Nile Delta Biography: Challenges and Opportunities

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Abstract The Nile Delta and its coastal zone are populated regions in Egypt and contain a variety of development activities. Those human activities which provide income and source of life to many also generate constraints to Nile Delta region. This introductory chapter presents a brief biography of the Nile Delta and presents a comprehensive and concise summary of recent research related to challenges in Nile Delta regions. In addition, possible opportunities are included. Five main themes of research, namely, land use challenge, coastal erosion, potential impacts of sea level rise (SLR), water quality deterioration, and seawater intrusion, are reviewed. Also, the chapter summarizes some suggested/proposed and/or implemented adaptation and/or mitigation acts for each challenge. The article concluded that further integrated research based on solid reliable field databases is urgently needed.

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Contents

1 Introduction

The Nile Delta of Egypt is one of the earliest deltaic systems in the world [1]. It was formed by sedimentary processes between the upper Miocene and the present period and built up by the alluvium brought by the old former seven active branches of the Nile. Those branches have been silted up and replaced at present by Damietta and Rosetta branches [2]. There are many low-lying areas forming salt-crusted sabkhas. The headland is inundated periodically by seawater during winter sea surges [3].

The Nile Delta covers only about 2% of Egypt's area but hosts about 41% of the country's population and comprises nearly 63% of its agricultural land [4–7]. It is among the most densely populated agricultural areas in the world, with 1,360 inhabitants per km^2. Egypt faces great challenges owing to its limited water resources, which is due to (1) its fixed share of Nile River water and its characteristic arid climate [8] and (2) the newly Nile water-based development plans in the upstream countries such as Ethiopia and Sudan. In terms of economic activities, the fish productivity is about 185,000 t/year from the northern lakes (Maryut, Manzala, Edkua, and Burullus) [9]. About 40% of all Egyptian industries are located in the Nile Delta. Most of the investments and economic activities go toward the Delta region. In recent decades, as a result of rapid economic development, increasing population in the Delta region and the associated industrialization have exerted high environmental pressures. Industrial wastes and municipal effluents have been largely pumped into the Delta coast lagoon wetlands, causing eco-environmental degradation with significant public health concerns [10]. This study presents an evaluation of the challenges across the Nile Delta and proposed mitigation and adaptation scenarios and opportunities.

Northern coastal lakes in the Nile Delta of Egypt have a distinctive ecosystem [11]. There are two main problems facing the coastal zone of the delta. Firstly, erosion due to dynamic effects and reduction in sediment transport and the rigid protection structures such as the revetment of Rosetta estuary and the seawall of Burg El Burullus. In addition, the waters of the coastal zone and the northern lagoons connected to the Mediterranean Sea severely suffer from pollution due to dumping wastewater from agricultural, municipal, as well as industrial wastes into the coastal waters.

2 Description of the Nile Delta

The total agricultural land in Egypt amounts to nearly nine million and 270,000 feddans in the year 2014. About six million and 95,000 feddans (1 feddan = 4,200 m^2 = 0.42 ha) are accounted for in the old land, and three million and 175,000 feddans in the newly reclaimed area. These proportions account for only around 3.8% of the total area (238 million feddans). About 2.4 million feddans from the irrigated agricultural areas suffer from salinization problems, water logging, and sodicity. The majority of salt-affected soils are located in the northern-central part of the Nile Delta [12]. All irrigation water comes from the Nile; thus, more than 80% of the Nile water is used in agriculture [13].

At present, only 5.4% of the land resources in Egypt are of excellent quality, while about 40% are of poor quality mainly due to the development of salinity and sodicity problems. Productive lands in Egypt are finite and irreplaceable; protection against degradation such as soil crusting, compaction, soil fertility depletion, and pollution of soils by toxic wastes and salinization should be carefully managed [13].

The Delta aquifer is considered one of the largest groundwater reservoirs in the world with a huge volume and storage capacity and its case is unique. It has a wide (245 km) and a deep (more than 900 m) exposure to the Mediterranean Sea. It is perhaps the only coastal aquifer in which the seawater has migrated to a distance of more than 100 km from the shore boundary [14].

2.1 Geography

The Nile Delta occupies an area of about 22,000 km^2; it accounts for two thirds of Egypt's agriculture and represents the most fertile areas in Egypt [15]. The length of the Delta is approximately 160 km from north to south, and it covers about 240 km of coastline at the Mediterranean Sea from west to east. The Nile Delta has its apex about 20 km north of Cairo (latitude 30°). The Nile is divided into two main distributaries: the Damietta branch at the east is 240 km in length and the Rosetta branch in the west is about 235 km in length. In the past, the Delta had several distributaries, but these have been lost due to flood control and silting. The Suez Canal runs to the east of the Delta, entering the coastal Lake Manzala in the northeast of the Delta. There are three other coastal lakes at the northwest: Lake Burullus, Lake Idku, and Lake Maryut. Since the Delta no longer receives an annual supply of nutrients and sediments from upstream due to the construction of the Aswan High Dam, the quality of soils of the floodplains has declined, and large amounts of fertilizers are now used.

2.2 Climate

The River Nile is considered the main freshwater supply because of the arid climate of Egypt which is characterized by high evaporation rates (1,500–2,400 mm/year) and very low rainfall (5–200 mm/year). However, the favorable climate of Egypt around the year is ideal for a wide variety of crops. This made it possible to adopt an intensive cropping system and thus permitted the production of more than one crop per year in most of the cultivated areas. The Delta has a hot desert climate as the rest of Egypt. However, its northern part is wet. The Delta temperatures are the hottest in July and August, with maximum average temperature of 34°C. Winter temperatures are normally in the range from 9°C at night to 19°C during the day.

2.3 Geology

The geology of the Nile Delta basin was extensively discussed by a number of researchers [15–17]. The Nile Delta aquifer is a semi-confined aquifer increasing in thickness from about 200 m in the south, near Cairo, to more than 900 m at the Mediterranean Sea. The base is clay with a slope of about 4 m/km, which is about 40 times the average slope of the ground surface [18].

The strata of hydrological importance belong to the Quaternary and constitute the main water-bearing formations. These strata consist of sand and gravel (Pleistocene and Holocene) containing a few lenses of clays. These deposits can be classified into Mit Ghamr formation in the lower parts and Bilqas formation in the upper parts [19].

Mit Ghamr formation of the Pleistocene constitutes the main aquifer of the Nile Delta region; it begins at Cairo to the south and spreads out in a fan shape toward the Mediterranean Sea. This formation consists mainly of sand and gravel with occasional thin clay intercalations. The sand and gravel are more common in the southern part. Clay is more observed in the north with occasional discontinuity and intercalation of sand and gravel. Alternating beds of clay and sand with gravel are encountered at different locations especially in north and northeast parts.

The thickness of the sediments gradually increases toward the north and northeast. The thickness ranges between 200 and 400 m in the south and from 500 to 700 m in the middle. In the north, the thickness of the sediments reaches a maximum value exceeding 950 m [20]. In some locations of the Delta, the aquifer is considered phreatic. Otherwise, it is covered by a semipermeable layer of clayey sand and silt with varying thickness and hydraulic properties. This clayey sand layer is permeable enough to allow vertical water flow through the clay to the aquifer and vice versa depending on the local levels of the water table and piezometric head. Therefore, the aquifer is considered as leaky or semi-confined in these areas. Soils in the Nile River and Delta are silt-clay mixtures of good quality, deposited during thousands of years of Nile flooding. Most cultivated soils in Egypt are clayey to loamy in texture, and only about one million feddans (420,000 ha) are sandy and calcareous [12].

3 Nile Delta Challenges

The main five challenges to the Nile Delta region are land use, coastal erosion, potential impacts of sea level rise, sea water intrusion, and water quality deterioration. Figure 1 shows the main reasons for each challenge. Each challenge will be presented in detail in the upcoming sections.

3.1 Land Use Change

A recent study [21] stated that a total expansion of urban area amounted to 2536.3 km^2 during the study period from 1984 to 2006. Another study added that land degradation was observed and found to be mainly due to human activities, such as the formation of quarries, free water bodies, and sabkhas (a specific type of land cover found on dry lands and salt-affected soils) [22]. The Egyptian government is demanding control of the urban encroachment and the loss of agricultural land in the Nile Delta by applying an effective horizontal urban expansion and reclaiming more land along the desert areas and near the fringes of the Nile Delta [23]. A recent paper recommended that the urban expansion should be strongly prohibited over the fertile agricultural land, and the expansion of the agricultural land in the desert areas should be wisely selected to pursue a water-saving plan [24].

Figures 2 and 3 show the land use in the Delta region and the land use change computed through remote sensing techniques [24].

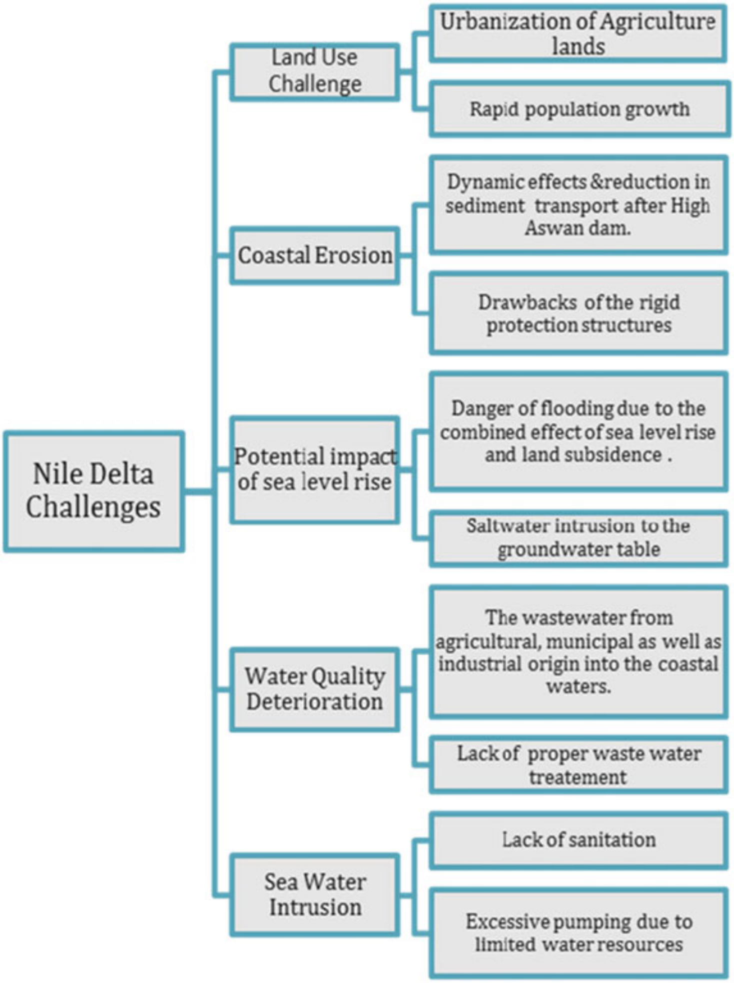

Fig. 1 Challenges facing Nile Delta and their reasons [41]

3.2 Coastal Erosion

The study conducted by El Banna and Frihy [1] utilized Landsat enhanced thematic mapper (ETM) imagery of 2002 and aerial photography of 1955, combined with published charts and field observations to interpret geomorphological changes in the coastal zone. They concluded that the erosion/accretion patterns denote the natural processes of wave-induced long-shore currents and sediment transport. In addition, the impact of man-made coastal protection structures was illustrated.

Another remote sensing-based research study was conducted by Hereher et al. [25] to assess how to the control the erosion caused by the River Nile flooding.

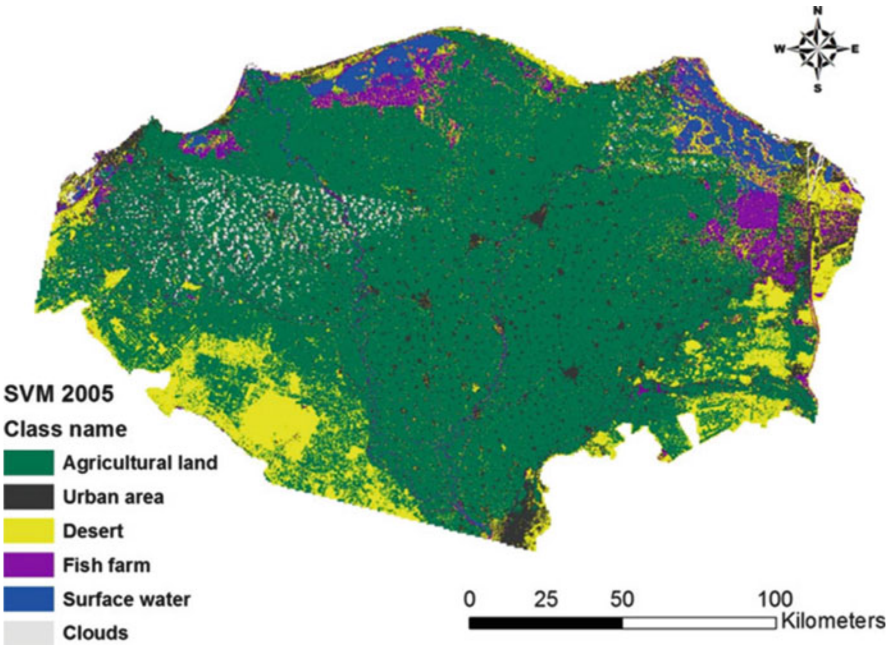

Fig. 2 A 2005 classification map based on Landsat ETM satellite image adopted from Elhag et al. [24]

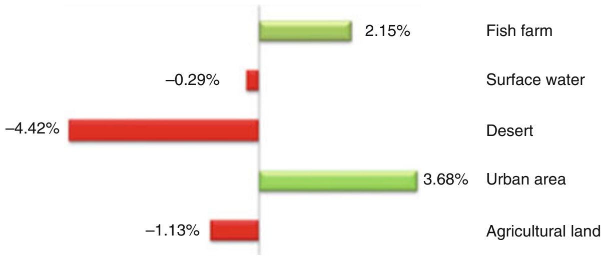

Fig. 3 Land use changes from the year 1984 to the year 2000 adopted from Elhag et al. [24]

This study showed that coastal erosion was severe near Damietta promontory and decreased eastward. However, accretion was observed near Port Said. About 50% of the coastal strip was under erosion and 13% was under accretion. In addition, a remarkable decline (34.5%) of the Manzala lagoon surface area was estimated. The impact of constructing the Damietta harbor was investigated by Dewidar et al. [26]. They found that Damietta harbor disturbed the shoreline stability causing downdrift erosion and updrift accretion on both sides of the harbor breakwaters.

3.3 Potential Impacts of Sea Level Rise (SLR)

According to the Intergovernmental Panel on Climate Change (IPCC) fourth report in 2007 [27], the Nile Delta region is one of the most extremely affected river deltas in the world due to climate change impacts. The prediction made by Mabrouk et al. [5–7] indicated this will intensify the threats to water security. Increasing potential evaporation (in response to increasing temperature) in combination with decreasing water levels in the Nile river, as well as reduced precipitation and groundwater recharge, will impact deteriorating groundwater quality and impose great challenges to ensure the supply of drinking water and irrigation is maintained. The study recommended that the current irrigation strategies are highly inefficient and must be replaced by new and adapted systems (whenever possible).

Moreover, using 1990 as the base year, El-Nahry and Doluschitz [28] computed sea level rise (SLR) by applying the quadrant equation for 10-year intervals. Mediterranean SLR along the Nile Delta coast could be estimated considering three different scenarios (low 0.20 m, medium 0.50 m, and high 0.90 m). Impacts of SLR are divided into (1) primary and (2) secondary impacts. Over the coming decades, it is expected that the Nile Delta might face greater threat due to SLR and land subsidence as well.

Climate changes might have an impact on the level of seawater intrusion in coastal aquifers. A numerical study conducted by Werner and Simmons [29] concluded that large areas in the coastal zone of the Nile Delta might be submerged by seawater and the coastline might shift landward by several kilometers in the eastern and western sides of the Delta.

3.4 Water Quality Deterioration

Prior to human intervention, all of the coastal lakes were open to the sea and had proper exchange rates with the Mediterranean Sea, but now receive agricultural, domestic, and industrial wastewaters. Three of the four lagoons currently have fewer exchange rates with the sea (Maryut does not) [9, 30]. The continuous charging of these wastewater changes the ecosystem of the coastal lakes. Fish production quantity and quality are negatively affected. There are large spatial gradients in lagoon salinities. For example, data from Manzalah Lagoon in September 1995 show ranges in salinity from 2.7 to 39.1, with the highest salinity near the breachway and lowest salinities inshore [9].

3.5 Seawater Intrusion

Due to lack of sanitation and random and excessive groundwater pumping, the Nile Delta is now affected by seawater intrusion. Most of the studies did not consider the possible effects of the seawater rise on the inland movement of the shoreline and the associated changes in the boundary conditions at the seaside and the domain geometry [29]. Such effects are more evident in flat, low land, coastal alluvial plains where large areas might be submerged with seawater under a relatively small increase in the seawater level.

Based on a numerical approach [31], using a finite element model FEFLOW, the seawater intrusion problem in the Nile Delta aquifer in the aerial view at the seawater level was simulated. The study concluded that large areas in the coastal zone of the Nile Delta might be submerged by seawater, and the coastline will shift landward by several kilometers in the eastern and western sides of the Delta. The 1-m rise in sea level represents the worst case scenario under which the volume of freshwater might be reduced to about 513 km^3 (billion m^3).

4 Proposed Mitigation, Adaptation Scenarios, and Opportunities

This section will present some proposed mitigation scenarios and opportunities.

4.1 Land Use Challenge Adaptation

A comprehensive study conducted by Eitzinger et al. [32] reported and assessed some suggestions to face the land use challenge. It concluded that land use change trends in the Nile Delta region could have both negative and positive roles in the impact of climate change on agriculture and its ability to adapt. The two main suggestions are (1) gradual decrease in the current cultivating area to obtain a higher level of crop management and (2) switch cropping activities to aquaculture.

The government of Egypt implemented a project called El-Salaam Canal to reuse drainage water, to create new communities along the Canal, and to re-chart Egypt's population map. Diverting considerable amounts of drainage water after blending of the Nile water to newly reclaimed areas for irrigation of 643,560 acres of new land in the northeastern Delta and northern Sinai peninsula is planned by using El-Salaam Canal water [33].

4.2 Coastal Erosion/Accretion Adaptation

Recently, Frihy and El-sayed [34] analyzed the risks of coastal erosion by ranking the vulnerability and suggesting adaptation measures to mitigate the impact of the SLR along the Mediterranean coast of Egypt. The main proposed adaptive options of the study are:

(1) Rehabilitation and strengthening of the existing engineering coastal structures, particularly on the low-lying lands and areas of higher risk
(2) Adopting and developing a quantitative risk assessment approach for the impact of the SLR along Egypt's Mediterranean coast
(3) Considering human and financial resource mobilization plans and developing an early warning system

Two related studies [30, 35] applied advanced numerical modeling on the Rosetta coastal zone and an integrated proposed solution to aid in controlling the pollution inside El-Burullus Lake and erosion problems at Rosetta (one outlet of the River Nile). The main aim was to improve the stability of the outlet cross section. It was proposed to increase the discharge through the outlet by diverting two drains discharging into El-Burullus Lake to discharge into Rosetta directly, therefore decreasing the cross section by a center outlet jetty, and/or eliminating the sediment supply by constructing a jetty in the nodal point of the sediment transport which is located just east of the entrance.

4.3 Potential Impacts of Sea Level Rise (SLR) Adaptation

The recent research work by McCarl et al. [36] concluded that climate change would have large impacts on Egypt's agriculture and water use with the damages increasing over time. A coupled modeling approach [5–7] using the land surface hydrological model WASIM-ETH and the hydrological model MOD-Flow was utilized to simulate and project the future impact translation of climate projections into hydrological impacts on Nile Delta. The study concluded that current irrigation strategies are highly inefficient and must be replaced by new and adapted systems.

A meeting [37] gathered Egyptian experts in the field of impacts of climate change on Nile Delta highlighted:

(1) The importance of changing the cropping patterns in the Nile Delta as a strategic climate change adaptation measures. Crops with high tolerance to salinity should be introduced to agricultural areas close to the Mediterranean.
(2) The importance of developing integrated coastal zone management (ICZM) plans for all coastal governorates and cities considering natural coastal protection measures such as sand dunes, along with other structures such as seawalls and considering the protection of the coastal highway.

(3) The importance of developing coastal protection policies that go in line with ICZM plans; such policies should specify the distance from the coast where the damage is expected.

4.4 Water Quality Deterioration Adaptation

A GIS-based study [38] developed a tool for planning and managing the reuse of agricultural drainage water for irrigation in the Nile Delta. This is achieved by classifying the pollution levels of drainage water into several categories using a statistical clustering approach that may ensure simple but accurate information about the pollution levels and water characteristics at any point within the drainage system. A recent study [39] investigated different hybrid treatment processes for handling the gray water for unrestricted reuse. An innovative approach, namely, a down-flow hanging sponge system [40], was suggested to make effective reuse of agricultural drainage water. In addition, they developed a model that was found to be a simple and useful tool for design and operation of a DHS system treating ADW in practical applications.

4.5 Seawater Intrusion Adaptation

An integrated study by Eitzinger et al. [32] assessed some adaptation and mitigation actions to face the threats of sea level rise. The analysis included a cost-benefit analysis. The proposed actions include: firstly, a gradual increase in cultivating salinity-tolerant crops and switch cropping activates to aquaculture as a form of adaptation strategy and, secondly, establishing a new drainage system in the field, equipped with a suction pumping unit to remove the excessive water table and control it at a constant level.

Regarding opportunities, recent research by Abayazid and Al-Shinnawy [11] stated that seawater intrusion would result in waters with high salinity levels approaching the ground surface and it may be easier to be used as a source to feed coastal lakes such as Lake Burullus and, hence, increase its water salinity level. This would lead to restoring its healthy environmental status.

A comparative study by Mabrouk et al. [5–7] discussed advantages and disadvantages of different adaptation and mitigation measures for groundwater salinization in Deltas worldwide as shown in Table 1. Some of these suggestions can be suitable for application in the Nile Delta. The study concluded that expansion in rice cultivation is uneconomic because of the large amount of water needed, but it is suggested that the Ministry of Agriculture can move some rice-cultivated areas toward areas of salinization to solve the problem without changing the total required water. Cultivating salt-tolerant crops and creating wetlands in salinized areas in low-lying areas are very suitable in Egypt.

Table 1 Different adaptation and mitigation measures for groundwater salinization in Deltas worldwide [5–7]

Measure	Advantage	Disadvantage	Conclusion
a. Adaptation			
1. Rice cultivation [41, 42]	Soil salinization patterns decrease considerably	Needs a large amount of water which is already a scarce resource	Not recommended as it is uneconomic
2. Permitting 10–20% of the freshwater of irrigation to leach the soil [43]	No salt accumulation, salt export will match salt import and will eventually prevent salt infiltration to groundwater	This could be risky because it might cause salt returning to the root zone again	Not recommended
3. Cultivating salt-tolerant crops [44]	Tolerant crops can withstand salt concentration in the north	Very limited types of plants	Highly recommended
4. Creating wetlands in salinized areas [45]	Egypt has four lakes in the northern coast of the Nile Delta which could be considered as natural adaption	Only applicable in low-lying deltas of the Nile Delta	Highly recommended in Egypt
5. Extraction of saline groundwater	Getting rid of saline water	Disposal of extracted saline water could cause another environmental problem	Not recommended in shallow coastal aquifers
6. Increasing land reclamation [46]	Increase freshwater recharge	Need of land and freshwater	It is recommended
b. Mitigation measures			
1. Artificial recharge [47]	Increase freshwater outflow to the aquifer. The degree of efficiency of this method depends on pumping/injection rates, depth of the wells, the coastal aquifer properties, and the location of the wells	Needs a large amount of water which is already a scarce resource	It is recommended in case of water abundance as it is a highly effective method
2. Physical barriers [48]	This method stabilizes the coast and decreases saltwater intrusion. The height of the barrier has a very significant role in the degree of flushing rates	It is one of the most expensive methods either using sheet piles or clay trenches. Nevertheless, it is only applicable in shallow aquifer because of its huge cost	Economic feasibility is the cornerstone
3. Air injection [49]	This method minimizes the aquifer permeability and decreases the discharge temporarily	In experimental stage and not fully developed	Further experiments on bigger scale is needed

5 Summary

This chapter creates a comprehensive and concise summary of recent research related to challenges in the Nile Delta regions. In addition, possible opportunities are included. This chapter mainly reviewed five themes of research: land use changes, coastal erosion, potential impacts of sea level rise (SLR), water quality deterioration, and seawater intrusion. The chapter also suggested, proposed, and/or implemented adaptation and/or mitigation acts for each challenge.

After presenting the main challenges, adaptation, and mitigation acts in the Nile Delta region, it is now evident that proper management will not only contribute to combating real challenges but also create opportunities as discussed before. The established plan for adaptation of the coastal zone under climate change should be linked to a comprehensive integrated plan for solving all problems found in the Delta region; for example, an integrated plan for solving soil salinization, water quality deterioration in shallow coastal lakes, erosion problems at estuaries, and impacts of climate change should be connected.

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