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IMPACT OF SEA LEVEL RISE ON THE NILE DELTA, EGYPT

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ABSTRACT

Sea Level Rise "SLR" is one of the main impacts expected due to Climate Change with SLR predictions over the next decades vary from 0.3 to 2.0 m. The Nile delta is vulnerable to flooding due to SLR and it is essential to understand the impacts of any expected SLR on the delta. This study attempts to understand the impacts on existing coastal systems, infrastructures and properties and suggests some long-term adaptation measures. An inundation model is developed using Geographic Information System "GIS" accounting for connectivity with the sea or lakes, with Digital Elevation Model as the main input. Topographic maps of scale 1:25,000 are digitized together with the surveying of key features that are not included in the original maps. The impact of SLR is assessed by producing maps for the inundated areas due to a 0.5, 1.0, 1.5, 2.0 and 2.5m SLR. The study shows that initially the water will mainly enter the low areas from the coastal lakes "Manzala and Burrullus". The embankment surrounding the Salam canal will protect the areas behind it till a level of about 1.0m. Finally, vulnerability maps are produced based on the expected SLR and the activities in these areas.

KEYWORDS: Climate Change, Mediterranean Sea, Inundation, DEM, Topographic Maps, SRTM.

1. INTRODUCTION

Low- elevation land areas and their populations are at risk globally from rising sea level. Global sea level has risen by about 2 millimeters per year over the past century. About half of this rise may be attributed to thermal expansion of the ocean and the melting of temperate- latitude glaciers [1]. The remainder of the rise is

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believed to come from a net loss of mass from the Antarctic and Greenland ice sheets, although the exact contribution is unknown.

The coastal zones of Egypt that extend for about 3,500km along the Mediterranean and the Red Sea are perceived as vulnerable to the impacts of climate change, not only because of the direct impact of SLR, but also because of the potential impacts of climate changes on their water resources, agricultural resources, tourism and human settlements. The coastal zones of Egypt host a major part of the industrial activities including petroleum, chemicals and tourism distributed among a large number of highly populated economic centers such as the cities of Alexandria, Rosetta, Damietta, Port Said, Suez and Hurghada. Trading and transportation centers are also distributed among a large number of harbors which are considered highly attractive to employment from all over the country.

In particular, the low lying Nile Delta region as shown in Fig. 1, which constitutes the main agricultural land of Egypt and hosts over one-third of the population and nearly half of all crops [2], industrial activities and commercial centers, is highly vulnerable to various impacts of climate change. The Nile delta is rated as extremely vulnerable based on present rates of relative SLR to 2050, “including deltaic subsidence” [2]. It is identified that the Nile delta is one of the most vulnerable areas in North Africa and the Middle East to the impacts of SLR [3]. The Nile Delta could be at risk from both SLR and salinization in agricultural areas while 12 to 15% of arable land could be lost through SLR in this century with 5 million people affected by 2050 [4].

Continued growth of greenhouse gas emissions and associated global warming and the unexpectedly rapid breakup of the Greenland and West Antarctic ice sheets could induce high values for SLR by the end of this century. Sea level change reflects a complex and dynamic interaction between local, regional and global contributions from both land and ocean processes. Relative SLR, the rate of sea level changes at a specific location relative to a local land benchmark, is composed of the eustatic and steric contributions to global-mean change adjusted to account for regional and local processes, including vertical local land displacement, local sediment transport, isostatic adjustment, and sea level responses to local and regional meteorological and oceanographic variations [5-7].

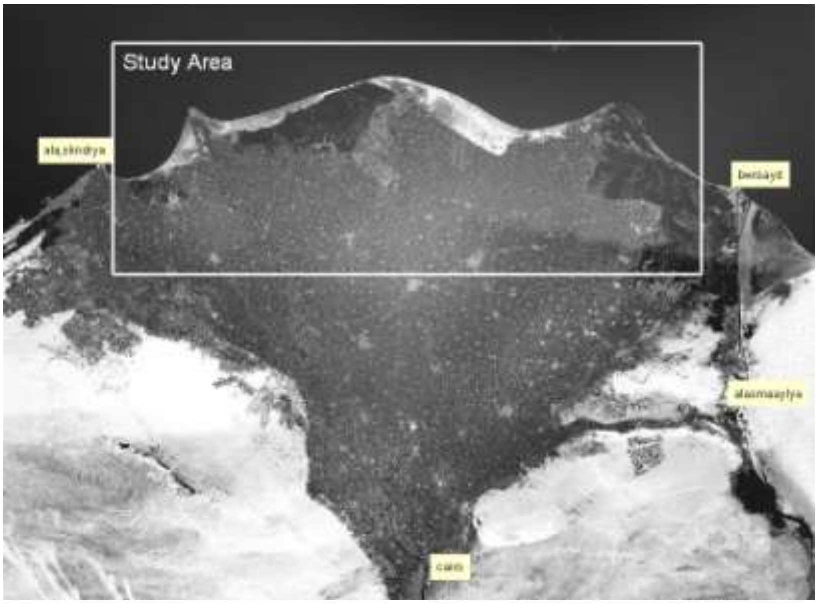

Fig. 1. Google Earth Satellite Image Showing the Study Area of the Northern Nile Delta in Egypt.

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In analyzing SLR impacts and responses, it is fundamentally understood that impacts are a product of relative “or local” SLR rather than global changes alone[3]. Relative sea level change takes into account the sum of global, regional, and local components of sea level change. The underlying drivers of these components are: 1) climate change and changing ocean dynamics, and 2) non-climate uplift/subsidence processes such as tectonics, glacial isostatic adjustment “GIA”, and natural and anthropogenic induced subsidence [3].

Despite the scattered nature of long tidal records, with a concentration in the northern Atlantic, there appears to be emerging consensus that the globally-averaged rate of rise over the latter half of the 20th century was around 1.7 to1.8mm/a [8, 9]. Over the past decade and a half the records from tide gauges have been supplemented by satellite altimetry which offers broader monitoring across the ocean surface in all except Polar Regions. Rates of SLR determined from altimetry over this period have been reported as averaging 3.1mm/a [9], with the latest compilations indicating a rate as high as 3.2mm/a [10]. It is important to recognize that there is going to be considerable geographical variation in the pattern of SLR in the future, just as there has been in the past [11].

A number of authors have suggested that the widely reported figures for the possible magnitude of SLR in the IPCC-AR4 underestimate the range of potential SLR during the twenty-first century [3]. A graphical summary of the range of IPCC-AR4 sea-level-rise scenarios “for 2000-2099” and post-AR4 projections with a 4°C world ranges from a minimum of 0.2m to a maximum of 2.15m [9, 12-16], as shown in Fig. 2. It is mentioned that the SLR may well exceed one meter by the end of this century and over several centuries will likely be several meters [10]. The conclusions of the Scientific Conference in Copenhagen in March 2009 indicate that the projected sea-level rise during the 21st century may be much higher “up to 1-2m by 2100”, which will put the highly populated coastal regions and the fertile deltas “Nile, Po, Rhone” at risk of partly disappearing into the Mediterranean Sea [17].

Previous studies on Nile Delta inundation due to SLR did not pay much attention to enhance the accuracy of the employed topographical data that is the determinant factor in the accuracy of the inundation results. Most of the available inundation studies are based on the global DEM dataset “DEM or ASTER”. A recent study by the Coastal Research Institute “CoRI” included different features to improve the predictions obtained from 90 m SAR digital elevation model (DEM) data. In their study they used a varying relative SLR over the Nile Delta [18].

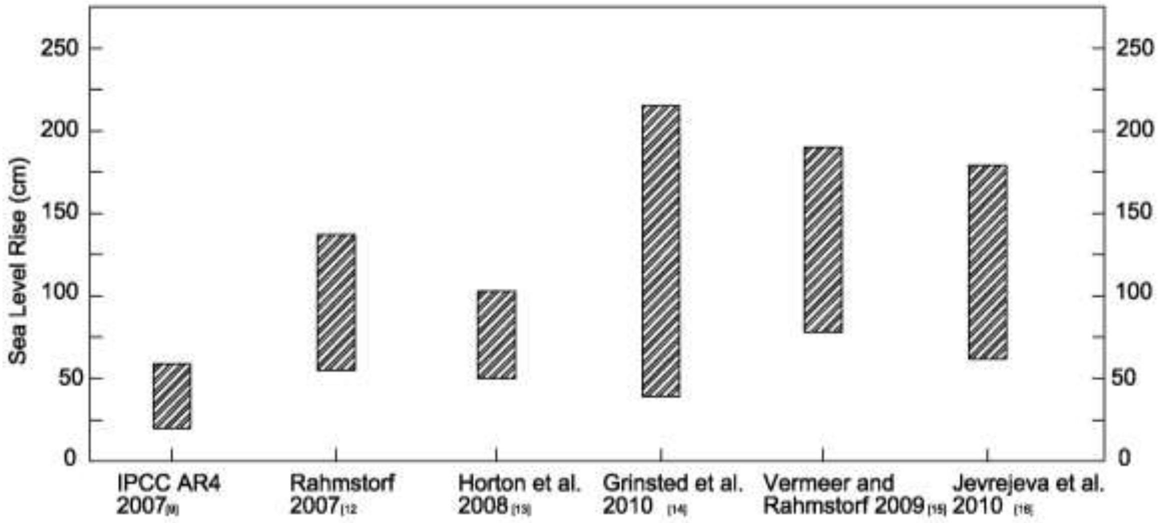

Fig. 2. Graphical Summary of SLR as depicted in IPCC-AR4 and Post Projections.

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The main objective of this paper is to understand the associated impacts of SLR on existing Nile Delta coastal systems, infrastructure and property and suggest possible long-term adaptation measures. A new DEM is developed based on available topographic maps and surveying of existing key features. An inundation model is then developed using Geographic Information System "GIS" to assess the potential impacts of the SLR and identification of the vulnerability areas.

2. DEVELOPMENT OF NILE DELTA DIGITAL ELEVATION MODEL

Various techniques and approaches can be used for the creation of DEMs. These techniques vary with respect to the technology used to collect elevation information from the surface of the Earth. Each approach has its advantages and disadvantages. The optimum approach depends on the nature and specific needs of the mapping project. Different techniques for DEM generation include: Aerial and Satellite Photogrammetry, Radargrammetry, Synthetic Aperture Radar Interferometry “InSAR”, Light Detection and Ranging “LIDAR”, Shuttle Radar Topography Mission “SRTM”, Advanced Space borne Thermal Emission and Reflection “ASTER”, Cartographic Digitization of Existing Maps, and Traditional and modern surveying.

Different data sources are investigated for the current study and the main concern has been the available budget, the required accuracy and the resolution. The scale and level of detail required in an individual study will determine the spatial resolution and accuracy of the DEM. For large scale projects covering thousands square kilometers, the SRTM and GDEM global DEMs are probably most appropriate. At the very detailed level, the demand for DEMs is met by LIDAR surveys from aerial platforms which typically have horizontal spatial resolutions of a meter and vertical accuracies better than 15cm. Such surveys may be very expensive because of location charges or may not be available due to flying restrictions. In such circumstances, DEMs based on satellite platforms which have lower vertical accuracies but cover much large area and are less expensive per sq. km, or from available topographic maps with adequate horizontal and vertical resolution may be the best options.

2.1 Topographic Maps

Because of the insufficient vertical accuracy of the available free data sources, the alternative was to use the available paper topographic maps produced by the Egyptian surveying Authority. The maps with scale 1:25000 are used to provide the required elevation data. The proposed area is covered with 60 maps of scale 1:25000. These maps are requested officially from the Egyptian Surveying Authority. Three additional maps with scale 1:50000 are used to fill in some gaps “not shown”. The maps with scale 1:25000 are available with 0.5m contour interval, while maps with scale 1:50000 are available with 1 m contour interval. Other data obtained from field surveying are also included for important features as will be explained later.

The topographic maps are referenced to the Old Egyptian Datum with Ellipsoid Helmert 1906. The project area is located in the red belt zone which is one of the

Egyptian Transverse Mercator ETM zones. This information is required for the transformation from Egyptian maps data to the global coordinate system "GPS Satellite Datum" referenced to the World Geodetic System 1984 and ellipsoid WGS84. This transformation is necessary to use different data sources, and to assign the coordinate system within ArcGIS software for different shape files. The Coordinate system and datum are also necessary for adjusting the scanned maps and used satellite images. Accordingly, Datums should be appropriately managed, all source data critically evaluated, and the DEM should be consistent with the source data and charts of the area.

2.2 Field Work and GPS Leveling

Some of the key features that could prevent potential inundation in the Nile Delta are the International Coastal road, the embankment of Al-Salam Canal, and the road around Burullus Lake, Fig. 3. These featuresare not included in the digitized topographical maps since the original maps were issued prior to the construction of these features. Thus these key features were subject to field surveying mission conducted in November-December 2012 using GPS leveling technique. Two GPS Dual frequency receivers with their accessories areused for the current survey.The dual frequency receivers allowfor data redundancy in field and for rigorous quality control during office processing in relation to atmospheric effects, multipath and occasional cycle slips. One of the GPS receivers isused at a fixed point with known level, while the other one is used as a moving unit attached to a vehicle. The fixed points arechosen very close to the irrigation marks with known levels. GPS recorded data were checked for integrity and completeness.

2.3 Resultant DEM of the Nile Delta

The DEM of the study area is generated from interpolation of the data extracted from the digitized contours and elevations together with the field data from kinematic GPS as in Fig. 4. The first step for DEM generation is to create Triangulated Irregular Networks "TINs" which represent a surface as a set of irregularly located points linked to form a network of triangles with z-values stored at the nodes. TINs consist of nodes that store z-values, connected by edges to form contiguous, non-overlapping triangular facets. The edges in TINs are used to capture the position of linear features that play an important role in the surface such as ridgelines or stream courses.

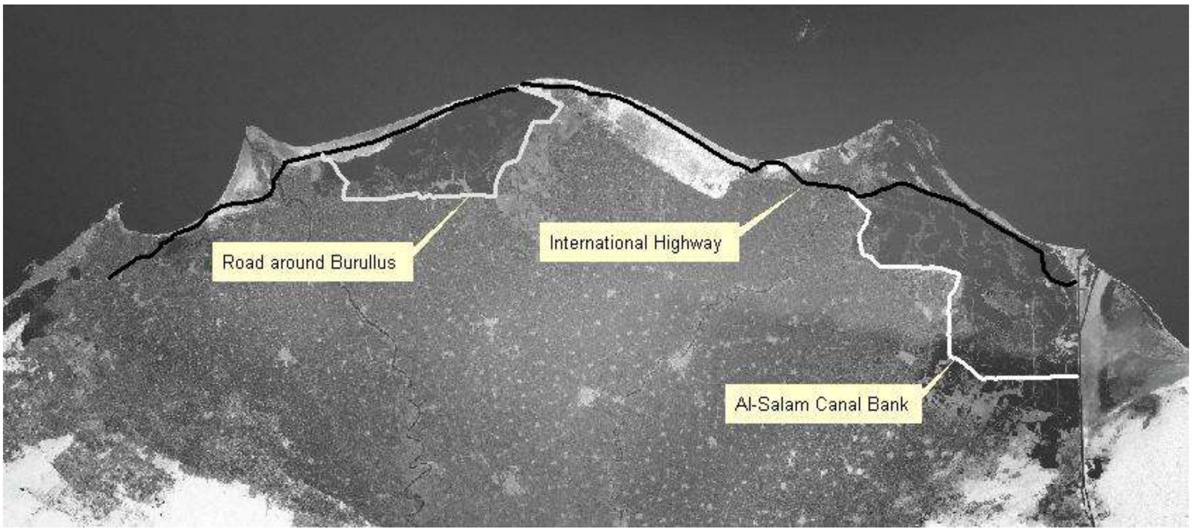

Fig. 3. Selected Roads surveyed using Kinematic GPS leveling.

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The resolution of any DEM used for developing inundation map should not be greater than the resolution of the base topographic data. Use of a DEM built with greater resolution than is supported by the base topographic data implies a false precision in the final inundation mapping. This may mislead the intended audience by portraying more accuracy than is true. The spacing among used spot levels, contour lines, and ground level data exceeds 100 m. Accordingly, the used resolution or the average point spacing of mass points or size of grid cells is chosen to be 100 m x 100 m. The accuracy of the used elevation data is around 25 cm. Fortunately, the study area is agriculture land which is nearly flat relief. Dense data in this case will not significantly improve the accuracy of the inundation map.

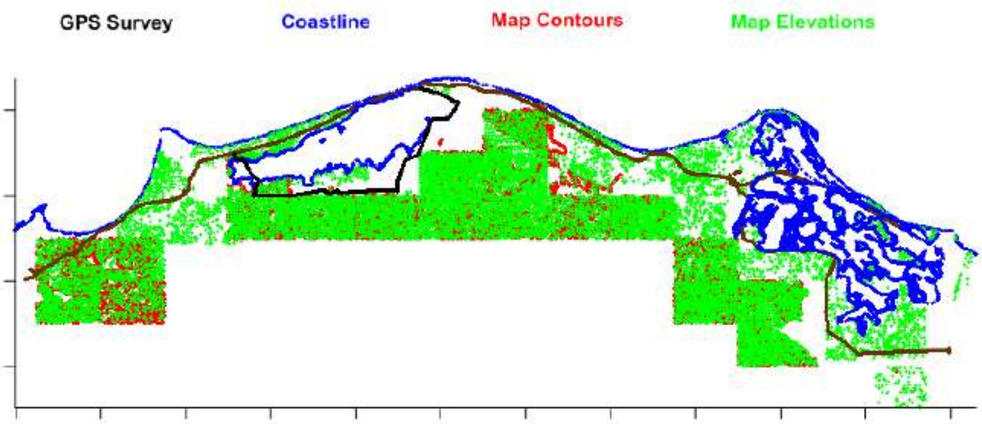

Fig. 4. Selected Roads surveyed using Kinematic GPS leveling.

Figure 5 shows the levels determined from the DEM where it can be seen that most of the study area is below 2.0m. Furthermore a large part of the northern delta is below 1.0m. an area of sand dunes with levels from 2.0-2.5m exists between Damietta branch to the east toward Burullus Lake. The area to the south of Burullus Lake is mostly with levels from 0 to 1.0m. The resultant DEM shall be extended to cover larger areas to the south as well as toward the Alexandria in the west.

3. SEA LEVEL RISE INNUNDATION MODEL

Inundation modeling is a process in which the water level along the shoreline is raised by selecting a land elevation above the current water level elevation and then delineating all areas at or below that elevation, thus placing them into the inundation zone [19], and it has been improved in later studies by accounting for hydrologic connectivity [20, 21]. Future SLR models with single values i.e. 0.5m, 1.0m, 1.5m, 2.0m and 2.5m scenarios are applied to the DEM of the Nile Delta. The inundation map projected for each sea level rise scenario is overlaid upon the land use coverage to determine land use types that are most likely to be affected. Two inundation techniques are adopted in this paper as explained in the following subsections.

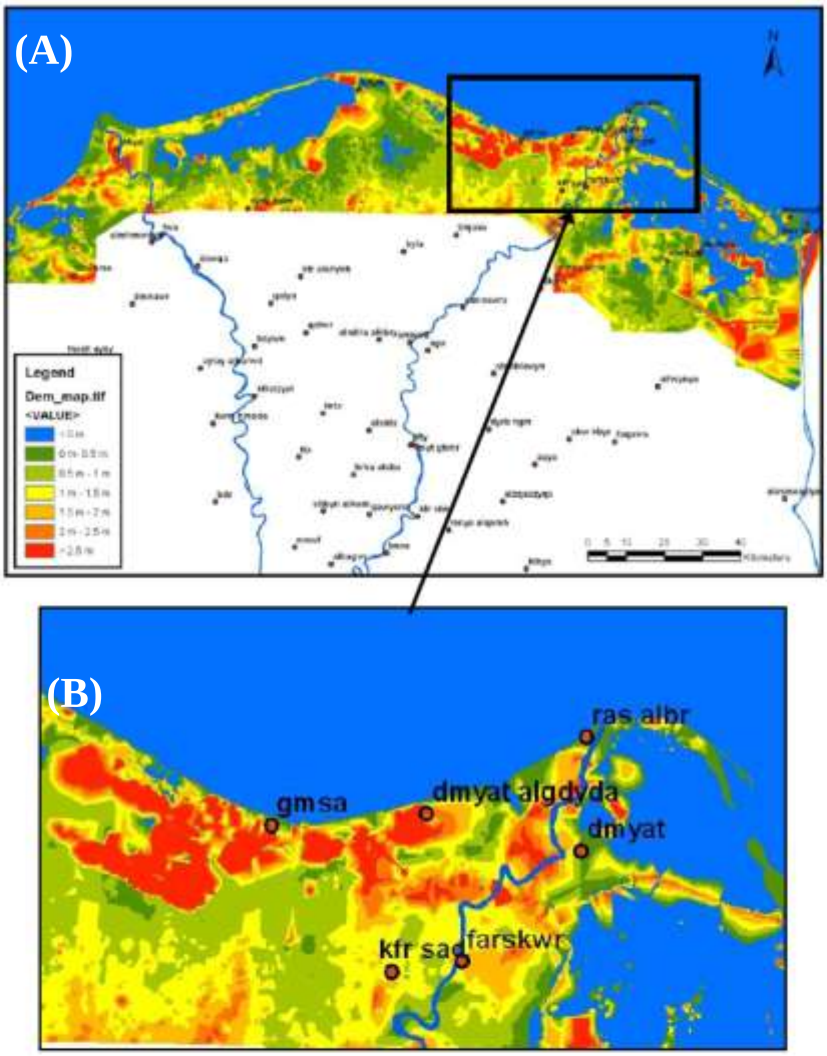

Fig. 5. A) Generated DEM for the Northern Part of the Nile Delta,
B) A focused view of the area enclosed by the Black Box
covering the north east part of the Delta.

3.1 Single Value Inundation Model

As an initial attempt a single value water surface based on a single numerical value representing a water level is applied. This value is then applied consistently overan entire study area. This approach is most commonly used for mapping SLR for local areas where only one water level gauge is used for the transformation.

In this case, different scenarios of sea-level rise “beginning with 0.5 meters with increment 0.5 m and up to 2.5m” are applied, with output results providing a “snapshot” of the inundation of the area at each of these moments in time. The output inundation map represents the potential impact of the mitigation strategies both on the final extent of inundation, and on the rate of inundation over time “gradual or extreme“. The results of this analysis are not provided since they overestimate the inundation due to the existence of low areas not connected to the sea or the lakes.

3.2 Connectivity Inundation Model

Inundation model is developed from the 100-meter horizontal grid resolution DEM and projection of SLR models, described above, using GIS raster analysis. First, raster cells in the DEM that lie adjacent to the contiguous sea or lakes are identified. Then, cells within that group of identified cells whose elevation values are less than or equal to the desired SLR increment are selected and reassigned as sea cells. For example, to determine an inundation area for a sea level increase of 1 meter above the current sea level, all cells in the DEM that are adjacent to the sea and that have a value less than or equal to 1 are selected and converted to water.

The model also includes an assessment of hydraulic connectivity that identified low-lying areas that are not connected to adjacent inundated areas because they are protected by topographic features, and therefore would not be flooded. To add this connectivity to the model, the first step is to determine the flow directions of each DEM. This process determines to what direction water would flow if it is in each cell in the DEM, and creates a new raster grid representing this information. In other words, starting from the first cells inland from the shoreline, the model looks at all of the surrounding cells and, based on elevation, decides which direction a drop of water would flow and gives that cell a new value of 1-8 “each number represents one of the eight possible directions that the water could flow in such as up, upper-left, right, etc.”. This Flow Direction raster is important; because if one knows which direction water would flow in from any given cell than they are one step closer to discovering how water will flow inland due to sea-level rise.

4. INNUNDATION MODEL RESULTS AND VULNERABILITY MAPS

4.1 Inundation Scenarios

Maps visualizing the inundation analysis are developed for all future climate scenarios. The DEM cells in raster format are reclassified to be equal to a value of one if the cell is below a sea-level rise threshold, and equal to “NoData” otherwise. Obviously, in this case cells with a value of one are represented as submerged, and those with a value of NoData are represented as dry. The output of this processes shows how the shorelines would change if sea level were to rise for each increment. Several maps are produced of inundation and interactive map animations are produced.

These areas are uniquely identified on the final maps because while they are not directly exposed to SLR impacts, they are at risk of flooding if the topographic feature protecting them fails or breaches. The extent and depth of inundation is depicted for the SLR projections “Figs. 6-8”. Details of the inundation maps around Al-Burrullus and Manzala lakes are provided in Figs. 9-10.

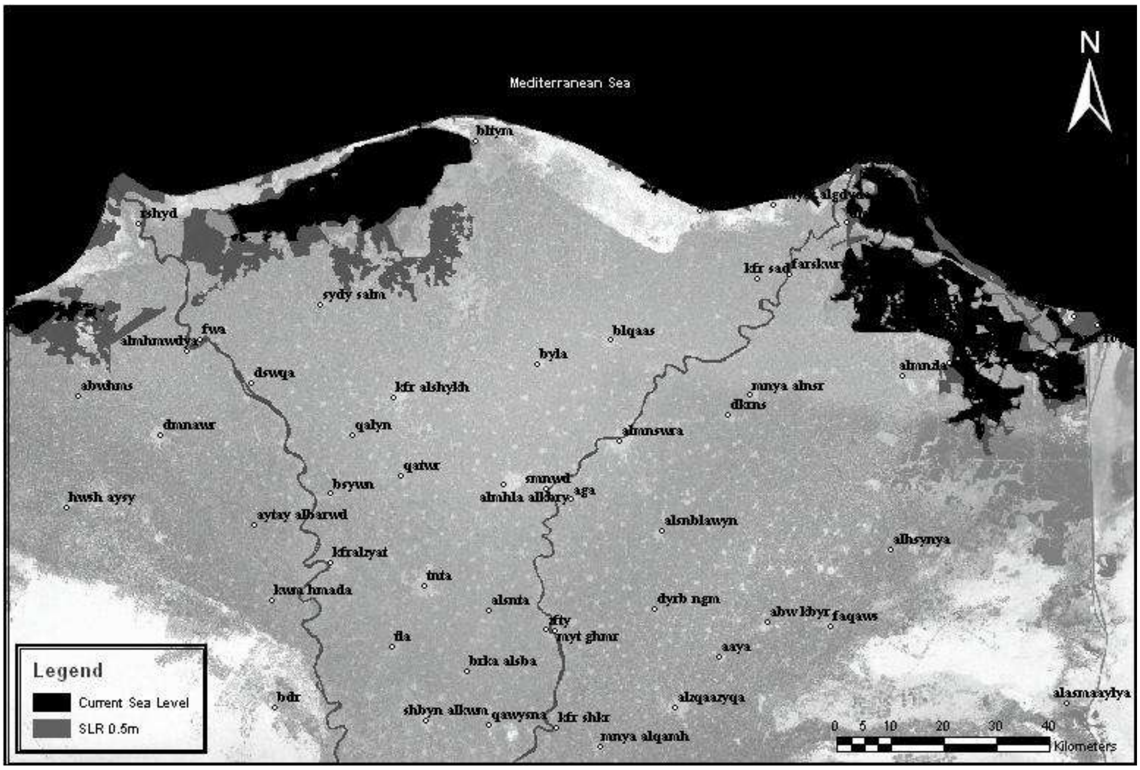

Fig. 6. Inundation Map for 0.5m SLR.

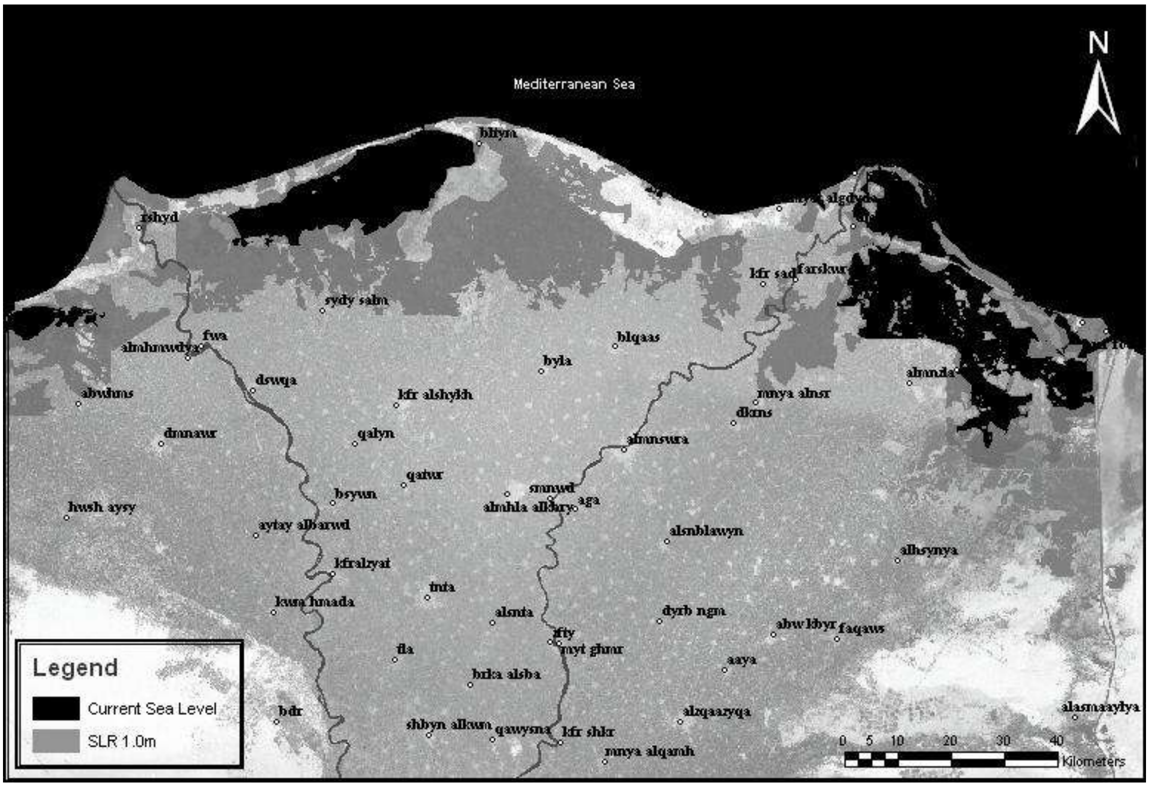

Fig. 7. Inundation Map for 1.0 m SLR.

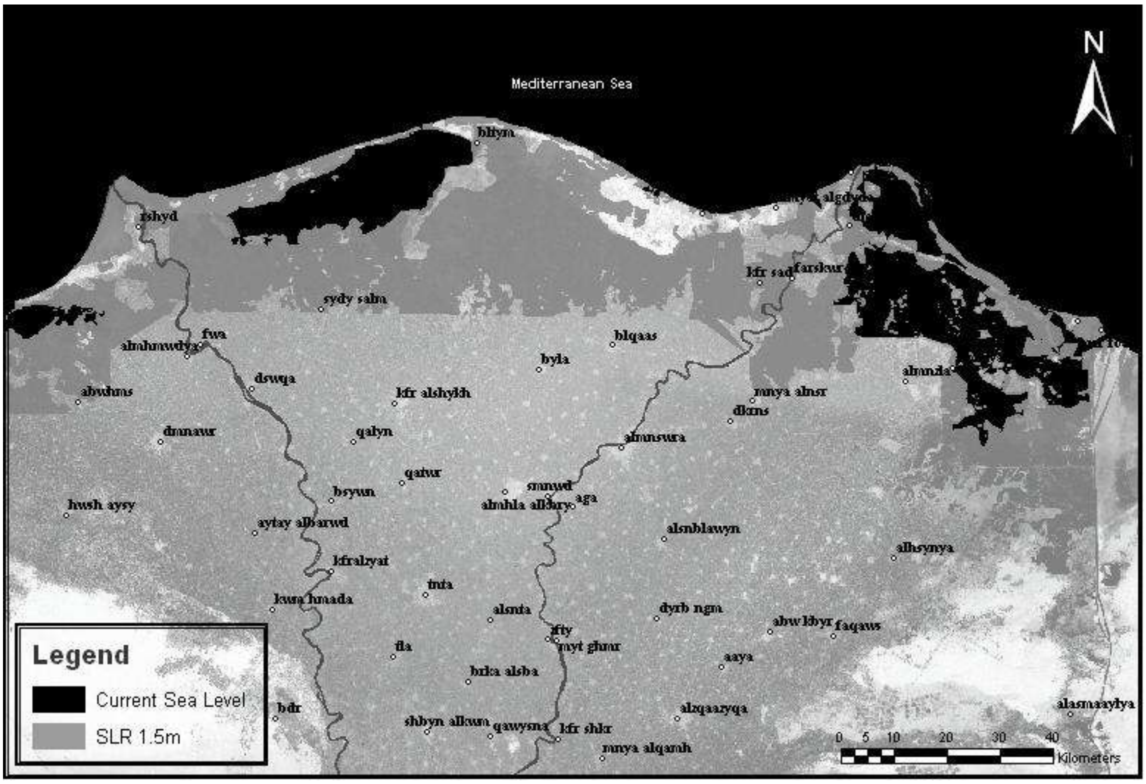

Fig. 8. Inundation Map for 1.5 m SLR.

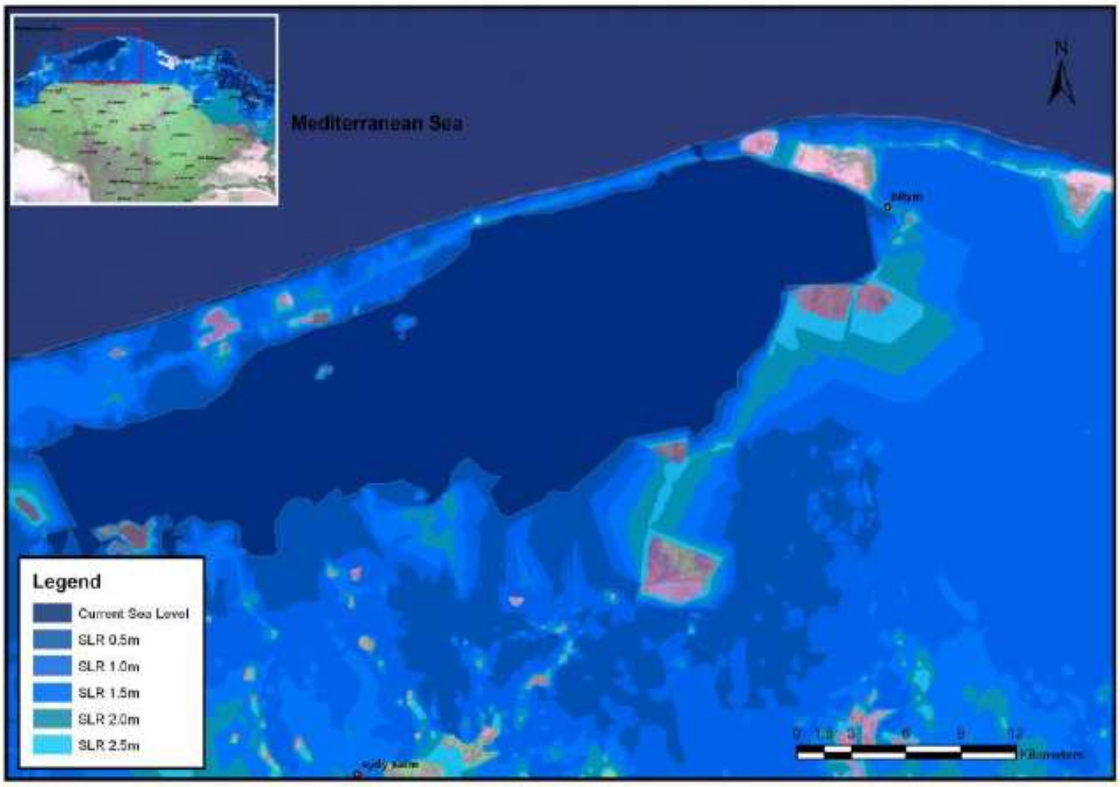

Fig. 9. Inundation Map for SLR Scenarios around Al-Burrulls Lake.

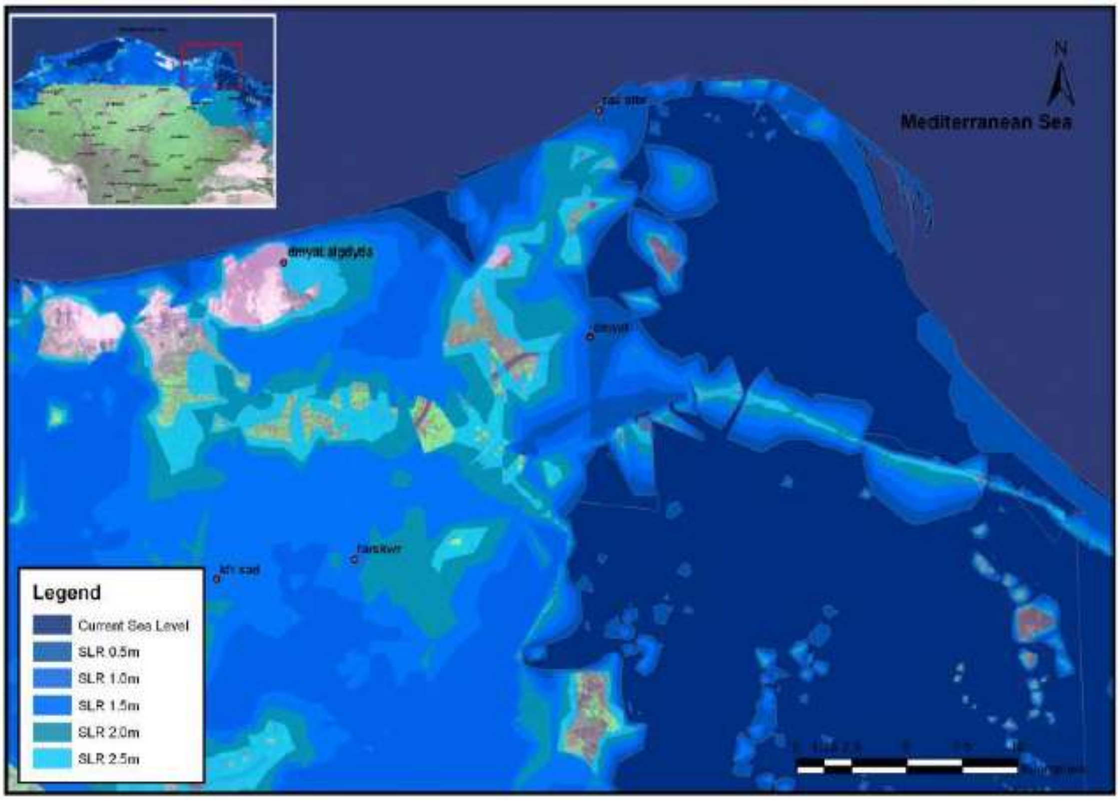

Fig. 10. Inundation Map for SLR Scenarios around Al-Manzala Lake.

It can be seen that the SLR initially inundates land from the lakes and not directly from the sea. Water inundates considerable areas around the Burrullus even for a 0.5m SLR as shown in Fig. 6. Water passes the road around the Manzala Lake once it reaches 1.0m along a small section as shown in Fig. 10. The 1.5 m SLR will result in the loss of most of the northern Delta as shown in Fig. 8.

4.2 Vulnerability Maps

Vulnerability is defined as the potential for loss or harm/damage to exposed assets largely due to complex interactions among natural processes, land use decisions, and community resilience. Inundation caused by SLR is identified as an important natural hazard that affects densely populated and built-up areas. GIS plays an important role in vulnerability assessment, allowing the planning team to store, manage, analyze, and display spatial data. GIS allows the team to compare the extent of impacts and consequences across scenarios and better understand where vulnerability is greatest, which supports decision making.

The geoprocessing tools in ArcGIS software are used for this section. The shape files for the inundated area for each SLR scenarios are intersected with the residential zones defined by shape files. The results of the land area and the population affected by SLR are shown in Figs. 11-12. These areas are of high population density with economic importance and political influence that, as the results indicate, would sustain marked impacts resulting from SLR. The impacts are definitely evident when taking into account population alone, yet the large amount of high- value property for residential, agricultural, and industrial uses is another important factor that needs further investigation. Equally important is the potential humanitarian crises that is likely to occur as a result of coastal inundation in economically less developed regions with high population densities. As part of the vulnerability using the inundation map the risk assessment is evaluated by computing the areas for the associated damage as provided in Table 1.

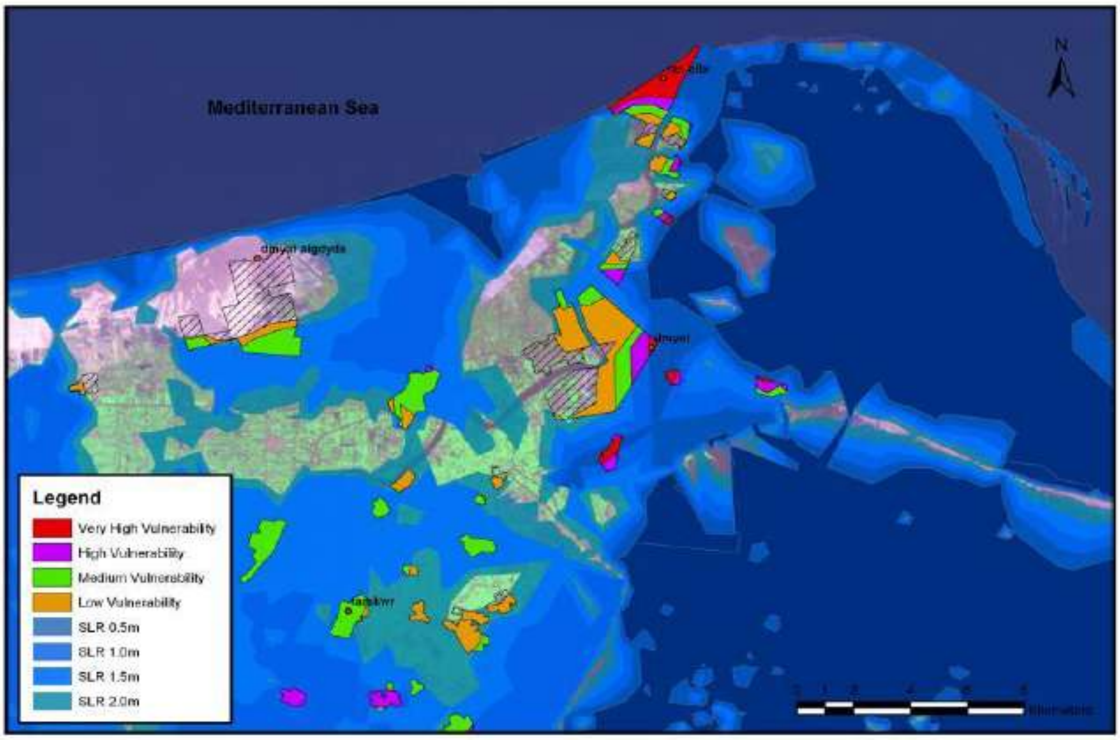

Fig. 11. Vulnerability Map for Residential Zonesaround Al-Manzala Lake due to SLR of 0.5, 1.0, 1.5, and 2m.

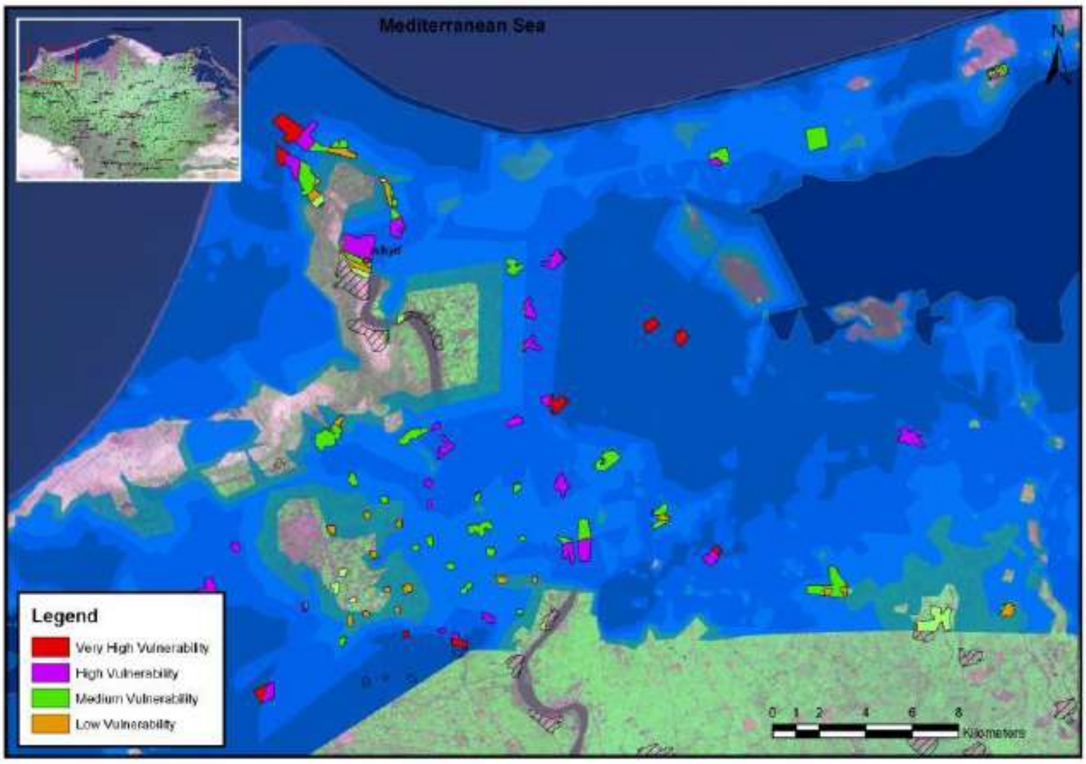

Fig. 12. Vulnerability Map for Residential Zonesaround Al-Burrulls Lake due to SLR of 0.5, 1.0, 1.5, and 2m.

Table 1. Areas of Associated damage in Agricultural and Residential Areas due to Vulnerability based on the Inundation Maps.

SLR Scenario (m)	Area of Associated damage (km^2)	
	Residential	Residential & Agriculture
0.5	58.5	975
1.0	103	2831
1.5	142.5	3914
2.0	194	5282
2.5	221.5	5685

A recent study on the potential impacts of climate change on the Egyptian economy [22] assessed the economic impacts of two SLR scenarios, which include subsidence and rise in global sea levels, on the Nile Delta. The high SLR scenario "109 cm at Port Said, 60.3cm at Al-Burrullus Lake, and 55.0 cm at Alexandria" inundated 774.3, 523.9, and 625.6km^2 of agricultural land in the Northeast, North-Middle, and Northwest of the Nile Delta, respectively, assuming that no SLR protective measures are implemented. These figures are in line with the results estimated from our model calculations and prove that this model provides an acceptable basis for further enhancement and utilization in SLR impact assessment in the northern Nile delta.

5. CONCLUSIONS

This paper provides an assessment of the impact of different SLR scenarios on the Nile Delta. An inundation model is developed using GIS that accounts for connectivity with the sea or lakes. The main input to the inundation model is a Digital Elevation Model "DEM". In this study, topographic maps of scale 1:25,000 were digitized together with the surveying of key features using GPS leveling to produce the data required for the DEM. The main key features were the International road and the road along the Salam canal.

The impact of SLR was assessed by producing maps for the inundated areas due to a 0.5, 1, 1.5, 2.0 and 2.5m SLR. This SLR will include global SLR and land subsidence. The study showed that initially the water will mainly enter the low areas from the coastal lakes "Manzala and Burrullus". The embankment surrounding the

Salam canal will protect the areas behind it till a level of about 1.0m. This embankment is mostly at a level of 2 m and thus it could be possible to increase the level for the lower parts of this embankment to act as a dike. The Burrullus Lake however, does not include any embankment surrounding it and thus such an embankment should be considered. Finally, vulnerability maps were produced based on the expected SLR and the activities in these areas.

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تاثيرات ارتفاع منسوب سطح البحر على دلتا النيل بمصر

التغيرات المناخية تعد من أهم الظواهر البيئية التى تهدد العالم بأكمله ويتناول البحث تأثير ظاهرة ارتفاع منسوب سطح البحر الناتجة عن الاحتباس الحرارى على منطقة شمال دلتا نهر النيل من خلال دراسة مجموعة من السيناريوهات المحتملة لزيادة منسوب سطح البحر وتطبيقها على نموذج طبوغرافى رقمى تم اعداده باستخدام الخرائط الطبوغرافية وعمليات المسح الحقلى، وأوضحت النتائج أن البحيرات الشمالية "المنزلة و البرلس" هى المدخل الرئيس لدخول مياه البحر للمناطق المنخفضة فى شمال الدلتا، وأظهرت النتائج أنه يمكن الحد من الأثار السلبية لزيادة منسوب سطح البحر على الدلتا عن طريق منسوب الطرق المحيطة ببحيرتى المنزلة والبرلس كى يعملا كحواجز صناعية.