Discover Water

Case Study

Cost–benefit analysis on the implementation of nature-based treated wastewater reuse: case of sekem farm El-Wahat, Egypt

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Abstract
In a context of increasing pressure on water resources and severe aridity; expansion in the reuse of naturally treated wastewater can be a viable and low-cost solution particularly for irrigation forests, green non-fruit trees, fabric crops, industrial oils, and non-edible raw crops. Wastewater treatment is increasingly recognized as a potential means in El-Wahat El-Bahariya in Egypt. However, investment decisions concerning the reuse of treated wastewater in irrigation needs to be justified in terms of financial and economic feasibility and profitability. Therefore, this research study aims to conduct a cost–benefit analysis (CBA) of an investment project "reuse treated wastewater in irrigation compared to other modes of water irrigation projects. The CBA results revealed that the cost of the initial investment for the production of treated water used for irrigating green non-fruit trees, Bamboo trees, and Cactus in Sekem El-Wahat, is economically efficient with 88% compared to the exploitation of aquifer groundwater for irrigating the same crops. That project allows for an economic gain of about 4,428.5 €/ha compared to the cost of producing aquifer ground water in Sekem Farm El-Wahat is estimated at 10,800 €/year. Substituting the use of aquifer ground water for irrigating crops with reuse of treated wastewater helps reducing energy consumption and offers great financial benefits to the beneficial communities. A net benefit of the reuse of treated wastewater project is largely positive with NPV equivalent to 4599 €/year with a medium economic efficiency (BCR) of about 0.44.

Keywords Wastewater treatment · Low-cost · Nature-based · Constructed wetland technology · Reuse · Operation cost · Maintenance cost · Cost Benefit Analysis · Economic efficiency

1 Introduction

The growing population exacerbated the demand for water, food, energy and other human needs, particularly in regions with sever aridity in the world. Yet, changing climate's impacts on surface water supplies and demands caused increasing reliance on groundwater resources. Egypt, as an arid and highly populated country, faces severe water challenges. On the top of it is the limited fresh water resources from the Nile and deep groundwater aquifer, and the dramatic population increase. Rainfall is very scarce and concentrated in the Northern coastal areas and Saini. The Nile Delta aquifer in Egypt is replenished directly by the surface Nile water. Egypt's economic growth in various sectors depends on the availability of water resources [1]. The supply of Egyptian water demand is ensured

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by approximately 82% of surface water, and 12% of groundwater, and the remaining 6% comes from the reuse of agricultural drainage water and treated wastewater [2]. The virtual water approach allows Egypt to meet the critical food needs of its population while managing its limited water resources. However, it also highlights the country's vulnerability to global markets and the importance of a diversified food security strategy [3, 4]. Egypt is increasingly using groundwater to meet its needs, particularly in agriculture [5]. However, the growing water demand exceeds the capacity of the groundwater reservoir [2]. Particularly in areas of the Western Nile Delta and along the desert fringes of the Nile Valley, there is overexploitation of aquifer waters. The Egyptian overall renewable water resources come mainly from the Nile River, scatter rain and deep groundwater with a total of approximately 59.2 billion cubic meters per year [3].

Efficiency in the use and distribution of water resources is a measure of good governance and a regulatory framework. This should result in maximizing the use of available and newly developed water resources. The tools involved are the use of a rigorous system of monitoring, compliance, and sanctions supporting its legal framework. By focusing on demand management, Egypt can develop more sustainable and resilient strategies to address its water challenges. This involves not only technological changes, but also transformations in agricultural, industrial and domestic practices, as well as in water management policies [6].

According to the Egyptian Waste Water Treatment Law (The Egyptian Code of Practice: ECP 501, 2017), [7], the reuse of treated wastewater is regulated for non-fruitful trees, fiber and industrial oil crops, according to the effectiveness of the treatment with safeguard considerations. The reuse of treated wastewater holds promise for the future as an increasing water resource [5], particularly in areas with a high fresh water deficit (such as El-Wahat El-Bahariya Oasis, Egypt). However, this reuse of treated wastewater presents secondary risks of ingestion linked to bacteria and parasites [7]. It is necessary to plan a broader follow-up assessment covering health risk, particularly the inhalation aspects.

In this context, the reuse of naturally treated wastewater can be a viable solution to face water scarcity in Egypt. Wastewater treatment is increasingly recognized as a potential means of water supply [4]. In addition to reducing the negative human and environmental impacts resulting from the discharge of raw wastewater into waterways, it reduces pressure on the available fresh water resources if used for crops irrigation, so more fresh water can be secured to satisfy the drinking needs. Also, it is more convenient for the isolated communities without sanitation facilities to practice low-cost and nature-based local wastewater treatment. It provides additional source of water that can be potentially used for agricultural crops needs for the local communities provided that the health safeguard measures are considered [8].

Irrigation using treated wastewater for investment needs to be justified in terms of financial and economic profitability and the resulting results contributing to the prosperity of, and benefiting to a country, a society, or even a private sector [9]. Such justification is particularly necessary to determine, based on econometric investigations, whether the measures taken are in favor of agro-environmental measures within the national agricultural policy and water resource management [10]. Irrigation projects and programs generally represent the most expensive type of investment, in terms of specific unit costs per developed area. There is a need to understand the determinants of costs and benefits of efficient water reuse [11]. Therefore, the cost–benefit analysis process estimates the benefits and costs of an investment for two reasons: (1) to determine whether the project is viable and whether it is a good investment; and (2) to compare a project investment with other competing projects, to determine which is more feasible [12–15].

Not all types of wastewater treatment systems or technologies work for the desert or remote rural environment. The constructed wetlands treatment (CWT) technology treats wastewater naturally by means of soil filtration, aquatic weeds and micro-organisms uptake, aeration by natural weirs and sun penetration effect. The typical CWT system follows a gravitational flow model (instream wetland system) with potential hydraulic head difference between upstream and downstream with additional integrated natural weirs and soil filters. Suitable native aquatic weeds and submerged plant species are cultivated in natural substrate to extract specific pollutants and release the inflow of wastewater in cleaner condition. The soil filters as well as micro-organisms capture various chemical and organic constituents from the wastewater. The sun penetration, aeration in the shallow and slow flow of water kills significant amount of germs, microbes and viruses [16]. The aim is to "clean" the wastewater and produce reclaimed irrigation water that can be used for agriculture without human or environmental risks. The climatic conditions are quite different from one region to another, so each CWT system should be operated independently according to its local physical and climatological conditions [17].

Implementing such nature-based treatment systems raises questions about its long-term economic viability. A comparative analysis between CWT case and the reference groundwater abstraction case is the focus of this research. This research study aims to conduct a cost–benefit analysis (CBA) of new investment project "the reuse of treated wastewater in irrigation", called the REUSE project in Sekem Farm El-Wahat El-Bahariya in Egypt compared to the conventional practice of production of aquifer groundwater water for irrigation of green spaces.

2 Materials and methods

2.1 Description of the study area

Sekem Farm for Land Reclamation in El–Wahat El-Bahariya Oasis, is considered an integrated agricultural community located in the Western Desert of Egypt. It is located about 450 km distance South West of Cairo (Fig. 1). The area of Sekem Farm El-Wahat is about 2100 acres with about 1000 inhabitants. El-Wahat El-Bahariya Oasis includes more than 500,000 inhabitants. Half of its area is under cultivation now using modern irrigation system (drip and central pivot systems) and organic agriculture in dominant. The land reclamation and development of the other half of Sekem farm is on-going [18]. The REUSE project aims at reusing the treated domestic wastewater (from Sekem Farm) for irrigation of wood trees among other non-fruitful and industrial crops within Sekem Farm El-Wahat. This REUSE project is a low-cost, nature-based, and efficient engineering instream constructed wetland technology used for treating domestic as well as agricultural drainage water (Fig. 2). The technical details are explained in the PRIMA/Horizon 2020 funded MED-WET project (Component 3: The REUSE project), [19].

The REUSE technology in Egypt explores the use of constructed wetlands, which are engineered systems that use native weeds, soils, microorganisms and aeration weirs to remove contaminants such as nitrogen, phosphorus, heavy

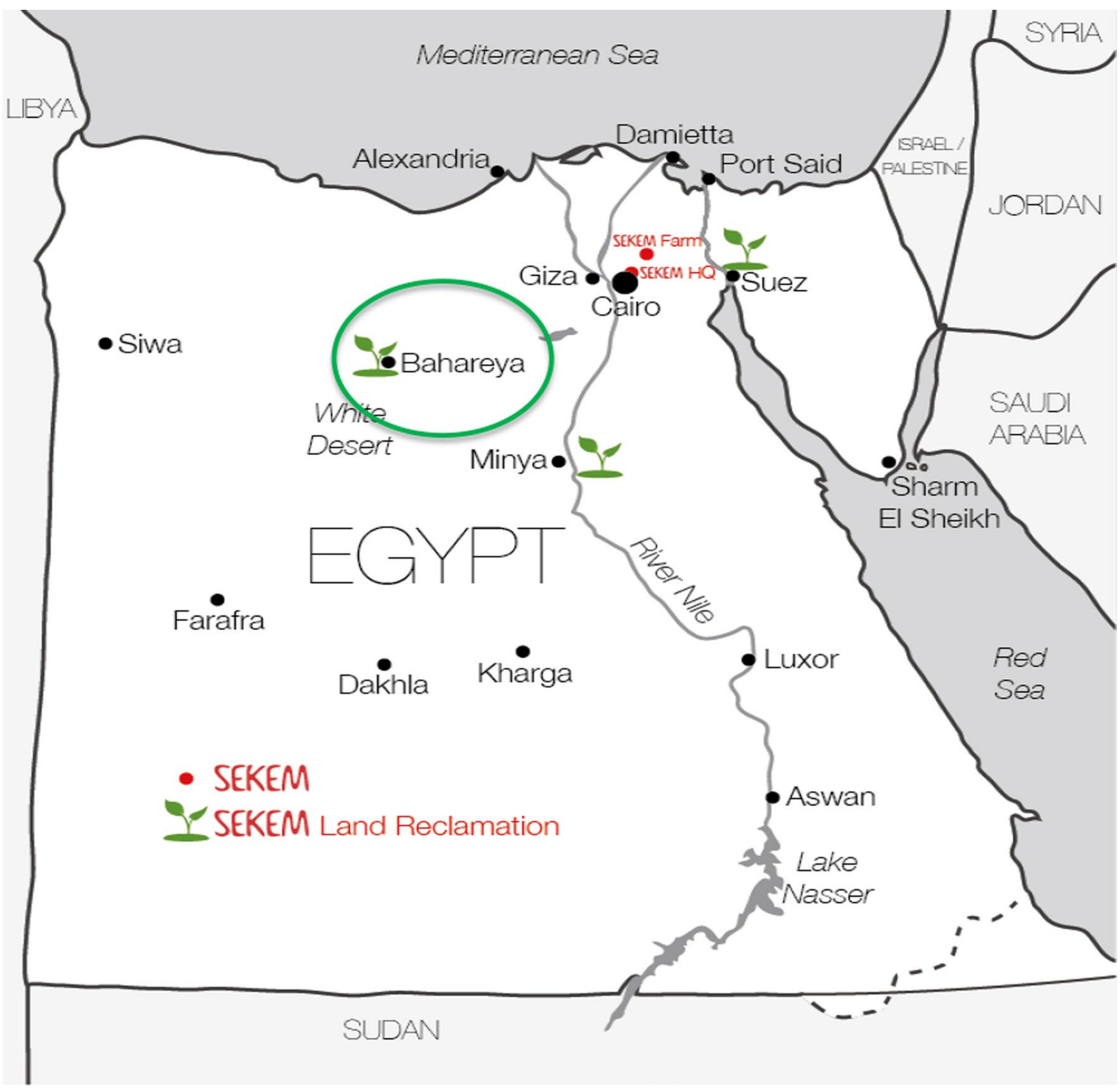

Fig. 1 The location of the study area Sekem Farm for Land Reclamation in El-Wahat El-Bahariya, Source: www.sekem.com

metals and pathogens from wastewater by mimicking processes in the natural wetland ecosystems. This nature-based technology can be used to increase the availability of water resources for irrigation, particularly in rural and desert communities as it is low-cost and does not require energy or sophisticated machinery. Constructed wetlands are efficient in treating the liquid municipal effluents and agricultural drainage water, thus can be of great value to remote communities.

In Sekem Farm El-Wahat, there are difficulties encountered in installing the CWT site of the REUSE project. It replaced the disposal of raw domestic wastewater into the groundwater aquifer through septic tanks, into opportunity which is additional safe irrigation water. The project leader (Heliopolis University for Sustainable Development, Egypt) called HUSD, pioneered the treatment of wastewater practice in rural area such as Sekem Farm El-Wahat. In 2023, HUSD completed the installation of a natural-base wetland for treatment (engineering constructed instream wetland treatment). The treated water is used for irrigating green spaces for carbon sequestration, industrial crops production and achieving socio-economic benefits [19].

The installation and operation of a low-cost and nature-based CWT site in Sekem Farm El-Wahat was accomplished under the research REUSE project [19]. The target is to get-ride of the wastewater hazard and to increase water availability for irrigation while reducing pressure on conventional freshwater groundwater resources. The treated water is used for irrigating non-fruitful trees, Bamboo trees, canopy, shrubs, cactus and vegetation. Irrigating edible crops is prohibited because of the possible health risks [17]. At the outlet of the CWT system, an irrigation pump conveys the treated water to the irrigation ditches, so that the green spaces are getting surface irrigation water by gravity. The REUSE project results emphasized that the treatment efficiency is higher than 90%, therefore the residual constituents in the treated water are insignificant. Accordingly; the human and environmental impact was proven nil on the long term [19].

Fig. 2 The installed low-cost nature-based and efficient engineering constructed wetland treatment site in Sekem El-Wahat El-Bahariya, Egypt, source: https://www.medwet-eu.com/wetlands

Sekem farm managers are using the treated wastewater to mainly irrigate a forest belt (12 km length and 50 m width surrounding Sekem Farm El-Wahat) of various types of non-fruitful trees. The target is to increase carbon sequestration (reducing carbon dioxide emissions in the atmosphere) and improve the micro-climate. Currently, the total number of planned trees is between 70,000 and 80,000 non-fruitful trees, constituting a green corridor. The types of grown trees are Acacia Trees, Tamaris Trees and Desert Willow Trees. Perhaps other native desert trees are also irrigated (Bamboo trees, canopy, shrubs, cactus and vegetation). Bamboo weed is being used in building construction in Sekem Farm. Cactus and other vegetation are being used for several industries as well as animal fodder and compost production. Those green spaces are adapted to a dry climate, and saline irrigation water, and can survive in harsh climate conditions and alkaline soils [18, 19].

2.2 The CWT operation and its reference framework

The operation of the CWT (two cells) can be summarized as follows. The domestic wastewater is abstracted (by a pump of 1.0 horse power capacity) from the main underground septic tank of Sekem farm (isolated for groundwater protection from seepage of pollution), filling the inlet over-ground tank. Water flows through a manual valve and then discharge meter (to control the inflow of row domestic wastewater) according to the design discharge (15–16 litter per minute). A cross-sectional perforated pipe is installed to assure uniform distribution of the domestic raw wastewater flowing by gravity into the cell (trapezoidal cross section with 50 m' length, 0.6 m hydraulic depth, 0.5 m and 5 m bottom and top widths, respectively). Gravel and coarse sand filters are used for initial filtration process occurs to stop the progressing of coarse and fine suspended particles by trapping them forming a biological micro-film layer of small organisms, leaving the domestic wastewater in a cleaner condition. Sedimentation segment of about 19 m length followed by a 1.0 m height sealed nature-materials weir. In this segment the large and heavy suspended particles deposit to the bed of the segment. Flow over weir allows aeration and mixing of oxygen into the domestic wastewater reducing the Biological Oxygen Demand (BOD) concentration. Those processes improve the quality of domestic wastewater by reducing various types of micro-biological loads as well as suspended solids. In the following segment, native aquatic weeds (Cat-tail and reeds) reduce the concentration of salts as well as heavy metals significantly due to plants update and storing those elements in its stem and leave tissues [16]. Flow over the second weir ensuring more oxygen mixing into the domestic wastewater reducing the BOD concentrations significantly.

This process improves the quality of domestic wastewater by reducing the majority of physical, chemical and biological loads. A following segment of fine sand filters plays a second filtration intervention to stop the progressing of the very fine suspended particles by trapping them forming a biological micro-film layer, leaving the treated water in a cleaner condition. Then, the treated water moves to the Azolla algae segment, in which the majority of the carbonic substances and other organic pollutants are abstracted as food for the Azolla. The third and last segment of fine sand filters stops the progressing of the micro fine organisms and particles, leaving the domestic sewage water in a cleaner condition. Along the whole cell segments, the sun rays penetrate the shallow depth of water (0.6 m maximum) killing various types of germs, protozoans, pathogens and microbes. The hydraulic retention time (residence time) of the domestic wastewater takes about three days to move from the inlet to the outlet of the cell driven by a gravitational force, then forming the treated water.

The outlet tanks (underground) allows the treated water to be collected slowly by gravity in that tank, ready for a second pump (1.0 horse power capacity) to pump the water to the irrigation ditches for irrigating green spaces. The net discharge of treated water is about (28–30) cubic meters from the two cells per day. The difference between the design discharge (16 cubic meters per cell per day X 2 = 32 cubic meters per day) and the actual discharge is the evaporation losses within the three-day residence time [19].

Thus, the environment of El-Wahat El-Bahariya is a primary beneficiary from the CWT site. For the managers of Sekem farm El-Wahat, it constitutes a net cost. The net benefit of the Sekem Farm El-Wahat green space, however, from the point of view of the community, it largely offsets the net costs of the investments of other actors. This highlights the need to seek financial compensating solutions to get closer to win/win solutions [12, 13]. The reference situation is the irrigation of non-fruitful trees in alignment with the green space of Sekem Farm El-Wahat using drip irrigation from the aquifer's groundwater. The irrigation of the green spaces of Sekem farm El-Wahat is presented as an outlet for this treated wastewater, a solution alternative to an outlet in an aquatic environment, widely criticized by environmental protection associations. The Cost Benefit Analysis (CBA) is based on an economic analysis of water production by naturally treating the domestic wastewater and agricultural drainage in comparison to tapping the groundwater aquifer [14, 15].

It is estimated that the geographical proximity between users (domestic case and farmers) and the treated wastewater reservoir (1000 m distance) is almost the same as that of the groundwater well water abstraction source for irrigation (1100 m distance). However, there is no sufficiently productive aquifer groundwater. Furthermore, the surface Nile water pumping into the desert area is too expensive because it is too far away (nearly 450 KM from the Nile). It is also noted that the Nile water contains some contaminants due to direct disposal of domestic raw wastewater from villages in proximity to the Nile Course [20]. It is therefore in this context of absence of alternative resources that the REUSE project is being implemented. In addition, the reuse of treated wastewater is only valid if it meets two conditions in addition to the related national regulatory constraints, as follows: (1) demand close to the supply of treated wastewater to minimize investments necessary in terms of distribution network and ensure a certain profitability (economic and financial) for the various stakeholders involved. This assumption is considered in the present research study; and (2) compliance with certain qualitative and quantitative criteria of domestic wastewater from Sekem farm El-Wahat both receptacles of water from the treatment site in a context of respecting the recommendations of environmental protection associations and to meet the future increase in demand for aquifer's groundwater for municipal irrigation [15].

2.3 Identification and classification of relevant impacts of the REUSE project

The estimated benefits and costs of a project may vary depending on different assumptions regarding the input data and the methodology applied in the cost–benefit analysis [13, 21]. These costs will have repercussions on social and environmental aspects. To initiate this phase of identification and classification of the existing REUSE project compared to the reference case, a set of CBA indicators was developed, following a thorough and in-depth bibliographic synthesis, based on physical criteria relating to the cost of production of the treated water and aquifer, equipment for the water production system and irrigation of non-fruitful trees, and operation & maintenance. There are rehabilitation costs directly induced by the depreciation of irrigation water storage and pumping equipment. The estimation of benefits is linked to the turnover in water production and the savings in water and labor, in relation to the reuse of treated wastewater for irrigation. These benefits will work in favor of the social and environmental returns (particularly the carbon sequestration and improving the micro-climate). A hypothesis is applied in this research study that there are no significant long-term adverse impacts from the REUSE project on the soil and groundwater quality nor on human and environmental health aspects.

2.4 The lifespan of equipment

Lifespans determine the estimated cost of water when we wish to make comparisons between irrigation methods [22, 23]. The lifespan of the water pump amortization up to the area of the non-fruitful tree was estimated at 30 years. Consider that the water storage and pumping equipment are constant for the reference and REUSE project cases.

2.5 Monetizing the costs and benefits

Data from HUSD and MED-WET Project, expressed in euros according to variations of the year 2023 were collected. This includes data on the costs of equipment, infrastructure, and buildings used to produce treated domestic water and aquifer groundwater for irrigation of non-fruitful trees. Annual repair, operating, and maintenance costs were assumed to be added to the initial equipment's investment. Fixed costs are related to insurance, social charges, and advice, on one hand, and the depreciation of equipment on the other. Depreciation is estimated using the linear relationship. Operation costs (social cost) are linked to the daily activities of workers and vary depending on the working time per treated water production system compared to that of the aquifer and the frequency of irrigation. The cost of labor is the same for both water production systems. The benefits of the REUSE project are the added value of water production and operating costs.

Although these marketable costs and benefits are easier to assess, it is crucial not to neglect less tangible environmental aspects in the overall evaluation of the REUSE project. A balanced approach, combining the analysis of market and non-market elements (environmental impacts), is essential for informed decision-making and a complete assessment of the value of the project. Those are in particular the effects induced on the upstream and downstream sectors, such as the employment. Finally, certain non-market costs and benefits are difficult to monetize, such as non-fruitful tree yield (carbon sequestration and wood production among other benefits), environmental impacts or return, individual satisfaction, etc. The environmental costs were estimated based on the revenue from the water.

In the "reference case" (Table 1): Sekem farm El-Wahat El-Bahariya exploits the groundwater aquifer using uncontrolled pumping for drip irrigation of date palm trees, olives, various vegetables, and wood trees. The selling price of groundwater is estimated at 1.5 €/m^3 during the year 2023. The cost of producing groundwater could increase by 30% in the next 10 years. The objective is to control and regulate the current use of groundwater in the Sekem farm El-Wahat in irrigation (7200 m^3/year). Fertilization requirements could be estimated at 2000 €/year. In this context, the farmers and beneficiaries of the Sekem farm will have to face drought seasons requiring them to partially lose their crops by about 1500 €/year. So, the reuse of treated wastewater comes as a priority and sustainable solution.

In the case of the "REUSE project": The reuse of treated wastewater is destined to irrigate green spaces planted by the non-fruitful trees for carbon sequestration, Bamboo trees and cactus production inside Sekem farm El-Wahat. Those agro-products have economic values, as Bamboo wood is used for building environment-friendly houses for the inhabitants of Sekem farm, likewise the Cactus is used in various non-edible industries and compost production due to their unique properties and resilience. The benefit accrues to the community of Sekem farm is assumed equivalent to the surplus of users of groundwater for drinking purposes. The produced volume of treated wastewater in Sekem farm El-Wahat is about 14,400 m^3/year. The treated wastewater could be sold for 0.5 €/m^3. 570 €/ha is the cost of treated wastewater quantity in the study region, to which are added numerous additional costs mainly linked to changes in (costs of workers, tillage, soil siltation, depreciation of the irrigation systems parts, … etc.), as well as the cost of energy required for pumping. On the other hand, the REUSE project could reduce its agricultural land fertilizer expenses by 20% and no longer have any expenses for crop loss or restrictions on use.

2.6 Estimating costs and benefits

In this research study, the technical and economic data were processed with EXCEL spreadsheets to produce qualitative estimates of indicators (costs and benefits). These cost–benefit analysis (CBA) indicators are based on net present benefit (NPV) and cost–benefit ratio (CBR) [9, 11, 22, 23].

3 Results and discussion

Based on the qualitative analysis conducted using Excel spreadsheets' calculations, reasonable assumptions, and baseline data shown above, the following economic, social, and environmental costs analysis results can be derived.

3.1 The economic cost

As shown in Table 2, the cost of the initial investment for the production of treated wastewater for irrigating non-fruit trees in Sekem farm El-Wahat is estimated about 598.4 €/ha. It is lower than the abstraction of groundwater, which is estimated at about 5,026.9 €/ha. The difference in economic cost between the two water production methods for irrigating the same crops is about 88%. Furthermore, the REUSE project using treated wastewater allowed for an economic gain of about 4,428.5 €/ha for the Sekem Farm El-Wahat, compared to the abstraction and use of aquifer groundwater for irrigating the same crops [19]. REUSE Project produced inexpensive water supply solution allowing for an economic benefit of about 88% compared to the abstraction of the depleted groundwater aquifer. Thus, the frequent use of groundwater as a source of fresh water leads to lowering the groundwater tables and accordingly increasing the pumping costs.

Table 1 Determination of the characteristics of reference case of irrigating green spaces with groundwater in Sekem Farm El-Wahat El-Bahariya, Egypt

Reference case: characteristics	Estimation of the characteristics
Water type	Groundwater aquifer
Type of irrigated green spaces	Date palm trees, olives, various vegetables, and wood trees
Price of groundwater (2023)	1.5 €/m^3
Estimated groundwater consumed per year (case of "Without CWT"), in irrigation of Sekem El-Wahat region	7200 m^3/year
Cost of fertilization requirements	2000 €/year
Cost of lost crops	1500 €/year

Table 2 Economic costs comparison between the two cases: production of treated wastewater (REUSE Project) and abstraction from the aquifer groundwater, for irrigating non-fruitful trees in Sekem Farm El-Wahat El-Bahariya, Egypt

	Reuse project case	Reference case
	Reuse of treated domestic wastewater	Production of aquifer groundwater
Initial investment of equipment cost (€/ha)	570	4860
Investment cost in installation of water storage (€/ha)	0.39	4.90
Equipment rehabilitation cost (€/ha)	28.0	162
Investment cost (€/ha)	598.4	5026.9

To cope-up-with the recurring periods of drought and limit groundwater withdrawals at Sekem farm El-Wahat, as well as similar cases in certain countries (e.g. France, Spain, and Italy) are already well mobilized to develop reuse of treated wastewater [10]. However, the transformation towards a circular economy must be inherited into the national water management strategy and plans. REUSE project is considered one of the means to better promote investments in the field of wastewater treatment, especially in the desert and for remote rural communities. Consequently, the model of the "REUSE project" produces non-conventional water resources, available to isolated smallholder farmers and desert communities. In addition, it complies with the environmental safeguards.

3.2 The social cost

Table 3 illustrates the social cost comparison of the operation cost of the two cases of water production (groundwater and treated wastewater) for irrigation purposes in Sekem farm El-Wahat. Supplying treated wastewater as a feasible solution in rural and desert communities is advantageous and recommended especially for regions where labor for groundwater abstraction is critical. It is a technique where the flow of treated wastewater is used for continuous irrigation without interruption. It does not require high labor costs for the abstraction of groundwater (390 €/ha/year) compared to the cost of labor necessary for the production of aquifer groundwater necessary for the irrigation of non-fruitful trees, which is equivalent to about 6940 €/ha/year.

The REUSE project plays a real springboard for the spread of the circular economy throughout the Egyptian territory and beyond while creating new opportunities, and securing human activities and jobs endangered by the local water deficiency [19]. As a result, the project concept is in favor of securing sustainable job opportunities.

3.3 The environmental cost

In the REUSE project case, the average benefit linked to the environment of region is the development of treated wastewater of about 14,400 m^3/year (Table 4). The supply of treated wastewater in Sekem farm El-Wahat reduces the pressure of using aquifer groundwater for irrigation by about 7200 m^3/year. Consequently, the benefits of the REUSE project increase the replenishment and availability of the groundwater in the region, thus contributing to the restoration of the environment (improving groundwater quality and human health by the safe transformation of the wastewater into an opportunity). This will contribute to the recharge of aquifers in the Case of REUSE project in Sekem farm El-Wahat by about 7200 m^3/year, besides avoiding the possible deterioration of groundwater by mixing with the untreated wastewater.

Table 3 Social cost comparison between the two cases: production of treated wastewater (REUSE Project) and abstraction from the aquifer groundwater, for irrigating non-fruitful trees in Sekem Farm El-Wahat El-Bahariya, Egypt

	REUSE project case	Reference case
	Reuse of treated domestic wastewater	Production of aquifer groundwater
Labor cost for operation and maintenance of the storage basin (€ /ha/year)	102	460
Average cost of water for watering green spaces with trees (€/ha/year)	288	6480
Total	390	6940
Additional gain (€/ha/year)	6550	0.0

Table 4 Environmental cost comparison between the two cases: production of treated wastewater (REUSE Project) and abstraction from the aquifer groundwater, for irrigating non-fruitful trees in Sekem Farm El-Wahat El-Bahariya, Egypt

	REUSE project case	Reference case
	Reuse of treated domestic wastewater	Production of aquifer groundwater
Volume of water available (m^3/year)	14,400	7200
Cost of selling water (€/m^3)	0.5	1.5
Cost of water production (€ / year)	7200	10,800
Cost of re-cultivation (€/year)	0.0	1500
Cost of fertilization (€/year)	0.0	2000

The estimated cost of producing aquifer groundwater in Sekem farm El-Wahat is about 10800 €/year compared to that of treated wastewater, which is about 7200 €/year (Table 4). Substituting the use of aquifer groundwater for irrigating non-fruitful trees helps reducing the cost of energy consumption and offers great financial benefits to isolated and desert communities. It also benefits the environment by reducing carbon dioxide emissions (carbon sequestration), which are a major contributor to global warming. Additionally, reducing fuel consumption as it decreases air pollutants released in case coal, oil, or other fossil fuel sources are burned to produce energy.

The prolonged droughts are becoming more and more common in the desert region where Sekem farm El-Wahat is located, and in the Mediterranean regions in general. The growing competition on using non-conventional water resources under climate change has especially exacerbated the problems of water shortage (case of aquifer groundwater in Sekem farm El-Wahat). The unavailability of aquifer groundwater in the Sekem farm El-Wahat region will contribute to cultivating less greening places with the cost estimated at about 1500 €/year (Table 4). On the other hand, the REUSE project will allow for additional non-conventional treated wastewater source, that contributes to improved socio-economic and environmental returns.

In addition, the environmental and health benefits of the REUSE project contribute to reducing the chemical fertilizers application in reference case (aquifer groundwater). This provides natural nutrients, dissolved with fairly concentrations in the treated water, when irrigating non-fruitful trees. The case of aquifer groundwater includes chemical fertilizers application estimated at about 2000 €/year (Table 4). Yet, there are marginal disadvantages of reusing treated wastewater [5], such as the REUSE project that must be controlled –if exist- examined and overcome, such as the presence of polluting substances and pathogens, which implies a potential direct risk for the human and environment health. Furthermore, indirect risk could be the accumulation of pollutant agents and salts present in wastewater [7]. This subject needs further long-term study and evaluation.

3.4 Findings of cost and benefit analysis

The indicators NPV and BCR of the cost and benefit analysis of the treated wastewater (REUSE project) are presented in Table 5. As the treated wastewater cost is about 0.5 €/m^3, it was observed that the net benefit (NPV) of the REUSE project is significantly positive at about 4599 €/year. This means that the benefits of cash inflow are greater than the costs of cash outflow during the first year of the operation of the REUSE project in Sekem farm El-Wahat. This NPV value is therefore taken as the benefits of the community and the development of the region (isolated rural and desert areas). The REUSE project represents a real interest in implementing more sustainable and resilient non-conventional water management, across the entire value chain by reducing groundwater withdrawals while limiting the costs of wastewater discharge into the groundwater aquifer.

Table 5 Cost and benefice analysis (CBA) comparison between the two cases: production of treated wastewater (REUSE Project) and abstraction from the aquifer groundwater, for irrigating non-fruitful trees in Sekem Farm El-Wahat El-Bahariya, Egypt

	Reuse Project (treated wastewater for irrigating non-fruitful trees)
Net present value (NPV, €/year)	4599
Cost–benefit ratio (BCR)	0.44

In addition, the estimated Benefit–Cost Ratio (BCR) of the REUSE project is about 0.44 (Table 5). The estimated economic efficiency (BCR) value is less than 1.0 indicating that the benefits associated with the REUSE project case during the first year are considered moderate. The REUSE project therefore focuses on the supply side by developing non-conventional water production as well as on the demand side, by proposing a new form of water consumption built on multi-use of the water resources. The economic efficiency indicator can be improved by reconsidering the costs and benefits of non-fruitful trees return, and environmental improvement, among other benefits. In addition, it is necessary to take into account the benefits linked to the wastewater treatment co-products (energy saving, animal fodders, organic fertilizers such as compost production, etc.) maximizing all the positive benefits of this good practice [9, 10].

4 Conclusion and recommendations

This research study presents a cost–benefit analysis of the reuse of treated wastewater in Sekem Farm El-Wahat El-Bahariya in Egypt versus the conventional use of groundwater aquifer. The initial investment cost for the production of treated wastewater (598.4 €/ha) is significantly lower than that of the abstraction of groundwater (5,026.9 €/ha). This allows a saving of 88%. Also, the implemented REUSE project requires much lower labor costs (390 €/ha/year) compared to the groundwater abstraction (6940 €/ha/year). This promotes a social gain of 6550 €/ha/year. On the environmental level, it was shown that the REUSE project reduces pressure on groundwater, contributes to the recharge of aquifers, and reduces Carbon Dioxide emissions in favor of improving the micro-climate in El-Wahat region. The major environmental and health benefits of the REUSE project is reducing the chemical fertilizers application by providing natural nutrients for irrigating non-fruitful trees. On the contrary, the case of aquifer groundwater abstraction, inherits risk of chemical fertilizers application estimated at about 2000 €/year. The cost–benefit analysis (CBA) estimated the Net Present Value (NPV) indicator of the REUSE project as positive in the amount of 4599 €/year, indicating that the benefits exceed the costs. The Cost–Benefit Ratio (CBR) is estimated 0.44, which implies that the benefits are moderate in the first year. Those findings and recommendations highlight the significant potential of the REUSE project for sustainable water management in arid regions, while highlighting areas requiring continued attention to maximize its benefits.

The advantage of reuse of treated wastewater increases over time by taking into account the following recommendations:

- Integration into the national strategy: incorporate the reuse of treated wastewater into the national water management strategy to promote the circular economy.
- Optimization of benefits: reconsider costs and benefits, particularly those related to non-fruit trees and environmental improvement, to improve CBR.
- Valorization of by-products: take into account the benefits linked to by-products of wastewater treatment (energy savings, animal fodders, organic fertilizers such as compost production) to maximize positive externalities.
- Project expansion: encourage the application of this model in other remote rural and desert communities to create sustainable employment opportunities and improves water security.
- Risk management: examine and mitigate potential risks associated with the presence and accumulation of pollutants and pathogens in the treated wastewater.
- Continued research: continue studies to determine the impacts of the use of treated wastewater on soils, crops, and environment on the long-term.
- Awareness: promote the environmental and economic benefits of reuse of treated wastewater among the smallholder farmers and remote rural communities.
- Pricing policy: develop a pricing structure that reflects the real value of water while remaining affordable for farmers.

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Data availability Water data, costing and economic data.

Declarations

Competing interest The authors declare no competing interests.

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