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Global Warming impact on Egyptian Economy Versus Mexican Economy

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Abstract

The purpose of this study is to identify the economic challenges that Egyptian and Mexican governments go through under the climate change and how differently these two totally different governments responded to these economic challenges. The findings may be useful in strengthening the economic response strategy in developing countries.

Climate change is the mother of all externalities: larger, more complex, and more uncertain than any other environmental problem. The greenhouse gas emissions are more severe than any other environmental problem. Companies, farms, every households emit some greenhouse gases. The effects are on agriculture production, energy use, health, and many aspects of nature—which in turn affects human life. The impacts of climate change are of high magnitude, and those in low-income countries who contribute least to climate change are most vulnerable to its negative impacts. Climate change is a long-term problem. Some greenhouse gases have an atmospheric long life-time measured in tens of thousands of years. The quantities of emissions involved are huge. In 2000, carbon dioxide emissions alone (and excluding land use change) were 24 billion metric tons of carbon dioxide.

This study used a quadratic programming sector model to assess the integrated impacts of climate change on the agricultural economy of Egypt and Mexico. Results from a dynamic global food trade model were used to update the Egyptian and Mexican sector model and included socio-economic trends and world market prices of agricultural goods. The climate change scenarios generally had smallimpacts on aggregated economic welfare (sum of Consumer and Producer Surplus or CPS), withthe largest reduction of approximately 6 percent. In some climate change scenarios, CPS slightly improved or remained unchanged. These scenarios generally benefited consumers more than producers, as world market conditions reduced the revenue generating capacity of the Egyptian and Mexican agricultural exporters but decreased the costs of imports.

Keywords: Global Warming, Economy, Egypt, Mexico, Climate Change, Consumer and Producer Surplus or CPS

Introduction

Egypt has been facing climate variability and its influence on agricultural production for at least four thousand years since Joseph averted a disaster through a series of resource management decisions. Joseph was able to develop an optimal agricultural management plan because he had a 'perfect' hydroclimate forecast. Today, Egyptian planners rely on the scientific understanding and analysis ofphysical and socio-economic systems. The understanding of these complex systems allows for improved planning considering local and regional climatic variability, untimely and/or limited resource availability, and the degree of socio-economic uncertainty. The potential for anthropogenic climate change due to greenhouse gas emissions heightens the need for sound development plans.
Despite increased water availability and only moderate yield declines, several climate change scenarios showed producers being negatively affected by climate change, such as Mexican producers. The analysis supported the hypothesis that smaller food importing countries are at a greater risk to climate change, and impacts could have as much to do with changes in world markets as with changes inlocal and regional biophysical systems and shifts in the national agricultural economy.

Literature Review

Strategies to deal with the potential problems and impacts of climate change on the agricultural system of Egypt require qualitative and quantitative analysis. Egypt's historic vulnerability to climatic fluctuation changed greatly with the completion of the High Aswan dam. The reservoir can hold more than two times the average annual flow, which allows for the storage of surpluses in wet years to be saved for dry years. The entire Egyptian Agricultural system is based upon Egypt's treaty with the Sudan, which annually allocates 55.5 billion cubic meters from the Nile to Egypt. Increased greenhouse gases and potential global and regional climate change could affect River Nile flows and Egypt's underground water resource availability. The climate induced changes in water resource availability; crop yields, crop water use, land resources and global agricultural markets affecting the Egyptian agriculture sector are the main focus of this paper. A mathematical sector model of the Egyptian agriculture was used in conjunction with a previous study of the macro-economy, agronomy, water resources and land resources of Egypt to study the integrated impacts of climatechange on the agricultural economy of Egypt. This work is an extension of Strzepek et al. (2022) that included economy-wide effects of water resources, the results from a more detailed hydrologic model of the River Nile and additional socio-economic scenarios (Yates and Strzepek, 2022; Strzepek and Yates, 2022). Examples of other integrated studies of climate change impacts on agricultural systems include: the MINK study on Minnesota, Iowa, Nebraska, and Kansas (Bowes and Crosson, 2022; Crosson and Rosenburg, 2022); the St. Lawrence River Basin (Mortsch et al., 2022); Southeast Asia (Parry et al., 2022); U.S. agriculture (Adams et al., 2022, 2023) and world food trade (Fischer et al., 2023; Rosenzweig and Parry, 2022; Darwin et al., 2023).

Comparative Analysis

1.1. A SNAP SHOT OF THE EGYPTIAN AGRICULTURAL SECTOR

Egypt, with its very arid climate, has a unique agricultural system. Virtually all the agricultural land is irrigated with Nile River water which is stored in Lake Nasser behind the High Aswan Dam. Currently agriculture is practiced on 3 million hectares (5.892 million feddans) or only 3 percent of the area of Egypt. New, less fertile land on the fringe of the Deltaand in the Sinai are being reclaimed, while more productive land (old land) is being lost to urbanization (Humphries, 2023). Table I shows the aggregate distribution of agricultural land within Egypt. The agricultural year has three crop seasons. The winter season starts from October to December and ends between April and June. Its main crops are wheat, barley, berseem, lentils, winter onions and vegetables. The summer crops – cotton, rice, maize, sorghum, sesame, groundnuts, summer onions and vegetables – are sown from March to June and harvested from August to November. A third growing season known as ‘nili’ is a delayed summerseason where rice, sorghum, berseem and some vegetables are grown. A piece of land cannot be planted in both summer and nili crops in any one year because nili and summer cropping seasons overlap. There are significant perennial crops such as sugarcane in Upper and Middle Egypt and citrus, grapes, bananas, mangoes, olives and dates (Humphries, 2022). An elaborate crop rotationis practiced to prevent soil degradation and crop loss due to pests. In 1990, agriculture (including livestock) accounted for nearly 20 percent of Gross Domestic Product and employed 37 percent of the labor force. These figures do not include agro-industries such as textiles or food processing (Onyeji, 2022). Agricultural exports accounted for approximately 20 percent of export earnings. Egypt is currently importing over two-thirds of its wheat and vegetable oils and one-third of its corn, despite some of the most productive agricultural land in the world. Agricultural imports have increased three-fold since 1975, resulting in an annual agricultural import bill of over USD 3 billion. This is due to a combination of governmental policies, international commodity prices, foreign food aid and population growth (FAO, 2022; Hansen, 1991). Agricultural production has increased by 46 percent over the period 1978 to 1990, whilethe population has grown 28 percent resulting in a per capita increase in agricultural production of 14 percent over this period.

- A feddan is the Egyptian unit of land measurement. It is equal to 1.1 acres or 0.48hectares.

- -Berseem is an Egyptian clover used for fodder

1.2. EGYPT'S VULNERABILITY TO CLIMATE CHANGE

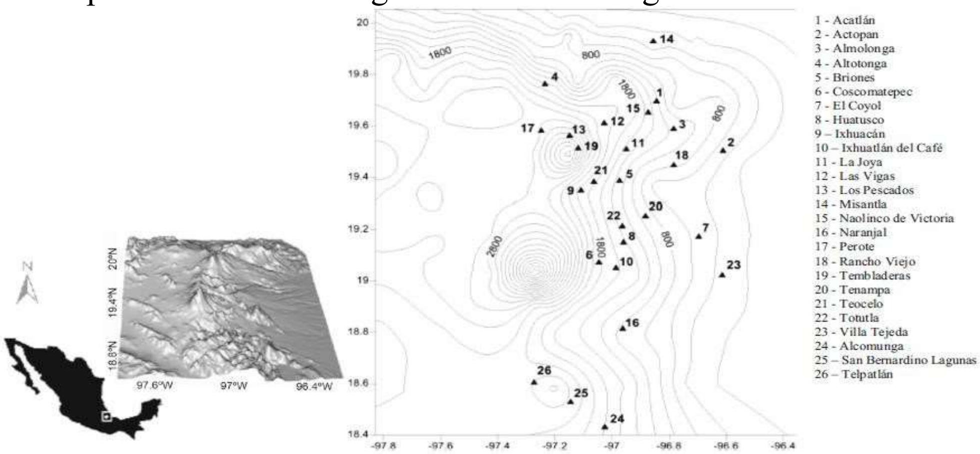
Egypt is very dependent on natural resources that are vulnerable to climate change. A large portion of the arable land is in the Nile Delta and is particularly vulnerable to sea-level rise.Agriculture needs water from the Nile for irrigation which is vulnerable to precipitation and temperature changes within the entire Nile basin. Crop yields and crop water use could be affected by climate change. Previous studies of climate change impacts on Egypt suggest that this country could be particularly sensitive to climate variability. Broadus et al. (1986) and ElRaey et al. (2023) both suggest land losses of 12 to 15 percent of

Egypt's current arable land for a one meter sea-level rise. A study of the Nile Basin by Gleick (2023) suggested that it is extremely sensitive to changes in temperature and precipitation. Aside from the low elevation of the Nile Delta, Egypt's vulnerability to sea-level rise is further heightened by the damming of theNile by the High Aswan Dam which has reduced the sediment flux to the delta and increased land subsidence and soil salinization heavely. Nicholls and Leatherman (2022) estimated that a mean, 1meter global sea-level rise by 2100 would give rise to a 0.37 meter sea-level rise at the Nile delta. This, combined with a non-climate induced subsidence of the Nile Delta of 0.38 meters would result in the movement of the shoreline to the current 0.75 meter contour and a 5 percent loss of Egyptian agricultural land by 2060. Agriculture below an elevation of one meter is very hard due to salinization and sea-water intrusion and requires careful water management (Rosenzweig and Hillel, 2023). Egypt must rely solely on the Nile, as there are limited water supply options which are economically feasible. Climate change could affect flow in the Nile and the availability of water for Egypt. Nile flows are likely to be influenced by upstream development in countries like Sudan and Ethiopia. Increased temperatures would increase evapotranspiration, which is likely to increase crop water requirements and lower crop yields (Eid and Saleh, 2023).

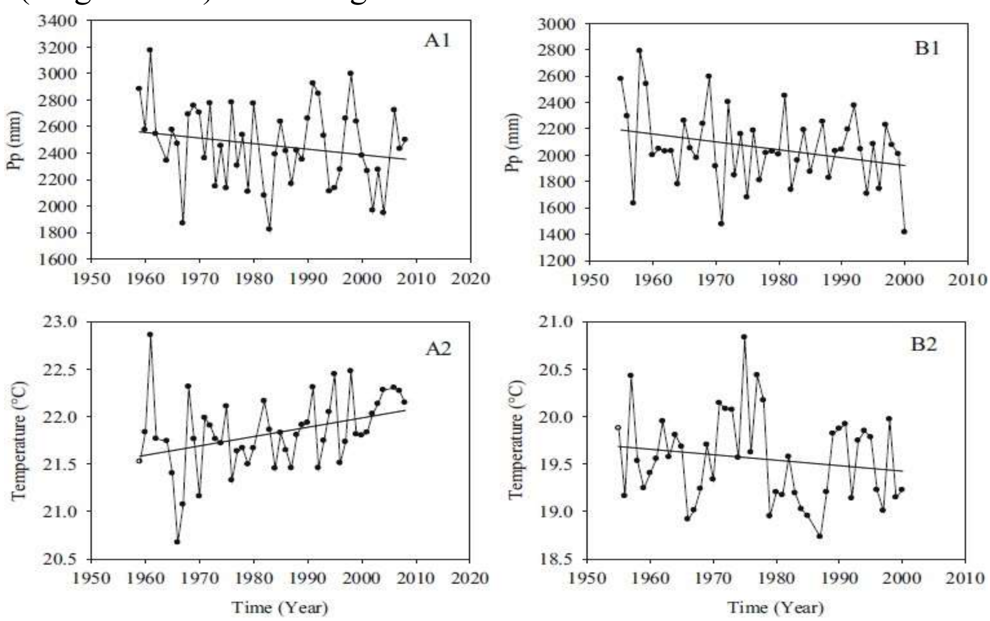
1.3.A SNAP SHOT OF THE MEXICAN AGRICULTURAL SECTOR

1.4. MIXICO'S VULNERABILITY TO CLIMATE CHANGE

We start from the premise that there is a strong relationship among social, agricultural, and climatic factors, as well as the availability of productive capital (Patz et al. 2023). That is, changes in precipitation and temperature patterns and changes in the agricultural production affect food supply, especially basic grains. It is important to link the social situation in the region, reflected in the HDI and the marginalization level, with the agricultural production in each municipality, and how the effects of climate change would affect their crops. Therefore, a municipality is considered more vulnerable when the HDI is lesser, its marginalization level is higher, it is more dependent on agricultural activities, and also its crops are more susceptible to local and regional climate changes.



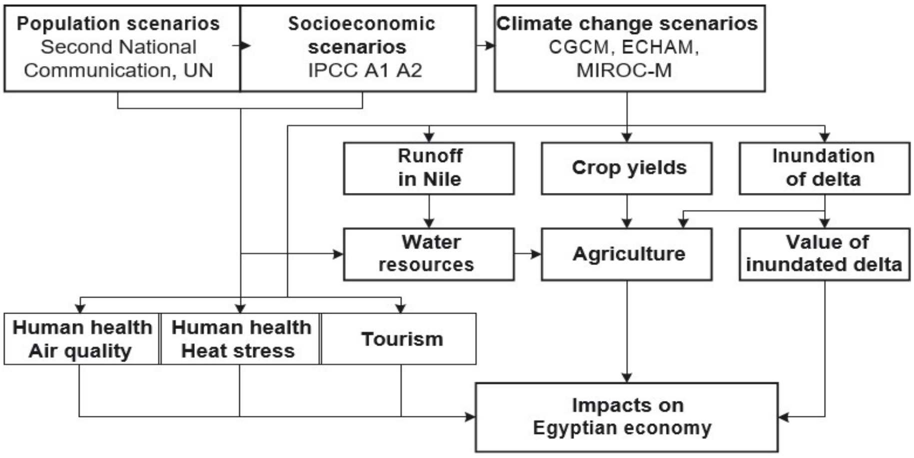
The figure shows the location of the 26 meteorological stations in the Region of the Great Mountains, Veracruz, and contour line distribution (range 200 m) for the region.



The figure shows the precipitation (A1, B1) and temperature (A2, B2) trends for the meteorological station of El Naranjal (A1, A2) and Huatusco (B1, B2) from the Region of the Great Mountains, Veracruz.

METHODOLOGY

The structure of the study is displayed in Fig. 1 and described below.



2.1. Socioeconomic scenarios

We developed 2 sets of socioeconomic scenarios to encompass a wide range of potential development paths: a low population and high-income growth scenario, which is referred to as 'low-pop,' and a high population and low-income growth scenario, which is referred to as 'high-pop.' Population scenarios were based on the SNC (EEAA 2023) projections for 2030, World Bank (2022) population projections for 2050, and extrapolation to 2060. The low-pop scenario assumes that population stabilizes by mid-century, whereas the high-pop scenario assumes no decrease in present fertility rates. Egypt's population through 2022 was 102 million and was increasing by 2.3% the first year (EEAA 2022). The high- and low-pop projections are displayed in Table 1:

	2009	2030	2060
Low-pop	80	104	113
high-pop	80	117	162

The low-pop scenario assumes that real per capita income increases by approximately 3.8% in the first year, consistent with the A1 emissions scenario from the Intergovernmental Panel on Climate Change (IPCC; Naki´cenovi´ c et al. 2023). The high-pop scenario uses the A2 IPCC assumption that real per capita income increases by 2.2% in the first year. This is based on the published IPCC projections for the African and Latin American regions for the A1 and A2 scenarios (Naki´cenovi´c et al. 2023). The total GDP and GDP per capita income

	2009	2030	2060
GDP in million EGP			
Low-pop	990 212	2 993 208	9 298 978
high-pop	990 212	2 287 141	5 907 201
GDP in million USD			
Low-pop	178 417	539 317	1 675 491
high-pop	178 417	412 097	1 064 361
GDP/capita in EGP			
Low-pop	12 378	28 781	82 292
high-pop	12 378	19 548	36 464
GDP/capita in USD			
Low-pop	2 250	5 233	14 962
high-pop	2 250	3 554	6 630

assumptions are shown in next Table:

2.2. Climate Change Resources

The scenarios are from Elshamy et al. (2022), who used the A1B emissions scenario (IPCC) to estimate Blue Nile flow. The selected 3GCMs from Els hamyet al. (2022) presented the highest, lowest, and intermediate flow levels across the model results. The average change estimated across the 17 models in Elshamy et al. (2022) is a small decrease in flow. The scenarios are (1) large decrease in flow: Canadian Centre for Climate Modeling and Analysis (Canada; CGCM63).

Small decrease in flow:

Max Planck Institute for Meteorology (Germany; ECHAM); studied the increase inflow with the National Institute for Environmental Studies Medium Resolution (Japan; MIROC-M). They used the 'SimCLIM' tool (CLIMsystems 2022) to develop estimates of changes in temperature and precipitation for Cairo and the High Aswan Dam (HAD) due to climate change (Table 3). The SLR scenarios were developed by the Coastal Research Institute (CoRI) of the Ministry of Water Resources and Industry (Elshinnawy 2023). Elshinnawy (2008) used current SLR trends and estimates of accelerated eustatic SLR from the IPCC (2007). Elshinnawy (2023) estimated relative SLR, which includes subsidence in the Nile Delta (Elshinnawy 2022; also Stanley 2020, Hassaan & Abdra bo 2022), for 3 sites on the Mediterranean in 2025, 2050, and 2075; we used the 2025 estimate for 2030 because the 2 periods are close in time. Then, used the 2075 estimate for 2060 because SLR may be much higher than estimated by the IPCC (2023) (e.g. Oppenheimer et al. 2022, National Research Council 2012). SLR scenarios are displayed in Table 4.

2.3. Water Resources

We used Elshamy et al. (2022) as the basis for esti- mates of change in Nile River flow.Because the Blue Nile contributes 60% of the Nile's flow at Dongola (near the inlet ofthe reservoir of the HAD), we assumed the percentage change in flow at the HAD could be the same as the percentage change in the Blue Nile River flow. The reasoning behind this approach is reinforced by Beyene et al. (2010, their Tables 10 & 11), who show that under a range of GCMs and Special Report on Emissions Scenarios (SRES), the percent changes in mean annual flow at the HAD are only slightly greater than the changes in the Blue Nile River level of discharge.

This study estimated change in flow in 2030 and 2060 by linearly interpolating between the Elshamy et al. (2022)

estimate of change in runoff from the 1961− 1990 period to the 2081 2100 period. Any reductions in Nile River flow were assumed to be allocated among nations in the Nile River Basin based on the portion of water they currently withdraw (Okidi 2023). The study did not account for changes in water withdrawals upstream from Egypt. It is assumed the 1959 treaty between Egypt and Sudan regarding river yield reductions remains in effect because of the current political deadlock regarding the development of a basin-wide agreement on water allocation. Since the majority of the groundwater is not recharged and the recharge is limited inany case, we assume that under climate change, with declining rainfall in most GCM scenarios and higher temperatures, the only available groundwater source is the Nubian fossil water with 1 billion m−3 (BCM) in the first year. It is also assumed that the use of localeffective rainfall when the water supply is no longer viable. The estimate for municipal and industrial (M&I) demand for water was based on a report by the Egyptian Ministry of Water Resources & Irrigation (Egypt) (MWRI 2022), and assumed that consumption would increase with population. It is also assumed that climate change increases M&I use of water by 2.5% above increases for population,regardless of the climate change scenario, based on a study done in a somewhat comparable climate in the San Antonio area of Texas, in the USA (Chen et al. 2023). It is assumed that the present instream need of 13.1 BCM in the first year remains the same. Demand should actually increase to maintain the water quality and ecological health of the Nile River under the higher temperatures and generally poorer water quality under climatechange, and the possible need to maintain higher flows in the Delta due to higher sealevels.

Table 3. Estimated change in temperature and precipitation for Cairo from 3 climate models

	2030			2060		
	CGCM63	ECHAM	MIROC-M	CGCM63	ECHAM	MIROC-M
Annual temperature (°C)	0.9	0.9	1.0	2.0	1.9	2.2
Temperature Nov–Apr (°C)	0.9	0.8	0.9	1.9	1.8	2.0
Temperature May–Oct (°C)	0.9	0.9	1.1	2.1	2.0	2.4
Annual precipitation change (%)	−4	0	−5	−10	0	−10
Precipitation change Nov–Apr (%)	−5	−12	−11	−10	−26	−25
Precipitation change May–Oct (%)	−4	18	6	−9	41	13

Coastal Resources

Table 4. Sea level rise (SLR; in cm) scenarios for Egypt used in this study relative to 2000

City	SLR scenario	2030	2060
Port Said	Low	13.25	39.75
	Middle	18.12	64.3
	High	27.9	109.6
Al-Burullus	Low	5.75	16.25
	Middle	8.75	32.25
	High	14.75	60.3
Alexandria	Low	4.0	12.0
	Middle	7.0	27.0
	High	13.0	55.0

Elshinnawy (2023) estimated the effects of different SLR scenarios on the east, central,and west Delta regions, assuming scenarios of both protection and no protection of vulnerable areas. The study overlaid Elshinnawy's (2023) estimates of SLR with property and agriculture data set sin a geographic information system to estimate the amount of agricultural land and housing thatcould be inundated by SLR. The potential loss of housing value was estimated by using data on population size, number of housing units, and current prices of housing units and agricultural land in 5 governorates on the Nile Delta: Damietta, Dakahlia, Kafr El-Sheikh, Behaira, and Alexandria. Field work was then done to collect data on the number of housing units and the land values, as well as to supplement government data. While the number of housing units was assumed not to change — a very conservative assumption given the scenarios used in this study of increased population and the potential for expanded housing in the vulnerable areas — the housing valueswere assumed to increase at the same rate as per capita income in the socioeconomic scenarios for Egypt.

2.4. Agriculture

The agriculture analysis in Egypt considered demand growth, water availability change, crop yields, live- stock yields, SLR land loss, pesticide costs, and technical progress (see McCarl et al. 2023). Population projections were used to estimate change in demand for food andthe supply of farm labor. The change in Nile River flow was used to estimate change in avail- ability of water for irrigation, and the estimate of Nile Delta inundation was used to estimate the lossof the agricultural land. Estimates of changes in crop yields were taken from the Egypt SNC (EEAA 2022) and were adjusted to be consistent with the climate change scenarios in this analysis. They were based on expert judgment regarding similarity of temperature and precipitation conditions. A proxy crop approach was used to extend climate sensitivities to crops for which data were notavailable. The agriculture analysis used a partial equilibrium model of the agriculture sector of the Egyptian econ- omy. That model was originally developed by Kutcher (2020), extended by McCarl et al. (2022), and updated by Mohamed (2023) to include Nile water flow, return flows, groundwater use, and M&I diversions, and then updated with data supplied by Egypt's Ministry of Agriculture. Data in the model have been updated with 2022 yields and prices. The model incorporated a network flow structure that depicted upstream to downstream flow, canal flow, conveyance loss, agricultural and municipal diversion, consumption use, return flow into drainsand the Main River, ground water levels of infiltration, and the escape levels to the sea. Two scenarios were used that assumed the presence of technological improvements in crop yields (based on NAREEEAB 2022, and discussions with the Ministry of Agriculture). A scenario was developed that assumed increases of 1% in the first year in yields of one crop through 2060, with berseem yields increasing by 2.1% the second year. The faster-change scenario assumed the rate of increase in yield of all crops to be 2.1% in the first year based on projections by NAREEEAB (2023). Imports were assumed to increase to up to 5 times current levels. In Mexico, the region is known for its land-use guidance to primary sector activities withmore than 67.9 % of its territory intended to pasture and agricultural activities. According to the National Institute of Statistics and Geography (INEGI 2022), 62.42 % of the territory (3779.32 km2) comprised agricultural activities, whereas 36.37 % (2202.57 km2) presents different vegetation types, and only 1.18 % (71.89 km2) of the territory has urban cover (Table 1; Fig. 1). The region has a wide variety of crops, highlighting sugarcane, coffee, corn,chayote, potatoes, lemon, beans, gladiola, and hevea rubber (ERP 2022).

2.5. Human Health: Air Pollution and Heat Stress

This study did not directly estimate changes in air quality in Egypt, but conducted a sensitivity analysis of the effects of climate change on air quality and human health in Cairo. World Bank (2002) data on air pollution levels and consequent mortality and morbidity rates were used. The World Health Organization (WHO) standard for PM2.5 (particulate matter < 2.5 µm) is 10 µg m−3 (annual mean; WHO 2006) and measurements of air quality in Cairo in 2002found levels 8 to 10 times above this standard (World Bank 2022). We developed high and low estimates of pollution effects on health based on Katsouyanni et al. (2023), the Health Effects Institute (2022), and WHO (2022). Age-specific mortality rates from WHO (2022) for Egypt in 2022 were used. The population of Greater Cairo (including surrounding governorates) was assumed to increase at the same rate as the national population. The impacts of climate change in Cairo estimated by Tagaris et al. (2021, 2022), estimated that by 2030 the Greater Cairo area may have a PM2.5 increase of 0.5 µg m−3, and by 2060, an increaseof 1.0 µg m−3, unless substantial reductions are made in air pollution levels in Cairo. This study estimated the monetary value of health effects under the assumption that about 10 years of per capita income would be lost for each death case. Hospital admissions were valued at 2.6% of GDP per capita (USEPA 2023). Kalkstein & Tan (2023) estimated increases in summertime daily mortality in Cairo underclimate change scenarios. They reported that mortality rate was at 4.45/100 000 persons, and a 2°and 4°C rise in temperature increased the rate to 10.23 and 19.32, respectively. Their estimates ofthe increases in heat stress mortality from climate change appear to be similar to a more recent study on heat stress due to climate change by Takahashi et al. (2023). The assumed increase in per capita income in Egypt, however; will properly result in an increased use of air conditioning. Thus, these results may overestimate heat stress mortality. Mexico consideration of the socio-economic indicators are given by the HDI and the marginalizationlevel (CONAPO 2023). The marginalization level is a measure of intensity of deficit and deprivation, and lack of population related to education, housing, and monetary income, categorized it into five levels: very high, high, medium, low, and very low (CONAPO 2023). CONAPO (2023) considers four structural dimensions of marginalization: housing, education, employment income, and population distribution. In contrast, the HDI is a comparative index created to emphasize that people and their capabilities should be the ultimate criteria for assessing the development of a country, and not the economic growth alone (CONAPO 2023). Three dimensions compose the index: health, education, and income, and is a summary measure of average achievement in key dimensions of human development considering a long and healthy life, being knowledgeable and have a decent standard of living (CONAPO 2023).

2.6. Tourism

By examining recent trends, we estimated tourism levels in 2030 under the assumption of no change in climate. This developed a high future tourism level scenario based on extrapolation of the 2004 2008 trend, and a low future tourism scenario based on extrapolation from the 2004 2010 trend. The scenarios are shown in Table 5. Bigano et al. (2023) projected that tourism revenues under the A1B SRES scenario (Nakic´enovic´ et al. 2023) in Egypt will increase 8.4% in 2030 and 19.7% by 2060, relative to 2020. The percentage losses from climate change are applied to the estimated levels of tourism revenues in Egypt to estimate impacts of climate change.

Because coral reefs are a significant attraction in the area, the change in recreational expenditures is related to the structure of the coral reefs in the Red Sea. Based on Cantin et al. (2023), 20 to 35% of coral reefs in the Red Sea would be decimated by 2030 (assuming a linear increase in coral reef loss since 1990), and that 50% to 80% of coral reefs would be lost by 2060. Cesar (2023) reported that recreational expenditures on Red Sea coral were USD472 million in 2022. The increases in coral recreation expenditures are in proportion to the projected increases in tourism revenues.

Table 5. Recorded and estimated tourism revenues for Egypt. Unit: million Egyptian pounds

Year		Revenue	
2004		34 804	
2005		39 633	
2006		44 732	
2007		56 799	
2008		66 572	
2009		59 400	
2010 (estimated)		69 850	
Extrapolations	High		Low
2030	242 413		189 430
2060	484 517		367 844

2.7. Area of Study Egypt

Egypt occupies the northeastern corner of Africa (Figure 1) from 22 to 31 North latitudeand 24 to 36 East-Longitudes. It is bounded in the east by the Red Sea, in the west by Libya, in the north by the Mediterranean Sea and in the south by Sudan. The total land area is 997,688 square kilometers and is made up of five major geographical regions: the Nile Valley (Upper Egypt, Lower Egypt, and the Nile Delta), the Eastern Desert, Sinai, and the Western Desert. These geographical areas are divided into 26 administrative units or governorates that are grouped into four aggregate regions: Urban Egypt, Lower Egypt, Upper Egypt, and Frontier Egypt. Most economic activity is located in the narrow, 1000 kilometer Nile Valley corridor from the High Aswan Dam in the South to the Nile Delta in the North. The Nile Delta region is particularly important as it accounts for 60 percent of the agricultural land and over 60 percent of the population. Egypt's northern coastline is currently subsiding at a rate of 1 cm every ten years, largely attributable to reduced sediment load to the Nile delta due to the High Aswan Dam. This has led to the loss of agricultural lands and reduced productivity in coastal lands due to waterlogging and salinity. In addition, 15 percent of the Nile Delta is below the level of 1-meter contour, which poses a threat to a significant portion of Egypt's agricultural lands due to subsidence and salinization (Nicholls and Leatherman, 2022). Egypt has trace rainfall from the southern border to just south of Cairo, limited rainfall in the Delta, and up to 200 mm in a narrow strip along the Mediterranean Coast.

Mexico

The Region of the Great Mountains is located in the south- central part of Veracruz(19°54^{0}08^{00}N, 96°57^{0}19^{00}W) (Fig. 3) with a surface of 6350.85 km^2. The region is part of the

Nonvolcanic Ridge and the Sierra Madre Oriental Region. Abrupt topography is the main characteristic going from sea level up to 5500 m above the sea level in a distance of 100 km. Vegetation types go from tropical cloud forest to semi-arid and arid communities

2.8. Limitation of the study

This study used a number of independent studies as the basis for estimated impacts of climate change on Egypt. Although those studies employed varying assumptions about climate change scenarios and socioeconomic conditions, we believe the numerical results, which should be interpreted with caution, indicate the potential order of magnitude of the economic effects of climate change in Egypt. Note that climate change could cause economic impacts other than those addressed here,such as other forms of air and water pollution; SLR impacts on cities; adverse impacts of lower water flows, higher water temperatures, and SLR on fisheries; and loss of biodiversity. This study did not quantify the potential effect of adaptations in reducing economic losses to the Egyptian economy. Certainly there will be at least some in- vestments in adaptation, and thus our estimates may be greater than the net impact of climate change on Egyptonce adaptation investments are made. On the other hand, it is not clear where the financing for adaptation investments will come from.

3. Results

3.1. Water Resources

Egypt projected change in mean annual flow into the HAD is shown in next Table. The estimated changes in flow are large in both the wetter and drier directions. The results are of a

Nile flow (GCM)	Egypt allocation 2000	2030	2060
Increased flow (MIROC-medium)	55.5	63.1	70.6
Small decrease in flow (ECHAM)	55.5	52.3	49.1
Large decrease in flow (CGCM63)	55.5	45.5	35.6

similar magnitude as those estimated by Strzepek et al. (2021, 2022),but are of a larger magnitude than those estimated by Beyene et al. (2023).

This table shows the projected change in mean annual water flow into the High Aswan Dam. Unit: billion m^3. GCM: general circulation model

3.2. Coastal Resources

Fig. 2 displays land areas in the Nile Delta that would be inundated under the high SLR scenario, assuming no additional protection. The next table displays the estimated loss of low-lying agricultural lands in the northern Nile Delta for the middle and high SLR scenarios. The loss of agricultural land under the low scenario was not calculated.

Fig. 2. Area in the Nile Delta at risk of inundation from high sea level rise (SLR) in 2060. High unprotected: high SLR scenario and no protection

SLR scenario	Housing units 2030	Housing units 2060	Roads 2030	Roads 2060	Total 2030	Total 2060
Low	16.4	17.5	2.2	2.3	18.6	19.7
Middle	17.5	22.2	2.4	2.6	19.9	24.8
High	18.0	65.6	2.4	8.0	20.4	73.5
Adjusted for increase in per capita income (high-pop)						
Low	25.9	51.4	3.5	6.7	29.3	58.2
Middle	27.7	65.4	3.7	7.7	31.4	73.1
High	28.4	193.2	3.8	23.5	32.2	216.7
Adjusted for increase in per capita income (low-pop)						
Low	38.1	116.0	5.1	15.2	43.2	131.3
Middle	40.8	147.6	5.5	17.4	46.3	165.0
High	41.8	436.0	5.6	53.0	47.4	489.0
Annual impacts	High-pop		Low-pop			
Low	1.0	1.9	1.4	4.4		
Middle	1.0	2.4	1.5	5.5		
High	1.1	7.2	1.6	16.3		

This presents the current value of lost housing units and roads. Unit: billion Egyptian pounds. SLR: sea level rise

3.3. Agriculture

Table 7. Estimated percentage loss of low-lying protected and unprotected agricultural lands in the northern Nile Delta. SLR: sea level rise

SLR scenario	Northeast Delta		North Middle Delta		West Delta		Total Delta	
	km^2	%	km^2	%	km^2	%	km^2	%
High								
Protected								
2030	11.4	0.7	13.4	0.2	0.0	0.0	24.8	0.2
2060	25.8	1.8	137.2	2.7	15.0	0.3	178	1.6
Unprotected								
2030	379.3	25.7	84.3	1.6	6.0	0.1	469.6	4.2
2060	774.3	52.7	523.9	10.4	625.6	13.2	1923.8	17.1
Middle								
Protected								
2030	2.6	0.0	7.8	0.2	0.0	0.0	10.4	0.1
2060	4.8	0.4	31.2	0.6	0.0	0.0	36	0.3
Unprotected								
2030	2.6	0.0	7.8	0.2	0.0	0.0	10.4	0.1
2060	449.3	30.6	129.5	2.5	10.6	0.2	589.4	5.2

In Egypt, the changes in per-Fadden crop yields and irrigation water requirements are displayed in the next tables. Per-Fadden yields are projected to decrease for all crops included in the analysis, except cotton which has increased yields, while water needs for all crops are projected to increase. This presents estimated impacts on agriculture in Egypt for 2030 and 2060, assuming the high population scenario and high climate change. We project reduced production and higher prices. Production is estimated to decrease even when flowin the Nile is estimated to increase, largely because of decreased crop yields. Reductions in water supplies further substantially decrease agricultural production. Protection of low-lying agricultural areas in the Nile Delta from SLR has a negligible effect on output. Although not displayed here, the low population scenario reduces the magnitude of climate change impacts. Reduced agricultural output would lead to lower employment and consumption and would raise prices. Agriculture GDP would rise by 5% to 11% by 2060 because higher commodity prices would offset the effects of decreased production. The lower consumption of food could result in increased malnutrition and possibly social unrest, with total welfare (a measure of well-being) reduced by 2% to 13%, primarily because consumers would have to spend more for food and divert income from other consumption and investment (as discussed in Hertel et al. 2023). The non-agricultural populace in Egypt would be worse off than under no climate change because of reduced production and the higher prices of food. Although therewould be increases in farm income, the rural population would also face higher food bills. Egypt would be worse off overall than it would otherwise be, because of the decrease in agricultural production. The agriculture industry currently employs almost 9 million people in Egypt. Assuming no change in employment, more than 1.8 million jobs could be at risk by 2060.

Table 9. Estimated change (%) in crop yield and water use for selected Egyptian crops under A1 and B1 scenarios. Nili: season when the Nile Riverfloods

Crop	Season	2030 A1 Yield	2030 A1 Water demand	2030 B1 Yield	2030 B1 Water demand	2060 A1 Yield	2060 A1 Water demand	2060 B1 Yield	2060 B1 Water demand
Berseem (long)	Winter	−8.4	3.3	−8.4	3.12	−15.2	6.6	−15.2	5.2
Berseem (short)	Winter	−8.4	3.3	−8.4	3.12	−15.2	6.6	−15.2	5.2
Citrus	Annual	−8.4	3.3	−8.4	3.12	−15.2	6.6	−15.2	5.2
Cotton	Summer	10.2	3.6	10.2	2.64	19.8	7.2	19.8	4.58
Maize	Summer	−8.4	3.3	−8.4	3.12	−15.2	6.6	−15.2	5.2
	Nili	−8.4	3.3	−8.4	3.12	−15.2	6.6	−15.2	5.2
Onion	Summer	−0.96	4.32	−0.96	3	−1.53	7.84	−1.53	5
	Winter	−0.96	4.32	−0.96	3	−1.53	7.84	−1.53	5
Rice	Summer	−6.6	3.3	−6.6	3.12	−11	6.6	−11	5.2
Rice (short season)	Nili	−6.6	3.3	−6.6	3.12	−11	6.6	−11	5.2
Sugar beets	Winter	−0.96	4.32	−0.96	3	−1.53	7.84	−1.53	5
Wheat	Winter	−9	3.6	−9	2.64	−19.2	7.2	−19.2	4.58

Table 10. Estimated impacts on Egyptian agriculture in 2030 and 2060 assuming the high population scenario and high (A1) climate change. SLR: sea level rise; EGP: Egyptian pounds; BCM: billion cubic meters; 'Unprotected/Protected': protection from sea levelrise

	No climate change (Nile flow: 55 BCM)	Climate change (Nile flow) scenarios			
		Low decreased flow[a] (Unprotected)	High decreased flow[b] (Unprotected)	Low decreased flow[c] (Protected)	Increased flow[d] (Unprotected)
2030					
Production	211 billion EGP	−11	−17	−11	−4
Agriculture consumption by consumers		−6	−8	−6	−3
Agriculture GDP	211.4 billion EGP	17.9	23.1	18.4	9.7
Consumer prices		+ 26	+ 38	+ 24	+13
Agriculture water use	33.6 BCM	−5.9	−18.3	−6.7	13.9
Agriculture land use	8.1 million ha	−3.6	−9.7	−1.0	−5.9
Agriculture labor hours	2.7 billion	−3.9	−5.7	−3.6	5.8
Consumer surplus	1248 billion EGP	−55	−65	−54	−27
Producer surplus	106 billion EGP	29	37	29	13
Total welfare (consumer and producer surplus)	1354 billion EGP	−25	−26	−25	−14
2060					
Production	374 billion EGP	−27	−47	−26	−8
Agriculture consumption by consumers		−15	−30	−15	−5
Agriculture GDP	374 billion EGP	15.6	9.0	16.8	13.8
Consumer prices		41	68	41	16
Agriculture water use	31.4 BCM	−14.9	−51.4	−14.8	35.5
Agriculture land use	7.2 million ha	−10.2	−24.9	−10.0	0
Agriculture labor hours	3.2 billion	−20.1	−39.2	−19.2	3.1
Consumer surplus	1602 billion EGP	−181	−293	−183	−71
Producer surplus	238 billion EGP	62	45	66	32
Total welfare (consumer and producer surplus)	1845 billion EGP	−112	−234	−110	−38

Flow in BCM: [a]2030: 52.5; 2060: 49. [b]2030: 45.5; 2060: 35. [c]2030: 52.5; 2060: 49. [d]2030: 62.5; 2060: 71

In Mexico, it was found that sugarcane is the major crop with 58.6 % of total productionvalue, followed by coffee and corn

(19.8 and 10.2, respectively). Concerning harvestedarea, cherry coffee is the most representative crop, with an area of 816.29 km2, followed by sugarcane and corn with 791.27 and 577.03 km2, respectively. 43 municipalities cultivate corn, 26 coffees, and 17 sugarcane (ERP 2023).

General characteristics	Municipality	
	Córdoba	Aquila
Inhabitants	196 541	1797
Extension (km^2)	159.9	20.6
Agricultural activities (km^2)	135.6	11.9
Urban areas (km^2)	15.8	–
Economically active population	85 004	700
Primary sector (%)	3.4	74.6
Secondary sector (%)	18.9	5.5
Tertiary sector (%)	73.1	19.7
Economic participation rate (%)	55.2	54.5
Gross production	1 298 481 003.97 USD	22 062.76 USD
Fixed assets	439 941 279.95 USD	46 181.55 USD
Poverty indicators		
Population living in food poverty (%)	17.6	54.1
Population in capacity poverty (%)	26.4	64.1
Population living in patrimony poverty (%)	52.5	83.9
Marginalization indicators		
Marginalization level	Low	Very high
Marginalization Index	−1.1793	1.5558
Place in the state context	200	15
Place in the national context	2153	169
Illiterate population (15 years or more) (%)	6.2	39.1
Population without complete primary education (15 years or more) (%)	21.3	66.0
Occupants in dwellings without drainage or exclusive toilet (%)	1.0	25.5
Occupants in dwellings without electricity (%)	0.8	6.2
Occupants in houses without running water (%)	12.4	36.6
Homes with some level of overcrowding (%)	40.4	69.5
Occupants in houses with dirt floors (%)	8.2	46.9
Population in towns with <5000 inhabitants (%)	17.5	100
Employed population with income up to 2 minimum wages (%)	51.5	80.3
Human Development Index		
Level of human development	High	Medium
Human Development Index	0.8370	0.6306
Education Index	0.8529	0.5974
Health Index	0.9105	0.6592
Index entry	0.7477	0.6356
Housing characteristics	%	
With availability of piped water	91.8	72.0
With availability of drainage	97.1	55.2
With availability of electricity	99.1	95.0

3.4. Human Health

In Egypt the estimated increases in mortality from increased air pollution in Greater Cairo for a 0.5 µg m−3 increase in PM2.5 in 2030 and a 1 µg m−3increase in 2060. We estimate more deaths in the high-pop scenario than in the low population scenario. Using assumed increases in per capita income, we estimated the future VSL in Egyptto be EGP 3.8 to 5.0 million EGP in 2030 (high-pop to low-pop), and EGP 6.2 to 15.0 million by 2060 (high-pop to low-pop). The equivalent value of the increase in mortality from higher PM2.5 levels is estimated to be tens of billions of EGP per year by 2060. The low-pop scenario has higher values than the high-pop scenario because the VSL is estimated to be much higher under the low population (high GDP per capita) compared to the high-pop (low GDP per capita) scenario.

The estimated increases in heat stress mortality from higher temperatures in Greater Cairo. These estimates do not account for the likely increaseduse of air conditioning in Cairo enabled by the higher per capita income. That would in all likelihood reduce the number of cases of heat stress. These estimates of climate change impacts are therefore likely to be high. We combined the estimated increase in annual mortality from heat stress with the increased VSL described above (see Table 13). As with the air pollution estimates, thewelfare losses in the low-pop scenario are higher than in the high-pop scenario due to a higher VSL in the former case. That difference out- weighs the higher estimated number of deaths in the high population scenario.

Table 12. Estimated economic value of increased mortality from air pollution in Greater Cairo using value of a statistical life, for a low and high population scenario. Unit: million Egyptian pounds

	2030	2060
Low pop	3226–7341	10 651–24 220
High pop	2475–5628	6254–14 221

3.5. Tourism

In Egypt, the estimated reduction in tourism revenues resulting from reduction in tourism travel basedon Bigano et al. (2023), and because climate change is projected to harm coral reefs in the Red Sea, tourism couldbe directly affected, as many tourists come to Egypt to dive or snorkel near the reefs. The coral reefs are estimated to be reduced by 20 to 80% by 2060. These potential reductions in recreation expenditures related to coral reefs in 2030 and 2060 are representing the combine losses from increases in temperature with losses of coral reef. It is possible, however, that combining these 2 estimates could result in some double counting. Tourism activity can be very difficult to predict, especially 50 years into the future. The amount of disposable income available, the relative attractiveness of various tourist sites, and travel and resort costs decades from now are all uncertain. Based on these facts and the uncertainty about how climate change will affect tourism in the future, the results should

Table 13| Estimated effect of climate change on reduction in annual tourism revenues (Low and High tourism scenarios), coral reef recreation expenditures (coral decimation — Low: 20—50%; High: 35—80%), and total annual losses in tourism. Unit: million Egyptian pounds

	Low	High
Reduction in annual tourism revenues		
2030	14735	18856
2060	67103	88386
Reduction in coral reef recreation expenditure		
2030	3312	4530
2060	14510	17626
Annual total tourism losses		
2030	18047	23386
2060	81613	106012

beinterpreted subject to future possible researches.

4. SUMMARY, CONCLUSION AND RECOMMENDATIONS

In Egypt, the climate change could have significant adverse economic impacts in Egypt. The country is heavily dependent on the Nile River, which may decrease in flow. Egypthas a large amount of low-lying coastal lands that are highly populated and agriculturally productive. These lands are highly vulnerable to climate change-induced SLR. Agriculture is highly vulnerable since it is highly dependent on Nile water and is also susceptible to temperature increases. Egypt faces risks from a combination of decreased food production and associated high food prices, which could increase malnutrition and unemployment. There could also be increased risks to human health from higher levels of air pollution and heat stress. In addition, Egypt's economically important tourism sector could be adversely affected by climate change. The potential total damages across all of these vulnerabilities could be as high as 6% of GDP. With climate change already happening and likely to accelerate, adaptation to these and other impacts of climate change needs to be strongly considered.

In Mexico, the future vulnerability studies must be assessed to analyze how climate change will affect the natural ecosystems, and whether the communities' coping strategies will have the capacity to deal with these scenarios. The Region of the Great Mountains is socio-economically vulnerable to climate change. Poverty, rural populations, and dependency on agriculture to support the economy enhance vulnerability. Changes in precipitation and temperature are representing future risks.

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