COSTAL ENVIRONMENTAL ISSUES OF CLIMATE CHANGE ALONG THE NILE DELTA COASTLINE

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ABSTRACT

Coastal zones are the most vulnerable places on the planet for man-made activities. The behavior of coastal zones is dynamic and must be well understood before any infrastructure is built to avoid damage from natural processes. Furthermore, anthropogenic activities have major impacts on the coastal zone. Natural resources, coastal resilience, ecological sustainability, and sociocultural difficulties are only a few of the issues that need to be addressed. As a result of natural and man-made interference, the Egyptian coastal area is characterized by instability. The challenges along Egyptian coastal zone are investigated in this study. Environmental challenges in the Nile Delta are also mentioned. The stability of the Nile Delta coastline zone, the effects of climate change, and mitigation measures will all be investigated. So, collecting available information and field data on the Nile Delta coastline is crucial to the research process. In addition, El-Baneen case study is investigated using numerical modeling to select the optimal solution that reduces the problems in this area.

Keywords: Coastal resilience, Nile Delta, Climate change, Numerical modeling, Sustainability

1 INTRODUCTION

Egypt is the most sensitive country to the effects of climate change. Climate change will have an impact on many sectors of Egypt's development, but mainly water supply, agricultural and coastal resources, tourism, and public health are affected. Climate change, the incidence of extreme events, and extreme weather have an impact on tourism and agriculture. Due to expected sea level rise, the Nile Delta region is also highly vulnerable to flooding and seawater intrusion.

The Egyptian coastline stretches for 1000 kilometers along the Mediterranean Sea, while in the east, it stretches for 2000 kilometers along the Red Sea. The Egyptian coastlines are characterized as one of the most complex environments in which human activities, the economy, ecology, and geomorphology interact. The low-lying Nile Delta, the Northeastern and Northwestern coasts, as well as significant cities, agriculture, industry, and tourism, make up the northern Egyptian coastal zone. The Nile Delta's coastal areas produce over 40% of Egypt's agricultural output, half of Egypt's industrial output, and are densely populated. So, the Nile Delta's natural resources have deteriorated due to human activity, and the Nile Delta no longer functions as a natural maritime zone (Stanley & Warne, 1993). Coastal erosion, siltation within lake openings, saltwater intrusion, increased soil salinity, and increased pollution in coastal water and soil are all signs of deterioration in the coastal zone. A significant region from the Nile Delta is predicted to be submerged under the water due to climate change and other factors.

This paper describes the main resources in the coastal zones of Egypt, the climatic problems that demonstrates of each region, and details the contributions of these regions to the national economy. Various adaptation options could be employed to deal with the SLR impact on the risky coastal zones in order to reduce the risks caused by SLR along the Nile Delta Coasts. Finally, Case Study (Baneen City) was selected to apply the three alternatives (i.e., coastline retreat, accommodation, and coastal protection) to determine the suitable option to protect Al Baneen population and economical activities against SLR.

2 THE MAIN RESOURCES AND CLIMATIC ISSUES OF THE EGYPTIAN COASTAL ZONE

Egypt has a coastline that extends for more than 3,000 kilometers, with 70% of it in the Red Sea and 30% along the Mediterranean Sea, from Rafeh in the east to Salloum in the west. According to statistics, 100 kilometers or less from the shore is where 53% of Egyptians reside. In addition, Egypt has many inland lakes, the largest of which are the freshwater Lake Nasser and the saline Lake Qarun in Fayyoum.

The coastal zones of Egypt are relatively more important to all Egyptians. Because of the availability of agricultural resources and raw materials, 21.9% of the population of Egypt lives in the coastal regions. As shown in Fig. 1, these resources also contribute as the basis of economic development. Many important commercial coastal cities are heavily populated, including Alexandria, Damietta, Hurghada, Port Said, Suez, and Sharm El Sheikh. It is also a best possible way for shipping and transportation. For the fishing sector, it provides a significant source of income and food supply. An estimated 875,990 tons of fish are produced in Egypt each year, with 116,560 tones (13.3 percent of the total production) coming from coastal waters, according to statistics from 2004. (EEAA, 2005).

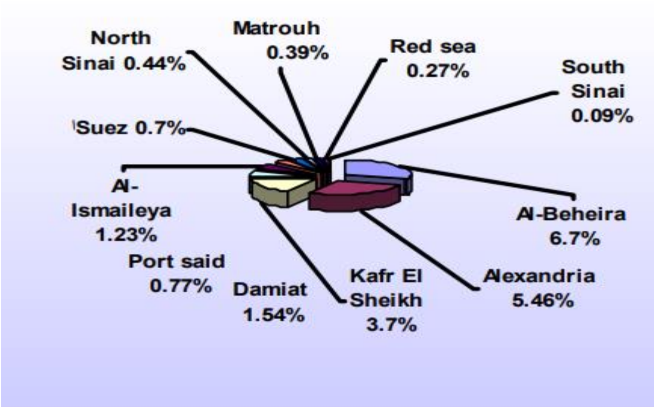

Figure 1. The Population Distribution of The Coastal Governorates in Egypt (Percentage of The Total Egyptian Population) (EEAA, 2005)

2.1 The Mediterranean Coastal Zone

The Mediterranean Sea coast differs from the Red Sea coast due to the geology, landform, and geographic location. The Mediterranean Sea's relatively long coastline. It is mainly formed of rocky beaches, coastal dunes, tidal flats, lakes and lagoons, and deltaic sediments, as may be seen in Figure 2. Approximately 25% of the wetlands in the Mediterranean area are found along Egypt's coastlines and in its five lakes. This coastal region is home to several important commercial and industrial centers, including Alexandria, Port Said, and Damietta, in addition to well-known beaches and tourism destinations. Precipitation along the Mediterranean coast varies between 130 and 170 mm per year and decreases gradually to the south. The tidal range is about 30 to 40 cm. Along the Mediterranean coastal zone of Egypt, it suffers from high population growth, soil loss in the Nile delta, extreme rates of erosion, seawater intrusion, salination, ecosystem pollution and degradation, and a lack of suitable institutional management systems.

2.2 The Red Sea Coastal Zone

The Red Sea's coast is often narrow because the mountain chain is located not far from the shoreline. it is divided into three main parts, the largest part is the main basin, which has an average of 1,350 km in length, 270 km in width, and 524 meters in depth. The second part is the 300 km long, 20 km wide, and 30 m deep Gulf of Suez, which is entirely contained inside Egyptian territorial sea.

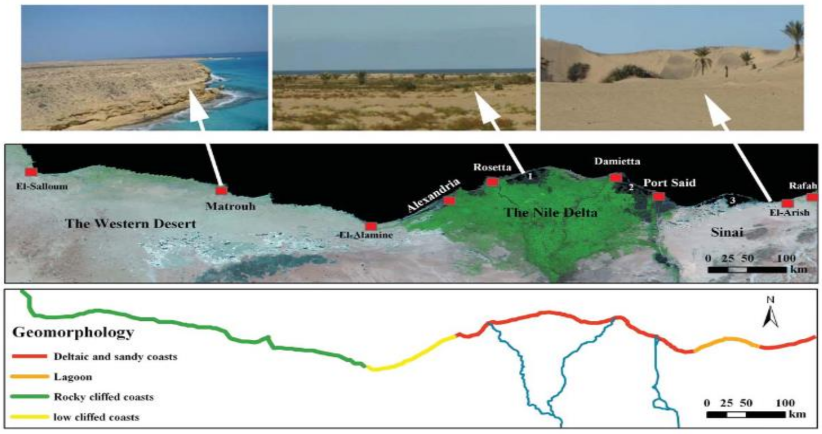

Figure 2. The geomorphology of the Mediterranean Sea coast of Egypt

On average, the Gulf of Aqaba is around 250 km long and 20 km wide. It has a sloping bottom and a depth of more than 2000 m in most places. The coast is consisting of several little gulfs and small beaches. The Red Sea is a remarkable body of water that is home to some of the most wealthy and productive coral reef ecosystems. A coral reef system covers ’s entire shores. It is the habitat of a diversity of marine species. (DiBattista et al., 2016; Riegl et al., 2012). The range of the tides is 110 to 130 millimeters. Many people stay in coastal cities. A substantial portion of the local population works in the major Red Sea resort towns of Sharm, Dhahab, Hurghada, and Nuweiba. In fact, tourism along the Sinai coast and in eastern Egypt along the Red Sea accounts for nearly 90% of the country's total tourism revenue, making a major contribution to Egypt's Economy (Handoussa et al., 2005).

Very limited freshwater resources are available along the Red Sea coast because of its geographical location. The region faces many environmental problems like habitat deterioration because of pollution, coastal landfilling, flash flooding, and the negative effects of tourism. The effects of climate change on the coral reefs of the Red Sea are coral bleaching caused by rising sea surface temperature, habitat loss, and biodiversity loss. A decline in tourism is most likely to follow from these impacts.

2.3 The Nile Delta Coastal Zone

Nile delta's sandy beaches extend for about 250 km from Alexandria in the west to Port Said in the east, facing the Mediterranean Sea as shown in Fig. 3. The Mediterranean is also linked to three lagoons (Idku, Burullus, and Manzala, from west to east). Sand dunes exist near Idku, El Burullus, Baltium and Gamasa (Mohamed, 2019). This region is a representation of the great industrial, agricultural, and economic resources of the country. Highest population centers (i.e., 38% of the total population) are found at the coastal zone of Alexandria and Nile delta as shown in Fig. 3 B. The Delta shoreline consists of sandy and silty shores. The Nile Delta zone is also extremely exposed to rising sea levels due to its extremely low land elevation. The lower Nile delta has a large area between zero and 1 m elevation, with parts below sea level (Fig. 3A). Moreover, there is some localized ground subsidence, which worsens the effects of sea level rise (Frihy, 2003).

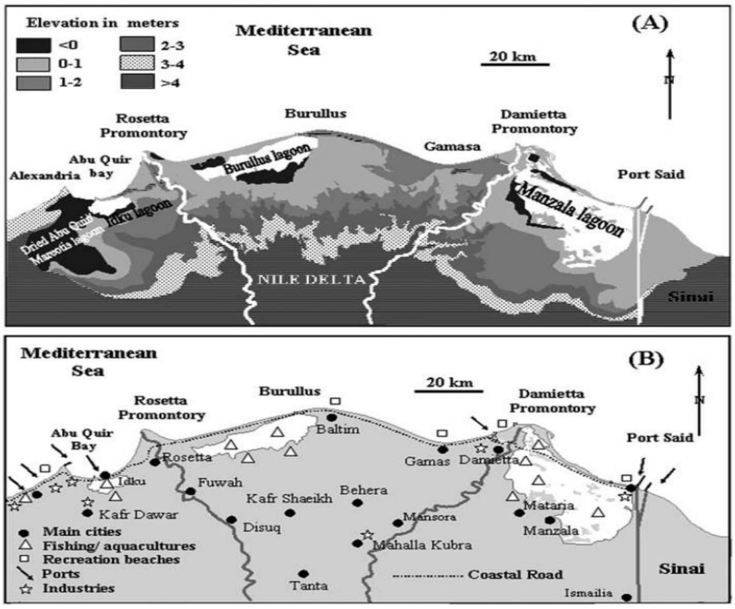

Figure 3. Map of Nile delta showing (A) main topographic features below and above mean sea level up to 4 m contour and (B) distribution of main socioeconomic elements across lower Nile delta coastal plain (Frihy, 2003).

Delta lakes are affected by several problems, including soil loss, extremely high rates of erosion, seawater intrusion, salination, ecosystem pollution, and a lack of appropriate institutional management mechanisms. Nile Delta is also vulnerable to shoreline changes caused by subsidence, sea level rise (SLR), and erosion and accretion. The following are some significant challenges in the Nile Delta region:

2.3.1. Nile delta Coast Erosion

The Nile Delta faces coastal changes due to erosion and accretion, land subsidence, and sea level rise due to climate change, like other deltaic areas worldwide. Many coastal regions throughout the world are attempting to deal with serious coastal erosion challenges. Construction of cities and harbors, coastal constructions and flood control works, and navigation infrastructure in the coastal zone may disrupt the delivery of sand to the coast (Magoon, Edge, & Stone, 2000). Furthermore, due to climate change, sea levels rise, and storms grow more frequently, and sediment instability in the coastal zone rises, producing extra coastal erosion. Natural forces may contribute to coastal erosion (e.g., waves, currents, tide, and sea level rise). Erosion is caused by a combination of human activity and natural processes (Phong, Parnell & Cottrell, 2017). Due to hydrodynamic forces, urbanization, industrial, and agricultural activities, sandy beaches have become extremely unstable. According to Komar (2000), building control devices along the Nile River, which prevent material from reaching the coast, has resulted in extreme erosion throughout Egypt's Nile Delta coast. Due to the lack of Nile sediments since 1964, the western shore of the Nile delta has suffered from a significant erosion of the delta coastline around the Rosetta headland as shown in Fig. 4 (Ismail et al., 2012).

Sand dunes formed by the sea were essential to preserving the coastline system as shown in Fig. 5. The instability of coastal sand dunes, a natural system for forming shorelines and maintaining their integrity, is responsible for the erosion problems on the western portion of the northern coast. Sand dunes are quickly depleted because of unintended operations. The category of coastal sand dunes in the Nile Delta coast decreased by around 45% between 1990 and 2014. (Ali & El-Magd, 2016). Numerous studies have investigated the effects of climate change on the Nile Delta, these studies concluded that a large percentage of the Nile Delta is directly vulnerable to flooding and seawater intrusion that could force millions of citizens leave their homes.

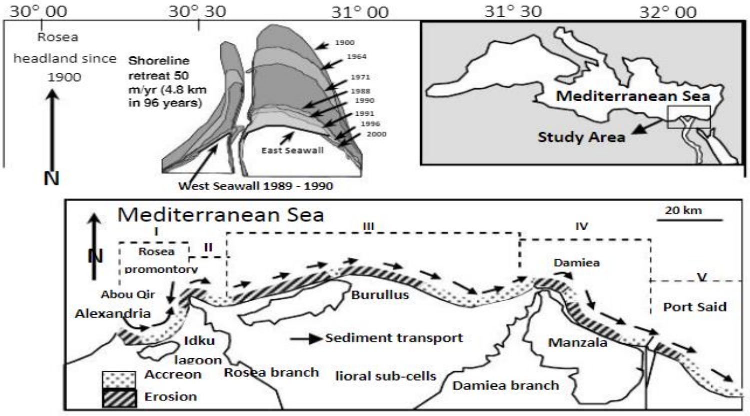

Figure 4. Erosion and accretion patterns and littoral sub-cells along the Nile Delta coastline (Ismail etal., 2012)

Figure 5. Natural chain of coastal sand dunes

2.3.2 Coastal Floods

Coastal flooding occurs when seawater inundates or otherwise covers coastal areas due to rising sea levels due to climate change, storm surges, and tsunamis. It may have various social and environmental consequences at spatial and temporal scales. Flooding can destroy dune systems and damage coastal cities (Nicholls, 2002). As observed in Fig. 6, flooding problems also occurred in eroded areas, affecting traffic flow. During the last few years, Alexandria’s coastline faced many flooding problems. In winter of 2003 to 2006, and 2010 many surge storms struck the Alexandrian coastline, water and sand overtopped the seawall and destroyed many parts of it. Figure (2-11) shows one example of this serious problem. In the coming years, these kinds of storms are expected to increase due to sea level rise (Mohamed, 2012). Many studies were conducted to predict and evaluate the impact of flooding along the Nile Delta coasts. According to recent projections, a one-meter sea level rise will result in the inundation and loss of 20–30% of the Nile Delta region.

Elshinnawy et al., (2017) used land surveying data from 200 hydrographic profiles along the Nile Delta coast and tide gauge field observations to study and evaluate the effects of SLR on coastal inundation. He concluded that coastal flooding caused by SLR is predicted to affect less than 1.0% of the Nile Delta region in CoRI and B1 scenarios and around 3% in A1F1 scenarios by the end of the current century.

To protect regions from flooding, a variety of protective measures have been utilized, such as hard engineering structures (e.g., seawalls, and breakwaters), and soft and natural defenses like gravel bars, sand dunes, and mangrove systems.

Figure 6. Flooding at the Alexandrian coastline ((Mohamed, 2012)

2.3.3 Sea Water Intrusion on Nile Delta

The Nile Delta aquifer in Egypt is one of the world's largest groundwater reservoirs, with irrigation activities providing most of its recharge. Due to its geometrical and geological features, limited natural replenishment, and overexploitation of the aquifer, the aquifer faced a significant seawater intrusion problem from the Mediterranean Sea. The movement of seawater into groundwater sources because of natural or human activities is known as seawater intrusion (Abd-Elaty et al., 2018). Groundwater levels decreasing or seawater levels rising both lead to seawater intrusion as shown in Fig. 7. Numerous researchers have investigated these issues from various perspectives, employing various approaches, following diverse functions, and reaching to various conclusions as a result. Dawoud, 2004 concluded that the influence of sea level rise combined with changes in Nile River flows may have a major impact on the quality of groundwater in this area, leading to an increase in groundwater salinity levels. In addition, Bear & Cheng (1999) showed the main causes of saltwater intrusion as the following:

- Over abstraction of the aquifers is one of the most common causes of saltwater intrusion
- Seasonal variation in natural groundwater flow;
- Tidal effects;
- Seismic waves;
- Dispersion; and
- Climate change (global warming and rising sea levels).
- Over abstraction is considered one of the main causes of saltwater intrusion

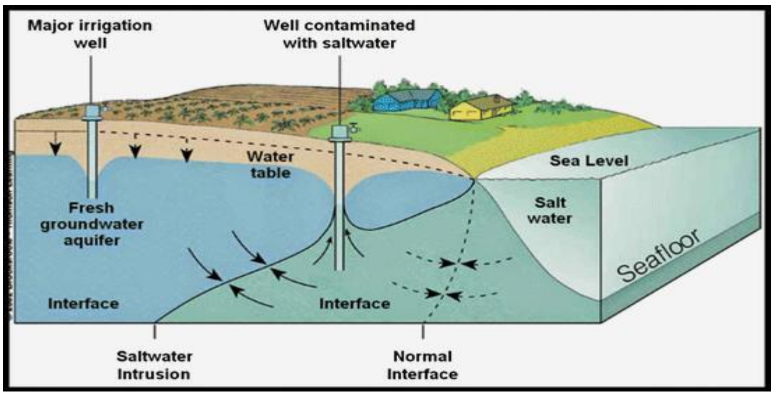

Figure 7. Movement of the saltwater interface under the increased saltwater intrusion due to Over-abstraction and sea level rise. (Abd-Elaty et al., 2018)

Long-term effects of sea level rise (SLR) on coastal locations include increased coastal erosion and seawater intrusion. The freshwater-saltwater interface is migrating inland because of SLR and over-abstraction, causing salinization of land and groundwater resources. This issue required a full investigation and the development of flexible adaptation strategies that can not only mitigate the negative effects of climate change, but also contribute to the growth of capacity for dealing with uncertain future possibilities.

2.3.4 Soil salinity

The main reasons for soil salinity in these areas include seawater intrusion, irrigation with low quality (saline) water as they are located at the downstream regions of the system, and an inadequate field drainage. Rising temperatures are also expected to accelerate soil evaporation and increase soil salinity. According to pervious soil assessment studies, the Lower Delta had 60% of its entire agricultural area damaged by salt, the Middle Delta had 25%, the Upper Delta and Middle Egypt had 20 %, and Upper Egypt had 25 %. According to recent studies, Egypt's agricultural areas are salinized to an extent of close to 35%. Fig. 8 shows the climate change threatens Egypt's fertile Nile Delta. The current situation challenges the sustainability of agriculture and the entire natural system (Kotb et al., 2000). Because salinity interferes with nitrate absorption, inhibits development, and prevents plant reproduction, it has an impact on the production of grasslands, trees, and crops. Some ions, most commonly chloride, are harmful to plants, and when their concentrations increase, the plant becomes infected and dies.

Figure 8. the Nile Delta lands are covered with sheets of dried salt

2.3.5 Land Subsidence of the Nile Delta

The vertical motion of land, or land subsidence are terms used to describe the lowering or emergence of the ground surface in reference to a geodetic datum. Rates of isostasy, tectonism, compaction, and anthropogenic influences (groundwater or oil extraction), individually or in combination, are responsible for local changes in vertical motion. Stanley (1997) concluded that the north-eastern side of the delta had greater values (lowering to 5 mm/year). For monitoring urban subsidence and coastline change in the Nile Delta, Aly (2005) utilized radar interferometry. He addressed the critical requirement for consistent monitoring of shoreline erosion and subsidence in the Nile Delta. Becker and Sultan (2009) used radar interferometry to reconstruct modern subsidence rates of as much as 8 mm/yr. around the Damietta mouth. They also found that the AlManzala Lagoon area suffered moderate subsidence rates (4-6 mm/yr.) in the northern part of the delta. The following two points explain their results: (1) Current subsidence in the Delta is significantly influenced by deformation of the most recent sediments; and (2) Extremely threatened areas are at the terminus of the Damietta and possibly the Rosetta branches, where active deposition is occurring. The lowest subsidence rates are in the areas situated inland that are more than 2 m above the sea level as shown in Fig. 9 (Marriner et al., 2012).

2.3.6 Siltation within lakes entrances

Sediment pollution or siltation near the harbor and river mouth is a global issue in different countries such as Egypt, Spain, Italy, etc. Large quantities of sand move in the near shore zone due to the action of waves and currents and cause siltation problem at shoreline harbours. In addition, the main causes of siltation are soil erosion or sediment discharges. In fact, the littoral drift is one of the largest along the coastlines of the world. The rates of siltation due to littoral drift must be determined for the port approach channel and harbor basin to be monitored effectively (Sarma, 2015).

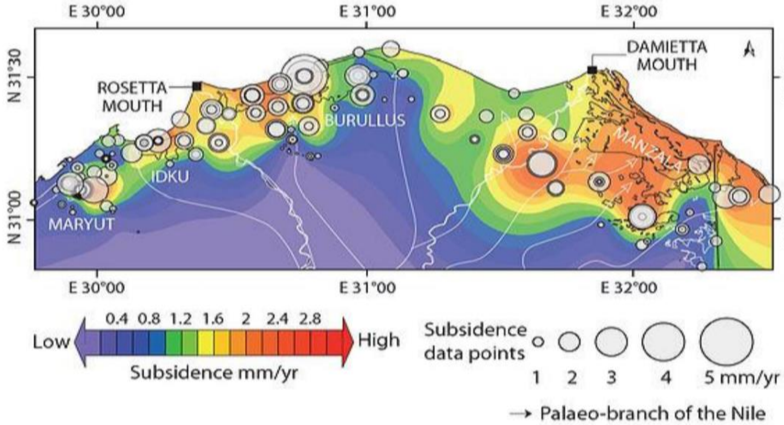

Figure 9. Subsidence in the Nile Delta (Marriner et al., 2012)

It affects the navigation process and the waterway's capacity to transport water. It has also a negative impact on marine ecosystem due to the siltation caused by lake basin erosion, reproductive grounds are covered, seabed food sources are destroyed, and water quality is decreased to the point that visual feeding animals cannot see their food. It is not feasible to regularly dredge inlet harbor mouths. Recent studies have estimated littoral drift to manage the siltation issues in waterways and harbor entrances. Kudale et al., (2018) illustrated that accurately estimating the longshore sediment transport is important. He mentioned that many harbors include guiding breakwaters on either side of the inlet to maintain the flushing velocity at the entrance. By trapping it on the outside of the entrance, the guide bunds also stop longshore drift from entering the navigation channel. In Egypt, Rosetta's estuary suffers from the siltation problem, Ahmed (2004) simulated the situation at the inlet of Rosetta by Delft-3D using some scenarios (different structures at the inlet in an attempt to get the best solution for the problem.

3 COASTAL ADAPTATION TO SEA LEVEL RISE

Several solutions and adaptation options could be used to deal with the SLR impact on the vulnerable coastal zones to mitigate the hazards caused by SLR around the world. The responses to SLR are outlined, along with problems that can occur when actions are attempted to reduce hazards to vulnerable coastal areas because of Sea Level Rise (SLR). In general, three alternatives can be used to identify the solutions needed to protect inhabitants and socioeconomic activities against SLR in vulnerable coastal zones: coastline retreat, accommodation, and coastal protection as shown in Fig. 10 (IPCC,1990). If the coastline retreat option is selected, the coastal region does not need to be protected from the water. A complete coastal region might be destroyed in the worst-case scenario. The coastal protection option's significant economic or environmental effects may be the driving force behind this decision. Unfortunately, the retreat option is not practical in densely populated locations with a wide range of socioeconomic activities. The accommodation is the second adaption solution indicates that under the threat of rapid SLR, people continue to use the coastal area. This approach comprises growing salt-tolerant crops, implementing emergency flood control measures, or changing from agriculture to fish aquaculture. The third option, coastal protection, integrates both hard and soft stabilization techniques. The shoreline is protected against the sea by building solid structures like sea walls, breakwaters, and rock revetments. Sand dunes are implemented as soft solutions to stabilize the coast so that current land activities can continue. Alternatives for adaptations are typically site-specific. Analyzing the available technological alternatives, environmental and socioeconomic effects, as well as long-term and short-term costs and benefits, is necessary for choosing the most effective approaches.

4 ADAPTATION MEASURES IN THE NILE DELTA COASTAL ZONE

Depending on the necessary action, specific coastal areas will have different acceptable adaptation options. If there is land available for migration, preventative land use restrictions and construction codes can be used to conduct shoreline retreat. Government regulation may not be necessary for accommodation but enhancing flood control measures may help. The Shore Protection Authority can put coastal protection into action. The Nile delta's present coastal zone protection measures are insufficient. Before implementation, coastal structures' effects on the shoreline should be considered.

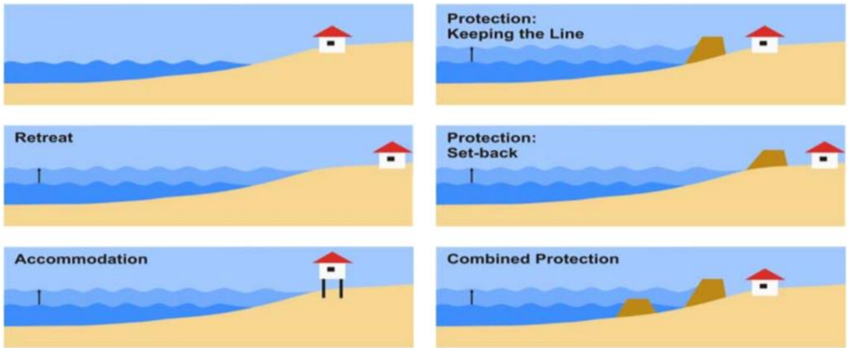

Figure 10. Basic strategic alternatives in response to sea-level rise (IPCC 1990) (Niemeyer, 2005)

The following adaption strategies are suggested for the Nile delta coastal zone:

- The Shore Protection Authority is responsible for constructing and maintenance of coastal protection structures, emphasizing low-lying areas that are vulnerable.
- Establishing rules to limit construction in risky regions, such as limitations on the fixed distance for new construction in low-lying zones.
- Rebuilding and maintaining the protective coastal sand belt and the sand dunes.
- Maintaining current wetlands (or establishing new ones), like Burullus lake.
- Modification of the use of the land, such as switching from agriculture to fish farming or salt-tolerant crops.
- Shifting infrastructures such as roads, buildings, and other things in a landward direction.
- Monitoring water extraction to reduce saltwater intrusion into the upper Nile delta's groundwater.
- Creation of extensive monitoring programs, decision support systems, and early warning systems.

Fig. 11 illustrates the most of these promising adaptation technologies, programs, and strategies show encouraging results to ensure adequate protection against SLR risks (Sharaan etal., 2022).

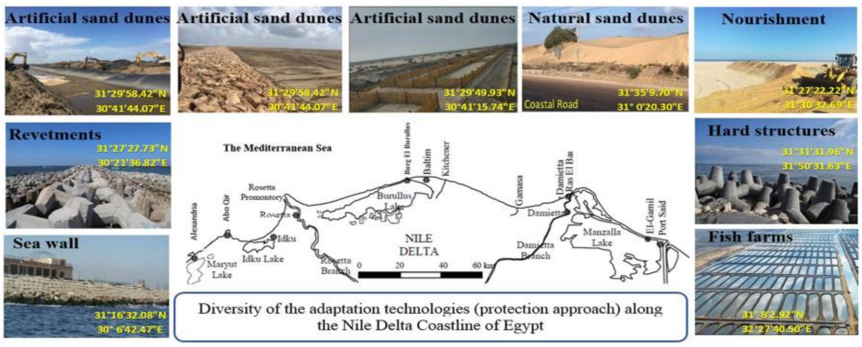

Figure 11. The adaptation technologies along the Nile Delta Coastline

5 CASE STUDY (BANEEN PROJECT)

Burullus coasts is the middle part of the Nile delta on the Mediterranean Sea. The erosion problem started at several important points of this coast by the end of the 19th century. Unfortunately, the Nile delta's coastal zone is going through significant changes driven on by human and natural factors, just like many other deltas. Sediment supply, coastal dynamics, geological activity, climate change, and variations in sea level are some of the natural forces that determine how the Nile delta shoreline varies. (Stanley and Warne 1993). The southern boundary of Burullus area is the Burullus lake, which is parallel to the Mediterranean Sea. It is also separated from the sea by a strip of land covered with sandbars and sand dunes. This land strip gradually decreases in width until the end at Burullus outlet. Al Baneen city, located in the eastern part of the Burullus outlet, had severe coastal erosion, particularly at the breakwaters downdrift, as shown in Fig. 12. There are also two separate breakwaters and one groin which is 150 meters long. El- Baneen project was launched in 2008 to secure the city from extreme erosion and promote local investment. The figure shows the shoreline change from two different years (2011 & 2021). According to Fig. 12, the length of the eroded area is 3.00 km with 200m width.

Figure 12. The shoreline changes at El Baneen beach in two years 2011 and 2021

The littoral drift along the Nile Delta must conduct extensive research to try to identify the best method for reducing or stopping the shoreline movement issue because the down-drift breakwaters suffer extreme erosion. In this study, the previously mentioned choices of coastline retreat, accommodation, and coastal protection can be used to determine the measures required to safeguard Al Baneen residents and economical activities against SLR.

Retreat option

Significant losses would result from a retreat from all coastal areas in threat of rising sea levels, storm surges, and tsunamis. The migration of the coastal population into locations protected from storm surge inundation without any requirement for storm surge protection would also place a severe burden on both society and individuals. This strategy is viewed as highly undesirable because it would completely abandon coastline protection, with the accompanying tremendous economic and cultural losses.

Accommodation option

To accommodate the lowlands, it is necessary to create several protected islands with settlements and industrial zones in the lowlands along the coast and tidal estuary. Accommodation as a different coastal protection strategy will require large investments, which will be matched by enormous economic losses from the abandonment of smaller settlements and agricultural revenues on the one hand and rising maintenance costs of infrastructure after flooding from storm surges on the other. This is because the sea level rise is accelerating, which will require high investments. Therefore, accommodations are greatly inferior to overall area protection.

Coastal protection option

Limiting the study area's erosion requires a protective measure, such as sand nourishment or dikes. To protect the region from flooding, the dike system across the Nile Delta shores is suggested. It has been designed to look like natural coastal features and/or sand dunes. To encourage dune growth, the dikes will be stabilized using a combination of marsh fences and local plant species. In addition, the coastal protection works will include the restoration and construction of landscape and recreation areas. This would build a new concept to enhance the advantages of coastal works, including using the ideal position of the protection works along coastal areas to support leisure activities in addition to protecting against erosion and flooding. This support will enhance the overall landscape throughout the coastline area and has the potential to have a significant social impact on surrounding communities.

CONCLUSIONS

The Nile delta coast could encounter significant effects from SLR, such as: accelerating coastal retreat, including erosion of sand dunes and the coastal sand belt, breaching of coastal barriers, and damage to coastal inlets; increasing erosion rates due to increased wave action in the nearshore area; and flooding wetlands and other low-lying lands. This article examines the most important resources found in Egypt's coastal regions, the climate challenges each region faces, and the economic contributions each makes to the country. To minimize the threats caused by SLR along the Nile Delta Coasts, various adaptation strategies could be applied to deal with the impact of SLR on the vulnerable coastal zones. So, the Case Study (Baneen City) was selected to assess the three options (coastal retreat, accommodation, and coastal protection) and figure out the best strategy for protecting city from SLR. Significant measures that will be taking into account include the creation of a system to track changes in sea level as well as the impact of climate change on beach stability and coastal erosion. In addition, building with nature concept should be enhanced to solve the climatic issues. It not only solves problems for nature that are created by infrastructural projects, but it also seeks to create opportunities for nature, or conserve ecosystems, while enhancing the design, operation and maintenance of the structure as possible as.

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