Journal of Al-Azhar University Engineering Sector

Vol. 19, No. 70, 2023, 51- 66

ASSESSING THE IMPACT OF IRRIGATION IMPROVEMENT PROJECTS ON WATER ACCOUNT ELEMENTS

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Citation:

A. N. Abdellatef, M.M.Sobieh, T.T. El-Gamal, A. F. Ellen, " Assessing the Impact of Irrigation Improvement Projects on Water Account Elements", Journal of Al-Azhar University Engineering Sector, vol. 19, pp. 51 - 66, 2024.

Received: 9 November 2023

Revised: 24 December 2023

Accepted: 31 December 2023

DOI: 10.21608/auej.2023.247547.1467

ABSTRACT

With the establishment of Irrigation Improvement Projects (IIPs) in the old lands, there was an expectation to improve irrigation efficiency to 75%, which should result in considerable water savings. An evaluation program was conducted by the Water Management Research Institute and the evaluation results rejects such a hypothesis, and it showed that the irrigation efficiency was not improved. The current study was conducted for investigating three regions, which are unimproved area, IIP1-type improved area, and IIIMP-type improved area. Therefore, the main objectives were: 1) Calculating water consumption for the selected three areas, 2) Calculating water supply for the selected three areas, 3) Irrigation efficiencies were calculated for selected three areas, 4) studying the farmers' behaviors.

To investigate the reason for not achieving the expected irrigation efficiency, two improved areas and one unimproved area were investigated and some water account elements were assessed. The two improved areas were related to the first phase of Irrigation Improvement Project (IIP1-type) and Integrated Irrigation Improvement Project and Management Project (IIIMP-type) Mesqas. The unimproved area does not have Low-Level Mesqa and one lifting point on a branch canal is serving the entire area through one Marwa. The main difference between IIIMP-type Mesqa and the other two areas is the improvement of the Marwas. Other differences include pump sizes, the dominant crop, and the irrigation cost. The dominant crop in IIMP-type Mesqa was rice crop, which is normally associated with low irrigation efficiency. In IIP1-type Mesqa and the unimproved Mesqa, the dominant crop was Maize crop.

The assessed elements were the on-farm irrigation efficiency and the conveyance efficiency through the Marwas. Water consumption was calculated based on remote sensing technique, water application was calculated for different areas and discussions with farmers were used to interpret the results.

Overall irrigation efficiency (the summation of on-farm irrigation efficiency and Marwa's conveyance efficiency) in the three areas was close to each other (55% for the unimproved, 49.9% for IIP1-type Mesqa and 50% for IIIMP-type Mesqa). The results showed that the variation between on-farm irrigation efficiency for different fields was considerably higher than the differences between the investigated areas. Discussions with the operators showed that decreasing the irrigation cost and distributing the cost based on the irrigated area without considering the water used encouraged farmers to use more water.

The study recommended having firm control of water distribution and enhancing the capacity building of Water Users Associations (WUAs) to improve water use efficiency in the improved areas.

KEYWORDS: Irrigation Improvement Projects, Water Saving, Irrigation Efficiency, Water Accounting

تقييم أثر تطوير الري على عناصر المحاسبة المائية

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الملخص

لقد تحسنت كفاءة الري تحسناً محتملاً بحوالي 75٪ بسبب إنشاء مشاريع تطوير الري بالأراضي القديمة، مما أدى الى توفير ملحوظ بكميات مياه الري، ولكن هناك برامج تقييم أجريت ونُفذت تحت اشراف معهد بحوث ادارة المياه، حيث أسفرت نتائج هذه البرامج على عدم قبول فرضية تحسن كفاءات الري بمشاريع تطوير الري بالأراضي القديمة، حيث ان كفاءة الري لم تتحسن. لذا، كانت الأهداف الرئيسية كالتالي: 1) حساب استهلاك المياه للمناطق الثلاث المحددة، 2) حساب إمداد المياه للمناطق الثلاث المحددة، 3) تم حساب كفاءات الري للمناطق الثلاث المحددة، 4) دراسة سلوك الفلاحين.
لدراسة ومعرفة السبب الرئيسي وراء عدم تحقق الكفاءة المتوقعة في الري، تمت دراسة ومعاينة مناطق مطورة ومنطقة غير مطورة، حيث تم تقييم ودراسة عناصر المحاسبة المائية. كانت المناطق المطورة هي مناطق نوع IIP1 ونوع IIIMP من المسقى.
أما المنطقة غير مطورة فليس لديها مسقى مفتوحة ونقطة رفع واحدة على قناة فرعية تخدم ري المنطقة بأكملها من خلال مروى.
الفرق الرئيسي بين مسقى نوع IIIMP والمناطق الأخرى هو تحسين المروى. وتشمل الفروقات الأخرى أحجام مضخات الري، والمحصول السائد المنزرع، وتكلفة الري. المحصول السائد في مسقى نوع IIMP كان محصول الأرز، والذي عادة ما يرتبط بكفاءة الري المنخفضة، أما في مسقى نوع IIP1 ومسقى غير مطور، كان المحصول السائد هو محصول الذرة.
تم تقييم عناصر المحاسبة المائية، وكانت كفاءة الري في المزرعة وكفاءة النقل عبر المروى من بين هذه العناصر. حيث تم حساب استهلاك المياه استنادًا إلى تقنية الاستشعار عن بعد، وتم حساب تطبيق المياه بدقة، وتم استخدام المناقشات مع المزارعين لتفسير النتائج.
كانت الكفاءة العامة للري (مجموع كفاءة الري في المزرعة وكفاءة نقل المياه عبر المروى) في الثلاث مناطق متقاربة من بعضها البعض، حيث بلغت (55٪ لغير مطورة، 49.9٪ لمسقى نوع IIP1 و50٪ لمسقى نوع (IIIMP). و قد أظهرت النتائج أن التباين في كفاءة الري في المزرعة لحقول مختلفة كان أعلى بكثير من الاختلافات بين المناطق المعاينة تحت الدراسة. أشارت المناقشات مع العمال إلى أن توزيع التكلفة استنادًا إلى المساحة المروية دون مراعاة المياه المستخدمة، يشجع المزارعين على استخدام المزيد من المياه.
و قد أوصت الدراسة بضرورة وضع رقابة صارمة على توزيع المياه وزيادة قدرة التحسينات في روابط مستخدمى المياه لتحسين كفاءة استخدام المياه في المناطق المطورة.

الكلمات الرئيسية: مشاريع تطوير الري، توفير المياه، كفاءة الري، المحاسبة المائية.

1. INTRODUCTION

Global agriculture will face multiple challenges over the coming decades to satisfy the world's food security while it must produce more food to feed the increasing world population [1]. Globally, agricultural water withdraws about 75% of all water withdrawals. In addition, there is a prediction of about a 14% increase between the years 2000-2030 to meet food demands [2]. The global challenge of agriculture is that water scarcity affects every continent wherein it was listed as the largest risk in terms of potential impact over the coming decades [3].

Egypt, as semi-arid region, is suffering from water shortage. The main water resource is River Nile. The fixed quota from River Nile is currently threaten by south countries. Other resources are very limited and not stable. Deep groundwater is limited and not renewable. Based on [4], Groundwater aquifers are ranging from shallow local aquifers in the Nile Valley and Delta system to non-renewable aquifer in western delta. The annual groundwater abstraction in the Nile aquifer system is about 4.6 BCM/year. The total groundwater abstraction in Delta, Sinai and New Valley is estimated to be 5.1 BCM/year. Non-renewable groundwater exploitation is estimated at a rate of 1.65 BCM/year. Regarding precipitation, and based on [5], rainfall in Egypt is very scarce, with an annual average of 12 mm and ranges from 0 mm/year in the desert to 200 mm/year in the north coastal region. The maximum total amount of rain does not exceed 1.8 BCM/year. However, the average annual amount of rainfall water that is effectively utilized for agricultural purposes is estimated to be 1.0 BCM/year. As an example, for the variation of precipitation. The precipitation in South Sinai region is varied from 1.0 to 94.5 mm/year [6]. Regarding the higher extreme daily precipitations for this area, the values during the period from1994 and 2014 ranged from below 65 mm to above 85 mm [7]. The gap between water supply and water demand increases gradually with the rapid increase of the population [8]. This resulted in a water gap between water supply and water demand. Based on [9], and after using three different models, the current unmet demand of water was 15.1 BCM/year, which was found only in the agricultural sector and water shortage in 2025 would be 26 BCM/year.

With such unsteadiness of other resources and the increase of water gap between water supply and water demand necessitated the Egyptian government represented by the Ministry of Water Resources and Irrigation (MWRI) to adopt new strategies for saving water through adopting water-saving projects to mitigate water wastage and maximize water use efficiency [10]. Egyptian agriculture is the main water consumer, and therefore improving agricultural water efficiency significantly affects water saving on a large scale [11]. From 1977 to 1984, the Egyptian Water Use and Management Project (EWUP) was conducted; it aimed to improve agriculture and water management [12]. The project drew attention to the importance of farmers' participation and sharing the responsibilities of irrigation management. This could be achieved by establishing water user associations (WUAs), replacing individual pumps owned by farmers with collective pumps operated between them, and replacing low-level Mesqas with either raised Mesqas or buried pipelines. Based on that criterion in 1991 the Egyptian government adopted and initiated Irrigation Improvement Projects (IIPs) to improve 1.5 million hectares by 2017, of which about 70% is in the Nile Delta [13].

Converting open Mesqas to pipeline or raised Mesqas should improve the conveyance efficiency. However, most of the reports stated that the original conveyance efficiency in old lands in Egypt is high due to soil classification and high water table. During the EWUP project [14], it was stated that deep percolation to the water table subsystem from the branch, distributary, and private canals (Mesqas) is insignificant. Regarding the change in the conveyance efficiency after the improvement, [15] stated that the current conveyance efficiencies are 95% for main and branch canals and 90% for Mesqas. The study expected that the conveyance efficiency in the Mesqas would increase to 95% after the improvement, while it would stay the same in the canals. The study presented other previous results, which defined the conveyance efficiency for Mesqas and canals as 85%, and it is expected that this conveyance will increase to 95% at the Mesqas level, and it will stay the same at canal levels after the improvement.

Regarding the expected change in on-farm irrigation efficiency after the implementation of IIP, [15] estimated that on-farm irrigation efficiency would increase from 65% to 73%, and it presented other results that on-farm irrigation efficiency would increase from 70% to 75%. Regarding the activities that should affect the on-farm irrigation efficiency, it was expected that the improved Mesqas, with the efforts of new water organizations, would control irrigation practices and water use. To investigate this hypothesis, it should be noted that the improved Mesqas were designed based on water requirements during the high consumption period assuming that the entire served of the Mesqa is cultivated by rice crop. There was a big difference between such design values and actual water requirements during the rest of the year, which means that farmers have the chance to use more water than the actual requirements during most of the year unless there is a control for water use. Moreover, the improvement did not stop using the old pumps, which were still used for the fields that had direct access to the canals. The rules of WUAs in scheduling the irrigation between farmers were almost absent and the improved Mesqas is operated by the operator alone based on the rule "first come – first served" [16]. Based on [17], WUAs participation was proven to be low, except for their high reputation, which was rather high according to the future role where they supposed to play greater role than the current state. The establishment of new collective points had no impact on water use as it was not associated with the removal of old lifting points [18, 19].

An evaluation program was conducted by the Water Management Research Institute (WMRI) during the period from 2002 to 2018. The main results were that there was no any confident evidence that the implementation of the project with the application of the continuous flow resulted in water saving. In addition, the irrigation efficiency was not improved as expected. The main conclusion was: "The evaluation results referred to a problem in achieving the improvement targets. The operation of the system was the main problem."

To interpret such results, which were against the expectation, the current study investigated three areas; one unimproved area, and two improved areas. The two improved areas were related to two different types and they have different characteristics. Irrigation efficiencies were calculated and compared in the three areas and the results were discussed to explain the sources of differences.

The objective of the current study is to assess the impact of Irrigation Improvement Projects on some water account elements and as a consequence on water saving. The study investigated three regions, which are unimproved area, IIP1-type improved area, and IIIMP-type improved area. The objective was achieved through the following steps:

- Calculating water consumption for the selected areas in the three regions. Water consumption values were calculated using a remote sensing technique. Crop coefficient values for some regions were verified using FAO tables.
- Calculating water supply for the selected areas in the three regions. In the unimproved area, a flume was used to calculate the water supply for different fields. In both improved areas, the pumps at the head of the Mesqas were calibrated and the irrigation hours for different fields were recorded.
- Irrigation efficiencies were calculated and compared in the three different sites.
- Farmers' behaviors, based on the discussion with randomly selected farmers, were discussed to explain the results.

2. MATERIALS AND METHODS

2.1. Calculating Water Consumption

Water consumption values are normally calculated based on reference evapotranspiration (ET0) and crop coefficient values (KC). Reference evapotranspiration is calculated based on metrological data. Crop coefficient values were using remote sensing technique, and the values were verified using FAO tables [20].

2.1.1. Remote sensing Technique

The applied approach for using remote sensing techniques to calculate water consumption depends on calculating crop coefficient values based on the vegetation index [21]. The absorption and reflection of the energy were calculated based on the values of two bands (Red and Near-infrared). From the values of these two bands, the Normalized Difference Vegetation Index (NDVI) was calculated using the following equation:

$$NDVI = (NIR-RED)/ (NIR+RED)$$

Crop coefficient values were defined based on a relation with NDVI. Satellite images will be downloaded for different periods of 2018/2019 and each image will be cut for the boundaries of the study areas. NDVI and KC will be defined for each area.

2.1.2. Crop coefficient from FAO tables

As a second verification, the calculated crop coefficient values, which were obtained from the previous step were discussed in the shadow of FAO tables [21]. In FAO tables, there are three stages for each crop, which are the initial season, med season, and late season. For instance, the values for these three seasons for rice crops were 1.05, 1.2, and 0.75. For Maize crop, the values were 0.30, 1.20, and 0.35. The values were calculated for some crops in the unimproved area.

2.2. Measuring of water supply values

Water supply values were measured by two different methods. For the unimproved region, a flume was used to measure the flow [22] as shown in **Fig. 1.** Head values at the upstream and downstream of the flume were measured and the flow is defined from the Table.

Fig. 1. The flume used in the unimproved area

For the improved systems (either IIP1 or IIIMP), the ultrasonic flow meters were used to calibrate the pumps **Fig. 2.** The flow was measured at the outlet pipe of different pumps.

Fig. 2. Ultrasonic flow meter used to calibrate the improved Mesqas

3. STUDY AREAS

Three different regions were investigated in this study: the first region was an unimproved area and the other two regions were improved Mesqas with different design criteria. The first Mesqa was improved under the criteria of the Irrigation Improvement Project (IIP) (World Bank 1994), and another was improved under the criteria Integrated Irrigation Improvement Project (IIIMP) (World Bank 2005). The details of the three regions are presented in the following sub-sections.

3.1. Unimproved region

The unimproved area is located on the El-Ninaiya canal (El-Shohada irrigation district – Monofiya irrigation directorate). El-Ninaiya intake is located on the left bank of El-Monofy Rayah at km 11.10. The canal length is 79.4 km and its served area is 56850 feddan. El-Ninaiya Canal has 52 branches and sub-branches. As is the case in many canals in Egypt, the environmental problem has adversely affected its performance. The study area is located in the middle of the El-Ninaiya Canal. The center of this region is almost N 30º 35' 0" & E 30º 50' 0" **Fig. 3.**

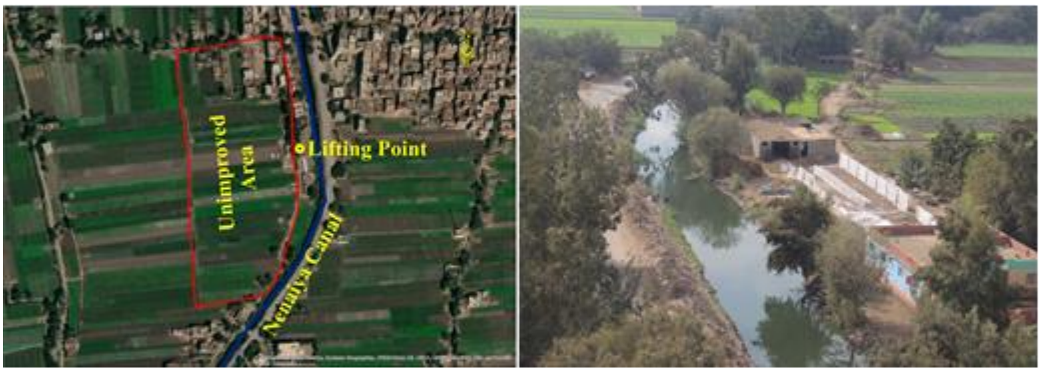

Fig. 3. Layout (https://earth.google.com) and photo of the unimproved area.

The total area of the investigated fields is 11.4 feddan and the sizes of different parcels are between 0.13 and .96 feddan **Fig. 4.** The pump that irrigates most of the area is owned by one farmer. He rents the pump and the cost is fixed for the irrigated area regardless of the cultivated crop.

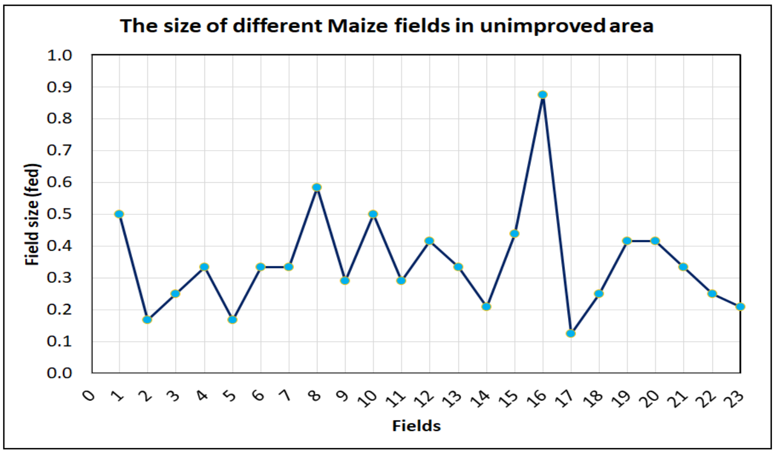

Fig. 4. The sizes of different parcels in the first region.

3.2. IIP1 improved Mesqa

The first improved area (IIP1-type improved area) is located in the El-Atf canal (Quesna irrigation district – Monofiya irrigation directorate). El-Atf canal is one of the main branches in the El-Monofiya and Zefta irrigation directorates. The canal gets its water resources from Dalel El-Atf, which is a short entrance at km 28.96 on El-Monofiya Rayah. The canal is 48.6 km in length and it serves 33,000 feddan in three irrigation districts (Quesina, Berket El-Sabee, and Zefta). The investigated Mesqa is in the first district (Quesna irrigation district). **Fig. 5.** presents the layout of the Mesqa (Mesqa 16/15) and examples of the pumps and valves in the systems. Under the design criteria of IIP1, the improvement covered the Mesqa line without the Marwas. Alfa-Alfa valves were used at the head of different Marwas. The Mesqa had two diesel pumps, but farmers replaced one diesel pump with an electric pump that had a higher capacity. Based on the discussion with the operator, using the electric pump was limited because it is a big pump, and it requires opening four valves or more at the same time. Otherwise, water would overflow from the water tower. Because the served area of the Mesqa is relatively small, opening many valves at the same time does not happen frequently, and the diesel pump (the small one) is used most of the time. **Table 1** presents the general information about the valves in the Mesqa and **Table 2** presents the calibration results of the two pumps in the Mesqa.

Table 1. Valves information of IIIP1-style improved Mesqa.

Valve No	Served Area (Feddan)	Number of farmers
1	8.97	29
2	9.50	28
3	11.38	29
4	8.83	21
5	4.17	12
6	0.75	3
7	2.46	9
Total	**46.05**	**131**

Fig. 5. Layout of improved mesqa (https://earth.google.com) and photo of pumps and valves in the systems

Table 2. Calibration results of IIP1-style improved Mesqa

Type	Actual Discharge (m^3/hour)	HP	V	H
Diesel	175.00	9.90	1.33	1.94
Electric	390.50	15.00	2.98	1.92

Based on [23], water use efficiency in the first reach of the El-Atf canal, which has the investigated Mesqa, was considerably low **Fig. 6A.** In addition, there is a concentration of irrigation during certain hours. Irrigation was concentrated between 9:00 AM and 12:00-1:00 PM, and the average water use during this period was 48.0 m^3/fed/day **Fig. 6B.**

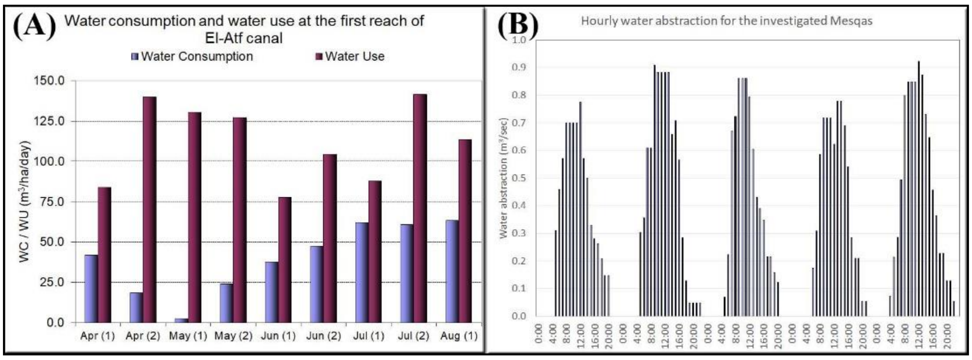

Fig. 6. Water consumption & water use in the first reach of EL-Atf (A) & water abstraction by the investigated Mesqas (B) [23].

3.3. IIIMP Improved Mesqa

The second improved area (IIIMP-type improved area) is located on Mars El-Gamal irrigation canal (Kafr El-Sheikh irrigation district – East Kafr El-Sheikh irrigation directorate). The main difference between IIP1 and IIIMP was using the electric pumps instead of diesel pump, which resulted in a significant decrease of the irrigation cost. Based on [23], changing the pumps from diesel pumps to electric pumps decreased the cost to 28% of the original cost.

Mars El-Gamal off-takes from El-Zawia canal (km 3.70). It is 11.50 Km long and it serves around 9400 feddan. The canal is served by two main secondary drains; the No 7 drain and the Farsh El-Ganaien drain besides other small secondary drains. The investigated Mesqa was in the middle of the canal. **Fig. 7** presents the layout of the Mesqa and examples of the pumps and valves in the systems. **Table 3** presents information about valves of IIIMP-style improved mesqa.

Based on [24], the Water Use Index, which is the invert of irrigation efficiency, for some investigated Mesqas in Mars El-Gamal canal during the summer of 2017 had varied values as shown in **Fig. 8**. The highest value was for the investigated Mesqa (14 R), and it was 1.94, which means that the average irrigation efficiency for the Mesqa was 51.5%.

Table 3. Valves information of IIIMP-type improved Mesqa.

Valve Number	Served Area (Feddan)	Number of farmers
1	2.00	2
2	3.00	4
3	3.00	3
4	6.00	4
5	5.00	5
6	3.00	5
7	3.00	2
8	5.50	4
9	8.00	8
10	7.00	5
11	8.92	14
12	2.00	3
13	0.42	1
14	6.50	5
15	5.46	10
Total	**68.80**	**75**

Fig. 7. The layout of second improved mesqa (https://earth.google.com) and photo of pumps and valves

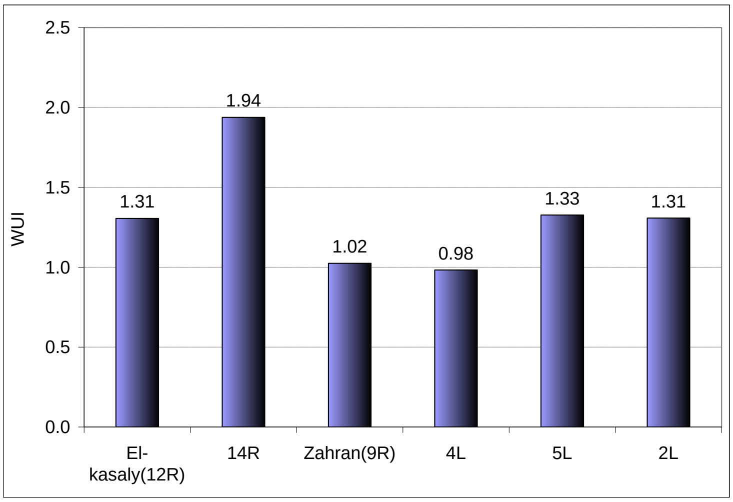

Fig. 8. WUI values for different Mesqas in Mars-El-Gamal canal during Summer 2017.

4. RESULTS

4.1. Calculating Irrigation Efficiencies

4.1.1. Irrigation Efficiency in Unimproved Area

Fig. 9 presents reference evapotranspiration, crop coefficient values, and actual evapotranspiration for three different maize fields in the unimproved study area. Reference evapotranspiration values were between 4.48 and 6.36 mm. Regarding crop coefficient values, the initial values for different fields were between 0.38 and 0.41. The highest KC values were between 0.98 and 1.03 and the end values were between 0.30 and 0.43. Considering FAO KC values for maize crops, initial, mid-season and late-season values were 0.3, 1.2, and 0.35. Maximum daily evapotranspiration for the three fields was 26.67, 25.92, and 26.23 m^3/fed/day with a variation in reaching these maximum values due to the variation in the cultivation dates. Total water consumption values for the three fields were 1934, 1758, and 1856 m^3/fed/season with an average of 1849 m^3/feddan /season.

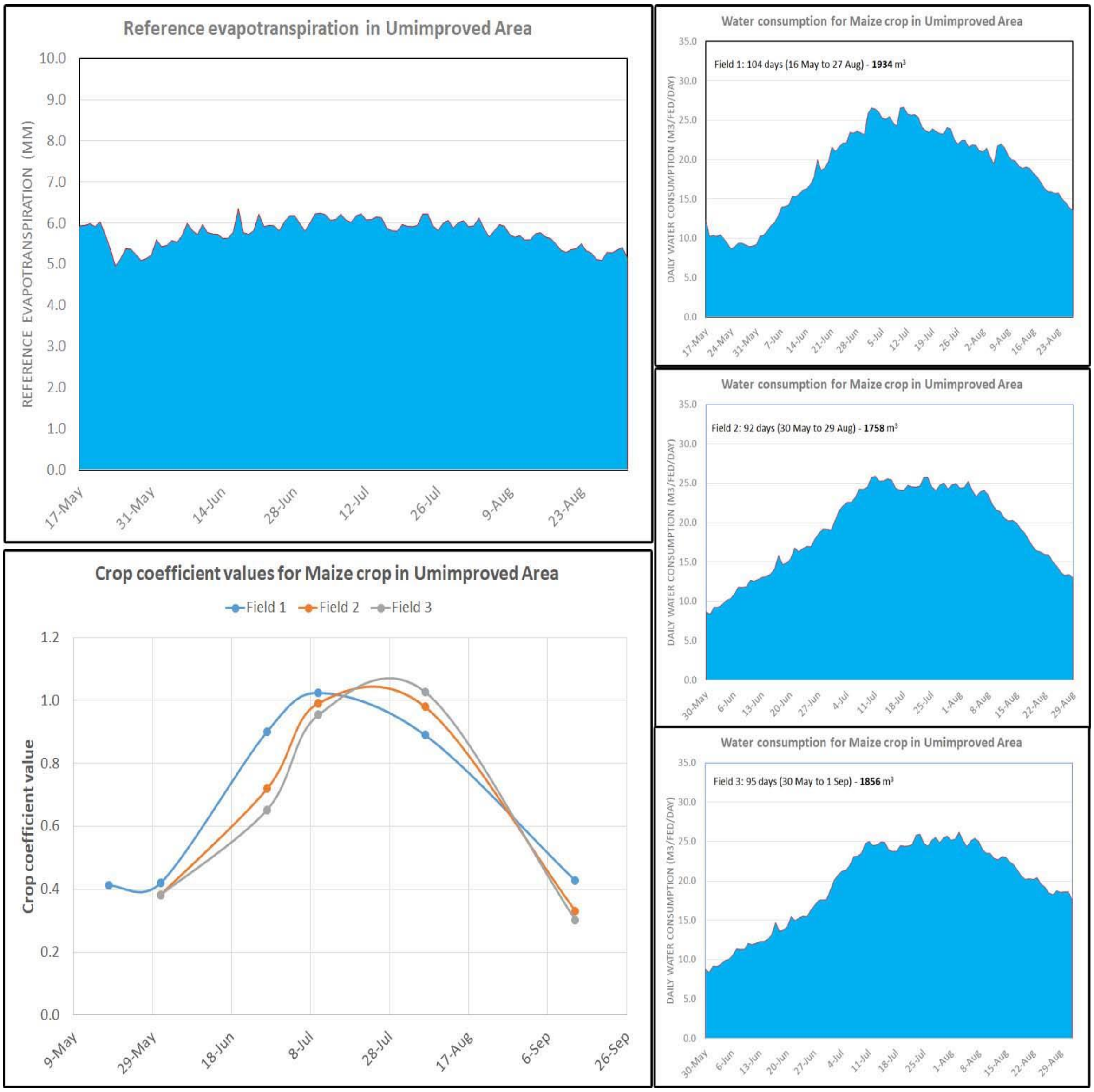

Fig. 9. Reference evapotranspiration, Crop coefficient values, and water consumption for three maize crops in the unimproved area.

Regarding water application and due to grinding the crop to use it for livestock, there were obvious differences between the fields. Number of irrigations was between 5 and 10 irrigations; life cycle values were between 65 and 110 days. **Fig. 10** presents the total water supply and total irrigation time values for different maize fields in the unimproved area. Total irrigation time values were between 24 and 49 hours/fed. Total water supply values were between 2411 and 4445 m^3/fed with an average of 3366.1 m^3/fed. Considering average evapotranspiration and average water supply, average irrigation efficiency was 54.9%.

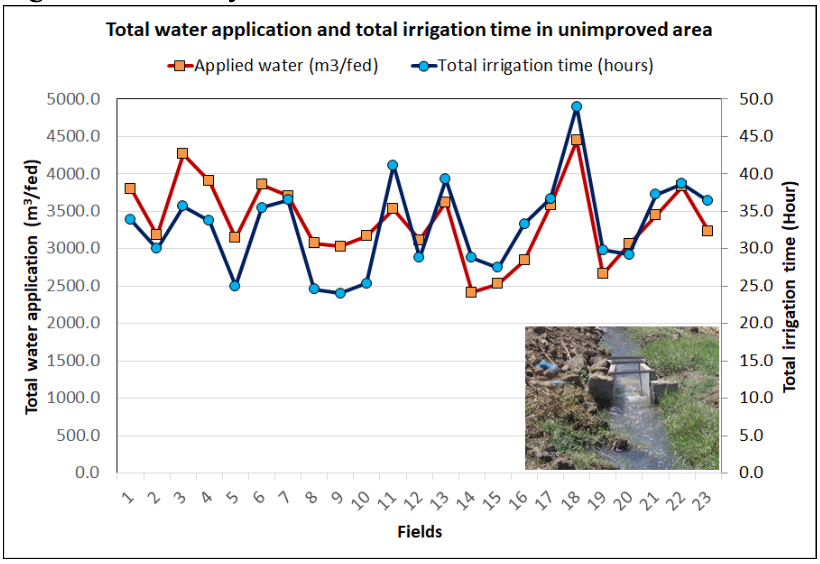

Fig. 10. Total water application and total irrigation time for Maize fields in the unimproved area

4.1.2. Irrigation Efficiency in IIP1 Improved Area

For the first improved Mesqa (IIP1 style Mesqa), **Table 4** presents the cropping pattern during the summer and winter seasons. During the summer season, the dominant crop was maize (84%). Other crops had little value.

Table 4. Cropping pattern of IIP1-style improved Mesqa

Summer Cropping Pattern				
	Maize Feddan	**Potatoes (Feddan)**	**Vegetable (Feddan)**	**Taro (Feddan)**
Upstream	13.73	3.13	0.92	0.71
Midstream	18.38	1.83	0.00	0.00
Downstream	6.79	0.00	0.58	0.00
Total	**38.90**	**4.96**	**1.50**	**0.71**

Winter Cropping Pattern		
	Wheat (Feddan)	**Clover (Feddan)**
Upstream	6.8	11.6
Midstream	9.9	10.3
Downstream	2.8	4.6
Total	**19.50**	**26.56**

For the two improved Mesqas, actual evapotranspiration and total water supply values were calculated for all Mesqas with different crops. Total water consumption for the Mesqa was calculated using a remote sensing technique and total water supply was calculated by calibrating the pumps at the heads of the Mesqa and recording the operation hours of these pumps. **Fig. 11** presents reference evapotranspiration (mm), average crop coefficient values, daily evapotranspiration (m^3/fed/day), and monthly irrigation efficiency for IIP1-style improved Mesqa. Reference evapotranspiration values were between 4.16 and 6.36 mm. The average crop coefficient value for the entire Mesqa increased from 0.45 as an initial value, increased gradually to 0.81, and decreased gradually again to 0.47. Daily evapotranspiration values were between 8.59 and 21.49 m^3/fed/day. Total water consumption for the Mesqa was 2369 m^3/fed/day. The figure contains average monthly water consumption and water supply values (for the unit area), and average monthly irrigation efficiency. The average monthly irrigation efficiency values were between 0.40 in May and 0.57 in June and July with an average seasonally of 49.9%.

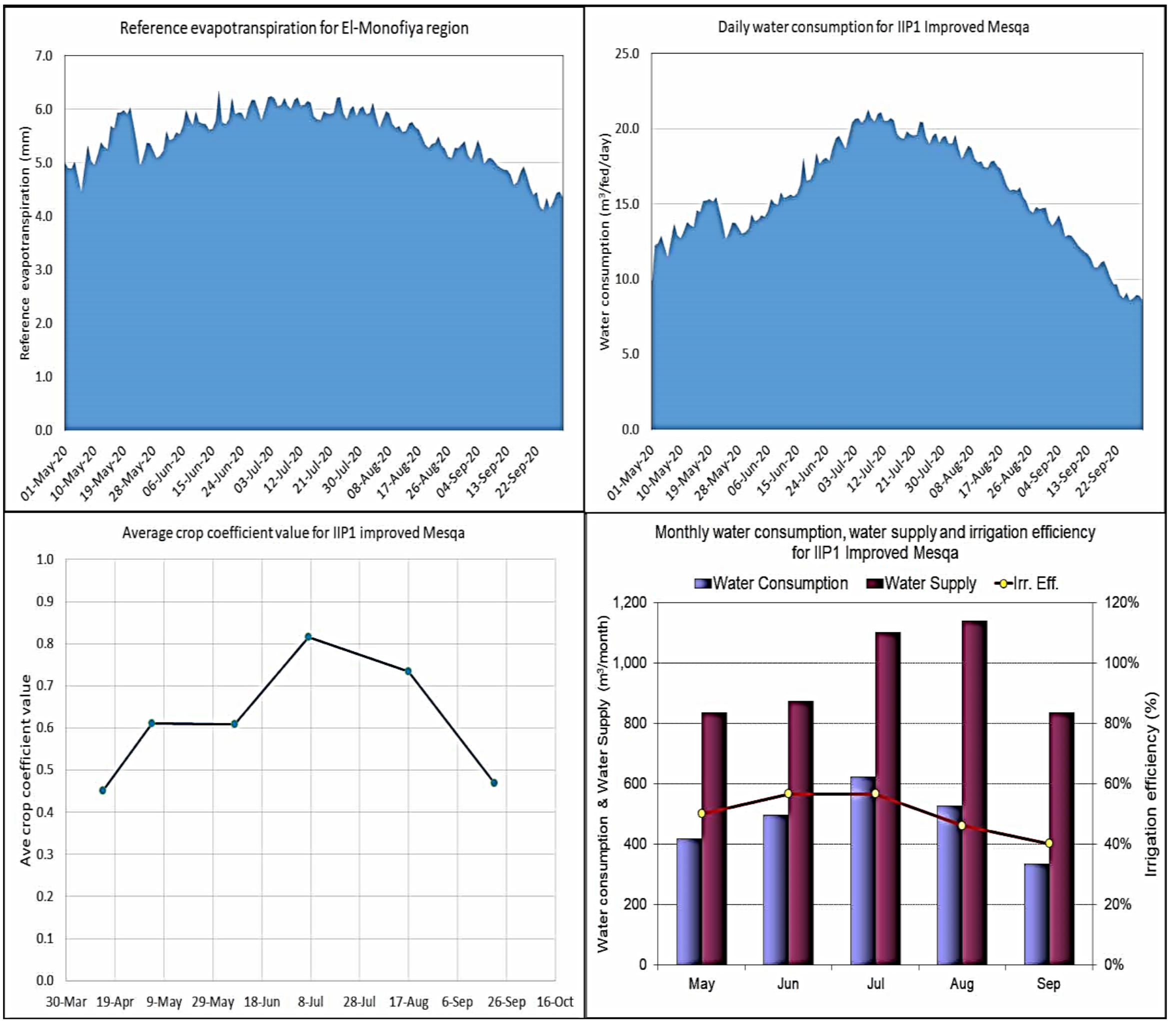

Fig. 11. Reference evapotranspiration, crop coefficient values, and water consumption for IIP1-style improved Mesqa.

4.1.3. Irrigation Efficiency in IIIMP Improved Area

For the second improved Mesqa (IIIMP style Mesqa), **Table 5** presents summer and winter cropping patterns. During the summer season, the dominant crop was rice crop (64%) followed by Maize crop (20%). During the winter season, the served area was distributed between wheat, Barseem, and sugar beet, with little deviation towards sugar beet.

Table 5. Cropping pattern of IIIMP-style improved Mesqa.

Summer Cropping Pattern					
	Rice (Feddan)	**Cotton (Feddan)**	**Maize (Feddan)**	**Sesame (Feddan)**	**Pulp (Feddan)**
Upstream	12.42	2.25	0.50	0.75	4.75
Midstream	18.00	1.00	6.25	0.00	0.75
Downstream	14.58	0.0	7.25	0.00	1.46
Total	**45.00**	**3.25**	**14.00**	**0.75**	**6.96**
Winter Cropping Pattern					
	Sugar Beet (Feddan)	**Wheat (Feddan)**		**Clover (Feddan)**	
Upstream	10.50	5.50		3.00	
Midstream	12.00	8.25		6.25	
Downstream	4.75	6.25		12.29	
Total	**27.25**	**20.00**		**21.54**	

Regarding average irrigation efficiency for the Mesqa, **Fig. 12** presents reference evapotranspiration, average crop coefficient values, water consumption, and average irrigation efficiency. Average crop coefficient values increased gradually from 0.27 to 1.0 and decreased gradually again to 0.44.

Regarding reference evapotranspiration, the values were between 4.05 and 6.0 mm. For actual evapotranspiration, the values were between 1.23 & 5.81 mm (between 5.17 & 24.40 m^3/fed/day). Monthly water supply values increased gradually from 871 m3/fed during May to 1251 m^3/feddan during July and decreased again to 447 m^3/fed during September.

Based on the previous data, average monthly irrigation efficiency increased gradually from 25% during May to 71% during August and decreased again to 64% during September. Seasonal irrigation efficiency was 50%.

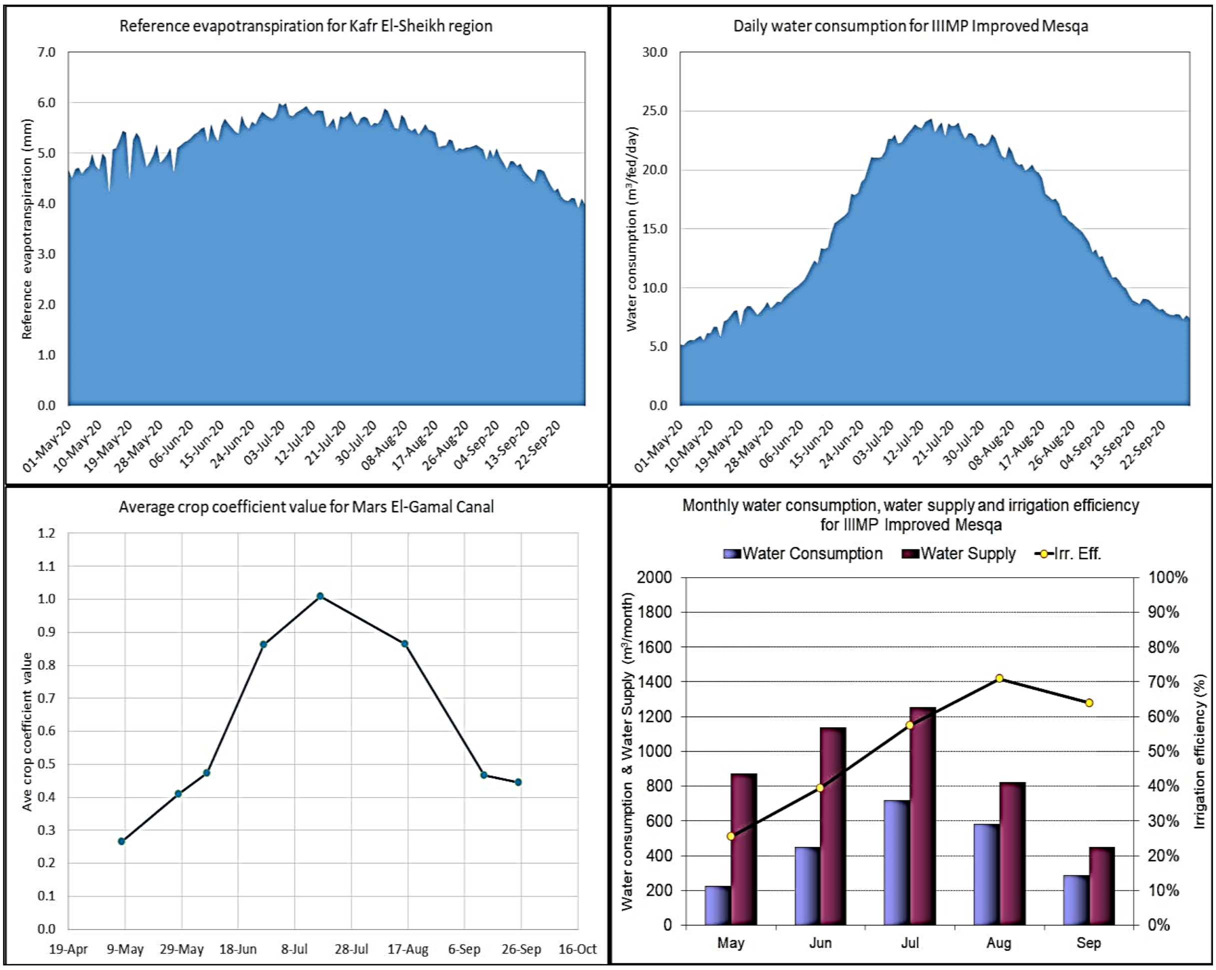

Fig. 12. Reference evapotranspiration, crop coefficient values, and water consumption for IIIMP-style improved Mesqa.

Discussion

The current study investigated three regions related to unimproved, IIP1-type improved and IIIMP-type improved regions. The general characteristics of the regions are as follows:

- The unimproved region shared the two improved Mesqas in having one lifting point for different fields, and it also shared them in having fixed irrigation cost for the unit area as the pump belongs to one farmer who rents it to the farmers, and the cost is defined based on the cultivated area regardless the crop. There is no open Mesqa and the pump lifted the water from a branch canal it distributed the water between fields through a Marwa.
- The main difference was between the unimproved region and IIIMP-style improved Mesqa, where the conveyance losses in Marwas were reduced by converting them to pipelines.
- Another factor that affected the irrigation efficiency was the cultivated crop. In IIIMP-style improved Mesqa, rice crop is the dominant crop. In general, the on-farm irrigation efficiency was lower in rice fields. Based on [16], high water availability didn't affect the irrigation efficiency in normal-crop fields, while it had a serious impact in rice fields.

It should be mentioned that the losses from Marwas are not losses and they benefit the surrounding fields. Based on the discussion with the operators in some IIP1-type improved Mesqas, they finished irrigating the fields in the same Marwa starting from the tail to the head before moving to another Marwa. This could reduce the irrigation time for head fields.

The previous results did not refer to a significant change in the irrigation efficiency between the three regions. This was against the expectation of establishing irrigation improvement projects, but it was consistent with the results evaluating the project [25, 26]. Based on [27], converting open Mesqas to pipelines could reduce seepage losses by 3%. This could increase with converting

Marwas to pipelines as well (IIIMP-type). Considering the previous results, the difference between water supply values for different fields in the unimproved area was considerably higher than this value. This means that the variation between on-farm irrigation efficiencies was much higher than the impact of conveyance efficiency and therefore, the impact of irrigation improvement projects on water saving was not obvious [28, 29].

Based on [25, 26], the main factor that could improve water use efficiency in the improved areas depends on improving water management, which did not happen.

Conclusions and Recommendations for future studies

The objective of the current study was to investigate the impact of Irrigation Improvement Project (IIP) on water account elements, and specifically the conveyance efficiency and on-farm irrigation efficiency. Three areas were investigated. The first area was unimproved area, and the second two areas were improved areas, which was different in their improvement aspects. The first area had only Mesqas improvement (IIP1-type), while the second area contains Mesqas and Marwas improvement (IIIMP-type). The unimproved area had one lifting point irrigating the fields through one Marwa without having low-level Mesqa.

The main results showed that overall irrigation efficiencies for the three investigated areas were close to each other, and there is no obvious impact of IIPs on improving irrigation efficiencies. The result could be explained by the following points:

- The conveyance efficiency in the old lands of Egypt was considerably high due to soil characteristics and high water table. As the unimproved area has no low-level Mesqa, it is equivalent to IIP1-type improved Mesqa.
- The on-farm irrigation practices were not changed in the improved areas, and therefore there was no change in on-farm irrigation efficiency. Moreover, decreasing the irrigation cost and distribution irrigation expenses based the served area without considering water use in the improved areas encouraged farmers to use more water.
- The main factor, which should affect water use in the improved areas was the expected changes in water distribution. It was expected to distribute water based on volumetric basis and it was expected that WUAs would have a role on applying an internal rotation between improved Mesqas and arranging the irrigation practices inside the Mesqas. Unfortunately, this was not implemented truly in any improved canal. The implementation of novel collective points demonstrated negligible effects on water utilization, given its lack of correlation with the dismantling of pre-existing lifting points. Moreover, Water User Associations (WUAs) exhibited notable inefficacy, displaying minimal impact on the realm of water management.

In conclusion, the main factor that could help improve irrigation efficiency in the improved areas is the firm control of water use, which is still an absent factor. Applying some on-farm techniques could also help improve irrigation efficiency, but some studies should be conducted to investigate its impact on salt and water balance.

Future studies should focus on enhancing water management in the improved areas. The studies should also contain applying some on-farm techniques while controlling water and salt balance.

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