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Authors: Hindiyeh, Muna, Albatayneh, Aiman, and AlAmawi, Rana

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Water Energy Food Nexus to Tackle Future Arab Countries Water Scarcity

Muna Hindiyeh, Aiman Albatayneh and Rana AlAmawi
German Jordanian University, Amman, Jordan

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ABSTRACT: Several Arab countries face numerous environmental problems in addition to climate change, desertification, and water crisis. Multiple issues related to water and energy need to be resolved. In this paper, we examine the most important topics to be studied, and the research conducted to elucidate the importance of the water problem in the Arab region, including the gap between increased demand and a lack of resources. Water problems include leakage, pollution, and depletion of water resources. We also focus on climate change and the role of young people, software, educational institutions, and training centers in achieving water security and sustainable development objectives. The paper also investigates the idea of water harvesting, the relationship between water, food security, and energy, the role of stakeholders, and good governance in solving the water crisis by understanding the problems and framing research within a multi-year work program with financial, legislative, and scientific support. Providing incentives and the necessary research structure to coordinate all sectors and organizations concerned with water is also essential.

KEYWORDS: Water, climate change, water security, Arab region, energy, nexus, food

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CORRESPONDING AUTHOR: Aiman Albatayneh, School of Natural Resources Engineering and Management, German Jordanian University, P.O. Box 35247, Amman 11180, Jordan. Email: Aiman.Albatayneh@gju.edu.jo

Introduction

It is well known that the Arab region is experiencing a significant water challenge, the social and economic impacts that citizens and farmers will have to live with over the coming years (Aghahosseini et al., 2020). Despite national efforts to manage water demand, enhance distribution and efficiency of use, increase available water sources "through the renovation of water networks, dam construction, water supply projects, desalination plants, sanitation, and wastewater purification" projects, and engage in reuse projects. All these projects are highly demanding in terms of energy (Roni et al., 2022).

The Arab world stretches from the extreme west of North Africa across the entire Sahara zone, the Arabian Peninsula, and the Middle East to the eastern borders of Iraq. A total of 22 states are assigned to the Arabic culture, the central common element of which is the Arabic language; Figure 1 shows the Arab World countries (Sawe, 2018).

North African countries are officially considered both African and Arab. North Africa is a geographic region located in the northern part of the African continent. The countries that makeup North Africa are considered a part of Africa and the Arab world. Therefore, North African countries can be considered both African and Arab, depending on the context and the aspect being considered. However, in various United Nations (UN) documents and reports, these countries may be referred to as North African or Arab, depending on the context and the aspect being considered. Some North African countries called "Maghreb" is not officially recognized by the United Nations (UN). It is a geographical and cultural region in North Africa, referring to Morocco, Algeria, Tunisia, Libya, and Mauritania. The term "Maghreb" is used in the Arab world to refer to the western region of North Africa. The term is derived from the Arabic word "maghrib," which means "west." The term has been used for centuries and is commonly used to refer to the region and its cultural, historical, and geographical distinctiveness.

Studies have demonstrated that notwithstanding all these measures and the subsequent significant capital expenditures (Tagliapietra, 2019), Arab countries cannot close the gap between what is required and the water available for drinking, industry, and agriculture. This gap, which may become an obstacle to economic and social development, will expand and thus increase poverty and unemployment and the associated adverse effects on the environment and public health (Odhiambo, 2017).

Applied scientific research is therefore essential in addressing the physical and geographical specificity of the Middle East. When we talk about scientific research, we necessarily mean raising the Middle East and Northern Africa's (MENA) national capabilities to face the immense water challenge that will be with us for many years. Hence, it is essential to give substantial attention and support to scientific research directed at national issues. This requires providing the necessary infrastructure and financial support and enacting legislation to construct an attractive scientific research and work environment. The results are compatible with national requirements and applicable research priorities far removed from theoretical and basic research.

This will be achieved through a genuine partnership between universities, scientific research centers, and national institutions concerned with developing, distributing, and managing water resources and the national industry. These institutions provide necessary information about the relevant research issues, including the training and qualification programs and

Figure 1. Arab World countries.

scientific and professional disciplines needed to meet the challenges at the national level. This will include the involvement of universities in projects and studies conducted by water sector institutions so that researchers can closely identify the problems and issues.

This review paper aims to examine and give an overview of the most important topics and the research conducted to explain water issues in the Arab region. Furthermore, this review paper includes the gap between increased demand and a lack of resources. Water problems include leakage, pollution, and depletion of water resources. In addition, this paper discussed several aspects regarding climate change and the role of young people, software, educational institutions, and training centers in achieving water security and sustainable development objectives. The paper also investigates the idea of water harvesting, the relationship between water, food security, and energy, the role of stakeholders, and good governance in solving the water crisis by understanding the problems and framing research within a multi-year work program with financial, legislative, and scientific support.

Detailed Account of the Problems

The gap between increasing demand and decreasing supplies

The Middle East suffers from a water insecurity crisis, which is defined as the "availability of an acceptable quantity and quality of water for health, livelihoods, ecosystems, and production, coupled with an acceptable level of water-related risks to people, environments, and economies" (Grey & Sadoff, 2007; Hindiyeh, Albatayneh, Tarawneh, et al., 2021). However, perhaps the most acute crisis it faces is the lack of water supply and increased demand, negatively affecting the socio-economic and agriculture sectors. This water shortage—exacerbated by explosive population growth, the overexploitation and destruction of natural ecosystems, and popular discontent—is overshadowing the future of these countries. Enormously high birth rates are another stress factor; Figure 2 shows the annual population growth rate of the Middle Eastern countries in 2017 (Hameed et al., 2019).

According to a United Nations report, the amount of fresh water available to a person in the Arab world per year could drop to 460 m^3—less than half the 1,000 m^3 threshold for water shortages (UNDP, 2019). In this scenario, already unsustainable water abstraction will continue to increase, and already limited resources will be depleted faster than ever—a situation that could fuel further unrest. The Arab world is increasingly caught in a vicious circle. Environmental, demographic, and economic pressures exacerbate water scarcity, and the resulting unemployment and insecurity fuel social and political unrest and extremism. Governments respond with increased subsidies for water and other resources, increasing environmental challenges that exacerbate shortages and fuel unrest.

The MENA region, which includes the majority of Arab countries, has the highest water scarcity in the world, with more than 60% of the population having little or no access to drinking water and more than 70% of the region's GDP subject to high or highly high-water stress (Aghahosseini et al., 2020).

It also harms social, cultural, and religious rituals, such as baptism in the Jordan River or the preservation of Kurdish cultural heritage in the Tigris and Euphrates rivers (Hindiyeh, Albatayneh, Altarawneh, et al., 2021), as well as environmental aspects, such as water and sewage pollution and climate change's impacts, including a rise in sea-levels and reduced

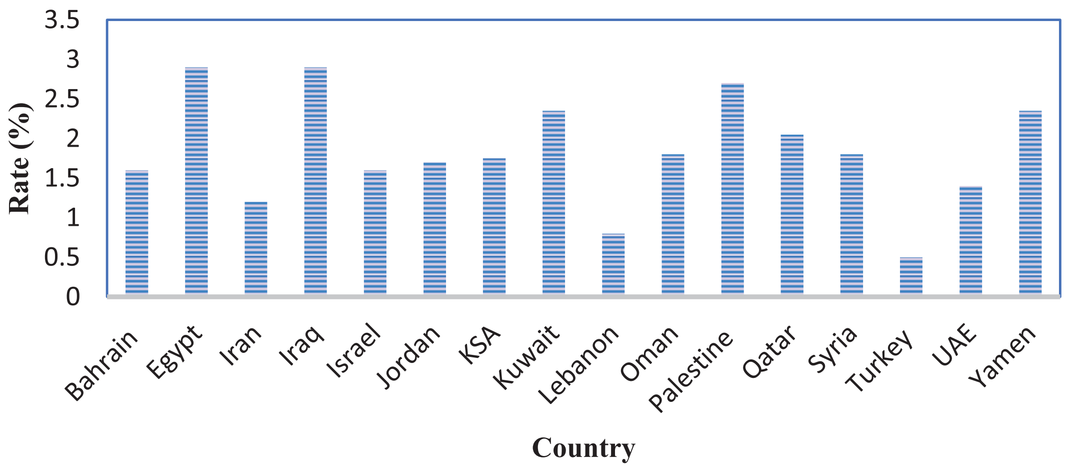

Figure 2. The annual population growth rate of the Middle Eastern countries in 2017.

rainfall (Hindiyeh, Albatayneh, Altarawneh, et al., 2021). Furthermore, negative behavior by the population that depends on the high use of water supplies resulted in a reduction in water availability per capita, which according to Facing Water Challenges in the Middle East, will be reduced by 50% by 2050 (EuroMeSCo, 2020; Hindiyeh, Albatayneh, Altarawneh, et al., 2021).

Water, energy, and food sectors

The relationship between the water, energy, and food sectors is essential in ensuring human life remains safe and comfortable. For example, a lack of access to water supplies lowers agricultural activity, exacerbates poverty, and reduces the ability of the poor to cope with risks (Hameed et al., 2019; Monna et al., 2022). A research paper entitled "The Water-Energy-Food Nexus and Process Systems Engineering: A New Focus" stated that 1.2 billion people globally do not have clean drinking water (Garcia & You, 2016). Climate change, socio-economic rise, dependency on foreign resources, and political conflicts all have an impact on the water-food link in the MENA region (McDonnell, 2014; Muhaidat et al., 2021). Therefore, it is necessary to study the relationship between all sectors and understand the factors that affect water-energy-food sectors to ensure a sustainable life. Water is a primary resource in the relationships between water-energy food and water-energy-waste. Water affects the economic sector, where its use in food production is one of the most critical challenges facing socio-economic sectors; agricultural usage accounts for 70% of worldwide water withdrawal, followed by industrial use (20%) and municipal use (10%).

Energy generation contributes 15% of worldwide water withdrawals, which might rise to 20% by 2035 (EuroMeSCo, 2020; UNESCO, 2014). Studies have also shown that the water sector depends on energy. For instance, in the Persian Gulf region, desalination units and wastewater recycling use a significant amount of energy (Abdallah et al., 2021; Albatayneh et al., 2022; McDonnell, 2014). It has reported rising CO_2 emissions in the Middle East (International Energy Agency, 2018) and the MENA region (Ardakani & Seyedaliakbar, 2019). This underscores the need to use hydroelectricity as a renewable resource to maintain sustainable life along with other renewable energy sources, including solar energy, wind energy, and geothermal heat (Albatayneh, 2021; Albatayneh et al., 2020; Jaradat et al., 2022; M. A. Khan et al., 2014). Water security has always been related to energy security. Water may be used as a source of hydroelectric power and a cooling agent for power generation (Pahl-Wostl et al., 2016). Egypt had the highest share of hydro energy consumption in the MENA region, with 50%, followed by Sudan, with 31%. Figure 3 shows the share of hydro energy consumption in the Arab world by country (Saleh, 2022).

The development of hydropower in the Nile region has faced several challenges, including limited water resources and the impacts of hydroelectricity projects on water availability. The Nile River is a significant water source for the countries along its basin, and its water resources are already heavily used for agriculture, industry, and human consumption. Developing hydropower projects on the Nile, such as the Grand Ethiopian Renaissance Dam (GERD), has further increased competition for the river's water resources. Moreover, hydropower projects can also significantly impact water quality and availability downstream, as they alter rivers' natural flow regimes and affect the basin's water balance. The GERD, for example, has raised concerns about the potential impacts on water availability for downstream countries, including Egypt and Sudan. In addition, the development of hydropower projects in the Nile region is also influenced by climate change, population growth, and economic development. In particular, climate change can significantly impact water resources, affecting the availability and quality of water for hydropower production. The development of hydropower in the Nile region faces significant challenges, including limited water resources, impacts on water availability, and the

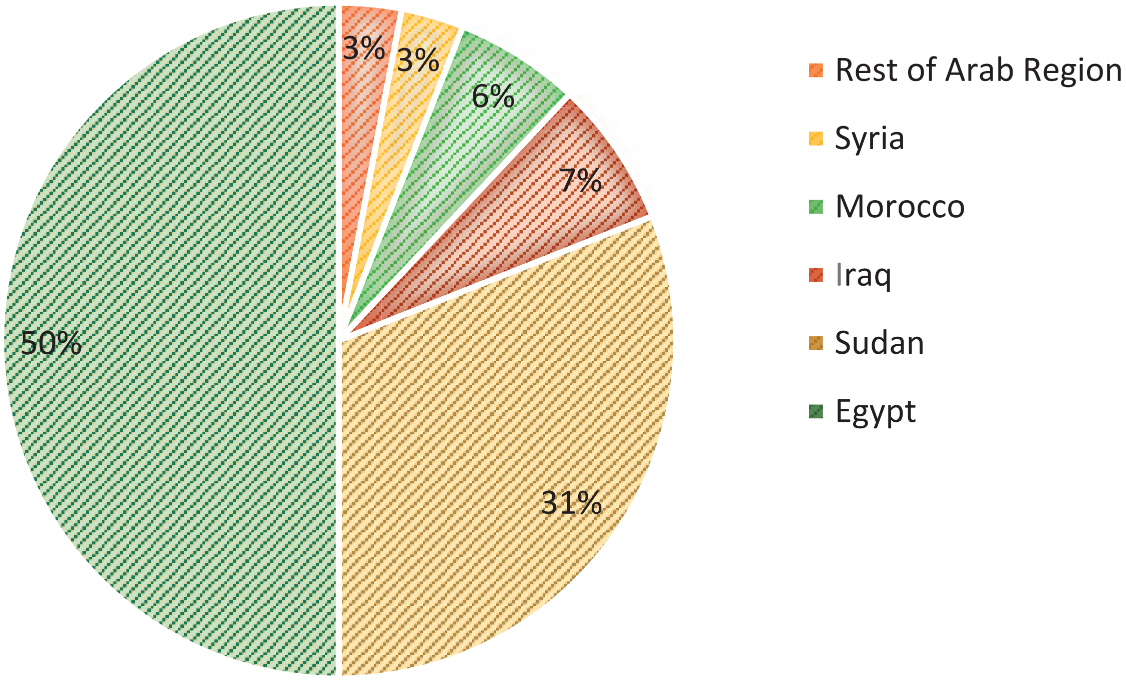

Figure 3. Share of hydro energy consumption in the Arab World countries.

influence of factors such as climate change and population growth. Addressing these challenges is essential for ensuring the sustainable and equitable use of the Nile's water resources for hydropower production (Borowski, 2022).

The earth's population is predicted to grow by around 800 million from its 2019 level by 2030, reaching 8,500 million people (United Nations, Department of Social Affairs, Population Division, 2019). This will result in irreparable environmental harm due to increased natural resource usage and the impeding of economic development, causing climate change and global warming (Albatayneh et al., 2017, 2021). It also risks people's water, energy, and food security (Pahl-Wostl et al., 2016). Therefore, the UN Convention has issued a proposal on specialized strategies to enhance environmental management on a global scale (UNCTAD, 2019). Its goal is to produce more food with existing natural resources while ensuring efficient land, water, and energy utilization, as many countries face constraints (Piñeiro et al., 2020).

Furthermore, the goal of the global food trade system should be to provide food security. At the same time, water security should be maintained by systematically addressing water scarcity through virtual water trade (von Braun et al., 2017), where water is incorporated into traded products and land degradation. The research paper "Global food and water security, trade, and market stability" includes two proposals to address the barriers between water and food security, including Improvements in the measurement of sustainable crop production practices and policies to promote dialog, information sharing, and trade agreements among food trading partners (Piñeiro et al., 2020).

Water strategic stock

Groundwater is a strategic resource for the Middle East and the second traditional water source. In Arab region countries such as Bahrain, Jordan, Oman, and Yemen, groundwater contributes more than 50% of total water withdrawals (UNDP, 2013). One of the most important reasons for dependence on groundwater is the population increase, which has decreased the per capita water consumption rate from approximately 3,500 m^3 per annum in 1960 to 700 m^3 in 2011 (Al-Zubari, 2012). This is important as excessive groundwater extraction has environmental, economic, and social impacts.

More than 50% of Arab countries depend on groundwater as the primary freshwater resource, as shown in Figure 4 (ESCWA, 2022). Groundwater use is also increasing in countries where surface water is the leading resource of fresh water. This increment is a result of several factors, such as; climate changes which resulted in variable surface water and the increasing demand due to population growth (ESCWA, 2022).

Groundwater exists as a renewable and non-renewable source. Renewable groundwater, found in shallow aquifers with a recharge area, is very limited in most Arab countries, with an average of 41 BCM per year. Non-renewable groundwater is relatively large and represents groundwater's leading source (ESCWA, 2022).

According to the United Nations Economic and Social Commission for Western Asia (ESCWA), the average total renewable water resources per capita in the Arab States is around 1,200 m^3/person/year, one of the lowest levels in the world. The primary water sources in the Arab States include surface water and groundwater. Surface water sources include

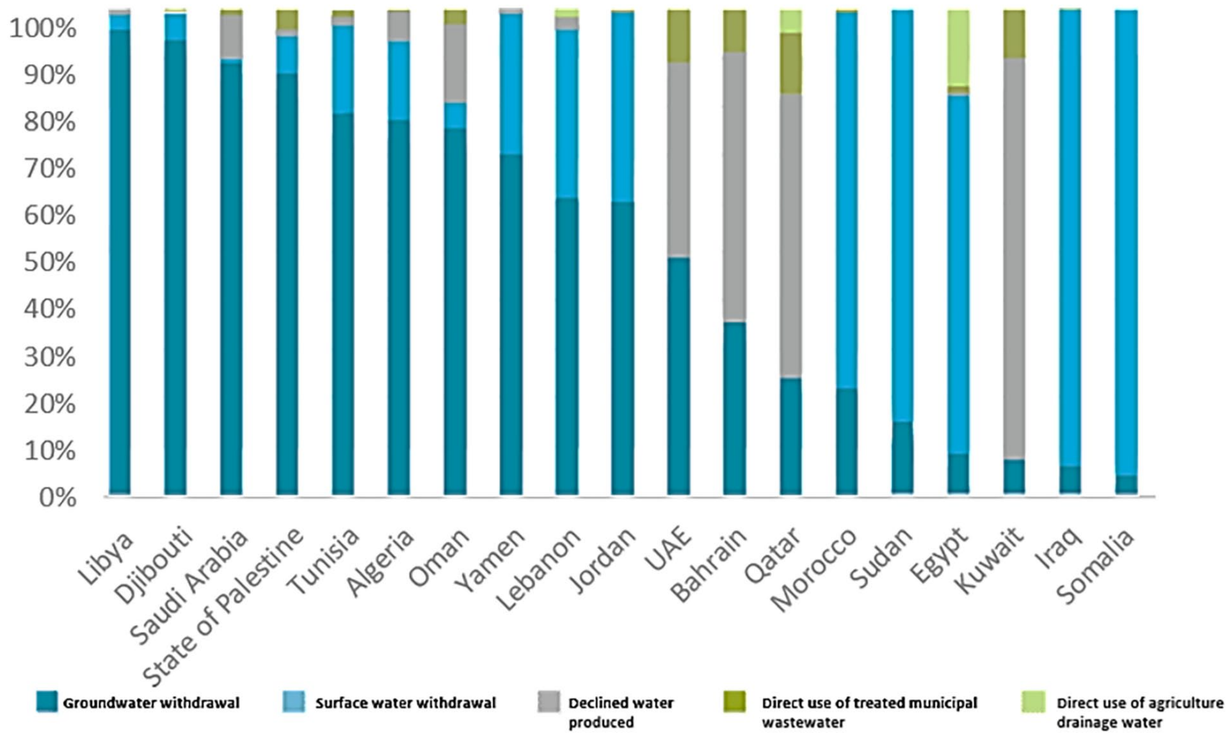

Figure 4. Water production and withdrawal in selected Arab countries.

rivers, lakes, and wetlands, while groundwater sources include aquifers, springs, and wells. In many parts of the region, groundwater is the primary water source, particularly in rural areas, due to the limited availability of surface water and the high demand for water for agriculture and other uses. However, the increasing demands for water and the impacts of climate change and other factors have put significant pressure on water resources in the Arab States. The over-extraction of groundwater, declining recharge rates, and the degradation of surface water sources have led to a decline in water availability and increasing water scarcity in the region.

With the introduction of unconventional water sources, mainly desalination, countries started to increase reliance on these resources to meet their water needs and decrease their dependency on non-renewable groundwater resources, as observed in Kuwait, Qatar, Saudi Arabia, and the United Arab Emirates. However, the percentage of unsustainable groundwater use is still high in these countries and others (ESCWA, 2022).

The Arab region is a global hotspot for groundwater overexploitation and unsustainable exploitation of water resources, which in turn leads to depletion as groundwater resources are extracted faster than they are being replenished. Estimates of the total exploitable groundwater reserves in the region are uncertain, which poses a significant risk and concern regarding these resources. Surface water consumption, such as the Nile River, and excessive groundwater withdrawal are concentrated in the Arabian Peninsula and the Maghreb (World Bank Group, 2018).

Methodology and Potential Solutions

This study was carried out to elucidate the significance of the water crisis in the Arab area. This qualitative study collects and analyzes non-numerical data using unstructured approaches such as in-depth interviews, focus groups, and participant observation. Understanding and interpreting human experiences, attitudes, and motives is the objective. The outcomes are frequently presented as narratives, themes, and patterns. The methodology started with analyzing the literature to determine the gap between rising demand and decreasing availability of supplies. Leakage, pollution, and the exhaustion of available water supplies are the three leading causes of the world's water woes. In addition, we emphasize climate change and the part that younger generations, software, educational institutions, and training facilities play in accomplishing water security and sustainable development goals. The paper also investigates the concept of water harvesting, the relationship between water, food security, and energy, the role of stakeholders, and good governance in the process of finding a solution to the water crisis by understanding the problems and framing research within a multi-year work program that has financial, legislative, and scientific support. It is also provided incentives and the required research framework in order to coordinate all of the many industries and organizations that are involved with water.

The water–energy–food (WEF) nexus

WEF in the Arab area emphasizes the interdependence and intricate interconnections between these essential resources.

The region is characterized by water shortages, high energy consumption, and food security concerns, which are predicted to deteriorate due to climate change and population expansion. Understanding the WEF nexus in the Arab area is critical for building coordinated and sustainable policies and practices to ensure the long-term management of these resources. The Arab region's water industry relies on fossil fuels for treatment, transportation, and distribution. This has resulted in excessive energy use, greenhouse gas emissions, and expenses. The food industry confronts similar challenges because of the extensive water and energy consumption for irrigation, food processing, and transportation. This has intensified resource competitiveness, potentially resulting in trade-offs between water, energy, and food security (Alkadi & Boulenouar, 2020; Alkhalifa & Ali, 2020).

Integrated water management strategies are critical for tackling the water-energy nexus in the Arab area. This involves decreasing water losses through better water distribution infrastructure and encouraging water-efficient technology and practices in the agriculture and energy sectors. There is also an increasing interest in employing renewable energy sources, such as solar and wind power, to reduce reliance on fossil fuels and improve regional energy security. The food industry is also crucial to the WEF nexus in the Arab area. Adopting sustainable agriculture techniques, such as lowering water consumption through drip irrigation, enhancing soil health, and encouraging agroforestry, may help assure food security while reducing the demand for water and energy resources. Furthermore, minimizing food waste and improving supply chain efficiency can assist in reducing energy consumption and greenhouse gas emissions while boosting food security (Alnour & El-Fadel, 2017; Naffouje & Dbouk, 2018).

Addressing the WEF nexus in the Arab area is critical for maintaining sustainable management of water, energy, and food resources. Integrated and sustainable policies and practices, such as decreasing water losses, boosting renewable energy sources, and implementing sustainable agriculture methods, can assist in ameliorating the region's interconnected difficulties.

Water losses

As stated previously, the Arab region suffers from a scarcity of water resources compared with the overall water demand. Unacceptably significant water losses occur due to high pressure on the pipes and other reasons. This leads to financial losses and failures in infrastructure, as well as posing a threat to water security (Abu-Mahfouz et al., 2016; McKenzie et al., 2012). Pumps in traditional pressurized systems run at a constant high pressure to guarantee enough water is available during peak hours. However, they have the drawback of consuming more power than necessary during off-peak hours, and the water pressure in the pipes is considerably greater than necessary at night, reducing pipe life. Consequently, water seeps through crevices, exacerbating the leaking (Abu-Mahfouz et al., 2016). Therefore, it is essential to use sensors or other technological applications to reduce losses.

Another research used a dynamic hydraulic model to plan and modify water systems. They used sensor data to assess the network's present state and automatically send control signals to other components to improve network performance and efficiency. A dynamic hydraulic model, an intelligent water network, and active network management make up the dynamic model. Today, the primary technologies used in leak detection that provide economic benefits are ground-penetrating radars, optical, moisture, sound, pressure, and robotic cameras (Abu-Mahfouz et al., 2016). Water technologies provide several advantages, including minimizing water loss, network damage, and the danger of infection in the water system and enhancing water distribution network management (Christodoulou et al., 2010).

Water harvesting

Water harvesting collects and stores rainfall, runoff, and other forms of precipitation for later use. It is beneficial in arid regions with limited freshwater resources, such as rivers or lakes. In these regions, water harvesting can provide a reliable water source for irrigation, livestock, and other purposes. Water harvesting can also help to mitigate the impacts of water scarcity and drought by reducing the dependence on traditional water sources, such as wells or reservoirs, which may be impacted by reduced rainfall or overuse. Water harvesting can improve soil fertility, increase crop yields, and provide additional income for farmers and rural communities. However, water harvesting has its challenges. In arid regions, water harvesting requires significant investment in infrastructure, such as storage tanks, pumps, and pipelines. Maintenance and repair of these systems can also be costly. Moreover, in some cases, storing water in tanks and other systems can lead to the growth of harmful microorganisms, such as bacteria or algae, which can compromise the water quality. Despite these challenges, water harvesting remains a valuable tool for improving water security in arid regions, mainly for communities and households reliant on agriculture for their livelihoods.

Water shortage is a problem in semi-arid and desert areas. To assist in alleviating worldwide water scarcity, it is critical to capture little water droplets or fog using natural or artificial water harvesting techniques. Atmospheric water harvesting is based on collecting water from humid air during the night hours using air below the dew point or a drier to capture water vapor and then refilling the water during the daylight hours using a heating process (Elashmawy & Alshammari, 2020). Sorbent materials such as hygroscopic salts, hydrogel, and zeolite are used to collect water, the most famous of which are metal-organic frameworks (MOFs) which are known as promising materials for water absorption due to their ideal isothermal shape, ability to saturate, and water binding energy, and are activated using solar thermal technologies (Kim et al., 2018). MOFs, on the other hand, have some drawbacks that raise water harvesting costs; for example, they require different mineral salts and bonds; they can only absorb water vapor from the atmosphere, and additives like carbon binder are required to convert solar energy into heat energy and improve absorption kinetics and heat transfer. As a result, low-cost materials containing solar absorbers have the potential for water collecting (J. Wang et al., 2020).

Multiple advantages of water harvesting can lead to socioeconomic gains; for instance, hydroponic harvesting can assist the cultivation process in dry environments and arid land (Baiyin et al., 2021). Water harvesting devices can provide enough water to supplement rainfall and improve and stabilize production in rainfed areas with minimal agricultural productivity. Water can also be provided through harvesting techniques in areas where the supply is insufficient for domestic and animal husbandry. These benefits will improve local people's lives, reduce rural people's migration to cities, and enhance local skills (Oweis, 2001).

Groundwater exploration

The groundwater surrounding saline lakes is a vital water resource, but recent hydrological modeling and Earth observations have identified and warned of increasing groundwater depletion worldwide (Dalin et al., 2017). Urbanization, population growth, and intensive agriculture are fundamental causes of groundwater salinity. Furthermore, unnecessarily withdrawing freshwater from the earth and using it in wasteful irrigation have also reduced the quantity and quality of groundwater, which has led to a decrease in soil fertility (Jeihouni et al., 2018). A paper entitled "A hydrogeological-based multi-criteria method for assessing the vulnerability of coastal aquifers to saltwater intrusion" demonstrated a new approach to vulnerability mapping. This method uses the ILDRT method (I), which shows the magnitude of saltwater Intrusion, groundwater level (L), existing Distance between the aquifer and the shore (D), recharge (R), and the saturated thickness of the aquifer (T) to develop a novel multi-criteria decision index, ILDRT. In addition, the Groundwater Quality Index of Saltwater Intrusion (GWQISI) and an electrical resistance method were developed to aid in managing water quality by determining the spatial variation of vulnerability throughout a coastal aquifer (Azizi et al., 2019). As previously stated, one of the primary sources of groundwater resource depletion is irrigation, an essential aspect of the international food trade since there is a set of worldwide estimates of crops for non-renewable groundwater extraction and international food trade statistics. Most Arab countries in the MENA region import nearly all of their primary crops from partners that deplete groundwater to grow them, compounding global food and water security issues (Dalin et al., 2017).

Drought and flood, marine invasion, industry, aquaculture, shipping, water projects, and urbanization are the seven primary categories of environmental contamination. Because it may disrupt the maritime environment and destroy marine ecosystems, shipping has become one of the sources of marine water pollution (Chen et al., 2012). The water is transported overland in trucks after being shipped by boat, piped, and drawn into giant water bags (Medusa bags). Importing water might assist in fulfilling expanding demand in the Middle East and North Africa. However, massive water transfer schemes could have substantial environmental consequences: Pumping water from one basin to another has the potential to have a significant impact on local ecosystems and hydrology (Roudi-Fahimi et al., n.d.).

Wastewater treatment

Over the years, water quality has deteriorated, and pollution has increased, mainly due to human activities, population growth, unplanned urbanization, rapid industrialization, and the misuse of natural water resources (Marie et al., 2012). For these reasons, obtaining the plant nutrients needed for agricultural processes, such as phosphorous and nitrogen, is essential from wastewater. Globally, the volume of wastewater available for reuse in agriculture is small compared with local levels, particularly in arid and semi-arid regions. Post-treatment wastewater can provide a stable and reliable supply and increase volume during dry and hot periods. Therefore, it is essential to encourage investments in urban wastewater treatment and reuse in agriculture to ensure an adequate water supply for peri-urban agriculture in the context of increasing urbanization (Food and Agriculture Organization of the United Nation, 2017).

There are several techniques for water treatment, but the difficulty is the high operating, maintenance, and generation costs of treatment, which includes the adsorption process, which is a superior option in wastewater treatment owing to its convenience, ease of operation, and simplicity of design (Bhatnagar et al., 2015). Activated carbon is the most common adsorbent (Chen et al., 2012), as it is replaced by by-products such as petroleum waste, scrap tires, and rice husks derived from various activities in agriculture and industry. The volume of waste can be somewhat decreased if these wastes are employed as low-cost adsorbents. Low-cost adsorbents like apricot shell can be used (Aygün et al., 2003), barley straw, citric acid (Pehlivan et al., 2012), cashew nutshell (Kumar et al., 2011), corncob (Juang et al., 2002), cotton and gingelly seed shell (Thinakaran et al., 2008), if developed, can also reduce wastewater pollution at a reasonable cost (Lofrano, 2012). Furthermore, there is a group of agricultural residues capable of absorbing various pollutants for wastewater treatment, including hemicelluloses, lignin, lipids, proteins, simple sugars, water, hydrocarbons, and starch (Bhatnagar & Sillanpää, 2010; Bhatnagar et al., 2015).

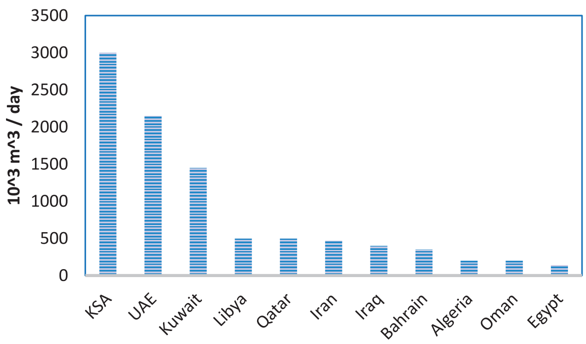

Figure 5. Desalinated water production in some Arab Countries.
Note. UAE = United Arab Emirates; KSA = Kingdom of Saudi Arabia.

Solar energy for water desalination

Desalination removes minerals and salts from saltwater water to generate freshwater for human consumption or irrigation (Zapata-Sierra et al., 2021). It is used to treat seawater and brackish water according to various parameters. Seawater desalination is accomplished on a large scale in Saudi Arabia and the Gulf countries, mainly using electricity. Figure 5 shows desalinated water production in some Arab Countries (Abu-Zeid & Hamdy, 2008). Desalination does have a role in the Arab-rich oil countries as one option among others to be considered (Abu-Zeid & Hamdy, 2008).

Solar desalination is an environmentally friendly technology that can help to address water scarcity and improve water security. This technology involves using solar energy to power the desalination of seawater or brackish water into fresh water. The use of solar energy makes this technology both sustainable and renewable, as it reduces the reliance on traditional sources of energy, such as fossil fuels, which emit greenhouse gases and contribute to climate change. Solar desalination effectively improves water security in regions with limited access to freshwater resources. In addition, solar desalination systems can be designed and implemented modularly, allowing for their deployment in remote locations. This makes them particularly useful in rural communities, where access to water and energy is often limited.

Regarding the technology, several types of solar desalination systems exist, including multi-effect distillation, reverse osmosis, and direct solar stills. Each system has advantages and disadvantages, depending on the specific application and environmental conditions. Despite the potential benefits of solar desalination, some challenges are associated with its implementation. For example, the initial cost of setting up a solar desalination system can be high, limiting its widespread adoption. Additionally, the maintenance and repair of these systems can also be complex and costly, requiring specialized training and technical expertise. Overall, solar desalination is a promising solution for sustainable water savings and improving water security in regions facing water scarcity.

Solar desalination has been so popular over the years that sailors with simple and compact solar trailers have used it to desalinate water. Solar energy is a free resource, but freshwater needs much energy to produce, and a sensitive study is required to assess the cost of solar water desalination (Compain, 2012). Water with salinity below 500 ppm is considered safe to drink. Above this value, it needs desalination, starting with the treatment of the water to be pumped from the water sources (sea or estuaries, etc.), followed by desalination, and, finally, the subsequent treatment, which includes adding minerals if necessary. Solar technologies can be divided into photovoltaic (PV) technology and concentrating solar power (CSP) technologies (Azouzoute et al., 2020). The latter mainly include parabolic troughs, Linear Fresnel reflector systems, and central tower receivers (Compain, 2012). Furthermore, several desalination processes and technologies are available to produce freshwater, including reverse osmosis, multi-stage flash (MSF), multi-effect distillation (MED), and vapor compression (VC) (mechanical [MVC] and thermal [TVC]) (S. U.-D. Khan et al., 2017). Desalination opportunities are likely to be more efficient and cleaner in obtaining and keeping freshwater available at any time through desalination technologies.

Solar-powered groundwater pumping systems

The technology for pumping water from its source to the place of demand has been used in remote areas where water is unavailable and cannot be easily used. Traditionally, the electricity generated has primarily been supplied by burning fossil fuels from national grids (Aliyu et al., 2018). This has led to a problem in providing water to remote areas that cannot be connected directly to a national network station (Meah et al., 2008), in addition to the environmental problems resulting from burning fossil fuels. Therefore, researchers are turning to alternative methods of pumping water that rely on renewable sources. There are multiple technical alternatives to powering or lifting groundwater systems, including wind turbines, windmills, generators, and solar arrays. Solar-powered groundwater pumping systems are robust and mobile and have long-term economic benefits.

Moreover, alternative energy is more cost-effective than the nearest electricity grid and cleaner than traditional methods. Therefore, solar-powered groundwater pumping systems have been adopted for livestock and remote watering applications (Colorado State University Extension, n.d.), grassland restoration, electricity generation, desalination, drinking water, mining application, and domestic uses (Aliyu et al., 2018). There are many factors to consider when selecting the appropriate water pumping technology, such as regional feasibility, water demand, system efficiency, and initial and long-term costs (Colorado State University Extension, n.d.).

Networks for monitoring water development

Given the scarcity of water across the entire world and in the World region in particular, and because of frequent and continuous water problems such as leakage, pollution, and increased demand, it is necessary to devise environmental monitoring systems specialized in the field of water to monitor and manage water quality, as well as create an information base for use by all bodies involved in research and implementation. Regrettably, developing countries rely on traditional water sampling methods and analysis methods. Due to a lack of technical knowledge and financial shortages, they lack the capabilities to obtain and analyze the data in real-time and quickly disseminate the collected information, which is necessary for the pursuit of effective water quality monitoring, not to mention arduous (Demetillo et al., 2019).

A Wireless Sensor Network (WSN) is suitable for monitoring the physical and chemical properties of water and water quality and has low cost and human resources requirements (De Marziani et al., 2011). Moreover, it has notable advantages, such as its portability (Rashid & Rehmani, 2016), the ability to obtain data almost instantaneously, and the ability to record and publish data as quickly as possible (Can & Demirbas, 2015). Because the electronic component of WSN applications does not tolerate water intrusion and moisture, WSN applications for water areas present more challenges than terrestrial WSN applications (Perez et al., 2011). Several studies have been conducted that complement research on changes in the various components of water storage, including surface and groundwater in the Middle East. These have reanalyzed the components of terrestrial hydrological storage from 1980 to 2019 by combining satellite remote sensing observations with a hydrological model. The results reveal a significant depletion of water storage in all regions of the Middle East, a significant depletion of water in groundwater and arid and semi-arid regions, and a further deterioration of water storage in the eastern, northwestern, and western parts of the region. There is a relationship between reduced water storage and other environmental factors, such as loss of vegetation cover (Khaki & Hoteit, 2021).

Off-grid rural water and energy systems design

Economic and social growth and poverty alleviation depend on the quality and availability of water and energy resources. The Middle East and North Africa region suffer from water scarcity, poor water management and distribution, and a shortage of water and power facilities. Therefore, it is essential to highlight this crisis to address it and avoid aggravating the problem.

Investments that alleviate the power and water facilities shortage can be encouraged by identifying the economic and geographic problems associated with expanding utility networks and implementing distributed power systems in low-income rural environments, as some countries have done (Tabatabaei et al., 2017). Pricing policies have been used to stimulate the development of clean technology and bring about changes in energy behavior. In addition, various utilities are priced according to the technical configuration of the system (Li et al., 2014; Mancarella, 2014; Zhou & Yang, 2016). Furthermore, decision-makers can also propose a tariff policy based on the economic and environmental performance of the system (Parra & Patel, 2016). A multi-objective pricing and tariff strategy (environmental, economic, and social) for water and energy utilities has been proposed that considers regulatory market constraints on developing countries. The price of water and power utilities is determined based on a trade-off between different objectives to reduce the total annual cost of the system. This also reduces the amount of land used, creating job opportunities and improving the social status of employees. Two methods have been proposed for setting the prices of the energy and water utilities provided by the system. The first is based on flat-rate tariffs and setting a low-interest rate to stimulate the domestic economy. The second is based on energy consumption levels per hour of water and on proposing reduced prices to the end-user.

Economic feasibility for irrigation methods

Much of the Middle East depends more on irrigated agriculture than rain-fed agriculture. Thus, they draw groundwater and other water sources to irrigate plants significantly as rainfall decreases due to climate change and global warming. To deal with the lack of water available for irrigation, researchers are striving to find the most efficient irrigation systems as a feasible way to reduce water use (Reynolds et al., 2020).

Three effective irrigation systems have been identified: conventional irrigation systems, sub-surface drip irrigation, and low-altitude sprinkler systems, with efficiencies of 60%, 97%, and 88%, respectively. Despite the high efficiency of sub-surface drip irrigation, it is a slight advantage because the costs associated with installing and maintaining the system can be prohibitive for producers. For this reason, another system, mobile drip irrigation, has been used, similar in its efficiency to drip irrigation (Amosson et al., 2011). Moreover, some articles have indicated that 50% of fertilizers can be saved through drip irrigation by achieving similar net returns (Kombali, 2017). A research paper entitled "Comparison of traditional and modern deficit irrigation techniques in corn cultivation using treated municipal wastewater" compared traditional deficit irrigation with partial root-zone drying. The results indicated that partial root-zone drying methods are superior to traditional irrigation. Determining the type of irrigation system and water needs depends on multiple factors related to the plant, such as dry and fresh weight, leaf area index, dry biomass percentage, and others (Melody et al., 2010). In summary, modern irrigation techniques such as drip irrigation are better in terms of the cost of use and effectiveness, regardless of type, and more economical than traditional irrigation techniques.

Improve energy efficiency and reduce operating costs

There is a strong interrelationship between water resources and energy. For instance, water is used to produce electrical energy, and large amounts of energy are consumed in water collection, treatment, distribution, wastewater provision, and recycling. Thus, it is necessary to maintain water quality at low costs by improving energy-saving technologies to increase energy efficiency. These technologies can improve water quality, increase production, reduce operating and maintenance costs, and raise energy efficiency, stimulating economic and social growth. Energy has the highest operating cost for a water system after personnel and supply costs. Depending on the region, the water system consumes energy at high rates of up to 80% for water and wastewater transmission and treatment, municipal water treatment and distribution costs, supply costs, and more (Melody et al., 2010). Although a small percentage of energy consumption is used in the treatment of underground wells, it is large, reaching 99% in pumping operations attributed to collection and distribution (EPA). Water and energy storage can improve efficiency and quality and reduce operating costs (Fuentes-Cortés et al., 2019).

ENERGY STAR is a voluntary program administered by the US Environmental Protection Agency (EPA) in coordination with the US Department of Energy (DOE). It aims to improve the strength of competitive industries by increasing energy efficiency and reducing environmental impacts. It also estimates the energy required to operate drinking water and wastewater facilities (Melody et al., 2010). This means the energy prices and operating costs of the water system can be reduced, efficiency is increased through water and energy storage, and energy use in pumping, distributing, transporting, collecting, and treating water can be improved.

Water security and sustainability

Numerous water problems, such as scarcity, leakage, and pollution, threaten water security. Many other phenomena are directly related to water security. They can affect it, such as climate change, agricultural and financial aspects, and the successful management of water by governments to prevent this resource from running out. Many researchers have focused their studies on the response of water resources to climate change. For instance, one study analyzed the effects of climate change and human activities on the hydrological process and water resources, proposing that global warming and excessive human activities are causing the hydrological process to deteriorate. This is compounded by the fact that the spatial distribution is not proportional to water resources and land, which has led to a regional water crisis (X. Wang et al., 2020).

Successful management and good governance ensure the development of social, environmental, economic, and industrial aspects. From an environmental point of view, the water aspect in particular, including rainwater management within national water management plans with successful leadership, ensures that water security is achieved at a high rate, enabling a comprehensive package of options to be proposed to meet desired societal goals and needs for water security. Regrettably, only one study has encouraged the inclusion of water security within the remit of national and international policy and for it to be a priority of the government so that the latter distribute water resources equitably among all users to enhance social life, health, employment, economic and development activity, and provide healthy and enjoyable recreational and cultural environments (Pahl-Wostl et al., 2016). The WWF Marseille document referred to the use of water security as a theme for the following priorities of the Asia Pacific regional process: addressing household water and sanitation needs in all societies; supporting productive economies in agriculture and industry; developing vibrant cities and towns; building societies that are resilient to change, and integrating promotion as a tool for managing water resources (Pahl-Wostl et al., 2016).

Water security affects the country's GDP. Water stress is expected to occur by 2050 due to the increased demand for freshwater exceeding 40% over the next two decades, putting 45% of the global GDP at risk. The analysis finds that water scarcity will increase in all countries in the region over the coming decades, primarily due to growing demands (https://blogs.worldbank.org/arabvoices/water-food-and-energy-arab-world-collective-challenge).

Recent reports and research, including "High and Dry: Climate Change, Water and the Economy" issued by the World Bank (Poberezhna, 2018), have emphasized that an increase in the price of water due to climate change could cost a significant amount of GDP in the event of water scarcity. In regions such as the Middle East, the Sahel region of Africa, Central Africa, and East Asia, water resources lack cooperation, financing, and investment, despite their global importance. Several factors have led to the decline in the number of water utility projects and the delay in the progress of industry and other water-related aspects. The main factors can be influenced by the following:

Level of community participation and ownership

Training and education level of the project leaders

The governance structure of the project

Basic management skills of leaders, among other factors, such as financial and technical support.

For instance, investment in the water sector in 2016 was \$1.9 billion, 53% lower than the 5-year average of \$4.06 billion. As reported by the World Bank in "The Private Participation in Infrastructure" 2016 report, the overall number of water utility projects in 2016 was 88% lower than the average of the previous 5 years (Poberezhna, 2018; World Bank, 2016). Thus, water must be financed by stimulating investments in water infrastructure, information technology, institutions, and communities. It is vital to establish appropriate incentives for water pricing and tariffs that encourage efficient water management, improve water quality, and reduce leakage and pollution (Melody et al., 2010). Regarding Africa and according to the World Bank, community-based projects in the African region have performed better than other projects. However, only one in five community–based development projects was likely to be sustainable (Poberezhna, 2018).

Water security is related to food, energy, and human health. The lack of potable water, sewage, and water pollution have caused severe health problems. According to the World Health Organization, waterborne diseases still account for half of all child deaths worldwide (Pahl-Wostl et al., 2016). Furthermore, the World Bank estimates that 1.7 million people, 90% of children under five, die annually due to a lack of sanitation and safe drinking water (World Bank, 2013).

Multiple strategies for maintaining water security can be summarized as water management through risk reduction. For example, controlling rivers and keeping water away from landscapes and human life using structural measures such as dams or reservoirs to protect cities and dry land cultivation from flooding; the detection of hazards in early stages using remote sensing and automation devices to reduce the penetration of water resources (Pahl-Wostl et al., 2016); working to address barriers between water and food security, including improvements in measuring sustainable practices in crop production and policies to facilitate dialog and information exchange, and strengthen trade agreements between food trading partners (Piñeiro et al., 2020); financing various water projects and encouraging investments that improve infrastructure (Melody et al., 2010). In addition, rainwater harvesting collectors and pumping systems, along with water treatment and storage units, have been used in rural communities to improve the coverage of water facilities in isolated areas (Kelly et al., 2018).

As discussed previously, the concept of water security must be included in the political plan of the state, but to what extent are these plans implemented and the concept of sustainability activated in the water system? In previous experiments with other concepts, such as food security, for example, a small part of food sustainability has been presented as an issue of food access at a human level (Cook & Bakker, 2012) or as a fossil fuels problem. Ongoing debates and disagreements about water security in areas where this occurs have created tensions between countries that do not lead to sustainable solutions (Fischhendler & Katz, 2013). Notwithstanding the difficulty of achieving sustainability in water security, it is necessary to continue research and spread awareness about vital concepts that concern humanity, such as water security and others, to devise a better approach that contributes to solving the problem as effectively as possible.

Young people must contribute to reaching sustainable environmental objectives in all sectors to achieve sustainability, given that they are more conscious than ever of their huge interest in identifying and tackling global concerns such as climate change, conflict, and poverty. Young people are also viewed as agents of change. According to Sam Loni, a Global Coordinator of the Sustainable Development Solutions Network (Youth), school and university students can react to instruction focused on tackling complicated problems. Their educational and research initiatives provide individuals with the information they need to comprehend and engage in Sustainable Development Goals and implement that knowledge. In addition, various UN organizations are working to improve young people's views to achieve Goal 16 on youth involvement (Izquierdo, n.d.; UNESCO, 2018). Furthermore, work will be undertaken on the participation and cooperation of stakeholders with young people to develop policies that reach sustainable development solutions through social media, increasing opportunities for greater recognition and creating stronger solidarity among youth. This must be preserved, especially in light of the COVID-19 pandemic (Mohd Yusof & Ariffin, 2021).

This message highlights the importance of universities, schools, colleges, training centers, unions, and any governmental or private institution in qualifying the sector's future leaders. This will enable them to serve the Arab region by contributing to realizing and disseminating the concept of sustainable development and understanding all interrelated water sciences such as engineering, science, agriculture, irrigation, economics, management, and other required sub-disciplines of computer and finance. Youth engagement can also be achieved by shifting school service-learning projects, diplomas, bachelor's, and job-related programs to align explicitly with the SDG framework.

Centers of Excellence for specialized studies (CoE)

The Center of Excellence (CoE) is aware that this is "a vital component for any organization wishing to achieve a digital transformation of its business." CoE aims to increase productivity, reduce costs, and improve production quality by creating operational initiatives. It is helpful in a range of cases, including the following (Nexus Integra EN, 2021):

- Arranging priorities in any project, along with the correct organization of resources, saves time and effort and speeds up production, thereby improving the financial situation.
- CoE facilitates communication because the center serves as a link between individual elements and governments.
- CoE achieves collaboration, exchange of ideas, and access to information quickly among all project participants, regardless of their geographical location or work location.
- Flexibility in operations is subject to change and improvement in production by creating reports that help make strategic decisions.

- Committing to investment projects, eliminating inefficient practices, and reducing the time required to implement new skills and technologies, resulting in restructuring resources and operating costs.

Concerning water, “The African Networks of Centers of Excellence on Water Sciences PHASE II (ACE WATER 2)” is a project that aims to promote sustainable capacity development at scientific, technical, and institutional levels in the water sector. The project supports 20 African Networks of Centres of Excellence in Water Science and Technology (CoEs) that conduct cutting-edge scientific research on water and related sectors. The expected results of this project are maps of seasonal changes, climate change, climate extremes such as floods, and future climate scenarios (Atheru, 2018). The project focuses on the objectives of the Center of Excellence and implements all the operations and benefits. The Center seeks to achieve, which indicates the importance of having centers of excellence in various regions and specializations.

Water software production

Software modeling and production in different fields help to verify the proposed theories and reduce risks and costs during project implementation. Modeling can be applied to architecture, aviation, renewable energy, etc. In the field of water, there is an abundance of software that collects and analyzes data to reach different results and then uses these to run the project with the least possible time, effort, and cost.

In order to study the hydraulic effect of leakage, MATLAB-based educational software (UAleaks) has been developed. UAleaks was developed to evaluate the impact of water loss and leakage in cases where manual calculations cannot address real network leaks. For this, the software has been developed into a new leakage network model and generates accurate calculations in the fields of water and energy (Pardo & Riquelme, 2019). UAleaks can also be used for sizing small solar water heating systems by allowing the sizing of natural and forced circulation systems and modifying the input parameters at any time, making it possible to simulate different situations and identify optimal technical and financial solutions (Camargo Nogueira et al., 2016). Some GIS software is free and open-source. GIS programs help water management systems by collecting, transmitting data, and conducting an inventory of water locations in the region and then presenting it as a map, thereby organizing a large body of information in a way that makes it easy to manage and understand (Fernández et al., 2016).

Instrumentation Control and Automation (ICA) are becoming increasingly prevalent in water, and wastewater treatment plants that depend on ensuring treatment systems run efficiently, achieve desired performance at a reasonable cost, and manage large fluctuations in loading (Olsson et al., 2005). Today, there is a greater focus on using ICA to improve the ability of existing systems to handle the increased load due to overpopulation and urban growth. Also, conventional planning for the increased demand for drinking water and wastewater services involves designing large treatment plants. Thus, ICA can help lighten the load, temporarily shift operational goals, and temporarily or even permanently reduce load. Efforts are also being made to develop and improve the ICA system for managing water supply systems to reduce energy requirements, support early detection, ensure localization of leaks, and meet customer demand at the lowest cost. Numerous technology “push” forces will make the application of ICA increasingly economical (Yuan et al., 2019).

In the Arab region, water is the most critical natural resource. The Arab world is facing significant challenges; the lack of water exacerbates the conflicts. Some of the reasons for the scarcity are homemade plans. Nowhere is fresh water more scarce than in the Arab world. The region is home to the world’s poorest water resource states or territories. This water shortage—exacerbated by explosive population growth, the overexploitation and destruction of natural ecosystems, and popular discontent—is overshadowing the future of these countries.

Urgent action is needed to break this vicious circle. First, countries must phase out the production of water-intensive crops. Grains, oilseeds, and beef should be imported from water-rich countries where they can be produced more efficiently and sustainably. For crops that continue to be grown in Arab countries, adopting more advanced technologies and best practices from around the world can help reduce water use. Membrane and distillation technologies can purify deteriorated or polluted water, treat wastewater, and desalinate brackish or seawater. Highly efficient drip irrigation can increase the region’s fruit and vegetable production without excessive water. Another important step would be to expand and improve water infrastructure to accommodate seasonal water availability, make distribution more efficient, and capture rainwater to provide an additional supply source.

To reduce poverty, it is imperative to achieve water security and vital aspects related to this, such as providing water, creating job opportunities for young people, and promoting their cooperation with stakeholders and decision-makers to confront the problem. This is due to the essential role young people play and their awareness of their responsibility in identifying global problems such as climate change, poverty, and conflicts. However, the requirements for success are not limited solely to those mentioned but instead require the ability of the concerned authorities to understand the problems and establish a research framework within work programs for many years, provide financial and legislative support, offer scientific incentives, and provide the necessary research structure to coordinate all sectors and organizations concerned with water so that all participants in such programs. Despite the lack of achievement in applying the concept of sustainable development in areas such as food security, we must not feel discouraged and instead strive to spread awareness through campaigns and conduct research on those concepts in general and water security in particular to reach a better solution to the problem.

The importance of establishing training and rehabilitation centers in cooperation with the water-energy-food (WEF) nexus in the Arab region highlights the interdependence and complex interconnections between these critical resources. The region is characterized by water scarcity, high energy demand, and food security challenges, which are expected to worsen due to climate change and population growth. Understanding the WEF nexus in the MENA region is essential for developing integrated and sustainable policies and practices that can ensure the sustainable management of these resources.

The water sector in the Arab region is heavily dependent on fossil fuels for the treatment, transportation, and distribution of water. This has resulted in high energy consumption, greenhouse gas emissions, and costs. The food sector also faces similar challenges, with the heavy use of water and energy for irrigation, food processing, and transportation. This has increased resource competition, leading to potential trade-offs between water, energy, and food security.

Integrated water management practices are crucial for addressing the water-energy nexus in the Arab region. This includes reducing water losses through improved water distribution systems and promoting water-efficient technologies and practices in the agriculture and energy sectors. There is also a growing interest in using renewable energy sources, such as solar and wind power, to reduce the dependence on fossil fuels and improve energy security in the region.

The food sector also plays a critical role in the WEF nexus in the Arab region. Adopting sustainable agriculture practices, such as reducing water use through drip irrigation, improving soil health, and promoting agroforestry, can help ensure food security while reducing pressure on water and energy resources. In addition, reducing food waste and improving supply chain efficiency can help to reduce energy consumption and greenhouse gas emissions while improving food security.

Addressing the WEF nexus in the Arab region is essential for ensuring the sustainable management of water, energy, and food resources. Integrated and sustainable policies and practices, such as reducing water losses, promoting renewable energy sources, and adopting sustainable agriculture practices, can help mitigate the region's interrelated challenges.

Educational institutions, unions, and all relevant sectors in achieving water security and, thus, its impact on food security, energy, health, and human security have also been clarified. The presence of centers of excellence will help solve the Arab World water crisis by promoting sustainable capacity development in the water sector. They will also help to organize projects that will save time and effort and speed up production, thus improving the financial situation. Furthermore, they will enable exchanging ideas and information to be quickly obtained among all project participants and encourage investment projects. The common issues facing the Arab country's water crisis were raised and discussed in this paper. This includes water harvesting, how to achieve water security, the importance of achieving sustainable development concerning water, the problem of water pollution and leakage, and the impact of energy efficiency on the operational cost of water systems, where water and energy storage increase energy efficiency and reduce costs.

Conclusions

A water-energy-food nexus is a multi-disciplinary approach that seeks to address the interlinked challenges of water scarcity, energy insecurity, food insecurity, and climate change in the Arab region. In conclusion, the water-energy-food-climate nexus can provide a holistic approach to solving water scarcity in the Arab region by addressing the interlinked challenges of water, energy, food, and climate change. The following are some ways in which the nexus can help to solve water scarcity in the Arab region:

- Integrated Water Management: Integrating the management of water, energy, and food resources can help optimize their use and increase the system's overall efficiency. This can result in a more sustainable and resilient water supply and help to address water scarcity in the Arab region.
- Climate-Smart Agriculture: Climate-smart agriculture involves using sustainable and resilient practices to climate change's impacts. This can help to reduce water use in agriculture and increase the efficiency of water use in the sector.
- Renewable Energy for Water Desalination: Renewable energy sources, such as solar and wind, can power water desalination plants, reducing the energy costs and greenhouse gas emissions associated with water production.
- Water-Efficient Energy Production: The production of energy can also be made more water-efficient, reducing the amount of water required for energy production and helping to address water scarcity in the Arab region.
- Water-Saving Technologies: The development and implementation of water-saving technologies, such as drip irrigation systems, can help reduce water use and improve water use efficiency in various sectors.
- Desalination: Desalination of seawater and brackish water is a standard solution for water scarcity in the Arab region, where access to fresh water is limited. Many Arab countries have already invested in desalination technology, and this trend will likely continue as the water demand increases.
- Reuse and Recycling of Water: Reusing and recycling wastewater can also help to address water scarcity in the Arab region. This involves treating wastewater to remove contaminants and using the treated water for non-potable purposes, such as irrigation or industrial processes.

- Water Harvesting: Water harvesting involves collecting, storing, and using rainwater for various purposes. This method is beneficial in arid regions, where water scarcity is a significant challenge.
- Improved Water Management: Improved water management, including more efficient irrigation systems and better water allocation policies, can also help to address water scarcity in the Arab region.
- Climate-Resilient Infrastructure: Building climate-resilient infrastructure, such as dams and water storage systems, can help to ensure a stable and reliable water supply, even in the face of changing weather patterns and increased water demand.
- Conservation and Education: Raising awareness about the importance of water conservation and promoting water-saving practices can also significantly address water scarcity in the Arab region.

In summary, a combination of these solutions and a continued investment in research and development is likely to be the most effective approach to addressing water scarcity in the Arab region.

Recommendations and Future Actions

To improve the water system and achieve water security in the Arab waters, their social and cultural characteristics become more sustainable with their unique and complex technical dimensions. It is necessary to conduct severe and specialized scientific research in the field of water that focuses on the gap between increasing demand and diminishing supply, the Water- Energy- Food sectors relationship, and the relationship between water and health. Also, it is necessary to study the concept of water security, which can only be achieved through research on numerous other concepts, such as the impact of climate change on water, as many studies have indicated that global warming and excessive human activities have resulted in the deterioration of the hydrological process. It is also essential to assess the impact of good governance on public water management at current and expected various levels and concerning various aspects (social, industrial, etc.), state financing policies on water and their effects on water security, and ways to develop strategies to achieve water security in the MENA region and the Middle East in partnership with relevant governmental and private agencies. It is also essential to include rainwater management within the national water management plan to realize water security at a high rate through comprehensive proposals that meet the desired goals and societal needs. These include supporting the economy necessary for production, agriculture, and industry sectors; developing cities to become vibrant; and building societies capable of change.

Moreover, water problems should be studied, including water loss, pollution, and groundwater withdrawal. A suitable solution should be designed for rural areas with a poor supply network and water harvesting problems. There should also be a focus on exploring groundwater wells, using solar-powered groundwater pumping systems, and increasing energy efficiency to reduce operating costs for water systems, all of which work to improve and develop Arab world waters. It is also essential to involve young people in achieving sustainability concerning water and establish educational institutions (schools, universities, training courses, and rehabilitation centers). These will contribute to spreading awareness of concepts that help develop water systems in the Arab region by changing the educational content to focus on sustainable development concerning issues such as water, food, energy, and so on. Young people must engage with stakeholders and decision-makers to enact laws supporting these ideas. Moreover, it is essential to work on awareness-raising initiatives and campaigns that highlight the need for young people to express their opinions on issues of critical concern to the world. Finally, a feasibility study, software design, and centers of excellence for water-related issues such as irrigation methods and others are required to reduce material losses, increase efficiency in time and effort, and achieve good management.

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M.H. conception or design of the work. A.A. Data analysis and interpretation; Drafting the article; Critical revision of the article. R.A. Data collection.

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ORCID iD

Aiman Albatayneh https://orcid.org/0000-0003-0829-7526

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