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ASSESSMENT OF THE SOCIO-ECONOMIC AND AGRICULTURAL ASPECTS IN WATER RESOURCES USING GIS, A CASE STUDY FROM EGYPT

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SUMMARY - The evaluation of the socio-economic and agricultural aspects related to any water resources system requires a detailed and diverse data. In a previous study, socio-economic and agricultural indicators were developed aiming at the evaluation of water resources current status in Egypt. The objective of the current study is to assess the status quo of the Egypt water resources system through evaluation indices for the agricultural, socio-economic and water aspects under a GIS platform. In addition, a GIS software application tool is developed to visually present the indicators and indices in a user-friendly way. The user-friendly interface was designed and implemented under the Arc view environment using the Avenue programming language.

A case study for Egypt is also demonstrated via the developed tool. The results from the study show powerful capabilities of the developed GIS software in presenting the indicators and indices for each category (agricultural, socio-economic, and water), using the user interface. Finally the developed GIS tool and indicators can give the decision maker a good idea about the current status of the water resources system for the whole country.

Keywords: Indicators, socio-economic, agriculture, water resources, GIS.

INTRODUCTION

Recently, there has been a considerable effort devoted to utilizing GIS to enhance the development of spatially distributed input data and to visualizing the results of simulation models (Srinivasan and Engel, 1991a). In particular, several studies have been carried out to demonstrate the integration of GIS with different models (Srinivasan and Engel, 1991b; Zhou and Fulcher, 1997) in watershed management. A graphical user interface was developed to incorporate the Soil and Water Assessment Tool, (SWAT), with ARC/INFO. The menu interface provided a tool to identify the relative contribution of sub-watershed areas to agricultural non-point source pollution and evaluate the effects of alternative land use management practices on surface and ground water quality at the watershed scale (Zhou and Fulcher, 1997).

Another study by Afify *et al.* (2003) for the assessment of the Nile river water quality aimed to develop a GIS based decision support tool capable of water quality data management, where a customized User Interface application was fully designed and implemented as a part of the GIS tool to facilitate accessibility and management of the Nile river water quality data for both technical and non-technical users. Spatial analysis and visualization of water quality data was presented and demonstrated through the developed interface (Afify *et al.*, 2003).

A beta version of a Decision Support System (DSS) for water resources planning was implemented to assist water policy makers in evaluating impacts of proposed development measures. The DSS described by Tawfik *et al.* (2002) considers the integration of environmental and socio-economic aspects through the analysis of water resources development measures and scenarios. The DSS is composed of three main components; a database component linked to a Geographic Information System (GIS) component to provide all required data and information to the modeling component. Besides, there is a Graphical User Interface (GUI) developed under AVS/Express (1998) environment to allow the integration between the three components of the DSS as mentioned by Tawfik *et al.* (2002). The link between the database and GIS components of the DSS was

demonstrated under the GUI using AVS/Express environment software, where the link proved to be capable of analyzing different queries and displaying the results (Afify and Abdel-Motaleb, 2002).

A study by Afify *et al.* (2005) aimed at developing applied indicators for the evaluation of socio-economic and agricultural aspects as related to water resources in Egypt. The results of the socio-economic and agricultural indicators were presented for selected governorates of Egypt, while water indicators were presented on a regional scale. The aggregation of such a huge amount of information on different spatial scales requires building a Geographic Information System (GIS) to be able to present the indicators' results on a user friendly interface. Therefore the current study aimed to the assessment of the status quo of the Egypt's water resources system through indices for the agricultural, socio-economic and water aspects, and building a GIS application tool along with a user interface to demonstrate the results. The developed application was used to illustrate the difference in the results under two cases considering agricultural water as an influencing factor in one case.

DEVELOPED INDICATORS

In the following paragraphs, a brief description or definition is given for each developed indicator. The indicators were calculated based on raw data obtained from different sources as indicated beside each category of indicators and shown in (Tables 1 and 2). Tables 1 and 2 give a summary for the maximum and minimum values for the main agricultural and socio-economic indicators, respectively. Details about the development procedure and results of the different categories of indicators (agricultural, water, and socio-economic) were presented by (Afify *et al.*, 2005 and Maherzi, 2002).

Crop yield and return

Crop yield is defined as the quantity of a crop produced by the unit area of agricultural land (feddan = 4200 m²). Crop return or the production output from a certain crop is defined as the average amount of money per feddan that the farmer will get it out from the cultivation of that crop. It is calculated using the following Equation.

$$Fo_i = Yield_i \times Qp_i \quad (1)$$

In which, Fo_i is the production output for a certain crop i and Qp_i is the price for one ton of the same crop.

Agricultural ownership

The agricultural ownership for a certain farm size or "category" is defined as the fraction of the total farm areas within this category (say; less than 5 feddans) to the gross total of all farm areas. Three indicators are considered representing the small, medium, and large size of farms.

Land use indicators

Three land use indicators are developed. The first one is called the inhabited area indicator, the second is the agricultural land indicator, and the third indicator is the house utility indicator. These indicators are calculated using equations (2, 3, and 4).

$$\text{Inhabited area indicator} = \frac{\text{Inhabited area}}{\text{Total area}} \quad (2)$$

$$\text{Agriculture land indicator} = \frac{\text{Agriculture land}}{\text{Total area}} \quad (3)$$

$$\text{House utility indicator} = \frac{\text{Total house area}}{\text{Inhabited area}} \quad (4)$$

Table 1. Summary for the maximum and minimum values of main agricultural indicators.

Category [@]	Indicator	Units	Min Value	Max. Value
Agricultural ownership ¹	Small (0-5 fedans)	%	28	74
	Medium (5-50 fedans)	%	15	49
	Large (More than 50)	%	4	60
Land use ³	Inhabited area	fraction	0	1
	Agricultural land	fraction	0	.86
	House utility	fraction	0	.36
Crop Yield ⁴	Wheat	Ton/fed	0	3
	Summer maize	Ton/fed	0	3.6
	Rice	Ton/fed	0	3.75
	Nile maize	Ton/fed	0	3
	Barley	Ton/fed	0	2.1
	Beans	Ton/fed	0	1.5

@ As indicated, for each category of indicators, row data needed to calculate the indicators comes from different sources; ¹ (CAPMAS, 1997), ³ (EDB, 1997), ⁴ (AEB, 1997).

Demography

This category constitutes four different indicators: 1) population density, which is defined as the number of inhabitants by square kilometer; 2) average household density, which is defined as the average number of households per each building; 3) agricultural power stock fraction, which is defined as the fraction of people ready to work in the agricultural field to the total labor force (power stock); and 4) employment fraction, which is defined as the number of the employees divided by the total labor force.

Agricultural owner size

The agricultural owner size for a certain farm-size or category is defined as the fraction of the total number of owners within this category to the total number of owners. Similarly, three indicators are considered within this group representing the small, medium, and large size of farms.

Drinking water services

Drinking water service is a group of three indicators, which is defined as the percentage of households belonging to a certain category of drinking water connection or service (say; tap inside the apartment, only inside the building, or public tap outside the building) to the total number of households. This group of indicators is evaluated for both urban and rural areas.

Sewerage services

Sewerage service is a group of three indicators, which is defined as the percentage of buildings having a certain type of sewerage connection (public sewerage, other, and no sewer) to the total number of buildings. These indicators are also evaluated for both urban and rural areas.

Table 2. Summary for the maximum and minimum values of main socio-economic indicators.

Category [@]	Indicator	Units	Min Value	Max. Value
Demography ¹	Population density	Inhab/Km ²	0	1200
	Average household density	Households/B uilding	0.75	3.6
	Fraction of the Agricultural power stock	fraction	0.24	0.28
Agricultural owner size ¹	Employment fraction	fraction	0.79	.98
	Small (0-5 fedans)	%	89	98
	Medium (5-50 fedans)	%	1.4	10
Sewerage services ¹	Large (More than 50)	%	0	0.8
	Urban buildings with public sewerage	%	1	74
	Urban buildings with other sewerage connection	%	0.4	87
	Urban buildings without sewerage	%	6	49
	Rural buildings with public sewerage	%	0	34
Drinking water services ²	Rural buildings with other sewerage connection	%	37	92.5
	Rural buildings without sewerage	%	2	60
	Urban households with tap water inside their apartments	Households %	56	98
	Urban households with water inside their buildings	Households %	65	99
	Rural households with tap water inside their apartments	Households %	9	92.6
	Rural households with water inside their buildings	Households %	15	95

@ As indicated, for each category of indicators, row data needed to calculate the indicators comes from different sources; ¹ (CAPMAS, 1997), ² (METAP, 1997).

DEVELOPMENT OF GIS APPLICATION

The developed GIS application consists of two different types of information; topographic information and attributed database. The topographic information includes elements such as lakes, the Nile River, canals, country borders, governmental borders, and any other water bodies. In general, raw data requires an additional effort of data processing and coding by geographic location to build and attributed database, so that each item of information can be associated with specific geographic location on the map. Therefore the analyst can display an image that shows the pattern of variation of a certain raw data, calculated group of indicators, or an index for each topographical location. The procedure of developing GIS attributed database have passed through two main steps; first normalization for all the values of the indicators using equation 5, and second calculation of the index using equation 6. This procedure is discussed in the following section. Finally, GIS attributed database files (dbf) are basically constructed to include all raw data for each governorate, calculated indicators and the normalized indicators.

Index calculation

In a previous study by Afify *et al.* (2005), applied indicators were developed for the evaluation of the socio-economic and agricultural aspects related to water resources in Egypt. In what follows, a generalized index is estimated from the aggregation of the relevant indicators. Aggregation of the different indicators requires that all indicators are unit less. A normalization procedure for all indicators is required since they are not all in similar units, for example the population density and the consumed drinking water are of different units. The normalized indicators were estimated using equation 5. Equation 5 allowed to obtain all the different indicators on a fixed scale (0-100), where the zero is for

the least value of the indicator, and 100 is for the maximum score of the same indicator from all records.

$$R_n = \frac{(R_a - R_{\min}) \times 100}{R_{\max} - R_{\min}} \quad (5)$$

In the above equation; R_n is the normalized indicator, R_a is the real value for the indicator, R_{\max} and, R_{\min} are the maximum and minimum values for the same indicator for all the records, respectively. A generalized index is estimated from the aggregation of the normalized indicators. The generalized index is calculated by using a weighted average for all the normalized indicators as shown by Equation 6.

$$I = \sum_{i=1}^m w_i \times R_{ni} \quad , \text{ and}$$

$$\sum_{i=1}^m w_i = 1 \quad (6)$$

In which, I is the generalized index, R_{ni} is the normalized value for each indicator, w_i is the weight associated with the same indicator, and m is the number of relevant indicators. As indicated by Equation 6, the summation of all weights should be equal to one.

GIS interface design and implementation

The main interface (Fig. 1) was designed and implemented under the Arc View 3.1 software to be the default interface that the user will get when he opens the system. In the view area, an abstracted map of Egypt is displayed. Figure 2 demonstrates a map of Egypt with the official boundaries of the governorates. At the top menu, there are other elements added to suite the application developed by Maherzi (2002). The added elements (Fig. 1) are mainly: buttons of indicators' categories, menu bar, and index calculator tool. Each button of the indicators' categories displays only the related main menu for the selected category. The menu bar represents the different indicators; it shows all the different indicators under a specific category, where sub-menus are further created under each main menu. In what follows, a brief list of main menus developed by Maherzi (2002) for the different indicators within each specific category; agricultural, socio-economic, and water indicators' category.

Agricultural indicators main menu

This category contains the following items: 1) cropping pattern for main crops; 2) agricultural ownership for small, medium and large farm size; 3) land use indicators; 4) crop yield and farm output for main crops; 5) production costs for main crops; and 6) cropping pattern performance indicators.

Socio-economic indicators main menu

This category contains the following items: 1) Demography, including the urban population fraction, the rural population fraction, the population density, the average household density, the employment fraction, and the fraction of the agricultural power stock; 2) agricultural owner size for small, medium and large farm size; 3) sewerage services for both urban and rural areas, obtained as a percentage of buildings with either a public, other, or no sewerage connection; and 4) drinking water services provided to households for both urban and rural areas.


Water indicators main menu

This category contains the following items: 1) drinking water, including consumed and produced water, as well as network efficiency; 2) agricultural water needed during the year; 3) agricultural water available during the year; and fraction of agricultural water availability during the year.

Index calculator tool

The index calculator is a powerful tool that helps the decision maker to first calculate the generalized index as given by eqns. 5 and 6, and secondly visualize directly the results on the map. The index is calculated based on the aggregation of the selected indicators from the three main categories as displayed in the calculator tool menu (Fig. 1). The user has a complete freedom of choice between more than one category and indicator at a time. The decision maker should make only an enquiry to determine the different weights assigned for each indicator, which are entered to the program to calculate the generalized index.

The only constraint on the choice of the weights is that the total summation of them should be equal to one hundred, other wise the program will recalculate new weights based on the percentage of weight given to each indicator compared to the total summation of all weights, (Maherzi, 2002).

The procedure is started by just a click on the index calculator icon  on the tools' bar menu, where a new window will be displayed as shown at the lower right corner of Figure 1 to further choose one category, or all categories of indicators that the user wants to include in the calculation of the index.

Implementation of the GIS interface

The interface as described earlier is just a mask which will help the user at the end to perform certain tasks. However, this feature is not possible unless the interface is activated or implemented. For this purpose, a series of scripts was written by Maherzi (2002) to perform a list of actions that the compiler should execute when a button or a menu is selected. These scripts were written in the avenue programming language, which is compatible with ArcView 3.1. The scripts are in three categories, the first category of scripts is related to the buttons that display the menus, the second category is related to the menus which display the indicators, and the last category contains only one script that calculates the index. This script is linked to the index calculator button.

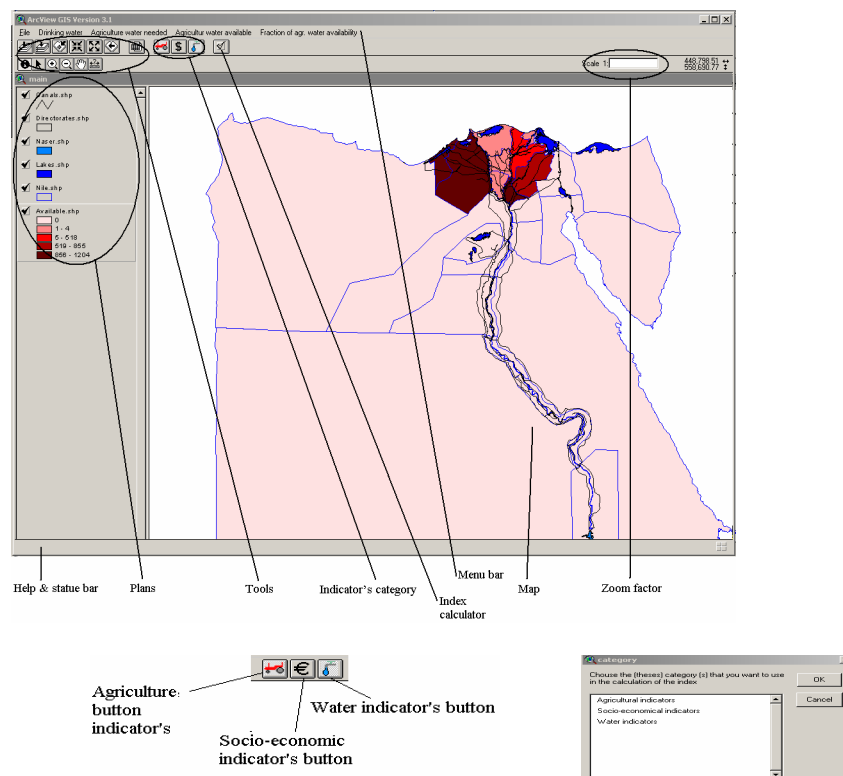


Fig. 1. Main interface with indicators categories and index calculator.

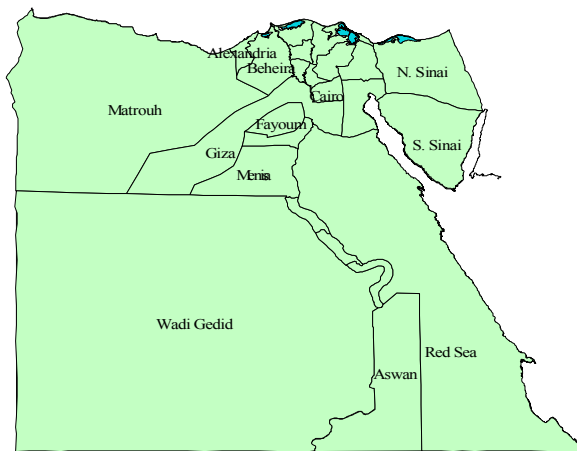


Fig. 2. Official boundaries for Egypt's governorates.

RESULTS AND DISCUSSION

Part of the results for the developed indicators by Afify et. Al. (2005) can be summarized and presented as shown in (Tables 1 and 2) for both agricultural and socio-economic indicators, respectively, where the values presented are the minimum and the maximum values among all the records corresponding to each indicator. It can be easily noticed the wide variations among the sources of raw data to obtain these indicators. The results presented for the indicators in this table and the following figures are all displayed in their real values before normalization. Normalization process is followed only for the index results at the end of this section. The results for the agricultural indicators (Figs 3, 4, 5) and socio-economic indicators (Figs 6, 7) are classified based on the real values for each indicator and categorized into five classes for each indicator as presented in the figures. The five classes are divided among all the records using natural breaks, a default Arcview GIS classification method. This method is mainly based on the minimization of the sum of the different classes' variance. The first class represents the minimum or the least range, whereas the second class represents the low range, the third represents the medium range, the fourth represents the high range and the last class represents the maximum or the highest range of real values for the indicator before normalization.

Agricultural indicators

In this section the results for the crop yield, crop return and agricultural land fraction are presented in Figures 3, 4 and 5 respectively. As of crop yield and crop return of wheat, North Sinai and Red Sea governorates have least values for both indicators. Suez Canal frontage governorates (Ismailiya, Suez and Port Said) have the least values for crop return of wheat. Giza and Menia governorates have the highest values ranging between (2.68 - 3.0) ton/feddan for crop yield, whereas Sohag has the highest value of (1396 - 3152) L.E/feddan for crop returns of wheat. Regarding agricultural land fraction (Fig. 5) North Sinai, Red Sea governorates and Suez Canal frontage governorates have the least values for the indicator. The majority of the Delta governorates represent the high range of values for the indicator (0.68 - 0.84). The highest range of values for the same indicator (0.84 - 0.90) is indicated for three governorates in the Delta and five governorates in the Upper Egypt.

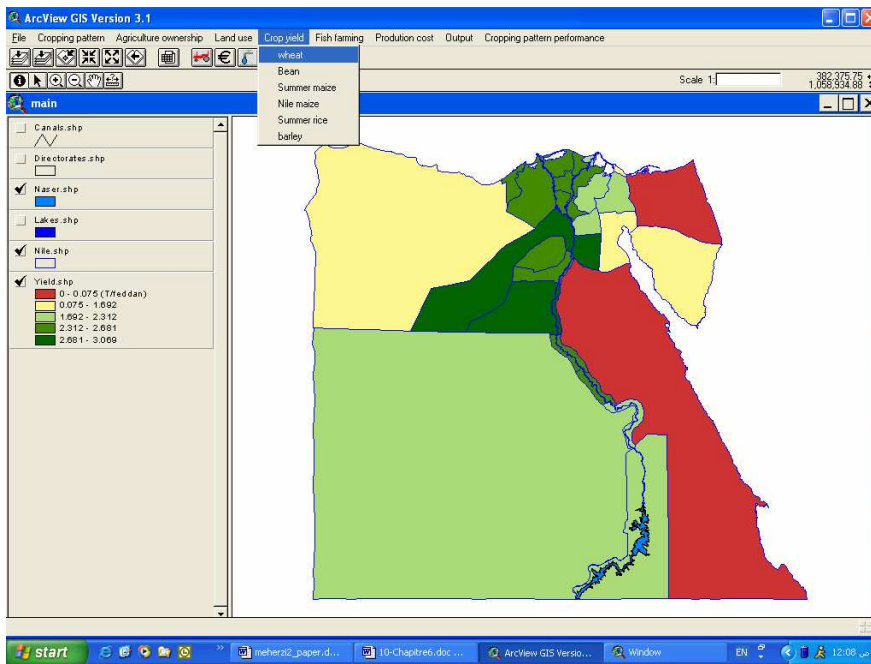


Fig. 3. Spatial distribution for the Wheat's crop yield.

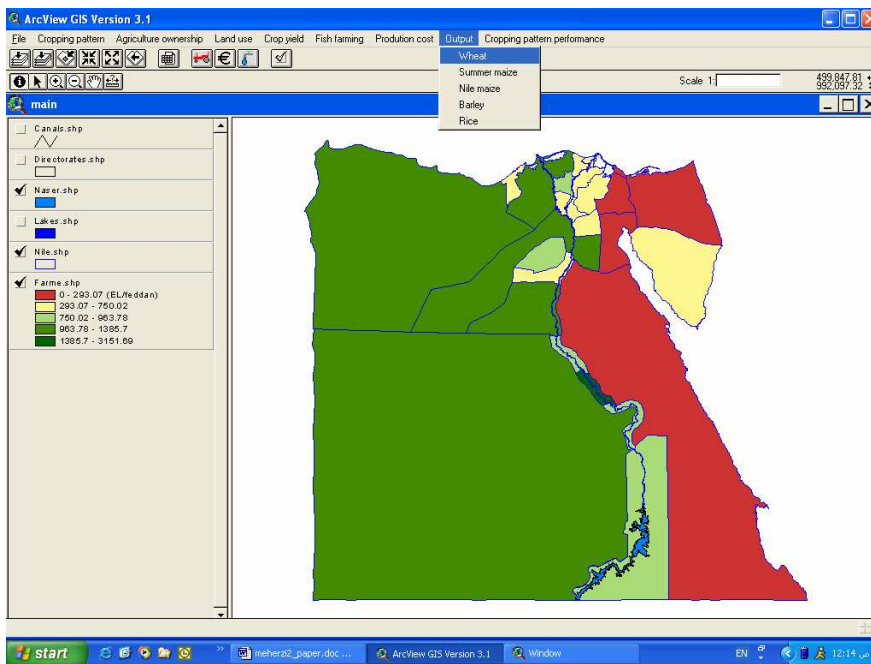


Fig. 4. Spatial distribution for the Wheat's crop return.

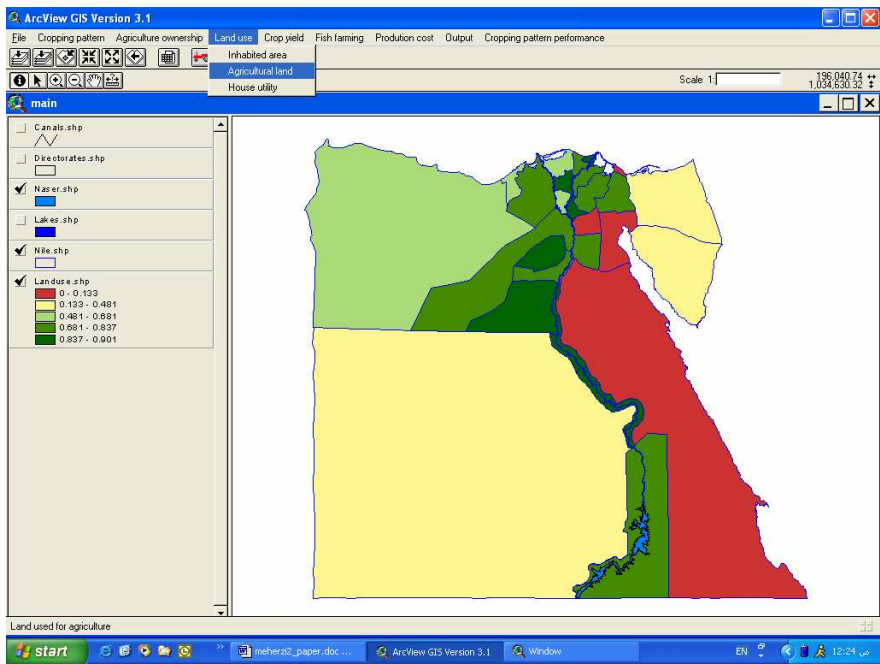


Fig. 5. Spatial distribution for the agricultural land fraction.

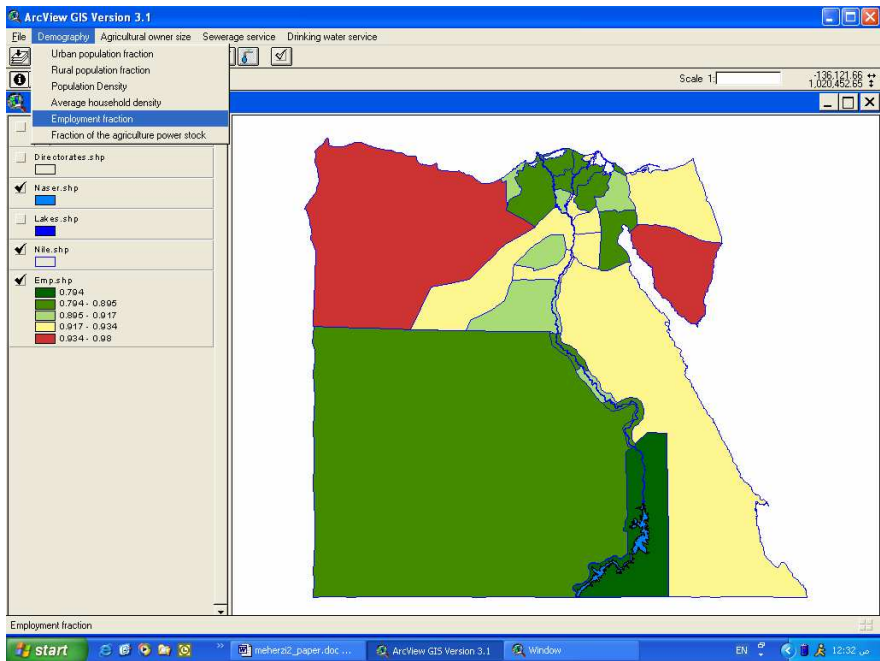


Fig. 6. Spatial distribution for the employment fraction.

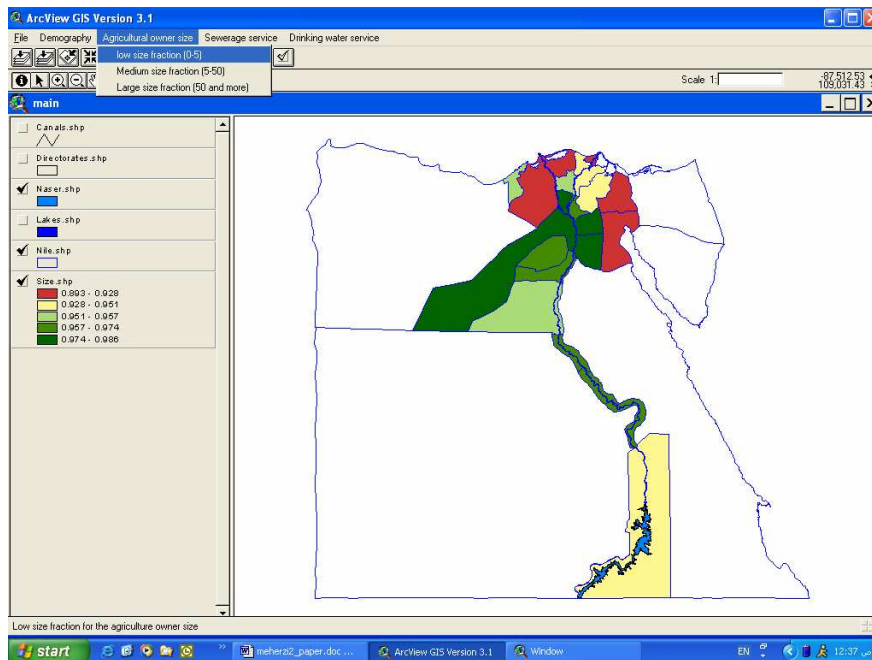


Fig. 7. Distribution for the agricultural owner size fraction for low class (0-5 feddan).

Socio-economic indicators

In this section the results for the employment fraction and agricultural owner size are presented in Figures 6 and 7. As of employment fraction (Fig. 6), South Sinai governorate has the highest value of (0.93 – 0.98) and Aswan has the least value of 0.79. Regarding the owner size fraction for low class (0-5 feddans), the highest range of values (0.97 – 0.99) is indicated for Giza and Cairo governorates. The least values for the same indicator (0.89 - 0.93) are indicated for Suez Canal frontage governorates besides three others in the Delta.

Water indicators

Sample of the results for the agricultural water availability during the month of September is presented in (Fig. 8). The results show that Middle Delta has the least availability of water; East Delta has average availability of water, while West Delta has highest availability of water for that month. This result may seem to be not realistic; however this may be due to the assumptions followed in earlier study by Maherzi (2002) for estimating water requirements.

Index results

In this section index results using the developed index calculator tool for two cases are presented, where the normalized indicators for each record are calculated using equation 1 and the index is obtained from equation 2. The presented indicators in the previous sections are selected for aggregation to obtain the index for the first case. For the second case, same indicators are selected together with the agricultural water availability indicator during the month of September to see the effect of this indicator on the index results.

The first case (Fig. 9) considers the aggregation of the previous indicators (crop yield and crop return for Wheat, agricultural land fraction, employment fraction, and agricultural owner size) with equal weights for each indicator. The results of the investigated case as shown in Fig. 9 show that both Red Sea and Matrouh governorates have the least value for the index, others such as Aswan and Suez have a low range of value for the index. Both Giza and Menia governorates have the highest range of value for the index. Almost all other governorates in the Delta have the medium range of value for the index.

The second case considers the aggregation of all the indicators mentioned for the first case, including the agricultural water availability indicator. Weights are assigned to be 50% for the water availability indicator and equal weights for the rest of the indicators. The results of the investigated case as shown in Figure 10 are almost as close as the results of the first case for the whole country. Middle Delta remained in the medium range of value for the index, whereas in the West Delta, Beheira Governorate has the highest range of value for the index. Little change is also observed in the East Delta from the first case. The changes in this case from the first one are mainly due to the magnification of the role of water availability indicator as compared to other indicators.

CONCLUSIONS AND RECOMMENDATIONS

GIS plays a key role in the developed application, where all raw data after processing are stored within the GIS application to display the results for the different indicators. Since the values of these indicators are wide spread and are obtained in different units, normalization for their values is adopted before aggregation under GIS platform. It can be concluded from the study that a combination of GIS and indicators can be very helpful in the evaluation of the agricultural aspects of water resources system in Egypt. The developed application is also very useful, where a user friendly interface facilitate the application for non-technical users. Finally the developed GIS tool and indicators can give the decision maker a good idea about the current status of the water resources system for the whole country and a powerful tool to compare among possible alternatives.

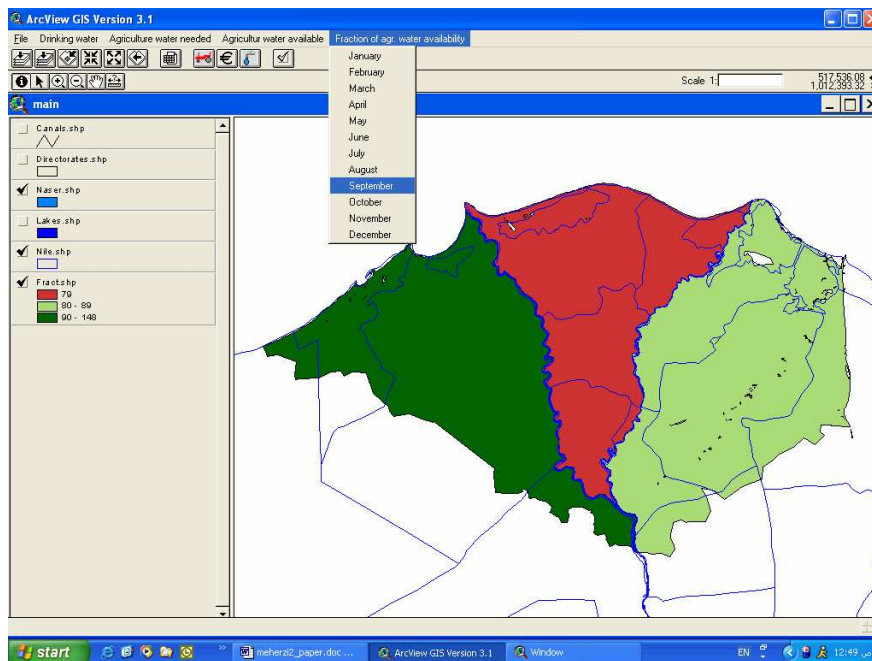


Fig. 8. Distribution for the fraction of agricultural water availability for the month of September.

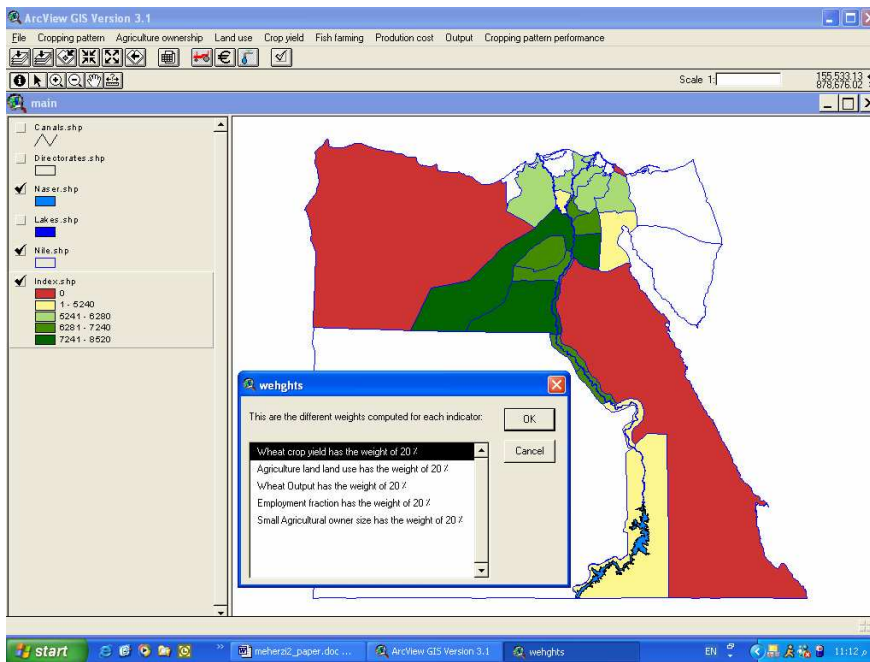


Fig. 9. Distribution of the calculated index for case 1 with equal weights.

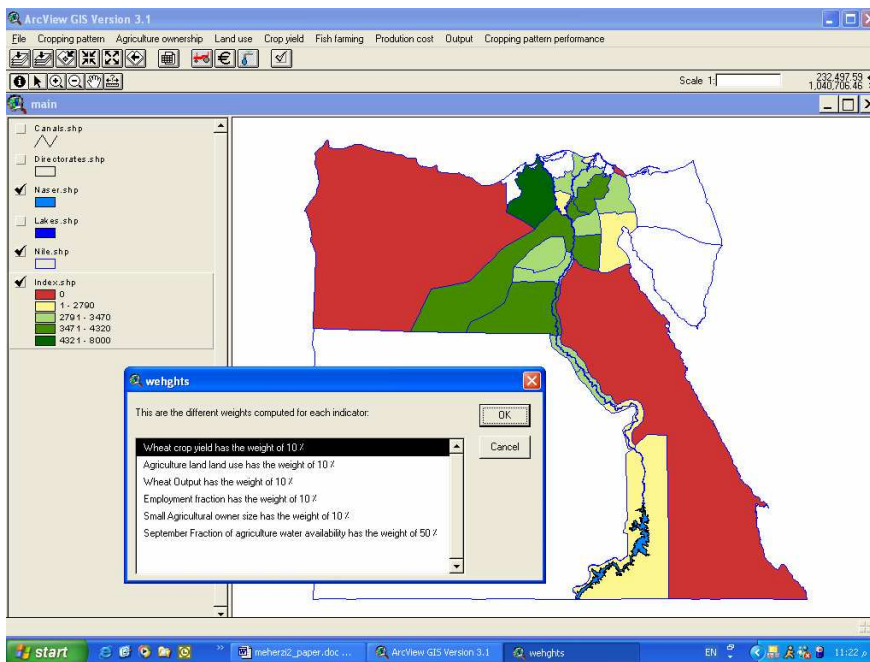


Fig. 10. Distribution of the calculated index for case 2 with non-equal weights.

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