Water Quality Assessment

SAM/CGE and Satellite Accounts Integrated Framework

Rehab Osman*,[1] Emanuele Ferrari,[2] Scott McDonald[3]

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* Corresponding author: Rehab Osman
Wheatley Campus, Oxford, OX33 1HX,
rosman@brookes.ac.uk

[1] Postdoctoral Research Fellow (Economics), Department of Accounting Finance and Economics, Faculty of Business, Oxford Brookes University, Wheatley Campus, Oxford, OX33 1HX, UK, Tel: +44 (0)1865 485964, rosman@brookes.ac.uk; and Lecturer (Economics), Institute of African Research and Studies, Cairo University, Giza, 12613, Egypt

[2] Scientific Officer, European Commission, Joint Research Centre (JRC), Institute for Prospective Technological Studies (IPTS), Edificio Expo, Inca Garcilaso 3, 41092 Seville, Spain, Tel: +34 954-488461, Emanuele.Ferrari@ec.europa.eu

[3] Visiting Professor, Institute of Agricultural Policy and Markets, University of Hohenheim, 70593 Stuttgart, Germany, Scott.Mcdonald@uni-hohenheim.de

Abstract

This study provides quantitative assessments for the impacts of crop yields enhancement associated with changes in water quality and soil fertility. It employs a single country CGE (STAGE) model calibrated to an extended version of a recently constructed SAM for Egypt 2008/09. The main contribution of this study is incorporating satellite accounts for water quality indicators into the SAM/CGE framework. The SAM segments the agricultural accounts by season and by irrigation scheme; Nile water- and groundwater-dependent as well as rain-fed agricultural activities. The simulations report strong positive economy-wide impacts, which imply that the planned investments in water quality improvements are worthwhile even with very low generated crop yields. Furthermore, the results show that, without increasing irrigation water requirements, Egypt can achieve outstanding expansions in rice output and exports. This highlights the importance of by investing in improving irrigation water quality for the overall economy.

Keywords Water, Water Pollution, Irrigation Efficiency, Agricultural Productivity, Egypt, Computable General Equilibrium (CGE) Models.

JEL code Q25, Q53, Q15, D24, O55, C68

1. Introduction

Water scarcity issue highlights the importance of substituting irrigation water with other agricultural inputs. The first available alternative is water of low quality. As water becomes scarcer, the demand for less quality water rises. Substituting high-quality water with low-quality water is not necessarily yield or profit maximizing. It however can generate significant changes in demand for high-quality water. Furthermore, with various input substitution options, the demand function for irrigation water becomes more elastic.

The association between water quality, soil productivity and agricultural potentials is particularly important for a semi-arid area like Egypt. On one hand, deteriorating irrigation water quality has been increasingly a major obstacle to the development of agricultural sector in Egypt. The impacts of using low quality water for irrigation purposes are indeed significant. The Ministry of Water Resources and Irrigation (MWRI) estimates total cost associated with using low quality water to be 1.8 percent of GDP, (2005, p. 41).

On the other hand, agricultural activities and the existing irrigation and drainage systems are the main determinants of water quality deterioration. Covering the whole Nile Valley and Delta, the drainage network discharges wastes into the Nile mainstream or the northern lakes and sea coast. This irrigation misconduct affects water quality through three channels: changing salinity level; adding chemical fertilizers and pesticides to irrigation water; and eutrophication of water bodies, (RIGW, 1996). These water pollutants eventually lead to soil degradation. In Egypt, soil degradation is mainly driven by salinization, alkalization and water logging, (Kawy & Ali, 2012).

It is against this background that there is an urgent need to gain more insights into water quality and its implication for agricultural productivity in Egypt. Lack of data on different types of water used in irrigation and their characteristics is the main obstacle for rigorous analysis of water quality issues. This paper fills this gap in the literature and provides a quantitative assessment of the implications of using water of different quality in agriculture within an internally consistent modelling framework.

This study incorporates water quality indicators into the social accounting matrix/computable general equilibrium (SAM/CGE) framework using Satellite Accounts following the conventions defined by the UN's System of National Accounts. The integration of the satellite accounts allows for considering various technical indicators affecting water quality, soil fertility and agricultural productivity. This innovative analytical framework allows for addressing multiple policy issues within the river basin frameworks. Among which are the impact of enhancing water and land quality on agricultural productivity and the quantitative assessment of various policy and technology interventions designed to affect water quality.

The analysis is conducted by using a single-country CGE model. The model is calibrated to an extended version of a SAM for Egypt 2008/09. The SAM contains a high level of details on the Egyptian agricultural and irrigation schemes. Furthermore, data on water salinity levels, soil properties and resilience levels are taken into consideration in examining the potential changes in crop yields. The policy scenarios assess the potential impacts of changes in water quality and soil productivity on crop yields across different irrigation seasons.

The rest of the paper is organized as follows. Section 2 describes the existing irrigation and drainage schemes. It also presents the water quality issues and the potentials for improvements within a cost/benefit analysis for an integrated water resources management project. Section 3 provides a context for this study in relation to previous CGE-based studies for water quality. The SAM database and the employed technical data on water quality indicators are detailed in Section 4 while the model is described in Section 5. Section 6 details the simulation scenarios designed for the purpose of this study. The analyses of the results and sensitivity analyses are reported in Section 7.

2. Water and Irrigation in Egypt

Irrigation and Drainage Systems

Egypt mainly relies on the Nile as a source of water, accounting for 95 percent of freshwater, Table 1. Irrigated agriculture absorbs 89 percent of Nile water (85 percent of the Egypt's annual water resource). Groundwater is the second largest source of water for irrigation; accounting for 8 percent of the irrigation water that is used for the 11 percent of irrigated agricultural production. The current rate of abstraction from the renewable groundwater aquifers in the Nile valley and Nile Delta[4] is 4.8 billion cubic meter (BCM)/year, which is yet under the potential safe yield 7.5 BCM (F., H., & A., 2005). Egypt does not receive rainfall except for a narrow strip along the Northern coastal area where the average rainfall does not exceed 200 mm (about 1.5 BCM/year).

In addition to these conventional water resources, Egypt has recently started intensive programmes to exploit other non-conventional sources of water that include recycling the agricultural drainage water, treating sewage water and desalinating sea water. Treating wastewater is a viable option worldwide since a unit of treated wastewater roughly costs (8-18) percent and (24-40) percent of corresponding cost of desalinated sea water and brackish water respectively, (WB, 1977). Indeed, desalinating sea water for irrigation purposes has proven to be economically infeasible in Egypt (Egypt, 1999).[5]

Table 1: Available and Used Irrigation Water Resources

Source	Usage		Availability	
	Billion m3/Annum	%	Billion m3/Annum	%
Nile Water	51.7	82.59	55.5	75.2
Groundwater	5.2	8.3	11.3	15.3
Drainage Water	3.7	5.91	5	6.8
Treated Sewage Water	1.5	2.4	1.5	2.03
Rain	0.5	0.8	0.5	0.67
Total	**62.6**		**73.8**	

Source: compiled from different sources.

Egypt has the oldest irrigation system in the world. Irrigation Nile water is percolated to the fields through a complex hierarchical system.[6] Drainage system is also complicated. In addition to the Aswan High Dam, eight barrages, public and farm drains, pumping station and water control structures are in operation, Hvidt (1998, 10). Drainage water is naturally reused

[4] Nile Delta is particularly important for agriculture in Egypt. It accounts more than 60 percent out of the 8.7 million feddans of total irrigated land. It is also the most populated area in Egypt. It inhabits more than 60 percent of total population.

[5] Desalination plants in Egypt annually generate around 30 million m3 at a cost of US$ 0.5 – 2/ m3, (Egypt, 1999). They are mainly located in touristic resorts alongside the Red Sea and the Northern Coast of the Mediterranean Sea, where very little sources of fresh water are available. Almost 40 percent of desalinated water is utilized by tourism sector and around 20 percent by industrial sector, ((CSF), 2010).

[6] This system starts from principle and main canals through which water is transmitted from the mainstream to rayahs (secondary canals or branch canals) and distributary canals. Subsequently, mesqas (private ditches) distribute water either directly to the near fields or through marwas (private off-takes) to other fields.

in Egypt in areas where rivers and canals compose natural drainage system for basin aquifer system. Two distinct drainage sytems can be identified in the Nile valley and Delta. In the Nile valley, drainage water is flowed back to the main stream river or to the irrigation canals. In the Nile Delta, only fraction of darainage water is pupmed back into the irrigation system. The bulk of it is drained into either the Northern lakes (for Eastern and Middle Delta) or the Mediterran sea, (Keller et al. 1996).

With natural flow of Nile water, this surface irrigation suffers low water efficieny vis-à-vis sprinkle and drip irrigation schemes.The fraction of water used by crops out of the total applied water is significanlty lower under surface irrigation compared to the capital-intensive irrigation techniques. Under the existing surface irrigation system, water consumptive ratio is estimated to be 57.5 percent of applied water in 1999/2000, (Rassoul, 2006) N. G. et al. (1999) argue that applying sprinkler or drip irrigation water systems in Egypt could save up to 8 and 13 BCM/year respectively. That is to say these irrigation systems reduce irrigation water demand by 15 and 25 percent respectively. Yakoub (2006) applies remote sensing technique in optimizing the irrigation water schedule for the Qalyubia governorate in Delta region. The study finds an extra discharge of 55 MCM/year is applied to the region's actual demand of irrigation water.

Water Quality and Soil Productivity

The most crucial deterioration in irrigation water quality occurs in the Nile Delta, World Bank (2005). With an intensive exploitation of the region natural resources, water and land quality in Nile Delta are, indeed, at a high risk of degradation. Table 2 portrays salinity levels in irrigation water for Nile Delta regions.

Table 2: Recycled Drainage Water in the Nile Delta 2000/2001, (BCM per annum)

Salinity Level	**East Delta**	**Middle Delta**	**West Delta**	**Delta**
< 750	0.664	0.085	0.575	1.324
750-1000	0.422	0.458	0	0.88
1000-1500	0	1.416	0.067	1.483
1500-2000	0.744	0	0	0.744
2000-3000	0	0	0.416	0.416
Total	**1.83**	**1.959**	**1.058**	**4.847**

Source: Drainage Research Institute (2004).

"In Egypt, perhaps the most critical factor in predicting, managing, and reducing salt-affected soil is the quality of irrigation water being used (The main sources of the salinity in the Delta soils are irrigation water, Mediterranean saline water and the high level water table). Besides affecting crop yield and soil physical conditions, irrigation water quality can affect fertility needs, irrigation system performance and longevity, and how the water can be applied. Therefore, knowledge of irrigation water quality is critical to understanding what management changes are necessary for long-term productivity", (Noureldeen, 2013, pp. 1-2).

Based on the Canadian Council of Ministers of the Environment Water Quality Index (CCME-WQI),[7] several water quality assessment case studies are carried out for Nile water. Agrama & El-Sayed (2013) apply the index on 19 sites in 6 Western Delta canals.[8] The study findings show that the selected areas are classified as marginal water quality with high concentration of the first 14 pollutants of the index. Low quality agricultural drainage water is being discharged into the mainstream canals for agricultural re-usage. Reported differences in water quality between these sites are virtually attributed to variations in drainage water quality and quantity mixed with fresh canals water. Other factors contribute to water quality deterioration are pollution of Rosetta branch and other misconducts in the agricultural activities.

Radwan & El-Sadek (2008) employ the index to assess water quality in Upper Egypt. The study finds that water quality for the selected areas widely range from marginal to good. The highest average water quality index is recorded at East Naga Hamadi. However, the lowest value recorded at Ibrahimia Canal (Bani Suef). The study identifies two main pollutants (i.e. organic matters COD and pathogenic bacteria T.C.) in the marginal water quality areas. Discharging domestic wastes into the mainstream canals are the main reason behind the existence of both pollutants.

Indeed, low water quality affects the soil properties and productivity in the region. Kawy & Ali (2012) assess the soil properties in North East Delta and the impact on soil productivity during 1976-2011. The study finds high values of EC_e in different types of soil

[7] The CCME-WQI is based on a range of water quality indicators. The main pollutants are Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Dissolved Oxygen (DO), Nitrate (NO3), Ammonia (NH4), Total Dissolved Solid (TDS) Boron (B), Sulphate (SO4), Iron (Fe), Copper (Cu), Cadmium (Cd), Manganese (Mn), Lead (Pb), Zinc (Zn), Total Phosphorus (TP), Nickel (Ni) and the power of hydrogen (pH).
The CCME-WQI value ranges between 1 and 100 with the following ranks: 0-44 poor, 45-64 marginal, 65-79 fair, 80-94 good and 95-100 excellent.

[8] The selected canals are El-Nubaria, El-Mahmoudia, El-Hager, El-Nassr, El-Khandak and Abo Diab canals. For these sites, the WQI values ranged between 48.19 and 64.83.

and estimates the reduction in soil productivity index by 45.82% of the study region. Table 3 provides quantitative estimations for potential yield reductions due to increases in salinity level of irrigation water.

Table 3: Potential Yield Reduction from Saline Water

Crop	Yield Reduction (%)			
	0%	10%	25%	50%
	EC_w			
Barely	5.3	6.7	8.7	12
Wheat	4	4.9	6.4	8.7
Sugarbeet	4.7	5.8	7.5	10
Alfalfa	1.3	2.2	3.6	5.9
Potato	1.1	1.7	2.5	3.9
Corn (grain)	1.1	1.7	2.5	3.9
Corn (silage)	1.2	2.1	3.5	5.7
Onion	0.8	1.2	1.8	2.9
Dry Beans	0.7	1	1.5	2.4

Source: Ayers & Westcot (1985).

Potentials for Water Quality Improvements

Egypt has large potentials for improving water quality, particularly recycled drainage and treated sewage water. The possibility to use recycled drainage water depends on many factors, among which are the quality level of water. F., H., & A. (2005) explain the potentials for expanding drainage water re-usage. Less quality water, basically recycled drainage and treated sewage water, can be blended with fresh water at certain ratio according to quality levels.

In 2005, Egypt has launched an Integrated Water Resources Management Plan (IWRMP) for the period (2000-2017). The project aims at securing the future water requirements through a set of measures designed to enhance water quantity and quality, (MWRI, 2005). The project action plan specifies several measures that aim at securing 14 percent of water requirements in the end of the project length. This is to be met by increasing recycled drainage water by 9.6 BCM which means around 74 percent increase in the current recycled drainage water. Furthermore, irrigation efficiency of the existing water resources is to be enhanced. Total cost for such long term plan is estimated to be around 162.7 billion LE. The bulk of this investment (77 percent) is actually directed to water quality measures with only 23 percent allocated for increasing water quantity.

3. Water Quality in CGE Models

CGE model are well equipped to address questions related to water, in particular water scarcity and irrigation issues. CGE models show increasing flexibility in adapting their production specifications to include water as both a production factor and a produced commodity. Dudu and Chumi (2008) and Ponce et al., (2012) review the partial and general equilibrium literature on modelling water at country and global levels. These surveys pinpoint that the area of water quality is scarcely explored in the economic modelling literature and needs further research.

Few examples of modelling water quality issues can be found in the literature. Tsur (2005) discusses the economic aspects of water pricing for different types of irrigation water. The study highlights the importance of differentiating water by source. Water from different sources have distinct characterises and qualities. As such, specifying water as a homogenous production factor leads to misleading results. Smajgl (2006) analyses climate change impacts on the Great Barrier Reef region (Australia) through CGE model integrated with hydrologic and ecological modules at the catchment level. The study examines water deterioration through the required increases in fertilizer uses.

CGE models have been extensively used to examine the economic implications of water availability in Egypt (Strzepek et al. (1995), Yates and Strzepek (1996), Yates and Strzepek (1998), Strzepek and Yates (2000), Strzepek et al., (2008), Osman et al. (2014)). Nevertheless, the use of this comprehensive tool has never to assess issues related to water quality in Egypt.

To deal with water quality issues within CGE models, the use of satellite accounts is fundamental.[9] Linking water satellite accounts on quantity and substance flows to economic flows allows gaining insights into the nature of the relationship between physical water systems and the economy. The integration of physical and economic databases and modelling allows the construction of integrated indicators too (Veeren, Brouwer, Schenau, & Stegen, 2004).

[9] Satellite accounts provide a framework linked to central accounts enabling to focus on certain aspects of economic and social life in the context of national accounts. Common examples are satellite accounts for the environment, tourism or unpaid household work, (UN, System of National Accounts, 2008).

Water accounts are introduced to the System of National Accounts (SNA) through environmental accounts, (UN, 2008).[10] In 2012 the UN Statistical Commission adopted the System of Environmental-Economic Accounting (SEEA). Water has been identified as a priority area. As a result, the SEEA-Water Sub-System is implemented (UN, 2012).[11]

The use of water satellite accounts in modelling economic is common. At global level, satellite accounts of water are employed to analyse impact of water restrictions (Berrittella, Hoekstra, Rehdanz, Roson, & Tol, 2007) or to model the competition for managed water among agricultural and non-agricultural activities (Taheripour, Hertel, & Liu, 2013), taking into account heterogeneity in land quality across AEZs and tracing supply of water at the river basin level. To assess water quality issues at national level, Brouwer et al. (2008) present an integrated hydro-economic model which employs an integrated satellite account system, Brouwer et al., (2005).

4. SAM and Satellite Accounts for Water

A SAM provides a consistent framework, within which flows of expenditure and income for the different agents in the economy are recorded. A SAM is a square matrix where each agent is represented by a column (expenditure) and a row (income) that record, respectively, each account's expenditures and incomes.

The SAM used for this study is an extension of a SAM for Egypt in 2008/09, (Osman, Ferrari, & McDonald, 2015) that encompasses Egypt's multi-cropping irrigation system. The SAM includes disaggregated agricultural activities and factors across different irrigation seasons with irrigation water as a separate production factor. Water and irrigated land are segmented by irrigation season and type of water. The three main contributions are: introducing groundwater irrigation scheme, representing rain-fed-dependent agricultural activities and distinguishing agricultural activities and factors by irrigation season.

[10] The environmental satellite accounts dates back to the 90s when Statistics Netherlands extended their National Accounting Matrix with a satellite account including the environmental pressures related to the production of goods and services. This resulted in the National Accounting Matrix including Environmental Accounts (NAMEA), which in 1994, was identified by the European Union as a relevant part of the framework for environmental satellite accounts of the National Accounts now known as Air Emissions Accounts (Eurostat, 2009).

[11] The SEEA-Water is a satellite system of the 2008 SNA providing a set of aggregate indicators to monitor environmental economic performance, both at the sectoral and macroeconomic levels, as well as a detailed set of statistics to guide resource managers towards policy decision-making.

For the purpose of this study, a set of water quality satellite accounts for Egypt are constructed using recently collected data. The accounts are designed to determine the crop yields for water of different quality. They provide information on hydrological specifications of irrigation water in Nile Delta regions. Two main water and soil quality indicators are taken into account: electric conductivity for water (EC_w) and for soil (EC_e).

5. Model

This study uses a comparative static single-country CGE Static Applied General Equilibrium (STAGE 2) model,[12] which has been extended to encompass the production technologies recorded in the SAM (STAGE-WL). Specifically the Constant Elasticity of Substitution (CES) nested production system has been extended to include derived demand for Nile water and land as well as other sources of irrigation water. Production relationships for agricultural activities are specified through a five level standard nested CES function, Figure 1.[13]

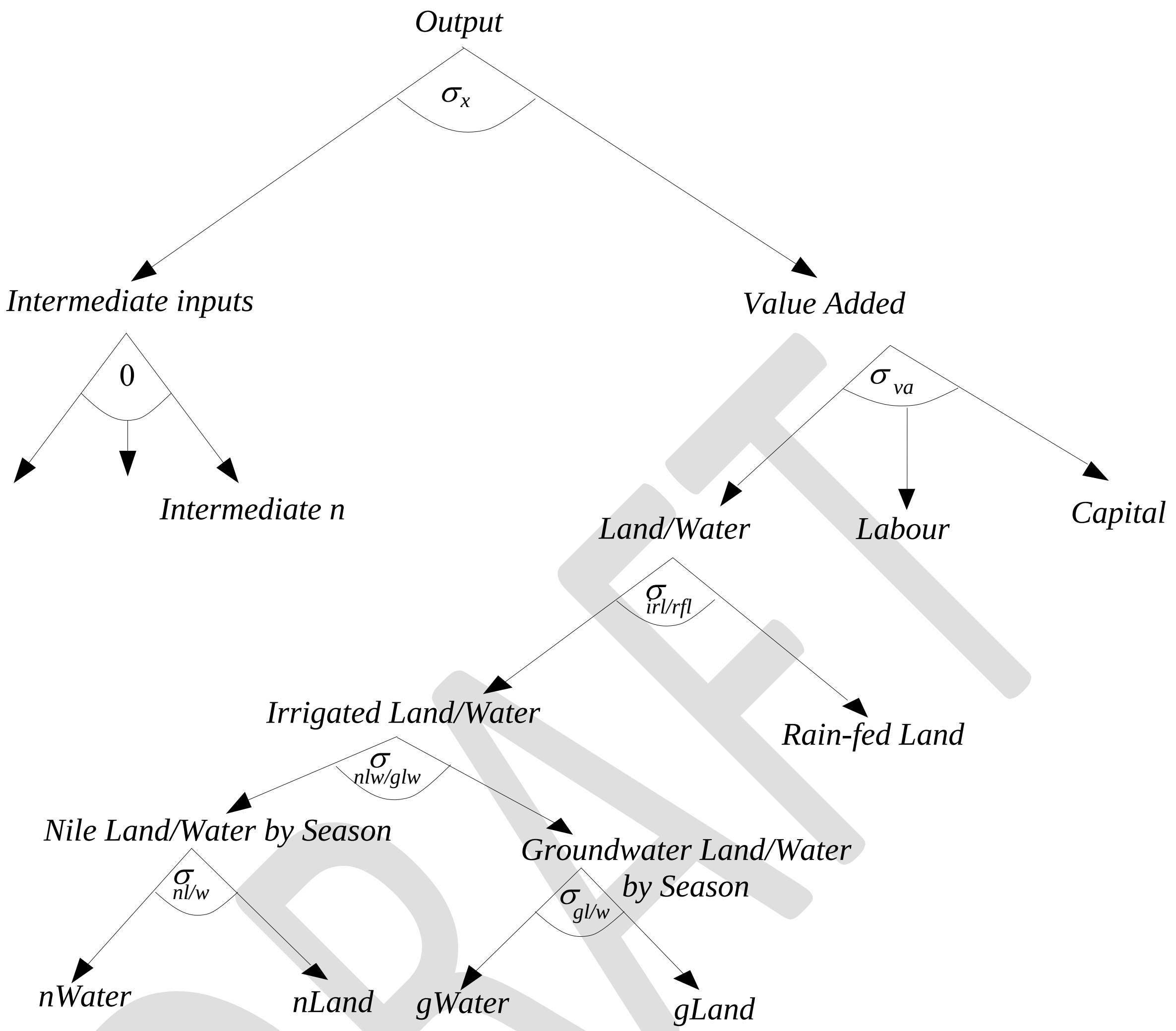
The model allows for an alternative specification for substitution possibilities at the different levels of the water/land production nest: either CES elasticities that greater than zero, but not one, or zero – the Leontief fixed coefficient approach. Second, the model specifies physical supply constraints for water and land (based on the above describes satellite accounts). Demand volume transactions for land (by thousands of feddan[14]) and water by agricultural activities are employed as upper limits for supply of water and land. And third, the water supply activity provides for non-agricultural uses of water.

[12] The STAGE 2 model, described in detail in McDonald S. (2014), is a descendant of the USDA ERS model (Robinson et al., 1990). Luckmann and McDonald (2014) provide a detailed technical documentation for the STAGE_W CGE model. In this advanced variant of the model, different types of water are specified as production factors, productive activities and as produced commodities. This elaborated presentation of water allows for simulating a wide range of policy scenarios.

[13] For a full description of the production specification adopted see Osman et al., (2014).

[14] Feddan is a non-metric measurement unit of land area used in Egypt, inter alia. A feddan is equivalent to 1.037 acres, 0.420 hectares or 4,220 m^2.

Figure 1: Agricultural Production Flows in STAGE-WL CGE Model



Source: authors' elaboration.

Model Closure Rules

Egypt is a small country in the world market and thus it is plausible to fix world prices for exports and imports. The model assumes that the current account balance is fixed at its initial level (in foreign currency units), and to clear the external balance the exchange rate adjusts. This is the typical choice for developing economies where foreign credit is limited and fixing current account reflects the economic reality. The model adopts an investment-driven closure; saving rates adjust to generate the required savings to finance the base year investment. The combination of exogenous investments and foreign savings, known as Johansen closure, avoids the misleading change in household welfare due to change in foreign savings and investments in a single-period model (Lofgren *et al*., 2002)[15].

Capital is mobile and fully employed (medium-run closure rule). On the other hand, labour is mobile, albeit under employed: underemployment in labour markets is the most reasonable assumption in a country where unemployment rate is constantly above 10 percent. Water and land, for both Nile water-dependent and groundwater-dependent activities, are fully employed, but season-specific. For the purposes of this study, water and land supply are fixed for each irrigation season. Thus, water and land are mobile across agricultural activities within each irrigation season but not across different seasons. This specification implies that water and land have distinct seasonal prices.

6. Scenarios

Three main policy scenarios as well as a set of sensitivity analyses are conducted as portrayed in Table 4. All policy scenarios are designed to simulate the cost the Egyptian government has to incur in order to finance water quality improvement projects as well as the acquired economic benefits.

On the cost side, the government expenditure allocated to water quality improvement projects are planned to be around 9.5 billion LE per annum, (MWRI, 2005). In other words, the average annual cost of this long term project is estimated to be around 34% of the baseline government deficit.

In accordance with the model's closure rules, this government expenditure is specified as an exogenous increase in government investments. Under the present comparative static analysis, it is plausible to assume that the simulated improvements in water/land quality are financed domestically. This is to avoid free-lunch issue that might arise by introducing external loans without considering the associated payments in future periods. Given a fixed level of public expenditure, the required fund is generated through an endogenous change in public savings financed by an increase in personal income tax. This is specified as a non-distortionary lump sum tax.

[15] The result could be misleading because increase of foreign savings (or investment decrease) raises households' welfare while a comparative static analysis does not take into account possible welfare decreases in following periods due to a higher foreign debt or a smaller capital stock.

On the benefit side, the integrated irrigating project aims reducing the concentration of pollutants in irrigation water by 10 percent, (MWRI, 2005). Simulation scenario design takes into account this potential improvement in water quality and the associated enhancements in land productivity and eventually increases in crop yields.

Table 4: Simulation Scenarios

Scenario Code	**Scenario Description**	
	Cost	**Benefit**
Scenario 1: High Water/Land Quality Improvements		
H-Yld	34% increase in gov. exp.	Full potential increases in crop yields
Scenario 2: Partial Water/Land Quality Improvements		
P-Yld	34% increase in gov. exp.	70% of potential increases in crop yields
Scenario 3: Low Water/Land Quality Improvements		
L-Yld	34% increase in gov. exp.	50% of potential increases in crop yields
Scenario 4: SSA Water/Land Substitution Elasticity		
SSA_ H-Yld	SSA for Water/land substitutability under the main scenario	

Source: authors' elaboration.

The scenarios take into account variations in salinity tolerance among crops, soil resilience and water salinity level. Three computation steps are conducted. Firstly, technical agro-economic estimations for crop yields under different water salinity levels, provided by Ayers & Westcot (2009), are mapped to the corresponding SAM crop accounts.

Secondly, based on estimation on salinity level in Egypt (Rhoades, Kandiah, & Mashali, 1992) and data collected by (NWRC, 2004), crop yield elasticities to changes in water salinity are computed. As typical floodplains, the soils in the Nile Valley and Nile Delta are basically clay soils. Some other types of soil are identified in the region. Using satellite images for the North East Nile Delta, Kawy & Ali (2012) identify three types of soil with distinctive properties: flood plain, lacustrine plain and marine plain. The results show high values of EC_e in different types of soil, with ranges (1.48 and 12.53), (11.40 and 15.45) and (17.40 and 20.34) dS/m respectively. All scenarios assume that the initial level of soil resilience and water salinity are those for floodplains. For cotton yield only the corresponding parameters for lacustrine plain are used.

Eventually, the potential improvement in water quality is translated into enhancements in crop yields modelled as increases in factor-specific productivity. At the third level of the production nest, the composite irrigated water/land productivity is simulated to increase uniformly across crops.

Three simulations scenarios are employed. The first scenario assumes the full potential increase of productivity is generated by the planned improvements in water/land quality. The second and third scenarios simulate 70 and 50 percent of the potential productivity respectively.[16] The last two scenarios assess the government cost-benefit analysis by reducing the positive impact of government projects on water quality and, subsequently, on crop yields. In other words, these scenarios address the important question whether, with less favourable generated improvements in crop yields, government investment remains beneficial.

In addition to the main policy scenarios, a set of sensitivity analyses are run to test the robustness of the results. The elasticity of substitution between water and land is analysed through a systematic sensitivity analysis (SSA). SSA is performed with a standard Monte Carlo approach.[17] The study assumes that the elasticity of substitution between water and land for each agricultural activity follows an independent identically distributed (i.i.d.) normal distribution, N(μ, σ2), where the mean is the value provided by Calzadilla et al. (2011). The study simulates 5,000 Monte Carlo draws for the H-Yld scenario.

Table 5: Macroeconomic Indicators (Real percentage change)

	H-Yld	P-Yld	L-Yld
Private consumption	3.01	2.07	1.45
Government consumption	0.33	0.14	0.05
Investment consumption	2.05	1.27	0.85
Total Absorption	2.55	1.72	1.19
Import demand	3.07	1.41	0.63
Export supply	4.36	2.13	1.06
GDP from expenditure	2.83	1.90	1.32
Total domestic production	3.14	2.17	1.54
Total intermediate inputs	3.16	2.41	1.82

Source: authors' elaboration on model results.

[16] For more details on the simulated changes in crop yields, see the Appendix A1.
[17] For more explanation of Mont Carlo approach, see (Belgodere and Vellutini, 2011).

7. Simulation Results

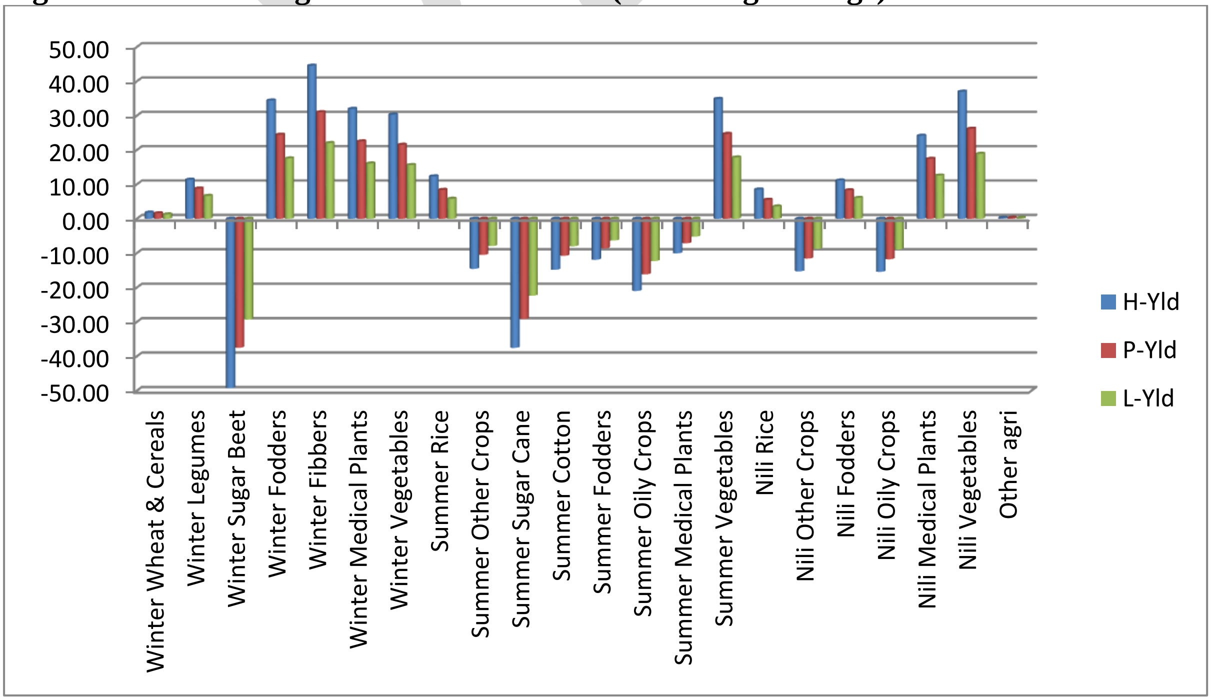
Macro-economic Impacts

Economy-wide strong positive impacts are reported under all scenarios (Table 5). The full potential water quality improvement scenario generates more than 2.5 percent increases in GDP and absorption. Even under the less optimistic scenarios, results show positive economy-wide impacts. Under the low yield scenario, changes in GDP and absorption range from 1 to 1.5 percent. These reported economy-wide positive effects imply that the planned investments in water quality improvements are worthwhile even with very low generated crop yields.

Sector-specific Impacts

At the sectoral level, water quality improvements generate noticeable favourable impacts on many seasonal crop sectors, (Figure 2).[18] This is particularly the case for most of the winter crops. Winter is the main agricultural season in Egypt. Winter crops contribute 36 percent of total agricultural products. As such, these expansion in winter crops partially explain the generated economy-wide positive impacts.

Figure 2: Domestic Agricultural Production (Percentage change)



Source: authors' elaboration on model results.

[18] For more details, see the Appendix A2.

The simulated improvements in water quality boost all seasonal vegetable sectors by virtually 30 percent. Most vegetables, as well as fruits, are salt-sensitive. This is reflected in the simulated increases in yields. For the same reduction in salinity level, the induced increases in yields are more for vegetable sectors in comparison to other seasonal crops, Appendix A1. Vegetables are important sectors for the overall economy. They comprise 23 percent of agricultural output, evenly spread over the winter and summer seasons, and consume some 6 percent of Nile water used in each of the irrigation seasons. This partially interprets the previous reported positive economy-wide impacts.

Interestingly, rice production in both summer and Nili seasons expand by 12 and 9 percent respectively under the F-Yld scenario. These output increments induce significant rice export expansions, ranging 30-60 percent under the three scenarios, Table 6. Rice is of a great importance to the Egyptian economy and accounts for more than 6 percent of agricultural production; a substantial share of production is exported. Rice is a water-intensive crop that consumes more than 30 percent of annual irrigation Nile water and more than half of summer Nile water; it is cultivated mainly in the summer season with only 0.4 percent of output grown in the Nili season. These results, therefore, imply that, without increasing irrigation water requirements, Egypt can achieve outstanding expansions in rice output and exports by investing in improving irrigation water quality.

Some negative impacts are reported for sugar beet sector (in winter) and sugar cane sector (in summer). These experienced shrinkages in sugar output adversely affect food product industries and exports, Table 6.

Despite its importance, wheat production experience trivial expansion under all scenarios. Wheat represents 13 percent of agricultural production, and is one of the main users of Nile land (almost 30 percent) and uses a tenth of Nile water.

In the summer season, the reported expansions in rice and vegetable sectors occur at the expenses of all other summer crops. In other words, improving water quality adversely affects most of summer crops. These negative impacts are less pronounced under P-Yld and L-Yld scenarios.

Clearly, interpreting these findings requires more detailed analyses for production technology prevailing in the base year as well as changes in factor prices and rents under the simulation scenarios. The next sub-section addresses these effects.

Table 6: Commodity Exports (Percentage change)

	H-Yld	P-Yld	L-Yld
Wheat	3.35	3.49	2.99
Cereals	22.24	17.10	12.86
Rice	63.18	43.55	30.58
Vegetables	71.13	48.71	33.94
Fruits	319.80	126.09	47.93
Coffee Tea	69.41	47.87	33.57
minerals gas	-9.12	-5.08	-3.08
Food products	-3.41	-0.79	-0.01
Other transportable goods	-1.18	0.06	0.26
Metal machinery	1.23	2.13	2.13
Construction	0.88	2.27	2.91
Trade	-5.76	-3.09	-1.85
Financial services	-4.48	-2.33	-1.33
Business services	-5.43	-2.87	-1.67
Social services	-5.44	-3.07	-1.92

Source: authors' elaboration on model results.

Agricultural Factor Wages and Incomes

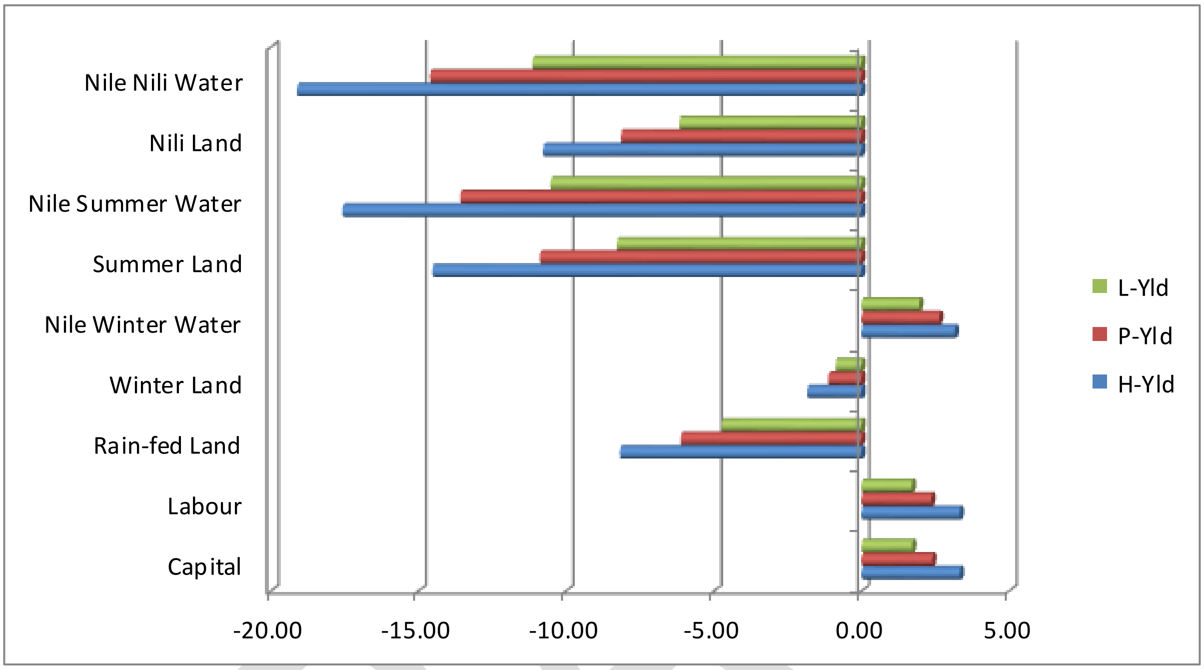
Virtually all seasonal water and land prices, as well as incomes, experience drops under all scenarios. For some cases, the decreases in groundwater-dependent factor prices are greater than those for Nile water-dependent factors. However, the changes in Nile water dependent factor are the main determinants of the generated structural changes. Nile water/land accounts for some 15 percent of agricultural value added and 90 percent of irrigated agriculture. Groundwater and land irrigated by ground water have small shares in agricultural value added (less than 2 percent) and in irrigated agriculture (8 percent).

Rents for Nile water and land irrigated by Nile water decrease as their qualities improve, Figure 3.[19] These decreases in factor prices are more pronounced in the summer season. The expanding summer activities (i.e. rice and vegetables) absorb the mobile factors,

[19] Increasing production 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.

mainly labour and capital, leaving other activities and push their prices and incomes to rise.[20] These increases in factor prices entail higher production costs for sectors that are relatively more dependent on these factors. As such, most of summer crops experience increasing production costs. Hence, these explain the reported shrinkages.

Figure 3: Agricultural Factor Prices (Percentage change)



Sensitivity Analysis

To analyse the robustness of the model to adopted elasticity of substitution between water and land, a SSA analysis is performed. Anew elasticity of substation is draw 5000 times, following an independent identically distributed (i.i.d.) normal distribution, N(μ, σ2), where the mean is the value provided by Calzadilla et al. (2011). The Monte Carlo draws are run for the H-Yld scenario, under which a 30 percent increase in irrigation efficiency is simulated. Appendix A3 reports the minimum and maximum values as well as the percentage change between them, the mean and the standard deviation (and coefficient of variation) for the quantity produced by each agricultural activity. The frequency distribution of the quantity of winter wheat produced (Figure 4) shows that 97 percent of the observations are within two standard deviations around the mean (84 percent within single standard deviation).

[20] In this general equilibrium framework, the causal relationship between factor demand and factor rents works in two directions. Excess demand for a production factor pushes its average rent to rise in order to clear the market. Simultaneously, producers substitute this factor, which became relatively more expensive, for other factors according the elasticity of substitution at the fourth level of the CES production function.

Results of the SSA show that the model is proven to be robust to the elasticity of substitution between water and land.

Figure 4: SSA Frequency Distribution, Winter Wheat Production

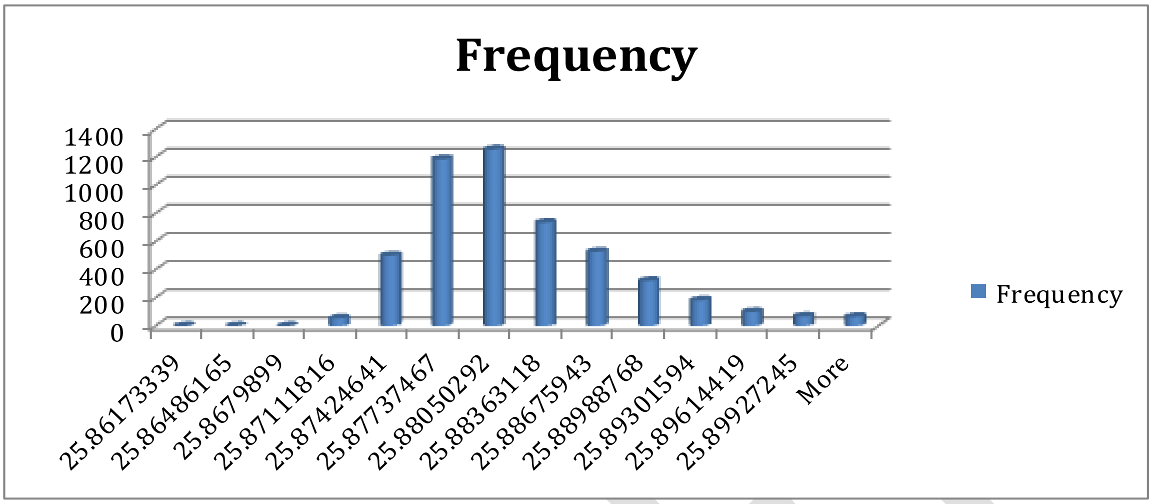


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Table A1: Simulated Changes in Crop Yields (Percentage change)

	H-Yld	P-Yld	L-Yld
	Winter Crops		
Wheat & Cereals	0.0357	0.0250	0.0179
Legumes	0.0836	0.0586	0.0418
Sugar Beet	0.0336	0.0321	0.0230
Fodders	0.2630	0.1841	0.1315
Fibbers	0.2945	0.2062	0.1473
Medical Plants	0.2630	0.1841	0.1315
Vegetables	0.3730	0.2611	0.1865
	Summer Crops		
Rice	0.1925	0.1347	0.0962
Other Crops	0.1613	0.1154	0.0824
Sugar Cane	0.0705	0.0493	0.0352
Cotton	0.0982	0.0687	0.0491
Fodders	0.0981	0.0687	0.0491
Oily Crops	0.1470	0.1029	0.0735
Medical Plants	0.0981	0.0687	0.0491
Vegetables	0.3730	0.2611	0.1865
	***Nili* Crops**		
Rice	0.1925	0.1347	0.0962
Other Crops	0.1630	0.1145	0.0819
Fodders	0.1806	0.1264	0.0903
Oily Crops	0.1470	0.1029	0.0735
Medical Plants	0.1806	0.1264	0.0903
Vegetables	0.3730	0.2611	0.1865
	Year-round Crops		
Fruits	0.5876	0.3052	0.1422
Other Agri, Forestry & Fishing	0.1960	0.1329	0.0915

Source: authors' elaboration on model results.

Table A2: Domestic Agricultural Production (Percentage change)

	H-Yld	P-Yld	L-Yld
	Winter Crops		
Wheat & Cereals	1.81	1.62	1.28
Legumes	11.39	8.83	6.67
Sugar Beet	-49.20	-37.46	-29.27
Fodders	34.44	24.48	17.58
Fibbers	44.57	31.05	22.05
Medical Plants	32.00	22.54	16.11
Vegetables	30.32	21.56	15.64
	Summer Crops		
Rice	12.36	8.42	5.83
Other Crops	-14.53	-10.48	-7.90
Sugar Cane	-37.50	-29.10	-22.33
Cotton	-14.80	-10.76	-7.98
Fodders	-11.89	-8.56	-6.29
Oily Crops	-20.95	-16.13	-12.27
Medical Plants	-10.02	-7.11	-5.18
Vegetables	34.90	24.72	17.86
	***Nili* Crops**		
Rice	8.54	5.53	3.59
Other Crops	-15.27	-11.53	-8.71
Fodders	11.17	8.31	6.08
Oily Crops	-15.40	-11.76	-8.89
Medical Plants	24.18	17.46	12.60
Vegetables	37.01	26.23	18.92
	Year-round Crops		
Fruits	192.69	75.11	28.52
Other Agri, Forestry & Fishing	0.28	0.30	0.23

Source: authors' elaboration on model results.

Table A3: Agricultural Production, Systematic Sensitivity Analysis

	Minimum	Maximum	%	Mean	SD	CV
	Winter Crops					
Wheat & Cereals	25.86	25.90	0.15	25.88	0.0063	0.0002
Legumes	1.04	1.05	0.86	1.04	0.0013	0.0013
Sugar Beet	1.48	1.49	1.02	1.49	0.0024	0.0016
Fodders	31.15	31.31	0.50	31.25	0.0192	0.0006
Fibbers	0.19	0.20	1.08	0.19	0.0003	0.0013
Medical Plants	0.51	0.51	1.15	0.51	0.0006	0.0012
Vegetables	25.22	25.35	0.52	25.29	0.0207	0.0008
	Summer Crops					
Rice	13.38	13.42	0.33	13.40	0.0073	0.0005
Other Crops	11.68	11.75	0.67	11.71	0.0131	0.0011
Sugar Cane	3.26	3.29	0.95	3.27	0.0051	0.0016
Cotton	3.66	3.69	0.77	3.67	0.0047	0.0013
Fodders	2.94	2.96	0.87	2.95	0.0042	0.0014
Oily Crops	1.69	1.70	0.56	1.70	0.0015	0.0009
Medical Plants	0.14	0.14	1.03	0.14	0.0002	0.0017
Vegetables	27.20	27.28	0.29	27.24	0.0116	0.0004
	Nili Crops					
Rice	0.05	0.06	2.28	0.06	0.0002	0.0034
Other Crops	1.83	1.85	1.19	1.84	0.0036	0.0019
Fodders	0.44	0.45	1.70	0.44	0.0011	0.0024
Oily Crops	0.01	0.01	3.54	0.01	0.0000	0.0051
Medical Plants	0.00	0.00	5.18	0.00	0.0000	0.0076
Vegetables	4.09	4.12	0.66	4.11	0.0040	0.0010
	Year-round Crops					
Fruits	31.89	31.89	0.01	31.89	0.0005	0.0000
Other Agri, Forestry & Fishing	39.50	39.50	0.00	39.50	0.0001	0.0000

Source: authors' elaboration on model results.