Current Applied Science and Technology e-ISSN: 2586-9396

Curr. Appl. Sci. Technol. 2025, Vol. 25 (No. 3), e0258101

Review article

Sustaining Productivity of Egyptian Water Resources Under Climate Changes – A Review

Sayed Abdelrahman Abdeen*

Soils and Water Department, Faculty of Agriculture, Al-Azhar University, Cairo, Egypt

Received: 23 March 2023, Revised: 21 June 2024, Accepted: 12 December 2024, Published: 27 January 2025

Abstract

One of the biggest economic and social concerns of the century will be the issues of water resources in the arid regions of the Mediterranean, where mismanagement of water resources is a threat to sustainable development. Egypt is one of the nations that will face significant issues due to its steady portion of the Nile water. Climate change influences the spatial and temporal distribution of water supplies and the amount of crop evapotranspiration. In addition, water use in agriculture is by far the highest and is frequently criticized as being the least efficient. So, gaining more output per unit of utilized water is the idea behind improving agricultural water productivity. Identifying water resources and improving water productivity techniques are essential in making the most effective use of agriculture in the Mediterranean regions. Freshwater resources in Egypt include the flow of the Nile, precipitation, and groundwater. Egypt also uses a variety of low-quality water sources including treated wastewater and agricultural drainage water, and desalination is also utilized to provide residential water for several regions along the Mediterranean and Red Sea coasts. In this paper, water resources in Egypt, its irrigation systems, methods of water-saving and improving water productivity are discussed.

Keywords: water resources; climate changes; Egypt

1. Introduction

Egypt, which depends mostly on the Nile River for its water supply, is experiencing water stress as a result of scarce water resources, increased population, and water competition with countries in the upper Nile Basin. Climate change affects the flow of the Nile and presents another challenge for Egypt water resources (Abd Ellah, 2020). Egypt is known for having a dry climate, little rainfall, and most of its area is covered by desert, and unreliable water supplies (Allam & Allam, 2007). The total land area of Egypt is about 1 million km^2 (238 million feddans). About 8.6 million feddans of the total land area is cultivated, the majority of which is made up of recently reclaimed ground. Between 80 and 85% of the yearly water supply is used for agriculture, which is largely sourced from the Nile (Cooper et al., 2007). The Nile Delta, which is situated between the Damietta east tributary and Rosetta tributary on the west, and the narrow strip along the river Nile, where

*Corresponding author: E-mail: dr.sayedabdeen@azhar.edu.eg
https://doi.org/10.55003/cast.2025.258101

the majority of Egypt's agricultural land is concentrated, together account for less than 4% of the country's total area. Freshwater scarcity and misuse are a severe and growing challenge to environmental conservation and sustainable development (Medany et al., 2001). Nearly 98% of Egypt's freshwater supplies come from sources outside of its borders. The Nile River meets more than 95% of the nation's needs for various types of water (Abdin & Gaafar, 2009). Recent challenges pose a great danger to Egypt's water security, with the impact of the Ethiopian Renaissance Dam standing out (Mulat & Moges, 2014). Additionally, population growth must be taken into consideration because urbanization, economic expansion, and population growth have all reduced the amount of commercially viable water resources in the area (Hamdy, 2007). Egypt seems to be especially sensitive to climate change, particularly given its issue with water scarcity. Climate change will have an impact on how water resources are distributed both spatially and temporally, and will also increase crop evapotranspiration (Khalil et al., 2016). It is important to understand the effects of climate on many management decisions, including crop selection, sowing season, and fertilizer application rate (Sadras & McDonald, 2012). Globally, the problem of water scarcity is enduring and getting worse, particularly in areas where water resources are being exploited for irrigation. According to climate change estimates, there would be an increase in evapotranspiration rates, which will have an impact on withdrawals and water stress. According to the FAO, agricultural water requirements will grow by 17% by 2050 under "business as usual" circumstances and by nearly 30% when climate change is taken into consideration, including projected expansions in irrigated areas. Climate change could result in a doubling of withdrawals by 2050 if the current water use efficiency (WUE), expressed as a ratio of crop water consumption to water withdrawals, stays around 50% (FAO, 2021).

Almost half of the world's population presently experiences acute water scarcity for at least some of the year due to climatic and non-climatic variables (IPCC, 2022). Developing nations, notably those in Africa, are most at danger of suffering severe climate change-related consequences. Climate variability is one of the constrains on achieving crop water productivity level particularly in water-scarce locations (Wallace, 2000). However, a practical approach to Egypt's water crisis consists of only bettering management and distribution procedures as well as modernizing and upgrading water supply systems. Development and management of water resources must be in harmony with energy policies and strategies for efficient resource conservation (Abou-Hadid, 2006). Enhancing water productivity in water-scarce regions requires a change in agriculture practices and irrigation techniques. On-farm water-productive methods in combination with better management will significantly increase water productivity (Waraich et al., 2011). Food production must be dependent on increasing irrigation and water use efficiency to support this expanding population. Researchers have demonstrated that significant and long-lasting increases in water production are possible by utilizing integrated approaches to managing natural resources (Oweis & Hachum, 2006). One of the most important and fundamental components for the development of crops is water. The agriculture industry must concentrate on increasing irrigation water productivity in order to increase crop yield and close the food gap (Darwesh, 2018). As Egypt is facing many challenges, there is a pressing need to improve water efficiency and supplement the current water sources with more sustainable alternatives. Therefore, this paper is overviewed on water resources and methods of improving irrigation water productivity in the soils of Egypt as a case study of arid and semi-arid regions.

2. Water Resources in Egypt

The main difficulty is to address the issue of the rapidly growing hole among the scarce water supplies and the growing demand for freshwater since the Egyptian water resources system is complex and uncertain (Figure 1). The traditional sources of water in Egypt are the inflow of the Nile River, groundwater, and rainfall. However, using wastewater and desalinating seawater are examples of unconventional water supplies (Djuma et al., 2016). The yearly per capita use of renewed freshwater in 2015 was 650 m^3, which is much less than the 1,000 m^3/year water scarcity criterion. Nearly 98% of the country's freshwater resources, like the Nile River and underground aquifers, are found outside of its borders. In fact, 93% of the country's water needs are met by the Nile River. An estimate of the overall volume of deep groundwater is around 40,000 billion m^3. The average amount of rainfall in Egypt is primarily concentrated in the north, totaling about 1.3 billion m^3 every year (El-Fellaly & Saleh, 2004).

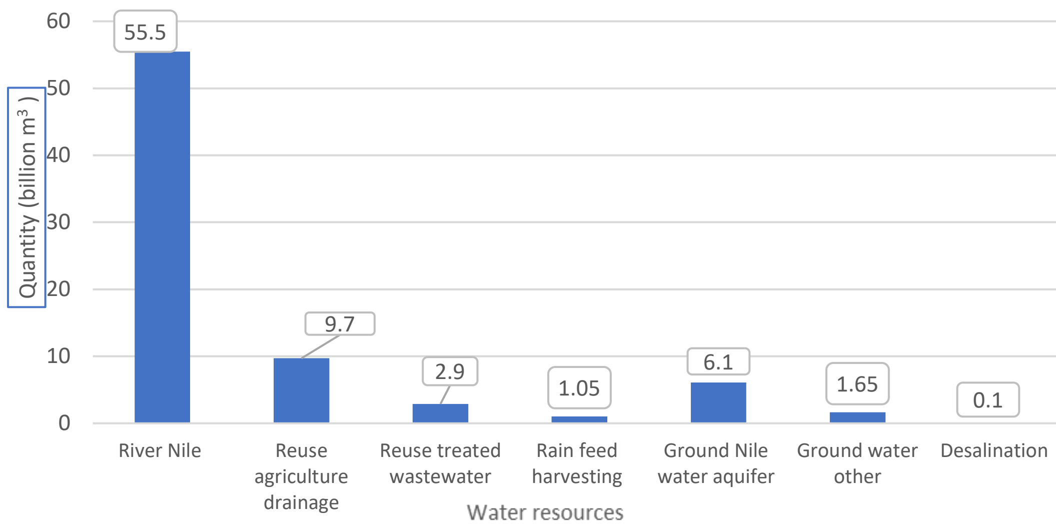

Figure 1. Water resources in Egypt (billion m^3) (Ministry of water resources and irrigation, MWRI) (Abd Ellah, 2020)

2.1 Nile water

The Nile River originates (Figure 2) in the center of Africa and flows through the nations of Tanzania, Burundi, Rwanda, Kenya, Congo, Uganda, Ethiopia, Eretria, South Sudan, Sudan and Egypt (Muala et al., 2014). The Blue Nile (59%), Sobat (14%), and Atbara (13%) contribute 86% of the Nile's flow, while the White Nile contributes 14%, both river systems originate in the Ethiopian Plateau (Swain, 2011).

Since there is extremely little rainfall in Egypt, most Egyptians live close to the Nile River and depend on it for all their water needs, where Egypt is dependent on the Nile River for 95% of its water resources, is experiencing water stress due to the limited water resources, expanding population and climate change (Ibrahim et al., 2018). According to the 1959 Nile water deal Egypt made with Sudan, Egypt receives 55.5 billion cubic meters

Figure 2. The countries of Nile River Basin (The World Bank)

of Nile water annually. Since then, Egypt's population has been steadily growing, and by 2050, the country's share of renewable water resources per person is anticipated to reach 250 m^3/person/year (Amer et al., 2017). Due to its limited water resources, which are mostly caused by its fixed share of Nile River water and general aridness, Egypt is experiencing considerable issues (Allam et al., 2015).

2.2 Ground water

Egypt has a significant hydrogeologic potential due to its extensive groundwater aquifer network. One of Egypt's most significant water resources is groundwater. Water source and the type of the rocks that hold the water are two key elements that affect the quality of groundwater. Most aquifers in Egypt are typically made of unconsolidated or consolidated granular (sand and gravel) material, or fissured and karstified limestone. These aquifers are either unconfined or partially confined. In the Nile River region, there are various groundwater aquifers with varying levels of importance for extraction. They range from local shallow aquifers that are replenished by rainfall to deep aquifers that are difficult to renew and have been heavily exploited (Moneim et al., 2014). Groundwater, which can be found in various regions, is considered the second source of freshwater in Egypt and provides around 12% of the country's water and it is not an easily renewable resource (Soliman &

Soliman, 2017). They range from local shallow aquifers that are replenished by rainfall to deep aquifers. The Nile Valley and Delta system's groundwater are examples of shallow aquifers. The "Western Desert-Nubian Sandstone Aquifer" is an example of the second category that are nonrenewable. It is projected that non-renewable groundwater will be used at a rate of 1.65 billion m^3/year (Abdel-Shafy & Kamel, 2016). As shown in Figure 1, around 6.1 billion m^3/year of groundwater is extracted in Delta, Sinai, and New Valley. The Nile, Nubian Sandstone, Moghra, coastal, fissured carbonate, pre-Cambrian fissured and weathered hard rock, groundwater in Sinai, and groundwater in the Western Nile Delta aquifer systems are the principal subsurface reservoirs in Egypt (Allam et al., 2003). The main groundwater aquifer systems in Egypt are shown in Figure 3 (MWRI, 2005).

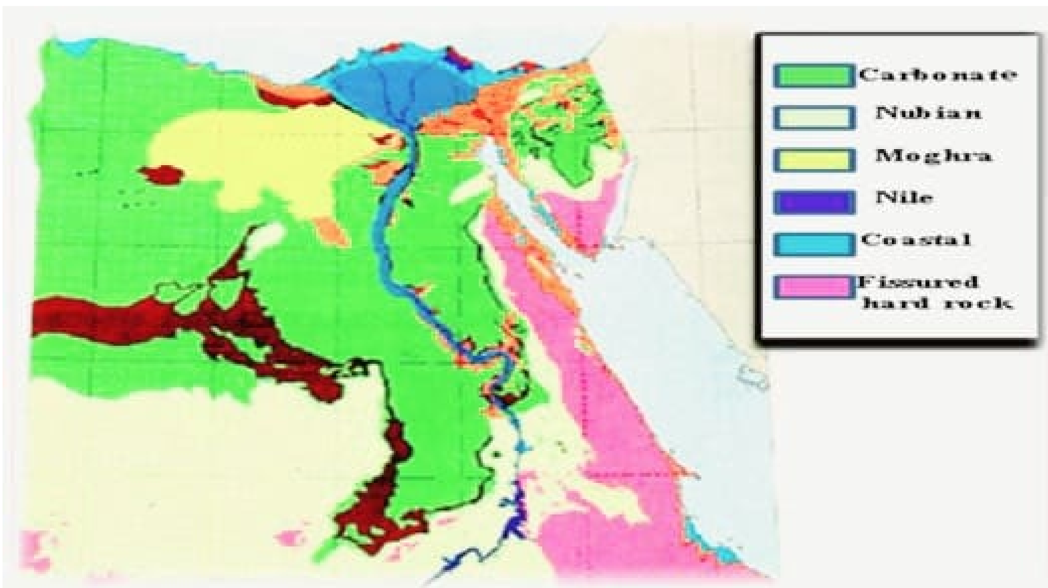

Figure 3. Main groundwater aquifers in Egypt

2.3 Rainwater

In Egypt, precipitation (mostly rain or rainfall) is limited to the country's narrow north coast. The majority of Egypt's remaining land (more than 95%) is desert. Rainfall ranges from zero millimeters per year in the desert to over 200 millimeters per year in the northern coastal area (Abdel-Shafy et al., 2010). In several parts of Egypt, flash flooding and sporadic heavy rain are seen. Severe incidents with more than 200 mm of rain per day occurred in October between 1973 and 2010 over the Mediterranean basin (Mariani & Parisi, 2014). Moreover, there have been exceptional rainfall events in Egypt, with Marsa Matruh (the northern coastal governorate) recording the highest total annual precipitation of 401 mm in 1994 (Gado, 2017). Figure 4 shows the spatial variation of the average annual total precipitation over the country.

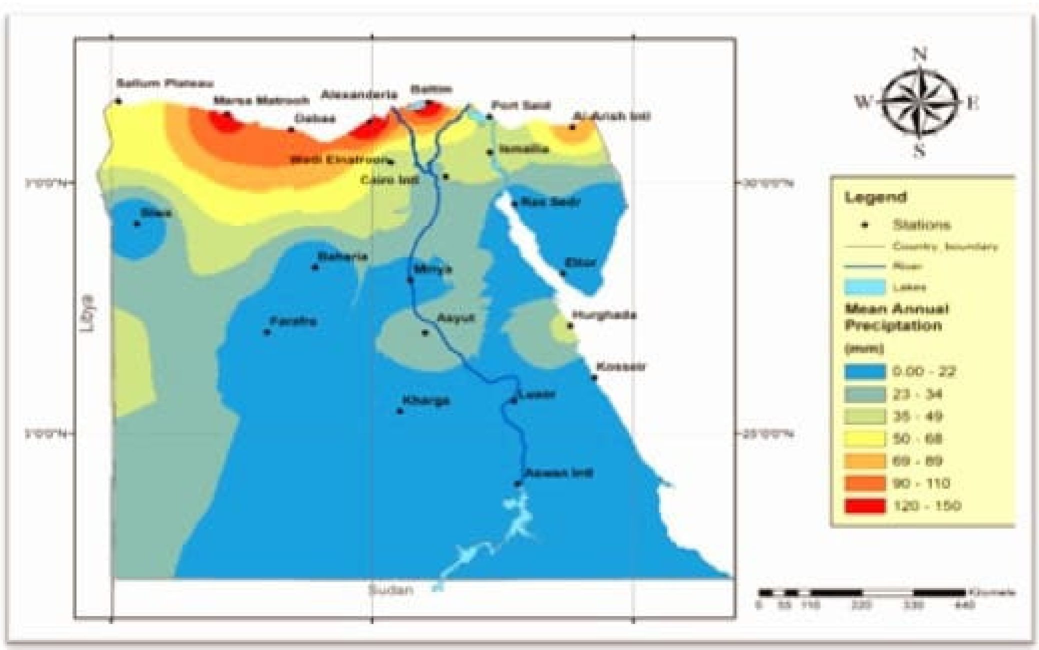

Figure 4. Allocation of mean annual precipitation in Egypt (Gado & El-Agha, 2020)

A severe rainfall occurrence with powerful storms in October 2016 in Ras Gharib city on the Gulf of Suez resulted in a flash flood tragedy for the city's oil production sector (Elnazer et al., 2017). Most of Egypt is a hyper arid country with limited rainfall in winter season (Abdel-Maksoud, 2018). Rainwater is mostly focused on a small area of land along Egypt's coast and gradually declines to the south (Rayan et al., 2004). Less precipitation and more evaporation result in less groundwater recharge. It is anticipated that these dry conditions and the decline in rainfall will increase the strain on the water supply. Additionally, rising sea levels and temperatures will also trigger seawater intrusion in coastal groundwater aquifers (Iglesias et al., 2007). The total amount of rainwater is about 1.3 billion m^3/year and the rainwater is used in different areas in Egypt as follows: 0.38 billion m^3/year to supplement irrigation in the Nile Delta, 0.45 billion m^3/year in Sinai, 0.20 billion m^3/year in the Red Sea Coast and 0.27 billion m^3/year in Alexandria and Marsa-Matrouh (Abdel-Shafy et al., 2010). As shown in Figure 4, a lot of rainwater is harvested in Alexandria, Baltim, Marsa Matrooh, and Dabaa. The rainfall resource comprises a minor part of the water resources of Alexandria governorate while it contributes comparatively substantial percentages in both North Sinai and Marsa Matrouh Governorates. Rainwater harvested from Alexandria's urban areas has the potential to boost rainfall in the governorate's water resources by 50%. Also, water harvest from urban areas like Marsa Matrouh and Dabaa cities can substitute for some of the water needed for seawater desalination, reducing the associated overall expenses (Gabr et al., 2022).

2.4 Drainage water

Egypt's water demand is greater than its traditional supply, making the utilization of unconventional water resources essential. Since 1920, Egypt has been one of the first countries to reuse water (Abu-Zeid et al., 2014). One of the newest applications for which Egypt has enough water is the treatment of drainage water (Abdin & Gaafar, 2009). At several locations, drainage water is reinjected into the streams that supply the Nile Delta. This recycling greatly raises the Delta's overall water efficiency (Molle et al., 2016). The reuse of agricultural drainage water in the Nile delta is 9.70 billion m^3/year and domestic treated wastewater is 2.90 billion m^3/year (Abd Ellah, 2020).

2.5 Desalination

Egypt's precarious water resource status compels the government to enhance its use of unconventional water sources (reuse of wastewater and desalination). These resources make up 22.2% of all the water that is readily available. According to estimates, desalination produces 0.5 billion m^3 /year of water annually, and by 2030, that number will have increased to 1 billion m^3/year (Wahaab et al., 2021). Desalination has been taken into consideration in Egypt as a strategic water resource alternative for the development of rural areas, particularly in coastal areas. Three sources of water that can be desalinated: groundwater, seawater, and wastewater. Desalination facilities are the most practical response to the enormous water demand in dry areas, particularly in Egypt with its constrained Nile River water resources and anticipated drought brought on by climate change and upstream dam construction. There are numerous desalination technologies in use, including thermal and membrane systems. Because of its low energy requirements, low investment costs, ease of use, and high production capacity, reserve osmosis desalination process is the best method for use in Egypt (Elsaie et al., 2022). Batisha (2007) showed that there are about 9 billion m^3/year agricultural drainage water discharges to the Mediterranean due to its high salinity which prohibits its reuse.

3. Climate Change

Climate change has implications for water management in Mediterranean regions (Madrigal et al., 2024). The studies forecast that global food and water resource issues will get worse due to prolonged climate change (Pokhrel et al., 2021). One of the main concerns in agricultural systems is global climate change, which is characterized by the global warming brought on by an increase in the atmospheric carbon dioxide concentration (IPCC, 2014). The increase in greenhouse gas emissions will result in a temperature rise of around 2.12^{o}C by 2050 and 3.96^{o}C by 2100 in the middle Egypt region. As a result, by 2050 and 2100, the irrigation water requirements for wheat crops are anticipated to rise by 6.2 and 11.8%, respectively. The productivity of wheat will also decrease by 8.6 in 2050 and 11.1% in 2100 (Mostafa et al., 2021). The availability of water resources may be impacted by climate change. In many areas, agriculture depends on groundwater. The recharge of groundwater is a by-product of irrigation return flow. Aquifer storage may therefore be important as a result of climate change (Yu et al., 2010).

Egypt may have major negative economic effects from climate change. The Nile River's flow may drop, and this could have an impact on the nation. Egypt features a sizable area of low-lying coastal regions that are densely populated and have a robust agricultural sector. These regions are extremely susceptible to climate change. Given its reliance on Nile water and susceptibility to temperature increases, agriculture in Egypt is extremely vulnerable (Smith et al., 2014). Also, many climatological studies predict that as temperatures rise, evapotranspiration will significantly increase on Egyptian soil, especially given the country's historically irrigated agriculture. Additionally, the anticipated high temperature would raise local water demands, particularly for the agriculture industry. The greatest obstacle to sustainable agricultural expansion in Egypt under the current and future climates is the country's limited water resources and water scarcity (Khalil et al., 2016). The total amount of water needed for agriculture in the Arabic countries will rise by a percentage ranging from 9% to 36% under a 2^{o}C temperature increase (Ouda et al., 2011). For example, in the El-Behira governorate (North Egypt), the water requirements for wheat and maize would rise by 2 and 15%, respectively, in 2040 (Ouda et al., 2015). Under future climate change, the pressure on agricultural water use will be increased. Climate change circumstances are predicted to raise the evapotranspiration values for all of Egypt's governorates, which will have an impact on water requirements, especially in Upper Egypt and some sections of Lower Egypt (Khalil et al., 2016). The rapidly intensifying water issue is made worse because climate change frequently alters both the quantity and quality of water available. The hydrological cycle has been negatively impacted by climatic extremes over the past few decades. These effects include significant changes in global precipitation patterns, an increase in atmospheric water vapor concentration, glacier melting, floods, soil erosion, and drought (Sukanya & Joseph, 2023).

Three major issues are the result of climate change in Egypt: (1) rising of sea level, which could endanger the coastal region and the Nile Delta; (2) the rising temperature, which would require Egypt to alter her agricultural policy; and (3) water shortage (Mahmoud, 2017). As a result, Egypt may face a serious threat from climate change in the areas of agriculture, food safety, and water shortage. Egypt should therefore establish an urgent plan to prevent any problems that may arise as a result of these changes in the country's climate (Froehlich & Al-Saidi, 2017). Due to its geographic location, Egypt experiences unusual weather, with Mediterranean-like conditions for its coastal parts in the winter and dry conditions in the summer, and with temperatures occasionally topping 40^{o}C in the deserts. The principal cities of Egypt that are situated in the desert, such as Luxor, Aswan, Asyut, Siwa, and Sohag, have greater summertime temperatures than at higher elevations, such as in some of the mountains in Sinai like Saint Catherine. Egyptian geological zones, which include the Sinai Peninsula (6%), the Eastern desert (22%), the Western desert (68%), and the Nile River and delta (approximately 4% of the country's total size), could be utilized to describe Egypt’s climate (El-Ramady et al., 2019). The Mediterranean Sea has a considerable impact on the climate of northern coastal areas. The climate in Egypt varies greatly, ranging from a temperate Mediterranean environment along the northern coast to a hot desert temperature in the Upper Egypt region. The winter months in Egypt are December through February, whereas the summer months are June through August. Crop production is extremely susceptible to climatic variations. Thus, climate change will result in significant changes in crop distribution. By 2100, the production of wheat (*Triticum aestivum L*.), rice (*Oryza sativa L*.), and maize (*Zea mays L*.) would decrease by 5-50%, 20-30%, and 20-45%, respectively, if the current changes in climate and greenhouse gas emissions had continued (Hassan et al., 2022). Water resources and agriculture in the dry areas will eventually be severely impacted by climate change. Because of the high temperatures and decreased rainfall during droughts, rain-fed agro-ecosystems will be more vulnerable to stressors (Alkatb, 2022). Monthly climatology of temperature and precipitation over the period of 1991-2020 of Egypt are shown in Figures 5 and 6, respectively.

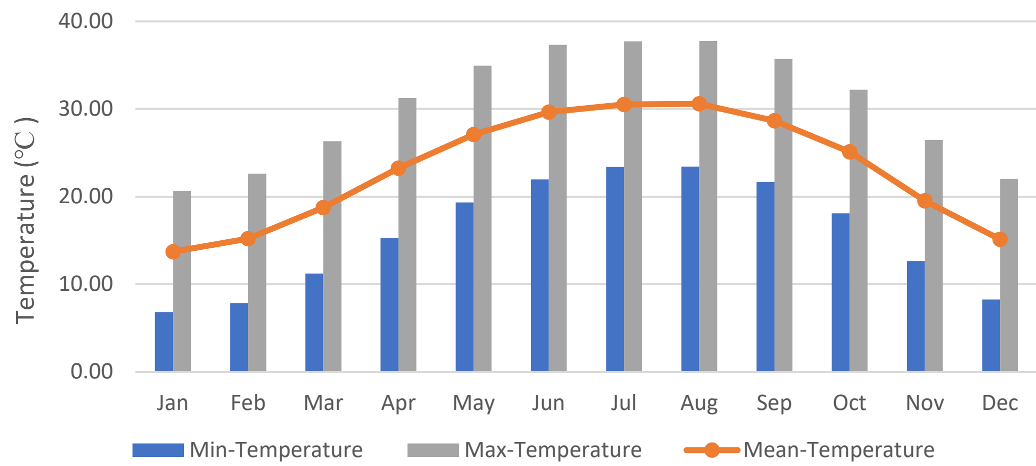

Figure 5. Monthly climatology of Min-temperature, Mean- temperature and Max-temperature (°C) 1991-2020 of Egypt. (Data is presented at a 0.5º x 0.5º (50km x 50km) resolution by the Climatic Research Unit (CRU) of University of East Anglia. (Climate change knowledge portal. https://climateknowledgeportal. World bank.org/country/Egypt/climate-data-historical)

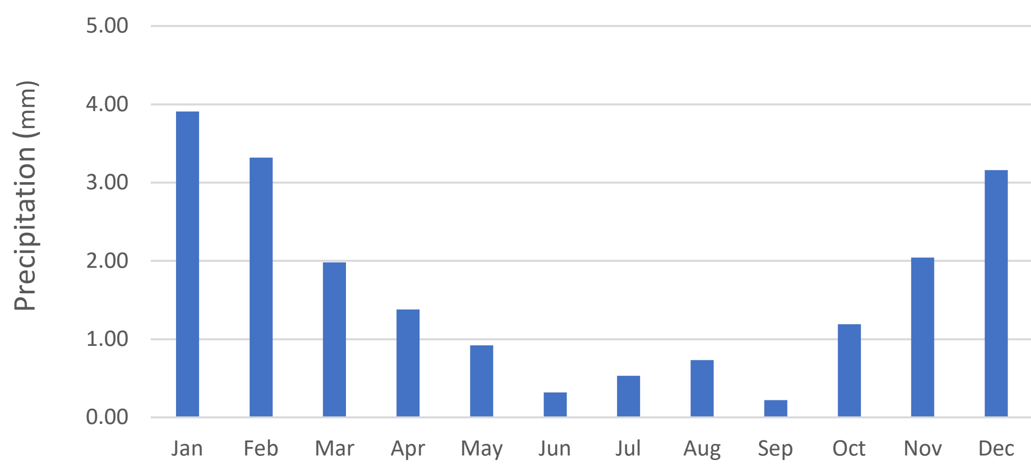

Figure 6. Monthly climatology of precipitation (mm) 1991-2020 of Egypt. (Data is presented at a 0.5º x 0.5º (50km x 50km) resolution by the Climatic Research Unit (CRU) of University of East Anglia. (Climate change knowledge portal. https://climateknowledgeportal. World bank.org/country/Egypt/climate-data-historical)

4. Improving of Irrigation Water Productivity

Crop water productivity is controlled by plant specific factors, climate factors and management factors (Connor et al., 2011). To boost water use effectiveness and make the transition to a more sustainable use of water in agriculture, there must be an improvement in water use efficiency through:

4.1 Water Saving

Improving of irrigation water use efficiency mainly depends on improving crop productivity or saving water. To produce a high yield with the least amount of water input, emphasis should be on how to increase utilization rates and water usage efficiency. An agricultural system that saves water is one that uses integrated farming practices to better utilize irrigation systems and natural rainfall (Shan, 2002). In other words, the aim is to maximize the ratios of economic benefit/biomass yield; water consumption/soil storage of water; transpiration/water consumption; and soil-stored water content/volume of precipitation (Deng et al., 2006). To meet crop water needs, irrigation scheduling techniques and proper irrigation system selection and use are critical components of water conservation and saving while conserving water use and simultaneously maximizing crop profit within the limitations of water shortage (Amer et al., 2017). The most effective water-saving techniques in irrigated agriculture are pressurized water application techniques (sprinkler and micro irrigation). Nowadays, sprinkler irrigation (35 million ha) and micro irrigation account for around 15% (44 million hectares) of the total irrigated land in the world (9 million ha). A high application efficiency is also provided by improved surface irrigation techniques like level furrows and dead level basins (Kulkarni, 2011).

4.2 Water harvesting

Conserving rainwater is one suggested method for meeting water demand. Water harvesting is the collection and storage of rainfall, either above or below ground, with the goal of reducing condensation brought on by hydrological activity (Gould, 1999). In dry areas, precipitation is typically insufficient to meet the essential needs of crops. It is negatively distributed throughout the growth season for crops and frequently manifests at a high intensity. The Mediterranean region frequently has dry spells throughout the growth season for crops because rain typically arrives in intermittent, unexpected storms and is largely lost to evaporation and runoff (Oweis et al., 1999). Water harvesting is a potential technique that has gained widespread acceptance around the globe and is used to address issues with water scarcity in agricultural production. Depending on the situation and the goal, micro- and macro water harvesting techniques are used in dry, semiarid, and tropical locations. By providing irrigation water at a crop's vital growing stage, the implementation of a water collecting system has been proven to have a favorable impact on agricultural productivity and increase yields (Komariah & Senge, 2013). In arid and semiarid environments, rainwater harvesting is crucial for water conservation. It is imperative that these techniques be improved in order to lessen water stress caused by climate change and population increase (Mourad & Berndtsson, 2011). Also, a great option for increasing crop yields in arid lands is supplemental irrigation, which combines dryland farming and minimal irrigation. It improves yield and water productivity in arid soils by supplying small amounts of water, especially during crucial times of crop growth (Alkatb, 2022).

4.3 Limited irrigation

Agriculture is undoubtedly being forced to cede some of its share to higher priority users, particularly the home and industrial sectors, due to a fierce competition among water-using industries. Limited irrigation refers to the provision of supplemental irrigation during crucial growth stages while inducing a soil water deficit during noncritical periods of crop development. It is a technique for crop management in which irrigation systems that can only deliver a part of the water needed for crop growth are paired with dryland farming (Kang et al., 2003). Deficit irrigation, which irrigates for less yield per unit land, can save a significant amount of water that can then be used to irrigate more land, increasing the amount of food that can be produced with the water that is available (Amer et al., 2017). For effective irrigation planning, the timing and volume of water applied must correspond to the actual field conditions. In limited irrigation as opposed to full irrigation, more control over water application level and timing is required (Jabeen et al., 2022). Reducing the frequency of irrigations and water applied could help alleviate water depletion. Deficit irrigation is defined as water application below crop water requirements. Moderate water deficit during grain filling increases mobilization of assimilate stored in vegetative tissues and grain, resulting in greater grain yield and water use efficiency (Zhang et al., 2018). The benefits of effective irrigation scheduling include not just increasing crop productivity but also conserving time and energy, which enables everyone to maintain environmental health. Wang & Cai (2009) found that optimal irrigation decisions can offer significant economic value over conventional irrigation decisions. In essence, proper soil moisture management and efficient water use are essential for improving the efficiency of agricultural water utilization in arid and semi-arid regions (Jabeen et al., 2022).

4.4 Crop management

Since water demand is outpacing supply on a worldwide scale, boosting agricultural output per unit evapotranspiration is becoming everyone's responsibility. Additionally, this requires a mindset change away from maximizing yield per unit. The photosynthetic metabolic process differs between C3 and C4 plants. Because of this, there are differences between these two plant groups in the trade-off between photosynthetic leaf carbon uptake and water loss, which is often higher in C4 plants. For instance, sorghum and maize produce more grain per unit of seasonal transpiration than their C3 counterparts, wheat and barley (Sadras et al., 2011). By selecting crop varieties that are well suited to the environment, decreasing wasteful water use, and maintaining healthy, vigorously growing crops through improved water, fertilizer, and agronomic management, agricultural water productivity can be increased (Descheemaeker et al., 2013). Generally, the adoption of various agronomic/management practices such as growing hybrid/improved varieties rather than local varieties, timely crop sowing, crop sowing at optimal inter and intra row spacing, and the application of the optimum dose of fertilizers at the proper time can lead to improve water use efficiency. Vala & Chavda (2021) concluded that adoption of different agronomic/management practices such as the growing of hybrid/improved varieties rather than local varieties, the timely sowing of the crop, led to increase water use efficiency.

4.5 Soil mulching

To encourage plant growth and crop, mulching is the process of applying an organic or synthetic ‘mulch’ to the soil's surface around plants. In arid and semi-arid regions, mulching has emerged as a crucial water conservation technique in current agricultural production. The mulch material blocks sunlight from reaching the soil's surface, preventing evaporation by holding onto soil moisture, and adjusting soil temperature, and thus increase water use efficiency (Kader et al., 2019). Mulch insulates soil, protecting roots of plants and living organisms from a variety of weather conditions (Yu et al., 2018; Kader et al., 2019). One primary function of mulching is to preserve soil moisture by minimizing surface evaporation and erosion (Qin et al., 2016). Mulching is a practical technique that may help to retain moisture, reduce evaporation, change soil temperature, improve aeration, and release nutrients from the soil profile (Sharma et al., 2005; Ahmad et al., 2007). As a moisture-conservation strategy, grass mulch should be used because it significantly boosted lettuce output (Mkhabela et al., 2019). Mulching was shown to be positively impact crop development as well as the quantity and quality of the yields produced (Ramakrishna et al., 2005). Plastic mulches can be effectively used for sustaining plant growth and yield (Sharma & Bhardwaj, 2017). Mulching is a method that entails putting materials into the field before, during, or shortly after sowing in order to support and spread throughout the soil surface. These materials can include plastic, agricultural waste, livestock manure, sand, boulder, and cement (Gan et al., 2008). Mulching can be added to improve crop productivity, plant growth, and reduce water usage (Yu et al., 2018). There are three different categories of mulching materials, which are organic, inorganic, and special materials. Organic mulching materials are created from agricultural waste, wood industrial waste, processed leftovers, and animal manures (El-Beltagi et al., 2022). Inorganic mulching materials include polyethylene plastic sheets and synthetic polymers. Moreover, surface coatings made of biodegradable polymer films for flexibility and simplicity of use that are environmentally friendly products include several novel biodegradable and photodegradable plastic films (Kader et al., 2017).

4.6 Soil conditioners

It is critical that the soil be properly managed to improve crop water productivity. Water use efficiency and soil water content retention may be significantly impacted by soil amendments mixed with irrigation water (Ali et al., 2018). Soil management practices that improve water retention, help roots draw more water from the soil, and reduce leaching losses all have the potential to improve water use efficiency. The capacity of the soil to hold water could benefit from improved soil management practices that increase the quantity of organic matter in the soil (Hatfield et al., 2001). Certain organic compounds and soil conditioners improve the water retention capacity of sandy soils with low aggregate stability and water retaining capacity (Brady & Weil, 2008). There are different soil additions, both natural (such farmyard manure, compost, and factory waste) and/or synthetic (like polymers, ratings, glue, and produced paper waste), that can assist the soil hold onto more water and prevent evaporation (Eldardiry& Abd El-Hady, 2015).

4.7 Nutritional management

A significant way to increase production and water use efficiency is through proper plant nutrition. When there is a limited supply of water, plant nutrients are crucial for improving water usage efficiency. Superoxide dismutase (SOD), catalase (CAT), and peroxidase (POD) concentrations are increased in plant cells by the application of nutrients such N, K, Mg, B, Zn, and Si, which minimize the toxicity of reactive oxygen species (ROS) produced under water-limited conditions (Waraich et al., 2011). In dry and semi-arid regions, the addition of organic fertilizer to N and P fertilizer improved soil water use efficiency (WUE) and crop yield (Liu et al., 2020). Furthermore, the rational fertilization application of fertilizers under water-limited conditions improved water use efficiency (Zhang et al., 2019). There is a need to develop new technology for the efficient use of water and fertilizer for agriculture due to rising food demand and declining water resources. The environmental sustainability and the preservation of soil and water resources must be taken into account. Therefore, using water and fertilizer efficiently and sparingly is crucial for protecting the environment (Hagin et al., 2003). According to Liu *et al.* (1998), nitrogen fertilizers increased root growth of wheat and improved root system development which in turn led to increased crop production and water use efficiency.

4.8 Irrigation systems management

Low crop water productivity (CWP) in water-limited settings, particularly in developing countries, has been caused by subpar irrigation methods and management (Lacirignola et al., 2014). It is necessary to apply water accounting and to change from traditional agricultural production methods that attempt to maximize yield per unit area of soil to more water-conscious techniques that strive to optimize crop output per unit water consumption, which is measured by evapotranspiration (Kilemo, 2022). The flood irrigation system, which accounts for 60% of the country's irrigated land, is the most popular one in Egypt. Its effectiveness is between 40% and 50% (Karajeh et al., 2013). To accomplish the aims of the 2030 Sustainable Development Strategy, which seeks to embrace the integrated water resource management method, it is crucial to increase the deployment of advanced irrigation technologies. Such technologies promise to improve the efficiency of the irrigation system from 40% to 80% (Wahba et al., 2018). Irrigation is essential for enhancing agricultural output in semiarid and arid climates. To boost productivity per unit area in the face of water scarcity, new technology must be used (Okasha et al., 2016). As is common knowledge, pressured irrigation systems like sprinkler and drip irrigation utilize substantially less water than traditional irrigation techniques (surface irrigation). The use of contemporary irrigation systems in newly reclaimed soil, and the conversion of surface irrigation to drip irrigation systems can achieve higher water use efficiency. Chemicals and fertilizers can also be used in the precise concentrations needed, and drip irrigation and fertigation have the capacity to greatly increase the availability and uptake of water and nutrients in soil, increasing crop yield (Çetin & Akalp, 2019). Using of water-drip irrigation fertilization technology increased crop productivity and water use efficiency (Fan et al., 2020). The adoption of sophisticated irrigation systems has raised irrigation efficiency. Additionally, adopting water-saving methods for water transportation and application is a requirement for irrigation that uses less water by converting to more effective irrigation system to improve WUE (Deng et al., 2006).

A smart irrigation system that can conserve water is necessary since irrigation uses a lot of water. By automatically watering plants and gardens according to their needs, water is conserved. Smart systems enable overall water savings of 67% when compared to conventional methods. So, in water-scarce places and for individuals living far from their farms, effective water use and visit-free monitoring offer clever solutions (Nawandar & Satpute, 2019). Smart systems ensures that irrigation pumps last for a long time, and often involve water recycling, which further contribute to water saving. In this way, smart systems can be used to make sure that different plants are watered according to the different amounts of water they require for efficient growth. This would be helpful in areas where the practice of irrigation is complicated by a lack of water (Ogidan et al., 2019). The use of new irrigation systems is very important to increasing the yield per unit of water used and decreasing water loss. Importantly, the management and creative design of integrated water distribution and application schemes could lead to enhance gain yield. This is essential to preserve water and encourage the highest crop growth to maximize water use efficiency (WUE) through the reduction of weed transpiration, runoff, seepage, and evaporation and the choice of cultivars that are well suited to the local soil and climatic conditions is another strategy to achieve the main goal (De Pascale et al., 2011).

5. Conclusions

Studies have shown that improving water productivity in irrigated agriculture is unavoidable due to climatic change and limited water. To increase water use efficiency, further development measures necessitate a review of current water allocations. Additionally, to close the gap between water supply and demand, nonconventional water resource choices must be investigated. Effective moisture conservation and efficient use of the limited water resources are necessary to significantly improve agricultural water use efficiency. This necessitates a shift in crop production practices from the more conventional ones that attempted to maximize crop output per unit area of land to more water-conscious ones that try to optimize crop yield per unit of water consumption, which is determined by evapotranspiration. Therefore, Egypt should create a quick plan to better control issues that may occur as a result of climate change and water shortage by the use of rainwater harvesting; the management of agricultural water resources to maximize crop productivity by using less water; enhancing the effectiveness of the water supply by identifying leaks and improving irrigation distribution and conveyance efficiency; and using modern irrigation systems and launching water-saving initiatives. Under virtual water trade agreements, it is advised that water-poor countries plant high-value crops and use the proceeds to acquire food from water-rich countries.

6. Conflicts Interests

The author has declared that no competing interest exists.

References

Abd Ellah, R. G. (2020). Water resources in Egypt and their challenges, Lake Nasser case study. *Egyptian Journal of Aquatic Research*, 46(1), 1-12. https://doi.org/10.1016/j.ejar.2020.03.001

Abdel-Maksoud, B. M. (2018). Estimation of air temperature and rainfall trends in Egypt. *Asian Asian Journal of Advanced Research and Reports,* 1(4), 1-22.

Abdel-Shafy, H. I., & Kamel, A. H. (2016). Groundwater in Egypt issue: resources, location, amount, contamination, protection, renewal, future overview. *Egyptian Journal of Chemistry,* 59(3), 321-362. https://doi.org/10.21608/EJCHEM.2016.1085

Abdel-Shafy, H. I., El-Saharty, A. A., Regelsberger, M., & Platzer, C. (2010). Rainwater in Egypt: quantity, distribution and harvesting. *Mediterranean Marine Science,* 11(2), 245-257. https://doi.org/10.12681/mms.75

Abdin, A. E., & Gaafar, I. R. (2009). Rational water use in Egypt. In M. Moujabber, L., G. Trisorio-Liuzza, I. Martin, A. Rabi, & R. Rodriguez (Eds.). *Technological perspective for rational use of water resources in the Mediterranean region* (pp. 11-27). CIHEAM.

Abou-Hadid, A. F. (2006). Water use efficiency in Egypt. In I. Hamdan, T. Oweis, & G. Hamdallah. *Water use efficiency Network* (pp. 39-57). ICARDA.

Abu-Zeid, K., Elrawady, M. & CEDARE. (2014). *2030 strategic vision for treated wastewater reuse in Egypt.* Water Resources Management Program.

Ahmad, M. D., Turral, H., Masih, I., Giordano, M., & Masood, Z. (2007). *Water saving technologies: myths and realities revealed in Pakistan\u2019s rice–wheat systems*. International Water Management Institute (IWMI).

Ali, S., Jan, A., Manzoor, Sohail, A., Khan, A., Khan, M. I., Inamullah, Zhang, J., & Daur, I. (2018). Soil amendments strategies to improve water-use efficiency and productivity of maize under different irrigation conditions. *Agriculture Water Management*, 210, 88-95. https://doi.org/10.1016/j.agwat.2018.08.009

Allam, A., Fliefle, A., Tawfik, A., Yoshimura, Y., & El-Saadi, A. A. (2015). A simulation-based suitability index of the quality and quantity of agricultural drainage water for reuse in irrigation. *Science of the Total Environment*, 536, 79-90.

Allam, A. R., Saaf, E., & Dawoud, M. A. (2003). Desalination of brackish groundwater in Egypt. *Desalination*, 152, 19-26. https://doi.org/10.1016/S0011-9164(02)01044-5

Allam, M. N., & Allam, G. I. (2007). Water resources in Egypt: Future challenges and opportunities. *Water International*, 32(2), 205-218.

Alkatb, S. H. (2022). Improvement of irrigation water efficiency and productivity using supplementary irrigation: A review. *Journal of Water Resources and Geosciences*, 1(1), 53-69.

Amer, M. H., Abd El Hafez, S. A., & Abd El Ghany, M. B. (2017). *Water saving in irrigated agriculture in Egypt*. LAP LAMBERT Academic Publishing.

Batisha, A. (2007). Water desalination industry in Egypt. In *Eleventh international water technology conference* (pp. 337-349). Sharm El-Sheikh.

Brady, N. C., & Weil, R. R. (2008). *The nature and properties of soils*. 13, 662-710. Upper Saddle River, New Jersy, Prentice Hall.

Çetin, O., & Akalp, E. (2019). Efficient use of water and fertilizers in irrigated agriculture: drip irrigation and fertigation. *Acta Horticulture et Regiotecturae*, 22(2), 97-102. https://doi.org/10.2478/ahr-2019-0019

Connor, D. J., Loomis, R. S., & Cassman, K. G. (2011). *Crop Ecology: Productivity management in agricultural systems*. Cambridge University Press.

Cooper, A. F., Antkiewicz, A., & Shaw, T. M. (2007). Lessons from BRICSAM about south-north relations at the start of the 21st century: Economic size trumps all else? *International Studies Review,* 9(4), 673-689. https://doi.org/10.1111/j.1468-2486.2007.00730.x

Darwesh, R. K. (2018). Water productivity for Egyptian clover as affected by different irrigation regimes and cultivation methods in the North Middle Nile Delta region. *Environment, Biodiversity and Soil Security*, 2, 193-203.

De Pascale, S., Costa, L. D., Vallone, S., Barbieri, G., & Maggio, A. (2011). Increasing water use efficiency in vegetable crop production: from plant to irrigation systems efficiency. *Hort Technology*, 21(3), 301-308. https://doi.org/10.21273/HORTTECH.21.3.301

Deng, X. P., Shan, L., Zhang, H., & Turner, N. C. (2006). Improving agricultural water use efficiency in arid and semiarid areas of China. *Agricultural Water Management*, 80(1-3), 23-40. https://doi.org/10.1016/j.agwat.2005.07.021

Descheemaeker, K., Bunting, S. W., Bindraban, P., Muthuri, C., Molden, D., Beveridge, M., Van Brakel, M., Herrero, M., Clement, F., Boelee, E., & Jarvis, D. I. (2013). Increasing water productivity in agriculture. In E. Boelee (Ed.). *Managing water and agroecosystems for food security* (pp. 104-123). CABI.

Djuma, H., Bruggeman, A., Eliades, M., & Lange, M. A. (2016). Non-conventional water resources research in semi-arid countries of the Middle East. *Desalination and Water Treatment*, 57 (5), 2290-2303. https://doi.org/10.1080/19443994.2014.984930

El-Beltagi, H. S., Basit, A., Mohamed, H. I., Ali, I., Ullah, S., Kamel, E. A. R., Shalaby, T. A., Ramadan, K. M. A., Alkhateeb, A. A., & Ghazzawy, H. S. (2022). Mulching as a sustainable water and soil saving practice in agriculture: A review. *Agronomy*, 12(8), Article 1881. https://doi.org/10.3390/agronomy12081881

El-Fellaly, S. H., & Saleh, E. M. A. (2004). Egypt's experience with regard to water demand management in agriculture. In: *Eighth international water technology conference* (pp. 5-29). Alexandria.

El-Ramady, H., Alshaal, T., Bakr, N., Elbana, T., Mohamed, E., & Belal, A.-A. (2019). *The Soils of Egypt.* Springer. https://doi.org/10.1007/978-3-319-95516-2

Eldardiry, E. I., & Abd El-Hady, M. (2015). Effect of different soil conditioners application on some soil characteristics and plant growth-Soil moisture distribution, barley yield and water use efficiency. *Global Advanced Research Journal of Agricultural Science,* 4(7), 361-367.

Elnazer, A. A., Salman, S. A., & Asmoay, A. S. (2017). Flash flood hazard affected Ras Gharib city, Red Sea, Egypt: a proposed flash flood channel. *Nat Hazards,* 89, 1389-1400. https://doi.org/10.1007/s11069-017-3030-0

Elsaie, Y., Ismail, S., Soussa, H., Gado, M., & Balah, A. (2022). Water desalination in Egypt; literature review and assessment. *Ain Shams Engineering Journal*, 14(7), Article 101998. https://doi.org/10.1016/j.asej.2022.101998

Fan, J., Lu, X., Gu, S., & Guo, X. (2020). Improving nutrient and water use efficiencies using water-drip irrigation and fertilization technology in Northeast China. *Agricultural Water Management*, 241, Article 106352. https://doi.org/10.1016/j.agwat.2020.106352

FAO. (2021). The state of the world's land and water resources for food and agriculture: systems at breaking point. https://www.fao.org/3/cb7654en/cb7654en.pdf

Froehlich, P., & Al-Saidi, M. (2017). Community-based adaptation to climate change in Egypt-status Quo and future policies. In W. L. Filho (Ed.). *Climate change research at universities* (pp 235-250). Springer.

Gabr, M., El-Ghandour, H., & Elabd, S. (2022). Rainwater harvesting from urban coastal cities using recharging wells: a case study of Egypt. *Port-Said Engineering Research* Journal, 26(3), 17-36. https://doi.org/10.21608/pserj.2022.103188.1151

Gado, T. A. (2017). Statistical characteristics of extreme rainfall events in Egypt. In *Twentieth international water technology conference* (pp. 645-653). Hurghada.

Gado, T. A., & El-Agha, D. E. (2020). Feasibility of rainwater harvesting for sustainable water management in urban areas of Egypt. *Environmental Science and Pollution Research,* 27(26), 32304-32317. https://doi.org/10.1007/s11356-019-06529-5

Gan, Y. T., Huang, G. B., Li, L. L., Liu, J. H., & Hu, Y. G. (2008). Unique conservation tillage practices in northwest China. In: T. Goddard, M. A. Zoebisch, Y. Gan, W. Ellis, A. Watson, S. Sombatpanit (Eds.). *No-till farming systems, world association of soil and water conservation* (pp. 429-445). Funny Publishing.

Gould, J. (1999). *Contributions relating to rainwater harvesting*. The World Commission on Dams Secretariat (WCD) Thematic Review IV.3.

Hagin, J., Sneh, M., & Lowengart-Aycicegi, A. (2003)*. Fertigation- fertilization through irrigation.* International Potash Institute.

Hamdy, A. (2007). Water use efficiency in irrigated agriculture: an analytical review. In N. Lamaddalena, M. Shatanawi, M. Todorovic, C. Bogliotti, & R. Albrizio (Eds.). *Water use efficiency and water productivity: WASAMED project* (pp. 9-19). CIHEAM.

Hassan, M.U., Aamer, M., Mahmood, A., Awan, M. I., Barbanti, L., Seleiman, M. F., Bakhsh, G., Alkharabsheh, H. M., Babur, E., Shao, J., Rasheed, A., & Huang, G., (2022). Management strategies to mitigate N_2O emissions in agriculture. *Life*, 12(3), Article 439. https://doi.org/10.3390/life12030439

Hatfield, J. L., Sauer, T. J., & Prueger, J. H. (2001). Managing soils to achieve greater water use efficiency: a review. *Agronomy Journal*, 93(2), 271-280. https://doi.org/10.2134/agronj2001.932271x

Ibrahim, M., Al-Zyoudand, S., & Elhaddad, E. (2018). Surface water quality monitoring for RiverNile, Egypt using GIS-techniques. *Open Journal of Geology*, 8, 161-173. https://doi.org/10.4236/ojg.2018.82010

Iglesias, A., Garrote, L., Flores, F., & Moneo, M. (2007). Challenges to manage the risk of water scarcity and climate change in the Mediterranean. *Water Resources Manage,* 21, 775-788. https://doi.org/10.1007/s11269-006-9111-6

IPCC. (2022). Summary for policymakers. In H. O. Pörtner, D. C. Roberts, E. S. Poloczanska, K. Mintenbeck, M., Tignor, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, & A. Okem (Eds.). *Climate Change 2022: Impacts, Adaptation and Vulnerability* (pp. 3-33). Cambridge University Press. https://doi.org/10.1017/9781009325844.001

IPCC. (2014). Climate change 2014: Impacts, adaptation, and vulnerability. In C. B. Field, V. R. Barros, D. J. Dokken, K. J. Mach, M. D. Mastrandrea, T. E. Bilir, & L. L. White (Eds.). *Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press.

Jabeen, M., Ahmed, S. R. & Ahmed, M. (2022). Enhancing water use efficiency and grain yield of wheat by optimizing irrigation supply in arid and semi-arid regions of Pakistan. *Saudi Journal of Biological Science*, 29(2), 878-885. https://doi.org/ 10.1016/j.sjbs.2021.10.018

Kader, M. A., Senge, M., Mojid, M. A., & Ito, K. (2017). Recent advances in mulching materials and methods for modifying soil environment. *Soil and Tillage Research*, 168, 155-166. https://doi.org/10.1016/j.still.2017.01.001

Kader, M. A., Singha, A., Begum, M. A., Jewel, A., Khan, F. H., & Khan, N. I. (2019). Mulching as water-saving technique in dryland agriculture. *Bulletin in the Natural Research Center,* 43(1), 1-6. https://doi.org/10.1186/s42269-019-0186-7

Kang, S. Z., Davies, W. J., Shan, L., & Cai, H. (2003). *Water saving agriculture and sustainable use of water and land resources*. Volume 2. Shaanxi Science and Technology Press.

Karajeh, F., Oweis, T., El-Gindy, S. A. A., El-Quosy, D., Khalifa, H., El-Kholy, M., & Abd El-Hafez, S. (2013). *Water and agriculture in Egypt*. Food and Agriculture Organization of the United Nation (FAO).

Khalil, A. A., Essa, Y. H., Hashem, F. A., & Refaie, K. M. (2016). Water consumption variability for major crops in Egypt under climate condition. *International Journal of Advanced Research,* 4(9), 1157-1168. https://doi.org/10.21474/IJAR01/1598

Kilemo, D. B. (2022). The review of water use efficiency and water productivity metrics and their role in sustainable water resources management. *Open Access Library Journal,* 9(1), 1-21. https://doi.org/10.4236/oalib.1107075

Komariah, & Senge, M. (2013). The development of water harvesting research for agriculture. *Reviews in Agricultural Science*, 1, 31-42, https://doi.org/10.7831/ras.1.31

Kulkarni, S. (2011). Innovative technologies for water saving in irrigated agriculture. *International Journal of Water Resources and Arid Environments*, 1(3), 226-231.

Lacirignola, C., Capone, R., Debs, P., El Bilali, H., & Bottalico, F. (2014). Natural resources-food nexus: food-related environmental footprints in the Mediterranean countries. *Frontiers in Nutrition,* 1, Article 23. https://doi.org/10.3389/fnut.2014.00023

Liu, Q., Mu, X. M., Zhao, G. J., Gao, P., & Sun, W. Y. (2020). Effects of fertilization on soil water use efficiency and crop yield on the loess plateau, China. *Applied Ecology Environmental Research,* 18, 6555-6568. https://doi.org/10.15666/aeer/1805_65556568

Liu, Z. M., Shan, L., Deng, X. P., Inanaga, S., Sunohara, W., & Harada, J. (1998). Effects of fertilizer and plant density on the yields, root system and water use of spring wheat. *Research in Soil Water Conservation*, 5(1), 70-75.

Madrigal, C., Bedri, R., Piechota, T., Li, W., Tootle, G., & El-Askary, H. (2024). Water whiplash in mediterranean regions of the world. *Water*, 16(3), Article 450. https://doi.org/10.3390/w16030450

Mahmoud, M. A. (2017). Impact of climate change on the agricultural sector in Egypt. In A. M. Negm (Ed.). *Conventional water resources and agriculture in Egypt. The Handbook of Environmental Chemistry*, *Vol 74* (pp. 213-227). Springer. https://doi.org/org/10.1007/698_2017_48

Mariani, L., & Parisi, S. G. (2014). Extreme rainfalls in the Mediterranean area. In N. Diodato, & G. Bellocchi (Eds.). *Storminess and environmental change, advances in natural and technological hazards research*, *Vol 39* (pp. 17-37). Springer Science + Business Media.

Medany, M. A., Wadid, M. M., & Abou-Hadid, A. F. (2001). New extension system for modern irrigation management in Egypt. *Acta Horticulturae,* 562, 407-411. https://doi.org/10.17660/ActaHortic.2001.562.49

Mkhabela, K. T., Dlamini, M. V., & Manyatsi, A. M. (2019). The effect of mulching on soil moisture retention and yield of lettuce (*Lactuca sativa L.*). *International Journal of Environmental and Agriculture Research*, 5(9), 47-50.

Molle, F., Gaafar, I., El-Agha, D. E., & Rap, E. (2016). *Irrigation efficiency and the Nile Delta water balance*. Egypt. Water and salt management in the Nile Delta. Report No. 9. IWMI.

Moneim, A. A. A., Zaki, S., & Diab, M. (2014). Groundwater conditions and the geo environmental impacts of the recent development in the Southeastern part of the western desert of Egypt. *Journal of Water Resource and Protection,* 6(4), 381-401. https://doi.org/10.4236/jwarp.2014.64040

Mostafa, S. M., Wahed, O., El-Nashar, W. Y., El-Marsafawy, S. M., & Abd-Elhamid, H. F. (2021). Impact of climate change on water resources and crop yield in the Middle Egypt region. AQUA-Water Infrastructure. *Ecosystem and Society,* 70(7), 1066-1084. https://doi.org/10.2166/aqua.2021.019

Mourad, K. A., & Berndtsson, R. (2011). Potential water saving from rainwater harvesting in Syria. *Journal of Water Management and research*, 67(2), 113-117.

Muala, E., Mohamed, Y., Duan, Z., & van der Zaag, P. (2014). Estimation of reservoir discharges from Lake Nasser and Roseires reservoir in the Nile basin using satellite altimetry and imagery data. *Remote Sensing,* 6(8), 7522-7545. https://doi.org/10.3390/rs6087522

Mulat, A. G. & Moges, S. A. (2014). Assessment of the impact of the grand Ethiopian renaissance dam on the performance of the high Aswan Dam. *Journal Water Resource and Protection,* 6, 583-598. https://doi.org/10.4236/jwarp.2014.66057

MWRI. (2005). *National water resources plan for Egypt-2017*. Ministry of Water Resources and Irrigation, Planning sector, Arab Republic of Egypt.

Nawandar, N. K., & Satpute, V. R. (2019). IoT based low cost and intelligent module for smart irrigation system. *Computers Electronic Agriculture,* 162, 979-990. https://doi.org/10.1016/j.compag.2019.05.027

Ogidan, O. K., Onile, A. E., & Adegboro, O. G. (2019). Smart irrigation system: A water management procedure. *Agriculture Sciences,* 10, 25-31. https://doi.org/10.4236/as.2019.101003

Okasha, A. M., El Metwally, W. F., & Attaffey, T. M. (2016). Effect of different types of irrigation systems on soybean production under clayey soil conditions. *Misr Journal of Agricultural Engineering,* 33(1), 43-62. https://doi.org/10.21608/mjae.2016.98154

Ouda, S., Khalil, F., Afendi, G. E., & El-Hafez, S. A. (2011). Prediction of total water requirements for agriculture in the Arab world under climate change. In *15th international water technology conference*. Alexandria.

Ouda, S., Noreldin, T., & Abd El-Latif, K. (2015). Water requirements for wheat (*Triticum* spp.) and maize (*Zea mays*) under climate change in north Nile Delta. *Spanish Journal Agricultural Research,* 13(1),1-10. https://doi.org/10.5424/sjar/2015131-6412

Oweis, T., & Hachum, A. (2006). From water use efficiency to water productivity: issues of research and development. In I. Hamdan, T. Oweis, & G. Hamdallah. *Water use efficiency Network* (pp. 13-37). ICARDA.

Oweis, T., Hachum, A., & Kijne, J. (1999). *Water harvesting and supplemental irrigation for improved water use efficiency in the dry areas*. International Water Management Institute.

Pokhrel, Y., Felfelani, F., Satoh, Y., Boulange, J., Burek, P., Gädeke, A., Gerten, D., Gosling, S. N., Grillakis, M., Gudmundsson, L., Hanasaki, N., Kim, H., Koutroulis, A., Liu, J., Papadimitriou, L., Schewe, J., Schmied, H. M., Stacke, T., Telteu, C-E., Thiery, W., Veldkam, T., … Wada, Y. (2021). Global terrestrial water storage and drought severity under climate change. *Nature Climate Chang,* 11(3), 226-233. https://doi.org/10.1038/s41558-020-00972-w

Qin, S., Li, S., Kang, S., Du, T., Tong, L., & Ding, R. (2016). Can the drip irrigation under film mulch reduce crop evapotranspiration and save water under sufficient irrigation condition? *Agricultural Water Management*, 177, 128-137. https://doi.org/10.1016/j.agwat.2016.06.022

Ramakrishna, A., Tam, H., Wani, S., & Long, T. (2005). Effect of mulch on soil temperature, moisture, weed infestation and yield of ground nut in northern Vietnam. *Field Crops Research*, 95(2-3), 115-125. https://doi.org/10.1016/j.fcr.2005.01.030

Rayan, M. A., Djebedijian, B., & Khaled, I. (2004). Evaluation of the effectiveness and performance of desalination equipment in Egypt. In *Eight International Water Technology Conference* (pp. 653- 668). Alexandria.

Sadras, V. O., & McDonald, G. (2012). *Water use efficiency of grain crops in Australia: principles, benchmarks and management*. Grain Research and Development Corporation.

Sadras, V. O., Grassin, P., & Steduto, P. (2011). *Status of water use efficiency of main crops. SOLAW background thematic report-TR07*. Food and Agriculture Organization of the United Nations.

Shan, L. (2002). Development of tendency on dry land farming technologies. *Agriculture Science in China,* 1, 934-944.

Sharma, A.R., Singh, R., & Dhyani, S. K. (2005). Conservation tillage and mulching for optimizing productivity in maize–wheat cropping system in the western Himalayan region. *Indian Journal of Soil Conservation*, 33, 35-53.

Sharma, R., & Bhardwaj, S. (2017). Effect of mulching on soil and water conservation-A review. *Agricultural Reviews*, 38(4), 311-315. https://doi.org/10.18805/ag. R-1732

Smith, J. B., McCarl, B., Kirshen, P., Jones, R., Deck, L., Abdrabo, M. A., Borhan, M., El-Ganzori. A., El-Shamy, M., Hassan M., El-Shinnawy, I., Abrabou, M., Hassanein, M. K., El-Agizy M., Bayoumi, M. & Hynninen, R., 2014. Egypt's economic vulnerability to climate change. *Climate Research,* 62(1), 59-70. https://doi.org/10.3354/cr01257

Soliman, A. M. M., & Soliman, M. M. (2017). Groundwater potential in the new valley southwest of the Nile Delta in Egypt. In A. Negm (ed.). *Groundwater in the Nile Delta* (pp. 585- 621). Springer International Publishing.

Sukanya, S. & Joseph, S. (2023). Climate change impacts on water resources: An overview. In A. Srivastav, A. Dubey, A. Kumar, S. K. Narang, & M. A. Khan (Eds.). *Visualization techniques for climate change with machine learning and artificial intelligence* (pp. 55-76). Elsevier. https://doi.org/10.1016/B978-0-323-99714-0.00008-X

Swain, A. (2011). Challenges for water sharing in the Nile basin: Changing geopolitics and changing climate. *Hydrological Sciences Journal*, 56(4), 687-702. https://doi.org/10.1080/02626667.2011.577037

Vala, Y. B., & Chavda, M. H. (2021). Enhancing water use efficiency through crop management practices. *Just Agriculture e-Magazine*, 2(3),1-6.

Wahaab, R. A., Mohamed, W. H. E., Ibrahim, M. S., & Hasballah, A. F. (2021). Application of water safety plans to improve desalination water supply at Matrouh Governorate, Egypt. *Egyptian Journal of Chem*istry, 64(11), 6749-6759. https://doi.org/10.21608/EJCHEM.2021.76398.3738

Wahba, S. M., Scott, K., & Steinberger, J. K. (2018). Analyzing Egypt's water footprint based on trade balance and expenditure inequality. *Journal of Cleaner Production*, 198,1526-1535. https://doi.org/10.1016/j.jclepro.2018.06.266

Wallace, J. S. (2000). Increasing agricultural water use efficiency to meet future food production. *Agriculture Ecosystem and Environment,* 82, 105-119.

Wang, D., & Cai, X. (2009). Irrigation scheduling—role of weather forecasting and farmers' behavior. *Journal of Water Resources and Planning Management*, 135(5), 364-372, https://doi.org/10.1061/(ASCE)0733-9496(2009)135:5(364)

Waraich, E. A., Ahmad, R., Ashraf, M., Saifullah, Y., & Ahmad, M. (2011). Improving agricultural water use efficiency by nutrient management in crop plants. *Acta Agriculturae Scandinavica, Section B-Soil & Plant Science,* 61(4), 291-304. https://doi.org/10.1080/09064710.2010.491954

Yu, Y. Y., Turner, N. C., Gong, Y. H., Li, F. M., Fan, C., Ge, L. J., & Ye, J. S. (2018). Benefits and limitations to straw- and plastic-film mulch on maize yield and water use efficiency: a meta-analysis across hydrothermal gradients. *European Journal of Agronomy*, 99, 138-147. https://doi.org/10.1016/j.eja.2018.07.005

Yu, Z., François, Z., Yanxin, W., & Yilian, L. (2010). Impact of climate change on irrigation requirements in terms of groundwater resources. *Hydrogeology Journal,* 18(7), 1571-1582. https://doi.org/10.1007/s10040-010-0627-8

Zhang, D., Li, R., Batchelor, W. D., Ju, H., & Li, Y. (2018). Evaluation of limited irrigation strategies to improve water use efficiency and wheat yield in the North China Plain. *PloS One*, 13(1), Article e0189989. https://doi.org/10.1371/journal.pone.0189989

Zhang, Y., Wang, R., Wang, H., Wang, S., Wang, X., & Li, J. (2019). Soil water use and crop yield increase under different long-term fertilization practices incorporated with two-year tillage rotations. *Agriculture Water Management*, 221, 362-370. https://doi.org/10.1016/j.agwat.2019.04.018