroaching shoreline or in a vulnerable area, with a low risk of flooding.
- A good tool for retrofitting certain low-lying infrastructures, such as airports.

3.4.3. Disadvantages

- It is also a short-term strategy.
- Also, it alters the characteristics of shorelines and will need protection just like low-lying development.

3.5. Floating development

In this strategy, the structures (buildings, roads and bridges) float on the surface of the water, or may be floated occasionally during a flood, making them largely invulnerable to changing tides. Floating homes can be moored to the shore or anchored to the sea floor.

3.5.1. Examples

- Floating homes in *Sausalito*, where the first houseboat communities were established in the 1960s. Floating homes also are popular in other waterfront cities with relatively protected waterfronts: Redwood City, Seattle, and Amsterdam.
- Floating infrastructure, a floating green house was built as a prototype in the *Netherlands*, and floating or pontoon bridges have been built in several places in Washington State, *USA*.

3.5.2. Advantages

- Managing the uncertainty of high tides and earthquakes.
- It could work in spite of the uncertainty surrounding the timing and nature of sea level rise.
- It is very resilient to seismic activity.

3.5.3. Disadvantages

- Working only in protected areas.
- It does not work well in places subject to high wind and wave.

3.6. Floodable development

This strategy depends upon structures that are designed to withstand flooding or to retain storm water. The idea of floodable development is two-pronged. One idea is to design buildings and infrastructure to resist damage by occasional or even periodic flooding. A second idea is to create retention areas for ocean surges or heavy rainfall. New floodable development built to handle sea level rise may be designed to manage storm water, both salt and fresh, at orders of magnitude above most low impact development tools.

3.6.1. Examples

- In Rotterdam, *Netherlands*, a large underground parking garage under construction will hold water instead of cars during peak floods.

- In the *United Kingdom*, the idea of a “village blue” has been proposed for several towns with growing river flood problems and growing populations. This concept is a central recreation area that becomes an expandable lake, complete with swimming and boating facilities, in flood conditions.

3.6.2. Advantages

- An effective small-scale toolbox to the next level.
- It may be better in urban areas versus agricultural or rural areas.

3.6.3. Disadvantages

- Floodable development could be hazardous. Storm water is usually polluted with heavy metals and organic chemicals, in addition to sediment and bacteria.
- Storm water is usually polluted so it could pose a public health hazard.
- Treatment methods will be needed.
- It requires emergency communication tools and public outreach.

3.7. Living shorelines

Living shorelines or wetlands are essential for the health of estuaries. They protect shorelines from floods and erosion by absorbing waves and slowing the flow of high water so they provide habitat. Wetlands take various forms such as tidal basins, marshes, mud flats, rocky shores, and pebble beaches.

3.7.1. Examples

- Major wetlands and restoration projects in the South and East the San Francisco Bay, *USA* include the Don Edwards Wildlife Refuge in Redwood City and the South Bay Salt Pond Restoration Project, the largest tidal wetland restoration project on the West Coast.

3.7.2. Advantages

- Benefit the society.
- Filter pollutants out of the water and sequester carbon.
- Provide recreational spaces.
- Create habitat for fish and wildlife.

3.7.3. Disadvantages

- It requires space and time to work.
- It requires management, monitoring and time to become established.

3.8. Managed retreat

Managed retreat is a strategy that safely removes settlement from threatened shorelines, allowing the water to advance unimpeded. It involves abandoning, demolishing or moving existing buildings and infrastructure to higher ground. It also includes banning new development in areas likely to be inundated. It is used when coastal armoring and other shoreline protection efforts become very expensive or are judged to be a losing battle. The "managed" part of retreating from the shoreline involves establishing thresholds to trigger activities such as demolishing buildings or abandoning efforts to control shoreline erosion. These thresholds can be coupled with buy-back programs to compensate property owners for loss, plus strict building codes that allow only certain types of re-locatable or floodable structures.

3.8.1. Examples

- In Great Lakes states, *USA* construction setback rules in most coastal and Great Lakes states allow development only within a certain distance of the water's edge.
- In Pacifica State Beach, California, *USA*, in the early 1990s, the City of Pacifica decided to collaborate to work toward a managed retreat strategy by removing vulnerable structures along the beach.

3.8.2. Advantages

- Minimizing human suffering, by relocating buildings and infrastructure to safer ground before a catastrophic flood.
- Usually it is less expensive than armoring strategies.
- It also can be designed to allow the restoration of flood-buffering wetlands and natural shoreline habitat, which affords protection.

3.8.3. Disadvantages

- Cause legal and equity issues.
- Requires costs for beyond relocation or property costs.

3.9. Integrated Coastal Zone Management (ICZM)

There are many definitions for Integrated Zone Coastal Management (ICZM). Knecht and Archer [22] defined ICZM as: “A dynamic and continuous process of administering the use, development and protection of the coastal zone and its resources towards common objectives of national and local authorities and the aspiration of different resource user groups”. Also, Sorensen [27] gives a definition of ICZM as: “Integrated management provides policy direction and a process for defining objectives and priorities and planning development beyond sectoral activities”.

The main principals of ICZM are:

- Adopting a wide ranging view of inter-related problems.
- Decision making based on good data and information.
- Working with natural forces.
- Involving all stakeholders and all relevant parts of the administration.
- Using a range of instruments (laws, plans, economic instruments, information campaigns, Local Agenda 21s, voluntary agreements, promotion of good practices, etc.) for coastal management.

3.9.1. Examples

Table 2 provides a summary of the some Projects of ICZM in each participating Member State, based on the final report on Lesson Learned from the European Commission's Demonstration Programme on Integrated Coastal Zone Management.

3.9.2. Advantages

- Develop public awareness, build capacity, foster cooperation, and implement issue-driven action plans.
- Provide local and national benefits and improve the quality of life.
- Optimize the use of natural resources by integrating horizontal and vertical institutions in decision-making and development.
- Minimize the degradation of natural systems and stimulate sustainable development.

3.9.3. Disadvantages

- The ICZM approach is somewhat theoretical, in that it lists a number of institutional initiatives but does not explicitly include implementation of actual adaptation measures

3.10. Legal development regulation

Legal development regulation involves the taking of legal or regulatory actions to restrict development or prohibit re-development of hazard-prone areas. Regulations may include the adoption of erosion-based setback regulations, restricting post-storm reconstruction, or changing the tax structure to discourage development.

3.10.1. Advantages

- Proper implementation of this measure could result in net benefits.
- No adverse environmental impacts.

3.10.2. Disadvantages

- Limited impact on fishing and farming sectors.
- Difficulty of the implementation.

3.11. Do-nothing strategy

One final alternative that must always be evaluated is the do-nothing or no-project case. The risk of flooding and wave damage continues or increases if historic erosion is also present at the site. Whenever all structural and nonstructural alternatives considered are too costly, then no economically viable solution exists. If the life-cycle costs for protection or relocation exceed the value of the investment, then do-nothing is the appropriate response.

4. The Impacts of Sea Level Rise on Egypt as a Study Case

Egypt appears to be particularly vulnerable to climate change, because of its dependence on the River Nile as primary water source, its large traditional agricultural base, and its long coastline, already undergoing both intensifying development and erosion. The shoreline of Egypt extends for more than 3,500 km along the Mediterranean Sea and the Red Sea as shown in Figure 1. In addition, a number of lagoons situated along the Nile delta coast and to the east of the Suez Canal. Coastal lagoons and lakes are, in general, zones of high productivity and are extremely sensitive to disturbances.

4.1. Impacts of sea level rising on Egypt

There are several studies discussed the impacts of the sea level rising on Egypt such as Delft [4], Sestini [26], El-Raey et al. [8], El-Raey et al. [9, 10], Eid et al. [5], Frihy [15], Eid et al. [6], Elsharkawy et al. [11] and Frihy et al. [16]. According to these studies, the following impacts will be happened if no action is taken in Egypt:

1. Direct inundation and loss of beaches and archaeological sites with associated loss of tourism.

2. Loss of arable and agricultural land and fishing grounds and a decrease of fish catching in some areas and an increase in other areas.
3. Increase in the rate of salt water intrusion, soil salinity, water logging, desertification and a loss of land productivity.
4. A change in of the coastal water circulation pattern, with associated changes in fish catching and navigation.
5. A decrease of life spans of coastal buildings and archaeological sites due to increase of saltwater intrusion.
6. Contamination of fresh water aquifer, with associated agricultural losses.
7. A decrease of the River Nile budget and flow rate (as predicted by some models), would result in an increase of the rate of erosion and salt water intrusion at the Northern Delta coast.
8. Impacts on the harbor designs due to changes in sea level and frequencies of storm surges. This may cause severe economic losses.
9. About 15% of the arable delta land will possibly be subject to inundation over the next century with extension as far as 20 km inland from already existing coasts.
10. Land productivity will also suffer due to salt water intrusion effects up to the belt of 2 m contour which is 30 to 60 km wide.
11. This belt includes important cities such as Alexandria, Port Said, Kafr El-Dawar, Rosetta, Damietta, Mataria and Manzala.
12. A vulnerability assessment including a preliminary assessment of socio-economic impacts and impacts on northern wetlands and fisheries.
13. In one scenario, it was assumed that aquaculture development in northern lakes will have a large effect on fish production potential.

4.2. Most vulnerable Egyptian cities

Egypt's Nile delta with its coastal front on the Mediterranean is considered vulnerable to the impacts of climate change. In addition, expected rise in sea level, shoreline erosion, stresses on fisheries and saltwater intrusion in groundwater create major challenges. The most vulnerable Egyptian cities are Alexandria, Rosetta, and Port Said, shown below in Figure 2 under current conditions, as well as scenarios for 0.5 and 1 meter sea level rise.

4.2.1. Alexandria city

Alexandria city is located to the west of the Rosetta branch of the Nile and is famous for its beaches, historic and archeological sites. It has a population of about four million and hosts the largest harbor 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: Lake Maryut. Water level in Lake Maryut is kept at 2.8 m below sea level through continuous pumping of water into the Mediterranean. To assess the impacts from sea level rise (SLR), 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 as shown in Table 3.

4.2.2. Rosetta city

Rosetta city is a well-known Pharaonic and Islamic city located in the Rosetta region near the intersection of the Rosetta branch of the River Nile with the Mediterranean Sea east of Alexandria. Similar to Alexandria, a quantitative vulnerability assessment of the potential impacts of sea level rise has also been carried out for Rosetta (El-Raey et al. [9]). The expected economic losses in land cover of Rosetta for a sea level rise of 0.5 m were estimated. Studies showed that about 1/3 of the employment in the city will be affected and a loss of about $2.9 billion is expected over the next century.

4.2.3. Port Said city

Port Said is located on the Mediterranean Sea east of the Damietta branch of the River Nile at the entrance/exit of the Suez Canal. Port Said Governorate has a total area of 1,851 km^2 and is divided into five districts: El Shark, El Monakh, El Arab, El Dawahi and Port Fouad. The vulnerability of Port Said to sea level rise is particularly high given the socio-economic importance of its coastline and the fact that it has one of the highest rates of local land subsidence in the Nile Delta which amplifies the effects of climate change induced sea level rise. As shown in Table 4 (for example), the most severely impacted sectors are expected to be industry (12.5%) and transportation (11.7%). In case of a SLR of 0.5 m, a loss of 6,700 jobs (5.3%) is expected.

4.2.4. Other vulnerable areas on the coastal zone

Beaches and tourist sites at other cities such as Matruh City to the west of the Delta and Arish City to the east are also vulnerable to a rise in to sea level. Water-logging and water bogging problems in low lying areas close to the coast have already emerged in many localities. Besides, the continuous degradation of coral reefs along the coasts of the Red Sea would severely impact bio-diversity, fish catching and tourism in that region. The socio-economic impacts associated with these changes are far reaching and include migration, unemployment and possibly political unrest.

4.3. Famous coastal protection works in Nile delta

Fanos et al. [12] and El-Raey et al. [10] presented a review for all the protection works along the Nile delta coast. This, together with a discussion of the lifetime of the structure can be summarized in Table 5. Some examples of the coastal structures within the Egyptian coasts are shown in Figure 3.

5. Conclusions

Climate change is considered as one of the hottest global environmental problems facing the world community. The sea level rising is an associated phenomenon to this climate change. This phenomenon has directly affected on many sectors such as water resources, coastal zones, agriculture, rangeland and livestock, human health, human settlements, energy, forest, bio-diversity: species, communities and ecosystems and fisheries. The main conclusions of this paper are:

1. The global mean surface temperature is projected to increase about 1-3.5 C by the year 2100 caused in sea level rising by about 15-95 cm.
2. Without serious adaptation measures, millions of people will be displaced from their homes. In addition, the loss of productive land will have serious implications on job opportunities, food availability and population movement.
3. The use of barrier is successfully strategy for protecting the harbors and lagoons entrances in different countries. In addition, the coastal armoring and beach stabilization structures are widely used methods to protect the coasts from sea level rise around the world. Also, the nourishment and sand dune stabilization are economical, environmentally friendly, and are not regarded as unattractive.
4. The elevated development, floating development, living shorelines and manage retreat strategies can be developed for the low important coasts.
5. The coastal zone of Egypt is seriously vulnerable to the effects of sea level rise and changes in weather patterns from both the physical and the socio-economic points of view. Large areas of the governorates of Alexandria, Behaira, Kafr El-Shiekh, Port Said, Damietta and Suez, are particularly vulnerable to sea level rise.

According to the results, the study recommends the following:

1. Research activities for coastal vulnerability assessment.
2. Research budget and funds should be increased to cope with the climate change and its impacts and adaptation studies.
3. Building trust among concerned parties.
4. Building co-operative approach to integrate all efforts such as the Integrated Coastal Zone Management (ICZM).

5. Work to raise the capacity in the areas of assessing the risks posed by climate change and the identification and implementation of adaptation actions; and
6. Work to raise community awareness of the implications of climate change and the role of community in the face and adapt to these effects.

Table 1. Types and functions of coastal structures (EM 1110-2-1100, Part VI) [29]

Type of structure	Objective	Principal function
Sea dike	Prevent or alleviate flooding by the sea of low lying land areas	Separation of shoreline from hinterland by a high impermeable structure
Sea wall	Protect land and structures from flooding and overtopping	Reinforcement of some part of the beach profile
Revetment	Protect the shoreline against erosion	Reinforcement of some part of the beach profile
Bulkhead	Retain soil and prevent sliding of the land behind	Reinforcement of the soil bank
Groin	Prevent beach erosion	Reduction of long shore transport of sediment
Detached breakwater	Prevent beach erosion	Reduction of wave heights in the lee of the structure and reduction of long shore transport of sediment
Reef breakwater	Prevent beach erosion	Reduction of wave heights at the shore
Submerged sill	Prevent beach erosion	Retard offshore movement of sediment
Beach drain	Prevent beach erosion	Accumulation of beach material on the drained portion of beach
Beach dune and nourishment	Prevent beach erosion and protect against flooding	Artificial infill of beach and dune material to be eroded by waves and currents in lieu of natural supply
Breakwater	Shelter harbor basins, harbor entrances, and water intakes against waves and currents	Dissipation of wave energy and/or reflection of wave energy back into the sea

Floating breakwater	Shelter harbor basins and mooring areas against short-period waves	Reduction of wave heights by reflection and attenuation
Jetty	Stabilize navigation channels at river mouths and tidal inlets	Confine streams and tidal flow. Protect against storm water and crosscurrents
Training walls	Prevent unwanted erosion or sedimentation and protect moorings against currents	Direct natural or man-made current flow by forcing water movement along the structure
Storm surge barrier	Protect estuaries against storm surges	Separation of estuary from the sea by movable locks or gates
Pile structure	Provide deck space for traffic, pipelines, etc., and provide mooring facilities	Transfer of deck load forces to the seabed
Scour protection	Protect coastal structures against instability caused by seabed scour	Provide resistance to erosion caused by waves and current

Table 2. Some examples of ICZM projects in Europe

Country	Project	Partnership	Focus	Lessons learned
England	Isle of Wight - Integrated Management of Coastal Zones	Isle of Wight Council, SCOPAC and English Nature	To examine mechanisms used to deliver sustainable policy. To highlight 'good practice' in a number of areas leading to integrated management.	The local voluntary approach works best within the bounds of national legislation. Employment of a project officer is crucial. Visioning - towards preferred future state of coastal area is often successful.
Spain	The CONCERCOST project (La Costera-Canal, Gandia/ Valencia)	Municipality Associations in Spain (and Portugal)	To develop consensus between the public officials responsible for the integrated management of the territory and the coordination of management policies through comprehensive land use planning.	Integration between the different administrations and improved participation are necessary to advance ICZM.

Portugal	The Maria Project	University and open fora	To develop participation and coordination.	Multiple use management and zoning was suggested as a way of integrating objectives and also of bringing together the various government sectors.
Netherlands	The Haringvliet Project	Decision makers, consultative group, policy analysis group and technical working group	To recreate lost and polluted wetlands.	Complex stakeholder interests were mapped. Comprehensive stakeholder involvement slowed the process, but is also reduced animosity and created trust. Ranking of solutions allowed conflicts of interests to be effectively addressed

Table 3. Percentage of sectors losses for Alexandria city (El-Raey et al. [10])

Sector/Elevation(m)	0.0	$SLR = 0.25$	$SLR = 0.5$	$SLR = 1.0$
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 4. Percentage of sectors losses for a SLR of 0.5m in the Port Said Governorate (El-Raey et al. [9])

Losses	El Shark	El Arab	El Monakh	El Dawahy	Port Fouand	Total
Beach area	0.426	0.377	7.419	-	13.039	21.26
Urban area	0.034	0.044	0.339	-	0.046	0.47
Industry area	0.015	0.002	0.018	-	0.016	0.05
Agriculture area	0.000	0.000	0.000	-	0.000	0.00
Aquaculture area	0.000	0.000	0.000	-	0.024	0.024
Municipal services (#)	0.000	0.000	0.000	-	0.000	0.000
Transportation network (km)	10	7	3	-	3	23
Population (persons)	3968	16699	6503	-	1021	28191
Employment	953	4000	1558	-	248	6759

Table 5. Protection works along the Nile delta coast, Egypt

Location	Description	Reference
West of Alexandria	The new drain at western Nobariya drain outlet is about 20 km to the west of Alexandria. Two jetties of 65 m length were constructed in 1986 to protect the exit from siltation, and they are functioning effectively.	EL-Raey et al. [10]
Alexandria beaches	Five beaches, El Shatby, Stanley, Sidi Bishr, El Asafra and El Mandra, were nourished by medium to coarse sand transported from the desert near Cairo.	EL-Raey et al. [10]
Abu Quir Bay	Abu Quir Sea wall was built in 1780 and has been maintained by placement of additional large concrete blocks. This wall was modified and reinforced in 1980 by constructing a sloping face (2:1) and placing modified cubes of 0.5 ton each as an armor layer	EL-Raey et al. [10]
Rosetta Promontory Sea Walls	Two dolos sea walls were constructed as protective works in 1989-1991. The western promontory is protected by a sea wall of 1.5 km length and the northern end of the eastern promontory by a sea wall of 3.5 km length. Four ton dolos were used as armor and are designed to be stable for a scour of 8 m and wave height of 5.3 m.	Fanos et al. [12]
Eastern Harbor of Alexandria	A 180 m extension of the existing west breakwater would narrow the gap between the west and central breakwaters from its existing 300 m width to 100 m. This decrease in gap width would reduce wave heights along the critical area of the Cornish.	EL-Raey et al. [10]

Burullus Headland	In 1972, a jetty was constructed on the western side of the Burullus Lake outlet which, due to the strong easterly directed transport, became completely filled in 1980, advancing the shoreline sea-ward by more than 500 m. A new project, now being implemented, consists of an extension of the western jetty to a water depth of 3.5 m and construction of a new eastern jetty which will narrow the channel thereby improving its flushing characteristics. In addition, the jetties, revetments were built on both sides of the outlet.	Fanos et al. [12]
Burg El-Burullus Sea Wall	During the period 1937 to 1940, a series of five groins was constructed to limit the erosion in front of Burg El-Burullus village which is located immediately downdrift (east) of the Burullus Lake outlet. In 1950, a wall of 600 m length was constructed between the groins to limit landward re-treat. Many parts of this wall have collapsed due to erosion and undermining and extensive maintenance was carried out prior to 1981. In 1982, the concrete wall was modified. To the east end of this wall, a basalt wall was attached in order to provide erosion and flooding protection for the remainder of the village.	Fanos et al. [12]
Baltim Sea Resort	To limit erosion in the Baltim Sea Resort area and to provide a sheltered recreational area, construction of four detached breakwaters, each of 250 m length, was started in 1991. Sand nourishment is planned immediately following completion of the breakwater construction.	Fanos et al [12]
Damietta Promontory	In 1941, a jetty was constructed to reduce sand deposition in this branch of the Nile. Due to progressive erosion at the southern end of this jetty, a sea wall was constructed in 1963 to join it with the land. Three concrete groins were constructed in 1971 to the southwest of this wall, with a basalt wall. Two short breakwaters were constructed in 1980 on both sides of the navigation channel at the new Damietta Harbor Channel which extends in the sea to 15 m contour. A second jetty was constructed on the eastern side of the Damietta Estuary entrance in 1976 to reduce siltation in the outlet. However, some shoaling still occurs and limited periodic dredging is required due to the	Fanos et al. [12]

	reduction in the equilibrium cross-section resulting from the impoundments constructed on the Nile. In 1972, a vertical concrete wall 1,500 m long was constructed to protect the coastal road located in the eastern part of the Damietta Promontory.	
Protection of the Highway between Damietta and Port Said	A small bituminous dike of 3,925 m length was constructed to protect the low parts of the coastal road near Port Said from flooding.	Fanos et al. [12]
Protection of El-Bardawil Lake Outlets	The proposed stabilization projects for two controlled outlets to El-Bardawil Lake include: (1) modifying the deteriorated western jetties and extending them to water depths of 5.0 m, (2) constructing new jetties on the eastern sides to water depths of 3.00 m, and (3) in anticipation of future erosion construction of two embankments on the eastern side, one facing the sea and the second facing the outlet with sand filling behind them.	Fanos et al. [12]
West of El Gamil Regulator and Inform of El Fardos village	In 1994, four detached breakwaters began to be constructed in the area to protect it from erosion. Each breakwater is 250 m long and is constructed from a barge, mounted plant at a water depth of 4 m. The cost of these four breakwaters is 11.7 million pounds.	EL-Raey et al. [10]
El Gamil Outlet	Two jetties of 225 and 200 m on the western and eastern sides of El Gamil outlet, respectively, are constructed to protect this outlet from siltation and migration. The cost of these two jetties was 2.57 million pounds.	EL-Raey et al. [10]
Highway near El Gamil Airport	A small bituminous dike of about 4l0 m length was constructed to protect the low parts of the coastal road near the airport from flooding. The cost was 3.3 million pounds.	EL-Raey et al. [10]

Figure 1. Map of the Arab Republic of Egypt.

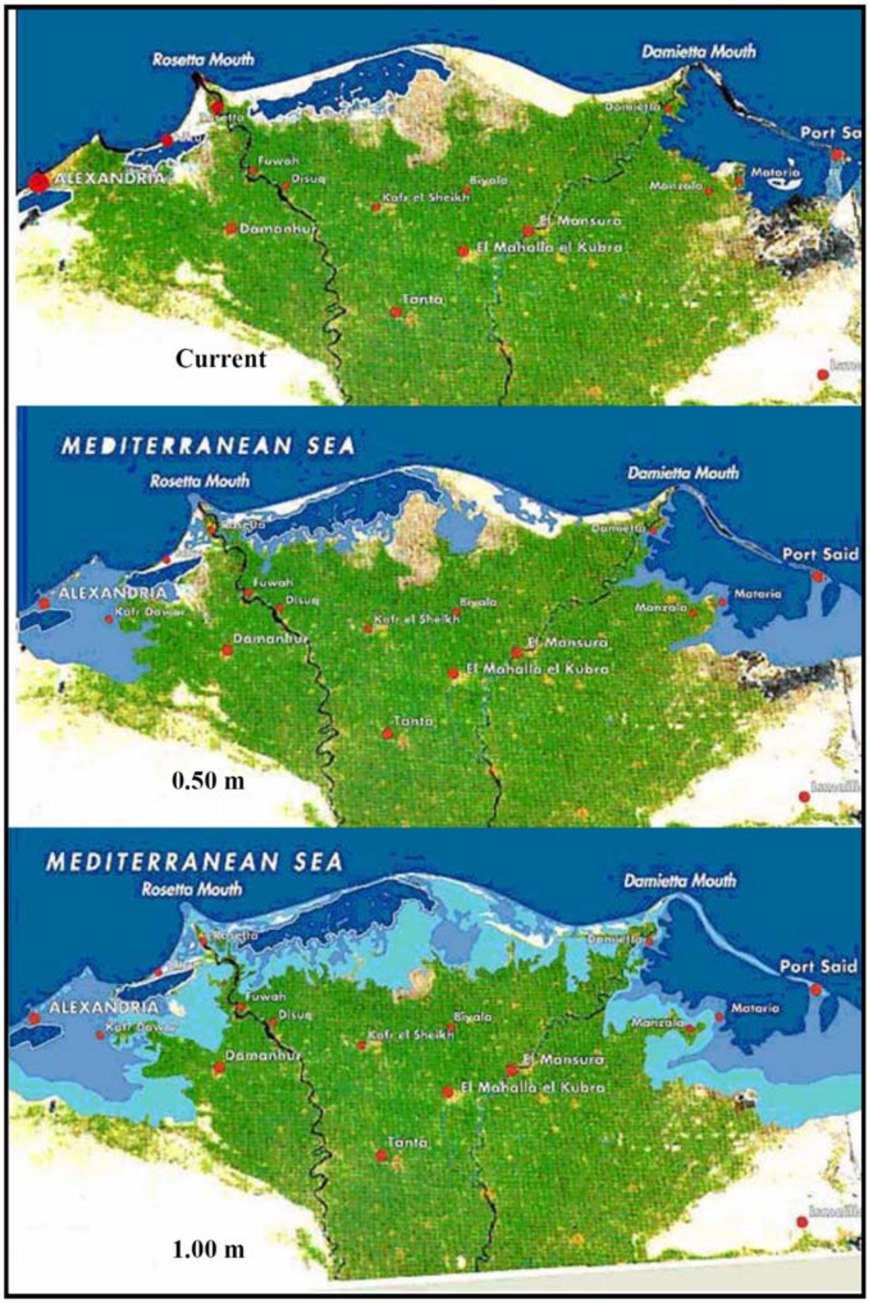

Figure 2. Coastal inundation in the Nile delta under sea level rise (Current; 0.5m; 1.0m) OECD [24].

Figure 3. Examples of the coastal structures in Egypt (Iskander [19]).

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