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Nile Water Availability and Agricultural Productivity in Egypt: A CGE Approach

EMANUELE FERRARI*, SCOTT MCDONALD*, REHAB OSMAN*

*Oxford Brookes University

Department of Accounting, Finance and Economics – Faculty of Business

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Address for correspondence:
Rehab Osman
Business School
Department of Accounting, Finance and Economics
Oxford Brookes University
Wheatley Campus
Oxford
OX33 1HX
Email: rosman@brookes.ac.uk
Tel: +44 (0)1865 485964

Abstract

Agriculture and irrigation in Egypt are highly reliant on Nile water availability. Examining the potential implications on the anticipated changes in Egypt's share of the Nile water for Agriculture is one of the most crucial political issues in the Nile Basin region. This paper undertakes quantitative impact assessment of potential water availability implications using a variant of the single country CGE model (STAGE) for Egypt. Its ultimate goal is to establish a benchmark for analysing how potential changes in Nile water supply would affect the Egyptian economy and for understanding how the optimal allocation of scarce irrigation water would be defined. The study results inform policymakers the best measures directed to minimize potential adverse impacts of water availability shock to the economy. Simulation scenarios conduct different water losses across irrigation seasons. Preliminary results indicate negative economy-wide impact, particularly under the restricted construction plan for the Grand Ethiopian Renaissance Dam. The Egyptian economy would be more affected by water reduction in the summer season whereas the least impact occurs during the Nili season.

Table of Contents

1. Background and Policy Relevance

Since their independency in the 1960s, the upstream Nile riparian states have been challenging the validity of the historical 1959 Nile Waters Treaty whereby Egypt and Sudan allocate over 95% of the Nile waters to themselves. The dilemma in the Nile context is that the upstream riparian states that generate 86 percent of Nile water use less than 5 percent of it. In order to establish more equitable regime for Nile water, Entebbe Agreement, signed in 2010 in the absence of the downstream states, allows upstream states to use higher shares of Nile water for irrigation and hydropower generating activities. In April 2011, Ethiopia has launched the construction of the Grand Ethiopian Renaissance Dam, GERD. With water storage capacity of 63 billion cubic metres and energy generation capacity of 6,000 MW, the GERD is anticipated to be the biggest hydroelectric power plant and one of the largest water reservoirs in the continent.

Egypt and Sudan have expressed serious concerns of diminishing their shares of Nile water. As a step towards more cooperation and trust among the Nile basin states, Ethiopia proposed forming the Nile Tripartite Committee. In effect, the Committee was composed from Ethiopian, Egyptian and Sudanese as long as international experts in order to investigate the potential impacts of the Dam.

Egyptian experts give indications of 20-34% water reduction when the filling period overcuts the drought period. This is estimated to be 11-19 billion m3 on average over the Dam's filling period. Other potential impact on reducing the High Dam capacity to generate electricity by 40% is also reported.

The inevitable reduction of Nile waters for the agricultural and industrial sectors and private consumption in Egypt will require a re-assessment of the productivity of irrigation water and land, efficiency of irrigation system and optimal allocation of irrigation water. Agriculture is by far the major water-consuming sector in Egypt. Irrigated agriculture absorbs 89 percent of Nile flows, which is the major source of freshwater. The urgent tasks are, therefore, to examine the current and potential water supply and uses and to evaluate their implications for agricultural productivity in Egypt.

Indeed, the actual significance and direction of water availability impacts on agriculture is an empirical exercise. Overall economic responsiveness to water availability shocks depends on the macroeconomic structure. In accordance with the forward and backward linkages across sectors, the net effect is formulated and the new production mix is defined. Furthermore, temporal and spatial water availability generates differentiated impulses among agricultural activities and across irrigation seasons and land. Clearly, CGE models provide a theoretically consistent and empirically sensible framework for contemplating such interlinked economy-wide impacts.

Therefore, this study undertakes quantitative impact assessment of potential water availability implications using a CGE model for Egypt. Its ultimate goal is to establish a benchmark for analysing how potential changes in Nile water supply would affect the Egyptian economy and for understanding how the optimal allocation of scarce irrigation water would be defined. The study results inform policymakers the best measures directed to minimize potential adverse impacts of water availability shock to the economy.

2. Literature review

Despite its major importance, the area of irrigation water allocation and agricultural productivity is still deficient and has potential for further research. (Dudu & Chumi, 2008) and (Ponce, Bosello, & Giupponi 2012) review the partial and general equilibrium literature on modelling water issues at both country and global levels. Several studies have examined the implications of water availability on the Egyptian economy as part of climate change models. Examples are (Strzepek K. M., 1995); (Yates & Strzepek, 1996) and (Yates & Strzepek, 1998). Strzepek and Yates (2000) employ a recursive dynamic CGE model to examine impacts of changes in the Nile River on the Egyptian Economy to the year 2060. (Strzepek, Yohe, Tol, & Rosegrant, 2008) use a comparative static CGE to evaluate the economy-wide impacts of the High Aswan Dam on the Egyptian economy. The study specifies water in a nested CES production function through a fixed land-water technology. Distinguishing different irrigation seasons, the results report negative impact of the Dam on summer crops. Overall, studies tend to simulate agricultural productivity as an external shock and neglecting water availability endogenous impact on factor productivity. Robinson & Gehlhar (1995) specify physical supply constraints for both land and water. The first order conditions for land and water constraints are given by a linear cost function. To ensure that at least one of the two constraints is binding, the model introduces an explicit maximand.

3. Research Questions, Objectives and Contributions

The current study introduces three major contributions to the CGE literature on water issues. The first one is accounting for water reallocation among agricultural products on the basis of differences in sectoral water and land productivity. The study uses recent data on water and land requirements, water and land actual use, agricultural yield and agricultural production by crop and irrigation season for Egypt. These data allow the study to differentiate between irrigation water uses according to productivity. Changes in water availability, thereby, generate distinguishable effects among agricultural products and across irrigation seasons and land. Final optimal allocation for irrigation water is, thus, determined and the associated structural changes are quantified within the economy-wide framework.

Secondly, the study introduces water as an explicit production factor to the employed single-country CGE for Egypt. This specification requires adding a new nest to the production function where land and water are compounded according to fixed requirement coefficients whereas the aggregate land/water input is imperfect substitute to other primary inputs. Shadow price is calibrated for water under the assumption of excess water supply. Water pricing system is, then, introduced when the scenario of constraint water supply is simulated.

Lastly, this is the first study that deals with the on-going Nile Basin argument, the under-construction GERD and potential economy-wide implications for the Egyptian economy. To the best of our knowledge, no study, to date, investigates the impacts of Nile water availability on agricultural productivity in Egypt within a CGE framework.

4. Water Supply and Use

Nile is the main source of freshwater in Egypt, with a share of more than 95 percent; Table 1. The storage reservoir of Nasser Lake provides 56 billion cubic meters over the year. Rains provide a small proportion of water used in agriculture alongside the northern coast. Nile flows are mainly absorbed by irrigated agriculture; 89 percent. Besides, Nile water accounts for 80 percent of irrigation requirements. These facts emphasize the importance of potential impact of Nile water availability on the agriculture productivity in Egypt.

Table 1: Water Resources and Uses in Egypt

Annual Renewable Water Balance							
Average Water Resources (Billion m3)					Water Withdrawal by Sector, %		
External Surface Water	Internal Surface Water	Net Groundwater*	Total	Per Capita (m3/year, 2011)	Agricultural	Industrial	Domestic
55.5	0.5	1.3	57.3	694	86	6	8

Annual Irrigation Water Use (km3, 2000)			
Irrigation Water Requirements	Water Requirement Ratio	Water Withdrawal for Agriculture	Water Withdrawal (% of Renewable Water Resources)
28.43	0.53	53.85	0.92

* After deducting overlap between surface water and groundwater.
Source: FAO-AQUASTAT

Egypt follows a multi-cropping system that permits planting up to three crops a year. Planting crops rotates round the year during three irrigation seasons; winter (November-May), summer (May-September) and *nili* (i.e. Nile flood), from September to November. The main crops are wheat, berseem and broad-beans (in the winter rotation) cotton and rice (in the summer rotation) whereas maize and millet are flood crops. This rotating irrigation system helps in improving land productivity.

Table 2: Main Agricultural Crops, 2010/2011

	Cultivated Land		Water Requirements			Production	
	Area (1000 feddan)	Share %	Water Usage (million m3)	Water /Land Ratio	Water Intensity (million m3/1000 ton)	Production (1000 ton)	Yield (ton/ feddan)
Winter Field Crops							
Wheat	3133	20	4,556	0.15	0.54	8493	3
Cereals	170	1	199	0.12	0.72	275	
Sugar Beet	362	2	514	0.14	0.07	7486	21
Fodders	2040	13	9,391	0.46	0.19	50613	
Fibbers	16	0	27	0.17	0.68	40	
Medical & Aromatic Plants	48	0	61	0.13	0.29	214	
Vegetables	965	6	1,144	0.12	0.10	11228	
Summer Field Crops							
Rice	1410	9	10,839	0.77	1.91	5667	4
Other Crops	2129	14	6,461	0.30	0.96	6716	
Sugar Cane	326	2	2,766	0.85	0.18	15765	48
Cotton	520	3	1,038	0.20	1.22	853	1
Fodders	702	4	1,530	0.22	0.21	7130	
Oily Crops	273	2	361	0.13	1.21	298	
Medical & Aromatic Plants	24	0	61	0.25	0.29	208	
Vegetables	1539	10	1,679	0.11	0.11	14607	
Nili Field Crops							
Rice	3	0	1	0.04	0.12	9.7	
Other Crops	360	2	1,563	0.43	1.56	999.2	
Fodders	82	1	0	0.00	0.00	653.3	
Oily Crops	3	0	1	0.06	1.14	1.3	
Medical & Aromatic Plants	0.7	0	82	11.81	390.07	0.2	
Vegetables	226	1	578	0.26	0.26	2244	
Fruits							
Fruits	1277	8	4,197	0.33	0.41	10144	

Source: (The Central Agency for Public Mobilisation and Statistics, December 2009) and (Ministry of Agriculture and Land Reclamation, 2012)

For example, cultivating berseem in winter improves the soil quality before the soil-demanding cotton is being planted in summer. Most crops are not region-specific with the exceptions of sugarcane, which is mainly planted in Nile Valley, and rice which is planted in Nile Delta. Egypt is self-sufficient in most of crops. It exports cotton, rice, potatoes, vegetables and fruits. Cotton is the most important export and it has been a source of foreign currency. Nevertheless, Egypt is a main world importer of wheat and wheat flour. It also imports sugar, maize and vegetable oils.

Table 2 provides detailed data on agricultural production costs and quantities in addition to water requirements for major crops. The next Section provides further description for the underlying database.

5. SAM for the Egyptian Economy

A SAM for Egypt for 2008/09 is constructed. Data are mainly based on the most recent (Central Agency for Public Mobilization and Statistics (CAPMAS), 2010). In addition, data for institutional sector accounts are collected from (Ministry of Planning (MOP), 2011).

Data for detailed agricultural crops by irrigation seasons are compiled from the most recent issues of Bulletin of Agricultural Statistics, (Ministry of Agriculture and Land Reclamation, 2012). In addition, data on agricultural cost and return is the most recent issues of Bulletin of Agricultural Prices, Costs and Net Returns, (Ministry of Agriculture and Land Reclamation, 2011)Data on water requirements are compiled from (The Central Agency for Public Mobilisation and Statistics, December 2009). It is worth noting here that water requirement refers to blue water only.

Data on agricultural trade are compiled from (Ministry of Industry and Foreign Trade & Egyptian International Trade Point (EITP), 2008-2009). It is worth mentioning that agricultural trade data is sourced from Central Agency for Public Mobilization and Statistics (CAPMAS).

Table 3: SAM Basic Accounts

No	SAM Commodity	No	SAM Commodity
1	Wheat	9	Food products
2	Cereals	10	Other transportable goods
3	Rice	11	Metal machinery equipment
4	Vegetables	12	Construction
5	Fruits	13	Trade
6	Coffee Tea	14	Financial services
7	Other agriculture forestry fishery	15	Business services
8	Ores minerals gas	16	Social services

No	SAM Activity	No	SAM Activity	No	SAM Activity
1	Winter Wheat	19	Nili Oily Crops	37	Education
2	Winter Cereals	20	Nili Medical Plants	38	Social Services
3	Winter Sugar Beet	21	Nili Vegetables	39	Arts Entertainment
4	Winter Fodders	22	Fruits	40	Other Services
5	Winter Fibbers	23	Other Agriculture, Forestry, Fishing	41	Financial Services
6	Winter Medical Plants	24	Mining	42	Insurance
7	Winter Vegetables	25	Manufacturing	43	Public Services
8	Summer Rice	26	Electricity gas	44	Defence
9	Summer Other Crops	27	Water Supply	45	Public Safety
10	Summer Sugar Cane	28	Construction	46	Economic Affairs
11	Summer Cotton	29	Trade	47	Environmental Protection
12	Summer Fodders	30	Suez Canal	48	Housing and Community Amenities
13	Summer Oily Crops	31	Transportation	49	Health
14	Summer Medical Plants	32	Accommodation Services	50	Recreation, Culture and Religion
15	Summer Vegetables	33	Information Communication	51	Education
16	Nili Rice	34	Real Estate	52	Social Protection
17	Nili Other Crops	35	Professional Services	53	Non-profit Activities Serve HH
18	Nili Fodders	36	Administrative Services	54	Subsistence HH Activities

Cross entropy method is used to balance the original SAM and then to disaggregate the agricultural activity and commodity. Table 3 portrays the basic account in the Egyptian SAM. Aggregates from national accounts and supply/use tables are used to control the transaction values for the disaggregated SAM.

6. Single Country STAGE CGE Model

This study uses a comparative static version of the single-country CGE STAGE model; i.e. STAGE2-wl1_Egy.

Adopting Armington insight, the model specifies constant elasticity of substitution (CES) function for import and constant elasticity of transformation (CET) function for export. Egypt is a small country in the world market. It is, thus, plausible to fix world prices for exports and imports. The model assumes that current account balance is fixed at its initial benchmark level. To clear the external balance, real exchange rate is allowed to adjust.

The model adopts investment-driven closure in the sense that saving rate adjusts to generate the required savings to finance the baseline investment. Foreign saving is, exceptionally, specified as exogenous.

Production relationships for each activity are specified through three level CES function. For the purposes of this study, the model is developed to add water as a production factor at the third level of the production function. At the top level, value added and intermediate demand are combined using a CES aggregator. At the second level of the nest, CES production function specifies capital, labour and land/water composite. At the bottom level, land and water are aggregated according to fixed Leontief shares.

Production factors are mobile and fully employed. Exceptions are labour; which is specified to be mobile but under employed, and land and water which are fully employed but season-specific. For the purposes of this study, land and water supply are set to be fixed for each irrigation season. In other words, land and water are allowed to be mobile across agricultural activities within each irrigation season but not across different seasons. This specification implies that land and water would have seasonal prices. The model solves for land and water seasonal prices that ensure efficient allocation of land and water across crops cultivated in the same season. It is worth noting here that water supply activity deals with non-agricultural uses of water. The model assumes no distribution cost of irrigation water.

Figure 1: Production Flows in STAGE2-wl1_Egy CGE Model

7. Simulation Scenarios

The study considers four sets of simulation scenarios that reflect the alternative options for irrigation water availability and efficiency across the three agricultural seasons and for the whole year. Table 4 depicts the employed simulation scenarios. The model solutions inform the impact effects on welfare, production structure, irrigation water uses and prices.

Table 4: Simulation Scenarios

Simulation Scenario	Simulation Description
Set1: Extended Construction Plan	
20% Less Winter Water	20% reduction in water supply over the winter season
20% Less Summer Water	20% reduction in water supply over the summer season
20% Less Nili Water	20% reduction in water supply over the Nili season
20% Less Water	20% reduction in water supply over the whole year
Set2: Restricted Construction Plan	
34% Less Winter Water	34% reduction in water supply over the winter season
34% Less Summer Water	34% reduction in water supply over the summer season
34% Less Nili Water	34% reduction in water supply over the Nili season
34% Less Water	34% reduction in water supply over the whole year
Set3: Water Efficiency	
Winter Water Efficiency	5% increase in water efficiency over the winter season
Summer Water Efficiency	5% increase in water efficiency over the summer season
Nili Water Efficiency	5% increase in water efficiency over the Nili season
Water Efficiency	5% increase in water efficiency over the whole year
Set4: Water Availability & Efficiency	
Less Winter Water, Agri. Efficiency	20% reduction in winter water with 5% increase in agricultural efficiency
Less Summer Water, Agri. Efficiency	20% reduction in summer water with 5% increase in agricultural efficiency
Less Nili Water, Agri. Efficiency	20% reduction in Nili water with 5% increase in agricultural efficiency
Less Water, Agri. Efficiency	20% reduction in water over the whole year with 5% increase in agricultural efficiency

The first set of scenarios simulates the case in which the GERD construction Dam is being extended to ten years. It assumes *ceteris paribus* 20% reduction in irrigation water supply over the three seasons and for the whole year. Secondly, the restricted five-year construction plan is represented by Set2 where 34% reduction in irrigation water supply over the three seasons and for the whole year is simulated. Thirdly, improvements in agricultural productivity are simulated. External shocks of 5 percent increase in agricultural water productivity are specified. The model does not specify the underlying source for funding this improvement in productivity. That is to say, government expenditure on R & D, for example, is not explicitly specified by the model. Lastly, potential 20% reduction in water supply and 5% increase in water efficiency are combined together. The simulation set informs the increases in water efficiency required to compensate negative impacts induced by potential water losses.

Increasing agricultural factor productivity implies higher effective factor endowment, which consequently affects factor demand and price. Within this multi-sector modelling framework, changes in productivity of specific factors/sectors affect demand and price for other factors/sectors through different transmission channels. The higher the factor productivity, the lower is its effective price. Consequently, producers substitute other factors/intermediate inputs by the cheaper factor. Changes in factor productivity entails also lower production cost and, hence, lower price. Consumers gain and their demand increases, which consequently boosts production.

8. Scenarios Results

At the economy-wide level, negative impact is reported under the less water availability scenarios. This negative impact is more pronounced under the restricted construction plan. Preliminary results indicate that the Egyptian economy would be more affected by water reduction in the summer season whereas the least impact occurs during the Nili season.

This is attributed to the baseline agricultural structure as well as water requirements; see Figure 2 and Table 2 respectively. In the winter season, only one crop (i.e. fodders) consumes one-fifth of total irrigation water used over the whole year. Also, wheat absorbs 10% of total used irrigation water. Summer crops are mainly hydro-intensive crops; rice, sugarcane & cotton in particular. In addition, summer crops absorb more than 50% of total irrigation water used over the whole year.

Reduction in water availability would push the agricultural structure to be more concentrated in less hydro-water crops, see Table 5. Agricultural sectors like sugar cane, summer rice, other summer crops and winter fodders shrink. Production factors move towards less hydro-water crops. As aforementioned, water and land are allowed to move across activities within each irrigation season, but not across seasons. As such, sugar beet, fibbers and vegetables (in the winter season) cotton, fodders and vegetables (in the summer season) experience expansions.

Table 5: Domestic Production, Percentage Change

	Extended Construction Plan				Restricted Construction Plan			
	20% Less Winter Water	20% Less Summer Water	20% Less Nili Water	20% Less Water	34% Less Winter Water	34% Less Summer Water	34% Less Nili Water	34% Less Water
Winter Wheat	1.00	-0.07	-0.01	0.90	0.75	-0.17	-0.02	0.54
Winter Cereals	11.85	-0.10	-0.07	11.51	32.96	-0.26	-0.15	32.10
Winter Sugar Beet	5.12	0.82	0.46	6.45	4.22	1.91	0.94	6.13
Winter Fodders	-12.82	-0.15	-0.17	-13.15	-29.75	-0.05	-0.26	-29.84
Winter Fibbers	16.59	-0.43	-0.35	15.63	23.92	-0.56	-0.61	23.22
Winter Medical Plants	27.11	-0.44	-0.37	25.90	71.01	-0.54	-0.63	69.53
Winter Vegetables	3.28	0.92	0.51	4.69	8.54	2.15	1.05	10.63
Summer Rice	0.03	-3.15	-0.12	-3.30	0.03	-5.29	-0.19	-5.41
Summer Other Crops	-1.87	-3.98	0.31	-5.37	-4.50	-11.27	0.62	-14.90
Summer Sugar Cane	-0.84	-20.21	0.53	-20.58	-1.54	-35.35	1.07	-37.00
Summer Cotton	15.49	1.13	-0.40	16.24	40.27	1.00	-0.70	41.77
Summer Fodders	16.44	0.46	-0.45	16.39	42.92	-0.84	-0.79	41.90
Summer Oily Crops	-2.05	7.55	0.32	5.67	-4.91	15.20	0.64	9.78
Summer Medical Plants	15.60	-1.54	-0.47	13.26	40.37	-5.78	-0.85	32.54
Summer Vegetables	-1.68	5.97	0.39	4.56	-3.87	12.69	0.79	8.38
Nili Rice	-4.81	36.19	70.62	117.01	-11.61	85.02	115.79	66.92
Nili Other Crops	0.08	0.49	-17.19	-16.63	0.35	1.17	-27.85	1.34
Nili Fodders	14.01	-1.57	38.47	52.47	36.03	-3.28	64.10	32.18
Nili Oily Crops	-5.93	-1.59	72.36	56.07	-13.78	-3.88	113.79	-16.10
Nili Medical Plants	24.49	0.70	-45.45	-34.11	70.21	2.43	-58.16	73.30
Nili Vegetables	-1.67	0.33	1.86	0.77	-3.75	0.73	-1.48	-3.00
Fruits	-4.05	-4.17	-4.23	-3.99	-7.34	-7.67	-7.77	0.66
Other Agri, forestry, fishing	-0.09	-0.19	-0.02	-0.29	-0.31	-0.41	-0.04	-0.71

Figure 2: Agricultural Structural at the Baseline Scenario

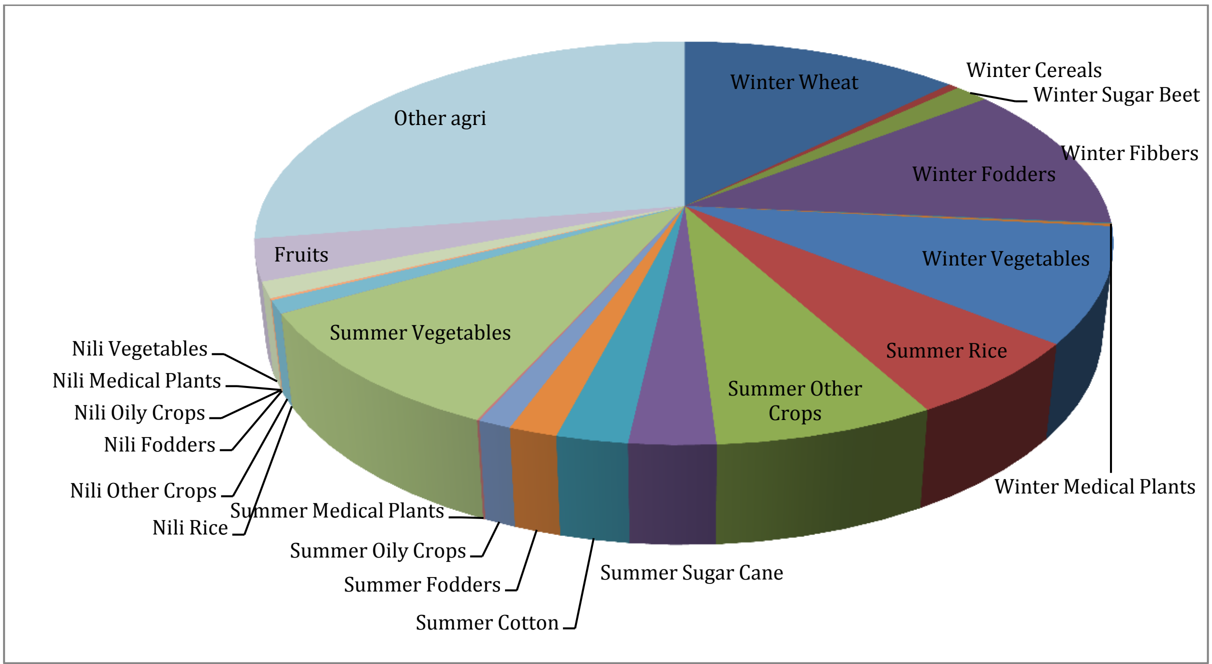

Table 6: Exports, Percentage Change

	Extended Construction Plan				Restricted Construction Plan			
	20% Less Winter Water	**20% Less Summer Water**	**20% Less Nili Water**	**20% Less Water**	**34% Less Winter Water**	**34% Less Summer Water**	**34% Less Nili Water**	**34% Less Water**
Wheat	4.74	0.02	-0.02	4.64	3.92	-0.03	-0.06	3.75
Cereals	25.34	-0.09	-0.13	**24.73**	77.02	-0.28	-0.28	75.17
Rice	0.45	-21.10	0.10	**-20.81**	1.01	-36.97	0.13	**-36.97**
Vegetables	0.98	-0.67	-0.35	-0.12	1.98	-1.61	-0.72	0.25
Fruits	-6.05	-6.18	-6.34	**-5.88**	-10.89	-11.33	-11.65	1.27
Coffee Tea	-14.68	0.44	0.36	-14.03	-31.10	0.42	0.60	-30.85
Minerals Gas	0.49	0.18	0.07	0.57	1.23	0.32	0.13	1.25
Food Products	0.23	-0.14	0.04	0.00	0.44	-0.36	0.08	-0.16
Other Transportable Goods	0.09	-0.17	0.02	-0.14	0.11	-0.39	0.03	-0.42
Metal Machinery	0.04	-0.21	0.01	-0.22	-0.01	-0.48	0.01	-0.60
Construction	0.14	0.06	0.03	0.18	0.36	0.11	0.05	0.37
Trade	0.28	0.10	0.05	0.32	0.69	0.18	0.09	0.66
Financial Services	0.25	0.08	0.03	0.28	0.61	0.13	0.07	0.58
Business Services	0.29	0.10	0.05	0.33	0.70	0.19	0.09	0.70
Social Services	0.19	0.16	0.07	0.31	0.48	0.33	0.13	0.62

9. Concluding Remarks

Bases on the preliminary results, Egyptian negotiators should aim for more extended construction plan for the GERD project that minimizes the reduction in water level available for irrigation. Flexible construction plan that avoid significant impact on irrigation water in the summer season vis-à-vis the Nile season would be recommended.

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