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# Egypt's economic vulnerability to climate change

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ABSTRACT: Climate change is likely to have profound economic consequences for Egypt. This study evaluates the potential economic impacts resulting from changes in water supplies, agriculture, air quality, heat stress, and tourism. Other sensitive sectors, including water pollution, energy consumption, and biodiversity, were not assessed. Sea level rise threatens agricultural land and property in the Nile Delta. Higher temperatures can reduce agricultural production, a situation that can be made worse with lower water supplies. As a result, unemployment and food prices may increase, risking increased malnutrition. Human health in Cairo could be adversely affected by increased particulate matter and heat stress, potentially leading to thousands of deaths valued at tens of billions of Egyptian pounds per year. Annual tourist revenues are estimated to decrease as well. Total economic losses for the sectors mentioned above are estimated to reach ~200 to 350 billion Egyptian pounds (EGP; US $36–64 billion), which is equivalent to 2–6% of future gross domestic product.

KEY WORDS: Climate change · Egypt · Economy

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## 1. INTRODUCTION

As Egypt's Second National Communication (SNC) to the United Nations Framework Convention on Climate Change (UNFCCC) states, 'Egypt is one of the most vulnerable countries to the potential impacts and risks of climate change' (EEAA 2010, p. 69). The reasons are numerous, starting with the potential effects on the Nile River, which supplies the vast majority of Egypt's water supply: a reduction in average flow of the Nile could seriously threaten Egypt's water supplies and the well-being of its citizens, of which 97% live along the river or in the Nile Delta. In addition to this impact on water resources, valuable lands in the Nile Delta face the threat of inundation from sea level rise (SLR). Agricultural production is also at risk from the direct effects of climate change: higher temperatures could lower crop yields, and a decrease in water supplies could reduce the availability of water for irrigation. In addition, climate

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change could worsen Egypt's already severe air pollution and increase heat stress. The combination of higher temperatures and SLR could lead to reduced tourism by making the climate less inviting and threatening ecological tourist attractions, such as coral reefs. Note, it could also create damages in other sectors.

A key rationale for conducting this assessment is that even preceding the 2011 Revolution, climate change received limited attention in natural resource policy discussions in Egypt. Since the start of the Revolution, the country has been consumed with sorting out its short-term political future. Yet, climate change remains as a potentially significant threat to Egypt's long-term economic health. This study attempts to raise the profile of climate change by estimating the potential economic risks the country faces from it.

### 1.1. Previous studies

Hotter and drier conditions are projected for much of Egypt. Christensen et al. (2007) concluded that Mediterranean Africa is likely to become warmer and drier, but that East Africa, the source of the Nile, is likely to get wetter. Funk et al. (2008), however, found that March through May precipitation in East Africa decreased by ~15% since about 1980, and question whether precipitation in East Africa will indeed increase with further climate change. Thus it is possible that flow in the Nile could decrease in the future.

Egypt has been the subject of climate change impact studies for more than 2 decades. Milliman et al. (1989) and El-Raey (1997) assessed the vulnerability of coastal resources to SLR, while Strzepek et al. (1995, 2001) examined the vulnerability of agriculture to changes in climate and water supply, and coastal resources to changes in climate and sea level. The potential for significant changes in the flow of the Nile are reflected in various studies: Conway & Hulme (1996) estimated that flow in the Blue Nile in 2025 could change within the range of a 15% increase to a 9% decrease. Strzepek et al. (2001) estimated that by 2020, the flow could decrease by 10 to 50%. More recently, Elshamy et al. (2009) used bias-corrected statistical downscaling of 17 general circulation models (GCMs) to estimate an average 15% reduction in flow of the Blue Nile by the end of the century, and a range of change from a 60% decrease to a 45% increase.

To our knowledge, no study to date has attempted to estimate the economic impact of climate change on a number of key sectors in the Egyptian economy. This study covers more sectors than have been assessed in a single study before. It is neverthelessnot comprehensive, and did not include such important sensitive sectors as energy, water quality, fisheries, and biodiversity. Note that Robinson et al. (2012) used a dynamic computable general equilibrium model of Ethiopia, and estimated that climate change would reduce that country's gross domestic product (GDP) by ~6 to 10% by the 2040s — a percentage impact on Ethiopian GDP that is higher than the impact on Egyptian GDP estimated in this study.

### 1.2. Objectives

The literature on climate change in Egypt has tended to focus on SLR, water resources, and consequences for agriculture. Impacts of climate change on health and tourism have not been assessed, nor have the implications for the Egyptian economy. This study estimates the potential impacts of climate change on Egypt's economy in 2030 and 2060 by examining the consequences of changes in water supply, agriculture production, value of property in the Nile Delta, increases in air pollution and heat stress, and consequences of changes in climate and coral reef health on tourism.

## 2. METHODS

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 2010) projections for 2030, World Bank (2008) 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 2010 was 82 million and was increasing by 2.3% $yr^{-1}$ (EEAA 2010). The high- and low-pop projections are displayed in Table 1.

The low-pop scenario assumes that real per capita income increases by ~3.8% $yr^{-1}$, consistent with the

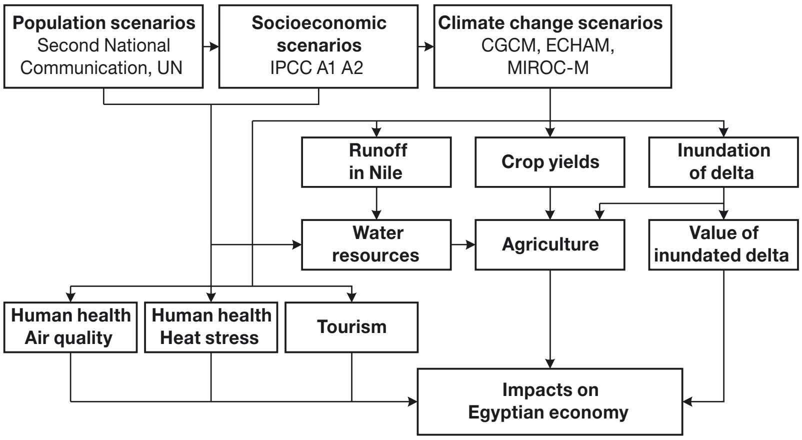


Fig. 1. Study structure

Table 1. Low (low-pop) and high (high-pop) population assumptions for current population (2009) and population scenarios for 2030 and 2060. Data are millions of people

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

A1 emissions scenario from the Intergovernmental Panel on Climate Change (IPCC; Nakićenović et al. 2000). The high-pop scenario uses the A2 IPCC assumption that real per capita income increases by 2.2% $yr^{-1}$. We used published IPCC projections for the African and Latin American regions for the A1 and A2 scenarios (Nakićenović et al. 2000). The total GDP and GDP per capita income assumptions are shown in Table 2.

Table 2. Projections of gross domestic product (GDP) and GDP per capita. EGP: Egyptian pounds; USD: United States dollars

| | 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 |

### 2.2. Climate change scenarios

The scenarios are from Elshamy et al. (2009), who used the A1B emissions scenario (IPCC) to estimate Blue Nile flow. We selected 3 GCMs from Elshamy et al. (2009) that presented the highest, lowest, and intermediate flow levels across the model results. The average change estimated across the 17 models in Elshamy et al. (2009) is a small decrease in flow. The scenarios are (1) large decrease in flow: Canadian Centre for Climate Modeling and Analysis (Canada; CGCM63); (2) small decrease in flow: Max Planck Institute for Meteorology (Germany; ECHAM); (3) increase in flow: National Institute for Environmental Studies Medium Resolution (Japan; MIROC-M).

We used the 'SimCLIM' tool (CLIMsystems 2011) 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 2008). Elshinnawy (2008) used current SLR trends and estimates of accelerated eustatic SLR from the IPCC (2007). Elshinnawy (2008) estimated relative SLR, which includes subsidence in the Nile Delta (Elshinnawy 2008; see also Stanley 1990, Hassaan & Abdrabo 2013), 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. We used the 2075 estimate for 2060 because SLR may be much higher than estimated by the IPCC (2007) (e.g. Oppenheimer et al. 2007, National Research Council 2012). SLR scenarios are displayed in Table 4.

### 2.3. Water resources

We used Elshamy et al. (2009) as the basis for estimates of change in Nile River flow. Because the Blue Nile contributes 60% of the Nile's flow at Dongola (near the inlet of the reservoir of the HAD), we assumed the percentage change in flow at the HAD would be the same as the percentage change in Blue Nile 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,

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 |

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 |

for the most part, only slightly greater than the changes in the Blue Nile discharge.

We estimated change in flow in 2030 and 2060 by linearly interpolating between the Elshamy et al. (2009) 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 1990). We did not account for changes in water withdrawals upstream from Egypt. We 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 in any 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) $yr^{-1}$. We also assume the use of local effective 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 Ministry of Water Resources & Irrigation (Egypt) (MWRI 2005), and assumed that consumption would increase with population. We 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, USA (Chen et al. 2001). We assume the present instream need of 13.1 BCM $yr^{-1}$ 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 climate change, and the possible need to maintain higher flows in the Delta due to higher sea levels.

### 2.4. Coastal resources

Elshinnawy (2008) 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. We overlaid Elshinnawy's (2008) estimates of SLR with property and agriculture datasets in a geographic information system to estimate the amount of agricultural land and housing that could 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 values were assumed to increase at the same rate as per capita income in the socioeconomic scenarios for Egypt.[1]

### 2.5. Agriculture

The agriculture analysis considered demand growth, water availability change, crop yields, livestock yields, SLR land loss, pesticide costs, and technical progress (see McCarl et al. 2013). Population projections were used to estimate change in demand for food and the supply of farm labor. The change in Nile River flow was used to estimate change in availability of water for irrigation, and the estimate of Nile Delta inundation was used to estimate loss of agricultural land.

Estimates of changes in crop yields were taken from the Egypt SNC (EEAA 2010) 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 not available.

The agriculture analysis used a partial equilibrium model of the agriculture sector of the Egyptian economy. That model was originally developed by Kutcher (1980), extended by McCarl et al. (1989), and updated by Mohamed (2001) 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 2010 yields and prices. The model incorporated a network flow structure that depicted upstream to downstream flow, canal flow, conveyance loss, agricultural and municipal diversion, consumptive use, return flow into drains and the main river, groundwater infiltration, and escape to the sea.

Two scenarios were used that assumed the presence of technological improvements in crop yields (based on NAREEEAB 2011, and discussions with the Ministry of Agriculture). (1) A slow scenario was developed that assumed increases of 1% $yr^{-1}$ in yields of all but one crop through 2060, with berseem yields increasing by 2.1% $yr^{-1}$. (2) The faster-change scenario assumed the rate of increase in yield of all crops to be 2.1% $yr^{-1}$ based on projections by NAREEEAB (2011). Imports were assumed to increase to up to 5 times current levels.

[1]The assumption that the percentage increase in housing value is the same as the percentage increase in per capita income is based on analysis of the increase in per capita income in the US compared to the increase in mortgage spending from 1985 to 2005. Income before taxes increased 234%, while spending on mortgages increased 240% (US Census Bureau 2011). A change in mortgages is not only a function of the price of homes, but also of the interest rate.

### 2.6. Human health: air pollution

We 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 $PM_{2.5}$ (particulate matter < 2.5 µm) is 10 µg $m^{-3}$ (annual mean; WHO 2006) and measurements of air quality in Cairo in 2002 found levels 8 to 10 times above this standard (World Bank 2002). We developed high and low estimates of pollution effects on health based on Katsouyanni et al. (1996), the Health Effects Institute (2004), and WHO (2005). Age-specific mortality rates from WHO (2011) for Egypt in 2009 were used. The population of Greater Cairo (including surrounding governorates) was assumed to increase at the same rate as the national population.

Because no studies of climate change and air pollution in Egypt have been conducted to date, we assumed that modeled climate changes in PM for Phoenix, Arizona would give an indication of potential changes in the air quality of Cairo. $PM_{2.5}$ levels in Phoenix are substantially lower than those in Cairo under current conditions, however, so the impacts of climate change in Cairo may be larger than we estimated. Tagaris et al. (2009, 2010) estimated that by 2080, increases in $PM_{2.5}$ concentrations in Phoenix will range from 0.3 to 0.7 µg $m^{-3}$. Because Cairo will likely still have higher PM concentrations than Phoenix, we assumed that by 2030 the Greater Cairo area may have a $PM_{2.5}$ increase of 0.5 µg $m^{-3}$, and by 2060, an increase of 1.0 µg $m^{-3}$. Unless substantial reductions are made in air pollution levels in Cairo, the impacts of climate change could be greater than what was assumed here.

We estimated the monetary value of health effects under the assumption that about 10 yr of per capita income would be lost for each death. Hospital admissions were valued at 2.6% of GDP per capita (USEPA 2010). We also used the value of a statistical life (VSL) in the US based on USEPA (2010), and lowered it by the ratio of Egyptian:US per capita income.

### 2.7. Human health: heat stress

Kalkstein & Tan (1995) estimated increases in summertime daily mortality in Cairo under climate 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 of the increases in heat stress mortality from climate change appear to be similar to a more recent study on heat stress and climate change by Takahashi et al. (2007). We assumed that maximum temperatures increase at the same rate as average temperatures, and assumed no increase in the use of air conditioning. The assumed increase in per capita income, however, will likely result in an increased use of air conditioning. Thus these results may overestimate heat stress mortality.

### 2.8. Tourism

By examining recent trends, we estimated tourism levels in 2030 under the assumption of no change in climate. We 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. (2007) projected that tourism revenues under the A1B SRES scenario (Nakićenović et al. 2000) in Egypt will decrease 8.4 % in 2030 and 19.7 % by 2060, relative to 1990. We applied the percentage losses from climate change 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, we estimated change in recreational expenditures related to coral reefs in the Red Sea. Based on Cantin et al. (2010), we estimated that 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 (2003) reported that recreational expenditures on Red Sea coral were $472 million in 2000, and we assumed the same level of expenditures in 2004. We also allowed for increases in coral recreation expenditures 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 |

### 2.9. Limitations 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 investments in adaptation, and thus our estimates may be greater than the net impact of climate change on Egypt once 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

Projected change in mean annual flow into the HAD is shown in Table 6. The estimated changes in flow are large in both the wetter and drier directions. The results are of a similar magnitude as those estimated by Strzepek et al. (1995, 2001), but are of a larger magnitude than those estimated by Beyene et al. (2010).

Table 6. Projected change in mean annual water flow into the High Aswan Dam. Unit: billion $m^3$. GCM: general circulation model

| 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 |

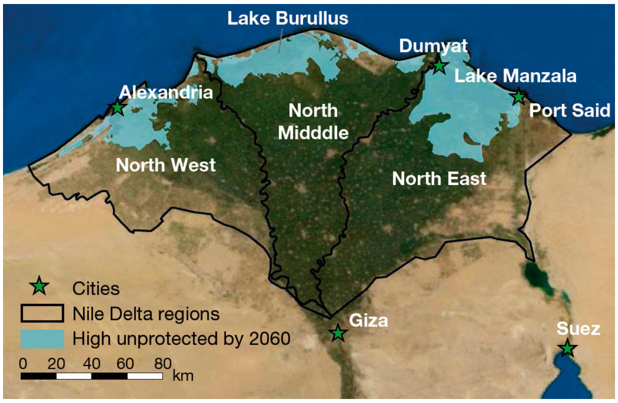


Fig. 2. Area in the Nile Delta at risk of inundation from high sea level rise (SLR) in 2060. High unprotected: high SLR scenario and no protection

### 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. Table 7 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.

Table 8 presents the current value of housing units and roads at risk from SLR. Assuming there is no additional protection from SLR, losses would be between ~1 and 7 billion Egyptian pounds (EGP) per year in 2030 and between 2 and 16 billion EGP $yr^{-1}$ in 2060. The analysis did not evaluate the costs of protecting low-lying coastal areas from SLR.

Table 8. Current value of lost housing units and roads. Unit: billion Egyptian pounds. SLR: sea level rise

| 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 | | |

### 3.3. Agriculture

Changes in per-hectare crop yields and irrigation water requirements are displayed in Table 9. Per-hectare 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.

Table 10 presents estimated impacts on agriculture in Egypt for 2030 and 2060, assuming the high-pop scenario and high climate change. We project reduced production and higher prices. Production is

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 $km^2$ | Northeast Delta % | North Middle Delta $km^2$ | North Middle Delta % | West Delta $km^2$ | West Delta % | Total Delta $km^2$ | Total Delta % |
|---|---|---|---|---|---|---|---|---|
| **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 |

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

| 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 level rise

| | 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

Table 11. Estimated population and changes in deaths from a 0.5 µg $m^{-3}$ (2030) to a 1 µg $m^{-3}$ (2060) change in sub-2.5 µm particulate matter ($PM_{2.5}$) levels in Greater Cairo, for a high (high-pop) and low population (low-pop) scenario

| | Greater Cairo population (millions) | | Change in no. of deaths | | | |
|---|---|---|---|---|---|---|
| | | | $PM_{2.5}$ – low estimate (adult only) | | $PM_{2.5}$ – high estimate (adult only) | |
| | Low-pop | High-pop | Low-pop | High-pop | Low-pop | High-pop |
| 2010 | 19.7 | 19.7 | 501 | 1140 | 501 | 1140 |
| 2030 | 25.5 | 28.8 | 649 | 1477 | 733 | 1667 |
| 2060 | 27.8 | 39.9 | 708 | 1610 | 1015 | 2308 |

estimated to decrease even when flow in 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-pop 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. 2010). 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 there would 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 (CIA 2012). Assuming no change in employment, more than 1.8 million jobs could be at risk by 2060.

### 3.4. Human health: air pollution

Table 11 presents the estimated increases in mortality from increased air pollution in Greater Cairo for a 0.5 µg $m^{-3}$ increase in $PM_{2.5}$ in 2030 and a 1 µg $m^{-3}$ increase in 2060. We estimate more deaths in the high-pop scenario than in the low-pop scenario.

Using assumed increases in per capita income, we estimated the future VSL in Egypt to be 3.8 to 5.0 million EGP in 2030 (high-pop to low-pop), and 6.2 to 15.0 million EGP by 2060 (high-pop to low-pop). Table 12 presents the estimated value of increased mortality from air pollution health effects in Egypt. The equivalent value of the increase in mortality from higher $PM_{2.5}$ 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-pop (high GDP per capita) compared to the high-pop (low GDP per capita) 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. Human health: heat stress

The estimated increases in heat stress mortality from higher temperatures in Greater Cairo are presented in Table 13. These estimates do not account for the likely increased use 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, the welfare 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 outweighs the higher estimated number of deaths in the high-pop scenario.

Table 13. Estimated increase in annual mortality, and annual welfare loss, from increased heat stress in Greater Cairo under 3 climate models, for a low- and high population (pop) scenario

| | 2030 | | | 2060 | | |
|---|---|---|---|---|---|---|
| | CGCM63 | ECHAM | MIROC-M | CGCM63 | ECHAM | MIROC-M |
| **Mortality (no. of individuals)** | | | | | | |
| Low-pop | 662 | 662 | 736 | 1662 | 1579 | 1924 |
| High-pop | 722 | 722 | 802 | 2302 | 2187 | 2665 |
| **Welfare loss (million EGP)** | | | | | | |
| Low-pop | 3291 | 3291 | 3657 | 24 999 | 23 749 | 28 937 |
| High-pop | 2437 | 2437 | 2708 | 14 186 | 13 476 | 16 420 |

Table 14. 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 |

### 3.6. Tourism

The estimated reduction in tourism revenues resulting from reduction in tourism travel based on Bigano et al. (2007) is displayed in Table 14.

Because climate change is projected to harm coral reefs in the Red Sea, tourism could be 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. Table 14 lists the potential reductions in recreation expenditures related to coral reefs in 2030 and 2060.

We 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. The total revenue losses to tourism are listed in Table 14.

Tourism activity can be very difficult to predict, especially 50 yr 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. Because of this and the uncertainty about how climate change will affect tourism, the results should be interpreted with caution.

### 3.7. Combined impacts

Table 15 displays estimated economic impacts in 2030 and 2060 on selected sectors, and Fig. 3 displays economic impacts in 2030 and 2060, assuming low reduction in Nile flow, a high population socioeconomic scenario, unprotected coastal areas, and high SLR. In both time periods, agriculture is projected to have the largest economic losses, with tourism coming in second. By 2030, the level of economic impact differs little across scenarios, suggesting that future

Table 15. Estimated economic losses from climate change in selected Egypt sectors. Units: billion Egyptian pounds. Scenario 1: high population, low GDP, large decrease in Nile flow, and high sea level rise (SLR) with no protection. Scenario 2: High population, low GDP, small decrease in Nile flow, and high SLR with no protection. Scenario 3: Low population, high GDP, small decrease in Nile flow, and high SLR with no protection. VSL: value of a statistical life

| | **2030** | | | **2060** | | |
|---|---|---|---|---|---|---|
| Scenario | 1 | 2 | 3 | 1 | 2 | 3 |
| Welfare loss in agriculture | 26 | 25 | 20 | 234 | 112 | 41 |
| Annual coastal property losses (excluding agriculture) | 1 | 1 | 2 | 7 | 7 | 16 |
| Value of deaths from air pollution (using VSL) | 3–6 | 3–6 | 3–7 | 6–14 | 6–14 | 11–24 |
| Value of deaths from heat stress (using VSL) | 2–3 | 2–3 | 3 | 14 | 14 | 24 |
| Reduction in annual tourism revenues | 18 | 18 | 23 | 82 | 82 | 106 |
| Total of selected impacts | 50–54 | 49–53 | 51–55 | 343–351 | 221–229 | 198–211 |
| Percent of GDP | 2.2–2.4 | 2.2–2.4 | 1.6–1.8 | 5.9–6.0 | 3.8–3.9 | 2.1–2.2 |

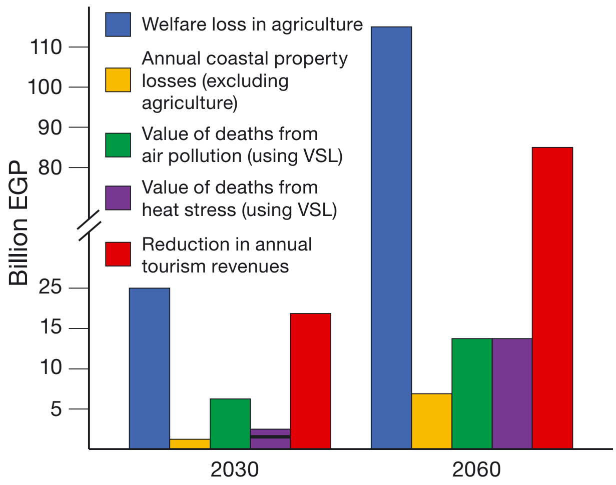


Fig. 3. Estimated economic impacts by sector in 2030 and 2060. VSL: value of a statistical life; EGP: Egyptian pounds

emissions make little difference in just a few decades. By 2060, the level of losses differs substantially by scenario. The scenario with the largest estimated losses combines high population growth with a large decrease in Nile flow. Lower population and a lower reduction in Nile flow reduces losses by almost half. Nonetheless, the results suggest that up to 2–6% of Egypt's GDP could be at risk from climate change.

## 4. CONCLUSIONS

Climate change could have significant adverse economic impacts in Egypt. The country is heavily dependent on the Nile River, which may decrease in flow. Egypt has 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.

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