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Climate Havens of Egypt: Facing Extreme Weather Events

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1 ABSTRACT

Climate change is expected to impact the habitability of many places around the world which will displace millions of individuals. According to the IPCC Fourth Assessment Report, the Nile Delta is one of the world's most vulnerable areas when it comes to sea-level rise, extreme weather conditions, and other factors worsened by climate change, which will lead to a significant population shift. Despite the evidence of this population shift in Egypt there is no obvious framework or strategies for dealing with such migration trends. Little research has been done to assess the number of people that may actually be displaced and where they will choose to go.

So, in this paper the effect of Sea Level Rise (SLR) on migration as an extreme weather event will be examined among governorates of Egypt especially the Nile Delta zone, predicting migration pathways between them. Secondly, the paper analyses and aggregate destination governorates of the Nile Delta zone to spot climate havens. Finally, a map will be concluded for vulnerable areas to SLR and probable destination areas in Nile Delta of Egypt which can help -in addition to the other climate factor- to navigate the challenges of planning for future climate-migration to plan for more sustainable, inclusive, and equitable cities for all.

Keywords: Sea Level Rise, climate migration, climate change, Egypt, Climate havens

2 INTRODUCTION

2.1 Climate vulnerability of Egypt

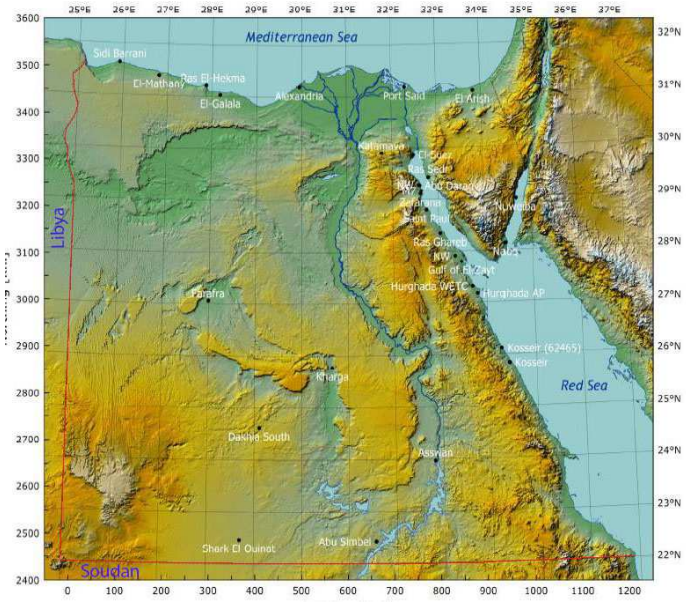

Figure 1: Egypt, its border with Libya from west and Soudan from south is highlighted (EGYPT THIRD NATIONAL COMMUNICATION: Under the United Nations Framework Convention on Climate Change, March 2016)

Egypt is located in northern Africa surrounded by Libya from the west, Gaza from the east and Soudan from the south, with a coastal strip extending for about 3,500 kilometers, overlooking the Mediterranean Sea in the north, and the Red Sea in the east. The River Nile extends from the south to the north forming the low laying Delta of the river with large cities and agriculture. The delta and its narrow valley are about 5.5% of Egypt's area and accommodates more than 95% of its population and agriculture (EGYPT THIRD NATIONAL COMMUNICATION: Under the United Nations Framework Convention on Climate Change, March 2016). As mentioned by the climate change knowledge portal, Egypt's climate is dry, hot, and dominated by desert.

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It has a mild winter season with rain falling along coastal areas, and a hot and dry summer season. Egypt is a highly arid country and receives very little annual precipitation (Climate change knowledge portal , 2021).

According to the ND-GAIN matrix which illustrates the comparative resilience of countries (Dame, n.d.), Egypt is in the upper left quadrant which indicates a high vulnerability to climate change with a low level of readiness to face it. That make Egypt in need of an adaptation plan for climate change, as well as investments and innovation to improve readiness Figure 2.

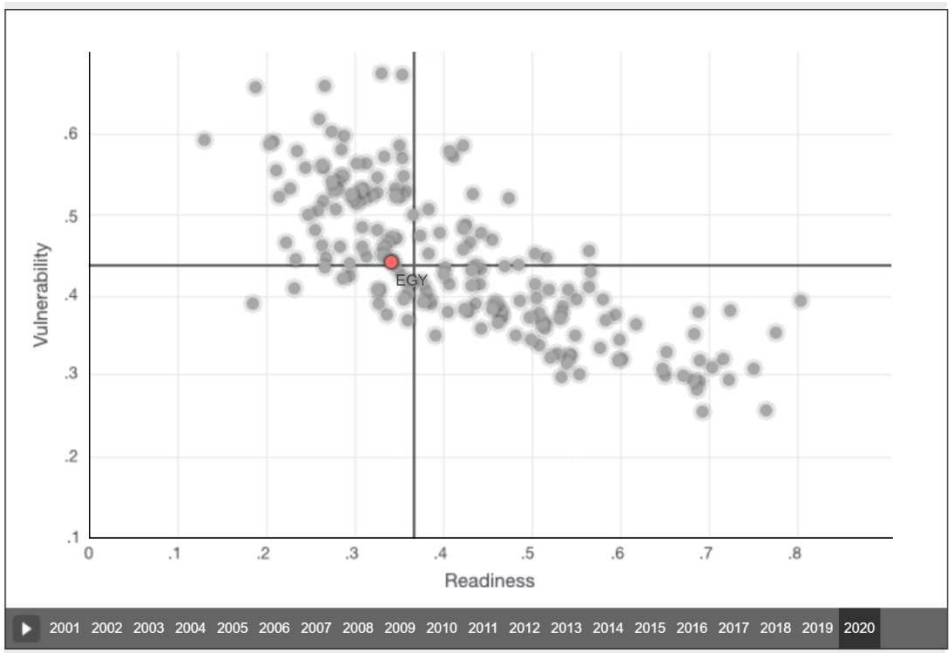

Figure 2: The ND-GAIN Matrix illustrates the comparative resilience of Egypt, in which the vertical axis shows the score of vulnerability to climate change and the horizontal axis shows the readiness score, source: Notre Dame global university (Dame, n.d.).

2.2 What is expected for Egypt?

A number of climate change studies considering Egypt (EGYPT THIRD NATIONAL COMMUNICATION: Under the United Nations Framework Convention on Climate Change, March 2016) (Perez, et al., 2021) (Mohamed Arouri, may 2017) stated that mean annual temperatures are increasing and expected to increase by 1.64°C and 2.33°C degree by the next 50 years (Figure 4). Precipitation, flooding and rainfall projections are uncertain, but they indicate slight reductions in precipitation for most months by mid-century (Figure 3). This increase in temperature and reduction of precipitation besides urban encroachment, pollution, depletion of soil fertility, water and soil salinity, sand dunes, soil erosion, and other indirect reasons leading to land degradation formed the desertification phenomenon in Egypt.

Moreover, there is uncertainty regarding the magnitude to which flood season discharge into the Nile River could be affected by climate change, but according to climate change knowledge portal south, Cairo may experience flash flooding due to sudden extreme rains. Variability in Nile flows is moderated by the High Aswan Dam. The dam has one year's worth of storage capacity, to help in handling periodic droughts, although Egypt remains vulnerable to multiyear droughts.

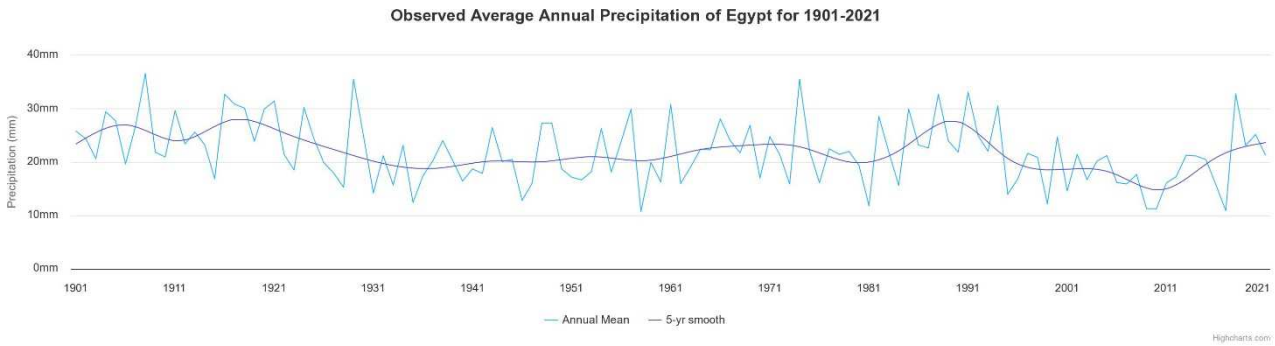

Figure 3: Average annual precipitation of Egypt for 1901-2021, source (Climate change knowledge portal , 2021)

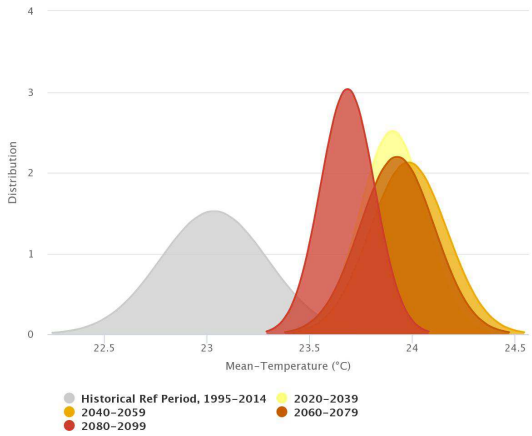

Figure 4: Projected change in distribution, mean-temperature, Egypt. Source (Climate change knowledge portal , 2021).

On the other hand, the sea level is continuously rising at a rate of 1.8 and 4.9 mm/year with an average of 3 mm/year, it is expected to rise between 3 and 61 cm this century, depending upon local heat and salinity levels of the Mediterranean (Figure 5). Risk areas in the Alexandria region are: Mandara and El Tarh (east of the city), and risk areas in the Nile Delta region are Al Manzala Lagoon barrier, east and west of the Rosetta City, Gamil, and the Tineh plain. Finally, Increased severity and frequency of sandstorms and haze have been documented (USAID, September 2015).

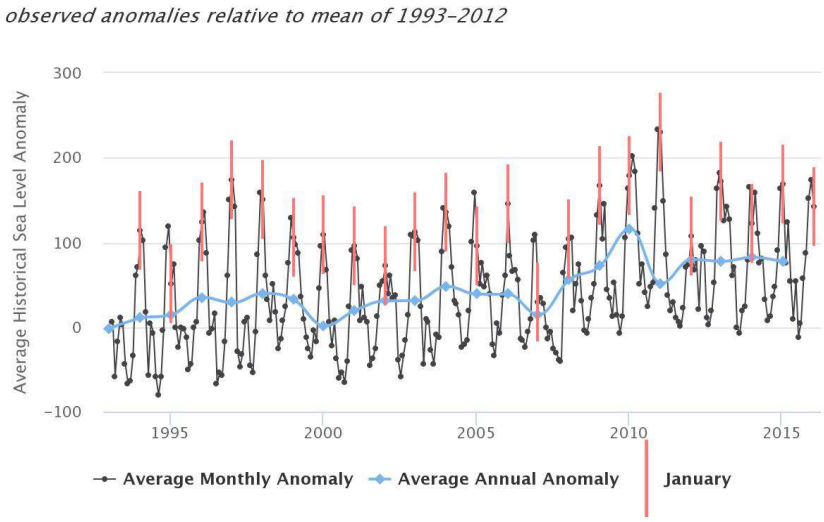

Figure 5: historical sea level for costal Egypt, source (Climate change knowledge portal , 2021).

2.3 Challenges

According to the climate change knowledge portal, the primary challenges are centred around water resource availability, changing precipitation patterns, and increasing population demands. Having high evaporation rate with the virtual absence of permanent surface water over large parts of the country results in water as a highly scarce resource. Moreover, the rising of the sea level which is not only threatening the physical coastline but also the costal ecosystem, can contaminate freshwater aquifers affecting agriculture and natural ecosystems, especially the densely populated Nile delta. Dr. Khaled Kazem in his report states that if the sea level rose by 0.5 m only, 67% of residents, 65.9% of the industrial sector, and 75.9% of the services sector would be submerged. Therefore, 1.5 million persons would better be displaced, which will result in social and economic repercussions in addition to security threats (Kazem, 2021).

The UNDP added that the most vulnerable areas in Egypt to climate change are: agriculture, coastal zones, aqua-culture and fisheries, water resources, human habitat and settlements, and human health. More than 95% of fresh water consumed in Egypt is generated outside its territory from the Nile River flowing through nine countries and its use is controlled by international agreement. Although the impact of climate change on the Nile basin is not clear yet, there are indications that we will witness a significant impact (EGYPT THIRD NATIONAL COMMUNICATION: Under the United Nations Framework Convention on Climate Change,

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March 2016), especially the sea level rise due to its low elevation like all world deltas (Marzouk & Abo-ElHassan, May 2014). Egypt depends mainly on the agriculture and the Nile is the main source of water which will be greatly affected by climate change, and accordingly people who work in the agricultural field. The Nile Delta is already receding by 3-5 mm per year. This will lead to internal migration. On the other hand, East Africa and South Desert are one of the threatened areas in Africa, and because of Egypt's location it will be a desirable land for international refugees (Mohamed Arouri, may 2017).

So, among all the challenges the sea level rise phenomena will have a direct impact on the vulnerable spots in Egypt; from agriculture to coastal zones, water resources, and specially human habitats. In addition to the lack of accurate data to other consequences of climate change on Egypt this research will focus on the SLR phenomena from the climate change consequences, not only because of direct inundation, but also because of the potential impact on saltwater intrusion, extreme events, loss of biodiversity, socioeconomic and health implications (El Raey, El-Askary, El-Hattab, & Kafatos, December 2009). In particular, this research will focus on the Nile Delta area from the coastal zone as it is the lowest in elevation and most vulnerable to inundation due to SLR (EGYPT THIRD NATIONAL COMMUNICATION: Under the United Nations Framework Convention on Climate Change, March 2016). Besides it is the main agricultural land of Egypt and hosts over one-third of the population and nearly half of all crops, also hosts most of the industrial activities and commercial centers, and is highly vulnerable to various impacts of climate change (El Raey, El-Askary, El-Hattab, & Kafatos, December 2009).

3 DATA SETS AND DESCRIPTIVE ANALYSIS

To achieve the research goals, three main data sets are used to fulfil a three parts methodology to create the final results:

First, mapping and examining the sea level rise scenarios of the Nile delta Coastline, using SLR scenarios from different sources: The Intergovernmental panel on climate change IPCC, the scenario of the costal research institute CORI, the World Bank reports, and different researches and publications.

Second, examining the push and pull effects of the sea level rise phenomena on migration internally in the Nile Delta region to determine the movement of migrants. Data sets for migration variables is the Population and Housing Census of Egypt held by the Central Agency for Mobilization and Statistics (CAPMAS) in 1996 and 2006.

Finally, generating the finale results of the vulnerable and proposed destination zones.

4 CASE STUDY

4.1 Study area

The study area includes the Nile Delta region in Egypt and its coastline extending from Alexandria in the west to Port Said in the east with a total length of about 240 km. It extends from the seacoast in the north to the borders of Greater Cairo in the south, it is bordered on the east by the Suez Canal region and the eastern desert extends westward to Alexandria and the Western Sahara.

The coastline has two promontories, Rosetta and Damietta. There are three lakes connected to the sea: Idku, Al-Burullus, and Al- Manzalla. In addition, there are five harbors located on the coast: Idku fishing harbor, New Burullus fishing harbor, Damietta commercial harbor, El Gamil fishing harbor, and Port Said commercial harbor.

It is the most fertile land of the country and hosts most of the agricultural productivity with high density of population. Agricultural land use accounting for 75% of the total area of the region, followed by the urban uses by 17.9%, then the fallow land by 6.3% of the total area of the region. It is highly vulnerable to potential impacts of climate change due to its relatively low elevation (El Raey, El-Askary, El-Hattab, & Kafatos, December 2009) (Marzouk & Abo-ElHassan, May 2014) (Figure 6).

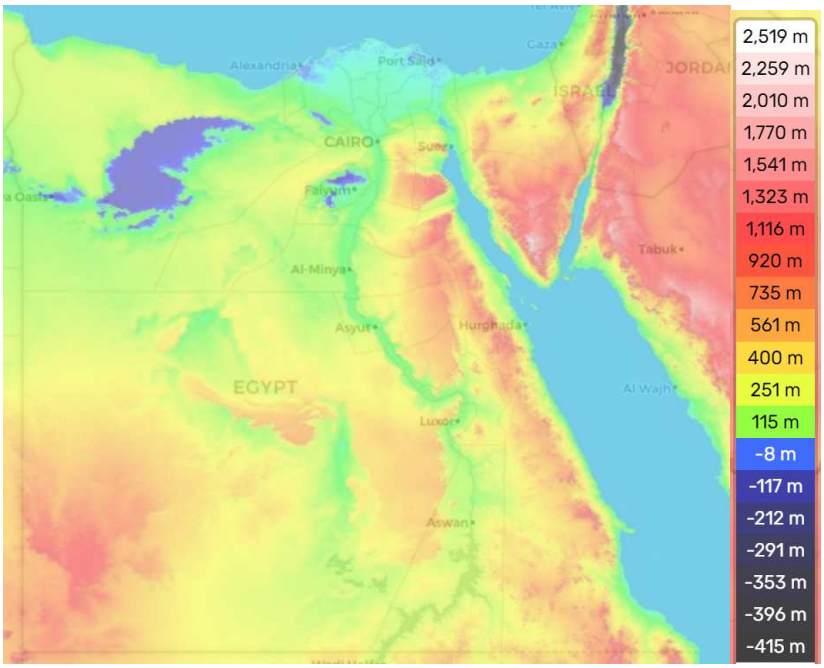

Figure 6: Egypt's elevations map, The Nile Delta with low elevation is highlighted, source: topographic maps (map, n.d.).

4.2 Vulnerability Assessment

By analysing the different expected scenarios of sea level rise, they can be summarised in two common scenarios: first, the scenario of the Intergovernmental panel on climate change IPCC which assumes that sea level will rise by only 0.5m in coming by 2050 (Figure 7). Second, the scenario of the costal research institute CORI which depended on areal surveying maps to develop the digital elevation model (DEM) for the Nile Delta coastal zones if sea level rises by one meter (Figure 8).

Figure 7:Inundation according to the Intergovernmental Panel on climate change IPCC (SLR 0.5m) (Dawod & Mohamed, October 2015) (Marzouk & Abo-ElHassan, May 2014), source: author.

Figure 8: Inundation according to the Intergovernmental Panel on climate change IPCC (SLR 1m) (Dawod & Mohamed, October 2015) (Marzouk & Abo-ElHassan, May 2014), source: author.

SLR	Affected population	Affected cropland km2
0.5m	3800000	1800
1m	6100000	4500

Table 1: estimated population and cropland affected by SLR (Marzouk & Abo-ElHassan, May 2014).

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From examining the different Sea level Rise scenarios, the total number of affected population and cropland is estimated in Table 1 (Marzouk & Abo-ElHassan, May 2014) (EGYPT THIRD NATIONAL COMMUNICATION: Under the United Nations Framework Convention on Climate Change, March 2016).

The Nile Delta consists of 11 governorates: Qalyobia, Gharbia, Monofiya, Sharkia, Port Said, Ismailia, Dakahliea, Damietta, Kafr El-Sheikh, El-Bohaira and Alexandria (Figure 9). According to FAO organization Nile Delta governorates comprise about 60% of the land cultivated with cereals, and 50% of sugar crops and many other products, besides its high population. According to the Central Agency for Public Mobilization and Statistics, Egypt's population the Nile delta region is nearly half Egypt's population (Table 2). In addition, as shown in Figure 6, the lower region of Egypt which make it highly vulnerable to inundation due to sea level rise and its other consequences.

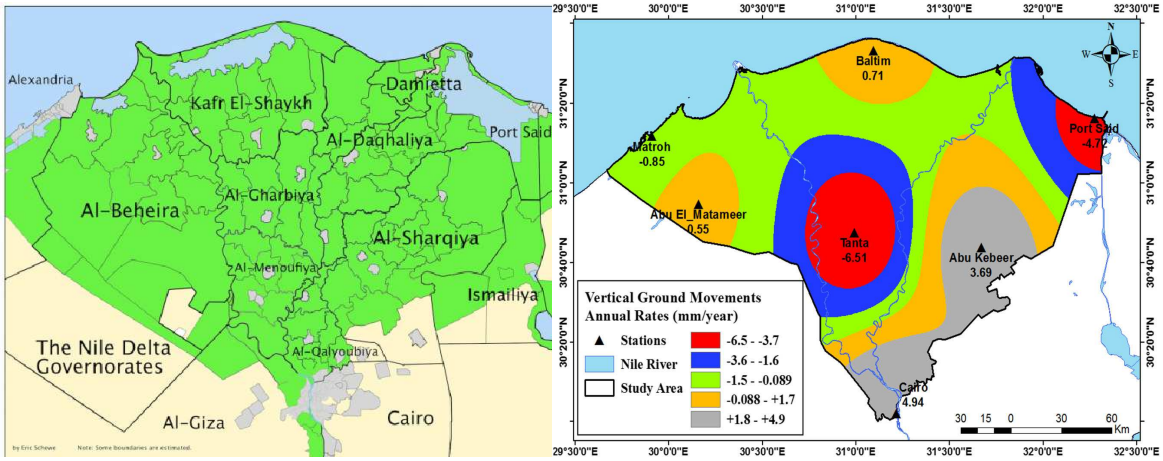

Figure 9: Nile Delta governorates (Al-Agha, Closas, & Molle, 2015). Figure 10: Vertical Ground Movements Annual Rates in mm/year (El-Quilish, El-Ashquer, Dawod, El feki , 2022).

Governorates	%	Total population	
Total Egypt	100	102 878 749	
Cairo	9.8	10 100 166	
Giza	9.1	9 323 196	
Nile Delta governorates			
Total	48.9	50318343	
Sharkia	7.5	7 744 815	
Dakahliea	6.7	6 930 797	Costal governorates
El-Bohaira	6.5	6 723 269	
Qalyobia	5.9	6 024 438	
Alexandria	5.3	5 469 480	
Gharbia	5.2	5 343 756	
Monofiya	4.5	4 640 003	
Kafr El-Sheikh	3.5	3 645 111	
Ismailia	1.5	1 419 631	
Damietta	1.5	1 593 610	
Port Said	0.8	783 433	

Table 2: estimated population and their percentage, source: CAPMAS Egypt.

Taking into consideration land subsidence (Figure 10) according to (Dawod & Mohamed, October 2015) (El-Quilish, El-Ashquer, Dawod, & El feki , 2022) the subsidence is maximum in Port Said and Tanta followed by Damietta and Matrouh. By comparing the map of land subsidence and the SLR map it is concluded that the coastal zone will be affected by the Sea Level Rise in different time stages. By applying the worst scenario (SLR by 1m) and land subsidence it is found that about 19 urban agglomerations will be affected with approximate six million residents (Marzouk & Abo-ElHassan, May 2014).

4.3 Migration in Egypt

There are a lot of studies related to migration in Egypt but few are examining how it is linked to climate change. One of them is a working paper which found that temperature and precipitation does not affect migration among governorates but the weather of the destination areas (Mohamed Arouri, may 2017). But according to the expected climate changes in Egypt there will be a significant impact that may cause

migration between Egypt's governorates, especially coastal and delta governorates which is the study area of this research.

Illustrating internal migration rates in Egypt, the 2017 census found that the Red Sea and the Sinai governorates have the highest in-migration rates because of the touristic project, thus job opportunities. The Giza and Qaliobia governorates follow for being near to the Cairo governorates, while Suez has the highest out-migration followed by Port Said and Cairo (sector, September 2019). According to Table 4 the cause of migration is mainly work, followed by study and marriage. However, by time when Egypt's governorates witness a significant climate change consequence specially sea level raise those statistics should be affected and the motivations of the migrants and their choices for their future location will be affected.

Governorate	In-migration rate	Out-migration rate	Net migration rate
Cairo	1.8	4.5	-2.7
Alexandria	1.2	1.5	-0.3
Port Said	1.1	5.8	-4.7
Suez	1.2	7.8	-6.6
Damietta	0.5	3.3	-2.8
Daqahlia	0.4	0.4	0.0
Sharqia	0.6	0.8	-0.2
Qalioubia	3.5	0.4	3.1
Kafr Sheikh	0.4	0.8	-0.4
Gharbia	0.4	0.4	0.0
Menoufia	0.5	0.6	-0.1
Behaira	0.4	0.5	-0.1
Ismailia	1.9	0.7	+1.2
Giza	4.0	0.3	+3.7
Bany Swaif	0.3	0.7	-0.4
Fayoum	0.3	0.8	-0.5
Menya	0.2	0.6	-0.4
Asiout	0.3	0.7	-0.4
Sohag	0.3	0.7	-0.4
Qena	0.2	0.7	-0.5
Aswan	0.5	0.6	-0.1
Luxor	0.3	0.4	-0.1
Red Sea	8.2	0.6	+7.6
New Valley	3.2	0.4	+2.8
Matrouh	1.7	0.5	1.2+
North Sinai	1.9	1.5	0.4+
South Sinai	6.0	1.3	4.7+
Total	1.2	1.2	-

Table 3: internal migration in Egypt, source: CAPMAS Egypt

Causes of Migration	Urban			Rural			Total		
	Male	Female	Total	Male	Female	Total	Male	Female	Total
Work	44.0	13.3	28.2	36.0	10.6	21.3	42.3	12.6	26.6
Study	8.3	5.4	6.9	7.4	4.6	5.8	8.3	5.3	6.6
Marriage	16.6	45.3	31.3	15.9	52.1	36.8	16.4	47.0	32.7
Divorce/Widowhood	0.5	1.7	1.1	0.5	1.8	1.3	0.5	1.7	1.1
Accompanying Others	24.0	29.3	26.7	27.1	22.8	24.6	24.6	27.6	26.2
Other	6.6	5.0	5.8	13.1	8.1	10.2	7.9	5.8	6.8
Total	100	100	100	100	100	100	100	100	100
Number (in thousands)	413	439	851	109	150	260	522	589	1111

Source: Population Census in 2017.

Table 4: Causes of Migration, source: CAPMAS Egypt

4.4 Migration due to Sea Level Rise

By illustrating the worst scenario of sea level rise in the Nile delta and the land subsidence of the study area, it is predicted that costal zones of Port Said, Damietta, Kafr El-Sheykh, and Alexandria will witness an obvious out-migration movement due to the sea level raise. Among these, Alexandria and Kafr el-Sheykh have a higher population density, while Damietta and Port Said have a lower density. On the other hand, Al Daqahliya, Al Gharbiya, Al Menoufiya, Al Sharqya, and Al Qalyoubiya are expected to witness in-migration due to the sea level rise to be a destination governorate.

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In a previous study Mohamed Arouri (2017) examined the effect of extreme weather events on migration among governorates of Egypt. He used the gravity model in order to draw the flow of migration between governorates of Egypt. The Gravity model is inspired by Newton's law of universal gravity. It states that any two objects attract each other with a force that is proportional to their masses and inversely proportional to the squared distance between them. In other words, the migration flow between two distinct geographic locations is positively associated with their population size, geographic area, or GDP, and negatively associated with the distance between them. On the other hand, Davis, Bhattachan, PaoloD'Odorico, & Suweis (2018) used a radiation model to simulate migrations among districts of Bangladesh that were affected differently by SLR. Both agreed that - regardless of the climate factor- firstly, the distance between governorates negatively affects the migration flows. If the distance between two governorates increases by 1 percent, the probability of migration happening between them decreases by 0.2 percent. Secondly, people move from governorates with low population to those with high population. Finally, highly educated people tend to have better information and employment opportunities and they are more likely to migrate than low educated people.

According to Figure 9 Al Menoufiya, and Al Qalyoubiya are the remotest in distance from the costal governorates while Al Gharbiya, Al Sharqya, and Al Daqhaliya are less in distance; and according to Table 2, Al Sharqya and Al Daqhaliya are the most populated, followed by Al Qalyoubiya, Al Gharbiya, then Al Menoufiya. Applying the findings of the models described above, the five expected destination governorates Al Sharqya, and Al Daqhaliya may witness the biggest share of migrants.

5 RESULTS AND DISCUSSION

In order to determine which of the previous governorates are the most liable for the expected migration due to the predicted consequences of sea level rise in the Nile Delta of Egypt, we need first to define the climate havens. According to (Marandi & Main, 2021) climate havens are countries or governorates or any regions which are ready to welcome climate migrants, they are characterized by: climate resilience, not prone to sea level rise or wildfires and prolonged heat waves, with ready access to fresh water supply, high vacancy rates or abundance of affordable housing, high infrastructural capacity designed to support more residents than currently live there, an expressed desire to grow, history of or interest in improving adaptive capacity through sustainability or resilience efforts. There are several sources that provide information on climate havens. One such source is a website named Lucid Home which provides a list of cities that are considered climate havens in the United States (Lucidhome, n.d.). Another website is Climate Refugees which provides a map of potential climate havens in North America and some parts of Africa (Refugia Research Coalition, n.d.). Unfortunately, there are no similar applications or websites that can detect or help find climate havens in Egypt.

By illustrating the use of buildings in the previous possible destination governorates (Table 5), it is found that Al Sharqia has the highest number of buildings, including unoccupied buildings and under construction buildings, followed by Al Dakahlia and Al Qalyubia, with Al Gharbia and Al Minoufia having fewer buildings .

Governorate	No. of buildings	Housing	Work	Housing & work	Unoccupied	Closed	Under construction
Al Sharqia	1304132	862288	76333	66420	192140	30312	44605
Al Dakahlia	1094653	763740	53502	84142	98466	11931	38455
Al Qalyubia	843226	507149	44198	87465	133690	10404	37267
Al Gharbia	806850	572927	41736	61291	71103	10680	29466
Al Minoufia	746272	507091	30432	48483	107964	15053	25119

Table 5: Current use of regular buildings, source: CAPMAS Egypt.

The water supplies in those governorates were also analyzed (Figure 11) and it was found that Al Minoufia and Al Gharbia have the highest number of water stations for pure water. followed by Al Sharqia and Al Dakahlia, and then Al Qalyubia.

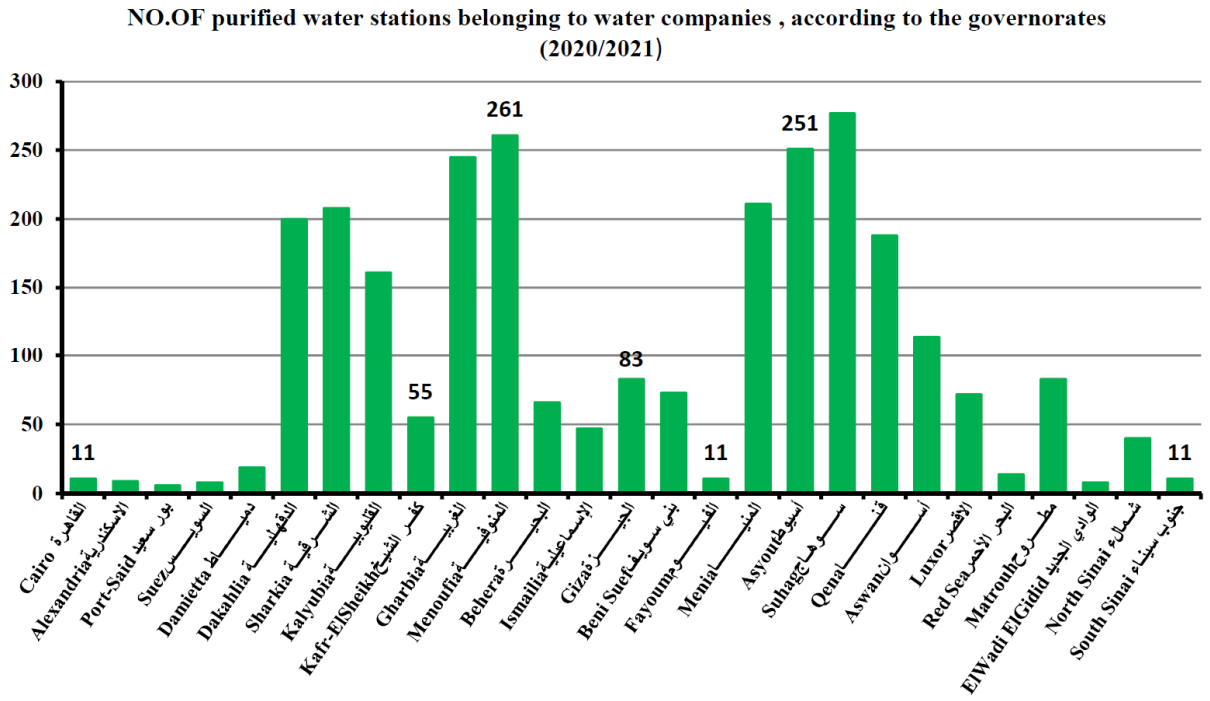

Figure 11: purified water stations, source: CAPMAS Egypt.

Based on the land subsidence data of Nile Delta governorates shown in Figure 10 and the definition of climate havens, the research concluded that the east of the Nile delta, especially Al Sharqia is considered a climate havens and is the most reliable governorate which is ready to host migrants due to its demographic and geographic characteristics.

On the other hand, this conclusion differs from the findings of the previous study (Marzouk & Abo-ElHassan, May 2014) which proposed that the direction of the expansions and mitigation in the Nile Delta have to be towards the west as shown in Figure 12. However, this research proposes that the expansion and mitigation is better directed towards the east of the Nile Delta, as shown in Figure 13.

In order to have the most accurate conclusion more factors must be taken in the consideration. Factors considering more consequences of climate change besides the sea level raise, in addition to taking in the consideration more factors that lead migrants other than the climate change.

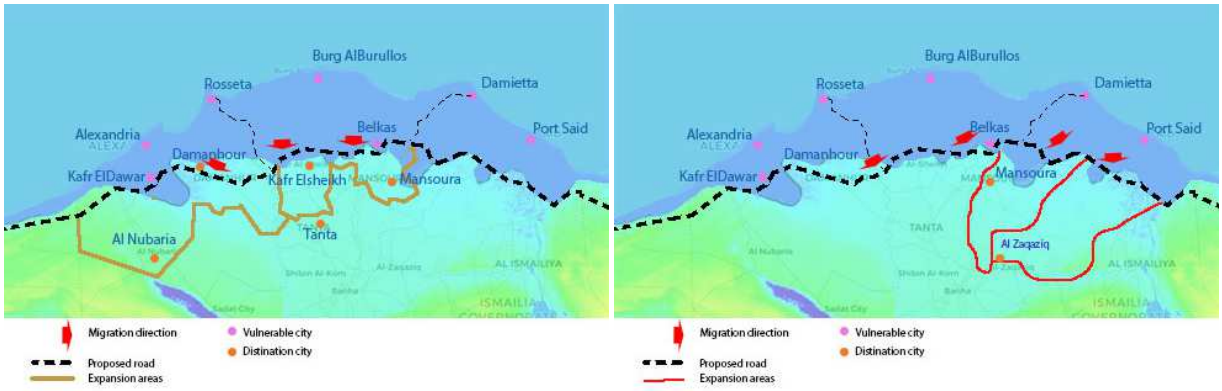

Figure 12: migration direction and mitigation areas, inspired by (Marzouk & Abo-ElHassan, May 2014). Figure 13: proposed migration direction and mitigation areas, source: author

6 CONCLUSION

This research focuses on assessing the vulnerability of the Nile Delta coast to sea level rise SLR caused by climate change, and the subsequent migration flow. Understanding these factors is crucial for adapting to the effects of a changing climate, especially sea level rise. Yet many aspects of human migration in response to climate change remain poorly understood. The Nile Delta region of Egypt with its highly populated governorates and vulnerability to the potential impacts of SLR and inundation was examined.

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The research projects that by 2050, under various scenarios of sea level rise and its impacts, as many as six million people in the coastal area of the Nile Delta may be forced to migrate due to direct inundation. To assess the relocation of these migrants and where the best destinations are, models from existing literature have been applied to determine migration flow, and the destination of the migrants have been predicted accordingly. In addition to evaluating those destinations it is found that the most reliable destination is the east of the Nile Delta, especially the Al Sharqia governorate. The study also highlights the need for further research in understanding the complexities of human migration in response to climate change.

7 RECOMMENDATION

Further studies on the coastal zones of the Nile Delta and other Deltas worldwide should cover aspects such as groundwater salinity, infrastructure, and the natural resources of the coastal zone, in addition to the emphasis on coastal flooding due to expected sea-level rise. It is also recommended that vulnerable areas prone to inundation in the coastal zone of the Nile Delta should have additional protective construction to prevent inundation and subsequent migration.

To be fully aware of the migration flow due to climate change more data about climate change consequences other than the sea level rise must be studied and to be available for researchers so that climate havens can be spotted properly.

To prepare for the expected migration trend due to climate change, the government must develop policies and regulations that prioritise safety and equity. In addition, further research could come up with applications or sources that would help migrants to find the perfect spot.

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