



Holistic Assessment of the Egyptian National Land Reclamation Project from the view of IWRM

Ayman Ayad^{1*}, AbdelKawy Khalifa², and Mohamed ElFawy²

¹ Water and Utilities Sector Manager, European Union Delegation in Egypt, Cairo, Egypt

² Irrigation and Hydraulics Department, Faculty of Engineering, Ain Shams University, Cairo, Egypt

Received: 14/02/2021

Accepted: 19/09/2021

Published: 20/12/2021

Abstract

Agriculture is the primary sector and central component of the Egyptian economy. The Agriculture economy's early estimates are about 17% of overall GDP and 20% total exports, as well as, accommodating around 30% - 40% of the labor force. Under the 1st Priority Land Reclamation Projects of the New Land development in Egypt, it is planned to reclaim 1.5 million feddans of agricultural land in nine reclamation areas in the Western Desert, mainly irrigated on groundwater. In this paper, the project is assessed in terms of groundwater occurrence, environmental screening, and economic sustainability with the rules of Integrated Water Resources Management (IWRM) is applied. The review highlights that the literature on groundwater withdrawal and use from all aquifers as a whole is significantly outdated, and might not represent the actual conditions of the groundwater occurrence and regime currently prevailing. Concurrently, updated information on monitoring groundwater levels and quality are not easily accessible, making it difficult for assessing long-term trends on groundwater dynamics, reserves, and quality. Finally, the paper presents an excel based model for optimal crop pattern selection in response to water different water quantities and qualities. The used model is named the "Water Allocation Model for computing optimal crop patterns on water or "AFWAM". In general, implementing the project is financially feasible, the project is expected to have a direct, positive social impact. Toshka site is the optimal choice for intervention early due to low initial investment costs. Still, the project is feasible in all proposed areas.

Keywords: Land Reclamation, IWRM, Groundwater Management, Crop productivity

1 Introduction

The National land reclamation project, particularly the 1.5 million feddan, is mainly located in the western desert region. The western region is characterized by covering some 700 000 km²; it is almost 65% of Egypt's total land. Its formation spread out from the Mediterranean Sea to the Sudanese border. It includes the Jilf al Kabir Plateau at 1000 m height and deep depressions occupied by oases apart from the largest depression, "the Qattara"; its lowest point below the sea level (133 m). Limited agricultural production occurs in the oases. The western desert mainly limestone and sandstone and dunes in some parts, primarily far west near the west of borders.

The north area mainly covers basal elastic overlaid by carbonate, marine limestone in most western deserts' central parts. The data availability was a significant restriction, as no recent data are available, especially groundwater potentials and extraction and water quality. However, so little development occurred in the decade preceding the national land reclamation program (2007-2017). Therefore, it could be deduced that data available, even dated before 2017, could be considered suitable for such rapid analysis.

2 Groundwater Assessment

The groundwater review has focused mainly on: i) aquifer identification and characteristics, including a synthesis of the hydraulic characteristics of the various aquifers in the Western desert, ii) quality of groundwater, and iii) quantitative

assessment of the groundwater resources in the four new reclamation areas.

3 Recharge

3.1 Groundwater Occurrence in the NSA Aquifer

The origin of most groundwater circulating in the Nubian Sand Aquifer (NSA) is fossil. Isotopic studies carried out for decades demonstrate that the massive part of the groundwater within the Nubian Sandstone complex was trapped in the sediments during humid periods, having occurred through the late Pleistocene and Holocene epochs. The NSA's natural discharge by evapotranspiration in the depressions has been estimated at 10-15 mm/year. Various authors have provided quite different estimations of the discharge of the Nubian aquifer through the Qattara Depression. [1] provides a comparison of compares the multiple estimates:

Table 1: Estimated annual flow in NSA

Author	Estimated annual flow (Million m ³ /yr.)
Ball (1933)	1008.86
Ezzat (1982)	504.43
Amer, Nour, Mishriki (1980)	114.92
Ezzat (1982), in USAID (1998)	90.245

Corresponding author: Ayman Ayad, Water and Utilities Sector Manager, European Union Delegation in Egypt, Cairo, Egypt, E-mail: ayad.ayman.r@gmail.com

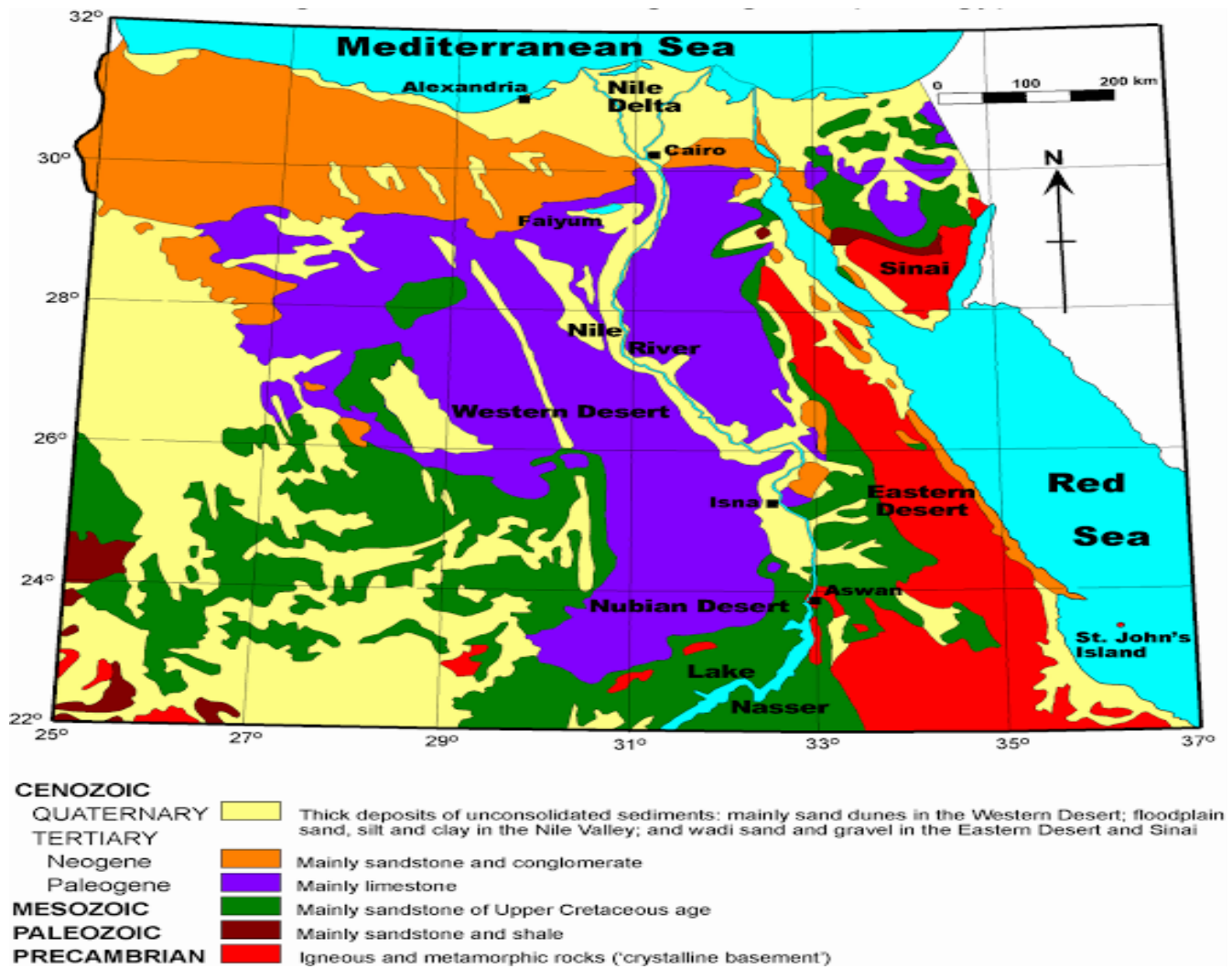


Figure 1 Soil classification Map - Reference USAID 1998

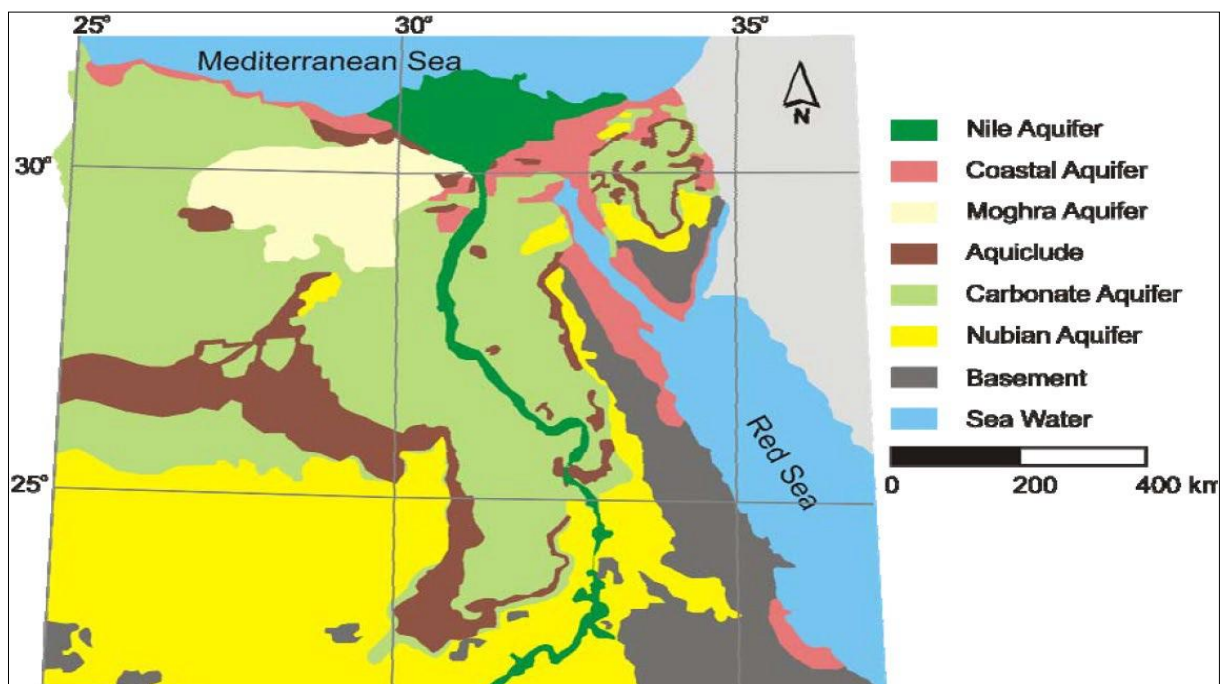


Figure 2: Main Hydrogeological Units in Egypt-- Reference USAID 1998

[1] referred to [28], estimated that groundwater is lost annually by evapotranspiration from the Nubian sandstone aquifer in the Qattara-Siwa depression 90 million m³ [1].

3.2 Groundwater Occurrence in the Moghra Aquifer

The groundwater circulating in this aquifer is a mixture of fossil and renewable water. The existence of buried paleo-channels being part of the lake Moghra system was identified by Radar-based geophysical investigations [2]. The Moghra aquifer is recharged from i) seepage from the western part of the aquifer of the Nile delta; ii) through flow from hydraulically upstream groundwater, namely the overlying Miocene limestone aquifer (Mamaria limestone; iii) upward leakage from the deep NSA in hydraulic charge under the Cenomanian Shale; and iv) a minor contribution from rainfall [3].

The hydraulic gradient from the Nile Delta aquifer to the Moghra aquifer is low: 10-4- 2x10-4. The annual recharge by seepage from the Nile Delta aquifer to the Moghra aquifer was estimated in the range of 50- 100 million m³ (RIGW – IWACO, 1998). Direct recharge from rainfall is insignificant [4]. In the Eastern part of the Moghra formation, a localized aquifer in thick Pliocene sediments is known as *Wadi Al Natrun* [5].

The natural discharge of the groundwater circulating within the Moghra aquifer occurs by i) throughflow into the limestone sequences of the aquifer west of the Qattara depression and ii) evaporation from the Qattara Wadi Al Natron depressions. Through a steady-state groundwater simulation model, [3] estimated the flow of groundwater transferred from the deep NSA into the overlying Moghra aquifer and eventually into the Qattara Depression at 75 Mm³/yr. [1] and [8] estimated the transfer at 90 and 87 Mm³/yr, respectively. The estimated annual extractions in 2007 were 200 Mm³/yr (El Tahlawi, 2007).

3.3 Groundwater Occurrence in the New Toshka Area Aquifer

Long term records of groundwater level in piezometers between 1964 and 2004 [9] indicate that the groundwater level in the NSAS in the area between the Lake Nasser and the

Toshka lakes rose to an average of 25 m during the 40 years, corresponding to an average of 0.62 cm year. The uprising of the groundwater is attributed to the Aswan hydropower Reservoir's impoundment (Lake Nasser), constructed between 1964 and 1971, thus providing evidence that the Nubian sandstone in this area receives recharge from the Lake Nasser. Based on direct estimates and results of a groundwater simulation model of the local Nubian sandstone aquifer [9] estimated that the cumulative recharge occurring by induced recharge from the Naser Reservoir would have reached 966,000 million m³, corresponding to an average 23,600 million m³/yr over the period 1964 to 2005.

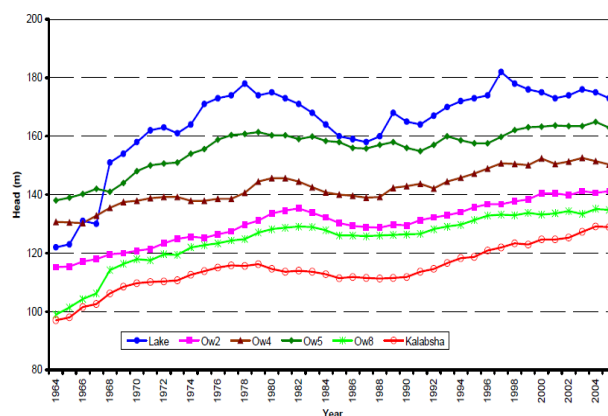


Figure 3: Recorded Changes of Groundwater level in Observation Wells West of Lake Nasser

Monitoring of groundwater level over the period 1998 to 2006 in existing observation wells (Figure 4). indicate that the groundwater level has instead steadily decreased in all monitoring wells during the period in a range between 1 and 14 m [7].

Table 2: Terms of Groundwater Occurrence and Extractions in the Moghra Aquifer

Inflow Component	Volume Mm ³ /yr	Ref	Outflow Component	Volume Mm ³ /yr	Ref
Rainfall	Negligible	[5]	to Qattara & lakes	90	[3]
Nile Delta aquifer	50-100	[4]	to hydraulic downstream & Wadi Natrun	?	[3]
Hydraulic Upstream (Miocene limestone)	N/A	[3]	Irrigation & WS	52.7 / 200	[5]
deep NSA	90	[3]		120	[8]

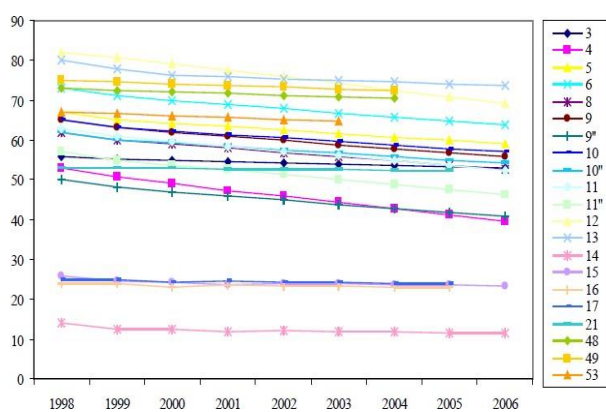


Figure 4: Changes in Groundwater Level in monitored Wells

Based on bi-dimensional simulations of the groundwater flow [10] have estimated the seepage of Lake Nasser into the surrounding Nubian aquifer at an average of 1200 million m³/yr over the simulation period 1965-2004, with a decreasing trend in the second part of the simulated period due to the decrease of the hydraulic gradient. This Figure contrasts very much with the findings of [9]. Earlier, [11] estimated a recharge rate from Lake Nasser at 1770 million m³/yr. More recently, [7], estimated the aquifer's recharge by seepage through Lake Nasser's left banks at 238 million m³/yr or 257,000 m³/yr per km.

Long-term records show that the Nasser Lake's water level fluctuates between 158 and 182 m with a periodicity of some 15-20 years. It is assumed that low impoundment levels in the lake correspond with minimum recharge into the groundwater aquifer. Conversely, the reservoir's maximum impoundment situations would correspond to the highest recharge due to a higher hydraulic gradient. It can be provisionally concluded that the Nubian sandstone aquifer in the Toshka area receives an induced recharge from Lake Nasser; the recharge's estimated amount varies significantly from an author to another. For working purposes, we might assume a conservative Figure of 1500 million m³/yr. Additional recharge can occur by throughflow from the hydraulically upstream aquifer through the SW border of the local aquifer and from the Toshka lakes. This latter is, however, estimated as marginal [12]. Some recharge could also occur along with leading transfer and irrigation canals in the pump irrigated Toshka reclamation project (500,000 Fed). This project, commissioned in 2007, involves allocating 5000 million m³/yr from lake Nasser and the planned extraction of 25 million m³ of groundwater per year [7]. According to previous evaluations ([25]; [28]), groundwater extraction for irrigation needs from the Nubian aquifer in the area of Abu Simbel, Afia, Toshka would have been in the order of 200 million m³/yr. Natural discharge of the NSA's groundwater in the Toshka development area occurs by transfer to hydraulically downstream portions of the aquifer to be quantified. A two-dimensional finite element model covering the Nubia basin on both sides of Nasser Lake was developed in 1987 by Soliman [28]. The model's objective was to estimate the Nubia Sandstone aquifer yield at periods of low floods when the lake's level is the lowest and the recharge to the aquifer is minimal. The model results indicated that the aquifer's potential groundwater extraction at the different locations selected for irrigated agriculture (Wadi Allaqi, Afia, Toshka, Abu Simbel) amounts to 257 mcm /year anticipated drawdowns ranging between 60 m and 70 m.

3.4 Groundwater Occurrence in the West Minia Aquifer

Quantitative estimates of groundwater balances of the aquifers in this area were not found during literature research. Regionally, groundwater exhibits a northward trending gradient in this area [15]. The recharge of the Upper Eocene-Pleistocene water-bearing units may occur by seepage from the Nile and upward percolation of groundwater in hydraulic charge from the deep NSA through the upper confining Cenomanian shale. No recharge of the upper Pleistocene aquifer is expected to occur from the average 4 mm of the annual rainfall occurring as very limited precipitations of the order of 1 mm throughout the year, believed to be lost in evaporation. The Total Dissolved Solids (TDS) content of the groundwater in the Pleistocene aquifer is between 352 and 1664 mg/l. The salinity content of groundwater in the fractured Eocene limestone varies between 499 and 8,768 mg/l, with a tendency to decrease westwards [15].

Table 3: Provisional Terms of Groundwater Occurrence and Extractions in the NSA in Toshka Area

Inflow Component	Volume (Mm ³ /yr.)	Reference
Transfer from hydraulically upstream aquifer	NA	
From Nasser reservoir	238 -1200 - 1700	[7]; [10]; [11]
Form Toshka Lakes	Negligible	[12]
Outflow Component	Volume (Mm ³ /yr.)	Reference
Extractions for agriculture	<200	[28]
Planned extractions from wells along the main irrigation canal	10?	[28]
Irrigation wells under the Toshka Pump irrigated Project	25?	[7]

The groundwater in the Pleistocene is classified as calcium-magnesium-potassium carbonate. The groundwater in the Eocene limestone is of the sodium-chloride type. [13] confirmed the deduction regarding low salinity of the groundwater varying from 560 mg/l to 930 mg/l in most wells. The stable isotope values ensure that groundwater has an isotopic signature of the modern Nile water with a bit of contribution of the Nubian sandstone's paleo-water. Accordingly, sustainable development activities can be established after determining this aquifer's safe yield to protect it from deterioration. While [14] states that about 85% of the aquifer is classified as medium vulnerability and about 11% is low to medium, and 4% is medium to high.

4 Discussion Regarding the Groundwater Resources

4.1 Groundwater Needs for the national program

Some Estimates of Groundwater Reserves and potential for development are outlined in Table 4. For preliminary estimates, the Ministry of Agriculture and land reclamation have adopted a standard application of 5000 m³ per Fed and year. Based on such an assumption, the following demands were calculated (Table 5).

Table 4: Estimates of Potential of Groundwater for Development within the Western Desert

Area	Aquifer	Amount	Unit	Reference
Siwa, W. Oweinat, New Valley	NSA	2.385	Bm ³ /yr (100 yr)	Simulation in [28]
Siwa, Bahariya, Farafra, Dakhla, Kharga, E. Oweinat, Toshka	NSA	2.9	Bm ³ /yr (100 yr)	[9]
	NSAS	5.18	Bm ³ x 1000	[19];[20]

Table 4: Highlights of planned Reclamation Areas and Groundwater Requirements

Project Name	Area (Fed)	Irrigation Water source	Demand (Mm ³ /yr)
Toshka	142,000	Surface Water	
Toshka Groundwater	10,000	GW from NSA	50
West of West Mania	420,000	GW from NSA – Eocene	2,100
Moghra	150,000	GW from Moghra Aquifer	750
Siwa	30,000	GW from NSA	150
Total Groundwater demand	610,000	GW from NSA+PNAS	3,050

Based on the above, it could be deduced that considering non-agricultural needs (Domestic water usage, industrial water usage, cooling, etc.; that the estimated lifetime shall exceed 100 years. This deduction is based assumption that at least 50% of water shall be returned to the system for reuse; For domestic and industrial water usage, it is assumed that two (2) persons shall reside/work per feddan (equal to 300 m³/fed equivalence/year). As for industrial use of water, a Zero Liquid Discharge (ZLD) is to be implemented with minimum inflow to the system (500 m³/fed/year) and 1000 m³/fed/year in total to account for other uses of water.

Table 5: Planned water needs and estimated lifetimes expectancy

Area	Planned withdrawal ² (Mm ³ /yr)	Optimal Withdrawal ³ (Mm ³ /yr)	Expected Lifetime
Siwa East	180	125	>100
Moghra	900	600	>100
Toshka Groundwater	60	45	>100
W-W Menia	2520	1500	>100

4.2 Ground Water Assessment conclusions

The tentative consolidation of hydrogeological information under the present paper highlights the significant scope for updating groundwater's main parameters in the western desert of Egypt and the Project areas. Updated groundwater balances should be carried out to i) ascertain with more accuracy the groundwater availability in quantity and quality sufficient to sustain the irrigation needs under the new Land reclamation program in the long term, and ii) acquire additional information on aquifer characteristics.

There is an evident and substantial lack of updated information on groundwater withdrawal and use from all aquifers included in the Nubian Aquifer System as a whole. This lack of information must be compensated by undertaking

adequate surveys and setting up a fair monitoring system of the groundwater withdrawal and quality to be operated in the future. Updated information on monitoring groundwater levels and quality is not easily accessible, rendering planners more difficult, particularly concerning analyzing and assessing long-term trends in groundwater dynamics, reserves, and quality. All the existing monitoring data on groundwater quantitative and quality monitoring should be collected and analyzed. Competent governance institutions such as MWRI and MALR should undertake to have all data related to groundwater monitoring ordered on a single server and rendered accessible to relevant administrations and professionals.

The rapid assessment of the groundwater resources in the four reclamation areas has highlighted the following issues: At a regional scale, there appear to be sufficient groundwater resources available for development in the long-range to satisfy the needs of agricultural use. Yet, when taking into consideration other water usages ; such as domestic water consumption , industrial water uses , and other uses; the sustainable lifetime is under questioning.

In Siwa, the NSA's characteristics are fair. There are optimistic perspectives for further developing groundwater from the deep NSA up to the supplementary 150- 180 Mm³ of groundwater required annually in the long term. Nevertheless, it is proposed to subordinate further massive groundwater development, which requires significant investments for deep production wells to a preliminary master plan. The master plan will seek the optimum reuse and management of the large amounts of a currently non-utilized well. Springwater and drainage water are largely diverted into the saline ponds or lost as waterlogging.

The New Moghra Reclamation area 1st Phase is located where the groundwater TDS is usually higher than 3,000 mg/l and may rise to 10,000 in the extensions near the Qattara depression. A preliminary review of quantitative groundwater occurrence indicates that the amounts of groundwater planned to be abstracted from a relatively small aquifer might not be sustained by the available reserves in the long-range. However, considering the groundwater's elevated salinity, extended groundwater mining from the Moghra aquifer would not constitute an environmental hazard. It might also be expected that the drawdown generated by the extraction of groundwater would, in the long-range, enhance and increase of induced recharge of freshwater from the Nile Delta.

In the New Toshka reclamation Area, groundwater in free surface conditions is available at a depth of 40 to 450 m within the NSA, characterized by a fair hydraulic coefficient. Development of required 50,000 m³/yr of groundwater for the irrigation of new 10,000 fed agricultural land appears feasible due to expected induced recharge from the Nile.

There is very little relevant information regarding aquifer identification, characteristics, and groundwater occurrence in West-west Minia. It is assumed that the groundwater in the deep NSA aquifer has fair attributes of quality. Elsewhere there is documented indication that the groundwater from the Eocene limestone aquifer exhibits relatively high salinity content. It is

² Including other non-Agricultural needs

³ Applying ZLD, efficient reuse mechanisms

advised to undertake a full, updated hydrogeological assessment of the aquifer.

5 Environmental and Social Assessment

In this paper, triple bottom lines assessment (TBL) checks the projects' financial, environmental, and social dimensions. TBL is defined as "a tool to evaluate the relative sustainability of options for urban water management" ([16]; [17]). Initially coined by ([18]), TBL is a flexible and practical tool used for planning, and development, besides its primary use as a sustainability benchmark. It also incorporates stakeholder participation [29] involves the social, economic, and environmental systems assessment in arid regions/ Egypt in general and for the new lands. In general, the triple bottom lines are vulnerable to climate change disruptions in the arid areas. The triple bottom assessment considers the interconnectivity between these factors and the land-water-energy nexus within the climate zone and its conditions.

5.1 Methodology

The environmental screening (TBL approach) has been carried out based on a screening matrix. The following components taken into consideration for the screening review are listed hereafter. A triple bottom lines assessment conducted for the four regions (Toshka, Siwa, West west Menia, and Moghra) represented different aspects: climate, hydrology and groundwater, water quality, soil, social infrastructure, environment, socio-economic, alternative irrigation water, and energy.

Based on data availability, some of the sub-criteria or indicators have been assessed qualitatively. When there were data available, indicators were assessed quantitatively (See Table 7). The traffic light indicator used to represent the situation as follow:

Traffic light	Situation
Red	High risk for water/energy/crop/economic/etc.
Yellow	Medium risk for water/energy/crop/economic/etc., and can be managed
Green	No risk or non-significant

Table 7 shows the overall assessment matrix based on the sub-criteria considered under each of the above aspects and its descriptions and qualitative/quantitative values under each area. The comment's Column captures some of the recommended actions to mitigate.

The preliminary environmental and social assessment was carried out based on a typical environmental screening matrix. Based on the review, no significant social and ecological threats are anticipated to occur shortly after implementing the reclamation projects in the four agricultural development areas. A complete environmental and social assessment is recommended to carry over before the project starts with ongoing five years frequency assessment to avoid any significant impacts on the long-term.

6 Financial and Economic Assessment

In this paper, the water allocation model using the Linear programming approach is used to determine a profit-maximizing combination of activities (crops) feasible concerning a set of constraints.: A decision-making unit (farm) has a specific land area, a given amount of water that can be abstracted for tube well, and other restrictions.

Table 6: TBL Assessment table

Risk/issue	Moghra	Toshka	Siwa	West West Menia	Overall Likelihood	Overall Consequences
Bedonie	Red	Green	Yellow	Yellow	Red	Red
Institutional and Regulation reform	Red	Red	Red	Red	Yellow	Red
Strategic change	Red	Red	Red	Red	Green	Yellow
Government changes	Red	Red	Red	Red	Green	Yellow
Government harmony and Overall project Delivery and achieving objectives	Red	Red	Red	Red	Red	Red
illegal influx to the land once project boundaries are announced.	Yellow	Green	Green	Yellow	Yellow	Red
Capacity to Implement and Manage by MWRI and MALR	Red	Red	Red	Red	Red	Red
Knowledge gap	Red	Yellow	Yellow	Red	Yellow	Red
Fail to attract the new settlers and investors	Yellow	Red	Yellow	Yellow	Yellow	Red
Lack of complete TBL information and assessment	Red	Red	Yellow	Yellow	Yellow	Red
Climate change and drought	Yellow	Yellow	Yellow	Yellow	Yellow	Red
Fail to establish modern farmers and settlers in the project areas	Red	Red	Red	Red	Red	Red
Inefficiency of energy	Red	Yellow	Yellow	Yellow	Red	Red
Nubian Sandstone Aquifer (NSA)	N/A	Yellow	Red	Red	Yellow	Red
Post-Nubian Aquifers System (PNAS)	Red	N/A	Yellow	Red	Red	Yellow

It also confronts a complex input and output price system and particular production technology (set of input-output coefficients). Enterprise budgets have been prepared and estimated for most fruits, field crops, and vegetable crops grown in different sites. The estimated enterprise budgets used are based on the average international estimates on returns and costs available in 2020. Enterprise budgets represent estimates of returns, costs, and net returns associated with crops' production activities. Each site's monthly water demands are estimated and used to evaluate each location's solar energy system's design and capacity.

It is worth mentioning that relying on pivot systems is not an option, as still an area to be irrigated by drip irrigation as per Figure 5 below. A farm of 200 feddan is suggested to be an ideal farm size that contains a pivot irrigation system of 150 feddan, and the remaining 50 feddan will be cultivated with winter and summer vegetables.

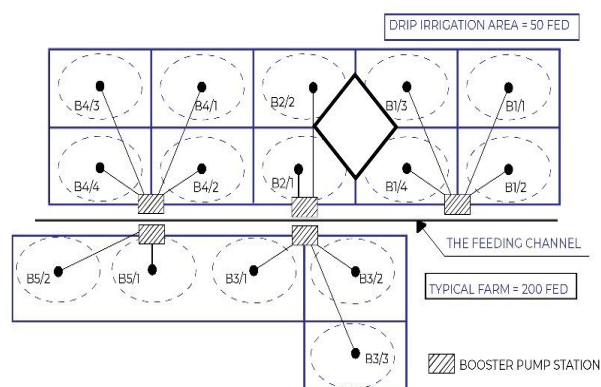


Figure 5: Schematic design of a typical irrigation system in the proposed areas

Agricultural Field Water Allocation Model (AFWAM) (Salman et al., 2011) is an excel based optimization linear programming model. It uses data on available land, water requirements per unit land area for different crops, and net revenues per unit of the land area generated by the growth of those crops. These net revenues do not include payments for water. The model takes the monthly water supply and allocates water among crops to generate an optimal cropping pattern that maximizes net agricultural income. AFWAM has many goals and objectives:

1. To quantify the Project benefits in Physical and Monetary terms such as Total Production and Total Revenues;
2. To quantify the Operational costs of agricultural activities;
3. To quantify the water demand under various water amounts available, qualities,
4. To determine the associated costs of water abstraction;
5. To provide the financial model with a soundly based analysis of cropping pattern, production intensity, Irrigation water demand, and optimal allocation around the whole year;
6. To derive the operational costs, revenues, water values per cubic meter.

The objective function is to maximize the total annual Gross margin (net income) from agriculture at the typical farm level (agreed on 200 feddans). The objective is to maximize net Revenues, and Net Revenue has two main parts.

The First is Total Revenue (TR):

$$TR = \sum P_y \cdot Y \quad (\text{Eq. 1})$$

where y is the product, P_y is the farmgate price. The Second is Production Costs, Total Variable Cost (TVC).

$$TVC = \sum P_x \cdot X \quad (\text{Eq. 2})$$

where X crop inputs and P_x is the input price. By subtraction equations 1, and 2 we get the Gross Margin (GM) = TR-TVC. The constraints for the model are as follows:

1. Water Availability Constraint: Max water availability per location
2. Water Salinity: Salinity constraints for selection of a specific type of crops
3. Energy availability: Water Supply by Solar Energy and/or Conventional Energy

The model can also be used to examine the effects of water quantity allocations. An objection that will naturally occur to the reader has to do with the usefulness of results obtained from an optimizing model. Actual cropping patterns reflect real people's behavior, and real people may not always respond optimally. To this, there are several replies [22].

1. Calibration of the AFWAM model to actual data confirms that the model reasonably approximates farmers' precise response to available water and output prices.
2. Even if AFWAM generates results that might not reflect actual human behavior, still the results can serve planners as an adequate base model. This is extremely useful in strategic planning.
3. A departure of actual behavior from the optimal generated by AFWAM can signal planners that further study should be done.
4. AFWAM can serve as a decision-making tool for strategic decision-making. Cropping patterns are likely to prove optimal under variable conditions and link these to various water policies.

[23] presented the use of linear programming in structuring a more productive Egyptian cropping pattern. There are three alternatives. The first alternative was maximizing net return to land and water per feddan using both financial and economical prices; secondly, maximizing return to water unit volume using both financial and economical prices. Finally, the third alternative was to rationalize the use of available water resources by minimizing existing water requirements. He suggests that applying the model considering both generated returns and irrigation water requirements is the most effective. [24] focused on assessing water productivity for different crops and supporting decision-makers in drawing sustainable agriculture policies in the future. He also aimed to maximize the national water resources' productivity in various agriculture activities considering supply and demand aspects based on efficient water resource utilization. The crop budget approach is regarded as an economic tool to estimate the net return or profit.

7 Mathematical representation of AFWAM

The objective function of the model can be written as [25]:

The Objective function

$$MaxZ = \sum_j P_j \cdot Y_j - [\sum_i (P_i \cdot X_i) + \sum_i (P_w \cdot Q_w)] \quad (\text{Eq. 3})$$

where Z is the objective function, P_j is the farm gate price of product j , x_i and P_i is the input I and price of input i . P_w is the cost of water, and Q_w is the quantity of water. Y_j is the yield of crop j and simulated using a yield crop response salinity. Water Constraints

$$\sum_j \sum_m \hat{a}_{ijm} X_{jm} + \sum_i \sum_m (-\hat{W}_{im}^0) \leq 0 \quad (\text{Eq. 4})$$

where $\hat{a}_{ij}$ is the crop water requirements (CWR) of crop j in month m simulated using FAO CropWat 8.. X_{jm} is the land allocated to crop j in month m . $\hat{W}_{im}$ is the water supply of month m simulated using solar radiation for each site.

The Land Constraints

$$\sum_j \sum_k X_{jm} \leq A_k \quad (\text{Eq. 5})$$

where A_k is the total land allocated to each crop category (cereals, legumes, winter and summer vegetables, fruit trees, etc. in each site).

8 Initial input Analysis

To best simulate the optimal crop pattern and calculate the project economics; the following analysis has to be made:

Irrigation method selection: The purpose is to provide a cost estimate for the choice of irrigation technology based on the least cost approach and find alternative scenarios for cost recovery after considering the trade-off between different irrigation techniques. The available irrigation technology applied in the Western Desert climate is drip irrigation, pivot system, and sprinkler irrigation. Other traditional irrigation systems such as flood and furrow irrigation are not allowed according to MWRI regulations. The comparison between irrigation technologies in term of CAPEX and OPEX are shown in Table 8. The results show that, besides using the Pivot system (150 feddan per farm), the suitable system for the remaining area (50 feddans) is inconclusive as both techniques have their pros and cons. Therefore, selecting the irrigation technology should depend on soil type, crop and land topography, and several other factors.

Table 7: Comparison of total investment costs and operational costs by irrigation Technology

Initial Investment Costs (Million euro)	Drip irrigation	Pivot System	Sprinkler Irrigation
Total Initial Investment Costs	46.99	39.43	42.81
Annual Depreciation Cost	4.07	2.26	3.28
Annual Interest on Equity Capital	1.88	1.27	1.55
Annual Maintenance Costs	1.46	1.1	1.29
Annual Operational Cost	6.42	4.37	5.04

Energy Mix selection: In this analysis, sufficient sunshine hours have been collected, and then based on the expert's opinion, an average solar pump discharge is estimated. Then as per the data available regarding the possible number of wells per site; the total max discharge is calculated via Renewable Energy, and therefore, the remaining % is expected to be fueled through conventional means; tables 9 – 12 summarise the calculation and results. The average water pumped from the solar energy fueled pump is 135 m³/hr; therefore, the overall estimated amount of withdrawn water using solar energy is expected to be as follows.

The CAPEX and OPEX per feddan show that PV is expensive in terms of initial cost per feddan and reaches 4,422 euro compared with conventional energy system with 2,936 Euro per feddan. However, PV has lower operational costs per feddan compared to conventional energy. The financial indicators show that PV alone has a lower IRR (15.1%) than

traditional Diesel energy (24%). However, The IRR of a hybrid system is (22.6%). For these results, one can conclude that adopting PV alone without combining other sources is not attractive.

Table 8: Effective Sun Shine hours for project sites (hrs/day)

Sunshine hrs	Moghra	Siwa	Toshka	West West Mania
Oct	7.6	10	10.4	9.6
Nov	5.7	8.4	9.6	9
Dec	5.1	7.7	8.9	7.9
Jan	5	8.3	8.9	8.1
Feb	5.8	9	9.8	9.1
March	6.7	9.9	10	9.2
April	7.1	10.2	10.7	9.9
May	9.2	11.5	11.6	11.4
June	11.5	13.4	12.9	13.4
July	10.9	13.5	12.4	13.3
Aug	10	12.5	12	12.7
Sept	8.8	11.6	11.4	11.7

Table 9: Annual Potential Water Supply for one tube well by Solar Energy fueled pump (m³/month)

Month	Moghra	Siwa	Toshka	West_West Mania
Total	369,837	498,602	508,638	495,690

Table 10: Proposed Number of Well per Site

No.	Project Site	Area (000 fed)	No. of Well
1	Toshka	10	50
2	West_West Mania	420	2800
3	Moghra	150	1352
4	Siwa	30	120

Table 11: Potential water supply by solar energy at site level in a million m³

Month	Moghra	Siwa	Toshka	West_West Mania
Total (Mm ³ /yr)	769.3	92.0	48.9	1,429.9
Energy Mix, Conventional %	27%	22%	17%	30%
Energy Mix, Renewable Energy %	73%	78%	83%	70%

Other factors play the leading role in adopting the PV system, such as risk related to the continuous supply of fossil energy, the transportation costs of conventional energy to the site, O&M costs, and grid connection availability in the farm site. In conclusion, it is suggested that the land reclamation project adopt a hybrid energy source system that combines a PV system with a conventional energy system.

9 Results at the Site Level, and Optimal Cropping Pattern

The model was run at a site level by feeding the model with total areas cultivated and potential water supply from solar energy. The suggested optimal cropping patterns for each site are shown in Table 13. The total physical output in tones is displayed in Table 14, the total breakdown revenues and operational costs are displayed in Table 15. The results are shown in thousands of euros for each site. [26] have studied the

crop water requirements of soils in the South El Farafra Oasis, Egypt. They found that the most suitable crops were clover, wheat, beans, sugar beet, onions, maize, sunflower, tomato, potato, groundnut, pea, lentil, barley, sesame, and carrots. The results obtained from this model confirm the same basic conclusion made by them, as the majority of crops (86.2% of the cropped area) suggested falls under the vegetables, perennial crops, and cereals categories. These results are compared with the above study in the Egyptian Oasis.

Table 12: Suggested Optimal Cropping Pattern for each project site in feddan

Cropping Pattern	Unit	Moghra	Siwa	Toshka	WW Menia	Whole Project
Cereal, wheat, barley	fed	32,000	500	6,000	100,000	51,000
Legumes	fed	15,000	1,000	9,890	24,000	60,000
Herbal & Aromatic	fed	3,000	50	450	5,000	20,000
Summer. Vegetables	fed	50,591	2,276	1,500	24,000	540,468
Winter Vegetables	fed	39,409	4,800	1,540	127,000	366,308
Fodder crops	fed	7,500	374	370	20,000	74,348
Perennial Crop/Fruit trees	fed	37,500	1,000	10,250	120,000	138,000
Total Land Area	fed	185,000	10,000	30,000	420,000	1,250,124

Table 13: Crop Production Resulted from Optimal Cropping Pattern for each project site in feddan

Site	Unit	Moghra	Siwa	Toshka	WW Menia
Cereal, wheat, barley	Ton	63,178	11,644	1,075	185,884
Legumes	Ton	54,000	44,695	1,440	72,091
Herbal & Aromatic	Ton	1,307	262	26	2,124
Summer. Vegetables	Ton	852,867	7,214	20,225	217,055
Winter Vegetables	Ton	645,650	24,213	61,758	1,089,848
Fodder crops	Ton	82,238	3,820	2,576	160,363
Perennial Crop/Fruit trees	Ton	258,072	35,514	1,839	700,050
Total Production	Ton	1,957,311	127,362	88,940	2,427,415

Table 16 shows the financial results at the site level in the proposed project areas. The net present value (NPV) is the highest in West_West Menia with 622 million Euros, and the lowest is Toshka with 32 million euros. Since each site has different land sizes to be reclaimed, the NPV is miss leading indicators since it does not consider the volume of initial investment that differs between sites due to different areas reclaimed. The profitability index, which considers the initial investment, shows that Moghra is ranked No 1 with a ratio of (2.33) followed by Siwa (1.96). The Profitability index for the whole project is (1.72).

The Benefit-Cost ratio (B/C) is the present value of the inflow stream (benefits) divided by the current value of the outflow stream (costs) at a specific interest rate. Moghra yields the highest B/C ratio with 1.47, followed by Siwa with a ratio (1.37). The Internal Rate of Return (IRR) is that the discount rate equates the net present value to zero. IRR is an important factor determining the project's validity when it exceeds the opportunity cost of capital. The highest IRR is found in Moghra at 23.88%. The IRR in Toshka is 19.89%, 20.31% in Siwa, and the lowest in West West Menia with 12.98%, which exceeds the opportunity cost of capital. This indicator shows that the

project is financially feasible and, in all cases and it is desirable to the investor(s).

Table 14: Physical Outputs, Total Revenues and Operational Cost breakdown by Sites

Economic Indicators	Unit	Moghra	Siwa	Toshka	WW Menia
Total Land Area	fed	185,000	10,000	30,000	420,000
Total Production (ton)	Ton	1,957,311	88,940	127,362	2,427,415
Total Revenue	Million Euro	243.768	14.822	48.143	243.768
Labor Wages	Million Euro	21.913	1.404	2.993	21.913
Machinery	Million Euro	10.941	0.594	1.712	10.941
Seeds/Seedling	Million Euro	7.468	0.490	1.198	7.468
Manure	Million Euro	3.126	0.226	0.640	3.126
Fertilizers	Million Euro	10.191	0.578	1.525	10.191
Insecticides	Million Euro	3.238	0.203	0.494	3.238
Other Expenses	Million Euro	7.222	0.393	1.383	7.223
Total cost without Rent	Million Euro	64.103	3.891	9.946	64.103
Quasi Rent	Million Euro	1.104	0.060	0.179	1.104
Total Cost	Million Euro	65.207	3.950	10.125	65.207
Gross Margin	Million Euro	178.793	10.931	38.296	178.793
Net Return	Million Euro	178.561	10.872	38.018	178.561

Table 15: Model Overall Summary Input and Outputs

Indicators	Moghra	Siwa	Toshka	WW Menia
Financial Indicators				
Initial Investment (million Euro)	680.21	44.00	145.48	2,030.60
Internal Rate of Return (IRR)	23.88%	20.31%	19.89%	12.98%
B/C @ 8%	1.47	1.37	1.27	1.13
NPV @ 8% (million Euro)	757	125	32	622
Payback Period (Years)	5.00	6.00	6.00	8.00
Profitability index	2.33	1.96	1.82	1.35
Efficiency Indicators				
Breakeven Point (ton)	1,649,628	115,499	88,713	2,670,183
ATC/Unit (Euro/ton)	824	2,875	1,288	2,088
AVC Cost/Unit (Euro/ton)	321	782	440	654
Direct Labor Cost/Total Cost %	24.59%	12.53%	19.00%	16.74%
Total Labor Cost/Total Cost %	38.94%	23.23%	30.53%	28.48%
Simple rate of Return %	13.24%	8.88%	6.60%	2.65%
Net Profit Margin %	30.91%	24.07%	17.28%	8.51%

The payback period is the length of time from the beginning of the project until the net value of cash flow reaches the capital

investment's total amount. The payback period of the proposed project is 5 years in Moghra, 6 years in Siwa, 6 years in the Toshka site, and it reaches its maximum with 8 years for the West-West Menia Site.

10 Sub-Project Ranking

Based on the review, a ranking of the four projects has been established based on groundwater resources indicators such as investment costs, static and dynamic depth to the groundwater table, aquifer characteristics, recharge, and groundwater quality.



Figure 6: Overall Area feasibility ranking

Based on the groundwater potential, groundwater depth, and associated extraction costs, as well as estimated soil salinity levels. The New Toshka area seems the most effective in both Groundwater potential and quality and cost and net return. Due to Substantial recharge of the aquifer expected to occur from the Nasser Lake, New Toshka is a favorable premise for sustainability regarding the use of water resources, and fair aquifer characteristics impose moderate pumping costs due to moderate static water levels and drawdowns. Also, it is noted that Groundwater from NSA is of good quality. In addition, the New Toshka Location is Close to internal market places such as Abu Symbol and Aswan cities, and relatively close to Abu-Symbel airport and transportation facilities, and closeness to an existing power supply grid.

The second priority area is Siwa, as the NSA aquifer is in artesian conditions and highly productive. The location has a low pumping cost due to relatively low drawdowns, significant groundwater reserves estimates, and good groundwater quality from the deep NSA suggests return efficiency. Yet, the groundwater depth is high, requiring high investment costs. Also, uncontrolled water withdrawal and accompanying lowering of the piezometric head in the NSA may influence wells' yield currently in service and decrease springs yield. Furthermore, excessive lowering of the piezometric head can induce a downwards percolation of highly salinized groundwater from the Lower Eocene aquifer.

Table 16: Summary of Technical and Financial Results

Indicators	Unit	Moghra	Siwa	Toshka	WW Menia	Full Project estimated
Energy Mix, Renewable Energy	Percent	78%	83%	70%	85%	73%
Energy Mix, Conventional	Percent	22%	17%	30%	15%	23%
Initial Capital Investment, CAPEX	million €	680.21	44.00	145.48	2,030.60	5,488
Project Revenues						
Total Production	ton/year	1,957,311	88,940	127,362	2,427,415	10,161,491
Total By-Products Production	ton/year	980,192	1,075	43,620	460,844	631,054
Total Sales (Euro)	million €	244	15	48	548	2,148
Total Operational Expenditures	million €	190.4	13.8	41.7	574.5	1,798
Financial Indicators						
IRR	Percent	23.88%	20.31%	19.89%	12.98%	16.2%
B/C @ 8%	Ratio	1.47	1.37	1.27	1.13	1.18
NPV @ 8%	million €	757	125	32	622	3,243
Payback Period	Years	5.00	6.00	6.00	8.00	7
Direct Labor Cost/Total Cost %	Percent	24.59%	12.53%	19.00%	16.74%	29.39%
Cropping Pattern						
Cereals	feddan	32,000	500	6,000	100,000	200,000
Legumes	feddan	15,000	1,000	9,890	24,000	120,000
Herbal & Aromatic	feddan	3,000	50	450	5,000	189,642
Summer. Vegetables	feddan	50,591	2,276	1,500	24,000	345,564
Winter Vegetables	feddan	39,409	4,800	1,540	127,000	366,308
Fodder crops	feddan	7,500	374	370	20,000	183,000
Perennial Crop/Fruit trees	feddan	37,500	1,000	10,250	120,000	300,000
Total cultivated Areas	feddan	185,000	10,000	30,000	420,000	1,704,514
Physical Production						
Cereal, wheat, barley	ton	63,178	1,075	11,644	185,884	394
Legumes	ton	54,000	1,440	44,695	72,091	170
Herbal & Aromatic	ton	1,307	26	262	2,124	162
Summer. Vegetables	ton	852,867	20,225	7,214	217,055	3,409
Winter Vegetables	ton	645,650	61,758	24,213	1,089,848	3,192
Fodder crops	ton	82,238	2,576	3,820	160,363	1,305
Perennial Crop/Fruit trees	ton	258,072	1,839	35,514	700,050	1,528
Total Production (ton)	ton	1,957,311	88,940	127,362	2,427,415	10,161

11 Conclusions

In general, implementing the project is financially feasible. Toshka site is the optimal choice for intervention early due to low initial investment costs, around €50 million. Including an additional €10 million for other non-foreseen social activities such as schools, praying places, shops, repair housing, clinic, etc., for a new community in the Toshka site. As represented by the base case, the project is feasible in all cases for all proposed areas. The assessment did not analyze the impact of any severe conditions of risk and uncertainties of price and costs. The comparison between irrigation technologies in terms of CAPEX and OPEX shows that no one can conclude a definitive answer regarding the selection of irrigation technology, besides the obvious choice of pivot for the 150 feddan. However, for the remaining 50, the will shall be based on a case-by-case. The irrigation technology depends on soil type, crop and land topography, and other factors discussed in the technical report. For the 1.5 million feddan project, the following results were obtained.

1. The initial investment cost is estimated at €5,488 million.
2. The annual Operation costs are estimated at €1,798 million.
3. The annual sales are estimated at €2,148 million.
4. The total agricultural production is amounted annually to about 10.1 million tons of agricultural produces
5. This number of expenditures on Labor Salaries could create more than 500,000 direct employment opportunities

The project is expected to have a direct, positive social impact. One of the most important investments of the project will be to focus on Global Agricultural Practice (GAP), which has emerged in the last decade as the most important private, voluntary standard in the horticulture subsector. Based on the financial outcomes, it is suggested to have a concession period of at least 20 years (equal to 2.5 X payback period) to incentivise the private sector. Finally, the AFWAM model proves to be a handy and user-friendly tool for decision-makers and planners to assess irrigation water's economic value through an optimised new cropping pattern to achieve self-sufficiency. The model has proven efficient when applied to the actual case of Egypt's new reclaimed land areas. This tool helps strategic analysis, yet further sensitivity analysis should be considered when using the micro-financial level model

Nomenclature

IWRM	Integrated Water Resources Management
Fed	Feddan (4200 m ²)
GDP	Gross domestic product
GAP	Global Agriculture Practice
AFWAM	Agricultural Field Water Allocation Model
NSA	Nubian Sand Aquifer
RIGW	Research Institute for Groundwater
USAID	US Agency for International Development
TDS	Total Dissolved Salts
NSAS	Nubian Sandstone Aquifer System
PNAS	Post Nubian Aquifer System
TBL	Triple Bottom Lines assessment
PV	Photo Voltic
NPV	Net Present Value
IRR	Internal Rate of Return
B/C	Benefit-Cost ratio
CAPEX	Capital Expenditure
OPEX	Operational Expenditure
GM	Gross Margin
LE	Egyptian Pounds
MWRI	Ministry of Water Resources and Irrigation
MALR	Ministry of Agriculture and Land Reclamation
GPR	Radar Remote sensing and Ground-penetrating Radar
ZLD	Zero Liquid Discharge

References

- [1] Ezzat, M. A. Impact of a future Qattara salt-water lake on the Nubian Sandstone aquifer system in the Western Desert, Egypt. In *Improvements of methods of long term prediction of variations in groundwater resources and regimes due to human activity (Proceedings of the Exeter Symposium, July 1982)*. IAHS Publ. no. 136, (pp. 297–314). http://hydrologie.org/redbooks/a136/iahs_136_0297.pdf.
- [2] Shuhab D. Khan, Mohamed S. Fathy, Maha Abdelazeem, Remote sensing and geophysical investigations of Moghra Lake in the Qattara Depression, Western Desert, Egypt, *Geomorphology*, Volume 207, 2014, Pages 10–22, ISSN 0169-555X, <https://doi.org/10.1016/j.geomorph.2013.10.023>.
- [3] Rizk, Z.S. and Davis, A.D. , Impact of the Proposed Qattara Reservoir on the Moghra Aquifer of Northwestern Egypt. *Groundwater*, 1991, 29: 232–238. <https://doi.org/10.1111/j.1745-6584.1991.tb00515.x>
- [4] RIGW. A plan for the development and management of deep groundwater in the Oases. Internal strategy report, Research Institute for Ground Water, Cairo, 1998, pp 86
- [5] Tahlawi, M.R. & Farrag, A. & Ahemd, Dr Sameh. (2008). Groundwater of Egypt: "An environmental overview". *Environmental Geology*. 55. 639–652. 10.1007/s00254-007-1014-1.
- [6] Abdel-Raouf, O., & Abdel-Galil, K. (2013). Conjunctive Use of DC Resistivity Method and Hydrochemical Analysis for Groundwater Potentiality of Wadi El Natrun Area, Egypt.
- [7] Abdel Moneim A. A., Zaki S., Diab, M. (2014). Groundwater Conditions and the Geoenvironmental Impacts of the Recent Development in the South Eastern Part of the Western Desert of Egypt. *Journal of Water Resource and Protection*, 2014, 6, k. 381–401
- [8] Amer, A., Nour, and Meshkiki, M. (1981). A finite Element Model for the Nubian Aquifer system in Egypt. *Water Resources Planning in Egypt. Proc. Int. Conf. Cairo, Jan. 1981*
- [9] Sefelnasr, Ahmed. (2007). Development of groundwater flow model for water resources management in the development areas of the western desert, Egypt. *Methodology*. 44. 61.
- [10] Elsawwaf, M., Feyen, J., Batelaan, O., and M. Bakry, M. (2012). Groundwater–surface water interaction in Lake Nasser, Southern Egypt. *Hydrological Processes*. Wiley Online Library. DOI: 10.1002/hyp.9563
- [11] Jeongkon Kim, Mohamed Sultan, Assessment of the long-term hydrologic impacts of Lake Nasser and related irrigation projects in Southwestern Egypt, *Journal of Hydrology*, Volume 262, Issues 1–4, 2002, Pages 68–83, ISSN 0022-1694, [https://doi.org/10.1016/S0022-1694\(02\)00013-6](https://doi.org/10.1016/S0022-1694(02)00013-6).
- [12] el bastawesy, Mohammed & Khalaf, Fikry & Arafat, Sayed. (2008). The use of remote sensing and GIS for the estimation of water loss from Tushka lakes, southwestern desert, Egypt. *Journal of African Earth Sciences*. 52. 73–80. 10.1016/j.jafrearsci.2008.03.006.
- [13] Mohamed Yousif, Hassan S. Sabet, Saad Y. Ghoubach, Ameer Aziz, Utilising the geological data and remote sensing applications for investigation of groundwater occurrences, West El Minia, Western Desert of Egypt, *NRIAG Journal of Astronomy and Geophysics*, Volume 7, Issue 2, 2018, Pages 318–333, ISSN 2090-9977, <https://doi.org/10.1016/j.nrjag.2018.07.002>.
- [14] Heba Abd El-Aziz Abu-Bakr, Groundwater vulnerability assessment in different types of aquifers, *Agricultural Water Management*, Volume 240, 2020, 106275, ISSN 0378-3774, <https://doi.org/10.1016/j.agwat.2020.106275>.
- [15] Tantawy, M., E. El Sayed, I. Setto and E. Abu El Seba, 2006. Hydrochemical evaluation of the groundwater resources in the area east of El Minya district, Egypt. *El-Minya Science Bulletin, Fac. of Sci., El Minya University*, 17(1): 24–57, ISSN 2352-801X, <https://doi.org/10.1016/j.gsd.2020.100517>.
- [16] Taylor, André & Fletcher, Tim. "Triple-bottom-line" assessment of urban stormwater projects. *Water science and technology : a journal of the International Association on Water Pollution Research*. 2006, 54. 459–66. 10.2166/wst.2006.598.

- [17] Novotny, V. and K. Hill . Diffuse pollution abatement – a key component in the integrated effort towards sustainable urban basins Invited Keynote presentation, Proc. 10th International Conference on diffuse pollution and sustainable basin management, Istanbul, Turkey 18-22 September 2006, published in *Water Science and Technology* 56(1):1–9, DOI: 10.2166/wst.2007.430
- [18] Elkington, J. *Cannibals with Forks: The Triple Bottom Line of 21st-century Business*, 1997, Capstone Publishing, Oxford, ISBN: 978-1-841-12084-3
- [19] Salem, O., Pallas, P. The Nubian Sandstone Aquifer System - NSAS. Proceedings of the International Workshop, Tripoli, Libya, June 2002
- [20] Gremillon, P. New Light Shed on the Nubian Aquifer. Using Isotopes Effectively to Support Comprehensive Groundwater Management. IAEA, Water and Environment News, No. 20, February 2010
- [21] Salman, Amer & Al-Karablieh, Emad & Al-Omari, Abbas & Hussein, & Al-Assad, T. 2011. Water Allocation Model.
- [22] Haidar, Ricardo & Fagg, Jeanine & Pinto, José & Dias, Ricardo & Damasco, Gabriel & Silva, Lucas & Fagg, Christopher. . Seasonal forests and ecotone areas in the state of Tocantins, Brazil: Structure, classification and guidelines for conservation. *Acta Amazonica*. 2013, 43. 261-290. 10.1590/S0044-59672013000300003.
- [23] El Gamal, A. & Kim, Y.-H. *Network Information Theory* (Cambridge University Press, 2011).
- [24] El-Atfy H, Abdin Alaa E, Shaban S. Crop water productivity towards future sustainable agriculture in Egypt. In: 4th International symposium, Egypt; January 9–11, 2011
- [25] Salman, Amer & Al-Karablieh, Emad & Fisher, F.M. An inter-seasonal agricultural water allocation system (SAWAS). *Agricultural Systems*. 2001. 68. 233-252. 10.1016/S0308-521X(01)00010-5.
- [26] Kawy, Wael & El-Magd, Islam. Assessing crop water requirements on the basis of land suitability of the soils South El Farafra Oasis, Western Desert, Egypt. *Arabian Journal of Geosciences impact factor*, 2012, 1.52. 6. 10.1007/s12517-012-0519-4.
- [27] CAPMAS. 2013. Central Agency for Public Mobility and Statistics (CAPMAS), Statistical Yearbook 2013, see: <http://capmas.gov.eg/book.aspx> .
- [28] Egypt - Integrated water resources management plan (English). Washington, D.C. : World Bank Group. <http://documents.worldbank.org/curated/en/561611468234311417/Egypt-Integrated-water-resources-management-plan>
- [29] Roebeling, P.C.; Bohnet, I.; Smith, M.; Westcott, D.; Kroon, F.J.; Hartcher, M.; Hodgen, M.; Vleeshouwer, J. Landscapes Toolkit for triple-bottom-line assessment of land use scenarios in Great Barrier Reef catchments. In: Zerger, A.; Argent, R.M. eds, editor/s. MODSIM 2005 International Congress on Modelling and Simulation; December 2005; Modelling and Simulation Society of Australia and New Zealand; 2005. 711-717. <http://hdl.handle.net/102.100.100/181813?index=1>
- [30] Arab Republic of Egypt (2012). Strategic Framework for Economic and Social Development Plan until the Year 2022. Proposal for Community Dialogue. Ministry of Planning and International Cooperation
- [31] Arab Republic of Egypt (2009). Sustainable Agricultural Development Strategy towards 2030. MALR, https://www.drylanddevelop.org/uploads/6/1/7/8/61785389/full_sads2030_eg.pdf