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Maximizing the economic value of irrigation water and achieving self sufficiency of main crops

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Abstract Water is a limited resource that needs sustainable management, which aims to develop and protect it. Without a proper management, water will become a constraining factor in the socio-economic development of Egypt.

Giving information on the economic value of water enable decision makers to take informed choices on water allocation to face the growing demands for all uses and drawing its sustainable future in agricultural and water policies. The current paper aims to assist decision makers in developing new cropping patterns considering the supply and demand aspects based on the efficient utilization of the water resources. It has proposed a cropping pattern which can increase the economic value of irrigation water from 0.88 LE/CM to 0.92 LE/CM. It can also decrease the gap between the national production and the imports, and increase self sufficiency of the main agricultural crops.

1. Introduction

Water characterized with the fact that there is no substitute alternative resource [1]. Water scarcity is a growing global problem, especially in Egypt. Egypt has reached a stage where the quantity of water supply is constant while there is rapid increase in the water demands. The population increase in Egypt and the related industrial and agricultural activities have increased the demand for water to a level that reaches the limits of the available supply. The population of Egypt has been growing in the last 25 years from a mere 38 million in the year 1977 to 66 million in 2002 and is expected to grow up to 83 million in the year 2017. The Egyptians are concentrated in the Nile Valley and the Delta: 97% of them live on 4% of the Egyptian land [2].

In Egypt, agriculture consumes the largest amount of the available water, about 80% of the total demand for water. Municipal water requirements include water supply for major urban and rural villages. Municipal water demand was estimated 9.0 billion cubic meters (BCM) in 2009. Ministry of Water Resources and Irrigation estimated that the value of the water requirements in the industrial sector during 2009 was 8.0 BCM/year [2].

Water value should reflect the societal economic, environmental, and cultural values [2]. The economic value of water depends on the user as well as on the use. Water can have a

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very high economic value because it is scarce and can be used in many different ways. Information on the economic value of water enables the decision makers to take informed choices for water development, conservation, allocation, and its usage when growing demands for all uses are made in confronting its increasing scarcity [3]. Conceptually, correct and empirically accurate estimates of the economic value of water are essential for rational allocation of water scarcity across locations, uses, users, and time periods [3].

2. Literature review

Nimah [4], focused on increasing water productivity based on per caput food consumption, and optimizing water resources allocations. The specific aims of this paper were developing an optimization model in terms of crop water productivity and balanced diet to elaborate more, developing a mathematical model to maximize revenue per unit water based on optimum cropping pattern, and the output of the first model and, test both models in field conditions. He developed an optimization model solved by linear programing utilizing the general algebraic modeling system to obtain the optimum cropping pattern that maximizes revenue per unit water, taking into account crop evapotranspiration, land, market, and water availability as constraints.

Gamal [5], presented the usage of linear programing models in structuring more rational Egyptian cropping pattern. There are three alternatives. The first alternative was the maximizing net return to land and water per feddan using both financial and economic prices; secondly, maximizing return to water unit volume using both financial and economic prices. Finally, the third alternative was rationalizing usage of the available water resources through minimizing water requirements. He suggested that the alternative which took both the generated returns and irrigation water requirements into consideration is the most efficient one.

Hussien et al. [6], focused on assessing water productivity for different crops, and assisting decision makers in drawing future agriculture sustainable policies in Egypt. He also aimed to maximize the national water resources' productivity in different agriculture activities considering supply and demand aspects based on the efficient utilization of the water resources. The crop budget approach is considered one of the economic tools to estimate the net return or profit. This study adopted this approach to assess the crop water productivity in terms of physical unit of production and monetary units.

In this paper, the optimized proposed cropping pattern will increase the economic value of irrigation water, taking into consideration the optimal use of irrigation water and the cropped area without any additional cost for the construction of new infrastructures or more water requirements. It can also help to avoid the conflicts with Nile basin countries.

3. Objective

The main objective of this paper is to maximize the economic value of irrigation water through an optimized new cropping pattern which could achieve self-sufficiency for some strategic crops in three Egyptian governorates (Dakhlia, Qaliobia, and Sharkia). Fig. 1 shows the selected study area in the Egyptian map. These governorates mentioned previously were selected because of the availability of its data. The importance that such selected governorates are close to each other is to make transportation of crops and labors easy, with low cost.

4. Collected data utilized

The possible different scenarios were developed based on data provided by official sources. These sources are primarily the ministry of irrigation and water resources (MIWR); Irrigation Sector (IS), Ministry of Agriculture and land Reclamation (MALR); Economic Affair Sector (EAS), and General Agency for Public Mobilization and Statistics (CAPMAS). These data include the following components:

1. Water requirements for each crop per feddan per season (summer, winter and nili) in the three governorates.
2. The current cropping pattern in the three governorates.
3. The total cost used for cultivating each crop included land preparation, seeds, fertilizers, irrigation, agricultural services, pests resistance, harvest, crop transportation, and the public expenses costs.
4. The total revenue per feddan for each crop.

5. Current cropping pattern

The pattern of crops in a given piece of land or cropping pattern means the area proportion of various crops at a point of time in a unit area. It should also indicate the yearly sequence and spatial arrangements of crops and follows in an area [7]. However, in all cases, the cropping pattern reflects the relative importance of specific crop to the total cultivated areas. Table 1 represented the cropping pattern structure at Dakhlia, Qaliobia, and Sharkia governorates by crop, and season.

5.1. Dakhlia governorate

In summer season, it could be noticed that rice and maize occupied about 70% and 17% respectively of the total cultivated area at Dakhlia governorate as shown in Table 1. In winter season, wheat and long clover occupied about 52% and 26% respectively of the total cropped area at Dakhlia governorate. Maize occupied about 99% of the total cropped area of nili season at Dakhlia governorate [7].

5.2. Qaliobia governorate

Maize occupied about 78% of the total cultivated area in summer season at Qaliobia governorate. In winter season, it could be also noticed that wheat and long clover occupied about 43% and 32% respectively of the total cultivated area in Qaliobia governorate. It is obvious that cabbage occupied about 99% of the total cropped area in nili season as shown in Table 1.

5.3. Sharkia governorate

The cultivated area of rice and maize occupied about 43% and 40% respectively of the total cultivated area at sharkia governorate as shown in Table 1. In winter season, it is obvious that

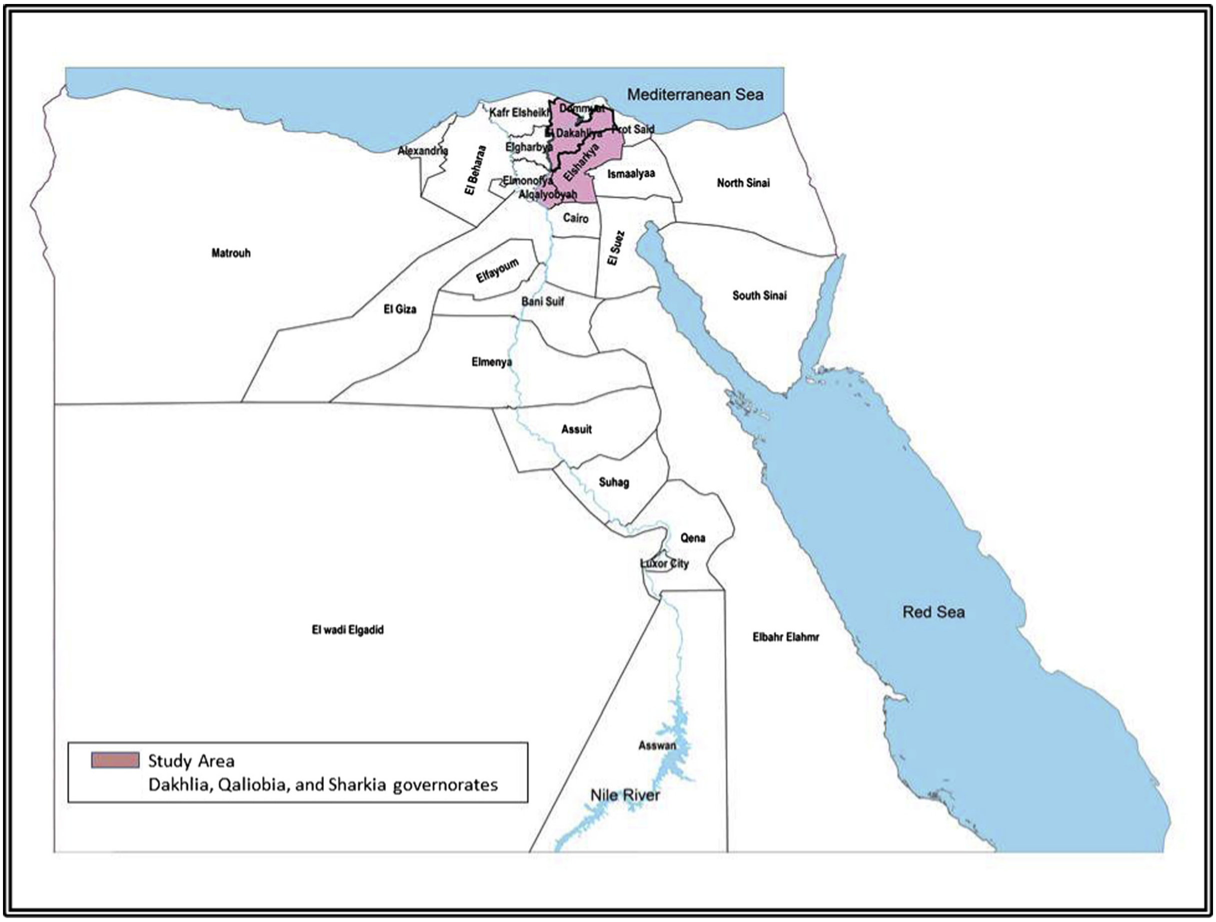

Figure 1 Egypt map shows the study area [7].

wheat and long clover occupied about 57% and 20% respectively of the total cultivated area in winter season. Maize and potato occupied about 54% and 29% respectively of the total cropped area of nili season at Sharkia governorate [7].

6. Current net return

In this paper the net return defined as the price of the crop multiplied by the yield minus the production cost. The net return per feddan at Dakhlia, Qaliobia, and Sharkia governorates sorted by crop and season could be represented in Table 2.

6.1. Dakhlia governorate

In summer season, onion and watermelon had the highest net return values 12.1 and 10.5 (Thousand LE/Feddan) respectively. In winter season, it could be noticed that eggplant had the highest net return value 17.4 (Thousand LE/Feddan). On the other hand, tomato had the highest net return 6.4 (Thousand LE/Feddan) among nili crops as shown in Table 2.

6.2. Qaliobia governorate

Onion had the highest net return value 11.3 (Thousand LE/Feddan) among summer crops at Qaliobia governorate. In winter season, eggplant had the highest net return value 14.4 (Thousand LE/Feddan). In nili season, it could be noticed that cabbage had the highest net return 5.2 (Thousand LE/Feddan) as shown in Table 2.

6.3. Sharkia governorate

At Sharkia governorate, the Potato had the highest net return value 9.0 (Thousand LE/Feddan) among summer crops. In winter season, eggplant had the highest net return value 20.3 (Thousand LE/Feddan). The Potato had the highest net return 5.3 (Thousand LE/Feddan) of nili season's crops as shown in Table 2.

7. Water consumption

It is assumed that the water consumption of each crop in the three governorates is constant. Table 3 represented the water consumption by summer, winter, and nili crops per feddan. It could be noticed that sugarcane and rice had the highest water consumption 7.2 and 6.3 (Thousand CM/Feddan) respectively. In winter season long clover and sugar beet occupied the highest water consumption 2.9 and 2.4 (Thousand CM/Feddan) respectively. Tomato, potato, and cabbage had the highest water consumption 2.6 (Thousand CM/Feddan) in nili season.

Table 1 Cropping pattern structure at the three governorates [7].

Governorate name		Cultivated area					
		Dakhlia		Qaliobia		Sharkia	
Season	Crop	1000 Fed	%	1000 Fed	%	1000 Fed	%
Summer	Rice	359.7	69.68	9.94	8.09	256.336	43.34
	Maize	89.662	17.37	95.677	77.85	234.58	39.66
	Cotton	43.447	8.42	1.23	1.00	27.413	4.63
	Tomato	4.867	0.94	3.599	2.93	20.437	3.46
	Potato	11.755	2.28	5.121	4.17	2.173	0.37
	Eggplant	2.443	0.47	3.526	2.87	7.111	1.20
	Watermelon	3.609	0.70	*	*	3.201	0.54
	Onion	0.744	0.14	2.218	1.80	*	*
	Sesame	*	*	0.033	0.03	8.835	1.49
	Soybeans	*	*	0.03	0.02	*	*
	Sunflower	*	*	0.015	0.01	*	*
	Zucchini	*	*	1.132	0.92	5.77	0.98
	Peanut	*	*	0.383	0.31	15.85	2.68
	Cucumber	*	*	*	*	1.602	0.27
	Pepper	*	*	*	*	8.136	1.38
	Sugarcane	*	*	*	*	0.035	0.01
Winter	Tahrish	31.504	5.28	9.664	8.23	27.666	3.78
	Flax	4.866	0.82	0.051	0.04	1.71	0.23
	Wheat	307.173	51.50	50.322	42.86	418.415	57.17
	Long Clover	154.655	25.93	37.063	31.57	148.742	20.32
	Tomato	1	0.17	1.415	1.21	28.259	3.86
	Broadbean	25.479	4.27	0.684	0.58	22.194	3.03
	Sugarbeet	33.311	5.59	0.017	0.01	22.307	3.05
	Garlic	0.325	0.05	0.249	0.21	0.467	0.06
	Green peas	6.81	1.14	2.197	1.87	3.24	0.44
	Eggplant	0.024	0.00	0.146	0.12	10.886	1.49
	Potato	18.409	3.09	2.278	1.94	7.167	0.98
	Onion	12.867	2.16	9.596	8.17	3.431	0.47
	Cabbage	*	*	3.472	2.96	2.653	0.36
	Zucchini	*	*	0.253	0.22	5.818	0.79
	Lentil	*	*	*	*	0.471	0.06
	Lupin	*	*	*	*	1.938	0.26
	Barely	*	*	*	*	15.996	2.19
	Pepper	*	*	*	*	10.548	1.44
Nili	Tomato	0.362	1.02	0.005	0.72	4.108	17.32
	Maize	35.026	98.87	*	*	12.719	53.63
	Potato	0.037	0.10	*	*	6.828	28.79
	Cabbage	*	*	0.689	99.28	0.06	0.25

* Not cultivated in the governorate.

8. Current economic value of water

In this paper the economic value refers to the amount of crop output in economic terms (the net return of certain cultivated area; in our study Dakhlia, Qaliobia, and Sharkia governorates) divided by the amount of agricultural water requirements for each crop. The economic value can be considered as an important indicator which is the average value per unit of water used. However, productivity is a measure of performance expressed as the ratio of output and input. Productivity may be assessed for the whole system or a single element. It could account for all or one of the production system inputs, two productivity indicators:

- *Total productivity:* the ratio of the total output divided by the total inputs; and
- *Partial productivity:* the ratio of the total output to the input of one or more factor within system. In agriculture system factors could be water, land, capital, and labor [8].

The economic value of water is a partial factor productivity that measures how the systems convert water into economic value. Its general definition can be recognized as:

Economic value = Output Derived from Water Use (Net return)/Water Input.

Economic value can be organized and presented in several different formats. However, they can typically contain two different sections: total revenue and total costs. Following are the steps required to estimate these sections in details:

- Total revenue (TR)

Table 2 The net return per feddan at the three governorates [7].

Governorate name		Dakhlia	Qaliobia	Sharkia
Season	Crop	Net return (LE/Feddan)		
Summer	Rice	2697	1066	2005
	Maize	2609	1314	951
	Cotton	898	486	249
	Tomato	3551	6826	5033
	Potato	5363	4912	9031
	Eggplant	3048	2888	2264
	Watermelon	10,511	*	5282
	Onion	12,103	11,284	*
	Sesame	*	968	968
	Soybeans	*	1067	*
	Sunflower	*	632	*
	Zucchini	*	3080	1800
	Peanut	*	6116	4873
	Cucumber	*	*	1350
	Pepper	*	*	4634
	Sugarcane	*	*	5437
Winter	Tahrish	2794	3086	2780
	Flax	2594	2722	2722
	Wheat	2554	2013	1372
	Long Clover	6034	6412	6088
	Tomato	2403	5489	5482
	Broadbean	2554	2013	1372
	Sugarbeet	4624	4067	4067
	Garlic	5530	9011	8461
	Green peas	5023	5543	3383
	Eggplant	17,361	14,314	20,298
	Potato	4154	609	4154
	Onion	6381	5529	6500
	Cabbage	*	4710	4086
	Zucchini	*	6487	5582
	Lentil	*	*	2701
	Lupin	*	*	1740
	Barely	*	*	1469
	Pepper	*	*	9058
Nili	Tomato	6437	4617	4617
	Maize	2307	*	1444
	Potato	5340	*	5340
	Cabbage	*	5175	1607

* Not cultivated in the governorate.

The first step to estimate total revenue is to measure the total production. Total production contains the main by product and the associated prices of such studied crops outputs.

$$TR_{ij} = P_{ij} \times D_{ij} \quad (1)$$

where P_{ij} = price of crop (i) at governorate (j) (LE/kg); D_{ij} = the production of crop (i) at governorate (j) (kg).

- Total costs (TC)

The total costs contained land preparation, seeds, fertilizers, irrigation, agricultural services, pest resistance, harvest, crop transportation, and public expenses costs. The variable costs calculated by multiplying the quantities of every input by the associated prices.

$$TC_{ij} = C_{ij} \times Q_{ij} \quad (2)$$

where C_{ij} = cost of crop (i) at governorate (j) (LE/kg); Q_{ij} = the production of crop (i) at governorate (j) (kg).

- Net return (NR)

Net return calculated as the difference between the total return; total production multiplied by their farm gate prices, and the total costs that calculated in the previous item.

$$NR_{ij} = TR_{ij} - TC_{ij} \quad (3)$$

- Water input (WR)

The water input can be specified as volume per cubic meter. Water input is the water requirements of each crop per feddan multiplying by the total area of each crop.

- Economic value of water (EV)

The economic value of irrigation water in the current paper is computed by applying a value-added method using Eq. (4):

Table 3 Water consumption of each crop per season [7].

Governorate name		Dakhlia	Qaliobia	Sharkia
Season	Crop	Water requirements (m^3/Feddan)		
Summer	Rice		6349	
	Maize		2904	
	Cotton		3292	
	Tomato		2967	
	Potato		2967	
	Eggplant		2967	
	Watermelon		2967	
	Onion		3724	
	Sesame		2496	
	Soybeans		2768	
	Sunflower		2171	
	Zucchini		2967	
	Peanut		3889	
	Cucumber		2967	
	Pepper		2967	
	Sugarcane		7220	
Winter	Tahrish		1340	
	Flax		1369	
	Wheat		1720	
	Long Clover		2875	
	Tomato		2175	
	Broadbean		1339	
	Sugarbeet		2419	
	Garlic		1365	
	Green peas		2175	
	Eggplant		2175	
	Potato		2175	
	Onion		1875	
	Cabbage		2175	
	Zucchini		2175	
	Lentil		1505	
	Lupin		1505	
	Barely		1480	
	Pepper		2175	
Nili	Tomato		2551	
	Maize		2377	
	Potato		2551	
	Cabbage		2551	

Table 4 Economic value of irrigation water at the three governorates [7].

Governorate name		Dakhlia	Qaliobia	Sharkia
Season	Crop	Economic value (LE/m^3)		
Summer	Rice	0.42	0.17	0.32
	Maize	0.9	0.45	0.33
	Cotton	0.27	0.15	0.08
	Tomato	1.2	2.3	1.7
	Potato	1.81	1.66	3.04
	Eggplant	1.03	0.97	0.76
	Watermelon	3.54	*	1.78
	Onion	3.25	3.03	*
	Sesame	*	0.39	0.39
	Soybeans	*	0.39	*
	Sunflower	*	0.29	*
	Zucchini	*	1.04	0.61
	Peanut	*	1.57	1.25
	Cucumber	*	*	0.46
	Pepper	*	*	1.56
	Sugarcane	*	*	0.75
Winter	Tahrish	2.09	2.3	2.07
	Flax	1.89	1.99	1.99
	Wheat	1.48	1.17	0.8
	Long Clover	2.1	2.23	2.12
	Tomato	1.1	2.52	2.52
	Broadbean	1.91	1.5	1.02
	Sugarbeet	1.91	1.68	1.68
	Garlic	4.05	6.6	6.2
	Green peas	2.31	2.55	1.56
	Eggplant	7.98	6.58	9.33
	Potato	1.91	0.28	1.91
	Onion	3.4	2.95	3.47
	Cabbage	*	2.17	1.88
	Zucchini	*	2.98	2.57
	Lentil	*	*	1.79
	Lupin	*	*	1.16
	Barely	*	*	0.99
	Pepper	*	*	4.16
Nili	Tomato	2.52	1.81	1.81
	Maize	0.97	*	0.61
	Potato	2.09	*	2.09
	Cabbage	*	2.03	0.63

* Not cultivated in the governorate.

$$EV_{ij} = \frac{NR_{ij}}{WR_{ij}} \quad (4)$$

In this study, the economic value calculated as the amount of crop output in economic terms (the net return of certain cultivated area; in our study Dakhlia, Qaliobia, and Sharkia governorates) divided by the amount of agricultural water available in the mentioned governorates. Table 4 represented the economic value of irrigation water at Dakhlia, Qaliobia, and Sharkia governorates by crop and season.

8.1. Dakhlia governorate

Watermelon and onion were found to have the highest economic value about 3.54 and 3.25 (LE/m^3) respectively among summer crops. On the other hand, cotton and rice had the smallest economic value about 0.27 and 0.42 (LE/m^3) respectively. In winter season, eggplant, garlic, and onion crops occupied the highest economic value about 7.98, 4.05, and 3.40 (LE/m^3) respectively. Otherwise tomato and wheat had the lowest economic value about 1.10 and 1.48 (LE/m^3) respectively. In nili season, the economic value of tomato was the highest value about 2.52 (LE/m^3) and the value of maize was the smallest about 0.97 (LE/m^3) as shown in Table 4.

8.2. Qaliobia governorate

It is obvious that onion and tomato crops had the highest economic value about 3.03 and 2.30 (LE/m^3) respectively among summer crops. On the other hand, cotton and rice had the smallest economic value about 0.15 and 0.17 (LE/m^3) respectively. In winter season, garlic and eggplant had the highest economic value about 6.60 and 6.58 (LE/m^3) respectively, while potato and wheat had the smallest economic value about 0.28 and 1.17 (LE/m^3) respectively. Cabbage crop had the highest economic value about 2.03 (LE/m^3) among nili crops and tomato had the smallest economic value about 1.81 (LE/m^3).

8.3. Sharkia governorate

Potato and watermelon had the highest economic value about 3.04 and 1.78 (LE/m^3) respectively among summer crops while cotton and rice had the smallest economic value about 0.08 and 0.32 (LE/m^3) respectively. In winter season, eggplant and garlic had the highest economic value about 9.33 and 6.20 (LE/m^3) respectively. On the other side, wheat and barley had the minimum economic values about 0.80 and 0.99 (LE/m^3) respectively. Potato had the highest economic value about 2.09 (LE/m^3) and maize had the smallest economic value about 0.61(LE/m^3) in nili season.

9. Development of the proposed optimization model

Linear programing (LP) is a mathematical method for determining a way to achieve the best outcome (such as maximum profit or lowest cost) in a given mathematical model for some list of requirements represented as linear relationships. It is a specific case of mathematical programing (mathematical optimization). Linear programing is a planning method that is often helpful in making decisions among a large number of alternatives and a useful tool for analysis. Through this paper, linear programing approach was applied as a tool to maximize the economic value of irrigation water in the selected governorates. The Windows version of Quantitative Systems for Business (WinQSB) was used as a tool to solve the developed linear programing equations.

The WinQSB is an application whose goal is to make the task of taking decisions easier on business. This Quantitative System for Business is an interactive decision support system that offers an array of powerful tools to help managers solve problems and make successful business decisions. The software offers a wide range of problem-solving tools from management science and operations management. In a user-friendly, easy-to-understand environment, these tools work and could be applied to tackle business problems. Data entry is a spreadsheet oriented and easy to use tool. The system output also includes spreadsheet tables and graphic analyses.

The model is an enhanced version of QSB+, QS, and QSOM. It is an interactive and user-friendly decision support system covering tools and methods in management science, operations research, and operations management. It runs in the Windows environment: Windows 3.1, Windows 95, Windows NT, or later version.

9.1. Model formulation

In principle, the model consisted of three basic elements: (i) Objective Function (Z); (ii) Variables (A_{ij}); and (iii) Constraints.

9.1.1. Objective function

Through this study, the objective function can be mathematically expressed as:

$$Z_{\max} = \sum_{j=1}^{j=m}\sum_{i=1}^{i=n} A_{ij} \times \mathrm{EV}_{ij} \tag{5}$$

where Z = overall economic value of irrigation water; A_{ij} = the cultivated area of crop (i) at governorate (j); E_{ij} = the economic value of irrigation water of crops (i) at governorate (j); n = is the number of crops under study (n = 1, 2, 3... 86); m = is the number of governorates under study (m = 1, 2, 3).

9.1.2. Variables

The variables are the cultivated area of each crop at the three governorates (A_{ij}). There are 86 variables in each scenario as shown in Table 5. Each crop has a variable name in the objective function. Each of the same crops in the three governorates had a different variable name .For example, Rice in Dakhlia governorate has the variable name "A1" but Rice in Qaliobia and Sharkia governorates has the variable names "A24, A52" respectively and so on because the economic value of the same crop differs from governorate to another [7].

9.1.3. Constraints

The constraints can be categorized as cultivated area of different crops seasonally, water available for the three governorates, and the required production of the same crop at the three governorates.

The model had a special set of constraints that restrict its feasible solution range. This study will help in decreasing the gap between the national production and the imports and increasing self sufficiency of the main agricultural crops [7]. This can be done by applying the following constraints on the proposed cropping patterns:

- The proposed cultivated area for all crops should not be less than 70% from the current cultivated area.
- Reduce the current cultivated area of rice according to the self-sufficiency rate for rice which is 112%.
- Increase the current cultivated area of some strategic crops like Wheat, Maize, Broad bean, Soybeans, and Sunflower according to the self-sufficiency rate of these crops.

Mathematically, the constraints can be expressed as follows:

9.1.3.1. Area constraint.

$$\sum_{i=1}^{k} A_i \le A_t \tag{6}$$

where A_i = area cultivated with crop i seasonally (summer or winter or nili); A_t = total area allowed to be cultivated with all crops in the same governorate seasonally; K = no. of crops seasonally at each governorate.

9.1.3.2. Water constraint.

$$\sum_{j=1}^{j=m}\sum_{i=1}^{i=n} A_{ij} \times \mathrm{WR}_{ij} \le \mathrm{WR}_t \tag{7}$$

where WR_{ij} = water requirements per feddan for crop i at governorate (j); A_{ij} = the cultivated area by crop (i) at governorate (j); WR_t = Total water available for all crops in the three governorates during the whole yearl n = is the number of crops under study (n = 1, 2, 3... 86); m = is the number of governorates under study (m = 1, 2, 3).

9.1.3.3. Production constraint.

$$\sum_{j=1}^{m} A_{ij} \times Y_{ij} = P_i \tag{8}$$

Table 5 Objective function variables [7].

(j = 1)	Variable A_i	Crop	Current Cropping Pattern (Feddan)	(j = 2)	Variable A_i	Crop	Current cropping pattern (Feddan)	(j = 3)	Variable A_i	Crop	Current cropping attern (Feddan)
Dakhlia				*Qaliobia*				*Sharkia*			
Summer	A_1	Rice	359,700	Summer	A_{24}	Rice	9940	Summer	A_{52}	Rice	256,336
	A_2	Maize	89,662		A_{25}	Maize	95,677		A_{53}	Maize	234,580
	A_3	Cotton	43,447		A_{26}	Sesame	33		A_{54}	Cotton	27,413
	A_4	Tomato	4867		A_{27}	Soybeans	30		A_{55}	Tomato	20,437
	A_5	Potato	11,755		A_{28}	Sunflower	15		A_{56}	Potato	2173
	A_6	Eggplant	2443		A_{29}	Onion	2218		A_{57}	Zucchini	5770
	A_7	Watermelon	3609		A_{30}	Cotton	1230		A_{58}	Cucumber	1602
	A_8	Onion	744		A_{31}	Tomato	3599		A_{59}	Eggplant	7111
Winter	A_9	Tahrish	31,504		A_{32}	Potato	5121		A_{60}	Pepper	8136
	A_{10}	Flax	4866		A_{33}	Zucchini	1132		A_{61}	Watermelon	3201
	A_{11}	Wheat	307,173		A_{34}	Eggplant	3526		A_{62}	Peanut	15,850
	A_{12}	Long Clover	154,655		A_{35}	Peanut	383		A_{63}	Sesame	8835
	A_{13}	Tomato	1000	Winter	A_{36}	Tahrish	9664		A_{64}	Sugarcane	35
	A_{14}	Broad bean	25,479		A_{37}	Wheat	50,322	Winter	A_{65}	Lentil	471
	A_{15}	Sugar beet	33,311		A_{38}	Long Clover	37,063		A_{66}	Lupin	1938
	A_{16}	Onion	12,867		A_{39}	Tomato	1415		A_{67}	Tahrish	27,666
	A_{17}	Garlic	325		A_{40}	Broad bean	684		A_{68}	Flax	1710
	A_{18}	Green peas	6810		A_{41}	Flax	51		A_{69}	Wheat	418,415
	A_{19}	Eggplant	24		A_{42}	Potato	2278		A_{70}	Long Clover	148,742
	A_{20}	Potato	18,409		A_{43}	Sugar beet	17		A_{71}	Tomato	28,259
Nili	A_{21}	Tomato	362		A_{44}	Onion	9596		A_{72}	Broad bean	22,194
	A_{22}	Maize	35,026		A_{45}	Garlic	249		A_{73}	Sugar beet	22,307
	A_{23}	Potato	37		A_{46}	Cabbage	3472		A_{74}	Onion	3431
					A_{47}	Zucchini	253		A_{75}	Barely	15,996
					A_{48}	Green peas	2197		A_{76}	Garlic	467
					A_{49}	Eggplant	146		A_{77}	Pepper	10,548
				Nili	A_{50}	Cabbage	689		A_{78}	Cabbage	2653
					A_{51}	Tomato	5		A_{79}	Zucchini	5818
									A_{80}	Green peas	3240
									A_{81}	Eggplant	10,886
									A_{82}	Potato	7167
								Nili	A_{83}	Maize	12,719
									A_{84}	Tomato	4108
									A_{85}	Potato	6828
									A_{86}	Cabbage	60

where A_j = Area cultivated with crop (i) at governorate (j); Y_i = Yield of crop (i) (ton/fed) at governorate (j); P_i = Total production requirements for the same crop in the three governorates; m = is the number of governorates under study (m = 1, 2, 3).

10. Applied scenarios

Five scenarios had been set to maximize the economic value of irrigation water for the three governorates in an integrated manner.

In the first scenario (Sc_1), it is assumed that 70% of the current cultivated area will be under a free cropping policy and the remaining cultivated area controlled by the governorate for all crops in the three governorates. This scenario contains ten constraints, Nine of them represented the cultivated area in each governorate seasonally (summer, winter and nili) and the last constraint represented the agricultural water available for the three governorates.

In the second scenario (Sc_2), it is assumed that 70% of the current cultivated area will be under a free cropping policy and the remaining cultivated area controlled by the governorate for all crops except rice in which 90% of the current cultivated area will be under a free cropping policy in the three governorates. The second scenario (Sc_2) had the same constraints as for the first scenario (Sc_1).

In the third scenario (Sc_3), it is assumed that 70% of the current cultivated area will be under a free cropping policy and the remaining cultivated area controlled by the governorate for all crops in the three governorates. The importance of using a new constraint related to the productivity of each crop at each governorate appeared. This constraint will help in cultivating the same production of any crop using less area of land because the productivity (Yield) of the same crop differs from governorate to another according to the type and quality of land. This scenario contains ten constraints mentioned in the previous two scenarios and also 38 constraints for the 38 crops cultivated in the three governorates in the three seasons.

In the fourth scenario (Sc_4), it is assumed that 70% of the current cultivated area will be under a free cropping policy and the remaining cultivated area controlled by the governorate for all crops in the three governorates. The production for some strategic crops differed in order to achieve self-sufficiency. The production constrains of rice were less than or equal 90% of the current production of rice and for wheat, maize-summer, broad bean, soy beans and sunflower equal 110%, 110%, 105%, 110% and 110% respectively of the current production of previous crops and less than or equal to the current production of remaining crops.

In the fifth scenario which is the optimum scenario, it is assumed that 70% of the current cultivated area will be under a free cropping policy and remaining 30% of the cultivated area controlled by the governorate for all crops in the three governorates. The production constraint of each crop determined according to the current self-sufficiency rate. For rice, wheat, and maize the production constraints were 90%, 1.05%, and 110 respectively from the current production. The production constraints of sesame, soybeans, and sunflower were more than or equal 8,000, 25,000, and 3000 ton.

The area and production constraints of each scenario can be represented in Table 6. In the first and second scenarios, there were over change in the cultivated areas of some crops especially the crops with the highest economic value; therefore, the third scenario was proposed. In the third scenario, it is assumed that the level of production of different crops remains as its current status. Consequently, the area of some crops increased such as rice which means more water consumption and no water saving produced. In the fourth scenario, the production of tahrish, flax, sugar beet, winter potato, winter cabbage, and barely decreased by 48, 9, 346, 96, 29, and 8 thousands ton respectively. This decrease will affect the market needs from these crops. Therefore, it is important to modify the production constraints for the remaining crops and make their production in the proposed scenario equal to the current production to satisfy the market needs of these crops. In order to overcome this problem in the fifth scenario, the constraints set for the strategic corps mentioned in the fourth scenario will be changed with respect to the area available in each season and governorate. The production constraint of each crop determined according to the current self-sufficiency rate. For

Table 6 The area and production constraints of each scenario [7].

Scenario	Area constraints		Production constraints
	A_L	A_U	
First scenario	For each crop: 70% A_C	For each crop: $\leqslant A_{ts}$	No production constraints
Second scenario	For each crop: 70% A_C For Rice: 90% A_C	For each crop: $\leqslant A_{ts}$ For Rice: 90% A_C	
Third scenario	For each crop: 70% A_C	For each crop: $\leqslant A_{ts}$	For all crops: the total production of each crop was set to be equal to its current production
Fourth scenario	For each crop: 70% A_C	For each crop: $\leqslant A_{ts}$	The production of rice at national level will be decreased by -10%. The production of Wheat, Maize-summer, Soybeans and Sunflower will be increased by +10% and production of Broad bean will be increased by 5%.
Fifth scenario	For each crop: 70% A_C	For each crop: $\leqslant A_{ts}$	The production constraints for sesame, soybeans, and sunflower were 8000, 25,000, and 3000 ton

Where: A_L = The minimum value allowed for the proposed area; A_U = The maximum value allowed for the proposed area; A_C = current area of the crop; A_{ts} = total area for all crops in the same season (Summer, Winter, Nili).

Table 7 Differences between current and proposed cultivated area at each governorate [7].

Governorate		Dakhlia			Qaliobia			Sharkia		
Season	Crop	Current	Proposed	Difference	Current	Proposed	Difference	Current	Proposed	Difference
		Area (1000 Feddans)								
Summer	Rice	359.70	251.79	−107.91	9.94	6.96	−2.98	256.34	316.30	59.97
	Maize	89.66	214.42	124.76	95.68	66.97	−28.70	234.58	164.21	−70.37
	Cotton	43.45	30.41	−13.03	1.23	0.86	−0.37	27.41	41.96	14.55
	Tomato	4.87	3.41	−1.46	3.60	9.78	6.18	20.44	14.31	−6.13
	Potato	11.76	8.23	−3.53	5.12	3.58	−1.54	2.17	6.67	4.50
	Eggplant	2.44	2.30	−0.14	3.53	4.28	0.75	7.11	6.44	−0.67
	Watermelon	3.61	4.23	0.62	*	*	*	3.20	2.24	−0.96
	Onion	0.74	1.44	0.69	2.22	1.55	−0.67	*	*	*
	Sesame	*	*	*	0.03	0.02	−0.01	8.84	14.44	5.60
	Soybeans	*	*	*	0.03	18.29	18.26	*	*	*
	Sunflower	*	*	*	0.02	3.00	2.99	*	*	*
	Zucchini	*	*	*	1.13	2.60	1.47	5.77	4.04	−1.73
	Peanut	*	*	*	0.38	5.00	4.62	15.85	11.10	−4.76
	Cucumber	*	*	*	*	*	*	1.60	1.60	0.00
	Pepper	*	*	*	*	*	*	8.14	8.14	0.00
	Sugarcane	*	*	*	*	*	*	0.04	0.04	0.00
Winter	Tahrish	31.50	22.05	−9.45	9.66	6.76	−2.90	27.67	38.12	10.46
	Flax	4.87	3.41	−1.46	0.05	0.04	−0.02	1.71	3.20	1.49
	Wheat	307.17	390.25	83.08	50.32	62.35	12.03	418.42	352.57	−65.85
	Long Clover	154.66	108.26	−46.40	37.06	25.94	−11.12	148.74	187.20	38.46
	Tomato	1.00	0.70	−0.30	1.42	0.99	−0.42	28.26	28.81	0.55
	Broadbean	25.48	21.53	−3.95	0.68	3.06	2.38	22.19	15.54	−6.66
	Sugarbeet	33.31	23.32	−9.99	0.02	0.01	−0.01	22.31	33.55	11.25
	Garlic	0.33	0.23	−0.10	0.25	0.46	0.21	0.47	0.33	−0.14
	Green peas	6.81	4.77	−2.04	2.20	4.96	2.76	3.24	2.27	−0.97
	Eggplant	0.02	0.02	−0.01	0.15	0.10	−0.04	10.89	10.92	0.03
	Potato	18.41	12.89	−5.52	2.28	1.59	−0.68	7.17	12.12	4.96
	Onion	12.87	9.01	−3.86	9.60	6.72	−2.88	3.43	10.50	7.06
	Cabbage	*	*	*	3.47	2.43	−1.04	2.65	3.77	1.11
	Zucchini	*	*	*	0.25	1.98	1.73	5.82	4.07	−1.75
	Lentil	*	*	*	*	*	*	0.47	0.47	0.00
	Lupin	*	*	*	*	*	*	1.94	1.94	0.00
	Barely	*	*	*	*	*	*	16.00	16.00	0.00
	Pepper	*	*	*	*	*	*	10.55	10.55	0.00
Nili	Tomato	0.36	0.48	0.12	0.01	0.00	0.00	4.11	3.97	−0.14
	Maize	35.03	34.91	−0.11	*	*	*	12.72	12.86	0.14
	Potato	0.04	0.03	−0.01	*	*	*	6.83	6.84	0.01
	Cabbage	*	*	*	0.69	0.69	0.00	0.06	0.06	0.00

* Not cultivated in the governorate.

rice, wheat, and maize the production constraints were 90%, 1.05%, and 110% respectively of the current production. The production constraints of sesame, soybeans, and sunflower were more than or equal 8000, 25,000, and 3000 ton respectively. The fifth scenario was the optimal because it avoided the withdrawal of previous scenarios.

11. Optimized cropping pattern

To achieve the objective of this study, the integration between the selected governorates in Egypt (Dakhlia, Qaliobia, and Sharkia) was analyzed. The three governorates were selected because they are beside each other therefore; the transportation of crops and other resources like labors will be easy with low cost. It is assumed, during the study, that the three governorates will share the available water for irrigation with each other according to the proposed cropping pattern. A new cropping pattern was set in order to maximize the economic value of water in the three governorates.

The proposed cultivated area of each crop was restricted to a certain level in order to avoid their domination in the solution, this step can be controlled using A_L and A_U which is the minimum and maximum values allowed for the proposed area. In the (WINqsb) model A_L set to be 70% of the current cultivated area for each crop and A_U set to the maximum value of the proposed area for each crop.

The constraints played an important role in this scenario. The constraints used to control the area of each crop in order to maximize the economic value primarily besides decreasing the gap between the national production and the imports and increasing self sufficiency of the main agricultural crops. This scenario contains 48 constraints, Nine of them represented the cultivated area in each governorate seasonally (summer, winter and nili), the tenth constraint represented the

Table 8 Total current and proposed optimum areas for three governorates [7].

Season	Crop	Cultivated area	Proposed area	Saving	
				Area	Water
		Feddan		Feddan	Million m^3
Summer	Rice	625,976	575,053	−50,923	−323.31
	Maize	419,919	445,598	25,679	74.57
	Cotton	72,090	73,233	1143	3.76
	Tomato	28,903	27,493	−1410	−4.18
	Potato	19,049	18,484	−565	−1.68
	Eggplant summer	13,080	13,028	−52	−0.16
	Watermelon	6810	6471	−339	−1.01
	Onion	2962	2989	27	0.10
	Sesame	8868	14,463	5595	13.97
	Soybeans	30	18,288	18,258	50.54
	Sunflower	15	3000	2985	6.48
	Zucchini summer	6902	6638	−264	−0.78
	Peanut	16,233	16,099	−134	−0.52
	Cucumber	1602	1602	0	0.00
	Pepper	8136	8136	0	0.00
	Sugarcane	35	35	0	0.00
Winter	Tahrish	68,834	66,941	−1893	−2.54
	Flax	6627	6639	12	0.02
	Wheat	775,910	805,170	29,260	50.33
	Long Clover	340,460	321,402	−19,058	−54.79
	Tomato	30,674	30,497	−177	−0.38
	Broadbean	48,357	40,128	−8229	−11.02
	Sugarbeet	55,635	56,883	1248	3.02
	Garlic	1041	1015	−26	−0.04
	Green peas	12,247	11,997	−250	−0.54
	Eggplant	11,056	11,040	−16	−0.04
	Potato	27,854	26,605	−1249	−2.72
	Onion	25,894	26,220	326	0.61
	Cabbage	6125	6196	71	0.15
	Zucchini	6071	6054	−17	−0.04
	Lentil	471	471	0	0.00
	Lupin	1938	1938	0	0.00
	Barely	15,996	15,996	0	0.00
	Pepper	10,548	10,548	0	0.00
Nili	Tomato	4475	4456	−19	−0.05
	Maize	47,745	47,770	25	0.06
	Potato	6865	6861	−4	−0.01
	Cabbage	749	747	−2	−0.01
Objective function value		3,020,272	3,117,735	97,463 (3.22%)	
Total area cultivated (Feddan)		2,736,182	2,736,182	0.00%	
Net return (LE)		7,796,049,803	7,904,397,776	1.4%	
Water consumption (m^3)		8,841,488,312	8,641,292,884	2.26%	
Economic value (LE/m^3)		0.88	0.92	3.74%	
Labor (person)		94,698,580	94,575,691	−0.13%	
Water saving (Million m^3)			200.2		
Net return increment (LE)			108,347,973		

agricultural water available for the three governorates and the remaining 38 constraints related to the production of each crop in the three governorates.

The production constraint of each crop determined according to the current self-sufficiency rate. For rice, wheat, and maize the production constraints were 90%, 105%, and 110% respectively from the current production. The production constraints of seasame, soybeans, and sunflower were more than or equal 8000, 25,000, and 3000 ton respectively. The differences between current and proposed cultivated area in the fifth scenario (Sc_5) at each governorate per season and crop were shown in Table 7. Therefore the following can be concluded.

11.1. Dakhlia governorate

In the summer season, the area of rice decreased by 108 thousand feddans and maize increased by 124.8 thousand feddans. In winter season, it could be noticed that wheat increased by 83.1 thousand feddans. In nili season, Tomato increased by 122 feddans and maize decreased by 111 feddans.

11.2. Qaliobia governorate

For the summer crops, the area of Maize decreased by 28.7 thousand feddans, soybeans increased by 18.3 thousand feddans and Sunflower increased by 3.0 thousand feddans. In winter season, wheat increased by 12 thousand feddans.

11.3. Sharkia governorate

In summer season, the area of rice increased by 60 thousand feddans and maize decreased by 70.4 thousand feddans. In winter season, wheat decreased by 65.8 thousand feddans. Tomato decreased by 140 feddans and maize increased by 137 feddans among nili crops at Sharkia governorate.

Table 8 showed the total current and proposed area of each crop per season and also showed the water and net return savings of each crop. So, the following could be concluded:

- The economic value at the national level will increase from 0.88 LE/CM to 0.92 LE/CM.
- The total water requirements at the national level will decrease by 0.2 billion cubic meters with decrement 2.2% compared to the current state.
- The total net return at national level will increase by 0.11 billion Egyptian bounds. With increment 1.4% compared to the current state.
- The cultivated area at the national level of Rice will decrease by 50.9 thousand feddans and maize, sesame, soybeans, and sunflower increased by 25.7, 5.6, 18.3, and 3 thousand feddans respectively.
- The cultivated area at the national level of wheat will increase by 29.3 thousand feddans and long clover will decrease by 19.1 thousand feddans.

To achieve the proposed scenario it is assumed that 70% of the current cultivated area will be under the free cropping policy. Moreover, the remaining cultivated area will be controlled by the governorate for all crops in the three governorates. Consequently, no need for infrastructures or other resources.

12. Conclusion

- This paper found that through the suggested optimum scenario the economic value at the national level will increase from 0.88 LE/CM to 0.92 LE/CM.
- Restricting the cultivated areas with the highest water consumption crops (rice) in the three governorates can reflect the government policy of distribution irrigation water. This policy agreed with the results obtained in this paper.
- The results produced from the proposed optimum scenario showed that a satisfied amount of water equal 0.21 billion m^3 can be saved. Therefore, the surplus in water supply could be used for new reclaimed areas.
- The results also showed that the total net return increased by 108 million Egyptian pounds.
- Efficient water saving programs, improving crop productivity, and increasing the economic value of water are the best ways to achieve food and water security.
- The water productivity plays a vital role in drawing future sustainable agricultural and water policies.
- This study aims to assist decision makers in drawing future sustainable agricultural and water policies in Egypt. It can also help in maximizing national water resources' productivity in different agricultural activities considering the supply and demand aspects based on the efficient utilization of the water resources.
- It is important to activate the role of agricultural extension as well as water users' associations in providing various farmers with the necessary information on the proposed cropping patterns. This can help to achieve a higher net return and economic value of water greatly.

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