Estimating Actual Evapotranspiration over a Large and Complex Irrigation System of the Nile Delta in Egypt

Mohie Eldin Mohamed Omar, Ahmed Medhat Ismail Abd Elhamid, Islam Sabry Al Zayed

Abstract*: In the Nile Delta region of Egypt, measurements of Actual Evapotranspiration (ETa) and Potential Evapotranspiration (ETp) are difficult, expensive and labor-intensive. The current paper aimed at finding the superior method for estimating the ETa and ETa/ETp in the Nile Delta governorates by comparing different methods. Three different methods were used for ETa estimates being; Remote Sensing approach by Moderate Resolution Imaging Spectroradiometer (MODIS) ETa-product (MOD16A2), FAO (33) method, and Irrigation Water Balance Calculation (IWBC) method. The three ETa methods were applied for five governorates in 2017, where the data for IWBC were available. However, only MOD16A2 was compared with FAO (33) for ETa/ETp ratio and the two selected methods were applied for all eight Nile Delta governorates for the period of 2008 -2017. The MOD16A2 product was derived from the MODIS satellite images using an improved evapotranspiration algorithm based on the Penman-Monteith equation. FAO (33) was based on the relationship between the relative yield loss of any crop to relative reduction of water consumption. The IWBC required estimation of both; the field application and conveyance water losses as the only unknown elements of irrigation water balance in Delta governorates. For comparison between applied methods, descriptive statistics, analysis of variance (ANOVA) for checking difference, and cluster analysis were applied. The results showed a significant difference values between MOD16A2 and FAO (33) for estimating ETa/ETp ratios. However, the difference for ETa estimation was insignificant between the three methods indicating a significant relationship, with a strong correlation between MOD16A2 and IWBC. It was observed that ETa values were impacted by the cropping pattern, since they were very close in governorates having the same dominant crops. In conclusion, both MOD16A2 and IWBC can be utilized for ETa estimation. Both MOD16A2 and FAO (33) are not confirmed for estimation of ETa/ETp ratio due to the significant difference between both results. FAO (33) cannot be utilized for both ETa and ETa/ETp ratio estimates. Further data collection and investigation on ETa and ETp estimates methods are recommended.

***Keywords*: Actual and potential evapotranspiration, remote sensing, yields' response to water**

I. INTRODUCTION

Water development is critical for food security in many regions of the world. Erratic rainfall, especially in arid and semi-arid zones, requires farmers to adopt irrigated agriculture to secure food production. Also, it is well-known that the crop yield from irrigated agriculture is double that of rain-fed agriculture [1]. Thus, development of large irrigation systems has a long history in many places worldwide. Moving from narrow analysis of on-farm water efficiency to large-scale water balances is a critically important shift in approach to better water use [2]. Actual evapotranspiration (ETa) is defined as the actual water consumed by crops and the potential evapotranspiration (ETp) is the maximum ETa from a vegetated surface with unlimited water supply. Reference [1] reported that ETa is an important indicator since its value used for calculation of the scheme irrigation efficiency, where it is defined as the ratio of ETa to the total irrigation water delivered from a surface or groundwater sources. The good estimation of scheme irrigation efficiency facilitates water managers to take the right decisions about cropping pattern, water deliveries, irrigation systems, and irrigation practices.

Measurements of ETa require meteorological information or specific equipment, which are not available due to the fact of high cost. This fact leads to inaccurate estimations of irrigation efficiency in the Nile Delta. Worldwide, there are a number of methods for estimating ETa and ETp. Lysimeter apparatus is one common method measuring the precipitation on an agricultural area, the losses through the soil, and the evapotranspiration. The eddy covariance tower is another technique correlating fast fluctuations of vertical wind speed with fast fluctuations of atmospheric water vapor density, and then estimates ETa. There are a number of equations for estimating the reference ET such as the Penman-Monteith, Blaney-Criddle, Makkink, and Hargreaves. The reference ET is converted to ETa by using a crop coefficient and a stress coefficient. However, both field measurement and estimation by equations of both ETa and ETp are difficult, expensive and labor-intensive and also require regular meteorological data, which are rarely existing for the entire Nile Delta. Scientific based methods for estimating ETa and ETp need to be approved and presented within the water planning process in Egypt. Remote sensing (RS) approach is one of the methods, where its data have been utilized to provide a significance spatiotemporal information on ETa [3], [4], [5]. ETa RS-base has long history and scientists developed several methods to enhance ETa estimation [6], [7]. Nowadays, several open-source ETa products derived from satellite imagery are widely available and freely accessible.

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In Egypt, the RS approach for estimation of ETa and ETa/ETp ratio has not extensively been utilized in the planning process, because its results lacked the comparison and confirmation with actual field data.

FAO 33 method is another method that has been internationally used to estimate the ratio of ETa to ETp. The method relies on yield response of crops to water. The first application of this method was conducted by [8], in which one single equation was presented relating the relative yield loss of any crop to the relative reduction of water consumption. This approach has been widely applied for planning and estimating water productivity at the basin scale [9]. However, this method has not been applied in Egypt yet, and hence its potentiality still needs to be provided.

Estimating ETa from irrigation water balance method might be another method. However, estimation of irrigation water losses, as a main component of irrigation water balance, is mainly based on a number of assumptions. Reference [1] set indicative values to obtain conveyance and field application efficiencies. However, the agreement of FAO indicative values with the actual field measurements in Egypt was rarely investigated. Comparing FAO indicative values with the results of an experiment in Sohag governorate, South of Egypt conducted by [10] showed that FAO values of conveyance efficiency are different from actual values. Therefore, calculating accurate values of conveyance losses is needed.

Therefore, the main objective of this paper is to find the superior method for estimating the ETa and ETp in the Nile Delta governorates of Egypt by comparing the RS approach utilizing MOD16A2 product, the FAO 33 method, and irrigation water balance calculation.

II. METHODOLOGY

A. Study Area

As one of the oldest cultivated areas on earth, the Nile delta is a heavily populated area. It occupies an area of about 22,000 km2, where is classified as the most fertile areas in Egypt, representing about two-thirds of Egypt's agricultural land. It has the shape of a triangle, its base (240 km) facing the coastline of the Mediterranean Sea, with a length of approximately 160 km from north to south. The head of the Nile Delta is about 20 km north of Cairo. The Nile is divided at this head into east and west branches namely Damietta (240 km) and Rosetta (235 km), respectively. The Nile Delta is characterized by hyper-arid climate except for the northern part, which can be considered semi-arid with average rainfall of 200mm in the winter season. Its summer temperatures reach the hottest values in July and August, with a maximum average value of 34°C. However, the winter temperatures vary between 9°C at night and 19^{o}C during the day [11].

The main irrigation resource in the Nile Delta governorates is the Nile surface water via its branches and channels. In most of these governorates, irrigation water from the Nile is mixed with agricultural drainage water to overcome the crop water demand. Other water resources are shallow groundwater, reuse of treated wastewater, rainfall, and desalination. Table (I) shows the amounts of different water resources for the Nile Delta governorates. The data in this table has been assembled from the Water Distribution Department at the Ministry of Water Resources and Irrigation (MWRI) and the Holding Company for Water and Wastewater (HCWW).

Table I: Water resources in Delta governorates in million m3/year (MCM/yr) (Data source: MWRI and HCWW).

	Irrigation Canals	Shallow GW	Treated Waste-water	Rainfall	Desalination
Menofia	2,217		91	5	
Gharbia	1,984	550	176	40	
Kafr El Shikh	4,483		86	200	4
Kalyoubia	2,313	0	62	5	
Sharkia	3,228		111	20	
Dakahlia	8,072	950	83	40	
Damietta	3,174		100	120	2
Behira	13,710	4,390	634	970	4
Total	**39,183**	**5,890**	**1,353**	**1,300**	**10**

In this paper, the RS approach by utilizing MOD16A2, FAO (33) method and Irrigation Water Balance Calculation were used for ETa estimation in only five Nile Delta governorates, namely Kafr El-Shikh, Gharbia, Menoufia, Kalyoubia and Sharkia, where data for the water balance method was available. However, the values of MOD16A2 and FAO (33) method were used for the calculations of ETa/ETp ratio in all eight Nile Delta governorates. Fig 1 shows the names and locations of the governorates for each analysis and the total and agricultural areas in each Nile Delta governorate are presented in Table (II). Fig 2 shows the step by step plan of current methodology.

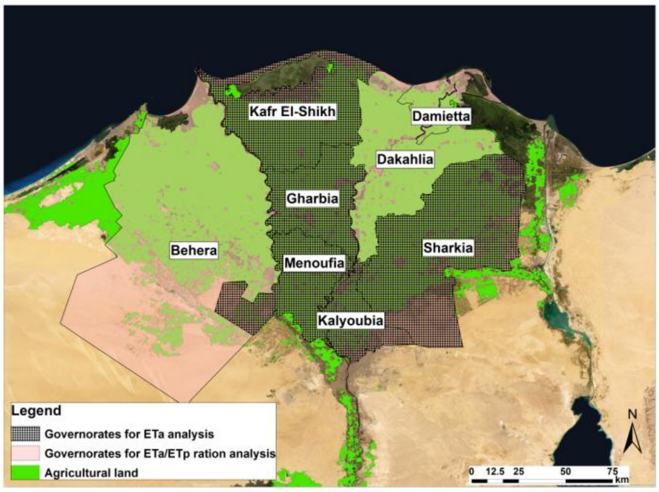

Fig 1: Five Nile Delta governorates where three ETa methods were applied and eight governorates where ETa/ETp methods were applied

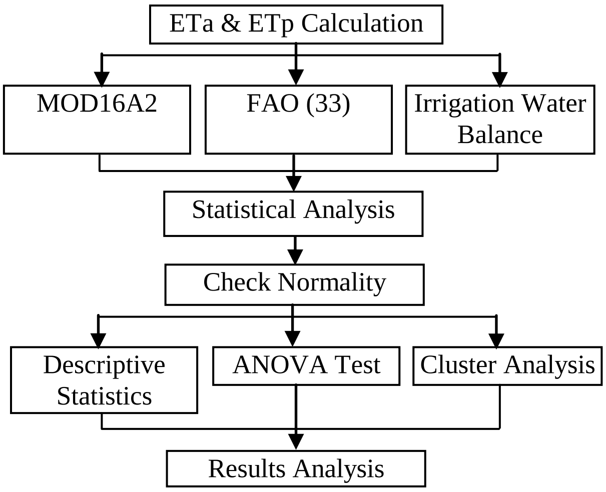

Fig 2: Methodology plan.

Table II: The agricultural and total areas for the Nile Delta governorates

	Area (km^2)	Agricultural Area (km^2)	
		Cultivated	Cropped
Menofia	1,632	1,542.36	2,952.24
Gharbia	1,942	1,537.38	3,065.61
Kafr El Shikh	6,911	2,316.45	4,602.36
Kalyoubia	1,001	694.96	1,283.39
Sharkia	4,180	3,680.30	6,767.36
Dakhliah	3,471	2,710.94	5,334.93
Damietta	589	449.89	882.42
Behira,	10,130	3,908.06	8,068.76

B. Remote sensing approach

ETa from Moderate Resolution Imaging Spectroradiometer (MODIS)/Terra 8-day product (MOD16A2 V006) by the Numerical Terradynamic Simulation Group (NTSG) (ETa-RS) was utilized in the current assessment. MOD16A2 has global coverage with a spatial pixel resolution of 500 meters and available from January 2001. The product is derived from the MODIS satellite images using the improved ET algorithm [12], which is based on the Penman-Monteith equation. Both ETa and ETp data are provided as separated layers. MOD16A2 tile of h20v05 covers all Nile Delta area. The granules were downloaded from the USGS earth explorer website [13] in Hierarchical Data Format (HDF) format. ETa-RS and ETp values were extracted from January 2001 to December 2017. Many researchers utilized MOD16A2 in the Nile Delta and found that it has a good performance [14], [15]. In addition, [16] reported that MOD16A2 products provided close estimates for ETa throughout the Nile Delta and Valley. However, Reference [4] reported that MOD16A2 product underestimated the ETa values in Sudan.

C. Yield response to water method (FAO 33)

In this work, the second method for estimating the ETa was based on the concept of the crop productivity response to water availability. There is a strong relationship between water consumption by a crop and its yield. FAO (33) addressed this relationship [9], where the yield response to the evapotranspiration was expressed as:

$$\left[1-\frac{Y_a}{Y_m}\right]=K_y\left[1-\frac{ET_a}{ET_c}\right] \qquad (1)$$

Where Ym and Ya are the maximum and actual yields, respectively, ETc and ETa-Y are the maximum and actual evapotranspiration, respectively, and Ky is a yield response factor representing the effect of a reduction in evapotranspiration on yield losses. This equation is a water production function and can be applied to all agricultural crops. FAO (66) described the procedures to quantify the yield response (Ky) to water deficits and presented the seasonal values of FAO (33) works [17].

In the current study, Ya was obtained for all crops in Delta governorates based on data of crops' yields and areas for each governorate, reported in the annual agricultural journal published by the Ministry of Agriculture and Land Reclamation for the period from 2008 to 2017. Ym was estimated for each crop from [18] based on its genetic makeup and climate, assuming that agronomic factors such as water, fertilizers, pest, and diseases are not limiting.

Crop Evapotranspiration (ETc) values were obtained based on the FAO Penman-Monteith method. Cropwat model is a computer program for calculating reference ETo and ETc using climate and crop parameters, respectively. Information on climate parameters (e.g. temperature, wind speed, rainfall) were obtained from two weather stations, namely Eltal El-Kbeer and King Mariott, in east and west of the Nile delta for the study period.

D. Irrigation Water Balance Calculation

In the Nile Delta, the irrigation water balance consists of two main components which are equal. One component includes known values being; fresh irrigation water mixed with drainage reuse via channels (Wd), shallow groundwater and rainfall. While the other side includes unknown values being; water losses and water consumed by plants (ETa) (Fig 3). Losses in the Delta irrigation system are conveyance loss and field application loss. The conveyance loss is caused by evaporation and seepage via irrigation channels. The field application loss is caused by percolation underneath the root zone in agricultural fields. The current paper estimated both the field application and conveyance losses in each Nile Delta governorate in 2017 to obtain ETa.

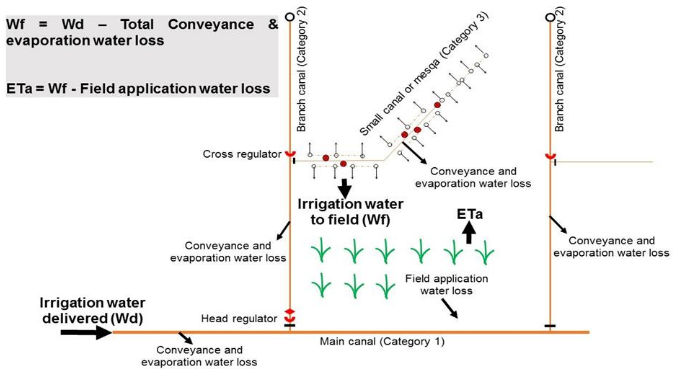

Fig 3: Scheme of irrigation water delivered to governorate, water losses and actual evapotranspiration

The field application efficiency for the Delta region based on FAO (1989) indicative values based was 60% considering surface irrigation as the dominant irrigation system.

In comparison with an experiment conducted by [11], the field application efficiency was 59.5% for a land area of 206,000 m2 served by surface irrigation systems in Sohag governorate, Upper Egypt. Since the FAO indicative value was almost equal to the measured value, hence the current paper assumed the value to be 60% in Delta governorates.

With regard to the conveyance efficiency, FAO indicative values were based on the length and the soil type of canals. FAO classified the canals' length into three categories; less than 200 m, between 200 – 2,000 m, and greater than 2,000 m. Reference [11] measured the conveyance efficiency for a 432 m earthen mesqa in Sohag governorate, Upper Egypt and the value was 82.42 %. But, the FAO indicative value for the same canal length and soil type was 90 %. A clear difference was found between both; the FAO and the measured values. Therefore, the current paper did not assume FAO indicative values on the Delta governorates for the conveyance efficiency. The current paper performed a series of calculations for estimation of the conveyance efficiency in each governorate.

D1. Conveyance efficiency calculation

According to [2], the conveyance efficiency (ec) was obtained as follows:

$$e_c = \frac{w_f}{w_d} * 100 \qquad (2)$$

Where, Wf = Water delivered to the irrigation plot (m^3)
Wd = Water delivered from the source (m^3).

In general, ec is measured in canals by measuring the inflow and outflow discharges. The difference between inflows and outflows is the conveyance loss, which is estimated as the sum of both evaporation and seepage loss [19], [11]. Seepage loss is the major and the most important part of the total water loss [19], [11], [20]. According to [19], the seepage discharge per unit length (qs) can be calculated as follows:

$$qs = kyF \qquad (3)$$

Where, K = hydraulic conductivity of the porous medium (m/s), and its value depends on the soil type. The dominant soil in the Nile Delta region is saturated clay. In a saturated clay soil with typically narrow pores, the order of magnitude of hydraulic conductivity ranges from 10^−6 to 10^−9 m/sec [21]. It was assumed in this paper that K = 10^-7.

y = depth of water in the canal (m);

F = the seepage function (dimensionless),

Since the dominant shape for canals' cross sections in Egypt is trapezoidal, the seepage function (F) with a trapezoidal shape and bank slope (m) can be calculated as:

$$F = \left(\left\{ [\pi(4-\pi)]^{1.3} + (2m)^{1.3} \right\}^{(0.77+0.462m)/(1.3+0.6m)} + \left(\frac{b}{y}\right)^{(1+0.6m)/(1.3+0.6m)} \right)^{(1.3+0.6m)/(1+0.6m)} \qquad (4)$$

In this paper, the irrigation canals network in the Nile Delta region was analyzed, and graded into three categories based on canal bottom width (Table III). The major canals divert Nile waters just upstream the barrages to different governorates. These canals have also regulators or weirs at intervals depending on their slopes and locations of lower order canals. Branch canals taking off from the main or lateral canals deliver water to smaller distributary canals. Because the water level in the system is below field level in most of the area, the water has to be raised through diesel pumps or the traditional water wheels. Due to bathometric data inadequacy, ec was calculated only in five governorates; Kalyoubia, Menoufia, Kafr El-Shikh, Gharbia, and Sharkia.

Table III: Canal lengths (km) and bottom-based categories (m) in five Delta governorates

Administration	Category 1 (≥ 5m)	Category 2 (2 – 5m)	Category 3 (≤ 2m)
Kalyoubia	289.520	609.751	498.104
Gharbia	295.400	325.815	399.430
East Kafr El-Shikh	258.625	234.660	273.040
West Kafr El-Shikh	258.510	264.600	294.966
Menoufia	371.712	475.645	521.670
Salhiya (Sharkia)	166.605	239.845	187.715
West Sharkia	227.785	303.275	602.222
East Sharkia	177.700	234.000	481.391

E. Statistical analysis of the three methods

There were two types of data that were statistically analyzed. The first type was the ratio of actual to potential evapotranspiration values (ETa/ETp)RS estimated by the MOD16A2 product and values of (ETa/ETp)Y from the FAO (33) method for all Nile Delta governorates for the period of 2008-2017. The second type was the (ETa)RS values obtained from MOD16A2 product, (ETa)Y values estimated from yield response method, and calculated field values (ETa)F for five governorates; Kalyoubia, Menoufia, Kafr El-Shikh, Gharbia, and Sharkia for 2017. For both data types, statistical analysis was applied using statistical following indicators:

- Basic/Descriptive Statistics.
- The Analysis of Variance (ANOVA) as a mean of checking the statistical significance for difference between different methods.
- Cluster analysis.

III. Results and Discussion

A. ETa/ETp for the period 2008-2017

Table (IV) shows the results of the basic statistical analysis for (ETa/ETp)Y and (ETa/ETp)RS for all Nile Delta governorates during the period from 2008 to 2017. It was noticed that the average value of (ETa/ETp)Y was about 0.4 with min. and max. values of 0.26 and 0.5 respectively and average value of standard deviation of 0.035. While the average values of (ETa/ETp)RS was about 0.24, with min. and max. values of 0.13 and 0.36 respectively and average value of standard deviation of 0.062. From the resulted values, it is clear that there was a significant difference in the basic statics items between the two methods. Assessing the normality between average values of both methods was undertaken by the ANOVA for all governorates (Table V). It was found that data followed the normal distribution.

Table (IV): The results of the descriptive statistical analysis of the (ETa/ETp)

	$(ETa/ETp)_Y$				$(ETa/ETp)_{RS}$			
	Mean	Min.	Max	Std. Dev.	Mean	Min.	Max	Std. Dev.
Dakahlia	0.415	0.364	0.479	0.036	0.267	0.191	0.346	0.062
Damietta	0.357	0.259	0.411	0.049	0.295	0.232	0.362	0.054
Behera	0.401	0.366	0.43	0.023	0.231	0.164	0.308	0.056
Gharbia	0.353	0.327	0.397	0.02	0.251	0.18	0.321	0.061
Kafr El-Shikh	0.406	0.345	0.452	0.029	0.27	0.19	0.36	0.069
Kalyoubia	0.422	0.366	0.493	0.034	0.198	0.131	0.28	0.06
Menoufia	0.398	0.277	0.499	0.063	0.212	0.133	0.303	0.073
Sharkia	0.415	0.381	0.474	0.025	0.206	0.134	0.292	0.061

Table V: The average values used in ANOVA test

Governorate	$(ETa)_Y$ /ETp	$(ETa)_M$ /ET_p
Dakahlia	0.41	0.267
Damietta	0.36	0.295
Behera	0.40	0.231
Gharbia	0.35	0.251
Kafr El-Shikh	0.41	0.27
Kalyoubia	0.42	0.198
Menoufia	0.40	0.212
Sharkia	0.41	0.206

From Fig 4 and Table VI, it was clear that P-value < 5% and the $(F_{assumed}) > F_{critical}$ so the results allowed to reject the null hypothesis H_0, and accepted the alternative hypothesis which means that the difference between two methods was statistically significant. Since this significant difference between both methods was clearly observed, hence there was no need to apply the cluster analysis.

Table VI: The ANOVA test's Results

Source of Variation	SS	df	MS	$F_{assumed}$	P-value	$F_{critical}$
Between Groups	0.0959	1	0.0959	100.0986	9.28E-08	4.60011
Within Groups	0.0134	14	0.00096	--	--	--
Total	0.1093	15	--	--	--	--

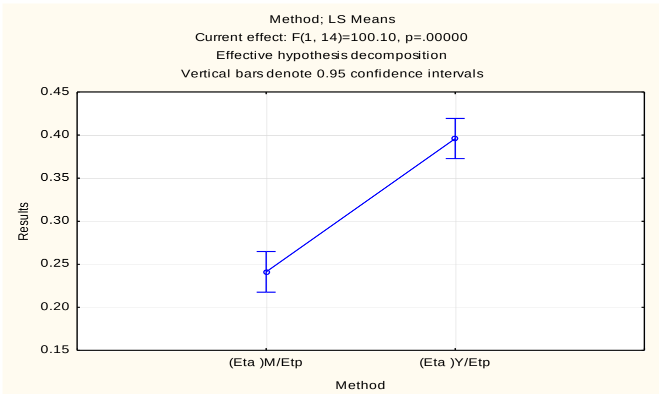

Fig 4: ANOVA test's results for (ETa)Y /ETp and (ETa)M /ETp

B. ETa values from the three methods

Fig (5) shows values of (ETa)RS, (ETa)Y, and (ETa)F for five Delta governorates in 2017. It was clear that (ETa)RS and (ETa)F are closely related in the five governorates. However, it was obvious that values of (ETa)Y were far from other values in Menoufia and Sharkia governorates. Since ETa values from the three methods were estimated only for the year 2017, the basic/descriptive analysis was not undertaken.

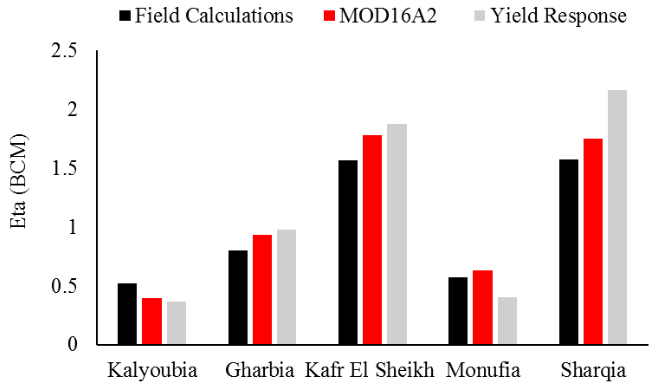

Fig 5: ETa values from the three methods for the year 2017

The check of normality was taking place on the value of (ETa) obtained from the above three mentioned methods for the five governorates for the year 2017. It was found that the data follows the normal distribution. The ANOVA was applied and the results are shown in Table VII. It was clear that P-value < 5% and the $(F_{assumed}) > F_{critical}$ so the results allowed to accept the null hypothesis H0, which means that the difference between three methods is statistically insignificant.

Table VII: ANOVA test Results for ETa

Source of Variation	SS	df	MS	$F_{assumed}$	P-value	$F_{critical}$
Between Groups	0.0594	2	0.0297	0.0649	0.9375	3.8853
Within Groups	5.4890	12	0.4574	--	--	--
Total	5.5484	14	--	--	--	--

Since the difference between the three methods was statistically insignificant, the cluster analysis was hence applied on the values obtained from the three methods. The results indicated that (Eta)RS and (Eta)F are closely related compared by (Eta)Y. This led to further application of cluster analysis on the results of different governorates obtained from only these two methods. The results are shown in Fig 6, from which it was obvious that the governorates were divided into three groups; (Sharkia and Kafr El-Shikh), (Menoufia and Kalyoubia) and (Gharbia).

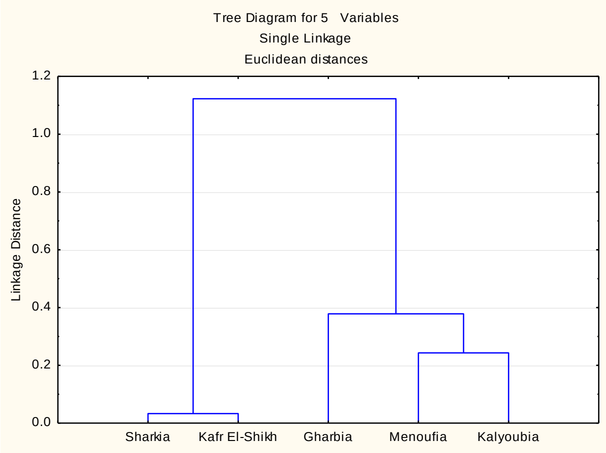

Fig 6: Cluster analysis of the five governorates

The ANOVA was hence applied on the data of the first and second groups obtained from the cluster analysis to test the degree of significance between each two governorates in each group. The results are shown in Fig 7 and 8 and Tables VIII and IX respectively.

Table VIII: ANOVA test results of the first group (Sharkia and Kafr El-Shikh)

Source of Variation	SS	df	MS	F assumed	P-value	F critical
Between Groups	0.000168	1	0.000168	0.00843	0.935225	18.51282
Within Groups	0.03996	2	0.01998	--	--	--
Total	0.04013	3	--	--	--	--

Table IX: ANOVA test results of the second group (Kalyoubia and Menoufia)

Source of Variation	SS	df	MS	F assumed	P-value	F critical
Between Groups	0.020746	1	0.020746	4.2423	0.17562	18.51282
Within Groups	0.00978	2	0.00489	--	--	--
Total	0.030526	3	--	--	--	--

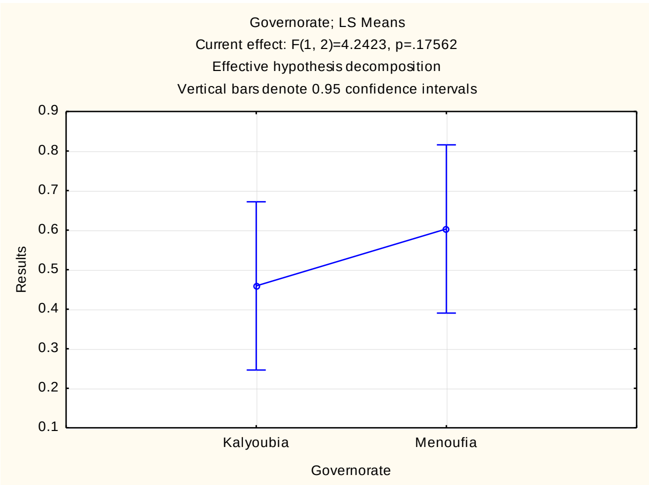

Fig 7: ANOVA test results of the second group (Menoufia and Kalyoubia)

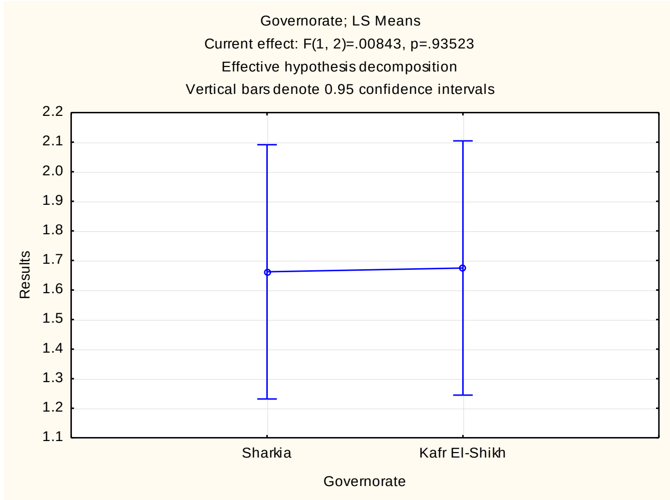

Fig 8: ANOVA test results of the first group (Sharkia and Kafr El-Shikh)

From the above-mentioned table and figure, it is clear that P-value < 5% and the (F assumed) >Fcritical so the results allowed to accept the null hypothesis H0, which means that the difference between the two governorates of the first and second groups is statistically insignificant.

Cropping pattern in the five governorates were analyzed to find their impacts on categorizing the five governorates into groups by cluster analysis. The highest four crops' areas of these five governorates are shown in Table X. It was clear that the first group (Sharkia and Kafr El-Shikh) had almost the same cultivated area of rice with about 1100 km2. While the second group (Menoufia and Kalyoubia) had no rice area, however, they had the same highest two crops' areas (Summer maize and Wheat). Meanwhile, the third group (Gharbia) was considered as a transition zone between the first and second group as it had a moderate area of rice compared with the first and second groups with only 537 km2. Its highest cropped area was cultivated with wheat with 400 km2, which was also cultivated in the other four governorates. Table XI presented the final conclusion of results.

Table X: The Highest four crops' areas and their percentages to the total cropped

	Crop 1	%	Crop 2	%	Crop 3	%	Crop 4	%
Sharkia	Wheat	25.39	Rice	16.54	Summer Maize	13.64	Clover	8.92
Kafr El-Shikh	Rice	24.79	Wheat	21.46	Clover	9.52	Cotton	4.31
Menoufia	Summer Maize	23.69	Wheat	18.47	Clover	16.99	Silage	12.99
Kalyoubia	Summer Maize	22.25	Wheat	17.77	Fruits	13.97	Clover	11.90
Gharbia	Wheat	20.81	Rice	17.52	Silage	15.25	Clover	13.96

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Table XI: Summary of results

Compared Items	Check Normality	ANOVA Test	Cluster Analysis
$(ETa)_Y$ /ETp and $(ETa)_{RS}$ /ET_p for all Nile Delta governorates (2008-2017)	The data follows the normal distribution	Difference was statistically significant	Due to ANOVA test results, there was no need to apply the cluster analysis
$(ETa)_{RS}$, (ETa)Y, and (ETa)F for five Nile Delta governorates in 2017	The data follows the normal distribution	Difference between three methods is statistically insignificant	-$(Eta)_{RS}$ and (Eta)F are closely related. -The governorates were divided into three groups; (Sharkia & Kafr El-Shikh), (Menoufia & Kalyoubia) and (Gharbia). -Governorates of each group have the same dominant crops.
Average ETa of two governorate s of Groups (1&2)	The data follows the normal distribution	Difference is statistically insignificant.	-------

IV. CONCLUSION

This study estimated and

compared values of ETa and ratios of ETa/ETp in the Nile Delta region in Egypt from different methods in order to find the superior methods. ETa values were estimated from Remote Sensing approach by Moderate Resolution Imaging Spectroradiometer (MODIS) ETa-product (MOD16A2),

FAO (33) method, and Irrigation Water Balance Calculation (IWBC) method. ETa/ETp ratios were estimated from MOD16A2 approach and FAO (33) method. The results showed a significant relationship between MOD16A2 approach, FAO (33) method, and IWBC method for estimation of ETa values, with a close relationship between MOD16A2 and IWBC methods compared to FAO (33). Hence, the current study proved that both MOD16A2 approach and IWBC method can be utilized for ETa estimation in the Nile Delta region. However, there was a significant difference between MOD16A2 approach and FAO (33) method for estimating ETa/ETp ratios, indicating that both methods are unconfirmed. The statistical analysis of ETa values in different governorates showed a significant influence of cropping pattern on ETa values. The current paper confirmed that FAO (33) method cannot be utilized, because the crops' yield response in the Nile Delta region might be affected by not only water availability, but also by other factors such as water salinity. The current paper recommended further collection of canals' bathymetry data and climate parameters in the all Nile Delta governorates.

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