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Recent Trends in Irrigation Engineering Using Solar Energy: Review

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EGYPT faces at the present time many major challenges, foremost of which is the limited and scarcity of water resources. Therefore, it is imperative for all workers and specialists in the field of sustainable water management to focus on, adopt and publish how to apply most water-saving technologies suitable for the conditions of the simple Egyptian farmer. Maximizing irrigation water use efficiency is a popular concept used by irrigation project managers. The country has recently paid a great attention to water policy, through the cooperation between the Ministries of Agriculture and Irrigation. The actual implementation has begun in some of governorates, including Ismailia, Suez, Port-Said, the New Valley and Behira as a first stage of replacing the traditional irrigation systems into fully controlled systems. Among the renewable sources of energy especially, in the Arab countries region, solar energy represents a good potential for the sustainable energy applications. Therefore, it is important to establish solar pumping systems for increasing the agricultural reclamation projects. The current case study is done by presenting a theoretical analysis to evaluate the water pumping technique using solar energy under several water demands. The dynamic simulation model output results covered all the performance affected parameters like solar energy input, water demands, and total dynamic head. On the other hand, the economic analysis of the system is also considered.

Keywords: Irrigation systems, Performance evaluation, Solar energy, Water management, Water resources.

Introduction

The available water and energy resources in Egypt are considered the main challenged issues for the sustainable development, especially after constructing Grand Ethiopian Renaissance Dam (GERD). Therefore, the main challenge is to fulfill the required water and energy demands.

Due to the increase in population and development of agricultural projects, the average water consumption per capita has decreased below water poverty line of 1000 m^3/capita/year. It decreased from 2500 cubic meter per person per year in 1950 to 700 cubic meter per person per year in 2015 and the last statistics concluded that it may reach 250 cubic meter per person per year in 2050 (El Gamal & Zaki, 2017; Amer et al., 2017).

In order to bridge the water scarcity gap between supply and demand: measures such as low-quality water recycling, use of shallow saline groundwater and water desalination has to be put under consideration, use of tolerant crops to water shortage and increasing salinity may be included.

Several challenges are representing the barriers to implement the water savings programs. For example, replace the low-quality surface irrigation networks which are old and have a less efficiency by a new micro irrigation system. Some of the suggested solutions to overcome the previously mentioned problems are using water saved from on-farm irrigation and drainage development and changing cropping pattern under water scarcity.

The stability of the limited amount of water is a serious problem with the continuous increase

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in the population. The starting construction of the (GERD) on the course of the Blue Nile threatens the stability of this quantity. This will lead to a sharp decrease in the per capita share of water. Due to the high percentage of water used for agricultural purposes, with a share of 70 to 80% of the total available water resources, there is a continuous need to focus on the efficient and sustainable use of these limited water resources, with the aim of increasing crop production per unit of water.

Egypt is pleased by a good solar radiation with an average values' of 2500kWh/m^2/year and 5.5kwh/m^2/day. The current article is performed to study the feasibility of using solar power irrigation system on sustainable crop production. As per a comparison of using solar energy versus diesel fuel, it is found that solar energy systems have initial cost higher than diesel engine water pumping system. On the other hand, the diesel engines had higher running costs than solar energy systems.

Shinde & Wandre (2015) presented a comprehensive review of a photovoltaic irrigation system as the best alternative methods for irrigation. It is concluded that solar powered automated irrigation system provided a sustainable solution to enhance water use efficiency in the agricultural fields using renewable energy system minimized workmanship that was needed for flooding irrigation. The use of PV-irrigation system contributed to the socio-economic development. When PV system compared to diesel powered pumping systems, the cost of solar PV water pumping system without any subsidy works out to be 64.2% of the cost of the diesel pump, over a life cycle of ten years. In general, photovoltaic pumps are economic compared to diesel pumps up to approximately 3 kWp for village water supply and to around 1 kWp for irrigation. It is concluded that the irrigation pump system should minimized water losses, without imposing significant additional head on the irrigation pumping system and be of low cost.

Belaud et al. (2019) presented several important challenges between the requirements of irrigation and energy. They focused on the importance of energy in the irrigation sector either in applying energy efficiency improvement in the conventional type or maximizing the benefits of using smart irrigation system to minimize the required energy demand.

RCREEE Technical Report (2017), reported the findings of a social study and environmental impacts on using solar energy in the society, it is observed that there is a good potential of applying Solar Power Irrigation System (SPIS) for newly land reclamation. It is considered an ideal solution to minimize the energy demand for irrigation systems and opened good chance for job opportunities.

Mohamed et al. (2017), presented several case studies on water saving in irrigated agriculture in Egypt. They concluded that the main challenge facing irrigated agriculture is to produce more than one type of food using less water per unit of output i.e. increasing water productivity in irrigated land. Therefore, a group of related water usage should be involved in the suggested irrigation system like water management: managers, farmers, workers, policy makers and stakeholders.

Ronak & Madad (2018), presented a comprehensive study for using solar energy as irrigation system for agriculture as an energy and water saving technology. They concluded that the solar smart system will be economical and cost effective. It considered as the best alternative solution to minimize the dependence of electric power supply and by using smart irrigation system lot of drainage wastewater will be minimized.

Shouman et al. (2016), presented an economic analysis for system based on diesel and PV water pumping system for irrigation in Egypt. Also, made a hybrid system PV-diesel and used HOMER software and some theoretical equations to obtain the optimum system. The studies illustrated the economic features of the photovoltaic energy.

Mahmoud & El Nather (2003), illustrated economic analysis of using PV technology in remote areas. The study concluded that using battery is more efficiently water pumping in East Owienat. Cost of water by using PV system is less than diesel system.

Hamidat et al. (2003), presented a system composed of four sizes of PV array and surface centrifugal pump for irrigation in two sites. This study focused on making a small-scale irrigation with pumping system in Sahara Algeria regions for different crops: wheat, potatoes, tomatoes and sunflower. Also, they used a program that use mathematical modeling of evapotranspiration and water need of crops at different heads and PV sizes. They got of system efficiency and found that the tomatoes had higher amount of water needs.

ALKhan et al. (2014), presented economical comparison between diesel and photovoltaic pumping system for twenty-seven crops using submersible pump in Bangladesh and used 5hp for the two systems. They found that diesel rate is unstable, and it is not eco-friendly rather than PV irrigation which is eco-friendly.

Obaideen et al. (2022), highlighted the contribution of smart irrigation using Internet of Things (IoT) and sensory systems. Their study was based on a qualitative design along with focusing on secondary data collection method. Automated irrigation systems are essential for conservation of water. Agriculture and farming techniques is also linked with IoT and automation, to make the whole processes much more effective and efficient. Sensory systems helped farmers better understood their crops and reduced the environmental impacts and conserve resources. Through those advanced systems effective soil and weather monitoring takes place along with efficient water management. Irrigation systems had been determined as positive contributor toward optimized irrigation systems. Some concluded remarks were observed:

- One of the recommendations was linked with the substantial R&D to identify the current inefficiencies in processes and approaches and establish a better technique for better results.

- More focus should be directed towards management and security issues, in deploying Smart irrigation systems. Elements of security strategies and systems played a vital role in operations of irrigation along with the organization.

- Focus on enhancing the sustainable operations and cost reduction. The environmental impacts of the irrigation system should be considered and well aligned with Sustainable Development Goals to achieve ultimate benefit of the three pillars (environment, social, economic).

Raturi (2011), performed a comparative study of using solar energy and diesel engine for water irrigation in rural areas. It is found that the cost of the water was EUR 0.65 per m^3 for diesel engine while the costs for solar energy rural areas were found 30 % lower than those for diesel system.

Zainutdinova & Lutpullaev (2011), studied the possibility of socio-economic development in remote and mountainous areas of Uzbekistan by using solar power. It is concluded that using solar energy is more applicable and efficient.

Cuadros et al. (2004), presented an approach to determine the required size of photovoltaic installation to be used to irrigate the olive crop by drip irrigation which called photo irrigation system in Spain. This method implied by three stages; (i) Determine the soil type, (ii) hydraulic system analysis, (iii) Determine PV peak power.

Glasnovic & Margeta (2007), presented a theoretical study for finding out the optimal design of the solar water pumping systems. The study is based on reducing the size of the solar system as a function of IWR and water quality for several irrigation water pumping systems (DIWPSP) in particular, solar energy, diesel engine and wind energy systems. The studied model is performed for the design of an optimal pumping system for irrigation operates in even more complex conditions.

Dhonde et al. (2022), presented a comprehensive overview focusing on key energy-saving strategies in agriculture farming. The technologies included in their research scope were mainly renewable and sustainable solutions, such as photovoltaic (PV) modules, solar thermal (T), hybrid PV/T collectors, energy-efficient pumping systems, various covering materials for improved thermal insulation and energy generation.

They found that integrating solar-PV technology in farm holdings was extensive and promises to minimize carbon footprints and improve business productivity. Implementing many hybrid technologies resulted in more creativity and versatility in applying PVT technology in almost all farm activities. Finally the concluded that adding cost-efficient strategies with affordable energy storage solutions was needed to increase PV technologies' adoption further.

Based on the previous challenges that facing Egypt in the fields of water and energy limitations, the latest technologies of the solar power irrigation system along with the Egyptian state policy in this field should be implemented.

Some definitions of irrigation engineering

Irrigation engineering

Irrigation engineering is mainly focused on the design and maintenance of irrigation networks, water managements, organizing the distribution of the water natural resources. It also participates in estimating the impact of irrigation in the agricultural sector. Irrigation technologies can be positively contributed to enhance the cultivation and protect the country from water shortage as they implement water saving policy program. The irrigation engineering also covers several tasks like policy planning and system design, solving problems which may found in the agricultural fields concerning either concerning water or land, hydrological systems, the relationship between water, soil and crops, and finally the design and management of canals, dams, and other infrastructure Omran (2017) and Omran et al. (2018).

Water productivity

The relationship between water as input value and agriculture product as output defines the water use efficiency. It can be also expressed as a water use index or the effectiveness relation between irrigation water delivery and water uses shown in Table 1.

Barrett et al. (1999), presented a study of the performance of all types of the irrigation systems (Barrett et al., 1999; Stephens & Hess, 1999), studied the water use efficiency on a generalized irrigation system framework and each element.

Hillel (2000), identified the relative output delivered from a given input by the term efficiency. Depending on the nature of the inputs and outputs, the efficiency can be defined in several ways. A newly term named agronomic efficiency of water use, F_{ag} can be expressed as shown in Equation (1).

$$F_{ag} = \frac{P}{U} \qquad (1)$$

where: P is the crop production, ton/feddan and U is the applied water volume, m^3/feddan.

TABLE 1. Common water use indices (WUI) relating to the application of water to a crop

Input		$\frac{output}{input}$	**Units**
Crop water use indices (WUI)			
Crop Economic WUI	=	$\frac{Gross\ return}{Evapotranspiration}$	$\frac{\$}{min}$
Crop WUI	=	$\frac{Yield}{Evapotranspiration}$	$\frac{kg}{min}$
Irrigation water use indices (WUI)			
Irrigation WUI	=	$\frac{Yield}{Irrigation\ water\ applied}$	$\frac{kg}{ML}$
Gross Production Economic WUI	=	$\frac{Gross\ return}{Total\ water\ applied}$	$\frac{\$}{ML}$
Irrigation Economic WUI	=	$\frac{Gross\ return}{Irrigation\ water\ delivered\ to\ the\ field}$	$\frac{\$}{ML}$
Yield per Drainage volume WUI	=	$\frac{Crop\ Production}{Drainage\ volume}$	$\frac{kg}{ML}$

where:

$\frac{\$}{min}$ = Crop economic ccommon water use index

$\frac{kg}{min}$ = Crop water use index

$\frac{kg}{ML}$ = Irrigation water use index

$\frac{\$}{ML}$ = Gross production economic water use index

Recent trends in managing limited water resources in Egypt

Limited water resources in Egypt

Most of Egyptian areas are desert land. The agricultural lands are formed adjacent to the Nile River banks, main canals, branches and in Nile Delta. It is known that rainfall has very small percent of Egyptian water resources that may reach 200mm in some seasons. Therefore, rainfall cannot be considered a reliable Egyptian water source. Since Egypt is considered as an arid country, where the freshwater availability resources are limited. It can also use different sources of low-quality water in Egypt for example treated agricultural drainage water, which has occurred as the most attractive alternative resource available. Approximately 7BCM/y of drainage water is reused in the Nile Delta directly or indirectly by mixing it with fresh water. The other source to be used in irrigation is treated wastewater of 2.5BCM/y. Another source of water is desalinated saline water and groundwater to be used in Nile Delta and in the desert. The current groundwater extraction is around 5.0BCM/y (Abdel-Shafy & Kamel, 2016).

Water distribution network in Egypt

West Delta is considered one of the biggest areas that withdrawal great attention from the government for the agricultural reclamation extension project after the establishment of Aswan High Dam. The reclaimed land is located in the Nubriya which is being irrigated through Nubriya canal (Fig. 1). In 1952 the added areas by the canal were 77,700 ha, and they were increased to 107,940ha in 1959 and to 172,200ha in 1969. After the installing of Aswan High Dam, it was strategic to increase the area served by the canal to 319,200ha by increasing the capacity. Al-Behery Rayah is going, digging new Rayahats parallel to the lake to feed the Nubriya canal (Nassery Rayah), and exploring a new branch of the Nubriya canal (Al-Nasr canal).

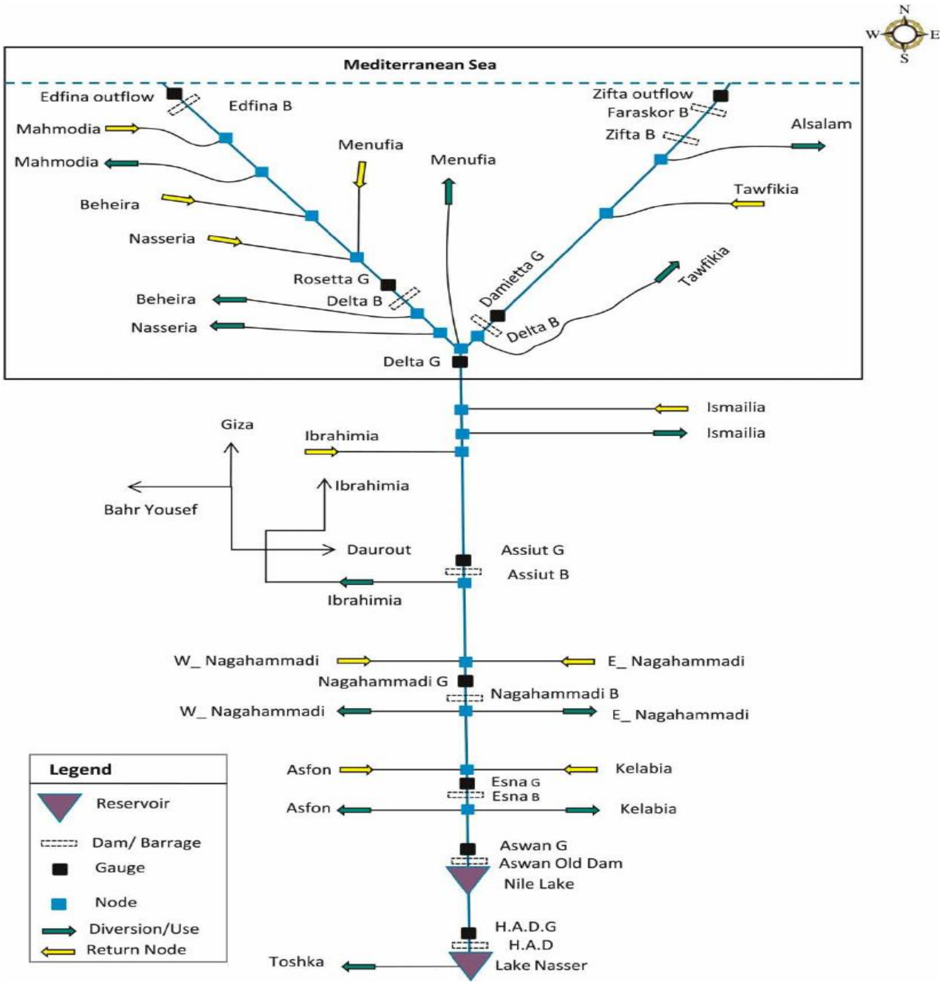

Fig. 1. Main canals of the Egyptian Irrigation Network (El Gamal & Zaki, 2017)

Agricultural expansion in East Delta: The expansion projects in East Delta have been implemented in two areas: Ismailia channel the first, and end of Tawfiqi Rayah was the second one. The Ismailia canal area serving reclaimed area increase from 82,572ha in 1954 to 141,078ha in 1963. The area of expansion in Tawfiqi Rayah was about 10,290 ha. The Mansouriya canal feed point was created for the source of the Zefta Barrages, and the Bahr Moues canal capacity increased from 10.5 to 12.5 MCM/day. Agricultural expansion in the Middle Delta took place in the northwestern part of the Middle Delta. The total cultivated area reached 26,460 ha. The same case in the western delta, it was difficult to increase the capacity of the main feeder (Monofy Rayah) upstream of the Delta Barrage.The requirements increased addressed by increasing the capacity of El-Abase Rayah, Zefta Barrage from 20.5 to 26.0 MCM/ day (El Gamal & Zaki, 2017).

Al-Salam canal: The idea of Al-Salam canal appeared at the end of the Domietta Branch at the source of Faraskur Dam. The canal extends for 78.0km west of the Suez Canal to reclaim 92,400ha. The canal passes through a siphon under the Suez Canal (East of the Suez Canal), the area designed by the Al-Salam canal is 168,000ha (Donia, 2012).

The Toshka Project: Toshka Project, which began in 1997, was planned to reclaim 226,800 ha of land in Upper Egypt in the north and west of Lake Nasser. El-Sheikh Zayed canal was the main channel of the project, which takes its water from the lifting station on the lake; it is the largest lifting station in the Middle East. The length of main channel about 50.87 km, and it has four branches with a total length of 157.5 km. The project still faces some difficulties (El Gamal & Zaki, 2017).

Irrigation engineering systems and energy resources

For fulfilling the world's food requirement, it should be paid attention to the availability of the irrigated lands. Dowgert (2010), reported that about 80% of total cultivated lands in the world using rain fed agriculture as a water resource, supplying about 60% of the world's food; while the remaining 20% of the world's cultivated lands under irrigation that contributing the other 40% of the food supplies.

In order to identify a proper irrigation method, the farmer must know the advantages and disadvantages of those irrigation methods. The farmer should familiarize to select suitable method for his best local conditions. To identify the best irrigation method , a carful techno-economic study of all the already available irrigation technologies should be made.

Irrigation methods

Irrigation methods may be classified into two main types; Surface irrigation and Pressurized irrigation systems (Drip irrigation, surface and subsurface, sprinkler , gun and pivot irrigation systems (Khanna & Malano, 2006; Capra & Scicolone, 2007; Subramani & Prabakaran, 2015; FAO, 2016; El-Kilani & Sugita, 2017). The new agricultural and irrigation policy of the Egyptian government aims at replacing the traditional irrigation systems by micro irrigation system with full control from the uptake water source to plant which has already been applied in several governorates like Ismailia, Port Said, El Wadi El-Gadid, and El-Behairah.

In the light of the current climate changes (high temperatures or limited rainfall), as well as the necessity to face the requirements of the population increasing and the need to reduce the environmental pollution resulting from excessive use of water is negatively affects the properties of the soil and its fertility. The productivity, in terms of quantity and quality, especially, strategic and export crops, crops of agricultural raw materials needed for local industries, as well as medicinal and aromatic plants.

Based on the scientific rule; "**All are not measured are not managed**", The sustainable technologies to develop the use of water resources and raise the water use efficiency lead to use surface or shallow groundwater (up to 60m deep) and actual ground water (from more than 60m) for more than one purpose at a time, such as fish or algae cultivation, which are only beneficiaries and not consuming water. Establishing lined and covered collection ponds to reduce or prevent water losses, provided that these ponds are in the middle of fields and farms to reduce the energy needed to transport and distribute irrigation water, especially, with the high price of energy and its unavailability in marginal and newly reclaimed areas, for the horizontal expansion of the cultivated areas.

Moreover, it can save the costs of establishing and maintaining agricultural drainage networks, reducing environmental pollution, and preserving the health of the Egyptian farmers. In addition to the interest in well-managed automated greenhouses, more efforts are exerted for development of strains and varieties with short lifetime and low water needs, as well as the tolerance of salinity through genetic engineering. Therefore, the government has recently paid a great attention to smart agriculture or digital agriculture while managing water usage and energy are applied.

Managing of energy resources in Egypt

Managing traditional energy sources in Egypt

Solar energy has been through to be a very reliable source of clean energy which can be provided to most of recent areas. It is environmentally friendly source of energy to produce water for irrigation and other purposes. Egypt planned to utilize 1.5 million feddan which will be irrigated from groundwater sources. The best energy source to cover the electric power loads for irrigating pumps is the solar energy because Egypt is blessed by an excellent amount of solar energy falling on horizontal surface with an average value of 5.5kW h/m^2/day. It can cover all the required electric energy needed to power the irrigation systems in the future strategic plan of Egypt. The increasing of the fuel price due to the continuous fade-out of diesel and electricity subsidies provides a great potential of exploiting SPIS in the Egyptian market. The SPIS cost decreased in the recent years due to the advanced technology and the plenty of production rate in the world. Solar water pumping, or photovoltaic water pumping and modern irrigation systems provides an alternative energy source for groundwater pumping. It is found that SPIS can be used for sustainability from the technical, financial, environmental points of views. Several policies are planned to adopt the implementation scenario of using SPIS as an energy source, water governance, and groundwater abstraction regulations and actions. It can be found that the energy options for irrigation and farming activities development is considered one of the main pillars of water, energy and food nexus. Hence, the need of solar pumps is very important issue to make sustainable development of large desert areas that have no infrastructure.

How to promote SPIS in Egypt:

- ▶ The strong political and public support will motivate having a government program.

- ▶ The decentralization and greater control of participants in water user associations will be accepted.

- ▶ Stop the subsidies to the diesel as an energy source.

- ▶ Covering more finance for green energy solutions.

- ▶ Prevailing awareness to farmers for using SPIS.

- ▶ Improve transportation to rural areas.

Egypt energy vision:

- ▶ Providing 20% of the electricity from renewable energy sources by 2022 (New and Renewable Energy Authority, Annual Report, 2018) as shown in Fig. 2.

- ▶ Providing 42% of electricity generated from renewable energy sources by 2035 (New and Renewable Energy Authority, Annual Report, 2018) as shown in Fig. 3.

- ▶ A nexus approach must account for and reduce energy demand across all sectors, through improving energy efficiency, demand management, etc.

Irrigation water in agriculture may be used in crop, fruits, medical herbs production and in fish farms production where the used water in fish farms can be reused in crop irrigation. Greenhouses, which are widely spread in the newly reclaimed deserts areas, adjacent to Nile Delta and valley, depend eventually on fully automated and controlled irrigation water.

Solar energy has been prevailed to be one of the most important clean sources of energy, making for providing energy requested to developing life conditions in the most remote isolated areas, but also in big towns and communities to provide water heating.

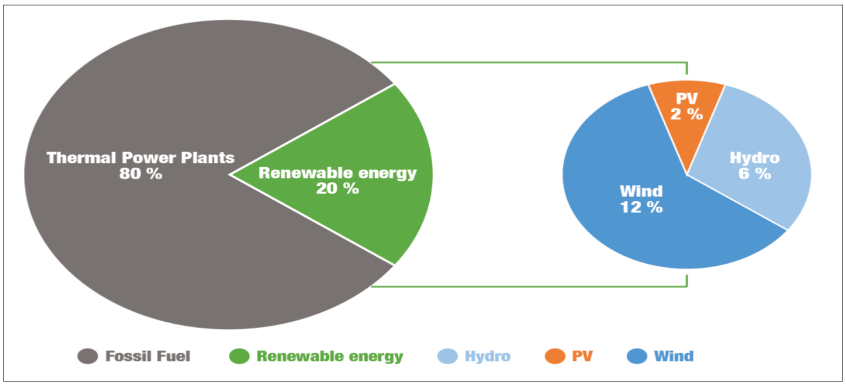

Fig. 2. Electricity generated from renewable energy sources (NREA, 2018)

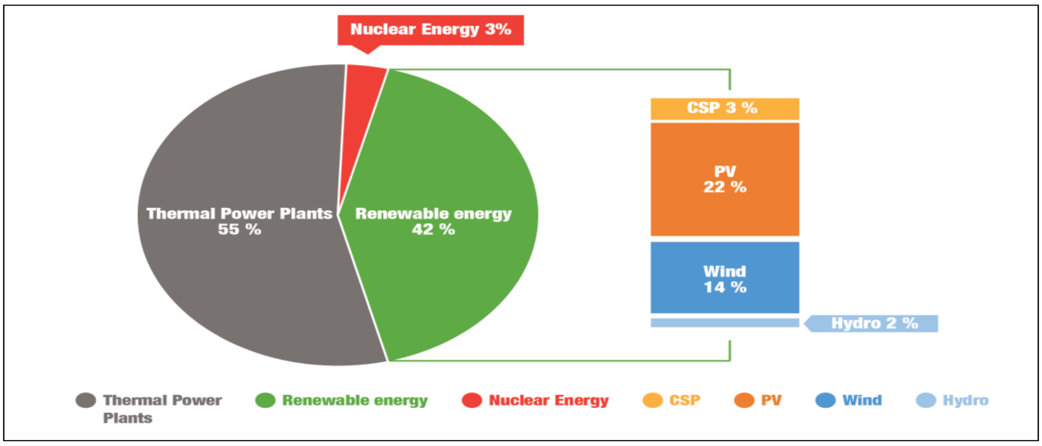

Fig. 3. Electricity generated from renewable energy sources by 2035 (NREA, 2018)

The necessity to apply solar energy technologies appropriate to the Egyptian conditions

Solar energy is the most suitable and applicable renewable sources of energy especially, in the Arab Countries region due to the following reasons:

▶ A plenty of solar energy available throughout Egypt and almost all the Arab Countries. It has about 3500-4000 sunshine hours per year as shown in Fig. 4.

▶ Public interest as thermal and power source of energy.

▶ Use of clean source of energy.

▶ Solar energy equipment has low operating costs.

▶ The need of solar pumps is very important issue to increase development of the desert areas. This can be achieved by the best utilization of solar energy and water resources.

Therefore, it is important to establish solar pumping systems to enhance a good environment for establishing new agricultural societies in the desert areas. The average values of the output electric energy from the photovoltaic panels are varied according to the geographical location as shown in the solar atlas of Egypt shown in Fig. 4.

The principal components shown in Fig.5 in a water pumping system using solar energy include:

- The solar photovoltaic modules associated with its metallic support structure,

- Inverter, and an electric water pump (It is recommended to identify the required information to properly design a PV solar system).

- Site location

- Water demand

- Water storage volume (A storage volume should be designed to be equal to three times the daily water pumping

- Technical information for solar water pumping system

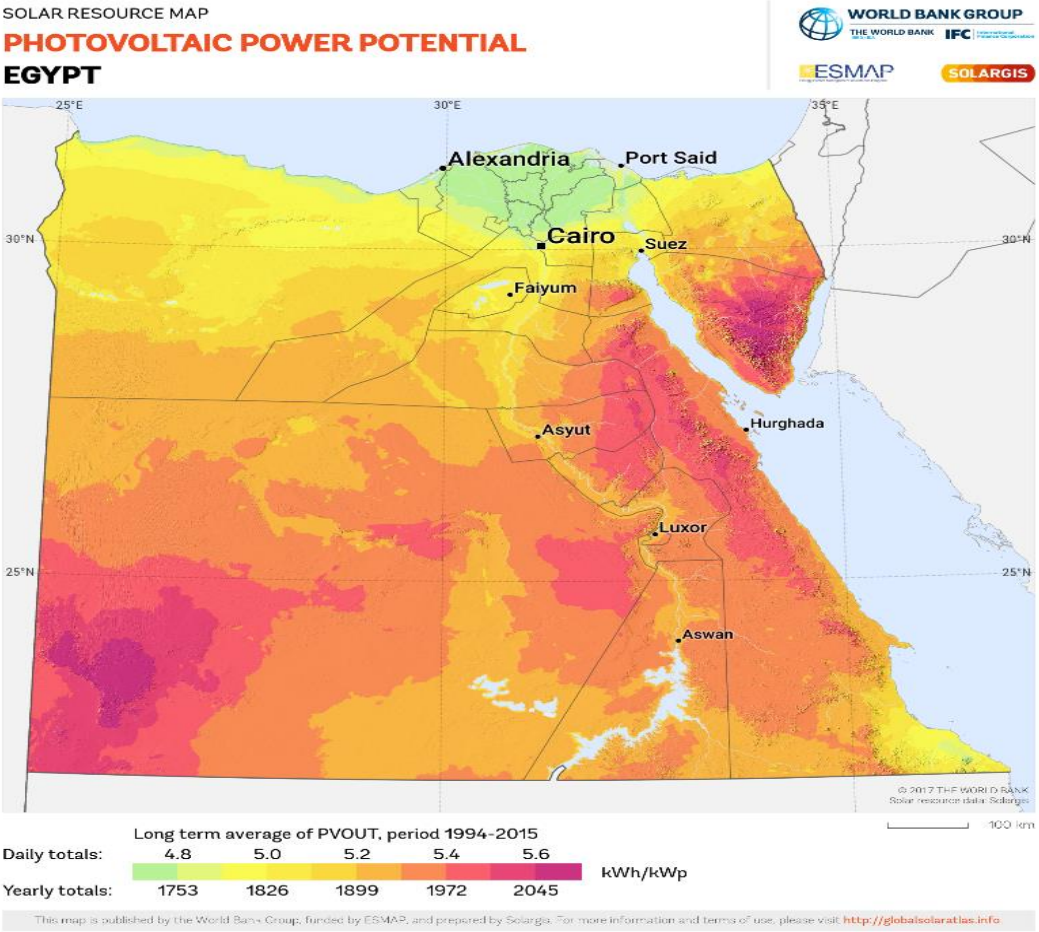

Fig. 4. Photovoltaic power potential map of Egypt (NREA, 2018)

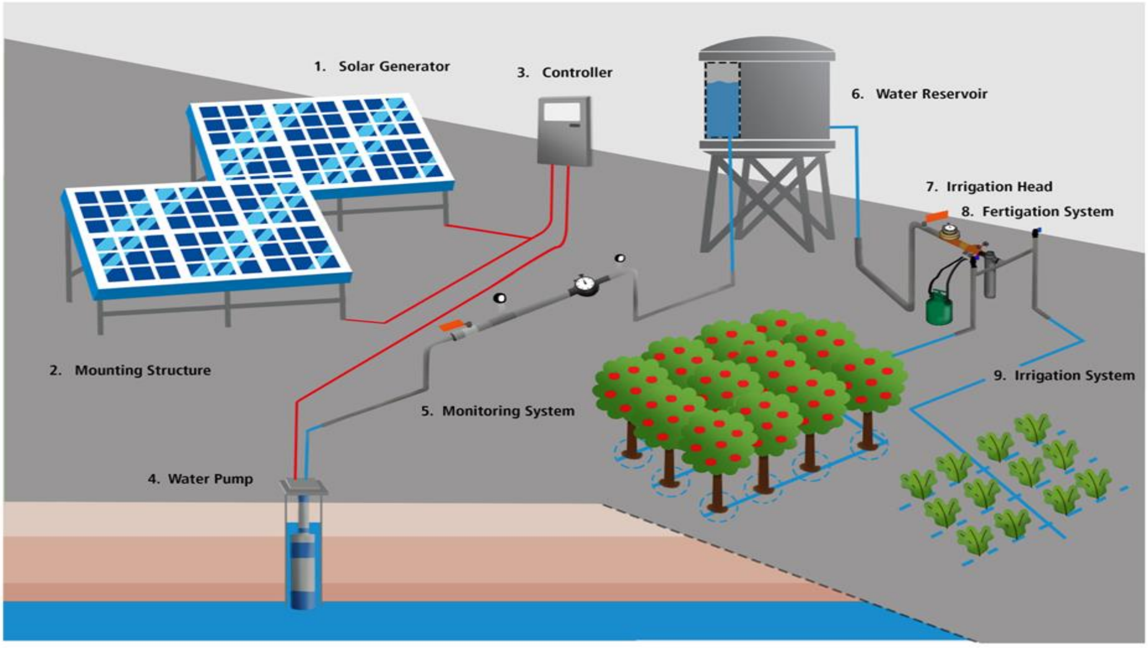

Fig. 5. Principle components in SPIS (Okasha et al., 2020)

Design of the solar water pumping system

To design and successfully applying solar water pumping systems, one should be aware of several concepts (Jenkins, 2014). These includes:

- Sunlight availability, which depends on location and climate conditions.
- Total Dynamic Head that include the static suction head, friction loss head, and the delivery head.
- Area to be covered.
- Water demand such as drinking for human or animal, industrial applications and irrigation, etc.
- Hydraulic components system such as pump, pipe, fitting, etc.
- Water Storage tanks such as elevated, ground, or underground tanks, concrete or plastic storage tanks, etc.
- Photovoltaic components system that driving pumping system such as solar panel, inverter, cable, etc.
- Costs such as initial, operation and maintenance, labor, life cycle, etc.

Several design criteria should be identified for sizing of the solar water pumping system (Lowder et al., 2014) which are:

- The availability of the site-specific solar energy.
- The Total Dynamic Head.
- The water demands.
- The piping system.
- Overall cost of SWPS.

To eliminate the solar radiation and the wind velocity fluctuations, a combination between photovoltaic power and wind turbines is suggested which is more reliable but complex water pumping system, (FAO, 2016).

Design of a solar power irrigation system

Water pumping systems using solar energy is a good solution in Egypt as it enjoys availability with a large daily solar radiation of about 5.5 kW h/m^2/day which is considered as a clean source of energy. The present work proposes a theoretical analysis of a solar water pumping system for several water demands.

Calculation of the water demand: Water demand calculation depends on a lot of different factors like user identity (human, kind of animal, kind of plant). The average water consumption for several activities per person and per a certain kind of animal is estimated as shown in Equation (2) (Darouich et al., 2014):

$$Q = Q_{HC} + Q_{AC} + Q_{AGC} + Q_{OC} \tag{2}$$

where: Q: Total water demand per day (m^3 / day), Q_{HC}: Daily water demand for Human Consumption, (m^3 / day), Q_{AC}: Daily water demand for Animal Consumption, (m^3 / day), Q_{AGC}: Daily water demand for Agriculture Consumption, (m^3/ day) and Q_{OC}: Daily water demand for other Consumption, (m^3 / day).

Calculating the total dynamic head: It is the summation of the total static head, the total delivery head, and the total friction head losses. The system can be designed based on two cases. The first case is direct feed irrigation system as shown in Fig. 6 while the second one is the tank irrigation system as shown in Fig. 4.

The TDH of the direct feed irrigation system can be calculated as shown in Equation (3):

$$TDH = H_s + D + H_e + H_m + H_f + H_l + H_{irr} \tag{3}$$

where: TDH= Total dynamic head, H_s= Static water level (for submersible pumps) or suction lift (for surface pumps), D= Drawdown (the lowering of the water level in a man –made reservoir or tank), H_e= Elevation difference well to tank stand, H_m= Head loss in flowmeter, H_f= Head loss in filter, H_l = Head loss in pipeline, H_{irr}= Pressure irrigation system.

While The TDH of the tank system irrigation shown in Fig. 7 can be calculated as shown in Equation (4)

$$TDH = H_s + D + H_e + H_t + H_m + H_f + H_l \tag{4}$$

where: H_t= Height of tank water inlet from ground, H_o= Height of tank water inlet, H_{tank} = Head of water tank, H_{fi}= Head Loss in pump pipe line fittings.

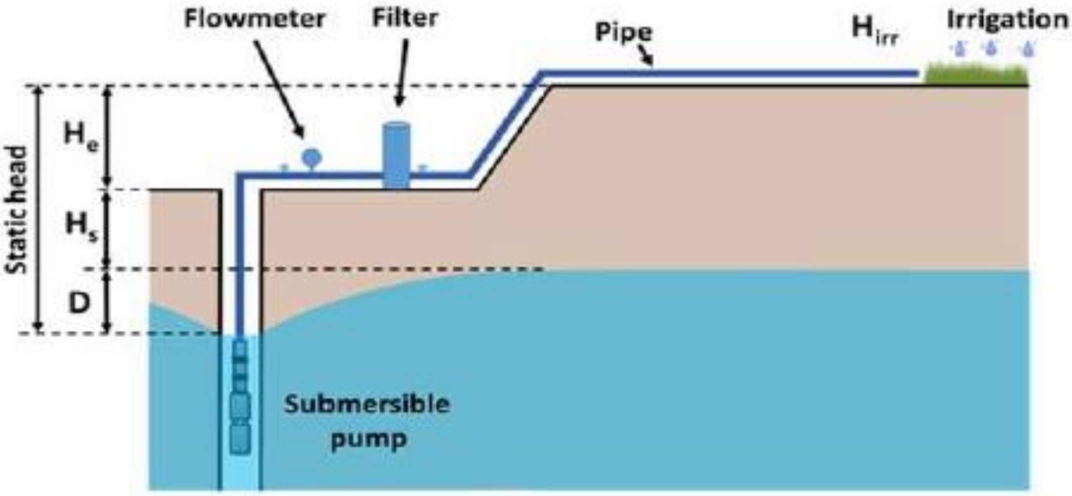

Fig. 6. Direct feed irrigation system

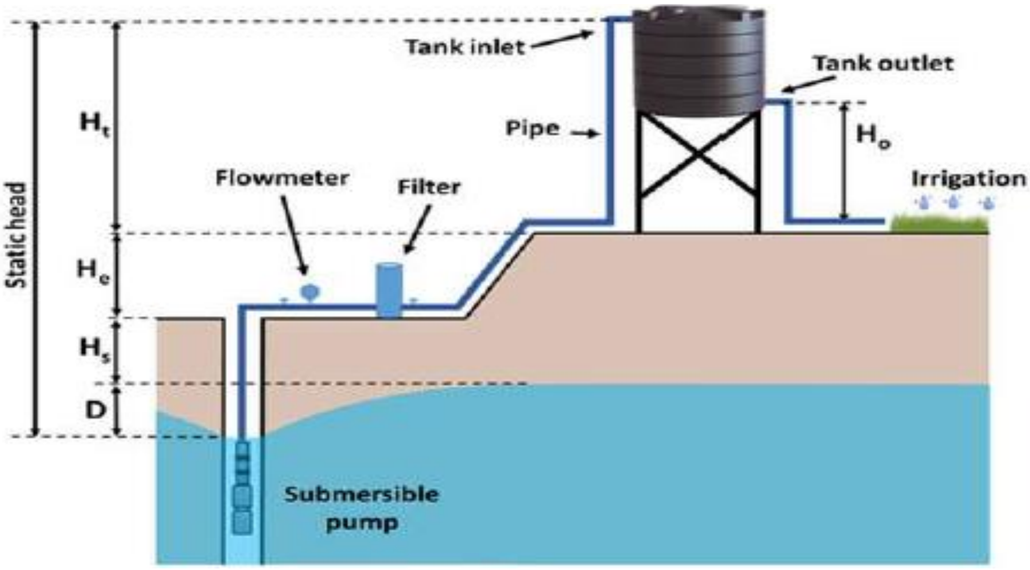

Fig. 7 Tank system irrigation

Pumps and motor selection: The pumps used in solar water pumping systems are categorized as either positive displacement pumps (e.g., diaphragm, piston, or helical rotor) or dynamic pumps (centrifuge or axial). It can be selected using the manufacture pump performance curves.

Hydraulic power (*Ph)*

It can be estimated as shown in Equation (5):

$$P_h = Q \ \rho_w g \ TDH \qquad (5)$$

where: ρ_w is density of water (1000 kg/m^3), g is acceleration due to gravity (9.81 m/s^2), and Q is flow rate or volume of water lifted per second in m^3/s.

Storage tanks: A water storage tank is important component element in SWPS. It is recommended that the tank should be sized to store at least a three-day water supply. In case of using large volume of water to be stored, multiple tanks may be recommended, Shinde and Wandre (2015). After calculating total water demand, it's easy to determine size of water tank considering the number of days for strategic stock, also can decide the shape of tank (circular, rectangular or spherical tanks) and type of the tank (ground, elevated or underground tanks). According to number of emergence days, the tank size can be estimated, V_t (m^3) as shown in Equation (6):

$$V_t = Q \ X \ D_e \qquad (6)$$

where: Q is total water demand per day (m^3 / day), D_e is number of emergence day (day).

Estimating the system land requirements: The required area of the PV system in Wp can be defined as shown in Equation (7) (Okasha et al.,, 2020).

$$APV = \frac{EL}{H \times \eta_{pv} \times \eta_{inv} \times \eta_B \times \eta_{cc} \times T_c} \quad ......(7)$$

where: A_{pv} PV modules area (m^2), E_L Daily electrical energy required (Wh/day), H Daily solar irradiation ($Wh/m^2/d$), η_{pv}, η_B, η_{cc} is efficiencies for PV modules, inverter, battery and charge controller, respectively, and T_c is temperature correction factor of the PV module.

Sizing the PV modules capacity (kW): The required PV modules power (W), to meet the electric load demand can be estimated as shown in Equation (8):

$$P_{pv} = A_{PV} \times Hsc \times \eta_{PV} \quad (8)$$

where: H_{sc} = Standard solar irradiation, 1,000 W/m^2.

The number of total PV modules () can be estimated based on the commercially available area of a single PV panel. The number of modules can be defined as shown in Equation (9):

$$N_m = \frac{PPV}{P_m} \quad (9)$$

where: is the power of the single module (W).

To calculate the actual area of all modules, and exact peak power for the total modules, , shown in Equation (10 and 11):

$$A_t = N_m \times A_m \quad (10)$$

$$P_t = N'_m \times P_m \quad (11)$$

where: A_m is Area of the single module (m^2), and N'_m is the corrected number of modules to the nearest integer number

Case studies of solar power irrigation systems

Several calculations are done on different water requirements, total dynamic heads, then the solar water irrigation system is designed and the following output results are declared:

- The hydraulic pump power in kW and in hp

- The solar panel surface area (m^2)

- The solar panel electric power (kW)

Input data

The input data shown in Table 2 represent the values of solar radiation and the details of a sample total dynamic heads calculations.

Output data

The output data is calculated based on two values of total dynamic heads and different values of daily water pumping rate as shown in Table 2 and Table 3. It includes hydraulic pump power in kW, solar panel surface area, m^2, solar panel electric power, kW, and Solar system cost, L.E.

The variations of solar panels surface area and electric power versus daily water requirements values are shown in Fig. 8. While the variations solar panels power and hydraulic pump power versus daily water requirements values are shown in Fig. 9.

TABLE 2. System input data

No.	Item	Value
1	Daily Solar Irradiance	5kWh/m^2/day
2	Pump pipeline diameter	2 inches
3	Pump pipeline length	200m
4	Static Water Level	20m
5	Drawdown	5m
7	Head Loss in Flowmeter	2m
8	Head Loss in Filter	2m
9	Head Loss in Pipeline	2m
10	Pressure head Irrigation System	9m

TABLE 3a. Output calculation data for total dynamic head = 50m

No.	Daily water pumping rate (M^3/day)	Hydraulic pump power in kW	Solar panel surface area (m^2)	Solar panel electric power (kW)	Solar system cost (L.E.)
			Total Dynamic Head = 50m		
1	25	0.63	5.2	1	7,500
2	50	1.26	10.4	1.87	14,025
3	75	1.89	15.6	2.8	21,000
4	100	2.55	20.8	3.75	28,125
5	150	3.78	32	5.65	42,375
6	200	5	41.5	7.5	56,250
7	300	7.6	62.5	11.25	84,375
8	400	10	83	15	112,500
9	500	12.62	104	18.75	140,625
10	1000	25.23	208	37.5	281,250

TABLE 3b. Output calculation data for total dynamic head = 100m

No.	Daily water pumping rate M^3/day	Hydraulic pump power in kW	Solar panel surface area (m^2)	Solar panel electric power (kW)	Solar system cost (L.E.)
			Total Dynamic Head = 100 m		
1	25	1.3	10.5	1.87	14,025
2	50	2.5	21	3.74	28,050
3	75	3.78	31	5.6	42,000
4	100	5	41.5	7.5	56,250
5	150	7.6	62.5	11.25	84,375
6	200	10	83.1	15	112,500
7	300	15	125	22.5	168,750
8	400	20	166	30	225,000
9	500	25	208	37.5	281,250
10	1000	50	415	75	562,500

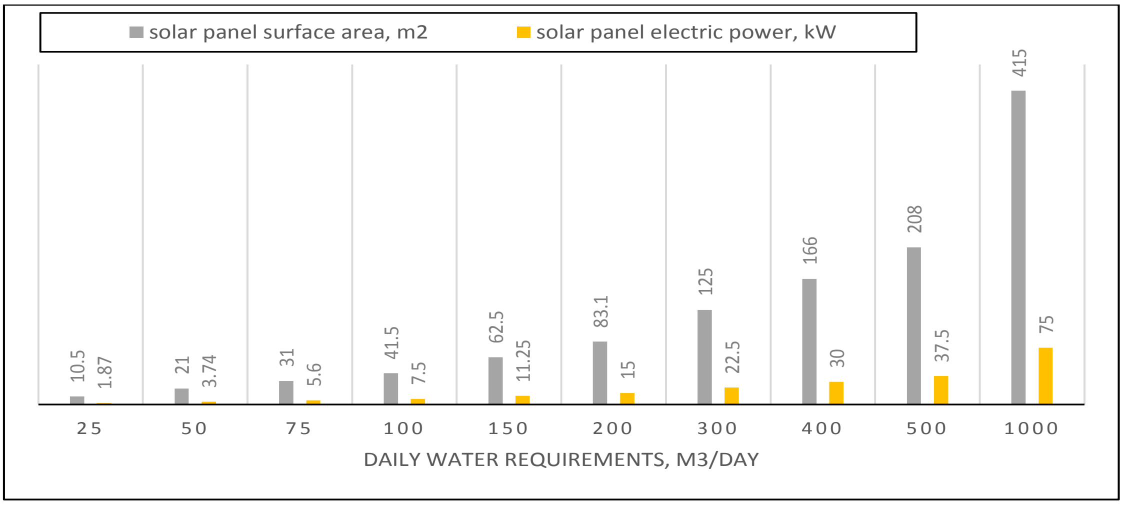

Fig. 8. Solar panels surface area, electric power versus daily water requirements values

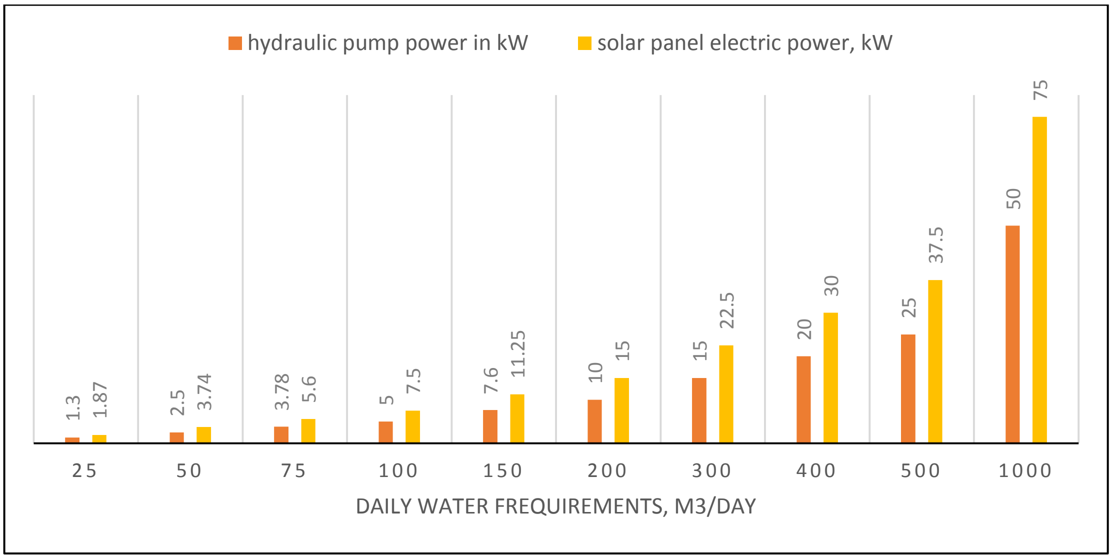

Fig. 9. Solar panels power and hydraulic pump power versus daily water requirements values

Conclusion

It could be concluded that for sustainable agriculture, the water pumping technique using solar energy under several water demands should be evaluated. The dynamic simulation model output results covered all the performance affected parameters like solar energy input, water demands, and total dynamic head. On the other hand, the economic analysis of the system should be also considered.

References

Abdel-Shafy, H.I., Kamel, Aziza H. (2016) Groundwater in Egypt issue: resources, location, amount, contamination, protection, renewal, future overview. *Egyptian Journal of Chemistry*, **59**(3), 321- 362.

ALKhan, M.T., Sarkar, S., Hossain, S., Ahmed, A.U., Pathik, B.B. (2014) The feasibility study of solar irrigation: Economical comparison between diesel and photovoltaic water pumping systems for different crops. *2013 International Conference on Electrical Information and Communication Technology (EICT)*. IEEE.

Amer, M.H., Abd El-Hafez, S.A., Abdel Ghany, M.B. (2017) "*Water Saving in Irrigated Agriculture in Egypt*", LAP, Lambert Acdemic Publishing, 216p.

Barrett, P. and Associates (1999) Determining a framework, terms and definitions for water use efficiency in irrigation. *Report to Land and Water Resources Research and Development Corporation,* September 1999. 26p. Land & Water Australia, www.lwa.gov.au

Belaud, G., Mateos, R., Aliod, M.C., Buisson, E., Faci, S., Gendre, G., et al. (2019) Irrigation and energy: issues and challenges, irrigation and drainage· *Irrigation and Drainage*, **69**(Suppl. 1), 177–185 Doi: 10.1002/ird.2343

Capra, A., Scicolone, B. (2007) Recycling of poor quality urban wastewater by drip irrigation systems. *Journal of Cleaner Production*, **15**(16):1529–1534. https://doi.org/10.1016/j.jclepro.2006.07.032

Cuadros, F., Rodrıguez, F.L., Marcos. A., Coello, J. (2004) A procedure to size solar-powered irrigation (photoirrigation) schemes. *Solar Energy*, **76**, 465-473.

Darouich, H.M., Pedras, C.M.G., Gonçalves, J.M., Pereira, L.S. (2014) Drip vs. surface irrigation. A comparison focusing on water saving and economic returns using multi-criteria analysis applied to cotton. *Bio systems Engineering,* **122**, 74-90.

Donia, Noha S. (2012) Development of El-Salam Canal automation system. *Journal of Water Resource and Protection,* **4**, 597-604.

Dowgert, M.F. (2010) The impact of irrigated agriculture on a stable food supply". In: *Proceedings of the 22nd Annual Central Plains Irrigation Conference,* Kearney, NE. Irrigation Direct Canada, IDC, www.irrigationdirect.ca

El Gamal, T., Zaki, N. (2017) “*Egyptian Irrigation After the Aswan High Dam*”. Springer International Publishing, p. 34. DOI: 10.1007/978-3-319-30216-4_4.

El-Kilani, R.M.M., Sugita, M. (2017) Irrigation methods and water requirements in the Nile Delta. In: "*Irrigated Agriculture in Egypt, Past, Present and Future*", (Chapter 6), pp. 125-151.

FAO (2016) AQUASTAT-FAO’s information, Regional report. Egypt, FAO, Rome, pp. 175- 196.

Glasnovic, Z., Margeta, J. (2007) A model for optimal sizing of photovoltaic irrigation water pumping systems. *Solar Energy*, **81**, 904-916.

Hamidat, A., Benyoucef, B., Hartani, T. (2003) Small-scale irrigation with photovoltaic water pumping system in Sahara Regions. *Renewable Energy*, **28**, 1081-1096.

Hillel, D. (2000) Improving water-use efficiency. In: "*Small-scale Irrigation for Arid Zones: Principles and Options*", Chapter 3, pp. 13-18. FAO Development Series No. 2. ISSN: 1020-0819.

Jenkins, T. (2014) Designing solar water pumping systems for livestock. Circular 670, College of Agricultural, Consumer and Environmental Sciences College of Engineering Water Management, **40**, 3-13.

Khanna, M., Malano, H.M. (2006) Modelling of basin irrigation systems: a review. *Agricultural Water Management,* **83**(1), 87–99.

Lowder, S.K., Skoet, J., Singh, S. (2014) What do we really know about the number and distribution of farms and family farms in the world. *ESA Working Paper* No. 14-02. Food and Agriculture Organization of the United Nations, Rome.

Dhonde, M., Sahu, K., Murty, V.V.S. (2022) The application of solar-driven technologies for the sustainable development of agriculture farming: a comprehensive review. *Reviews in Environmental Science and Bio/Technology,* **21**, 139–167. https://doi.org/10.1007/s11157-022-09611-6

Mahmoud, E., El Nather, H. (2003) Renewable energy and sustainable developments in Egypt: photovoltaic water pumping in remote areas. *Applied Energy*, **74**, 141-147.

Mohamed, H.A., Sayed, A.A., Mohamed, B. (2017) Water saving in irrigated agriculture in Egypt (case studies and lessons learned). LAP LAMBERT Academic Publishing, ISBN: 978-620-2-02402-0.

New and Renewable Energy Authority (NREA) (2018) Annual Report.

Obaideen, K., Bashria A.A., Yousef, Maryam N., AlMallahi, Yong Chai Tan, et al. (2022) An overview of smart irrigation systems using IoT. *Energy Nexus*, **7**, 100124, ISSN 2772-4271, https://doi.org/10.1016/j.nexus.2022.100124

Okasha, E.M., El-Awady, M.H., El-Ghetany, H.H., (2020) Integrated solar power system for greenhouses irrigation using treated surface mixed water, Delta, Egypt. *Egyptian Journal of Chemistry,* **63**(10), 4017-4027.

Omran, E.S.E. (2017) Cloud-based non-conventional land and water resources for sustainable development in Sinai Peninsula, Egypt. In: "*The Handbook of Environmental Chemistry*". Springer, Berlin. https://doi.org/10.1007/698_2017_63.

Omran, E-S.E., Negm, A., Abdel-Fattah, S. (2018) Environmental impacts of the GERD project on Egypt’s Aswan high dam lake and mitigation and adaptation options, pp. 175- 196.

Raturi, A. (2011) Feasibility study of a solar water pumping system. *Applied Solar Energy,* **47**(1), 11-13.

RCREEE (2017) Market Assessment Study of Socio-Economic Impacts for Solar Pumping Systems in terms of Local Job and Value Creation in Egypt. The Regional Center for Renewable Energy and Energy Efficiency”. (RCREEE) Technical Report.

Ronak, A.B., Madad, A.S. (2018) Solar powered irrigation system for agriculture based on moisture content in the field and saving energy and water with optimum designing. *Asian Journal of Engineering, Sciences & Technology,* **8**(1), 11-13.

Shinde, V.B., Wandre, S.S (2015) Solar photovoltaic water pumping system for irrigation: A review, *African Journal of Agricultural Research*, **10**(22), 2267-2273.

Shouman, E.R., El Shenawy, E.T., Badr, M.A. (2016) Economics analysis of diesel and solar water pumping with case study water pumping for irrigation in Egypt. *International Journal of Applied Engineering Research,* **11**(2), 950-954.

Stephens, W., Hess, T. (1999) Systems approach to water management. *Agricultural Water Management,* **40**, 3-13.

Subramani, T., Prabakaran, D.J. (2015) Uniformity studies and performance of sprinkler and drip irrigation. International Journal of Application or Innovation in Engineering & Management (IJAIEM), **4**(5), 284–293.

Zainutdinova, Kh.K., Lutpullaev, S.L. (2011) Solar power and the possibility of socio-economic development in the remote and mountainous areas of Uzbekistan. *Applied Solar Energy*, **47**(4), 327-335.

الاتجاهات الحديثة لهندسة الرى بإستخدام الطاقة الشمسية

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تواجه مصر في الوقت الحاضر العديد من التحديات الرئيسية، في مقدمتها محدودية وندرة الموارد المائية. لذلك من الضروري لجميع العاملين والمتخصصين في مجال الإدارة المستدامة للمياه التركيز على نشر كيفية تطبيق معظم تقنيات توفير المياه المناسبة لظروف المزارع المصري البسيط. يعد تعظيم كفاءة استخدام مياه الري مفهومًا شائعًا يستخدمه مديرى مشاريع الري. أولت الدولة مؤخرًا اهتمامًا كبيرًا بالسياسة المائية، من خلال التعاون بين وزارتي الزراعة والري. وقد بدأ التنفيذ الفعلي في بعض المحافظات مثل الإسماعيلية والسويس وبورسعيد والوادي الجديد والبحيرة كمرحلة أولى لاستبدال أنظمة الري التقليدية بأنظمة خاضعة للتحكم الكامل. تعتبر الطاقة الشمسية من أهم مصادر الطاقة المتجددة وقابليتها للتطبيق خاصة في الوطن العربى. لذلك من المهم إنشاء أنظمة ضخ تعمل بالطاقة الشمسية لاستخدامها في إنشاء مجتمعات زراعية جديدة في المناطق الصحراوية والمناطق الزراعية ذات الحيازات الصغيرة. تتم الدراسة الفنية الحالية باستخدام نموذج رياضي وتقييم أداء لنظام ضخ المياه بالطاقة الشمسية لمقننات المياه المختلفة من خلال نظام تصميم شامل. بحيث توفر نتائج التصميم العديد من الاحتياجات المائية والقدرة الكهربائية المناظرة للارتفاع الديناميكى للمضخة، والطاقة الكهروضوئية القصوى المطلوبة، ومساحة الخلايا الفوتوفولطية والتكلفة الإجمالية لمكونات النظام.