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Economic Valuation of Sea Level Rise Impacts on Agricultural Sector in Northern Governorates of the Nile Delta

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Abstract

It is widely believed, according to the IPCC (Intergovernmental Panel on Climate Change) projections, that there will be an increase in the global average sea level of 0.18 cm to 0.59 cm through the twenty-first century. The coastal area of the Nile delta is considered to be one of the most vulnerable areas to Sea Level Rise (SLR) in the world. Where, the Nile Delta consists mostly of lowland areas which accommodate a significant proportion of the Egyptian agricultural and economic activities. SLR is expected to have a profound impact on the agricultural areas of the Nile Delta, through either inundation or higher levels and salinity of groundwater. Due to the prevailed vulnerability of the Nile delta and as guidance for decision and policy making, it is necessary to provide estimates of potential economic damage that can result from such SLR. The paper in hand intends to estimate the economic value of the agricultural areas, in the coastal governorates of the Nile Delta, susceptible to inundation due to SLR according to most recent SLR scenarios and to estimate the economic value of potential impacts of rising groundwater table, associated with SLR, on agricultural productivity by the year 2100. The results indicate that about 7.5%, 36.3%, and 44.0% of the total cultivated area of the coastal governorates of the Nile Delta (with a market value of 51.7, 196.6 and 232.6 billion EGP (Egyptian Pound)) will be susceptible to inundation under the different scenarios of SLR. Moreover, it was found that the future accumulative crop yield loss due to increasing groundwater level was estimated, using segmented linear regression, to be as much as 32.3 billion EGP. It is worth mentioning that these estimates do not include indirect impacts of higher levels of groundwater table, which may include loss of jobs and/or earnings, impacts on food supply and food security in the area.

Keywords

Sea Level Rise, Nile Delta, Economic Valuation, Agriculture, Groundwater Table Level, Inundation, GIS

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1. Introduction

(SLR) Sea Level Rise is considered to be one of the main direct impacts of climate change, which may have profound effects on several economic sectors such as agriculture, tourism, Industry, health, etc. Generally coastal agricultural areas will face different stresses due to SLR, such as increases in the occurrence and scale of extreme weather events, saltwater intrusion, and higher levels of water table and inundation. Hence, agricultural areas and agricultural productivity will be highly affected by these profound impacts. Huge pressures on income and employment in the agricultural sector will occur as a consequence of increasing sea levels which may increase the threats on food security and malnutrition in the areas affected [1].

It is strongly believed that, under business as usual scenario, SLR will have intense impacts on agricultural production in the northern areas of the Nile Delta. These effects will take the form of inundation of agricultural land and the rise in groundwater levels [2]. These two effects will cause significant decline in agricultural yields, and hence food security.

In general, SLR will cause inundation of low lying lands and the loss of such agricultural areas and product, as well as higher groundwater table levels. Whenever a shallow groundwater table exists, productivity of most crops can be regressed on the depth of the groundwater table. The regression relationship between productivity and groundwater table depth curves differs from one crop to another, but they have a common shape. For most crops, a certain threshold is known where there is a certain groundwater table depth, at which aeration, moisture, and nutrients are optimum that crop productivity can be maximized. When the groundwater table rises above this threshold, crop yields begin to decline [3].

The paper in hand intends to estimate the economic value of agricultural areas, in the coastal areas of the Nile Delta, susceptible to inundation due to SLR according to most recent scenarios of SLR projections, and to estimate the economic value of potential impacts of rising groundwater table associated with SLR on agricultural productivity in the coastal governorates of the Nile delta using geographical information system (GIS) by the year 2100.

2. Study Area

At Cairo, the Nile spreads out into two branches to form the Nile delta. The Nile delta extends between Port Said in the east and Alexandria in the west constituting a coast with a total length of 240 km [4] and a total delta area of 23850.76 km^2 [5]. The most productive agricultural land in Egypt is located along the inland path of the Nile River and the Nile Delta, where the agricultural production in the Nile Delta and the Mediterranean coast amounts to 30% - 40% of Egypt's total agricultural production. Nile Delta agriculturally productive land are approximately 3.34 million feddan (feddan equals to 4200 m^2) [6].

The Nile delta is known by its heavy population density which amounts to 1600 inhabitants per square kilometer [4] with a total population of, approximately, 40 million inhabitants constituting half of the Egyptian population [7].

The area under investigation lies between longitudes 29˚30'0" and 32˚30'0" East and latitude 31˚30'0" and 30˚0'0" North as shown in **Figure 1**. The coastal zone of the Nile delta is divided into, administratively, six governorates namely Port Said, Damietta, Dakahlyia, Kafr El-Sheikh, Behaira, and Alexandria, which are further divided into 105 districts. These governorates are not only agricultural governorates, but also include a huge portion of the Egyptian industrial and economic sectors.

In the Nile Delta, crop year is divided into two main cropping seasons and one marginal season. First season, winter season starting in November and ending in May, while the second season is the summer season starting in May and ending in October. The marginal season is the Nili season, named after the annual Nile flooding extending from august to October. The main winter crops are Clover (berseem), wheat, beet and broad beans, while the main summer crops are corn, rice, cotton and tomatoes.

Due to the importance of the Nile Delta, as discussed earlier, scholars paid a considerable attention to the impacts of SLR on the Nile delta and examined it in a number of previous studies. For instance, Frihy concluded in a study which covered the whole Nile Delta coastal area, assuming a mean relative SLR ranging between 1.6 and 2.2 mm/year that about 30 % of the Nile Delta coast would be vulnerable to SLR and about 15% are artificially protected [8].

El Nahry and Doluschitz conducted a study in 2010 which took into consideration the impacts of three assumed SLR levels which are 1.0, 1.5 and 2.0 m. The study concluded that 28.93%, 35.33%, and 50.78% of the

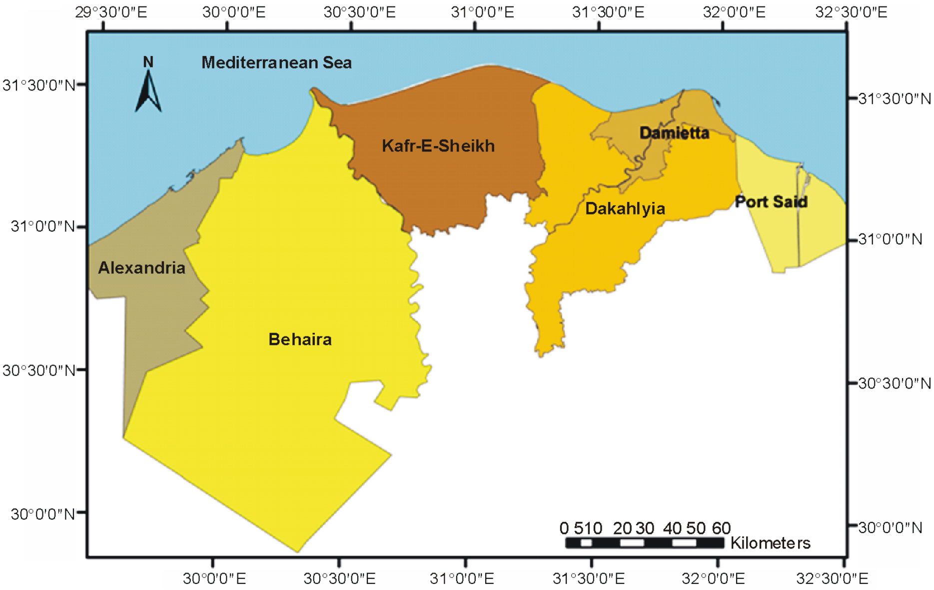

Figure 1. Study area.

coastal area of the Nile Delta, respectively, would be inundated [5].

A more recent study that measured the vulnerability of the Nile delta to three different SLR scenarios which are 0.59 meters, 1.4 meters and 2 meters and a range of land subsidence rates ranging between 0.5 and 4.5 mm/year concluded that about 22.49, 42.18, and 49.22%, respectively, of the total area of coastal governorates of the Nile Delta would be vulnerable to inundation under different scenarios of SLR. Also, it was found that 15.56 % of the total areas of the Nile Delta would be vulnerable to inundation due to land subsidence only, even in complete absence of SLR [9].

Abdrabo and Hassaan [10] under took a study aiming to estimate the economic value of potential primary impacts of higher levels of groundwater table due to expected SLR on agriculture productivity in Damietta Governorate as one of the Nile Delta coastal governorates. They concluded that, the future accumulative crop yield loss was estimated, using segmented linear regression, up to the year 2100 to be as much as L.E. 6.43 billion in Damietta Governorate only [10].

It is of worth to mention, that the work at hand is the first to study the SLR impacts in a holistic view either in respect of the geographical area covered or in the SLR impacts studied. Where this is the first study to estimate the economic loss in agriculture resulting from inundation due to SLR and the loss in agricultural productivity due to rising water table levels in the six northern governorates of the Nile delta.

3. Data and Methodology

The proposed model to estimate the economic value associated with SLR consists of three stages, as illustrated in **Figure 2**, each characterized by three separate activities: data collection, data processing and outputs. Stages 1 and 2 are parallel steps dealing with spatial distribution of agricultural production, Profits, SLR and water table depth. Stage 3 is a sequential step that combines the above and generates a comprehensive picture of total local economic costs.

In the first stage, inundation maps are created. The relationship between expected relative SLR and local topography can easily help in determining the coastal areas which are vulnerable to inundation due to SLR. In 2006, Ericson *et al.*, suggested that global SLR, gross accretion of fluvial sediment and land subsidence are the main parameters determining relative SLR. Hence, expected relative SLR at any future point of time can be estimated using the following equation [11]:

$$R_{SLR} = (G_{SLR}) + (G_{LS} \times n) - G_{FLUV}$$

where,

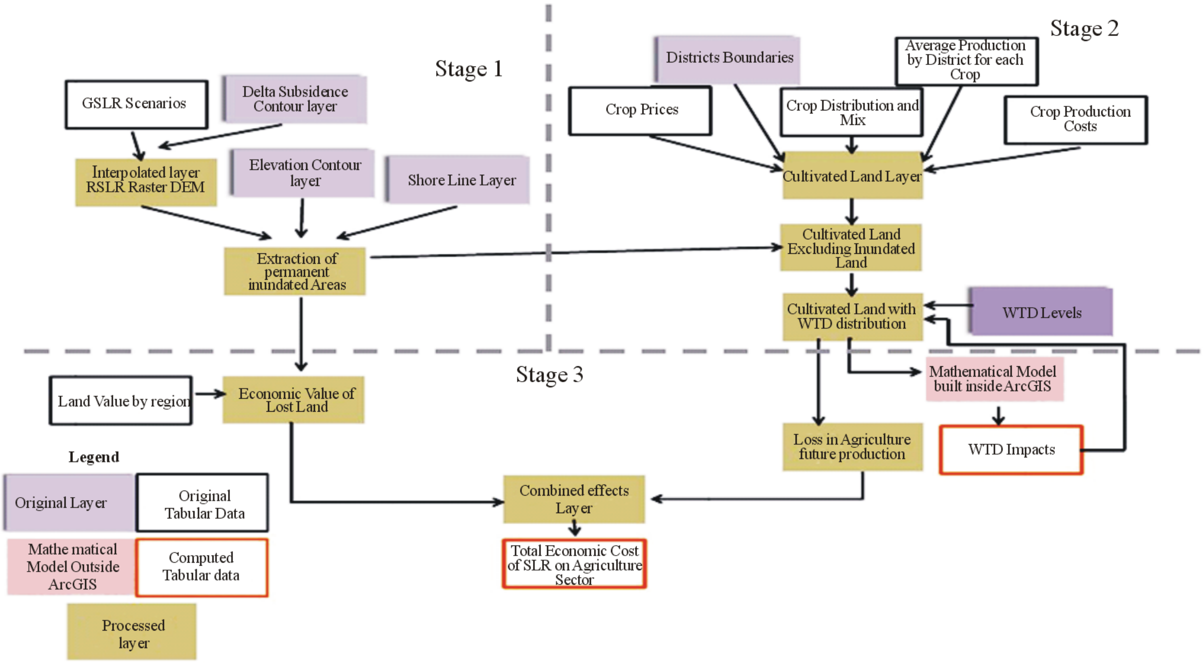

Figure 2. Outline of the suggested approach.

R_{SLR}	Relative SLR;
G_{SLR}	Global SLR;
G_{LS}	Gross natural deltaic land subsidence;
n	Number of years between present and future year of concern;
G_{FLUV}	Gross accretion of fluvial sediments.

Around 60 to 180 million tons of sediments and 18×10^8 to 55×10^9 m^3 of water were transported to the Mediterranean Sea by the Nile River yearly before the Aswan high dam was built. In 1964 and after the construction of the High Dam, all the discharge (including sediment) carried by the Nile, from the Ethiopian mountains, were locked in lake Nasser. Hence, gross accretion fluvial sediments (G_{FLUV}) in the case of the Nile Delta coastal Zone are almost equal to zero [12]. Therefore, expected relative SLR at any point of time in the future can be calculated according to the following equation [13]:

$$R_{SLR} = \left(G_{SLR}\right) + \left(G_{LS} \times n\right)$$

where,

R_{SLR}	Relative SLR;
G_{SLR}	Global SLR;
G_{LS}	Gross natural deltaic land subsidence;
n	Number of years between present and future year of concern.

The impacts and rates of the extensive subsidence occurring in the Nile delta have been studied previously by several researches. In 1988, Stanley concluded that, since 7500 years ago the northern parts of the Nile delta have subsided quickly at rates up to 0.5 centimeter per year [14].

For the purpose of estimating the expected relative SLR affecting the northern parts of the Nile delta, ArcGis 10.1 was used, where a DEM layer representing the annual subsidence rate at each point of the coastal region of the Nile delta was multiplied by the number of years up to 2100 resulting in a new raster surface representing total subsidence, up to 2100, for each point of the study area. Global SLR according to A1FI, IPCC (2007), Rahmstorf (2007) and Pfeffer *et al.* (2008) scenarios, which were 59 cm, 140 cm and 200 cm, respectively were then added to each point in the previously generated total subsidence raster surface resulting in a new raster surface layer representing the expected relative SLR.

As a final step in identifying lands vulnerable to inundation, spatial analysis was used to compare each two corresponding points in the expected relative SLR raster surface and the elevation raster surface (DEM layer representing a detailed coverage of land elevation in the study area). If pixel value of the expected relative SLR was more than or equal to the pixel value of elevation raster surface hence it is a case of low laying land. However, it should be noted that any low laying land would be vulnerable to inundation due to expected relative SLR, if and only if it is adjacent to and/or in direct contact with the coast line. Hence, previously identified areas representing low laying land which are spatially adjacent to the sea and/or in direct contact with the coast line were selected and exported to create a new polygon feature class representing areas that were defiantly vulnerable to inundation due to expected relative SLR [13].

These inundated areas, identified in the previous step, where intersected by cultivated land layer, to get the net cultivated land lost due to SLR. Thereafter, this lost cultivated land was multiplied by the current market value of land to get the total economic loss due to inundation and by completing this step, step one of the model is completed. It is worth mentioning at this point of time that the reason behind choosing the current market value of land as the economic value, although according to "time value of money" theory it should have been the discounted amount of the future land value, was the equality between future and current generations. Choosing the current market value of land implies that the discount rate is zero or near zero, this choice is based on the "Equity frame" which suggests that the public cares equally about present and future lives, and that there is no revealed preference between current and future generations, hence making the time preference and discount rate equal to zero [15].

Moving to the second stage of the model, which is the calculation of agricultural loss due to changes in water table depth levels, some data had to be identified namely: current cropping data, crop response parameters to variations in water table depth, and distribution of the current and future water table across the northern region of the Nile delta. The area specific (by district and season) cropping data that needed to be identified were as follows: crop type, crop prices, crop costs, crop pattern and average crop productivity. These parameters were obtained from the Egyptian Ministry of agriculture, Economic Affairs Sector in the form of tabular data for the year 2010.

Literature data compilation for crop response parameters, expressed as a linear regression line between crop yield and water table depth took place. This compilation resulted in the identification of different water table depth thresholds and response curve slopes for each crop cultivated in the six governorates under studying. These thresholds and slopes were added to the table obtained from the ministry of agriculture by crop in order to complete all the data needed by the model before uploading it in ArcGis 10.1. This table was uploaded in ArcGis using "adding x, y coordinate data as a layer" tool, where it became an x, y event layer and behaved like any other point feature layer. Thereafter, a new polygon feature layer having an attribute table of all the cropping parameters previously mentioned by district and by season. This layer is then intersected with the "cultivated land layer" not affected bySLR in order to obtain the cultivated area by crop in each district and in each cropping season (winter, summer and Nili).

The current and future distribution of water table depths until year 2100 was modeled and estimated in Elshinnawy research [16] through the use of a sophisticated hydrological model. This model resulted in raster data set representing the current and future water table depths under the IPCC, 2007, SLR scenario, which was 59 cm.

At this point of time it was necessary to calculate the total production of each piece of land up to 2100. So under the current water table depth and assuming everything is constant, including water table depth, total land production between 2010 and 2100 can be represented mathematically:

$$Q_{ij}^{n} = Q_{ij} \times n$$

where,

Q_{ij}^{n} is the total agricultural production throughout the years;
Q_{ij} is the production of crop i per feddan in area j;
n is the number of years under study which in this case is 90 years.

In the case of decreasing water table depth, while assuming that the decrease in water table depth is a linear function of years the total production can be represented as:

$$Q_{ij}^{*n} = \frac{n\left(100 - d_{ki} \cdot f_{ki} + d_{ki} \cdot WT_{cj}\right) + \left[d_{ki}\left(WT_{nj} - WT_{cj}\right)\left(\frac{(n+1)}{2}\right)\right]}{100} \times Q_{ij}$$

where,

Q_{ij}^{*n} is the total agricultural production throughout the years under linearly decreasing water table depth;
d_{ki} is the slope of the waterlogging response curve for crop i;
f_{ki} is the water table depth threshold at which crop i yields begin to be affected;
WT_{cj} is the current water table depth at area j;
WT_{nj} is the depth of water table in area j after n years.

Hence, the total profits under the current water table depth levels will be:

$$\pi_{ij}^{n} = \left\{\left(P_{ij} \times Q_{ij}^{n}\right) - \left(TC_{ij} \times n\right)\right\} \times S_{ij}$$

where,

π_{ij}^{n} is the total profits under current water table depth levels during the period n;
S_{ij} is the area cultivated by crop i in area j;
P_{ij} is the price per unit of crop i in area j;
TC_{ij} is the total cost for crop i in area j per feddan.

While the total profits under the decreasing water table depth will be:

$$\pi_{ij}^{*n} = \left\{\left(P_{ij} \times Q_{ij}^{*n}\right) - \left(TC_{ij} \times n\right)\right\} \times S_{ij}$$

Hence, the ground water table impact on agricultural production is

$$\sum EI_{j} = \sum \pi_{ij}^{*n} - \sum \pi_{ij}^{n}$$

4. Results and Discussion

Concerning the impacts of SLR in terms of cultivated land lost and its value, it was found that cultivated land which were vulnerable to inundation ranged between 250,816 feddan, 1,212,301 feddan and 1,467,500 feddan under the three different SLR scenarios A1FI, IPCC (2007), Rahmstorf (2007) and Pfeffer *et al.* (2008), respectively.

The result of this study shows that the six coastal governorates can be divided in two categories, according to the portion of cultivated area vulnerable to inundation under the different SLR scenarios. Alexandria, Dkahlyia and Behaira can be classified as less vulnerable governorates, where the total inundated cultivated areas in these governorates are less than 50% of its total cultivated area. While Port Said, Damietta and Kafr Al Sheikh can be classified as high vulnerable governorates (**Table 1**).

Adding to the above, it can be observed that under the A1FI scenario Alexandria and Behairah can be considered the only two governorates that will be affected in terms of value of lost cultivated land. Alexandria and Behairah will bear a loss of 11.6 and 39.8 billion Egyptian pound (EGP) worth of cultivated land respectively. While under Rahmstorf (2007) and Pfeffer *et al.* (2008) scenarios it can be noticed that all governorates will be variously affected. Behairah and Kafr Al Sheikh taking the lead with 80.4 and 53.1 billion EGP under the Rahmstorf (2007) scenario and 91.4 and 61 billion EGP under the Pfeffer *et al.* (2008) scenario respectively (**Table 2**).

As a continuation of the study results, the second part of the study objective was to estimate the net forgone profits incurred due to the increase of water table levels as a result of increasing sea levels. Using the crop yields estimated under the current conditions for cultivated areas up to year 2100, the total agricultural production value (APV) and standard (current) profit levels were estimated for the total cultivated land areas. **Table 3** shows the total annual APV and standard profit levels of the cultivated land areas for each government within the study area. According to the study results, it was estimated that 27 billion EGP worth of agricultural production were produced annually with a gross margin of 43.2% generating a gross profit of 11.7 billion EGP annually, with an annual profits per feddan ranging between 4981 to 29,320 EGP with a weighted average of 17,844 EGP (**Figures 3-5**).

Under the A1FI scenario, 684,941 feddan were found to be vulnerable to increasing water table levels up to year 2100 representing 20.5% of the total cultivated area in the six governorates. This area is represented graphically in **Figure 6**, where the cultivated areas that will be impacted by increasing water table levels excluding areas that were estimated to be vulnerable to inundation under the A1FI scenario (**Figure 6**).

Table 1. Inundated cultivated area in the northern governorates of the Nile delta.

Governorates	Inundated Cultivated Area (Feddan)			Governorate Total Cultivated Area (Feddan)	Percent of Inundated Cultivated Area		
SLR	50 cm	150 cm	200 cm		50 cm	150 cm	200 cm
Alexandria	55,674	57,149	57,777	227,129	24.5%	25.2%	25.4%
Behairah	193,275	379,731	430,233	1,377,541	14.0%	27.6%	31.2%
Dakahliya	408	251,257	327,399	751,715	0.1%	33.4%	43.6%
Damietta	1021	113,744	126,587	127,039	0.8%	89.5%	99.6%
Kafr Al Sheikh	438	364,984	420,065	680,224	0.1%	53.7%	61.8%
Port Said	-	45,437	105,440	172,320	0.0%	26.4%	61.2%
Grand Total	250,816	1,212,301	1,467,500	3,335,969	7.5%	36.3%	44.0%

Table 2. Value of inundated cultivated area in the northern governorates of the Nile delta.

Governorates	Value of Inundated Cultivated Area in Billion EGP			Governorate Total Value of Cultivated Area in Billion EGP	Value Percent of Inundated Cultivated Area		
SLR	50 cm	150 cm	200 cm		50 cm	150 cm	200 cm
Alexandria	11.6	11.9	12.0	79.7	14.6%	15.0%	15.1%
Behairah	39.8	80.4	91.4	299.5	13.3%	26.8%	30.5%
Dakahliya	0.1	35.5	46.3	122.7	0.0%	28.9%	37.7%
Damietta	0.2	11.8	13.0	13.6	1.6%	86.7%	95.4%
Kafr Al Sheikh	0.1	53.1	61.0	103.2	0.1%	51.4%	59.1%
Port Said	-	3.9	8.8	12.9	0.0%	29.9%	67.9%
Grand Total	51.7	196.6	232.6	631.7	8.2%	31.1%	36.8%

Table 3. Current annual total APV and profit levels by governorate.

Governorates	Current Annual Agricultural Production Value in Billion EGP	Current Annual Profits in Billion EGP	Governorate Total Cultivated Area (Feddan)	Annual Profits Per Feddan
Alexandria	2.1	0.9	227,129	15,829
Behairah	9.3	4.1	1,377,541	21,641
Dakahliya	7.5	3.3	751,715	19,322
Damietta	1.2	0.6	127,039	29,320
Kafr Al Sheikh	6.2	2.4	680,224	15,725
Port Said	0.7	0.4	172,320	4,981
Grand Total	27.0	11.7	3,335,969	17,844

These vulnerable cultivated lands generated, under the current conditions, an annual total agricultural production value of 2.89 billion EGP and annual profits of 1.14 billion EGP. Due to the increasing water table levels the annual total agricultural production value will decline to reach in 2100 2.51 billion EGP and annual profits will decline to reach 0.77 billion EGP (**Table 4** and **Table 5**).

Moreover, the total loss in agricultural profits, forgone profits, was estimated by comparing the current baseline profitability levels with the level of profitability linked to the yield reductions from waterlogging. The total value of lost profits as a result of waterlogging is estimated to be 32.3 billion EGP up to the year 2100 (**Table 6**). The average loss per feddan, as a result of future waterlogging, is estimated to be 5730 EGP, which reflects the

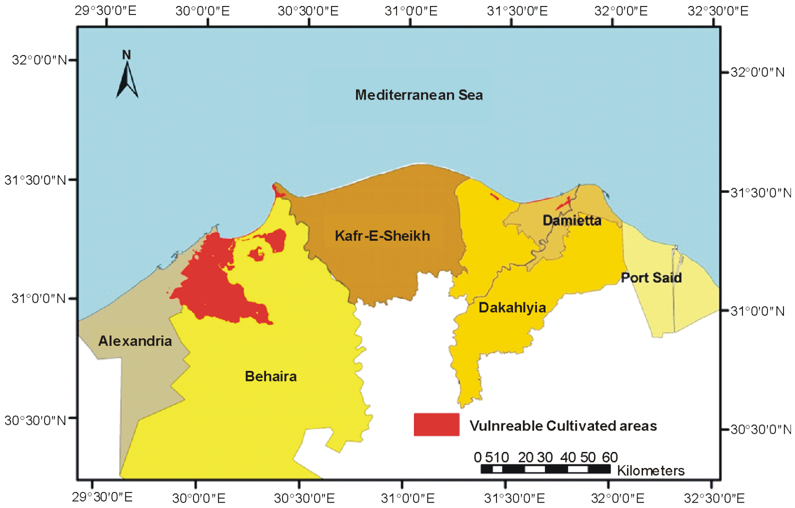

Figure 3. Cultivated lands vulnerable to inundation under A1FI scenario.

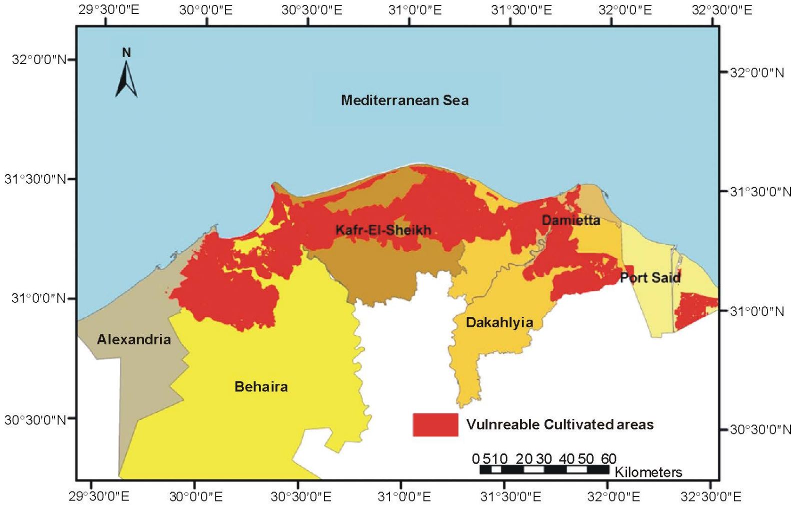

Figure 4. Cultivated lands vulnerable to inundation under Rahmstorf, 2007 scenario.

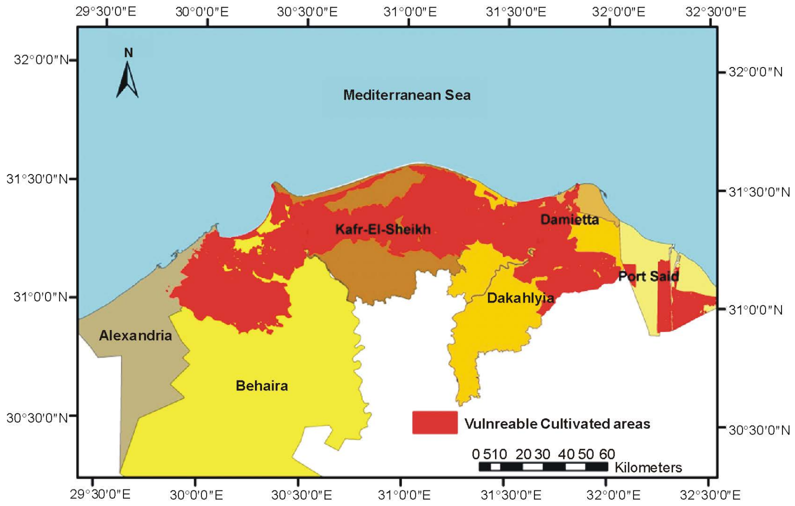

Figure 5. Cultivated lands vulnerable to inundation under Pfeffer *et al.* (2008) scenario.

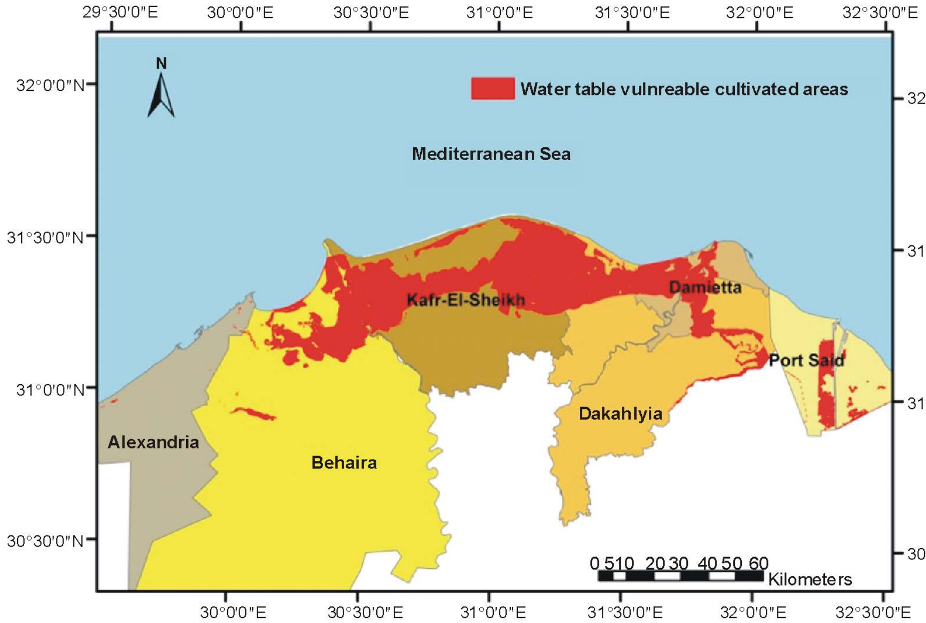

Figure 6. Cultivated areas vulnerable to increasing water table levels excluding areas that were estimated to be vulnerable to inundation under the A1FI scenario.

Table 4. Water table vulnerable cultivated land.

Governorates	Water table Vulnerable Areas in (Feddan)	Governorate Total Cultivated Area (Feddan)	Percent of Water Table Vulnerable Cultivated Area
Alexandria	249	227,129	0.1%
Behairah	128,495	1,377,541	9.3%
Dakahliya	129,938	751,715	17.3%
Damietta	79,451	127,039	62.5%
Kafr Al Sheikh	313,516	680,224	46.1%
Port Said	33,291	172,320	19.3%
Grand Total	684,941	3,335,969	20.5%

Table 5. Future and current annual total APV and Profits for the water table vulnerable cultivated land in the study area.

Governorates	Annual Current APV in Million EGP	Annual Current Profits in Million EGP	Annual Future APV in Million EGP	Annual Future Profits in Million EGP
Alexandria	1.6	0.6	1.7	0.7
Behairah	212.3	156.9	162.2	136.0
Dakahliya	335.5	229.9	312.7	126.1
Damietta	1771.1	114.8	1574.2	69.0
Kafr Al Sheikh	8.3	632.3	8.3	437.7
Port Said	557.6	1.8	453.7	1.8
Grand Total	2886.5	1136.4	2512.8	771.4

difference between the current average feddan profit level of 17,844 EGP and the future potential feddan profit level of 12,114 EGP.

It was noticed that, higher levels of groundwater table due to expected SLR will have some positive aspects,

Table 6. Future and current annual total APV and Profits for the water table vulnerable cultivated land in the study area.

Governorates	Current Conditions Accumulated Profits Up to 2100 in Billion EGP	Future Conditions Accumulated Profits Up to 2100 in Billion EGP	Net Loss/Gain Due to Water Table Level Increase Up to 2100 in Billion EGP	Annual Current Profitability/Feddan	Annual Future Profitability/Feddan	Avrage Annual Loss/Feddan
Alexandria	0.1	0.1	0.0	15,829	17,677	1848
Behairah	14.1	12.2	(1.7)	21,641	18,764	(2877)
Dakahliya	20.7	11.3	(9.3)	19,322	10,597	(8725)
Damietta	10.3	6.2	(3.8)	29,320	17,628	(11,691)
Kafr Al Sheikh	56.9	39.4	(17.4)	15,725	10,887	(4839)
Port Said	0.2	0.2	0.0	4981	4981	0
Grand Total	102.3	69.4	(32.3)	17,844	12,114	(5730)

for example affected areas in Alexandria will enhance its profitability by approximately 12% with increasing water table levels under the A1FI scenario. This can be attributed to the fact that increasing water table levels will enhance the availability of water in Borg Al Arab district.

Table 7 provides some alternate views on the lost profit due to increasing water table levels. Among the crops affected by increasing water table levels it can be noticed that water Melon and potatoes are considered to be extremely high vulnerable to increasing water table levels where the percentage loss of profits amounts up to 310.9% and 173.6% respectively. While, corn and wheat are considered to be highly vulnerable, the loss in profit amounts up to 86.8% and 57.8% respectively. As a separate note, wheat and corn vulnerability in reality will be much magnified due to the dependency of food security in Egypt on them. This point needs further analysis but it is out of scope in this study. The third category would be the medium vulnerability crops, which are cucumber and beet with 41.8% and 34.1% loss of profits. Last category is low vulnerability consisting of crops with loss in profits below 15% such as berseem, potatoes and other crops. From **Table 7**, it can be noted that Nili is the most vulnerable season between all the cultivating seasons in Egypt with 96% loss in its profits in comparison to 23% and 21.2% profit losses in summer and winter seasons respectively. It should be noted at this point that the model assumed the status quo of current crop patterns *i.e.* crop patterns will remain the same up to 2100.

To estimate the total economic cost up to 2100, on agricultural sector (stage 3), due to increasing SLR under the A1FI scenario, it was necessary to combine the two economic costs estimated earlier. The first one is the value of inundated cultivated land in **Table 2** and the other one is the loss in agricultural profitability due to increasing water table levels in table 6 to create the total estimate represented in **Table 8** and represented graphically in **Figure 7**.

The results of this study indicate that the direct land losses, due to inundation, and associated forgone profits as a result of increasing water table levels were estimated to be approximately 84 billion EGP accumulated up to year 2100 with 935,757 feddan affected either totally lost due to inundation, or partially affected through the decrease in its productivity as direct impact of increasing water table levels.

Table 8 showed that the total estimated economic loss due to increasing SLR and increasing water table levels is 84 billion EGP under the A1FI scenario. Where 51.7 *i.e.* 61.5% of the total loss resulting from land loss to inundation and 38.5% of total loss due to increasing water table levels. According to **Table 8**, Behairah and Kafr Al sheikh, share of total economic loss is 70%. This is due to the fact that Behairah is highly vulnerable in terms of inundation due to its status as low-lying land. While Kafr Al sheikh is highly affected in terms of agricultural product loss due to increasing water table levels. As for Alexandria, It is due to the fact that it is considered a low-lying land, most of its agricultural land will be lost due to inundation and a minimum impact of decreasing water table levels are shown. Moreover the three remaining governorates Dakahliya, Damietta and Portsaid will not be affected in terms of sea inundation and with a moderate economic water table impact on its total agricultural product.

5. Conclusions

Climate change may alter the frequency and intensity of SLR events which will likely challenge human and

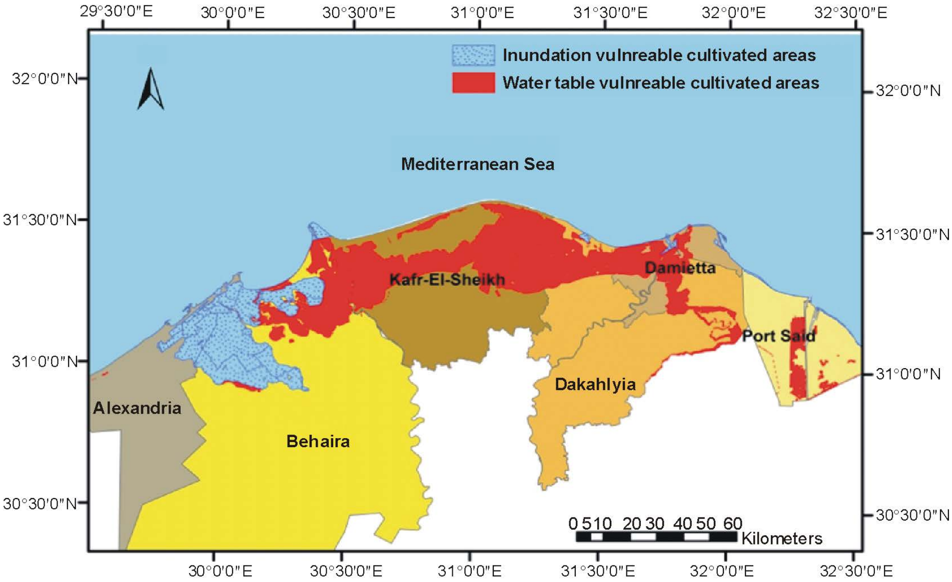

Figure 7. Cultivated areas vulnerable to increasing water table levels and areas that were estimated to be vulnerable to inundation under the A1FI scenario.

Table 7. Accumulated loss due to increasing water table levels in the study area up to the year 2100 by season and crop.

Crop	Current Conditions Accumulated Profits Up to 2100 in Billion EGP	Future Conditions Accumulated Profits Up to 2100 in Billion EGP	Net Loss/Gain Due to Water Table Level Increase Up to 2100 in Billion EGP	Percentage Loss in Profits
Water Melon	0.6	(1.2)	(1.7)	−310.9%
Potatoes	1.5	(1.1)	(2.5)	−173.6%
Corn	13.9	1.8	(12.0)	−86.8%
Wheat	1.8	0.8	(1.1)	−57.8%
Cucumber	4.5	2.6	(1.9)	−41.8%
Beet	12.3	8.1	(4.2)	−34.1%
Berseem	36.5	30.9	(5.4)	−14.7%
Tomatoes	9.8	8.6	(1.2)	−11.9%
Other	21.5	19.0	(2.3)	−10.8%
Total	102.3	69.4	(32.3)	−31.6%
Season				
Nili	13.5	0.5	(13.0)	−96.0%
Summer	30.5	23.3	(7.0)	−23.0%
Winter	58.2	45.7	(12.3)	−21.1%
Total	102.3	69.4	(32.3)	−31.6%

natural systems. Agriculture is considered as one of the most vulnerable sectors to SLR in Egypt. Quantifying the economic impact of SLR on agriculture can help reduce the environmental damages and maintain the profitability of agricultural systems.

The results that are obtained from the analysis show the magnitude and direction of SLR impact on crop agriculture. Most of the results of this study show that increasing SLR and decreasing water table depth are damaging the agricultural crop yield. The assessment conducted in this study showed that the flooded land area

Table 8. Accumulated loss due to increasing water table levels and inundation of cultivated land in the study area up to the year 2100.

	In Feddan			In Billion EGP		
Governorates	Area of Inundated Cultivated Land under 50 cm SLR Scenario	Area Affected by Water Table Level Increase Up to 2100 under 50 cm SLR Scenario	Total Area Lost/Affected under 50 cm SLR Scenario	Value of Inundated Cultivated Area 50 cm SLR Scenario	Net Loss/Gain Due to Water Table Level Increase Up to 2100	Total Economic Loss under the 50 cm SLR Scenario
Alexandria	55,674	249	55,923	(11.6)	0.0	(11.6)
Behairah	193,275	128,495	321,771	(39.8)	(1.7)	(41.5)
Dakahliya	408	129,938	130,347	(0.1)	(9.3)	(9.4)
Damietta	1021	79,451	80,472	(0.2)	(3.8)	(4.0)
Kafr Al Sheikh	438	313,516	313,954	(0.1)	(17.4)	(17.5)
Port Said	-	33,291	33,291	0.0	0.0	0.0
Grand Total	250,816	684,941	935,757	(51.7)	(32.3)	(84.0)

under the three different scenarios ranged from 5.6% to 34.6% of the total study area under consideration with a significant variation among the different scenarios. It's worth mentioning that agricultural land lost due to inundation ranged between 7.5% and 44% of the total agricultural area. Moreover, as a consequence of increasing water table levels, agricultural profits will decrease by 32.5%.

Although farmers and policy makers have some adaptation options to SLR, if they continue with their given technology, SLR will have a devastating effect on the Nile delta especially the low-lying land. In addition to that, the results of this study also confirm the importance of water table level for crop revenue/profits and the need to take actions to reinforce existing adaptation options and develop new ones.

Assuming no variation in the water table depth in the model, two potential problems arise: misspecification in the empirical estimation of the model, and bias in measuring SLR impacts. Empirical results show that the economic impact of SLR on the northern governorates of the Nile delta when including changes in water table depth can result in significantly larger losses as compared to simulations without these changes in water table.

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