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Sustainable Water Management Using Simulation Models Under Water Scarcity Conditions and Climate Change Scenarios in Egypt: A Review

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Abstract

The importance of sustainable development has increased in almost every field of science. When there are no shortages and the system is able to adjust to changing water needs, water resource management is considered sustainable. The management of the water resources system is actually carried out in a completely unpredictable environment because it is difficult to predict future trends in demand, legislation, or environmental circumstances. The growing problem of finite water supplies pushes experts and scientists to handle water resources far more deftly, ensuring that major challenges are surmounted and that water resources are maintained to guarantee that demand is satisfied under any conditions. The study showed that cooperation between researchers and practitioners is necessary to optimize the few water resources and achieve the objectives of water management. This study concluded on the importance of using simulation models in the sustainable management of fresh water, as well as with new and unconventional sources of irrigation. It also emphasized the importance of using the SALTMED simulation model as one of the most important new models with high accuracy in simulating the actual conditions of experiments under Egyptian conditions.

Keywords: Sustainable water management, simulation models, SALTMED simulation model, water scarcity, climate change, limited water resources in Egypt.

1. Introduction

Agriculture is essential to the economic growth of every nation. Supplying food for the existing population has become a challenging task due to population growth, frequent changes in climate, and limited resources. In agricultural practices, irrigation is extremely important, particularly when water is scarce [1].

The Nile River provides the majority of Egypt's irrigation needs. The annual share of water per capita is falling as a result of the population boom and the restricted and steady supply of water from the River Nile, which is 55.5 billion m^3 annually. Thus, there was a shortage of water. Furthermore, since Egypt's agricultural sector uses the majority of its water resources, primarily from the Nile, and because upstream nations intend to reduce Egypt's fixed annual income share, Egyptian agricultural policy must use all available resources to rationalize water use across the board and increase crop water use efficiency [2]. In arid Egypt, a major obstacle to food production is water constraint. By modernizing and creating cutting-edge, sustainable technology, it is crucial to preserve irrigation water and minimize consumption [3, 4].

The agricultural sector in dry Egypt faces a challenging problem in figuring out how to boost crop productivity by irrigation with less water volume, as this is now recognized to increase crop water yield. (5). Egypt's water supplies are severely limited and scarce, and this problem is getting worse as the country's population grows faster. Aside from the growing rivalry for scarce water resources, the majority of new irrigation technologies are in a race

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to improve and raise crop yield and quality as well as water productivity [6].

The global population grows by about 80 million people a year, and water consumption rises globally by 1% annually on average [7]. If the current trend of water use continues, only 60% of the world's water needs will be met by 2030 if the appropriate policies are not adopted [8]. FAO1 estimates that the agriculture sector will need to boost output by 60% by 2050 to meet the demands of population growth [9].

Water shortage is rising as a result of climate change and the construction of the Grand Ethiopian Renaissance Dam [10,11,12]. Climate change has resulted in decreased rainfall in northern Egypt, an erratic yearly inflow into Lake Nasser, and increased water requirements for agriculture [13].

Egypt now faces an annual water shortage of 13.5 billion cubic metres (BCM/yr), and this figure is expected to rise. Increasing control over drainage systems to reduce drainage water outflow is one strategy to reduce water scarcity [14]. The primary issues with sustainable water management are uncertainty and ineffective and inefficient management.

Building infrastructure alone won't be sufficient to ensure the sustainability of water resources; management operations must be optimised as well. Water operation management problem solving using simulation and optimisation can handle issues with reservoir operation, hydrology modelling, irrigation water allocation, and water supply—all crucial components of water management that have a direct impact on the sustainability of the water system management. The management of water supply for different users, the best way to allocate irrigation water to maximise crop productivity, the optimisation of hydrology model parameters for accurate hydrological prediction, and the appropriate operation of reservoirs can all be resolved through the use of simulation and optimisation techniques. This guarantees water availability even in situations where water resources are limited.

Many optimization strategies have recently been created and successfully used to address issues with the management of the water resources system. Dimensionality problems and long calculation durations are two common problems with water management optimization that have been reduced by merging computational intelligence algorithm models with conventional optimization techniques. In addition, the planning and administration of water resources systems will benefit greatly from the integration of simulation and optimization approaches. The system performance, which has already been optimized by the optimization algorithm methods, can then be evaluated using the simulation methodology because completing the preliminary water resources system optimization will cut down on the amount of time needed for simulation [14].

This essay reviews the main issue that irrigated agriculture is currently facing: increasing water productivity in irrigated agriculture to produce more food with less water per unit of output. In order to reduce adverse effects on the environment, all parties involved in irrigation and water management—managers, farmers, and laborers—need to be steered towards conserving water and minimizing waste through suitable rules and incentives. Only with the right water-saving technologies, management tools, and regulations in place will this aim be accomplished. It will be important to observe how creative concepts and methods are applied.

2. CLIMATIC CHARACTERIZATION OF EGYPT

Egypt has a semi-desert climate with hot, dry summers, mild winters, and little to no precipitation. The nation is known for its exceptional wind regimes, with great locations throughout the Mediterranean and Red Sea shores. In the majority of Egypt, the summers are hot and dry, whereas in the Delta and along the Mediterranean Coast, they are humid [15].

The country can be divided into three main climatic regions (Table1):

• The climate is Mediterranean along the Mediterranean coast, close to Alexandria and Port Said. Summers are hot and dry, and winters are moderate and humid in this area. In winter, average temperatures range from 13 to 21 degrees Celsius, while in summer, they range from 24 to 32 degrees Celsius.

• The climate in the inland regions, which includes the Nile Delta and Valley, is hot desert. These areas have scorching summers, with highs between 30 and 40 degrees Celsius. The average temperature during the milder winters is between 14 and 20 degrees Celsius.

• The climates of Egypt's eastern and western deserts are arid. These areas are known for their

extremely hot days and chilly nights. Winter temperatures typically range from 8 to 18 degrees Celsius, whereas summer temperatures can reach 45 degrees Celsius or higher [16].
(https://www.worlddata.info/africa/egypt/climate.php)

Sudan, Sudan, and Egypt, according to [19]. Only 14% of the Nile flow—the White Nile—comes from the Equatorial Lakes region, with the remaining 86% coming from the Ethiopian Plateau (Blue Nile: 59%, Sobat: 14%, and Atbara: 13%) [20].

Table (1) detailed climate data click on the name of the region.

Region	Temperature max Ø day	Temperature min Ø night	Sunshine hours	Rainy days	Precipitation	Humidity
Sinai Peninsula	29.3 °C	17.6 °C	3,395 h	11	69 l	51.0 %
Nile Delta	27.8 °C	17.4 °C	3,285 h	17	91 l	59.0 %
Nile Valley	31.8 °C	17.7 °C	3,650 h	2	7 l	41.0 %
Eastern Desert / Red Sea	31.6 °C	20.3 °C	3,504 h	2	15 l	38.0 %
Western Desert	29.0 °C	16.5 °C	3,541 h	8	51 l	51.0 %

3. Limited water resources of Egypt

Water resources in Egypt are limited to the following resources:

3.1. Fresh water

Resources for fresh water come first. organic materials There are differences in freshwater distribution all throughout the place. Egypt's climate is arid, there is little rainfall, a sizable chunk of the country is desert, and its water supplies are erratic [17]. Given Egypt's complex and unpredictable water resources system, addressing the issue of the rapidly widening gap between the country's limited water resources and the country's growing demand for freshwater is imperative. Water resources, both conventional and non-conventional, are scarce in Egypt (Fig. 1). In Egypt, precipitation, groundwater, and the Nile River's inflow are the main sources of water. Conversely, the use of desalinated seawater and wastewater represent non-conventional water resources [18].

3.2. River Nile

NR, with a length of 6695 km and a surface area of more than 2.9 million km2, the Nile River is the second-longest river in the world [15]. It has one of the greatest catchments in the world. The River (Fig. 2) is said to have its source in the centre of Africa and to pass through Tanzania, Burundi, Rwanda, Kenya, Congo, Uganda, Ethiopia, Ethiopia, Eretria, South

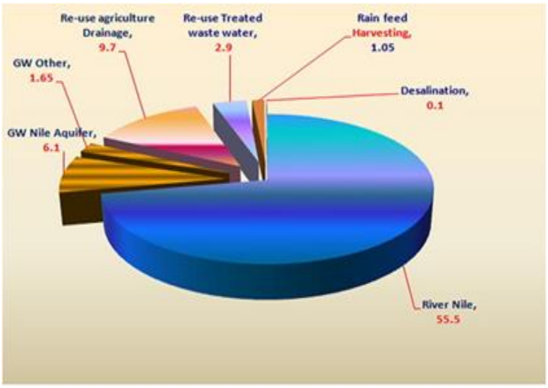

Fig. 1. Egypt's water supply availability (measured in billions of m {; Ministry of Water Resources and Irrigation, MWRI).

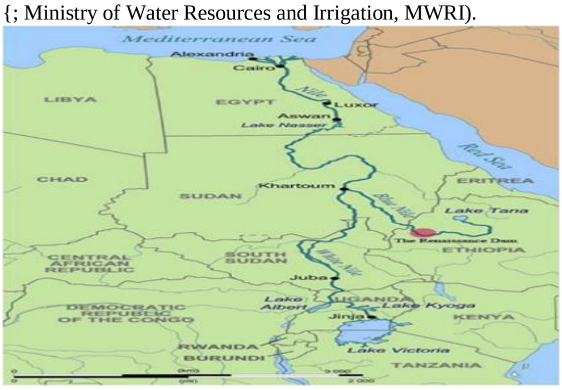

Fig. 2. The nations that make up the Nile River Basin; source: (World Bank).

Because Egypt receives very little rainfall and the Nile River meets all of their water demands, the majority of Egyptians reside close to the river [21]. Because the Nile's headwaters are located outside of Egypt, the region that supplies the river is particularly susceptible to changing weather patterns, which have an affect both inside and outside of the nation. The impacts of climate change on the Nile's flow may be the cause of Egypt's droughts and floods.

3.3. Groundwater

Groundwater (Fig. 3) is Egypt's second freshwater source, providing around 12% of the nation's water supply [22]. Restoring groundwater in the desert and Nile aquifers is a challenging task [23]. Although groundwater is a substantial source of water, there are some challenges associated with it. Egypt uses a lot of groundwater, so much so that the safe yield of the aquifer systems has been exceeded by overexploitation. Groundwater differs from surface water in both its physical and chemical composition due to its natural surroundings. Groundwater is impacted by surface activities, precipitation seepage, irrigation and drainage water, and other effluents [24].

A significant number of coastal aquifers in northern Egypt are being threatened by saltwater seepage. On the other hand, the effect on recharge rates—which can decrease in direct proportion to a decrease in precipitation and vice versa—is intimately related to how climate change impacts groundwater.

Fig. 3. Egypt's principal aquifer systems; source: (MWRI)

3.4. Groundwater

The majority of Egypt is believed to be a hyper arid nation with minimal rainfall, per [25] [23]. Rainfall is concentrated on the small strip of land that hugs Egypt's coast and goes off progressively towards the south [26]. Rainfall occurs only in the winter, but in little amounts. According to [27], the desert receives 0 to 200 mm of rainfall yearly, whereas the north coastal region receives an average of 12 mm (Fig.4). Every year, one billion m3 of rainwater fall on the planet. It cannot be regarded as a consistent water source because it fluctuates over time and between locations. Most of the Mediterranean African countries and the northern Sahara, including Egypt, are expected to have a decrease in annual rainfall [28].

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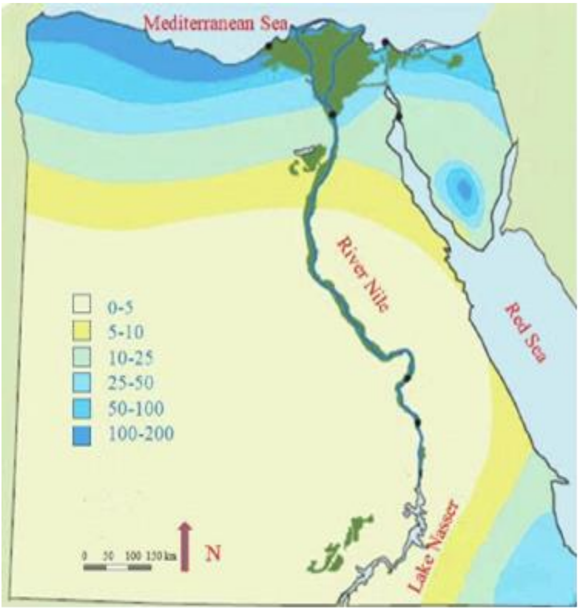


Fig. 4. Egypt's yearly average precipitation (mm); source: (MWRI).

3.5. Reuse of drainage wastewater

Egypt's water demand surpasses its traditional supply, making the use of non-conventional water resources essential. Egypt was among the first countries to reuse water. This procedure had started by 1920 [29]. Upper Egypt indirectly reuses drainage water as it returns to the Nile. The recycled water in the Delta comes from farmland. Egypt plans to recycle an additional three billion cubic metres per year for the supply of the Nubaria Canal and the Al Salam Canal Project. These days, treated sewage and industrial effluent can produce three billion cubic metres yearly [30].

Despite the importance of reusing drainage water, there are few components of agricultural drainage reuse. Because agricultural land is reused excessively, salts build up on it. Seepage of drainage water may contain chemicals that harm aquifers and cause harmful pollution, according to [31].

3.6. Water desalination

Desalination operation involves three main branches seawater desalination, groundwater desalination and desalination of wastewater. As mentioned earlier, Egypt has long shorelines on both the Red Sea and the Mediterranean Sea. It is already one of the pioneer countries using seawater desalination as a mean of water supply [32]. Concerning seawater desalination, there is modern technological methods, which are suggested to be used in Egypt in this field, as many sectors like tourism, petroleum, urban coastal communities and industry are depending on this water resource. Egypt includes vast reserves of brackish groundwater, and great potential for the water desalination, which can be applied at much lower cost. Treatment of drainage water is one of the new fields of application for which large quantities of water are available in Egypt [33].

Desalination is considered one of the alternatives for producing freshwater in the presence of abundant energy availability. Desalination cost is highly variable and is affected significantly by many factors. These factors include water quality, technology, energy cost, plant capacity and plant availability [34].

4. The water resources future challenges in Egypt

Currently, examining the problems with water resources in great detail is the primary issue when determining future orientations. While rising urban demand, shifting land uses, and environmental regulations are Egypt's primary freshwater concerns [35, 36], the most significant obstacle is the severe and varied effects of climate change, which are mostly related to the Ethiopian Renaissance Dam.

The Earth is called the water plant. Almost three-quarters of its surface is made up of water. This water is mostly salty [37]. Freshwater makes up less than 3% of this water (Fig. 5), and the majority of it is found in polar glaciers as ice and snow [38]. Be aware that there exist differing viewpoints [39] on the allocation of water worldwide. The global water cycle determines how much freshwater is available on Earth. One of the major issues that most countries currently face and will continue to face in the future is the availability of freshwater. Freshwater availability is linked to several global issues, including food security, human health, economic development, and regional conflicts [40]. People are becoming increasingly aware of the significant linkages that exist between the environment, water (lakes and rivers), and climate, according to [41], who summarized this fact. Changes in the climate lead to variations in lake levels, which in turn create a host of other environmental issues. On the other hand, changes in water velocity and climate have an effect on the biological environment and water chemistry. The observation of lakes' dimensions and water features serves as the foundation for knowledge about them.

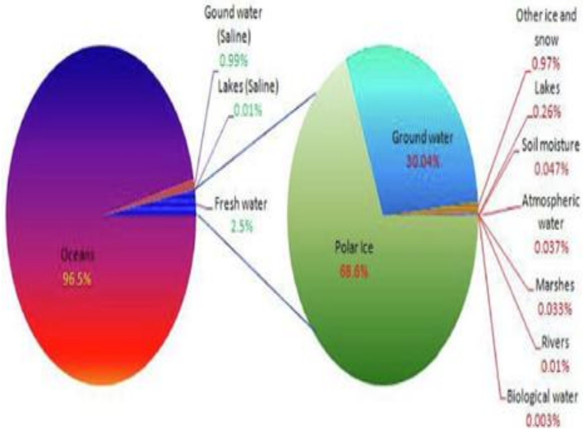


Fig.5. Global Water Distribution (Alberta Environment).

The most important economic and social challenges of the twenty-first century will be related to the world's water supplies. Egypt is among the nations that will face significant issues due to the restricted availability of groundwater, rainfall, and desalination water, as well as its fixed portion of the Nile water. An additional load on Egypt's water availability and accessibility is largely caused by climate change. Water shortages could result from the Grand Ethiopian Renaissance Dam and the increased competition among the nations in the upper Nile basin for water. Even though the Lake Nasser water budget serves as Egypt's national freshwater bank, there is still some water lost through evaporation and restricted seepage from Lake Nasser, depending on the amount of water entering through the Nile discharge and leaving through the High dam. The Toushka project is a component of a larger national initiative to address this unequal distribution of population potential.

The primary issue facing Egypt's water resources system is the restricted availability of supply resources. On the demand side, there are numerous difficulties. Seepage losses from drains and canals, evaporation losses from water surfaces, infiltration losses from agricultural fields, and aquatic weeds in canals are a few of these difficulties. Together with the lack of withdrawal control in deep groundwater, damage to drip irrigation systems, sprinkler installations, high distribution losses in drinking water networks, and a lack of public awareness in the domestic water sector, other challenges include the accuracy of water distribution operations, defects in control gates, the number of pumps that do not deliver water to the streams ends, the expansion of rice and sugarcane areas, and exceeding the permitted pumping rates of wells.

5. The impact of climate change scenarios on the limited water resources of Egypt

5.1. The Meaning of Climate Change

Any significant alteration to a specific region's weather, including variations in temperature, humidity, precipitation, and wind speed, is referred to as climate change. These changes can be caused by natural processes like volcanoes, by external factors like shifting sunlight patterns or the fall of large meteorites, or by human activity, as human activity is currently the primary cause of global warming [42]..

5.2. The main reasons that led to the occurrence of global warming:

There are numerous factors that contributed to the phenomena or crisis of global warming on Earth, such as:

First: The process of expanding industrial activity began with the excavation and burning of coal, which significantly contributed to the generation of carbon dioxide.

Second: when human growth started and dependency on the use of vehicles and airplanes rose, the process of developing the use of the fuel known as oil on a wide and very large scale, which worked on releasing more carbon dioxide emissions.

Third: One of the main factors contributing to the ozone layer's depletion in the Earth's atmosphere is Freon, the gas utilised in the various cooling systems.

Fourth: accelerating urbanization processes at the expense of agricultural areas and lands, which decreased their proportion and raised carbon dioxide concentrations in the atmosphere.

5.3. The effects of global warming on Earth:

Due to the harms caused by global warming, which include the following, attention has been paid to this issue, making it one of the most significant, intricate, and expansive issues confronting the globe today:

First: The increase in Earth's temperature caused the water content to expand and rise due to the melting of ice at the North and South Poles, endangering numerous water islands and coastal cities and potentially resulting in catastrophic floods due to the rising and expanding sea levels.

Second: the natural outcome of this environmental imbalance, which includes the loss of agricultural harvests, the expansion of desertification, and the extinction of numerous living things. It also naturally results in the development of diseases and epidemics brought on by pollution.

Third: Due to extreme pollution, air pollution increased the number of deaths from a variety of diseases, particularly lung ailments.

Fourth: the winter season's temperature increase, which significantly curtailed its initial length.

5.4. Climate change impact

The water industry is the most vulnerable to the current climate change, which is unavoidable [43, 44]. Egypt is among the nations in the Nile Basin that are impacted by the effects of climate change, both inside and outside of its borders. It is highly likely that there will be a significant drop in River Nile levels (Fig. 6).

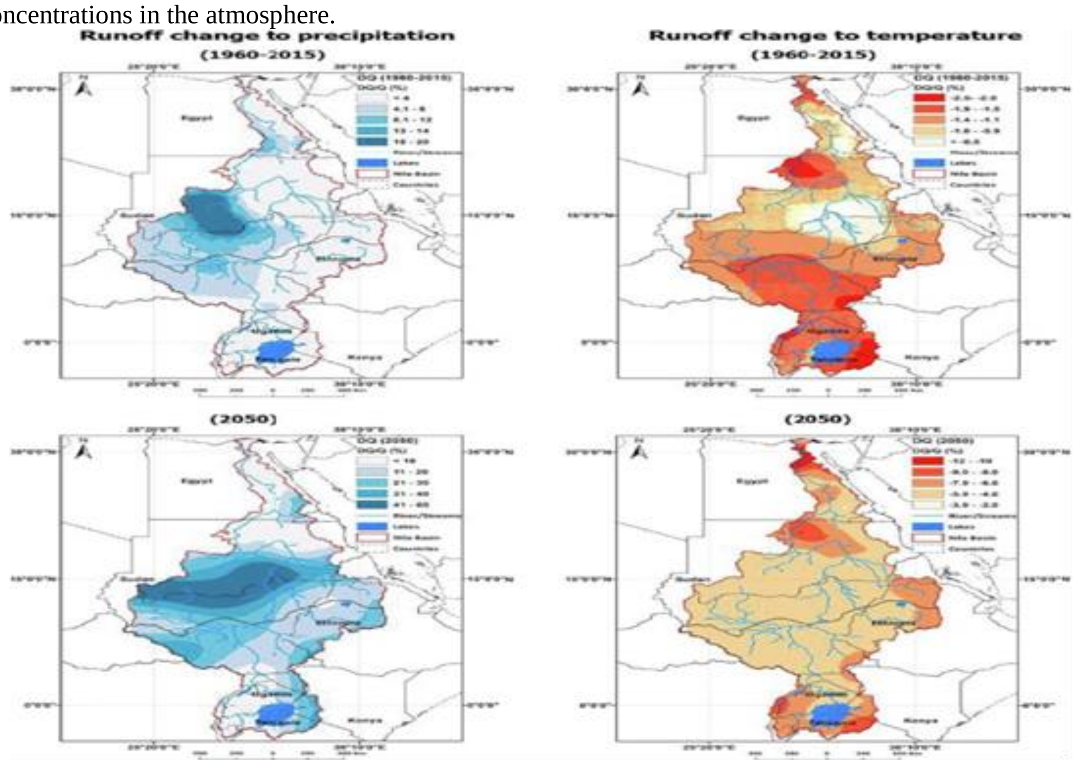


Fig. 6. Variations in runoff across the Nile Basin; source: (Hassan et al., 2018).

[45] discovered that it is unclear how climate change would impact the flow of the River Nile. On the other hand, [46, 47] projected a 20% drop in Nile water levels during the ensuing 50 years. In the meantime, as temperatures rise, natural ecosystems' evaporation processes will intensify, increasing the need for water [48]. Consequently, less precipitation and more evaporation result in less groundwater recharge. It is anticipated that the dry weather and less rainfall would increase demand on the water supplies that are available. Furthermore, seawater intrusion into the coastal groundwater aquifers will result from rising temperatures and, by extension, rising sea levels [49].

While the effects of climate change vary by place, they will generally arise from a combination of less ideal conditions for plant growth, such as decreased irrigation water availability, more variable rainfall, higher crop requirements, and increased evaporation, which may result in variations in WQ and SS [50]. This puts strain on food production because of declining water and land degradation, population growth, and shifting tastes in food production. [51] A number of additional issues should be taken into account, including rising living and food expenses and declining land productivity in coastal regions. The issue of climate change remains low on the agenda of national policymakers.52].

[53] gave policymakers information on how to address water scarcity in the context of the present environment and the anticipated climate change in 2040. However, as it is extremely difficult to predict the climate, responses to climate change should be sensible and flexible. Thus, long-term climate change plans should concentrate on making decisions that make sense for a variety of climatic circumstances. Furthermore, the demand for agriculture in 2040 would range from 5 to 10% of the additional water required, due to the growing competition for water between agriculture and the environment and the more difficult to manage matching of supply and demand. Climate change will therefore raise the amount of water needed for agriculture and reduce crop output. The development of the adaption plan will involve improvements in soil, crop, and water management, with the exception of the current water-stressed conditions. The following were the suggested adaption strategies:

- Enhancing agricultural practices.
- Enhancing the system of irrigation.
- Intercropping systems, which combine multiple crops on the same piece of land at the same time.
- Rotating crops.

It was suggested that actions be taken to mitigate the negative consequences of water scarcity and climate change on food security. [54] projected the impact of two future climatic data scenarios on peas parameters in the year 2040 using the SALTMED model. The model's ability to predict crop parameters and evaluate the possible effects of different scenarios on irrigation management is demonstrated by the results, which also indicate that the model projects an increase in predicted water requirements in both scenarios.

Therefore, political and institutional support will be crucial to encourage capacity and action in this area. Under any climate change scenario, the sustainability with the ongoing population growth and water use may be political considerations associated with introducing demand management policies in Egypt.

6. The importance of using simulation models in sustainable water management

Models can be very useful tools in agriculture water management. They could help in irrigation scheduling and crop water requirement estimation and to predict yields and soil salinization.

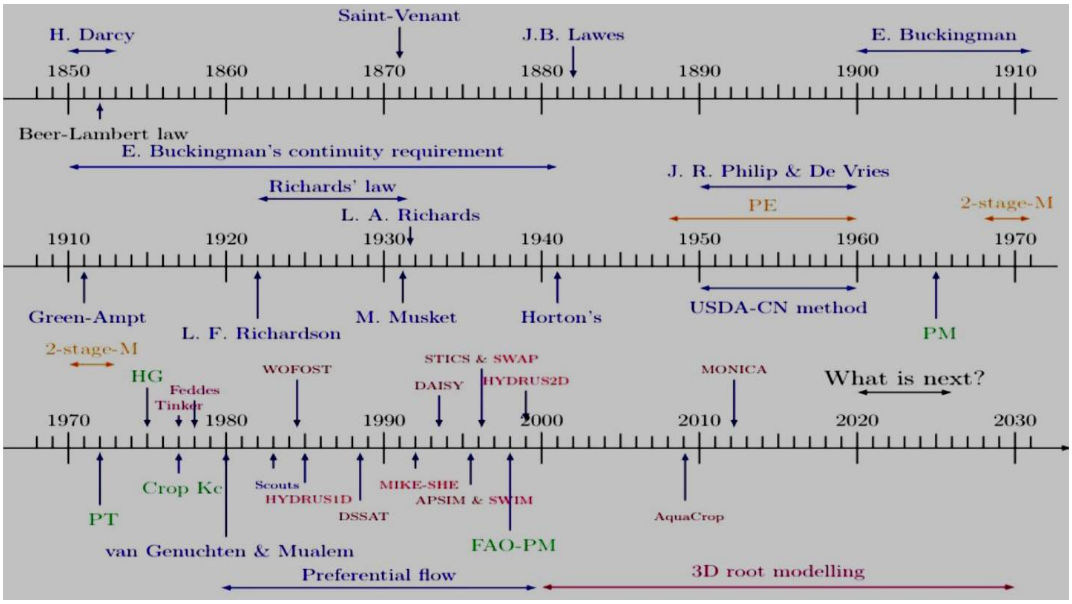
Computer programmers that mimic the growth and development of crops are called simulation models. Weather, soil, irrigation water requirements, crop management data, and other crop production factors are used to forecast crop yield, maturity date, fertilizer performance, and other elements of crop production. The estimations in crop models are based on current understanding of the physics, physiology, and ecology of crop reactions to their surroundings [55].

Crop models are built on more recent techniques, the foundations of which appeared in the 1950s and 1960s. Studies starting in the nineteenth century served as the foundation for hydrologic models [15, 16].

The development of soil-water movement modelling techniques, such as penetration, capillary forces, and drainage processes, was influenced by Beer-Lambert law and Darcy's equation. The historical background of the models, as illustrated in Figure (7) Chronological map of modelling methodologies [17], contributed to the diversity of approaches employed to simulate the function of water across models and processes.

Crop simulation models show how a crop develops step by step in response to climate and other variables. Models for crop simulation help farmers make well-informed decisions that will boost crop productivity. Crop models only forecast the phases at which crops will grow throughout time. Crop supervision, which includes planting, fertilisation, irrigation, and disease control, is typically evaluated along with crop growth and yield.

Figure (7): Models' historical context; source: [17]



Crop models can be categorised as explanatory, stochastic, dynamical, statistical, descriptive, or deterministic models [18]. Techniques for simulation modelling are still useful at the design, planning, and operations stages for solving a range of engineering issues (such irrigation management). Better resource utilisation performance results from irrigation water management techniques that use simulation models to reduce water and energy usage.

Most agricultural models were created and evaluated in controlled environments, despite the importance of hydrologic models in the management of natural resources. However, the application of these crop models for regions bigger than a single sector is growing. Model predictions are significantly erroneous when spatial uncertainty is not adequately represented at a wider scale. However, their usage is complicated by the paucity of data for validation and calibration. Therefore, it is essential to calibrate and validate models using the regionalization with physical similarity technique [19, 20].

One advantage of employing simulation models is that they are less expensive and easier to test than field investigations. The fact that models include far more detail than experiments is the second advantage of employing them.

A systems approach and a quick alternative for creating and evaluating agronomic practises that can capitalise on technological developments in restricted irrigation agriculture are offered by accurately calibrated and tested agricultural simulation models.

As a foundation for furrow irrigation design and management, [21] created and employed volume-balance irrigation models with a recession step to simulate the furrow irrigation method. The models also analysed the relationship between furrow irrigation variables and irrigation efficiency parameters, crop yield, and deep percolation. The model can be utilised to create efficient irrigation practises and prevent pollution, per the study's conclusions.

Models for simulating surface irrigation are useful for surface irrigation system design and management. When used for irrigation design, simulation models help optimise surface irrigation variables like field slope, field length, and design flow rate. In other words, the models will help the designer figure out what these variables should be set at in order to get the best results. This is especially helpful when transferring from one application process to another or when a surface system is being used. Changing these variables (especially field slope and length) after the system is operating is challenging or expensive [22].

Pressurised irrigation system design and management have shown to benefit greatly from the use of several simulation models, including the SpacePro model for choosing nozzle size and spacing for a given application, the SIRIAS model for simulating sprinkler droplets, and the TRAVGUN model for sprinkler application depth [23].

In order to better understand the flow dynamics involved in an irrigation event and enhance the structure and functionality of basin irrigation systems, a number of simulation models have been created. The governing equations for the simulation models were either the simplified zero-inertia approximation "neglecting inertial terms" or the absolute hydrodynamic Saint-Venant equations [24, 25].

The GPIMOD gated pipe irrigation simulation model was created and tested by El-Shafie et al. [26], who came to the conclusion that it is a helpful tool for forecasting water distribution homogeneity along gated pipes. AquaCrop, a model for predicting crop water efficiency established by the FAO, is reportedly dominating the use of water in large quantities. According to Razzaghi et al. and Mbangiwa et al. [27, 28], it can be used extensively in any place and at any time by regularising a water-productivity parameter for climate (evaporative demand and concentration of atmospheric carbon-dioxide). Numerous investigations confirmed that AquaCrop provided an accurate prediction of crop biomass, harvest, and irrigation needs. Furthermore, the model is applicable for researching climate change scenarios and their impact on irrigation.

[29] confirmed the validity of the WinSRFR simulation model as a tool for forecasting the effectiveness of furrow irrigation using a range of furrow lengths and slopes. The results showed that the statistical indicators for comparing the simulated and estimated advance times, recession times, and DU were more than sufficient and very suitable for using the application in Egyptian settings.

A field experiment for rice production was carried out by Arbat et al. [30] using Simulation HYDRUS-2D software, which proved useful in forecasting soil water distribution, deep drainage, and plant water extraction. Moreover, HYDRUS-2D simulations could be helpful in figuring out where soil water probes should be placed in order to efficiently control rice subsurface drip irrigation.

In the area of water management, several studies, publications, and articles were compiled and examined. It was evident that there are numerous numerical models available all around the world that can simulate various water resource systems and evaluate the effects of various management options.

In order to replicate the water resources system in the Fayoum Governorate of Egypt, the River Basin SIMulation (RIBASIM) model was used. Different scenarios under optimistic, moderate, and pessimistic situations were assessed. The three situations showed various testing action implementation rates [56].

Generic models that may simulate the configurations, institutional conditions, and management challenges of particular river basin water resource systems include WEAP, RIBASIM, and MODSIM. These sample programmes are all zero-dimensional models built upon a node-link network representation of the simulated water resource system. These models' equations are based on the idea of modifying the reach volumes and flows of streams and rivers by means of link storage nodes, or routing methods.

The University of Colorado's Centre for Advanced Decision Support for Water and Environmental Systems (CADSWES) created the RiverWare river basin modelling system. To create operational policies for the administration and operations of river basins, RiverWare use the RiverWare Policy Language (RPL). In order to simulate intricate river basin operations, users can input logical expressions in RPL that define the rules by which objects behave and the relationships between them using a rule editor [57].

South Africa is where the Water Resources Planning Model (WRPM) originated. It is applied to the evaluation of water distribution in catchments. Surface water, groundwater, and interbasin transfers are all simulated by the model. The model can be set up to produce outputs of various types of information and is intended for use by a variety of users with various needs [58].

Komati Basin Water Authority (KOBWA) adopted Decision Support Systems (DSSs). It is responsible for managing the water resources in the Komati River Basin, which is shared by Swaziland, Mozambique, and South Africa. KOBWA employs a suite for river hydraulic application, water curtailment (rationing), and water allocation (yield) [59].

Numerous nations, including the United States, Mexico, Brazil, Germany, Ghana, Burkina Faso, Kenya, South Africa, Mozambique, Egypt, and Israel, have assessed and developed their water resources using the Water Evaluation and Planning (WEAP) methodology. Tanzania's Pangani Catchment water resource development scenarios were evaluated using WEAP [60].

A field experiment for rice production was carried out by Arbat et al. [61] using Simulation HYDRUS-2D software, which proved useful in forecasting soil water distribution, deep drainage, and plant water extraction. Moreover, the optimal location for soil water probes to control subsurface drip irrigation in rice may be found using HYDRUS-2D simulations.

One of the most significant models ever created is the SALTMED model by Ragab [62], which has demonstrated its ability to simulate a wide range of crops under various field administrations. This includes accounting for all types of irrigation systems, as well as various water characteristics, irrigation strategies, soil types, crops, fertiliser applications, and the impact and simulation of abiotic stressors like temperature, salinity, drought, and different drainage systems. The model's most recent iteration, which was launched in 2015, enables the simultaneous modelling of 20 fields, each complete with irrigation methods, crops, soil, irrigation systems, N fertilisers, etc. The soil temperature, evaporation and water absorption, water salinity, groundwater level, crop production, soil nitrogen dynamics, requirements for salinity filtration, nitrate filtration and drainage, and effluent flow are all simulated by this model. Using field data that was seen, this model was validated and calibrated by [63,64,65,66]. Their remarkable prediction of salinity, water productivity, N-uptake, dry matter, yields, and soil moisture content was established and validated.

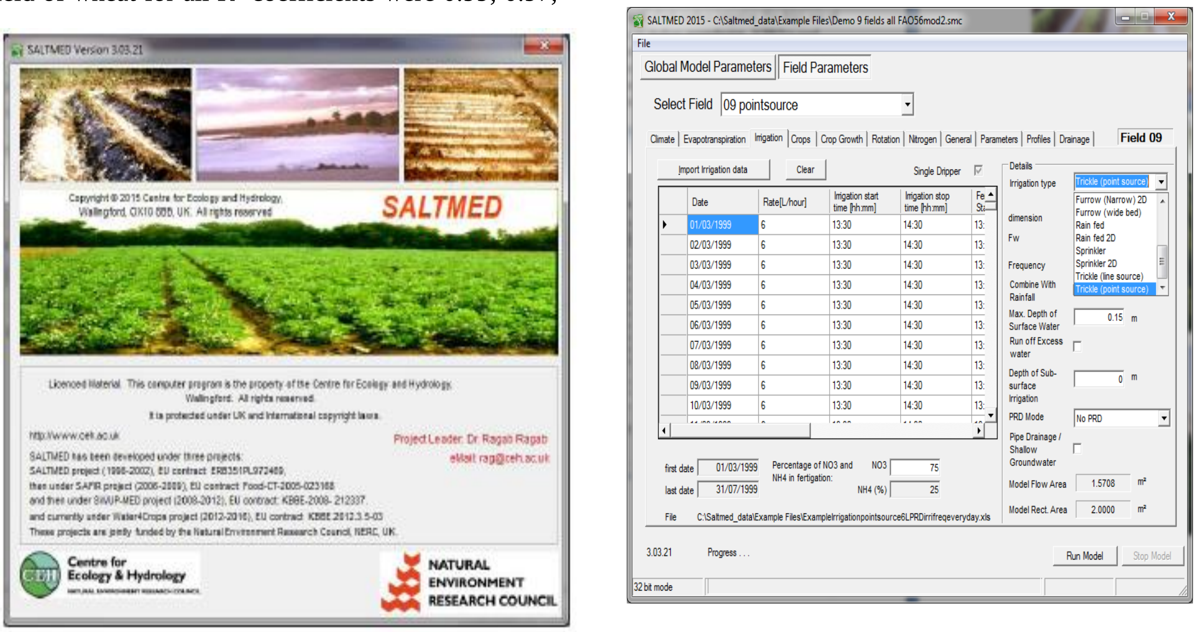
The SALTMED model is a general model that may be used to various soil types, crops, trees, irrigation systems, water application techniques, and water quality characteristics. Tests of the initial version using data from field experiments were successful. Additional sub-models, crop rotations, nitrogen dynamics, soil temperature, dry matter, and yield, subsurface irrigation, deficit irrigation (including partial root drying, or PRD), drainage flow to tile or open drain systems, the presence of shallow groundwater, evapotranspiration (ET) using the Penman-Monteith equation, and various options for obtaining the canopy conductance are all included in the most recent version of SALTMED (2015). Up to 20 fields or treatments can run concurrently in the present edition. The Souss-Massa river basin in Agadir hosted field trials utilising the model. These studies used a variety of crops, including chickpea, sweetcorn, and quinoa; various water qualities, including fresh, treated waste, and saline water; and various irrigation techniques, including deficit irrigation, which applies less water than the crop requires overall, and applied water stress during specific growth stages. The soil moisture, yield, and dry matter for every crop under various water quality, as well as every water application strategy, were all successfully predicted by the model. According to the findings, quinoa is the cereal crop that can withstand salt and drought the best. The outcomes also demonstrated the potential for large freshwater savings when applying moderate water stress or shortage and utilising treated wastewater, particularly in the non-sensitive growth stages. For three growing seasons, the SALTMED model provided "baseline data" for sweetcorn. To get future forecasts of crop productivity and ET under changing climate conditions, the SALTMED model was run in forecasting mode. According to the findings, because corn's growth season is getting shorter, crop ET is predicted to increase by 15% but crop water requirements are predicted to drop by 13% as temperatures rise. Additionally, the data indicate that a 20-day early crop harvest is anticipated. Dry matter and yield crop productivity may decline by 2.5 percent by the end of the twenty-first century.

To evaluate the effectiveness of the SALTMED model for simulating yield, total dry matter, and soil moisture, Dewedar et al. [31] conducted a field experiment spanning two seasons. The model accurately predicted yield, water productivity, total dry matter, and soil moisture. The model might therefore be used to land, water, and agricultural management in the face of present and future climate change.

Using the SALTMED model, Marwa et al. [32] predicted how two future climate data scenarios would affect pea parameters in 2040. The model's ability to predict crop parameters and evaluate the possible effects of different scenarios on irrigation management is demonstrated by the results, which also indicate that the model projects an increase in predicted water requirements in both scenarios.

Certain irrigation systems or processes, like the transport of water and salts, percolation, water uptake by plant roots, or a combination of these, are the focus of some of the current models. In order to accommodate a wide range of irrigation systems, soil types, soil layers, crops, and irrigation water addition tactics (such as incomplete irrigation, partial root drying, PRD, and subsurface irrigation), the SALTMED simulation model was created. Nitrogen is applied during this simulation from a variety of sources, including crop wastes that are already in the soil and chemical and organic fertilisers. Additionally, the model allows for the exact simulation of various water quality conditions, including freshwater, wastewater, saline, and agricultural wastewater. A tool for saving input files and parameters as text files for various processes is included in the SALTMED simulation model. Up to 20 fields or treatments may be run concurrently in the present iteration of this model [67].

The SALTMED model provided a high simulation of crop output, dry matter, and soil moisture, according to the actual findings of multiple researches [68, 69, 70]. The employment of simulation models is justified by the fact that they provide a quick and inexpensive alternative to carrying out different field experiments by providing a means of accessing and predicting crucial information that can be gained from the model simulation outcomes [71, 72, 73, 74]. Regarding the benefits and suitability of using wastewater for fish farms (DWFF) for irrigation rather than fresh water inside the canal, it was observed that the SALTMED model (Fig. 8) accurately represents soil moisture. More specifically, the dry matter, yield, and water yield of wheat for all R^2 coefficients were 0.99, 0.97, and 0.96, respectively, as was the nitrogen concentration in all sandy soil layers.



Source: https://link.springer.com/chapter/10.1007/698_2016_74

Figure (8): SALTMED model

7. Conclusion and recommendations

However, as fresh water supplies become scarcer and rivalry between various water-use sectors heats up, irrigation is becoming increasingly scarce.

Increasing water productivity in irrigated agriculture, or producing more food with less water per unit of output, is the main problem facing this industry today. In order to reduce adverse effects on the environment, all parties involved in irrigation and water management—managers, farmers, and laborers—need to be steered towards conserving water and minimizing waste through suitable rules and incentives. Only with the right water-saving technologies, management tools, and regulations in place will this aim be accomplished. It will be important to observe how creative concepts and methods are applied.

In this endeavor, all stakeholders—from farmers to policymakers—must be involved. Water management alone, even with savings and loss reduction, won't be sufficient. Thus, management and development of water resources must be the main priorities. In the agriculture sector, constructing storage facilities, cutting down on conveyance losses, and practicing effective water management can all help conserve water. land treatment, lowering water consumption, recycling wastewater, better irrigation operations and maintenance, rationalizing water pricing, combining the use of high- and low-quality waters, and technological advancement [62].

Egypt is situated in a desert region with notable regional differences. The western portion of the country is dominated by the Sahara, the largest sweltering desert in the world. The Nile, Egypt's lifeline, travels north to south and provides fertile soil for sustainable agriculture. The little stretch of green that is the Nile Valley stands in sharp contrast to the surrounding arid surroundings. The Sinai Peninsula's eastern region is rough and has a unique desert climate.

Only traces of precipitation fall on a yearly basis, with the majority occurring in the winter. The Mediterranean coast experiences the most precipitation, which gradually diminishes as one travels inland and towards the deserts.

Artificial intelligence (image recognition and perception, artificial neural networks, deep learning, and machine learning) and simulation models are examples of technologies that help improve irrigation water management, product quality and quantity, and water efficiency.

The study's conclusion emphasized the value of employing simulation models with novel and unconventional irrigation sources in addition to the sustainable management of freshwater resources. The use of the SALTMED simulation model, one of the most significant new models with excellent accuracy in modelling the real conditions of experiments under Egyptian conditions, was also underlined.

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