

## ASSESSING THE IMPACT OF IRRIGATION IMPROVEMENT PROJECTS ON WATER-ENERGY-FOOD NEXUS - CASE STUDY : AL-ATF CANAL, EGYPT

Talaat El Gamal<sup>1</sup> and Hanan Farg<sup>2</sup>

### ABSTRACT

Egypt is an arid country with limited water resources. There were also some problems regarding energy resources during last few years. In Egypt, both water and energy are closely connected to food production, as agriculture depends totally on irrigation, and the Egyptian irrigation system restricts lifting the water from canals to the surrounding fields. With the rapid population growth in Egypt, there is a necessity to produce more food, and this requires optimizing the use of limited water and energy resources. Irrigation Improvement Projects (IIPs) were among the solutions to improve Water-Energy-Food nexus. The projects were conducted to improve water productivity by improving water use efficiency and crops yield. Another important objective for IIPs was to decrease the irrigation cost through the optimal use of the energy. After the actual implementation, the evaluation of IIPs referred to difficulties in the achievement of some objectives, while other objectives were achieved successfully. The current study assess the Water-Energy-Food nexus in traditional situation in Egypt, the expected impact from IIPs on this nexus, and the actual impact of IIPs after the implementation. An improved canal in the Middle Delta (Al-Atf canal) was selected for such assessment. The measurements were conducted in the first reach of the canal. Measurements on the canal did not refer to real change in water use efficiency, mainly due to the unsuitable operation of the irrigation system and the lack of coordination between farmers. Regarding the energy, the single-point lifting and the dependence on the electric power had a significant impact of reducing the irrigation cost. The study discusses the reason for low water use efficiency, and it suggested developing an operation model that calculates actual water requirements based on remote sensing information to propose the optimal operation scenario for the improved Mesqas. Such model could improve water management, which should have positive impact on water use efficiency, and which could minimize the adverse impacts of Water-Energy-Food nexus in the improved areas in Egypt

**Keywords:** Water-Energy-Food nexus, Irrigation Improvement Projects, Water Management, Water Use Efficiency

### 1. INTRODUCTION

The connection between water, energy and food (agriculture) is obvious. Water is the basis for food production, and it is also used for energy production (hydropower) and even in thermoelectric power plants through cooling of these plants. Energy is another main element in food production, starting from cultivation (irrigation and agricultural machinery) to food industry to food distribution. Energy is also used for water production, processing and distribution (pumping and extracting water for different purposes, treating wastewater, and the desalination of seawater). Such interconnected relationship has other dimensions with the limitation of the resources.

---

<sup>1</sup> Water Management Research Institute (WMRI), National Water Research Center (NWRI), Ministry of Water Resources and Irrigation (MWRI). El-Kanater El-Khariya, CP ; E-Mail: elgamalt@gmail.com

<sup>2</sup> National Water Research Center (NWRI), Ministry of Water Resources and Irrigation (MWRI). El-Kanater El-Khariya, CP ;E-Mail: hananfarag71@gmail.com

Such limitation requires optimal use of different elements and therefore the integrated approach becomes more important.

In Egypt, the resources were not only limited, but also are threatened by the rapid population growth that requires more resources, and therefore the situation became more grim. Tackling such problem could have many axes, and one of the introduced solutions for better use of water and energy for agricultural purpose was the irrigation improvement projects.

Evaluating the impact of IIPs on the rational use of water and energy in the agricultural field is essential to define the next steps for this approach, and if it should be continued, adapted or stopped.

## **2. THE CURRENT SITUATIONS OF DIFFERENT WEF ELEMENTS IN EGYPT**

### **2.1 The Availability of WEF Elements In Egypt**

#### *Food gap in Egypt*

Along the history, Egypt was known as “World’s bread basket”. However, and with the rapid population growth in the modern history, food production began to be insufficient, and Egypt began to depend on imports to fill the food gap. According to Gamal Hemdan (1984), “Throughout the 1960s, the food gap was relatively moderate, but it exploded in the 1970s, nearly tenfold in just 10 years, and it included all crops except rice, vegetables and fruits”. He described the situation for the wheat as follows, “Self-sufficiency of wheat continued until 1945. From 1950 to 1970, local production covered the rural residents, while urban residents relied on imports from abroad. Since 1975, the stage of national inefficiency has begun. Since then, both rural and urban areas began to depend on imports.” Mady (2014) illustrated that there was a food gap in meat, wheat, and legumes, and the gap kept increasing. From 2000 to 2010, the food gap for meat, wheat and legumes increased by 53.1%, 35.6% and 1.7%, respectively. For sugar, vegetables and oil, the production was exceeding the consumption. However, the production surplus of these goods decreased during the same period by 2.8%, 17.4% and 44.8% respectively. Only for fruits, the production surplus increased during this period (2000-2010) by 44.3%.

#### *Water resources & water use*

There was a rapid reduction in per capita share of water in Egypt. The values, which was exceeding 2000 m<sup>3</sup>/capita at the middle of the previous century, dropped to less than 700 m<sup>3</sup>/capita in last years. Based on MWRI (2017), total water supply in Egypt in 2015 was 59.25 BCM. From this amount, municipal sector used 10.75 BCM, and 5.4 BCM was used by the industry sector. Total consumption from both municipal and industry sectors was around 3.78 BCM and around 12.37 BCM return to the system as polluted losses. Considering that there was around 2.4 BCM evaporated from the water surfaces, the share of the agricultural sector was around 40.7 BCM, which is very close to the required consumption (40.0 BCM as estimated in the report). However, the actual water use of the agricultural sector is 61.1 BCM thanks to the intensive reuse of water losses.

#### *Energy resource*

The energy sector in Egypt is now improving after a period of suffering. The main improvement was in the production of the natural gas. Based on Hussein and El Baz, “Egypt’s natural gas production was almost stable between FY 2010/11 and FY

2011/12, with a slight decrease from approximately 46.3 million tons equivalent per year (mton/y) to 46.07 mton/y. Since FY 2012/13, the level of production has been declining steadily. Annual production reached its lowest level of 31.3 mton/y in FY 2015/16, before recovering slightly in FY 2016/17 to reach 31.9 mton/y. It is expected that Egypt will return to exporting the natural gas from 2019-2020.

For the electricity, the production increased annually to face the gradual increase in the demand regardless the source of the fuel (nationally or imported). From figure (1), generated electricity increased gradually from 110,299 GWh in 2004/2005 to 189,550 GWh in 2016-2017. The highest annual increase was 8.4% in 2006/2007. The lowest increase were 1.7% in 2016-2017 and 2.4% in 2012-2013 (MEE).

## 2.2 The Change in the Consumption Trends of WEF Elements in Egypt

There was a fast change in life standard in Egypt during last decades. This affected the consumption trends, and it increased the difficulty of optimizing water and energy use. Based on Mady (2014), "The situation of agriculture and food in the current period (2001-2012) has reached a critical stage that was represented in the growing demand for agricultural products due to the population increase in addition to the general trend of consumption increase despite the increase in the prices." Consumption increase resulted in the increase of food waste despite the food gap in Egypt. Some international organizations stated that Food Losses and Waste (FLW) in Egypt are high, especially for perishable products (FAO).

Regarding water use, municipal water increased from 3.1 BCM in 1990 (~170 liter/capita) to 10.75 BCM in 2015 (327 liter/capita). Based on (MWRI, 2017), the last value (for 2015) is times the normal per capita consumption. For irrigation, the inability to control the system in last decades resulted in misuse of water. Irrigation Development Plan in Egypt (Ministry of Irrigation, 1979) stated that water duty increased during 1970's from 16429 m<sup>3</sup>/ha to 19047 m<sup>3</sup>/ha due to the misuse of water. However, and as the system is considered as a closed system, the problem is in wasting the water and reusing it more than once. The water losses is polluted, after mixing with sewage and industrial wastes, and therefore it has negative impact on crop production besides the health risk. Moreover, using the water more than one time is associated with more energy consumption.

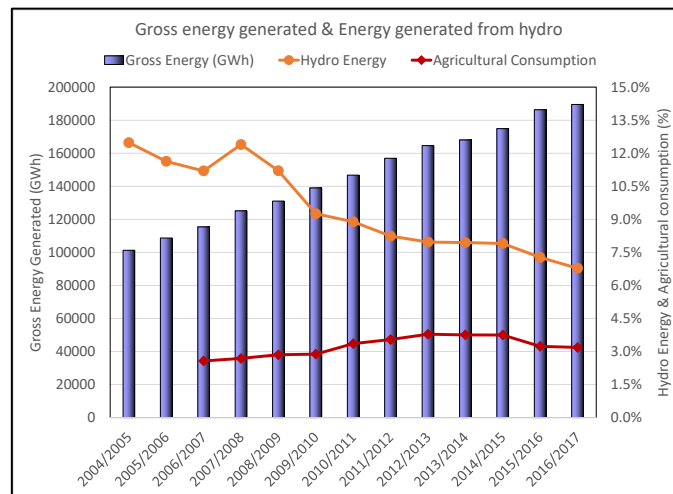
Average energy used per capita increased from 1650 KWh in 2006/2007 to 1910 KWh in 2011/2012 (MEE).

## 2.3 WEF Nexus for The traditional situations in Egypt

The relation between agriculture and water is obvious as agriculture depends principally on water. In Egypt, there is almost a complete dependence on the irrigation, as the rain is rare. Some investigations reported the Egyptian irrigation system as the third for land productivity among 56 investigated irrigation systems, but it was the tenth among these investigated irrigation systems for water productivity, which refer to low irrigation efficiency compared to the other irrigation networks (El-Gamal, 2018b). Regarding the future relation between water and agriculture, and as the share of agriculture of the fresh water is close to total crop consumption, the gradual increase in municipal and industrial water use will have a vital impact on the agriculture sector. The future scenarios to improve the relation between water and agriculture contains treating the wastes of these sectors to make use of these big amounts of water, and decreasing the dependence on the reuse by improving water use efficiency. Another scenario is to produce more crops with the same amount of water through cultivating new crop varieties.

Agriculture (producing food) has a close relationship with the energy as well. Besides agricultural machinery and food industry, there is a high dependence on the energy in irrigation sector, after diesel pumps replaced animal-driven wells (Saquias) for lifting the irrigation. Based on Nour El-Din and Kotb (2006), “the huge volume of water is currently lifted by small diesel pump sets owned by the farmers, consuming an estimated amount of about 700,000 tons of diesel fuel annually.” The irrigation cost, based on the statistics for 2016 (MALR, 2018), constituted between 4% and 10.3% of the agricultural inputs, coming after the agricultural machinery that constituted between 5.9% and 15.9% of these inputs. For the future relationship between agriculture and energy, there is a trend to use the electricity in agriculture, and this is likely connected to irrigation and the implementation of the new phases of IIPs that relied on the electric power. Total electricity sold for agricultural purposes increased from 2967 GWh in 2006/2007 to 6033 GWh in 2016/2017 (MEE). (Figure 1).

For the relation between water and energy, the dependence on hydropower started in Egypt before the middle of the previous century. With the construction of High Dam, the ratio of the hydropower exceeded 50% of total generated electricity in Egypt in 1970's. This affected the released water from High Dam, and therefore some fresh water was dumping into the sea during this time. The importance of the hydropower decreased gradually since 1970's until now with the construction of thermal power plants. From 2004-2005 to 2016-2017, the annual electricity produced from the hydropower was 12644 and 15510 GWh (MEE). This constituted 12.5% (in 2004-2005) and 6.8% (in 2016-2017) OF total generated electricity during this period (figure 1). It is expected that the relationship between water and energy will be flipped in the future. Previously, water was the main source to generate energy. In the future, the energy will be an essential source to pump water, through the extraction of deep groundwater, the treatment of the polluted water and the desalination of the seawater.



**Figure 1.** Total generated electricity, the share of Hydropower, and the electricity sold for agricultural purpose in Egypt.

### 3. IRRIGATION IMPROVEMENT PROJECTS&THE EXPECTED IMPACT ON WEF NEXUS

The idea of Irrigation Improvement Projects (IIPs) were started in Egypt in 1970's through a research project in Water Management Research Institute (Egyptian Water Use and management Project – EWUP). With the execution of IIPs, there was an expectation that the projects could contribute in considerable amount of water saving. For example, the strategic plan (1997-2017) for Ministry of Water Resources and

Irrigation contained improving 1.5 million feddan until 2025, which will result in saving of 1070 million m<sup>3</sup> water and the appraisal document of IIIMP expected that water savings from IIIMP would reach 22% (El-Gamal, 2011). There were other hopes to improve crop yields and reduce the irrigation cost as well.

The evaluation reports by Water Management Research Institute (WMRI) showed that the increase of the yield is associated with shift from the dependence on the drainage water to the fresh water. This happened at many Mesqas's end regions after the implementation of IIPs. This increased the yield in these areas by 32% for wheat crop and by 30% for rice crop (WMRI 2017 a,b).

Regarding water use efficiency, IIPs planned to have positive impact on water use efficiency by improving the conveyance efficiency through changing waterways from open Mesqas to pipelines. They also planned to enhance farmers' irrigation practices as the result of operational and institutional activities. Evaluations results showed that the only positive impact was the improvement of the conveyance efficiency, which saved around 3% of total water supply at the head of the command areas. This amount contributed in improving water availability at the tail end of the Mesqas (El-Gamal 2018a).

IIPs planned to reduce the irrigation cost as well. Aggregating scattered farmers' pumps for collective pumping at the head of the Mesqas was the first step. The second main step was the replacement of the diesel pumps by electric pumps. Regarding the change to electric power, Nour El-Din and Kotb(2006) stated, "Electric pumps option provides 10% savings in the cost of lifting each cubic meter of water when using financial prices. It also provides more than 29% savings under economic prices." WMRI evaluation results showed that the reduction in the irrigation cost after the implementation of IIPs was between 39% & 75% for rice crop, between 40% & 65% for maize crop, ~65% for wheat crop, and between 70% and 85% for sugar beet crop (WMRI 2017 a,b). These studies were conducted in improved areas using the electric power.

### 3.1 STUDYING AREA

El-Atf canal is one of the main branches at the south of Middle Delta (El-Monofiya and Zefta irrigation directorates). The canal is at the end of Dalel El-Atf, short distance of 28.96 km on El-Monofy Rayah (figure 2). El-Atf canal is 48.6 km long and it serves 13,860 ha in three irrigation districts. The canal has twelve branches having command areas between 168 and 840 ha. The first reach of the canal (in Quesina district) is 15.0 km long and it serves around 2,520 ha. In this reach, actual cross sections were not close to the design cross-sections, and there were some small branches dumped their excess water to El-Atf. IIP was implemented along the canal, but it faced many problems in downstream reaches. In the first reach (study area), the improved Mesqas were very steady, and farmers cooperated to improve the situation. They replaced the diesel pumps, with electric pumps. Some farmers connected the improved Mesqas to shallow groundwater besides the surface water to ensure water availability during the whole year. Twelve improved Mesqas, between km 2.7 to km 5.1, were selected for in depth investigation. Selected improved Mesqas serve areas between 18 and 50 hectare. Pumps capacities were between 60.0 & 90.0 l/sec. Some pumps are diesel pumps and the other are electric pumps. The cultivated crops in this area are the traditional crops, such as maize, wheat, Berseem (Alfalfa crop), taro besides some vegetables and some orchards.



**Figure 2.** Schematic drawing for El-Atf canal with a photo for its head regulator.

## 4. RESULTS

### 4.1 Crop Yield

Increasing the yield in the improved areas is normally associated with the improvement of water supply, at the areas that had water crises or that were depending on polluted water before the improvement. This was not the case in the study area, which is the head region of El-Atf canal. The problem of the study area was low water use efficiency. There was a little dependence on shallow groundwater in the study area, but the quality of this source was not bad, and it was only associated with high irrigation cost.

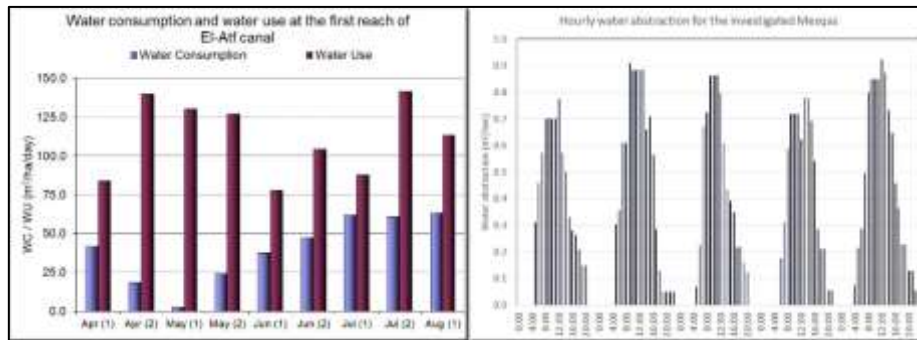
The information collected through a questionnaire from the farmers did not refer to any specific trend of crop yield improvement. Farmers' opinions indicated that the change in the crop yield is random and it is related to agricultural and irrigation practices of different farmers more than being related to IIPs.

### 4.2 Water Use & Abstraction Trends

Improving water use efficiency was the main objective of implementing irrigation improvement projects. However, most of the evaluation results referred to a problem in achieving such target. In the studying area, which represent the head of the canal, water use was considerably high. From figure (3), and considering the period from the beginning of April to the middle of August, irrigation efficiency was around 35%. The big difference could be observed at the second half of April and during May (harvest time). The results refer to the necessity to calculate water requirements precisely and use it as the basis to operate the canal.

Other problem was the weak coordination between farmers. One of the objectives of IIPs was to distribute water abstraction through the day, and stop concentrating the irrigation in specific hours, the trend that has started since using the diesel pumps in 1970's. Most of the evaluation results indicated that these situations were not changed after the implementation of IIPs. Figure (3) presents an example about water abstraction by the investigated Mesqas during five days of June 2018. There was a high concentration between 9:00 AM and 12:00-13:00 PM, and the highest water

abstraction values were between 0.7 to 0.9 m<sup>3</sup>/sec. The average water abstraction was 114.3 m<sup>3</sup>/ha/day.



**Figure 3.** Water consumption & water use in the first reach of EL-Atf (left) & water abstraction by the investigated Mesqas (right)

### 4.3 Irrigation Cost

The improvement project replaced farmers' pumps with single-point lifting at the head of the Mesqas. The original pumps in the improved Mesqas in EL-Atf canal were diesel pumps. In most of the improved Mesqas in the studying area, farmers replaced the diesel pumps with electric pumps. The main reason was to have more than one source to face the energy crises, which escalated during the political instability period (after 2011). However, this had positive impact on reducing the cost.

Most of the evaluation results at different improved areas confirmed that IIPs had a positive impact of reducing the irrigation cost. For the study area, the reduction in the irrigation cost for maize crop was between 25% & 75% with an average of 45.1%. For winter crops, the average reduction in the irrigation costs were 13% for wheat and 35% for Berseem. The reduction in the irrigation cost for wheat was little because the cost in the improved Mesqas is shared based on the served areas regardless of the crops. For crops, that require little irrigation water, and in consequence low irrigation cost, the average value that is shared after the improvement became close to the irrigation cost before the improvement.

Regarding the second step to reduce the irrigation cost, which is the introduction of the electric pumps, an example (Mesqa 18/16) was used to illustrate the difference between the operation costs for diesel pumps and the electric pumps. All diesel pumps in this Mesqa were replaced by electric pumps, and therefore, it was easier to compare the operation cost by the two situations precisely. Figure (5) presents the Mesqa and its electric panels, and table (1) presents the cost of both situations. Due to the rapid change in the energy prices, and to make a right comparison, the current prices of different items were used with the average consumption of these items. In the old situation (diesel pumps), the average diesel consumption was 820 liter/month during 5 months (summer season), and 205 liter/month during 6 months (winter season), and the system was stopped for one month (closing period). In addition, the system was consuming two bottles of oil/month for lubricant during summer months and half bottle of oil/month during winter months. The pumps were maintaining twice annually and the average cost for each maintenance was around 13000 L.E/year. The total cost was 66,365 L.E. The served area of the Mesqa was 50 hectares, and the annual share of each hectare was 1327 L.E. Regarding the electric pumps (current situation), the average electricity charge is 1500.0 L.E/month, and the oil costs around 360.0 L.E/year. Almost, there is no maintenance cost. The served area increased to 52.5 hectares, and the annual share of each hectare was 350 L.E., which is around 26% of the diesel cost. Average irrigation cost for some farmers, who

were not connected to the improved Mesqas, and who were depending on shallow groundwater, was ~ 6500 L.E./ha/year. The actual difference between total costs of diesel and electric pumps might be less than this example because there are common items that have the same costs in both systems like operator wages, and the maintenance of other items (like valves, etc.)



**Figure 4.** The connection of Mesqas (18/16) to the electricity and the electric plates inside the Mesqa (Figure 4 is not necessary and may be deleted)

**Table 1.** The operation cost of Mesqa 18-16 for diesel and electric pumps

Diesel Pumps					Electric Pumps				
	Unit	Amount	Price (L.E)	Total		Unit	Amount	Price (L.E)	Total
Diesel	Liter	5,330	5.5	29,315	Charging	Month	12	1500	18,000
Oil	Bottle	13.0	850	11,050	Oil	Year	1	360	360
Annual Maintenance		2.0	13,000	26,000	Annual Maintenance		0	0	0
Total (L.E)				66,365	Total				18,360
Served area (ha)				50.0	Served area				52.5
Annual irrigation cost (L.E/ha)				1,327	Annual irrigation cost (L.E/ha)				350

Regardless the reduction in the cost with using the electric pumps in comparison to diesel pumps; the dependence on the electric pumps was limited in some Mesqas. As an example, in Mesqa (16/15), using the electric pump was rare 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 (17.6ha), this does not happen frequently, and the diesel pump (the small one) is used during most of the time. In the previous example (Mesqa 18/16), there are three motors: 20.0 HP, which require opening at least eight valves, 15.0 HP, which require opening at least three valves, and 7.5 HP, which could work with only one valve,

## 5. DISCUSSION

Considering the general situation in Egypt, the relation between water and food production seems very critical, and it will be more critical with rapid increase in water demand in the future. Energy came second as a control element for food production. It will affect the food cost, but no problem is expected regarding its availability.

Regarding the impact of irrigation improvement projects on WEF nexus:

- (i) The project could improve the yield in some areas that depend on the polluted drainage water at the tail end of the Mesqas with the improvement of the equity of water distribution through these Mesqas. The impact at the tail end of branch canals is limited. The results expected 6% water saving from improving the conveyance efficiency in both Mesqas and Marwas. With using

this amount instead of using the drainage water, crop yield increased at an average of 30% as indicated in the previous results.

- (ii) There was a reduction in the energy cost after the implementation of IIPs, but the irrigation cost constitutes a small portion of the agricultural inputs. Therefore, the reduction in the irrigation cost has limited impact on the reduction of the food cost. As mentioned before, irrigation cost constitute between 4% and 10% of the agricultural inputs. Considering that IIPs could reduce the irrigation cost by 50% will mean only 2% ~ 5% decrease in total input costs. Through the evaluation of IIPs, farmers rejected the idea to share the irrigation cost (in the improved Mesqas) based on the operation hours instead of cultivated area regardless of the crop and its required water (WMRI 2017a, b). In addition, the results showed that some improved Mesqas in the study area were still depend on the diesel pumps. This indicated that the irrigation cost is not a serious issue for the farmers.

Enhancing the impact of IIPs on WEF nexus will be through improving water distribution in the improved areas. IIPs was conducted with an intention to distribute the water on volumetric basis, However, the real implementation was far from this

## 6. CONCLUSIONS

Producing food with the optimal use of water and energy becomes an essential issue with the fast growing of population and the limitation of water and energy resources. Irrigation improvement projects were a trail to provide a solution for the limitation of water and energy resources.

IIPs had limited impact on improving water use efficiency and crop yields, The impact on reducing the irrigation cost was significant, but the share of the irrigation cost on the total agricultural inputs cost is little

Improving water distribution strategies could be a superior solution in near future to decrease the dependence on the reuse of sewage and industrial waste water, The country is currently taking care of this problem seriously. The final step will the desalination of the seawater, and the technologies to cultivate using saline / brackish water.

## 7. ACKNOWLEDGEMENT:

This research was supported by Science and Technology Development Fund – Egypt (Project # 26318)

## 8. REFERENCES

- El-Gamal, T. T. Evaluating the Improved Irrigation Networks in Egypt. Journal of soil science and agricultural engineering. Mansoura University. Vol. 2 No (8). August 2011
- El-Gamal, T. T. Investigating the Impact of Irrigation Improvement Project on Water Saving. International Journal of Engineering Research and Allied Science (IJERAS). ISSN: 2455 – 9660. Vol. 3. Issue 03. March 2018
- El-Gamal, T. T. Examining an Egyptian Irrigation Network using MASSCOTE Approach. Journal of soil science and agricultural engineering. Mansoura University. Vol.9. No 2. March 2018
- Food and Agricultural Organization (FAO). <http://www.fao.org/egypt/programmes-and-projects/food-loss-waste-reduction/en/>
- Hemdan, G., 1984. Personality of Egypt, vol. 3. PP. 244 & PP. 269 (Arabic)
- Hussein, A. and El Baz, M. Egypt's Natural Gas: Bright Prospects. <https://egyptoil-gas.com/reports/egypts-natural-gas-bright-prospects/>

- Mady, A.M. 2014. The Food Gap in Egypt during the period (2010-2020). Scientific Journal of Business and Environmental Studies (Arabic). Vol. 4. PP. 287-312
- Ministry of Agricultural and Land Reclamation (MALR) - Economic Affairs Sector. Bulletin of the Agricultural Statistics. Summer and Nili Crops 2015-2016. January 2018.
- Ministry of Electricity and Renewable Energy –MEE. Annual Electric Reports. [http://www.moee.gov.eg/english\\_new/report.aspx](http://www.moee.gov.eg/english_new/report.aspx)
- Ministry of Irrigation. Irrigation Development Plan in Egypt. August 1979 (Arabic). PP. 114-115
- Ministry of Water Resources and Irrigation – MWRI. National Water Resources Plan 2017 – 2030 – 2037. July 2017 (Arabic). PP. 15
- Nour El-Din, M. and Kotb, T. Energyfor IrrigationinEgypt'sOldLands. 3rd International Conference on Water Resources in Mediterranean Basin, Tripoli, Lebanon, 1-3 NOV 2006
- Water Management Research Institute - WMRI. Monitoring and Evaluation Program for Integrated Irrigation Improvement & Management Project (IIIMP) –Winter 2016-2017.July 2017
- Water Management Research Institute - WMRI. Monitoring and Evaluation Program for Integrated Irrigation Improvement & Management Project (IIIMP) –Summer 2017.November 2017