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# Adapting Irrigation Strategies to Mitigate Climate Change Impacts: A Value Engineering Approach

**Walaa El-Nashar[1] · Ahmed Elyamany[2]**

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## Abstract

Water scarcity and climate change are posing new challenges to irrigation management. Climate change increases water demand and decreases crop yields. The aim of this paper is to propose a framework to select the most efficient irrigation strategy to mitigate the impacts of climate change and achieve food security. Value engineering (VE) methodology is utilized to assure the functionality of the strategy and add an element of creativity while creating the value alternatives. The life cycle cost (LCC) technique is utilized to provide the optimum irrigation strategy from an economic perspective. The findings showed three different value alternatives for different crops, soil types, and irrigation systems. This paper contributes to the current state of knowledge by a) utilizing the Value Engineering methodology in irrigation management studies; b) evaluating irrigation strategies to ensure efficient irrigation water management; and c) providing policymakers with a tool to incorporate the added value and functionality into their policies regarding irrigation water.

**Keywords** Climate Change · Irrigation · Strategies · Food security · Value Engineering · Life Cycle Cost

## 1 Introduction

As global warming continues, its negative impact on irrigation water is projected, perhaps affecting food sufficiency. The rate of evaporation of land and oceans increases as the temperature rises. Precipitation will increase in the tropics and high latitudes while decreasing in the arid and semi-arid mid-latitudes and within continents (FAO 2015). By 2100, it is predicted that global temperatures will rise by 4 °C and annual precipitation will fall by 20% (Bradley et al. 2006; Mostafa et al. 2021a, b). Mitigating the impacts of climate change on irrigation water will increase the need to evaluate the current irrigation strategies to maximize the utilization

✉ Ahmed Elyamany
drahmedelyamany@yahoo.com

Walaa El-Nashar
walaanashar@yahoo.com

1 Water Engineering Department, Zagazig University, Zagazig, Egypt

2 Construction Engineering Department, Zagazig University, Zagazig, Egypt

efficiency of available water. Value engineering (VE) is one of the tools that could potentially be utilized to increase the efficiency of irrigation strategies.

VE is a systematic, interdisciplinary, problem-solving technique that focuses on maximizing the value of a product, process, or service through increasing the functionality of its elements. The VE technique's goal is to perform the system's basic function(s) at the lowest possible life cycle cost (LCC) while maintaining the required performance, safety, and effective quality. The best results in VE are obtained when the goal is primarily to increase the value rather than to reduce expenses. VE determines the best design alternative for projects. The application of value engineering is supported by real-life applications that show a saving of 10–20% of the total cost of the project (Emami et al. 2017).

## 2 Research Background

Due to climate change, the irrigation water requirements and crop yield will be affected. It is anticipated that seasonal irrigation needs for both current and future crops in countries such as Portugal's will increase by 7–13% and 13–70%, respectively (Rolim et al. 2017). By 2080, the effects of climate change on irrigation water requirements may result in a 20% increase in worldwide irrigation water demand and a 10% decline in agricultural production (Fischer et al. 2007; Esteve et al. 2015). Based on the results of a quantitative climate change risk analysis, agricultural production losses due to climate change are expected to be 69%, 57%, and 45% at 90%, 50%, and 10% confidence levels, respectively (El-Nashar and Elyamany 2022). With climate change on the rise, irrigation water is becoming a more valuable resource around the world. Low efficiency in using water and more people wanting to use the same amount of water are forcing farmers to adopt more efficient irrigation strategies to save water and make the most of the little water that is available (Belay et al. 2019).

There is a difference between irrigation planning and irrigation strategies. Irrigation strategies serve as a guide to assist focus efforts, identify priorities and objectives, assign duties, and estimate realistic funding. It also lays out the guiding principles for the activities being undertaken to revive and extend irrigation projects in the nation. In general terms, a strategy is defined as a plan of action designed to achieve a long-term aim. Therefore, a strategy could be built out of multiple short-term plans of action. Irrigation planning is done in three steps: (i) preliminary planning, which involves gathering and analyzing all available data; (ii) comprehensive planning of water and land use to find the best site; and (iii) design of irrigation structures and canals.

The components of an irrigation strategy are irrigation method, crop pattern, and soil type. To maximize yield and water productivity, irrigation strategy and water-saving technology should be chosen carefully, as well as farm-level irrigation techniques, to increase the production per unit of agricultural water. Irrigation scheduling is critical for achieving water conservation, improving irrigation performance, and minimizing percolation caused by excessive water irrigation (ICID/FAO 1996).

## 3 Research Problem and Objective

VE was utilized in the field of water management to obtain the best design alternative for some of the most annoying irrigation challenges, such as developing alternatives to mitigate the water shortage at the canal tail (El-Nashar and Elyamany 2018). VE was also used to choose the best alternative for drain covering to minimize the negative impact on the environment (El-Nashar 2017).

A few gaps regarding the application of irrigation strategies have been identified in the literature. There is a lack of research on: 1) utilizing value engineering as a systematic, interdisciplinary, problem-solving technique to compare different irrigation strategies; 2) comparing between cost and return for each irrigation strategy; and 3) identifying the appropriate irrigation strategy in the presence of different conditions such as soil type, salinity extent, water availability, and crop need.

The aim of this paper is to propose a framework to select the best irrigation strategy to mitigate climate change impacts in the presence of different conditions such as soil type, crop type, extent of salinity, and water availability. This aim is achieved using value engineering (VE) methodology, first to generate multiple value alternatives for irrigation strategies and second to identify the value of different alternatives to irrigation strategies using life cycle costing (LCC). The LCC is used to integrate the cost and return of each irrigation strategy into one quantitative measure.

The main contribution of this paper to the current state of knowledge is a framework for selecting the best irrigation strategy under different conditions using VE methodology, which is not commonly used in irrigation management research.

## 4 Current Applications of Irrigation Strategies

Irrigation strategies are considered an adaptive strategy to face climate change. Irrigation strategies aim to save water and maximize yield and water productivity, resulting in increased output per unit of water used in agriculture. Irrigation strategies are useful to help manage the volume, rate, and timing of water application to match water holding capacities and soil salinity. Irrigation strategies can be helpful in counteracting the harmful effects of climate change.

There are many irrigation strategies relative to irrigation method, crop pattern, and soil type. An irrigation strategy is used to save water and decrease evaporation and seepage losses. Irrigation strategies include deficit irrigation, irrigation scheduling, effective irrigation, irrigation monitoring, water reuse, changing crop patterns, and modeling agricultural systems.

Sustainable agricultural water management and strategies for managing water supply and demand include the development and repair of the physical structure of the water resources system of the irrigation network; the improvement of operation management and maintenance of the water resources system; the management of wastewater; and the transfer of water between basins in the irrigation network (Radmehr et al. 2022). The use of deficit irrigation and irrigation scheduling solutions in conjunction with other strategies helps to increase water productivity. Irrigation that applies less water than the crop needs for complete growth is known as deficit irrigation. When solutions like mulching are added to solutions like deficit irrigation, water use efficiency goes up (Mubarak and Hamdanm 2018). To achieve more efficient use of limited water supplies, deficit irrigation and mulching technologies could be implemented. Low-cost alternatives like mulch and deficit irrigation maximize crop yields while lowering production costs (Mekonen et al. 2022).

A great range of models are available for computing the soil water balance and generating superior irrigation schedules, making computer models an accessible way to develop and evaluate different irrigation strategies**.** Using weather data, the Root Zone

Water Quality Model was utilized to examine different irrigation strategies for high production and water use efficiency The model showed that maize and wheat need pre-season irrigation to get the most out of the water they use (Fang et al. 2010).

Winter wheat response to irrigation scheduling simulations revealed that a greater yield is required to sustain the amount of evapotranspiration and transpiration. When compared to recommending irrigation with better grain production, single irrigation at early spring growth stages had a similar water consumption efficiency (Zhang et al. 2018). The advice for minimal irrigation varies. According to several studies, irrigation provided before planting under restrictive conditions boosts output (Li et al. 2005, 2001). Other research suggests that a single irrigation during jointing can boost grain yield while also maximizing water efficiency (Wang et al. 2016; Xu et al. 2016).

Some irrigation strategies advocate increasing crop productivity per unit of water consumed, such as replacing high-water-using crops with lower-water-using crops, planting drought-tolerant cultivars, and implementing management and system improvements (Evans and Sadler 2008). Water crop productivity can be improved in a variety of ways, including replacing high-water-using crops with lower-water-using crops. Water can be redirected from low-value crops to higher-value crops, increasing their economic output (Evans and Sadler 2008).

Reduced agricultural water use while increasing required productivity necessitates the innovation and integration of cultural, engineering, and managerial systems, as well as institutional alternatives (Howell 2006). Agricultural systems modelling has proven to be a useful method for examining the effects of climate variability and management strategies on crop productivity, resource efficiency, and environmental implications in farming systems (Zhao et al. 2015; Batchelor et al. 2002).

Other studies focus on cutting-edge methods for increasing horticultural yields through water applications. Support systems deal with fertigation efficiency by making decisions based on crop monitoring approaches (Incrocci et al. 2017). The importance of molecular genetics in finding and describing genes involved in enhancing water use efficiency and drought tolerance has been highlighted (Ruggiero et al. 2017).

Other irrigation strategies based on pan evaporation or soil water monitoring have been tested in various research. Irrigation quantities of 50–100 mm, separated over 20–40 mm applications, were advised in these schemes (Wang et al. 2013; Liu et al. 2011). The use of remote sensing to manage irrigation and water resources was demonstrated to solve the existing and future difficulties of agricultural water resource management (Alvino and Marino 2017).

## 5 Value Engineering Methodology

As mentioned earlier, this paper aims to propose a framework to select the best irrigation strategy in the presence of different conditions such as soil type, crop type, extent of salinity, and water availability. This aim is achieved using the VE methodology to generate multiple value alternatives for irrigation strategies and to identify the value of different alternatives to irrigation strategies using LCC. There are five steps that need to be taken to use VE for irrigation strategies. These steps are information, functional analysis, creativity, evaluation, and development. (El-Nashar and Elyamany 2018).

## 5.1 Information Phase

This phase examines and defines the system present conditions as well as the study's objectives. The irrigation strategy is used for one or more of the reasons listed below:

(i) Encourage regional-level efforts by the water regulator and farming firms to collaborate to mitigate the effects of drought on agriculture and the environment.
(ii) Improve water management to maximize water efficiency and productivity.
(iii) Enhance growers' management capabilities and determine how and where agricultural abstractors can participate in and contribute to local efforts.

## 5.2 Function Analysis Phase

The functions are defined in this phase using two words: "active verb" and "measurable noun." These functions are examined and studied to see which ones are required to achieve the objectives. Ensuring food security is the main function. Managing irrigation water and enhancing crop output are secondary functions. A fast diagram is used to define the functions of irrigation strategies. This diagram is useful for quickly identifying the objectives and determining which resources are required to support economic growth and ensure food security, as shown in Fig. 1.

## 5.3 Creativity Phase

Creative techniques are used to find additional ways to optimize irrigation water utilization. To achieve the purpose, the following irrigation strategies can be used as shown in Table 1.

## 5.4 Evaluation Phase

A questionnaire was undertaken to identify the problem from the perspective of 45 engineering professionals who are familiar with the nature of the area and its problems. The questionnaire is based on the following strategies for screening steps:

(i) GO—NO GO: Scratch concepts that don't pique your attention.

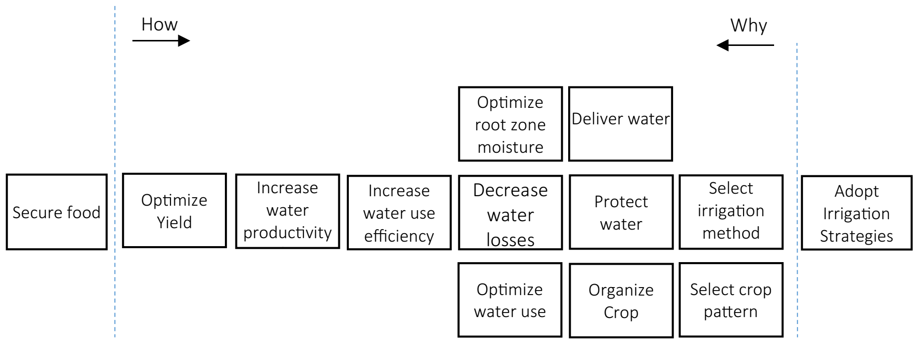


**Fig. 1** Fast diagram to adopt irrigation strategies

**Table 1** Irrigation strategies

| Strategy Code | Strategy Name | Strategy description |
|---|---|---|
| $S_1$ | Deficit irrigation | is an optimization technique that uses irrigation throughout a crop's drought-sensitive development phases. In the absence of these times, irrigation is minimal or even unneeded provided rainfall supplies enough water |
| $S_2$ | Irrigation scheduling | is the method employed by irrigation system managers to choose the ideal watering schedule in terms of frequency and length |
| $S_3$ | Crop planting dates | Changing crop planting dates to adopt the climate change |
| $S_4$ | Irrigation by rainfall | Precipitation, or water falling from the sky to the ground is nature's irrigation system |
| $S_5$ | Catchment management | Demand management and forecasting in the irrigation catchment |
| $S_6$ | Reduce drought impacts | Reduce drought impacts through increasing ecological resilience in river systems through river restoration |
| $S_7$ | Schedule management | Improve irrigation schedule management through encouraging the adoption of new tools and technology, such as enhanced weather forecasts |
| $S_8$ | Integrative technologies | Support for the development of new integrative technologies, including as smart sensor networks and artificial intelligence, to conduct precision irrigation |
| $S_9$ | Water storage | Farm-level attempts to increase water storage should be supported, whether individual or shared |
| $S_{10}$ | Catchment area development | Develop catchment-based approaches to improve agricultural water consumption and allocation |
| $S_{11}$ | Agriculture sector and industries | Determine how the agriculture sector may collaborate with other industries to lessen the industry's exposure to climate and water concerns |
| $S_{12}$ | Losses decreases | Decrease evaporation and seepage losses by covering or lining the canals to carefully regulate surface irrigation |
| $S_{13}$ | Farm irrigation system | Irrigate one row or side of a bed on one irrigation and the other row or side on the next irrigation |
| $S_{14}$ | Crop water stress | During the irrigation season, crop water stress was maintained at a steady level |
| $S_{15}$ | Irrigation frequency | Varying irrigation frequency in relation to yield susceptibility to water stress at various stages of growth |
| $S_{16}$ | Water reuse | Reusing water involves collecting it from various sources, treating it, and then using it again for beneficial purposes |
| $S_{17}$ | Effective irrigation | Using engineering methods to increase irrigation efficiency and deliver the water to canal tail |
| $S_{18}$ | Crop pattern changing | Replacing of crops that need a lot of water are by crops that use less |
| $S_{19}$ | Water redistribution | Water is redistributed from low-value crops to higher-value ones |

**Table 1** (continued)

| Strategy Code | Strategy Name | Strategy description |
|---|---|---|
| $S_{20}$ | Irrigation before or after planting | Irrigation applied before planting. If there isn't enough rainfall, irrigating fields prior to or just after planting can keep the planter moving while still achieving the "plant into moisture" criteria |
| $S_{21}$ | Irrigation monitoring | Irrigation based on soil water monitoring or pan evaporation |
| $S_{22}$ | Agricultural modelling | Due to the requirements of promoting agricultural practices that use water sustainably, agricultural systems modeling is used. these systems enable to evaluate irrigated agriculture, water use analysis and agricultural production |

(ii) Champion: Someone is in favor of the strategy.
(iii) Go for It: Discuss the advantages and disadvantages before voting. Strategies could be combined, and new ones could be added.
(iv) Trade-Off Study: Quantify the aspects of performance, using pair-wise comparison to select the best choices.
(v) Customer Acceptance: Determine and quantify the criteria for consumer acceptability, compare the surviving concepts to the norm and the danger, and create scenarios for the proposal.

The experts were provided with twenty-two strategies to vote on, as shown in Table 2. Following the vote, fourteen strategies have been approved. These strategies are examined and used to narrow down the final options and choose the best strategy as shown in Table 3. Ten strategies resulted from the trade-off process.

## 5.5 Development Phase

The development of irrigation strategies into value alternatives is the goal of this phase. The following section will discuss these value alternatives and the process to select the best value alternative.

**Table 2** Voting on irrigation strategies

| Strategy Code | Go or No-Go | Champion |
|---|---|---|
| $S_1$ | Go | Yes |
| $S_2$ | Go | Yes |
| $S_3$ | Go | Yes |
| $S_4$ | No-Go | - |
| $S_5$ | Go | Yes |
| $S_6$ | Go | No |
| $S_7$ | Go | Yes |
| $S_8$ | Go | Yes |
| $S_9$ | No-Go | - |
| $S_{10}$ | No-Go | - |
| $S_{11}$ | Go | Yes |
| $S_{12}$ | Go | Yes |
| $S_{13}$ | No-Go | - |
| $S_{14}$ | Go | No |
| $S_{15}$ | Go | No |
| $S_{16}$ | Go | Yes |
| $S_{17}$ | Go | Yes |
| $S_{18}$ | Go | Yes |
| $S_{19}$ | No-Go | - |
| $S_{20}$ | No-Go | - |
| $S_{21}$ | Go | No |
| $S_{22}$ | Go | Yes |

**Table 3** Trade-off study

| Code | Performance characteristics | | | Voting |
|---|---|---|---|---|
| | Optimization of Water Use | Increase water productivity | Easy application | |
| $S_1$ | √ | √ | × | |
| $S_2$ | √ | √ | √ | |
| $S_3$ | √ | × | × | Eliminated |
| $S_5$ | √ | √ | √ | |
| $S_7$ | √ | √ | √ | |
| $S_8$ | √ | √ | √ | |
| $S_{11}$ | √ | √ | √ | |
| $S_{12}$ | √ | × | √ | |
| $S_{16}$ | √ | × | × | Eliminated |
| $S_{17}$ | √ | √ | √ | |
| $S_{18}$ | √ | × | √ | |
| $S_{22}$ | √ | √ | × | |

### 5.5.1 Value Alternatives

Two methods were rejected after the voting because they failed to achieve more than one of the performance characteristics, which leaves only ten strategies at hand. Three value alternatives were formed out of these strategies with the objective of saving water and securing food. $S_1$ is considered a part of $S_2$, and $S_1$ should be used with knowledge of the sensitive times of the crop, which differ based on the agro-physiological characteristics of each crop. Therefore, $S_1$ is neglected. Accordingly, nine strategies are used to propose the value alternative. The suggested value alternatives are:

### 5.5.2 Value Alternative 1 (VA-1)

VA-1 is working to increase climate and water risk resilience. This alternative incorporates; catchment demand management and forecasting in the irrigation ($S_5$), schedule management to improve irrigation management through encouraging the adoption of new tools and technology, such as enhanced weather forecasts ($S_7$) and using of integrative technologies to support the development of new irrigation system such as smart sensor networks and artificial intelligence, to conduct precision irrigation ($S_8$).

Irrigation demand is determined by the types of crops planted, soil water-holding properties, and local agro-climate conditions. Understanding where catchment demand exists and recognizing climatic change will aid in predicting future irrigation requirements. When compared to existing conditions, crop water consumption is anticipated to increase by 10% to 30% in 2100 (Hopmans and Maurer 2008). To deal with the rise in water demand brought on by climate change, new integrative technologies such as smart sensor networks and artificial intelligence must be deployed.

A Smart irrigation system consists of a microcontroller, which serves as the system's brain. The moisture sensor is attached to the microcontroller's input ports. The controller turns on and off the pump based on the soil's needs. When the system is turned on, it adjusts the soil moisture level to its default value and initializes all components. The soil moisture sensor was then attached to the soil moisture level. The sensor's moisture content data is analyzed, and a decision is made regarding whether to water the field. When the soil is dry, water flows into the field, but when the soil is moist, the water flow is stopped. In the end, this method guarantees that the moisture content and water availability in the field are properly maintained (Pimpalkar et al 2021). This alternative includes using trickle irrigation system with microcontroller in sand soil with citrus, vegetables, and fruits as crop pattern.

### 5.5.3 Value Alternative 2 (VA-2)

The second value alternative focuses on current irrigation techniques related to water scarcity, with an emphasis on water quantity and quality. This alternative incorporates using scheduled irrigation to choose the ideal watering schedule in terms of frequency and length. ($S_2$), reducing the evaporation and seepage losses by covering or lining the canals to carefully regulate surface irrigation ($S_{12}$) and achieving effective irrigation by using engineering methods to increase irrigation efficiency and deliver the water to the canal tail ($S_{17}$).

Water-use rights, including both costs and benefits, must be shared equally among people, a concept known as equity of water sharing (Cai et al. 2003). This may be accomplished by supplying water at the correct time and in the proper quantity and quality, considering the need for water as well as the availability of water (Li et al. 2020).

The new irrigation schedules were created with two key goals in mind: water conservation and percolation management. With limited irrigation resources, giving 80% of the water to the most important stages of wheat growth and 20% to planting maize made the best use of the water and caused the least water to run off (Fang et al. 2010).

Irrigation systems for agriculture employ bulk water from a variety of sources; therefore, water efficiency is crucial. Water for irrigation is delivered to farmlands via distribution canals or pipelines (Koech and Langat 2018). Water usage efficiency is the amount of water given to fields through the canal system that is used by crops in a useful way.

Surface irrigation efficiency could be increased by lining open channels and using the best engineering method to deliver the water to the canal tail. Water saved by lining open channel represent only 30–40% (Swamee et al. 2002; Elyamany and El-Nashar 2016). Using separate pipes to irrigate branch and distribution canal tail-end property, as well as PVC pipes for field canals, is the greatest value option for preventing water shortages at canal tail. At the canal intake, a single pump pressurizes irrigation water in pipes (El-Nashar and Elyamany 2018). This alternative includes a surface irrigation system in clay soil with a major crop pattern of wheat, cotton, and maize.

### 5.5.4 Value Alternative 3 (VA-3)

The third value alternative is to encourage more adaptable collaborative techniques that make the most of available resources. This alternative determines how the agriculture sector may collaborate with other industries to lessen the industry's exposure to climate and water concerns ($S_{11}$), changing crop patterns by replacing crops that need a lot of water with crops that use less ($S_{18}$) and using agricultural systems modelling ($S_{22}$) which makes it feasible to plant cash crops that pay better than typical crops to growers.

Water crop productivity may be improved in several ways, including substituting high-water-using crops with lower-water-using crops, planting drought-tolerant cultivars or reducing inputs like fertilizers and water to reduce vegetative vigor, and upgrading management and systems to maximize production per unit of water consumed. The economic productivity of water may be increased by reallocating water from low-value crops to higher-value crops; hence, the most important sources of "new" water will be gains in productivity per unit of water through the adoption of suitable management and water application techniques. Each basin and watershed may have a different solution, depending on its soil, water supply, climate, and other factors.

Energy crops such as Jojuba and palm are the best alternatives in saline soil with different irrigation systems. Cultivating Jojuba using a trickle irrigation system for sand soil or a surface irrigation system for clay soil are the best choices for salt soil and a water shortage condition (Amer et al. 2021). This alternative includes trickle irrigation systems in clay or sand soil with an energy crop pattern such as Jojuba, Jatropha and Palm.

### 5.5.5 Evaluation Criteria of Alternatives

As indicated in Table 4, there are nine key evaluation criteria to evaluate the value alternatives. Because each evaluation criterion has a unique weight, a comparison matrix is used to establish the weights of the evaluation criteria. The relevance of each assessment factor in relation to the others is expressed using a scale of 0 to 5. A score of 0 is assigned for no significance of the chosen criterion over the other criterion, while a score of 5 is assigned for major significance of the chosen criterion over the other criterion. In other words, when both criteria are equally important, a score of 0 is assigned in the comparison matrix, whereas a score of 5 is assigned in the comparison matrix when one criterion is significantly more important than the other. The weighting scores of the comparison matrix in Table 4 are added up for each evaluation criterion and divided by the total weighting score of all evaluation criteria to calculate the relative weights of evaluation criteria shown in column 2 of Table 5.

### 5.5.6 Value Alternative Scoring

The alternatives scores in columns 3, 4, and 5 of Table 5 are the average scores assigned by a panel of 15 experts, with 5 to 15 years of experience in irrigation field consultancy. The panel was asked to assign a score of 0 to 10 for each value alternative against each evaluation criterion. The score of 0 indicates the least significance of the alternative in the assessment criteria, while the score of 10 indicates the highest significance of the alternative in the assessment criteria. The alternatives' scores in columns 3, 4, and 5 of Table 5 is multiplied by the evaluation criteria weights in column 2 to calculate the weighted score in columns 6, 7, and 8 of Table 5. The Technical Score (TS) of each value alternative shown in the bottom row of Table 5 is calculated by summing all the weighted scores of the evaluation criteria for the value alternative.

As reported by the panel of experts, Table 6 shows the average score for each assessment category as well as the overall score for value alternatives. Based on the evaluation criteria, the findings suggest that VA-1 has the greatest total score. To compute the Value Index, the next step is to calculate the LCC of each value alternative.

**Table 4** Evaluation criteria weighting

| **Evaluation Criteria** | | **A** | **B** | **C** | **D** | **E** | **F** | **G** | **H** | **I** |
|---|---|---|---|---|---|---|---|---|---|---|
| Recognize present water demands and potential supply–demand mismatches in the future | **A** | | B-3 | A-4 | A-3 | A-3 | A-3 | G-2 | H-2 | A-3 |
| Identify the environmental concerns posed by population increase and climate change | **B** | | | B-3 | B-2 | E-3 | B-3 | B-2 | H-2 | B-2 |
| Make their water infrastructure and delivery networks more resilient | **C** | | | | D-3 | C-3 | C-2 | G-3 | C-2 | I-3 |
| Consider the demands of customers as well as their financial ability to pay | **D** | | | | | D-4 | F-2 | D-1 | H-1 | I-2 |
| Forge new relationships and strengthen collaboration between water and all other sectors | **E** | | | | | | E-3 | G-2 | H-3 | I-3 |
| Address impacts of agriculture on the water environment | **F** | | | | | | | F-3 | F-3 | I-3 |
| Safety and health | **G** | | | | | | | | G-3 | I-3 |
| Friendly to the environment | **H** | | | | | | | | | I-3 |
| Easy to apply | **I** | | | | | | | | | |

**Table 5** Evaluation criteria weight and value alternatives score

| Evaluation Criteria | Weight | Scores | | | Weighted Scores | | |
|---|---|---|---|---|---|---|---|
| | | VA-1 | VA-2 | VA-3 | VA-1 | VA-2 | VA-3 |
| A | 0.168 | 8 | 6 | 7 | 1.344 | 1.008 | 1.176 |
| B | 0.158 | 9 | 6 | 7 | 1.422 | 0.948 | 1.106 |
| C | 0.074 | 6 | 7 | 5 | 0.444 | 0.518 | 0.37 |
| D | 0.084 | 5 | 6 | 6 | 0.420 | 0.504 | 0.504 |
| E | 0.063 | 8 | 7 | 8 | 0.504 | 0.441 | 0.504 |
| F | 0.084 | 9 | 8 | 8 | 0.756 | 0.672 | 0.672 |
| G | 0.105 | 8 | 9 | 7 | 0.840 | 0.945 | 0.735 |
| H | 0.084 | 8 | 8 | 8 | 0.672 | 0.672 | 0.672 |
| I | 0.179 | 7 | 8 | 7 | 1.253 | 1.432 | 1.253 |
| Total | 1.000 | | | | **7.655** | **7.14** | **6.992** |

### 5.5.7 Life Cycle Cost Analysis

Using LCC Analysis, the three proposed value alternatives for irrigation strategies are implemented on a study area in Egypt to select the best strategy. Egypt has been selected as a case study for countries facing irrigation water challenges due to population growth and limited or depleted water resources. Egypt's agricultural sector obtains more than 80% of its needed water from the Nile, so there is a possibility of a water shortage, taking into consideration climate change and the construction of the Grand Ethiopian Renaissance Dam (GERD). The traditional irrigation technology employed in Egypt resulted in significant water loss. Therefore, it is important to focus on solving the anticipated drought and salinity issues. It is necessary to use the irrigation strategies in Egypt to face these problems. Each value alternative as an irrigation strategy is estimated for Egypt using LCC.

**Table 6** Crop cost and revenue (LE/m$^2$)

| Crop | Present Value of Crop Cost (LE/m$^2$) | Present Value of Crop Revenue (LE/m$^2$) | NPV (LE/m$^2$) |
|---|---|---|---|
| Citrus | 1.61 | 11.88 | 10.27 |
| Vegetables | 1.82 | 13.1 | 11.28 |
| Fruits | 1.96 | 13.76 | 11.8 |
| Wheat | 1.37 | 10.2 | 8.83 |
| Cotton | 1.43 | 9.85 | 8.42 |
| Maize | 1.22 | 9.6 | 8.38 |
| Jojuba | 2.63 | 13.8 | 11.17 |
| Jatropha | 2.2 | 12.6 | 10.4 |
| Palm | 2.9 | 14.3 | 11.4 |
| Total NPV of crop revenue for VA-1 | **11.12** | | |
| Total NPV of crop revenue for VA-2 | **8.54** | | |
| Total NPV of crop revenue for VA-3 | **10.99** | | |

LCC is a method for estimating a system's overall cost from design through disposal. LCC is the total of all recurring and one-time costs, including the purchase price, setup, running, maintaining, and upgrading. LCC is used to assess value alternatives using net present value (NPV). The difference between the current value of cash inflows and outflows is what is known as net present value. To calculate NPV, the following equation is utilized (Peterson 2005).

$$NPV = C_i + R_e - S_r + A_a + M + E \tag{1}$$

where: $C_i$: investment costs; $R_e$: replacement costs; $S_r$: resale value towards the end of its lifespan; $A_a$: annually recurring operating, maintenance, and repair costs; $M$: non-annually recurring operating, maintenance, and repair cost; $E$: energy costs.

The crop revenue is calculated from the crop yield, which is cultivated per m$^2$ as a unit area for each value alternative over 30 years. The total NPV of the crop revenue for each value alternative is calculated as each crop represents a third of the unit area. These calculations are shown in Table 6. Equation (2) is used to calculate the Net Crop Benefit for each of the three proposed value alternatives.

$$Net\ Crop\ Benefits = NPV\ of\ Crop\ Cost - NPV\ of\ Crop\ Revenue \tag{2}$$

### 5.5.8 Alternatives Evaluation

Each value alternative is evaluated based on the calculated initial, annul operating, and maintenance costs per m$^2$. The calculations of net present value (NPV) for each value alternative are shown in Table 7. The Value Index (VI) is calculated using Eq. (3).

$$Value\ Index = \frac{Technical\ Score}{Net\ Present\ Value} \tag{3}$$

The higher the VI, the higher the value of the alternative. Accordingly, the most suitable irrigation strategy indicated by the calculation in Table 7 is VA-3, which encourages more adaptable collaborative techniques that make the most of available resources.

## 6 Discussion of Results

The main goals of different irrigation strategies are the ability of water use optimization, increasing water productivity, and ease of application. The results showed that the VA-1 achieved these characteristics, while the VA-2 and VA-3 almost achieved these characteristics.

**Table 7** Alternatives evaluation

| | VA-1 | VA-2 | VA-3 |
|---|---|---|---|
| Present value of Initial cost (LE/m$^2$) | 8.1 | 5.95 | 7.97 |
| Present value of Operating and maintenance cost (LE/m$^2$) | 0.56 | 0.4 | 0.6 |
| Present value of Crop Revenue (LE/m$^2$) | 11.12 | 8.54 | 10.99 |
| NPV (LE/m$^2$) | 2.46 | 2.19 | 2.42 |
| Technical Score | 7.655 | 7.14 | 6.992 |
| Value Index (VI) | **0.321** | **0.306** | **0.346** |

The irrigation strategy can be evaluated using the following: i) Recognize present water demands and potential supply–demand mismatches in the future; ii) Identify the environmental concerns posed by population increase and climate change; iii) Forge new relationships and strengthen collaboration between water and all other sectors; iv) Address the impacts of agriculture on the water environment; and v) Safety and health.

The results of the analysis showed that VA-1 achieves the highest score in all the evaluation criteria except evaluation criteria (v). VA-3 achieves the second highest score in evaluation criteria (i, ii, v), the highest score in (i), and the third highest score in (v), and VA-2 achieves the third highest score in all the evaluation criteria except evaluation criteria (v), where it achieves the highest score.

When LCC is used to calculate NPV for each value alternative, VA-1 achieves the highest value of NPV, VA-3 is second, and VA-2 comes last. For the value index (VI) calculated using Eq. (3), VA-3 achieves the highest value of VI, followed by VA-1 and then VA-2.

Although the highest VI refers to VA-3, each value alternative is suitable for different conditions. Accordingly, the decision to select the best irrigation strategy may be different based on the conditions of the soil and the environment, as will be discussed in the following 3 cases:

### 6.1 Case 1

VA-1 is preferred to be used for new lands with sandy soil, smart irrigation system and high revenue crops. The advantages of VA-1 include i) reducing human involvement, ii) possibility of being changed to meet the irrigation needs of different crop, and iii) using smart irrigation system can save up to 13% of the total water used for sprinkling, and iv) crops become healthier in the long term (Tyagi 2017). The disadvantages of VA-1 include i) high initial construction cost, and ii) suitability for specific crops and soil types.

### 6.2 Case 2

VA-2 is preferred to be used for old lands with clay soil, surface irrigation method, and usual crops. The advantages of VA-2 include i) practicality and economy, ii) suitable to produce major crops, iii) saving water lost by seepage, and iv) solving water shortage at canal tail. The disadvantages of VA-2 include i) suitability for heavy soil only and ii) water losses by evaporation.

### 6.3 Case 3

VA-3 is preferred to be used for saline soil with a surface or modern irrigation system and energy crops. The advantages of VA-3 include i) suitability for saline soil and ii) increased revenue from growing energy crops. The disadvantages of VA-3 include i) suitability for high-value crops that have a shorter growing season, and ii) high initial construction cost.

## 7 Conclusions

In order to mitigate the effects of climate change on irrigation water demand and crop yield, irrigation strategies need to be further investigated. In this research, the VE methodology was utilized to evaluate the irrigation strategies. The goal of VE is to identify "best value," or the optimal balance between worth and cost, by examining the functions of the strategy. VE aims to strike a balance between all the system's requirements.

Irrigation strategies required to achieve food security are defined using a FAST diagram. Twenty-two creative ideas related to irrigation strategies are proposed by experts. Through a process of progressive evaluation, these ideas were shortlisted to 9 ideas, which were then used to formulate three value alternatives for the irrigation strategy. VA-1 uses a trickle irrigation system with a microcontroller in sand soil with citrus, vegetables, and fruits as a crop pattern. VA-2 uses a surface irrigation system in clay soil with a major crop pattern of wheat, cotton, and maize. VA-3 uses a trickle irrigation system in clay or sand soil with an energy crop pattern such as Jojuba, Jatropha, and palm.

The three value alternatives were evaluated based on evaluation criteria related to irrigation method, crop pattern, soil characteristics, climate change, and impacts on the environment. Water use optimization, water productivity, and ease of application are the performance characteristics that were considered in the irrigation strategy evaluation.

The value alternative's weight relative to each evaluation criterion is determined using the VE and LCC techniques. The total costs, total benefits, and net present value are calculated for each alternative per unit area ($m^2$). The Value Index (VI) was calculated for each value alternative. Although the highest value index belongs to VA-3, the least value index belongs to VA-2. However, the value index is convergent for the three value alternatives. The conclusion is that VA-1 is preferred to be used for new lands with sandy soil, smart irrigation system, and high revenue crops; VA-2 is preferred to be used for old lands with clay soil, surface irrigation method, and usual crops; and VA-3 is preferred to be used for saline soil with surface or modern irrigation system and energy crops.

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## Declarations

**Ethics Approval** Not applicable.

**Consent to Participate** Not applicable.

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