

Article

Grains Production Prospects and Long Run Food Security in Egypt

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Received: 13 July 2019; Accepted: 15 August 2019; Published: 17 August 2019



Abstract: Egypt's population growth, scarce resources, and a struggling economy threaten its capacity to achieve food security. Water is of particular interest at this juncture given impending development projects under increasingly uncertain climate conditions. The main objective of this research is to forecast grains production in Egypt under different productivity scenarios, based on annual data from 1980 to 2017, to estimate and forecast cultivated area. Findings suggest that the potential reduction in the Nile flows into Egypt will adversely impact agricultural production, especially during the summer season, reducing cultivated areas and decreasing crop yields. These findings suggest that Egypt's reliance on imports will continue and grain imports will increase as the population grows and opportunities to reclaim lands remain limited. If food security and concerns about reliance on food imports persist among leaders, future policy options should focus on increasing water-use efficiency and raising productivity of both land and water.

Keywords: grains production; food security in Egypt; water scarcity and shortages

1. Introduction

A fast-growing population, dwindling access to already scarce resources, and a struggling economy threaten Egypt's capacity to achieve long-run food security. In short, Egypt's ability to feed itself has become a challenge and a great societal burden considering rising poverty and malnutrition levels together with stagnant food production. In 2015, 27.8% of the population in Egypt was living below the national poverty line, up significantly from 16.7% in 1999/2000 [1]. Additionally, 28.8% of children (0–17 years old) were living in extreme financial poverty in 2013, up from 21% in 1999/2000 [2]. Consequently, malnutrition-based growth stunting affected about 21.1% of children under 5 and the incidence of anemia was 27% among children in 2014 [3].

Part of the challenge for food security is based on escalating demand as Egypt's population grew to 95 million people in 2017, up from 73 million people in 2006 [4]. Given Egypt's high fertility rate, the population growth rate increased from 2.04% annually during the period 1996–2006 to 2.56% annually during the period 2006–2017. Moreover, 97% of the population inhabits only 4% of Egypt's total area in the Nile Valley and the Delta [5]. Assuming no change (constant fertility and constant mortality), Egypt's population is estimated to increase to 123 million by 2030 and further to 174 million by 2050 [6]. This growing population will aggravate food insecurity not only by increasing the demand for food but also by exacerbating the burden and access to agricultural resources considering development pressure (housing and urbanization) has historically resulted in the loss of scarce fertile lands, and the degradation of limited water resources.

With 55.5 billion cubic meters (BCM) of water flow a year, the Nile provides Egypt with about 96% of its total renewable water resources. The remaining 4% comes from groundwater aquifers and just a small share results from the scarce rainfall received. The agricultural sector consumes most of

the country's available water, accounting for 79% of the nation's total water withdrawals [7] due to cropping intensity and inefficient water use. Therefore, water scarcity is a significant threat to food production and food security in Egypt since the country is extensively encountering over-exploitation of the river basin and the water use structure in the MENA region (Middle East and Northern Africa) is anticipated to shift away from agricultural uses towards non-agricultural sectors in the next decades [8]. By 2025, Egypt is expected to suffer from physical water scarcity [9], and grains productivity is predicted to decrease by 11% compared to 1995 due to irrigation water scarcity [10]. Moreover, recent water infrastructure changes in the Nile Basin, including the construction of dams and other water projects, could result in a decrease in Egypt's share of the Nile's flow [11,12]. Furthermore, water pollution is worsening the water crisis and undermining agricultural production as it decreases the amount of appropriate water to use. In 2016, about 18.9 billion m³ of wastewater (untreated municipal wastewater, industrial wastewater, and agricultural runoff) was discharged directly into the Nile or into agricultural drains to be recycled back to the Nile [13]. This gradually deteriorates soil fertility. For instance, soil salinization is found on about 35% of the agricultural lands in Egypt, limiting the cultivated crops in the salt-affected lands such as the Lower Delta to salt-resistant crops such as rice [14].

Arable and fertile lands in Egypt are scarce and farming is limited to less than 4% of the total land area. In 2016, total agricultural land area was about 9.1 million feddans (One feddan equals 1.038 acres or 0.42 hectares) (3.8 million hectares) accounting for 3.82% of Egypt's area [15]. Additionally, land fragmentation into small units poses another challenge to agriculture in Egypt since smaller farms do not generate enough income and are not easily aggregated into more commercially viable plots that are better suited to modern production and supply chains. A growing population, especially in rural areas, and the use of land mainly as a de-facto social safety net in Upper Egypt have caused most land plots to shrink to tiny subsistence farms [16]. Recently, encroachment on agricultural lands has become one of the most challenging and pressing issues in Egypt. A report by the Egyptian Ministry of Agriculture and Land Reclamation (MALR) estimated that Egypt had lost 326,000 feddans (138,000 hectares) of arable lands between 1983 and 2018 due to development pressure and urbanization. Between 2011 and 2018 alone, the country reported 85,000 feddans transitioning out of agriculture [17].

Water shortages and a shrinking base of arable lands undermines food production goals in Egypt and could sharply increase the reliance on food imports if the impact of climate change is also considered. Most current research predicts a negative impact of climate change on primary crops yield such as wheat, rice, maize, soybeans, and barley [18,19]. In 2017, Egypt imported 65% of its total wheat consumption, compared to 43% in 2013, 53% of maize total consumption, compared to 43% in 2013, and 6% of rice consumption compared to no imports in 2013 [20]. Reliance on food imports makes the country vulnerable to commodity price volatility and requires a healthy economy capable of earning sufficient foreign exchange to cover the costs of necessary food imports [12,21].

This article briefly discusses the major threats to food production and food security in Egypt over the next few decades. By summarizing current trends in grains production as well as agricultural production and irrigation policies proposed to mitigate future threats, it helps to frame the potential production and food security concerns of the country. The main objective of the analysis presented is to forecast grains production in Egypt under different productivity scenarios and inform future policy and agricultural investments seeking to address the potential risk posed to food security.

2. Agricultural Production in Egypt

Farm production in most of Egypt is diversified with both crop cultivation and livestock production; a mixed crop-livestock farming system. Egyptian growers cultivate across 3 seasons: 2 primary seasons, winter from October to April and summer from May to September, as well as a third season called nili from August to late fall. Wheat, clover, sugar beets, and vegetables are the most commonly grown crops in the winter, while rice, maize, cotton, and sorghum are the main crops cultivated in the summer. Maize, rice, and potatoes are the most commonly grown crops in the nili season, while sugar cane and fruit crops such as oranges, grapes, and dates are the most popular permanent/perennial crops.

Additionally, Egypt's producers, mainly small landholders, raise livestock such as cows and water buffalo on diversified farms as an extra source of income as well as to provide dairy products for home consumption.

Among all crops planted in Egypt, grains are the dominant staple, especially for human consumption. Wheat is the main grain crop, accounting for 43% of total winter crop area in 2017 compared to 50% in 2016. During the winter season, wheat competes for land, water, and other resources: animal feed clover is the key alternative, accounting for 30% of 2017 total winter crop plantings. Egyptian farmers grow wheat throughout the north in the Lower Egypt region, mainly in the Delta, to the south in the Nile Valley along the riverbanks in the Middle and Upper Egypt regions as well as in the frontier (Areas outside the Nile Valley and the Delta include New Valley, Matruh, North Sinai, and South Sinai). Maize and rice are the most commonly grown grain crops in the summer season: in 2017, maize accounted for 38% of summer plantings while rice accounted for approximately 19%. Maize cultivation regions are similar to those of wheat, and the wheat-maize rotation is popular in Egypt. In contrast, the cultivation of rice is limited to the Nile Delta in the Lower Egypt region (Figure 1).

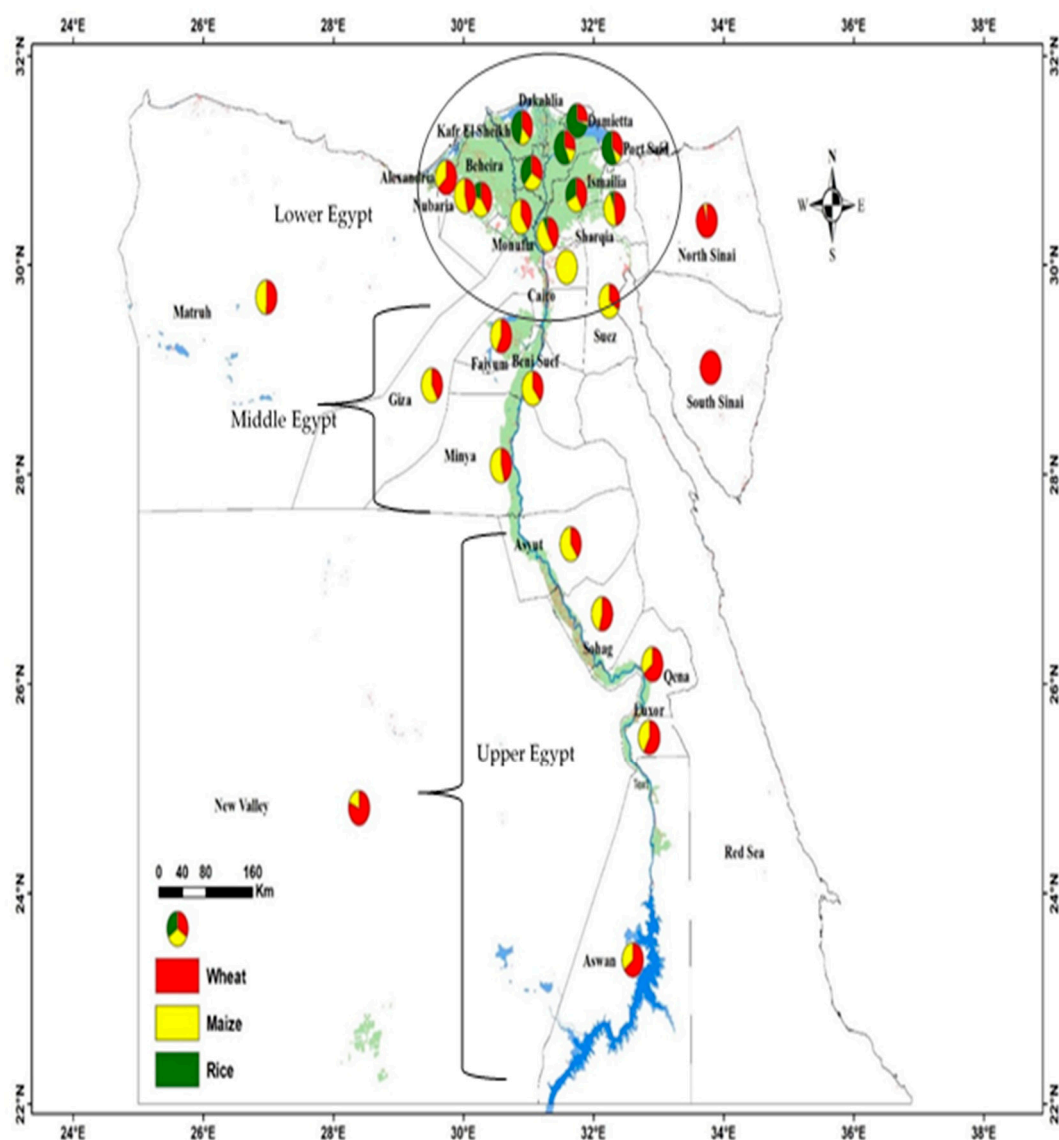


Figure 1. Grains area by region, 2017.

On one hand, Egypt's productivity per unit of land planted to cereal grains is one of the highest globally. However, the growth rate of land productivity has slowed in the last decade and most of the gains in the average crop yields per hectare occurred earlier during the 1980–1989 and 1990–1999 subperiods. As Table 1 exhibits, wheat, maize, and rice yields at the national level grew by less than one percent annually during 2000–2017, on average, down from an average of 3.50%, 3.53%, and 2.20% per year, respectively, during 1980–1999. The slowdown in land productivity in recent years can be attributed to the degradation of land fertility and water resources [22], as well as the decline in government spending on agricultural research and development [23,24].

On the other hand, the area planted in grains has expanded in recent years. Since 1980–1989, wheat plantings grew from an average of 559 thousand to 1.36 million hectares during 2010–2017 due to higher domestic wheat procurement prices which incentivized local wheat production relative to competing crops such as clover [25,26]. Clover plantings sharply decreased from 1.14 million hectares in 1980–1989 to 730 thousand hectares in the 2010–17 period. As a result of the horizontal expansion and higher productivity, the total average production of wheat has quadrupled since 1980 from 2.20 million tons during 1980–1989 to 8.75 million tons during 2010–2017. Likewise, maize area increased by 15% during 2010–2017 compared to 2000–2009 offsetting the sharp decline in cotton area (46%) during the same period as well as a small reduction in rice plantings (13%). Consequently, the total production of maize increased by 17% from 6.7 million to 7.8 million tons when comparing the 2000–2009 and 2010–2017 periods, while the total production of rice declined by 13% over the same period (Figure 2).

Table 1. Grains production in Egypt from 1980 to 2017.

Periods	Wheat				Maize				Rice			
	Area 000 ha	T.Q 000 tons	Yield ton/ha	GR ¹ %	Area 000 ha	T.Q 000 tons	Yield ton/ha	GR *	Area 000 ha	T.Q 000 tons	Yield ton/ha	GR *
1980–1989	559	2204	3.92	4.50	590	3662	4.57	3.71	406	2371	5.83	1.25
1990–1999	956	5238	5.46	2.50	701	5313	6.48	3.34	552	4472	8.04	3.14
2000–2009	1144	7376	6.45	0.10	729	6656	7.85	0.39	646	6239	9.65	0.77
2010–2017	1358	8751	6.45	0.90	936	7774	7.63	−0.04	559	5472	9.43	−0.76
1980–1999	757	3721	4.69	3.50	646	4488	5.52	3.53	479	3421	6.94	2.20
2000–2017	1239	7987	6.45	0.4	821	7153	7.75	0.2	607	5810	9.55	0.094

¹ T.Q = Total quantity produced, GR = Growth Rate and calculated as the first difference in the logarithms of crop yield.
Source: CAPMAS, Statistical Yearbook.

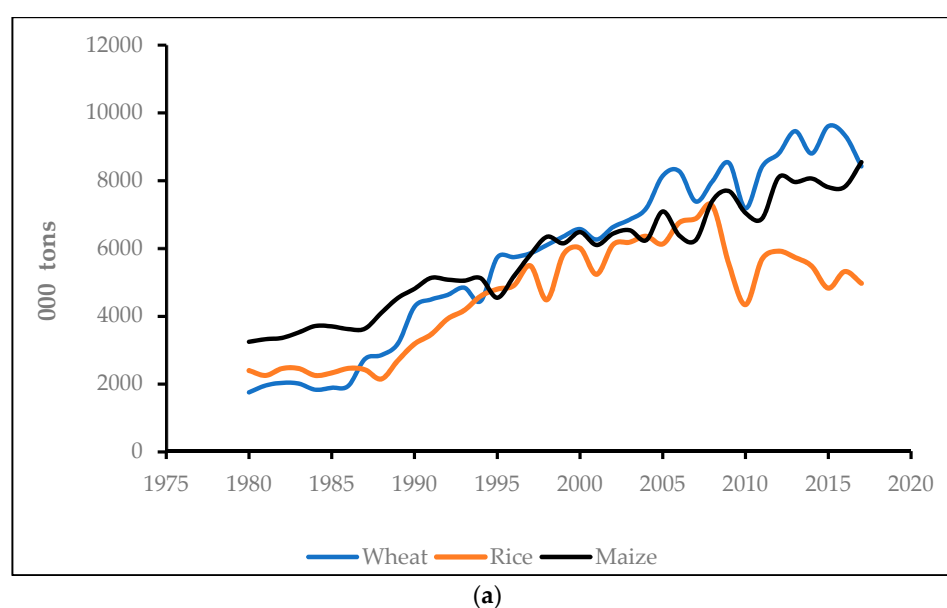


Figure 2. Cont.

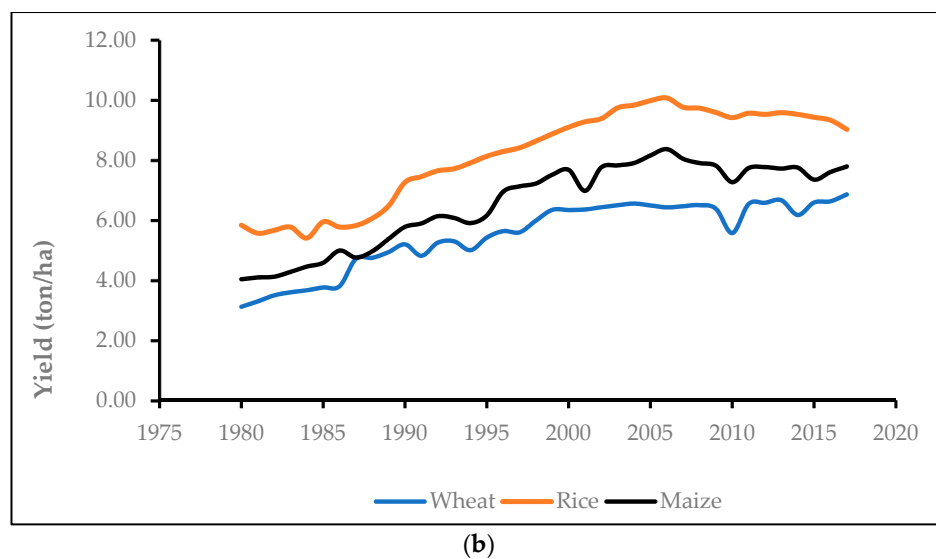


Figure 2. Grains production in Egypt from 1980 to 2017: (a) Total quantity produced (000 metric tons); (b) Yield per hectare (ton/ha).

Seemingly, grains production in Egypt relies on high productivity and the expansion of cultivated areas. But in the future, such increases are unlikely due to water shortages, climate change, and urban encroachment on arable lands as well as degradation of fertile lands due to agricultural intensification and pollution.

3. Agricultural Production and Irrigation Policies

Achieving self-sufficiency in primary crops, while promoting the sustainable use of land and water resources, are the top strategic goals of Egypt's current policies and development plans. Starting in 1975, The Egyptian Ministry of Water Resources and Irrigation (MWRI) established a "Water Resources Policy" to evaluate water supply and demand and estimate the potential balance between water demand and supply in the future. In 1981, MWRI prepared the "National Water Master Plan" in order to meet water needs for agricultural development and to study other sectors' demand for water [27]. In 1995, MWRI developed the "Water Resources Strategy of Egypt Until 2017". The strategy's main purpose was to secure an extra 24 BCM of water required for the projected land reclamation programs in 2017 through the reduction of rice and sugarcane cultivated areas (as they require significant irrigation), increasing utilization of groundwater, recycling agricultural drainage water, and the construction of the Jonglei Canal [28]. In 2005, MWRI prepared the "National Water Resources Plan" based on the approach of integrated water resources management to ensure sustainable development and management of water resources. Based on the plan, the Egyptian Ministry of Agriculture and Land Reclamation (MALR) developed a policy aimed at enhancing food security and increasing agricultural production through maximizing water-use efficiency [29].

In 2009, MALR developed the "Sustainable Agricultural Development Strategy Towards 2030" (SADS) paying great attention to the sustainable use of agricultural land and water resources through maintenance and protection of agricultural land, increasing water-use efficiency within the irrigation system from 50% in 2007 to 80% by 2030, and reducing rice plantings from 1.67 million to 1.3 million feddans between 2007 and 2030. These measures were intended to conserve the water needed for reclaiming 1.25 million feddans of land by 2017, and further to 3.1 million feddans by 2030 [30].

The strategy gives priority to the production of strategic crops that largely contribute to current food imports, particularly wheat, maize, and sugar crops, aligned with broader Egyptian goals aiming at increasing self-sufficiency ratios and improving food security. The SADS plans to increase agricultural productivity per unit of land and water through the development of drought, salinity,

and pest-resistant varieties, cultivating early maturing crop varieties, raising clover productivity, and adopting good agricultural and management practices.

4. Methodology

The production of crop i in year t is a function of the crop planted area and productivity per unit of land. This study estimated the planted area in year t as a response to the harvested area, Ah_{it-1} , in year $(t - 1)$, the commodity's own price, P_{it-1} , in year $(t-1)$, the cultivated areas with main competing crops, Ah_{kt} , in year t , and the growth rate of the total crop area, GCA_t , capturing the expansion as a result of increasing demand and availability of water and land, or the reduction as a consequence of water shortages and encroachment on fertile lands as well as water usage by the crop i in year t (IW_{it}) capturing the effects of water shortages on the crop area.

$$Ah_{it} = \beta_1 + \beta_2 Ah_{it-1} + \beta_3 P_{it-1} + \beta_4 Ah_{kt} + \beta_5 GCA_t + \beta_6 IW_{it}u \quad (1)$$

where β_1 is the constant, $\beta_2, \beta_3, \beta_4, \beta_5$ and β_6 are estimated parameters, and u is the error term.

Then, trends in productivity are estimated as a function of the historical growth rate (GY_{it}) in crop yield and a time trend (t).

$$Y_{it} = \alpha + \gamma GY_{it} + \delta t + e \quad (2)$$

where α is the constant, γ and δ are parameters to be estimated, and e is the error term. Then, the total quantity produced of the crop is calculated as a product of its harvested area and yield per unit of land.

$$TQ_{it} = Ah_{it} * Y_{it} \quad (3)$$

where TQ_{it} is total quantity produced of crop i in year t , Ah_{it} is the harvested area of crop i in year t , and Y_{it} is the yield per hectare of the crop i in year t .

5. Empirical Model and Data

5.1. Area Estimation and Forecast

Equation (1) was estimated for each crop as a log-linear functional form using Ordinary Least Squares Estimation (OLS) and annual data from 1980 to 2017.

$$\ln Ah_{it} = \beta_1 + \beta_2 \ln Ah_{it-1} + \beta_3 \ln P_{it-1} + \beta_4 \ln Ah_{kt} + \beta_5 GCA_t + \ln IW_{it} + u \quad (4)$$

where \ln is the natural logarithm and Ld is the first difference of the logarithm of certain variables.

Table 2 presents summary statistics for the data used to estimate Equation (4) for each crop. All the data are national level measures. Data on the total quantity produced in thousand metric tons (000 MT), area harvested in thousand hectares (1000 ha), and productivity per hectare for each crop (MT/ha) as well as total crop area in thousand hectares (1000 ha) were compiled from the Statistical Yearbook and the Annual Bulletin of Statistical Crop Area and Plant Production published by the Central Agency for Public Mobilization and Statistics (CAPMAS) in Egypt (available at <https://www.capmas.gov.eg>). Additionally, data on irrigation water for each crop are compiled from the Annual Bulletin of Irrigation and Water Resources Statistics published by the Central Agency for Public Mobilization and Statistics (CAPMAS) in Egypt (available at <https://www.capmas.gov.eg>). Producer prices per metric ton in Egyptian pounds were obtained from the FAO's food and agriculture database (FAOSTAT) and are available at <http://www.fao.org/faostat/en/#home>.

Table 2. Summary of data statistics: annual production of wheat, maize and rice from 1980 to 2017.

		Obs.	Mean	Median	Std. Dev.	Min.	Max.
Wheat	Area Harvested (000 ha)	38	985	1023	305.84	491	1458
	Total Production (000 MT)	38	5742	6174	2572.47	1736	9608
	Yield (MT/ha)	38	5.52	5.81	1.14	3.12	6.86
	Producer prices (LE/MT)	38	1060	685	980.94	82	3700
	Clover Area (000 ha)	38	982	1023	163.52	641	1192
	Water Usage (MCM)	38	3536	3665	1287	1640	6200
Maize	Area Harvested (000 ha)	38	729	706	137.08	471	1096
	Total Production (000 MT)	38	5750	6118	1608.46	3231	8543
	Yield (MT/ha)	38	6.58	7.18	1.40	4.04	8.37
	Producer prices (LE/MT)	38	954	592	852.89	95	3400
	Competing crops Area (000 ha)	38	985	1009	105.43	753	1163
	Water Usage (MCM)	38	4953	4580	1069	3289	8340
Rice	Area Harvested (000 ha)	38	540	566	103.28	352	745
	Total Production (000 MT)	38	4553	4857	1577.82	2132	7253
	Yield (MT/ha)	38	8.18	8.76	1.59	5.41	10.08
	Producer prices (LE/MT)	38	957	687	854	82	4000
	Competing crops Area (000 ha)	38	1162	1170	80.15	987	1323
	Water Usage (MCM)	38	7998	7811	1243.76	5426	10839
	Winter Crop area (000 ha)	38	2535	2648	290.38	2069	2884
	Summer Crop area (000 ha)	38	2417	2450	282.66	2016	2850

In order to forecast crop area, the study projected the key determinants representing strong drivers of future crop area decisions through 2030. Assumptions about total crop area, irrigation water, and competing crops area begin from a base period of 2010–2017 while assumptions about crop prices begin from a base period of the most recent year available (more recent estimates may be inconsistent due to volatility from floating the Egyptian pound at the end of 2016 through 2017). Wheat prices increased by 15% in 2019 from 3800 LE/MT in 2018 to 4367 LE/MT in 2019 [31] while maize prices were 38% higher in 2017 than in 2016, rising from 2458 LE/MT in 2016 to 3400 LE/MT in 2017 [32]. Likewise, rice paddy prices climbed to 4400 LE/MT in 2018 compared to 4000 LE/MT in 2017 [33].

Egypt's share of the Nile's flow is expected to decline as a result of the construction of the Grand Ethiopian Renaissance Dam (GERD) if the first filling of the GERD occurs during dry seasons, and not during wet or average years [34–37]. Accordingly, the irrigated crop area will decline, especially in newly reclaimed lands and upstream areas in the Lower Egypt region. Since the GERD is set to be fully operational by the end of 2022, the study assumes a 0.1% annual decline in total crop and a 1% annual decline in irrigation water from 2020 to 2022 as a result of water scarcity in addition to the expected urban sprawl and encroachment of human settlements on arable areas. Starting in 2023, the study projects a 3% decline a year in the total crop area and 2% decline a year in irrigation water in response to a modest reduction of future water supplies (Table 3).

Table 3. Total crop area, water usage, crop prices assumptions, 2020–2030.

Year	Growth Rate in Total Crop Area %	Log Difference of Water Usage	Crop Prices in year t-1 (LE/MT)		
			Wheat	Rice	Maize
2020	−0.1	−0.01	4367	4600	3600
2021	−0.1	−0.01	4467	4800	3700
2022	−0.1	−0.01	4567	5000	3800
2023	−3	−0.02	4667	5200	3900
2024	−3	−0.02	4767	5400	4000
2025	−3	−0.02	4867	5600	4100
2026	−3	−0.02	5067	5900	4300
2027	−3	−0.02	5267	6200	4500
2028	−3	−0.02	5467	6500	4700
2029	−3	−0.02	5667	6800	4900
2030	−3	−0.02	5867	7100	5100

5.2. Assumptions

Assuming moderate fluctuations in exchange rates and costs of production, this study projects wheat prices will increase by 100 LE/MT annually until 2024 starting from 4367 LE/MT in 2019 and by 200 LE/MT annually from 2025 to 2030 up from the projected price in 2024. For instance, the projected price of wheat will be 4467 LE/MT in 2020, 4567 LE/MT in 2021, and so on until it hits 4867 LE/MT in 2024 while it will be 5067 LE/MT in 2025, 200 LE/MT up from the 2024 projected price, and it continues to increase by the same rate until to 2030. Likewise, this study projects maize prices to increase by 100 LE/MT annually until 2024 starting from 3400 LE/MT in 2017 and by 200 LE/MT annually from 2025 to 2030 up from the projected price in 2024. Rice prices are projected to increase annually by 200 LE/MT till 2024 starting from 4400 LE/MT in 2018 and by 300 LE/MT annually from 2025 to 2030. Additionally, all the estimated prices presented in Table 3 are prices in year $t-1$.

Furthermore, the study assumes that the first filling of the GERD will occur in 2023 as it is announced by the Ethiopian government, resulting in a reduction in water inflows to Egypt and in turn, a decline in the total crop area and irrigation water as illustrated in Table 3. Moreover, it is presumed that clover plantings, the main competitor of wheat in the winter season, will remain unchanged while it is assumed a 1% decline per year in competing crop plantings in the summer season from 2020 to 2022, followed by a 3% decline per year from 2023 to 2030.

5.3. Yield Estimation and Forecast

Equation (2) presents the yield estimation model regressed using Ordinary Least Squares Estimation (OLS) and annual data from 1980 to 2017. After estimating yield, the future growth rates in crop yields were projected under three scenarios beginning from a base period of 2010–2017 and summarized in Table 4.

Table 4. Scenarios for growth rates in crop yields, 2020–2030.

Scenario 1: Stagnant Productivity	Scenario 2: Low-Yield	Scenario 3: High-Yield	Target Level (MALR)
Crop yields would freeze at the base period (2010–2017) levels: 6.45 tons/hectare of wheat. 7.63 tons/hectare of maize. 9.43 tons/hectare of rice.	Relative to Scenario 1: 10% decline in yield growth rate for wheat 15% decrease in yield growth rate for rice and maize	Relative to Scenario 1: 1% annual increase in all crop yields.	Projected crop yields with effective SADS policies: 8.57 tons/hectare of wheat 11.90 tons/hectare of maize 12.38 tons/hectare of rice

Scenario 1: Presuming no change in future water flows into Egypt, no significant increase of mean temperature in the next decade, and no change in government policies or management practices affecting productivity, the first scenario anticipates stagnant productivity to 2030. Such estimates explicitly reflect the current and assumed inadequate investments and spending on agricultural research and development, as well as the expected slowdown in yield growth. Under this scenario, the future crop yields would freeze at the base period levels notwithstanding the expected improved varieties and other agricultural inputs such as fertilizers and pesticides.

Scenario 2: Coupled with global warming, the anticipated future water shortages will have an adverse impact on crop yields in Egypt. Agriculture in Egypt depends heavily on irrigation, and a large portion of irrigated areas are under inefficient surface irrigation schemes. Further, Egypt is vulnerable to climatic warming because of its overdependence on the Nile as a water source, erosion of arable lands along the lengthy coastline and the large traditional agricultural sector [38]. A rise of mean temperature would escalate the evaporation rate and increase the demand for irrigation water. Previous research concluded there would be a severe reduction in water flows to Egypt due to construction of the GRED that would largely affect the agricultural sector in the summer season [39,40]. These same studies suggested that agricultural production would shift from water-intensive crops such as rice, sugar cane, and winter fodders to less water-consuming crops. Moreover, there are a number of studies that predict a negative impact of climate change on primary crop yields including

wheat, rice, and maize [18,22,38,41]. Thus, under the second scenario, the study projects a 10% decline in the growth rate of wheat yields and a 15% decrease in growth rate of rice and maize yields during 2020–2030 relative to the base period.

Scenario 3: Potential dire consequences from future water shortages, climate change, and degradation of fertile lands on Egyptian agriculture may encourage the government, as well as the private sector, to increase their spending on agricultural research and irrigation infrastructure in order to conserve water and increase crop yields. Based on the findings from previous research and recommended strategies, SADS projected crop yields to be 3.6 tons per feddan of wheat (8.57 per hectare) by 2030 up from 2.7 tons per feddan in 2007, 5 tons per feddan of maize (11.90 per hectare) up from 3.5 tons per feddan in 2007, and 5.2 per feddan of rice (12.38 per hectare) up from 4.1 tons per feddan in 2007. However, the progress towards the target levels of productivity is modest thus far. Therefore, the scenarios in this study assume a more probable 1% annual increase in crop yields.

6. Results and Discussion

6.1. Harvested Area

Table 5 displays a summary of regression estimates for the harvested area of wheat, maize and rice for Equation (4). Scarce resources (water and fertile lands) are the main determinants of the future planting areas. Water availability will allow the country to augment croplands through reclamation and, accordingly, the coefficient on water usage was statistically significant and large for the three crops. The coefficient on the growth rate of total crop area was statistically significant only in the case of wheat and maize but insignificant in the case of rice. Such findings may be because wheat and maize are grown throughout Egypt and are better suited to newly reclaimed lands while the cultivation of rice is limited to the Nile Delta in the Lower Egypt region and more closely linked to water availability.

Table 5. Summary of regression estimates: harvested area.

Variable	Wheat		Maize		Rice	
	Coefficient	Std. Error	Coefficient	Std. Error	Coefficient	Std. Error
Intercept	0.6192 *	0.2535	1.4973 *	0.6110	1.5353 *	0.6185
$LnAh_{it-1}$	0.8756 **	0.0511	0.7271 **	0.1083	0.7132 **	0.1141
LnP_{it-1}	0.0357 *	0.0161	0.0469 *	0.0186	0.0412	0.0222
$LdAh_{kt}$	−0.4487 **	0.0864	−0.4698 **	0.1245	−0.7161 *	0.3062
GCA_t	0.01397 **	0.0027	0.03277 *	0.0146	0.0056	0.0032
$LdIW_{it}$	0.2275 **	0.0424	0.1586 *	0.0703	0.2270 *	0.1050
R^2	0.9926		0.9207		0.8137	
Adj. R^2	0.9914		0.9083		0.7846	
F-statistic	857.05		74.330		27.9513	
p-value (F-statistic)	0.0001		0.0001		0.0001	
S.E. of regression	0.0320		0.05413		0.0917	
Akaike criterion	−148.298		−108.3308		−68.251	
Schwarz criterion	−138.47		−98.5053		−58.4257	
Durbin-Watson	1.7519		2.1689		2.2671	
p-value (DW)	0.1413		0.6746		0.7266	
Theil's U	0.7375		0.6159		0.7375	
Bias proportion	0.00		0.00		0.00	
Regression proportion	0.00		0.00		0.00	
Disturbance proportion	1.00		1.00		1.00	
MAPE ²	0.3545		0.5734		1.058	
RMSE	0.0294		0.04968		0.0842	

1. * significant at 5% and ** significant at 1%, ² MAPE = Mean Absolute Percentage Error, RMSE = Root Mean Squared Error.

Lagged variables are important factors for producer decisions related to future grain cultivation. Lagged planted areas have a significant impact on the harvested area in year t reflecting the cumulative experience and fixed human and built capital that producers have gained over time. Additionally, traditional crops like wheat, maize, and rice are less risky and do not require as much technical knowledge as producing higher-value crops such as vegetables. However, the area response to lagged prices is statistically significant only in the cases of wheat and maize, but less elastic for the other three crops since most Egyptian growers are smallholders and grow grains primarily for home consumption (in addition to using crop residue such as wheat straw as animal feed).

Moreover, grain crops compete with the other crops cultivated in the same season for scarce water resources and limited arable lands. For example, the coefficient on log difference of clover area ($LdAh_{kt}$) in the case of wheat emphasizes the heightened competition between the two crops as wheat has managed to displace clover since 1980. Rice, cotton, and maize are competing with each other in the Lower Egypt region while maize competes with sorghum in the Middle and Lower Egypt regions. For instance, maize area expanded by 15% during 2010–2017, replacing cotton and rice. This suggests that there could be a tradeoff between grain production and other crops in the future. The potential water shortages and concern about food security may force the country to choose grain production over other options such as sugar crops, winter fodder, and fiber crops.

These findings emphasize the sustainable use of water and land resources as a policy option to mitigate the impact of water scarcity and partially compensate for potential future water reductions. Increasing water-use efficiency through investing in irrigation infrastructure and improving water resources management practices could raise agricultural productivity, limit the degradation of land fertility, and provide more water for expanding the cultivated area, leading eventually to increased food production and enhanced food security [22,40,42–44]. Moreover, much support and attention should be paid to small farmers that are often seen as the driving force of agricultural development, and food security in many areas of the country. Policymakers, scientific researchers, private sector stakeholders, and NGOs should jointly work to facilitate small producers' access to improved irrigation technologies and practices, improved inputs, and up to date technical knowledge [45].

Table 6 shows harvested area projections through 2030 based on the regression estimation results in Table 5 and the underlying assumptions illustrated in Section 5.2 and Table 3. Assuming clover harvested area will remain unchanged, on average, it is expected that wheat harvested area would decline by around 5% during 2020–2030 compared to the base period (2010–2017) in response to expected water and land diversions to urban development. Before the first filling of the GERD, wheat harvested area is projected to slightly expand, exceeding the base period by 1.12% in 2022. Once there are reductions in water supplies in following years, wheat harvested area will annually decrease by 1.32% starting in 2023, and ultimately, decline to 9% in 2030 compared to the base period.

The impact of water shortages will be greater when considering summer crops. Rice cultivated area has varied greatly over 2010–2017 in response to the government's proposed reduction of rice planted area from 1.673 million feddans (703 thousand hectares) to 1.3 million feddans (546 thousand hectares) between 2007 and 2030 in order to conserve water. Hence, the government has limited rice plantings to 452 thousand hectares since 2017 and fined producers 8000 LE per hectare for cultivating rice outside the specified area. Because rice cultivation in the Northern Delta fights soil salinization resulting from the rise of the sea level, the study projects rice plantings to meet the government limit of 452 thousand hectares through 2030.

Maize harvested area is projected to decline, on average, by 7% during the period 2020–2030 compared to the base period as shown in Table 6, assuming a 1% decline per year in competing crop plantings from 2020 to 2022, followed by a 3% decline per year from 2023 to 2030. In the first three years, the area will increase from the base period, while later it will decrease annually ranging from a small decline of 1% in 2023 to a larger contraction of 18% by 2030.

Table 6. Projection of wheat and maize harvested areas to 2030.

Year	Wheat		Maize	
	Area 000 ha	% change	Area 000 ha	% change
2010–2017	1358	—	936	—
2020	1317	−3.05	1025	9.47
2021	1346	−0.89	1015	8.47
2022	1373	1.12	1010	7.88
2023	1340	−1.32	923	−1.40
2024	1313	−3.34	866	−7.53
2025	1290	−5.00	827	−11.65
2026	1273	−6.29	802	−14.33
2027	1259	−7.29	786	−16.06
2028	1249	−8.02	776	−17.12
2029	1242	−8.55	770	−17.72
2030	1237	−8.89	767	−18.00
2020–2030	1294	−4.68	870	−7.09

Egypt's SADS towards 2030 gives a priority to wheat and maize production in the future. Further, Gohar and Ward [43] suggested that food staples might not be affected by the modest water supply reductions (10% supply reduction) because of food security goals. However, severely reduced water inflows will have a substantial impact on agricultural production and, in turn, food security [40,43,46]. Furthermore, a focus on increasing self-sufficiency has resulted in allocating more water for irrigation with little attention to efficient irrigation practices [47].

6.2. Crop Yield

Table 7 exhibits a summary of regression estimates for crop yield resulting from Equation (2) using a Prais–Winsten regression in order to correct for first-order autocorrelation. Yield trends are estimated as a function of the growth rate in crop yield and a squared time trend. The growth rate in the crop yield captures the effects of water shortages and climate change on crop yield in the short run while the time trend reflects the impact of technology advancements, agricultural research, and development, and agricultural extension services to provide technical assistance that might augment crop yield in the long run.

Table 7. Summary of regression estimates: crop yield.

Variable	Wheat		Maize		Rice	
	Coefficient	Std. Error	Coefficient	Std. Error	Coefficient	Std. Error
Intercept	2.7797 **	0.2140	3.2800 **	0.3182	5.4770 **	0.6584
GY_{it}	0.02479 **	0.0036	0.0326 **	0.0051	0.0304 **	0.0063
t	0.2192 **	0.0251	0.2674 **	0.0366	0.2172 **	0.0543
t^2	−0.00314 **	0.0006	−0.00393 **	0.0009	−0.00314 *	0.0013
R^2	0.9769		0.9833		0.9896	
Adj. R^2	0.9749		0.9818		0.9887	
F-statistic	57.1747		39.9605		24.5325	
P-value (F-statistic)	0.0001		0.0001		0.0001	
S.E. of regression	0.1821		0.1920		0.1741	
Durbin-Watson	1.5500		1.3986		0.7510	
Theil's U	0.4728		0.5717		0.6556	
Bias proportion	0.0016		0.0030		0.0007	
Regression proportion	0.0282		0.0524		0.0621	
Disturbance proportion	0.9702		0.9446		0.9372	
MAPE ²	2.4153		2.2976		1.7762	
RMSE	0.1274		0.1829		0.1669	

¹. * significant at 5% and ** significant at 1%; ² MAPE =Mean Absolute Percentage Error, RMSE= Root Mean Squared Error.

As Table 7 shows, the coefficient on the quadratic trend is negative, indicating a decline in crop yields in the long run: such sluggish yields are assumed to be a result of current poor agricultural practices. Specifically, excess irrigation as a result of low water-use efficiency will cause the degradation of land fertility as well as deterioration of water quality leading to a decline in land productivity, especially in the vulnerable areas of the Delta that are susceptible to the rise of the water- table and the water salinization [22].

Table 8 shows the projected yield trends under 3 different scenarios; stagnant productivity, low-yield, and high-yield. Under the first scenario, crop yield will freeze at the base period levels during 2020–2030. This scenario is likely because of inadequate and inappropriate agricultural extension services, and insufficient investment in agriculture research and development. The second scenario considers the impact of water shortages and climate change on crop yields. As Table 8 exhibits, the wheat yield will decrease, on average, by around 8% while the projected decline in maize and rice yields is higher at around 12% in 2020–2030 compared to the base period. In contrast, if the government allocates more investment to agriculture R&D and increases spending on irrigation infrastructure, crop yields are projected to increase, on average, by around 6%.

6.3. Total Production

Table 9 shows the projected grains production through 2030 derived from the crop area projected in Table 6 and crop yield projected in Table 8. The potential reduction in the Nile flows into Egypt will adversely impact agricultural production especially in the summer season by reducing arable areas, limiting the country's ability to reclaim new lands, and decreasing crop yield. Indeed, rice production will be the most affected. The total rice production is projected to decline, on average, by 22% during 2020–2030 compared to the base period, and further to 31% under the conditions assumed in the second scenario. The projected modest increase in rice productivity under the third scenario will not compensate for the decline in rice area imposed in 2017, and therefore, rice production is projected to decline by around 17% during 2020–2030 compared to the base period of 2010–2017. Consequently, Egypt started to import rice in 2017 to compensate for the expected permanent reduction in rice planted area.

Similarly, maize production is projected to have the same pattern but will be less affected than rice. Under stagnant productivity, the projected maize production will decline, on average, by around 15% in response to the anticipated decline in maize planted area due to future water shortages. Under the second scenario, future water shortages will decrease both the area planted to maize and yield and, thus, the total production of maize will decline further: by 24% on average. Moreover, the one percent increase in maize yield per hectare projected under the third scenario will not increase aggregate maize total production since planted area is expected to decline in response to water supply reductions.

As it is grown in winter and requires less water, wheat is the least affected grain crop when considering the potential reduction in water inflows. If the productivity per hectare is frozen at the levels of the base period, total production of wheat would slightly decrease by an average of around 5% per year during 2020–2030 as a result of the slight reduction in planted area. If wheat yields declined, the projected wheat production would decline by 12%. By contrast, an increase in wheat yield by 1% would compensate for the reduction in cultivated area and increase wheat production by an average of 1% per year during 2020–2030.

Consequently, Egypt's reliance on imports will continue and food imports of grains would increase as the population rapidly expands, leading the total cultivable area under primary crops to decrease. Over the next few decades, grains will likely displace other choices as sugar cane, cotton, vegetables, and clover if the country decides to increase self-sufficiency of grains. Moreover, Egypt might add new crops such as vegetables to its targeted food import choices as a result of future water shortages.

Table 8. Projection of crop yields to 2030.

Years	Wheat (ton/ha)			Maize (ton/ha)			Rice (ton/ha)		
	Stagnant Productivity	Low-Yield	High-Yield	Stagnant Productivity	Low-Yield	High-Yield	Stagnant Productivity	Low-Yield	High-Yield
2020	6.45	6.24	6.52	7.63	7.14	7.70	9.43	8.66	9.52
2021	6.45	6.20	6.58	7.63	7.08	7.78	9.43	8.61	9.62
2022	6.45	6.15	6.65	7.63	7.01	7.86	9.43	8.56	9.71
2023	6.45	6.10	6.71	7.63	6.94	7.93	9.43	8.51	9.81
2024	6.45	6.04	6.78	7.63	6.86	8.01	9.43	8.45	9.90
2025	6.45	5.97	6.84	7.63	6.77	8.08	9.43	8.38	9.99
2026	6.45	5.90	6.91	7.63	6.67	8.16	9.43	8.30	10.09
2027	6.45	5.82	6.97	7.63	6.56	8.24	9.43	8.22	10.18
2028	6.45	5.74	7.03	7.63	6.45	8.31	9.43	8.14	10.28
2029	6.45	5.65	7.10	7.63	6.32	8.39	9.43	8.04	10.37
2030	6.45	5.55	7.16	7.63	6.19	8.47	9.43	7.94	10.47
Average 2020–2030	6.45	5.94	6.56	7.63	6.73	8.08	9.43	8.35	9.99
% change of 2010–2017	0.00	−7.87	6.06	0.00	−11.81	5.89	0.00	−11.88	6.00

Table 9. Projection of total production to 2030.

Years	Wheat (000 tons)			Maize (000 tons)			Rice (000 tons)		
	Stagnant Productivity	Low-Yield	High-Yield	Stagnant Productivity	Low-Yield	High-Yield	Stagnant Productivity	Low-Yield	High-Yield
2020	8495	8218	8587	7821	7319	7893	4262	3914	4303
2021	8682	8345	8857	7744	7186	7897	4262	3892	4348
2022	8856	8444	9130	7706	7080	7939	4262	3869	4389
2023	8643	8174	8991	7042	6406	7319	4262	3847	4434
2024	8469	7931	8902	6608	5941	6937	4262	3819	4475
2025	8321	7701	8824	6310	5599	6682	4262	3788	4515
2026	8211	7511	8796	6119	5349	6544	4262	3752	4561
2027	8121	7327	8775	5997	5156	6477	4262	3715	4601
2028	8056	7169	8780	5921	5005	6449	4262	3679	4647
2029	8011	7017	8818	5875	4866	6460	4262	3634	4687
2030	7979	6865	8857	5852	4748	6496	4262	3589	4732
Average 2020–2030	8349	7700	8847	6636	5878	7008	4262	3773	4518
% change of 2010–2017	−4.59	−12.00	1.1	−14.64	−24.39	−9.95	−22.11	−31.06	−17.44

7. Conclusions and Policy Implications

Among all crops planted in Egypt, grains are the most important. Although Egypt's grain productivity per unit of land is one of the highest globally, the growth rate of land productivity has slowed over the last decade. Egypt's strategies, policies, and development plans have placed emphasis on increasing self-sufficiency using strategic staple crops. Therefore, the country has invested considerable resources in land reclamation since 1952 to increase agricultural production. However, increasing production of such crops on new lands is currently limited due to scarce water and waning productivity on available land resources.

The estimates from this research show that grain productivity grew, on average, by less than one percent annually from 2000 to 2017. Further, grain crops directly compete with the other crops cultivated in the same season for the scarce water resources and limited arable lands. In order to increase grain production over the last couple of decades, the country depended heavily on expanded harvest areas and the formerly high (but recently lagging) yield per unit of land.

One valid alternative is the investment in irrigation infrastructure, particularly in heritage production areas of the Nile valley and Delta (with perhaps outdated practices) to increase efficiency of the irrigation system. Conserving water will ultimately raise crop yields if water is reallocated to more productive uses, and enhancing productivity by increasing water-use efficiency would optimize the potential increase in production from land reclamation [22]. Moreover, more effective water-utilization practices may compensate for the potential reduction in Nile water flows [40].

Another valid alternative for Egypt is to increase spending on agricultural research and development to raise both land and water productivity. Public spending on research and development in Egypt may be a constraint to productivity since the country spent an average of 0.45% of its total GDP per year from 2004 to 2016 compared to 0.67% in Tunisia, 0.73% in Turkey, 1.12% in Brazil, and 4.15% in Israel [48]. Further, in 2012, Egypt's agricultural research expenditures dropped to 0.4% of its to agricultural GDP compared to 0.5% in Tunisia, 0.6% in Turkey, and 2% in Brazil [49]. These reductions in research are counter to food security and sustainability goals since there is evidence research is necessary to increase productivity per unit of land and water.

In short, increasing self-sufficiency for Egypt's primary staple crops through sustainable use of land and water resources has become a top strategic goal of Egypt's development plans. However, a fast-growing population, dwindling resources, and the struggling economy could threaten the country's capacity to achieve food security for all Egyptians in the long run. The potential reduction in flow from the Nile into Egypt will adversely impact agricultural production, especially in the summer season by reducing cultivatable area, limiting the country's ability to reclaim new lands, and decreasing crop yields. Consequently, agricultural production is predicted to decline in the next decade, suggesting that Egypt's reliance on imports will continue and food imports of grains would increase as the population rapidly grows and the cultivable areas and yields are predicted to decrease.

Author Contributions: Author contributions were shared with the conceptualization, resources, validation, writine shared by H.S.A.A. and D.T.; methodology, formal analysis and data curation, led by H.S.A.A.; and, supervision and project administration, led by D.T.

Funding: This research was funded by the United States Agency for International Development (USAID) in Cairo with collaboration with the Cultural Affairs and Missions Sector, Ministry of Higher Education-Egypt through the Egyptian Cultural and Educational Bureau -Washington DC and the Colorado Ag Experiment Station.

Acknowledgments: Technical support by Muhammad Elwakeel, Department of Geography, Faculty of Arts, Minia University is appreciatively acknowledged.

Conflicts of Interest: The authors declare no conflict of interest.

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