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Review Article

Evaluation of agricultural expansion areas in the Egyptian deserts: A review using remote sensing and GIS ☆

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A R T I C L E I N F O

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A B S T R A C T

Agricultural expansion areas in the Egyptian deserts are one of the main governmental inputs that increased during the last decade. Evaluation of such agricultural lands helps decision makers in strategic planning of future projects. The present review paper highlights recent research studies conducted to evaluate some of the newly agricultural expansion areas in the Egyptian deserts using Geographic Information Systems (GIS) integrated with Remote Sensing technologies considering the main evaluation criteria and constraints. Moreover, various examples of agricultural expansion areas in the Western Desert are highlighted. Field observations, sampling, laboratory analyses, remote sensing and GIS are the most common tools used in the presented case studies. This review article supports the future governmental plans for protecting the wealth of cultivated lands and limits the illegal infringements on these lands that will accordingly protect other lands, planned to be used for urban expansion.

Contents

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1. Introduction

Egypt plans for proper agricultural expansion to face problems of food security, population increase, infringement on agricultural lands and to increase exports of goods and hence increase the national income. The Sustainable Development Strategy (SDS): Egypt Vision 2030, focuses on the challenges that face development processes in Egypt (MCIT, 2020). Examples of these challenges include: scarcity of natural resources including energy, land, water, environmental degradation and inadequate human development resources such as population, health and education.

Egypt water is mainly controlled by the water budget from the River Nile and Lake Nasser discharging through the Aswan High Dam that is about 55.5 × 10^9 m^3/year (Omran and Negm, 2020). Egypt covers an area of about 1,000,000 km^2 where the population lives on less than 5% of the whole area (Fig. 1). There is no periodic census for agricultural lands, urban encroachments and infringements upon cultivated lands which make it difficult to have an accurate estimation by well-known surveying methods (Omran and Negm, 2020).

Using the techniques of Geographic Information Systems (GIS) and Remote Sensing (RS); facilitates computer-based data storage and processing of complex geo-referenced, and thematic layers retrieved from various sources. This will provide decision makers with precise information in a short time and at a lower cost (Biali and Statescu, 2013).

Newly cultivated areas that were previously evaluated as being risky and over populated will help in providing available spaces for

Fig. 1. An overview of the Egyptian deserts.

urban expansions away from exhausted alluvial lands in the Nile Delta and its Valley. Moreover, using GIS techniques will enable the decision makers to get acquainted with the geographic characteristics of the planned lands. Accordingly, newly residential buildings will be located to fulfill the increasing population needs.

The present Review paper starts by an overview on the criteria and constraints used in evaluation of agricultural lands in deserts; described based on "The Environmental Perspective for Urban Development" published by the General Organization of Physical Planning (GOPP, 2017; GOPP, 2010). Then, several case studies for evaluating some agricultural expansion areas in the Egyptian deserts using GIS were explained in details. The concept is oriented to satisfy the remarked gap between geoscience, in its current state and land use decision makers and strategic planners' requirements. Therefore, this review focuses on the research studies conducted to evaluate some of the new reclamation lands in the Egyptian deserts and how they can impact or can be impacted with different man made or natural factors.

2. Criteria and constraints for agricultural lands evaluation in deserts

According to "The Environmental Perspective for Urban Development", the most important factors for land reclamation and cultivation are the availability of a water source (surface water/groundwater), soil suitable for agricultural reclamation, suitable climate, presence of energy sources and proximity to infrastructures. On the other hand, constraints for land reclamation include, existing cultivated areas, water logged areas, sand dunes encroachments, areas liable to flashfloods, rugged topography, urban areas, legally protected areas and natural reserves (GOPP, 2010).

2.1. Resources – based suitability criteria

2.1.1. Meteorological factor

Meteorological factor influence the amount of energy (in terms of renewable sources of energy) and climate (in terms of a suitable climate for each crop type). Renewable green energy is a future potential that provides sustainable development for vast desert zones. Changes in temperature, precipitation, carbon dioxide, and severity of extreme events, are expected to have obvious effects on soil water availability, carbon storage, and yields (Cox et al., 2018). Recent studies suggest that droughts will intensify in some seasons in areas such as the Mediterranean region and Africa (Smith et al., 2016; Muñoz-Rojas et al., 2017).

There are four main geographic zones in Egypt that classifies it; the Nile Valley and its Delta, Sinai Peninsula, Eastern and Western Deserts. The climate is characterized by being hot-dry in summer and warm in winter, and in the north, is named the Mediterranean climate. The humidity is high in the north during summer (70%) and low in the south (13%) (Omran and Negm, 2020).

2.1.2. Water resources factor

Egypt is mainly characterized by the Deserts and the River Nile where the area of cultivated lands have been controlled by the water budget from the Lake Nasser discharge through the Aswan High Dam (AHD) (55.5×10^9 m^3). From this water budget, Egypt's water demand for irrigation, industry, and domestic consumption exceeds the supply of the Nile (MWRI, 2010). This is substituted by recycling freshwater more than once, which implies that there is a shortage in the freshwater resources, and also reflects the high efficiency of the system as well as its sensitivity to deterioration in water quality problems that may arise.

The main challenges that face the water resources in Egypt are to fill in the gap between the limited water resources and the increasing needs for freshwater. In Egypt, water resources are conventional (Nile River water budget, groundwater, and rainfall) and non-conventional (seawater desalination and reuse of wastewater) (Abd Ellah, 2020). Table 1 shows the water budget of Egypt in 2010, as given in the 2050 water strategy of the Ministry of Water Resources and Irrigation (MWRI, 2010). In desert areas, the main source of water is groundwater and rainfall showers.

Most of Northern Egypt receives very little rainfall that is mainly at the narrow strip of land along the Mediterranean sea coast (150–200 mm), and decreases gradually inland towards the south (Abd Ellah, 2020). Precipitation is limited to winter that ranges between 200 mm/year in the wettest areas along the northern coast to about 0 mm towards the center and the south. The average precipitation /year is about 20 mm (Omran and Negm, 2020).

Groundwater in the Western Desert is the main source of water for domestic, industrial, livestock and agricultural purposes. Fig. 2 and Table 2 show the six main aquifer systems in Egypt (MWRI, 2005) and (RIGW/IWACO, 1999). Suitability of water for irrigation depends on the impact of the mineral components on plants and soil. In case of unsuitable water quality, irrigation could represent a possible risk to crops.

Table 3 summarizes the thresholds limits of groundwater quality and its suitability for irrigation purposes based on international recommendations (El-Zeiny and Elbeih, 2019).

2.1.3. Soil type factor

The Land Capability Classification (LCC) is a system of producing combinations of different land capacity ratings using a set of specific constraints on the sustainable use of soil properties, topography, drainage and climate. The guiding principles behind the LCC are: "to direct the use of the land so that it corresponds to its production capacity with due consideration to its treatment". These classes drop into two categories, the first are reasonable for agri-

Table 1
Water budget of Egypt (2010) and all sources and allocation/usage (MWRI, 2010).

Water supply	Volume (billion m^3/year)	Demand by sector	Consumption (billion m^3/year)	Usage/allocation (billion m^3/year)
Conventional water sources		Drinking (fresh water only)	1.8	9
River Nile (AHD)	55.5	Industry	1.4	2
Deep groundwater	2	Agriculture	40.4	67
Rainfall and flash floods	1.3	Drainage to sea		12.2
Desalination	0.2	Evaporation losses	3	3
Total supply conventional	59	Environmental balance	0.2	0.2
Unconventional sources				
	Total consumption	59		
Shallow groundwater (Delta)	6.2			
Reuse of agricultural drainage water	16			
Total supply nonconventional	22.2			
Total water supply	81.2	**Total allocated water usage**	81.2	

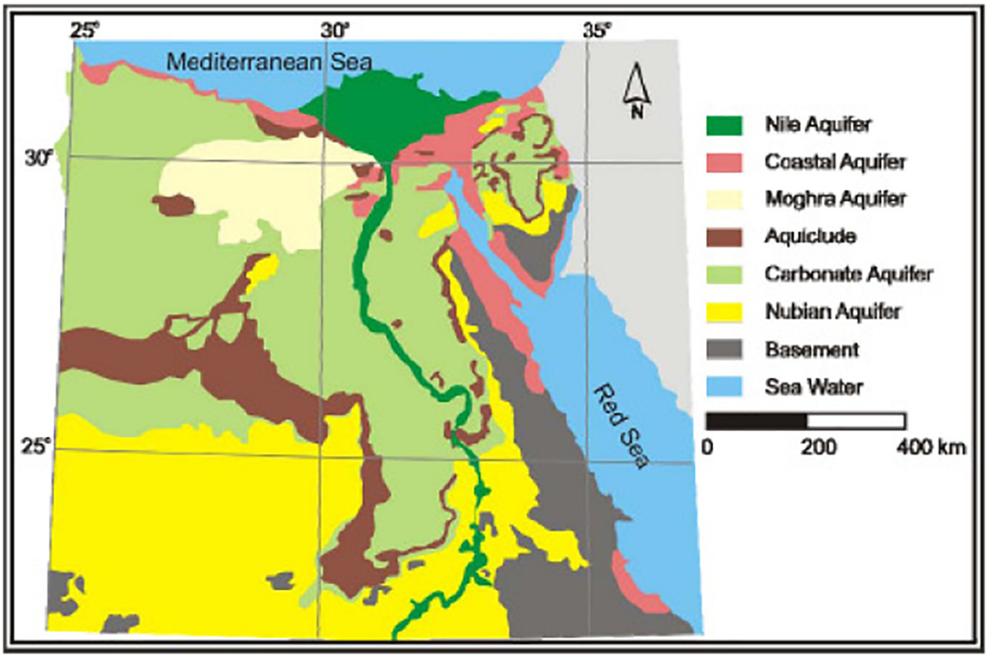

Fig. 2. Aquifer systems in Egypt (RIGW/IWACO, 1999) and (RIGW/IWACO, 1988).

Table 2
The six main aquifer systems in Egypt (RIGW/IWACO, 1999).

The Nile Aquifer System	Occupies the Nile flood plain and its surrounding desert. 90 % of Egyptians live on this area, which is regularly recharged by seepage from the River Nile, drains, and irrigations canals. It belongs to the Quaternary aquifer
The Moghra aquifer system	Occupies a large area in the North Western Desert. It belongs to the Lower Miocene Period
The Coastal aquifer system	Occupies the North Western Coast and North Sinai. It belongs to the Quaternary aquifer
The Nubian Sandstone Aquifer System (NSAS)	Occupies more than 43 % of Egypt's area. Egypt, Sudan, Chad, and Libya share this aquifer and it has a huge storage capacity of groundwater. It belongs to the Paleozoic-Mesozoic ages
The fractured carbonate aquifer system	Located in the central part of the Western Desert in central Sinai. It belongs to the Eocene Period
The fissured crystalline basement aquifer system	Located in the Eastern Desert and South Sinai and underlies the NSAS. It has a higher productivity and shallow depth to water table. It belongs to the Precambrian Period.

Table 3
Threshold limits of water quality for irrigation (El-Zeiny and Elbeih, 2019).

Parameter	Category	Threshold
Total Dissolved Solids (TDS)[a] (ppm)	Best water quality	200–500
	Water involving a hazard	1000–2000
	Water can be used for irrigation only with leaching and perfect drainage	3000–7000
EC[a] (μs/cm)	Low Salinity water	100–250
	Medium salinity water	250–750
	High salinity water	750–2250
	Very high salinity water	>2250
Sodium Adsorption Ratio (SAR)[b]	Excellent	2–10
	Good	10–18
	Doubtful	18–26
	Unsuitable	>26
pH[c]	Suitable	6.5–8.4
Manganese Mn[c] (ppm)	Unsuitable	>0.2
Iron Fe[c] (ppm)	Unsuitable	>5.0
Sulphates (SO_4) [d] (ppm)	Unsuitable	>980
Total Hardness (TH)[e]	Soft	<75
	Moderately hard	75–150
	Hard	150–300
	Very hard	>300

a (Wilcox, 1955), b (US Salinity Lab Staff, 1954), c (Ayers and Westcot, 1985), d (FAO, 1980), e (Sawyer and McCarthy, 1967).

Table 4
Salient features of Land Capability Classes (LCC) (Soil Conservation Service, 1963).

LCC	Characteristics
Land Suitable for Cultivation	
I	Very good cultivable, deep, nearly productive land with almost no limitation or very slight hazard. Soils in this class are suited for various types of crops, including wheat, barley, cotton, maize, tomato and beans. Need no special practices for cultivation
II	Good cultivable land on almost level plain or on gentle slopes, moderate depth, subject to occasional overland flow, may require drainage, moderate risk of damage when cultivated, use crop rotations, water control system or special tillage practices to control erosion
III	Soils are of moderate fertility on moderate steep slopes subject to more severe erosion and severe risk of damage but can be used for crops provided adequate plant cover is maintained, hay, or other sod crops should be grown instead of row crops
IV	These are good soils on steep slopes, subject to severe erosion, with severe risk of damage but may be cultivated occasionally if handled with great care, keep in hay or pasture but a grain crop may be grown once in 5 or 6 years
Land unsuitable for cultivation but suitable for permanent vegetation	
V	Land is too wet or stony which make it unsuitable for cultivation of crops, subject to only slight erosion if properly managed, should be used for pasture or forestry but grazing should be regulated to prevent cover from being destroyed
VI	These are shallow soils on steep slopes, used for grazing and forestry: grazing should be regulated to preserve plant cover, if the plant is destroyed, use should be restricted until cover is re-established
VII	These are steep rough, eroded lands with shallow soils, also includes droughty and swampy land, severe risk of damage even when used for pasture or forestry, strict grazing or forest management must be applied
VIII	Very rough land, not suitable even for woodland or grazing, reserve for wild life, recreation or wasteland consideration

Table 5
Land suitability Classification (LSC) (FAO, 2007).

Suitability order	Suitability class	Description
S (Land on which sustained use of the kind under consideration is expected to yield benefits which justify the inputs, without unacceptable risk of damage to land resources)	S1	Land having no significant limitations to sustained application of a given use, or only minor limitations that will not significantly reduce productivity or benefits and will not raise inputs above an acceptable level
	S2	Land having limitations which in aggregate are moderately severe for sustained application of a given use; the limitations will reduce productivity or benefits and increase required inputs to the extent that the overall advantage to be gained from the use, although still attractive, will be appreciably inferior to that expected on class S1 land
	S3	Land having limitations which in aggregate and severe for sustained application of a given use and will so reduce productivity or benefits or increase required inputs, that this expenditure will be only marginally justified
N (land which has qualities that appear to preclude sustained use of the kind under consideration)	N1	Land having limitations which may be surmountable in time but which cannot be connected with existing knowledge at currently acceptable cost; the limitations are so severe as to preclude successful sustained use of the land in the given manner
	N2	Land having limitations which appear so severe as to preclude any possibilities of successful sustained use of the land in the given manner

culture development and/or use, (lands within the first category (I) to the fourth category (IV)) and the second not reasonable for agricultural development/use but suitable for forestry, grass land and wild life which include class V to class VIII lands (Table 4) (Soil Conservation Service, 1963).

The Land Suitability Classification (LSC) is a soil assessment strategy designed by FAO. FAO expressed LSC as the appropriateness of a particular type of land for a specific use. The method of LSC is the evaluation and gathering of particular zones of use in terms of their reasonableness for characterized employments. Land Suitability orders demonstrate whether soil is evaluated as reasonable or not appropriate for being utilized for the required application (Table 5). There are two orders S and N; represented by symbols (S1, S2, S3, N1 and N2) (FAO, 2007).

2.1.4. Renewable energy factor

In Egypt, the most promising renewable sources of energy are solar and wind energy (EUD, 2015). Furthermore, small-scale hydro plants can be used as Egypt has the River Nile in addition to a large number of main canals and Rayahat, a huge irrigation network system, that provide an excellent hydraulic energy source (Eshra et al., 2021).

Solar energy is used in agriculture in several ways; drying crops, greenhouses, powering farms operations and water pumps, lighting, buildings can be designed to capture natural daylight, instead of using electric lights. The cost of using solar power is less than extending power lines (Union of Concerned Scientists, 2008). Solar radiation can be converted into electric direct current using PV arrays for pumping water from wells instead of diesel engines which have high costs and produces greenhouse gases and pollution (Gad and El-Gayar, 2011). The maximum, mean and minimum daily solar exposure for an average of 10 years are 7, 5.9 and 4.3 KWh/m^2, respectively of monthly mean of daily irradiation received on a horizontal plane (Alfaro and El-Metwally, 2017). At the north, the annual solar radiation is 5 kwh/m^2/day and increases to more than 7.1 kwh/m^2/day towards the south (Fig. 3) (Salim, 2013).

Wind energy has several uses including pumping water and generating electricity. Each turbine uses an area of not more than half an acre, so that farmers can plant crops beside the turbine's base (Union of Concerned Scientists, 2008). The wind resource map provides an overview of the climatological wind conditions over Egypt. A wind resources map (Fig. 4) classifies wind speed ranges at 50 m above ground level (a.g.l.) into zones. Wind

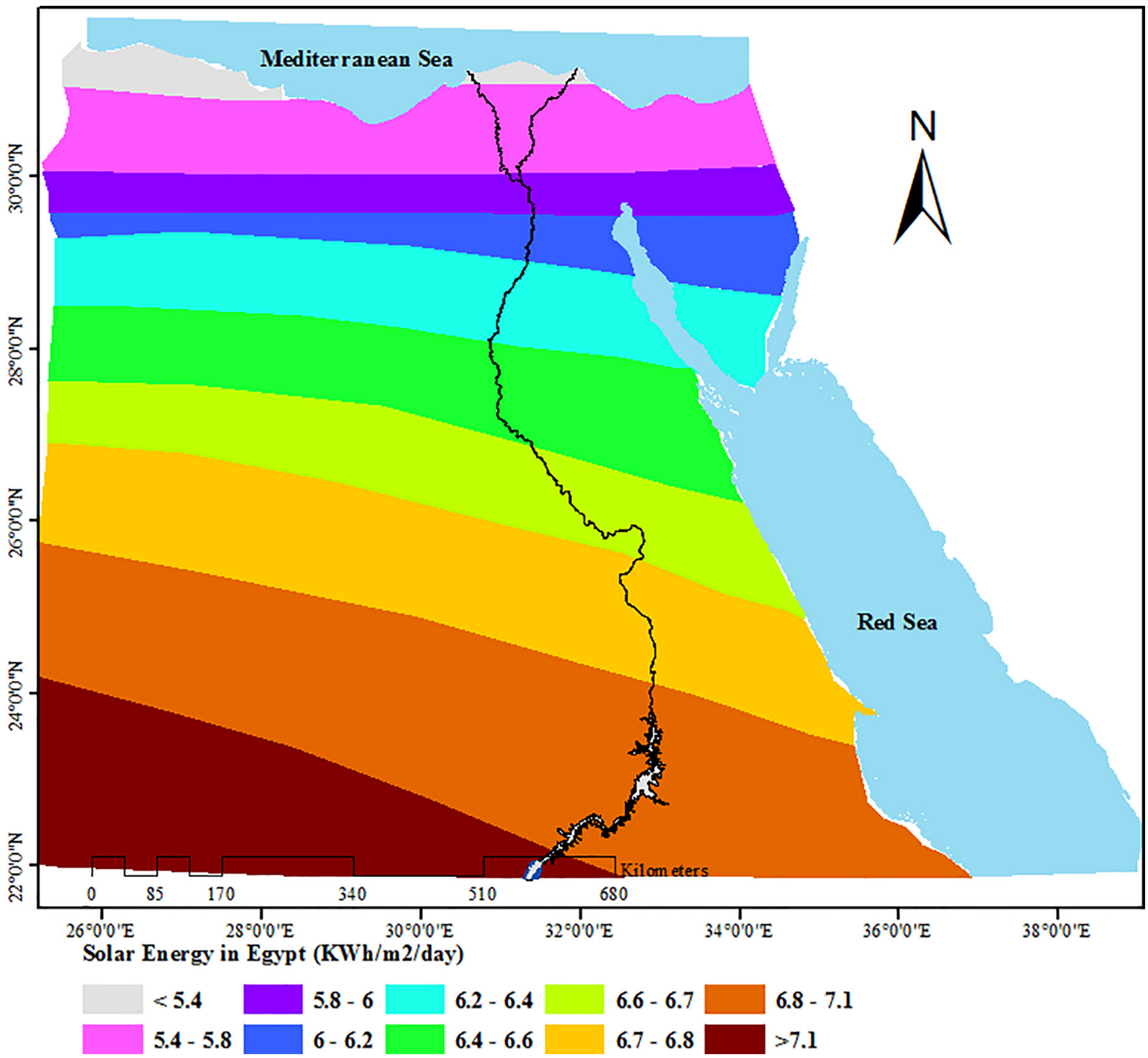

Fig. 3. Solar energy intensity in Egypt (Salim, 2013).

power density also is an important factor where it provides information on the areas feasible for locating wind power projects (Mortensen et al., 2006).

One of the most important current energy sources for generating electricity is hydropower generation and it is limited to the River Nile. The five dams (High Dam; Aswan 1; Aswan2; Esna; Naga Hammady) provide a peak load of 2995 MW and contribute to the maximum of their capacity to the overall electricity supply (NREA, 2016).

2.1.5. Infrastructures factor

The infrastructures factor includes national and regional roads and railway networks, airports and ports, in addition to communications networks, electricity, drinking water and sanitation (GOPP, 2010). Proximity to these infrastructures facilitates any agricultural activity. There is a good and diverse network of transportation in Egypt, which varies between a huge network of roads and maritime transport. This good network facilitates transportation of goods and products to the local and international markets (GOPP, 2017). New urban communities should be chosen at distances not exceeding 3 km from the existing roads (GOPP, 2010).

For identifying potential zones for agricultural development, distance to ports is also considered one of the main criteria. Egypt has 15 commercial ports distributed as follows: 6 ports belonging to the Red Sea authority, 6 ports belonging to the Suez Canal Economic Zone (SCZone) and 2 ports belonging to Alexandria Port authority and finally Damietta port belonging to Damietta port authority (Maritime Transport Sector, 2020).

2.2. Constraints

2.2.1. Sabkhas and water bodies

New reclaimed lands in Egypt are influenced by certain conditions including: soil salinity and waterlogging due to: poor surface and sub-surface drainage, lack of drainage maintenance systems and excess irrigation. Important factors that cause groundwater table rise below cultivated lands are hydrological and hydrogeological conditions, inefficient sewerage, excess irrigation and poor drainage systems (Zaghloul et al., 2020)

2.2.2. Sand dunes encroachments

Soil degradation causes desertification and hence a decline in land productivity, and abandonment of agricultural lands and

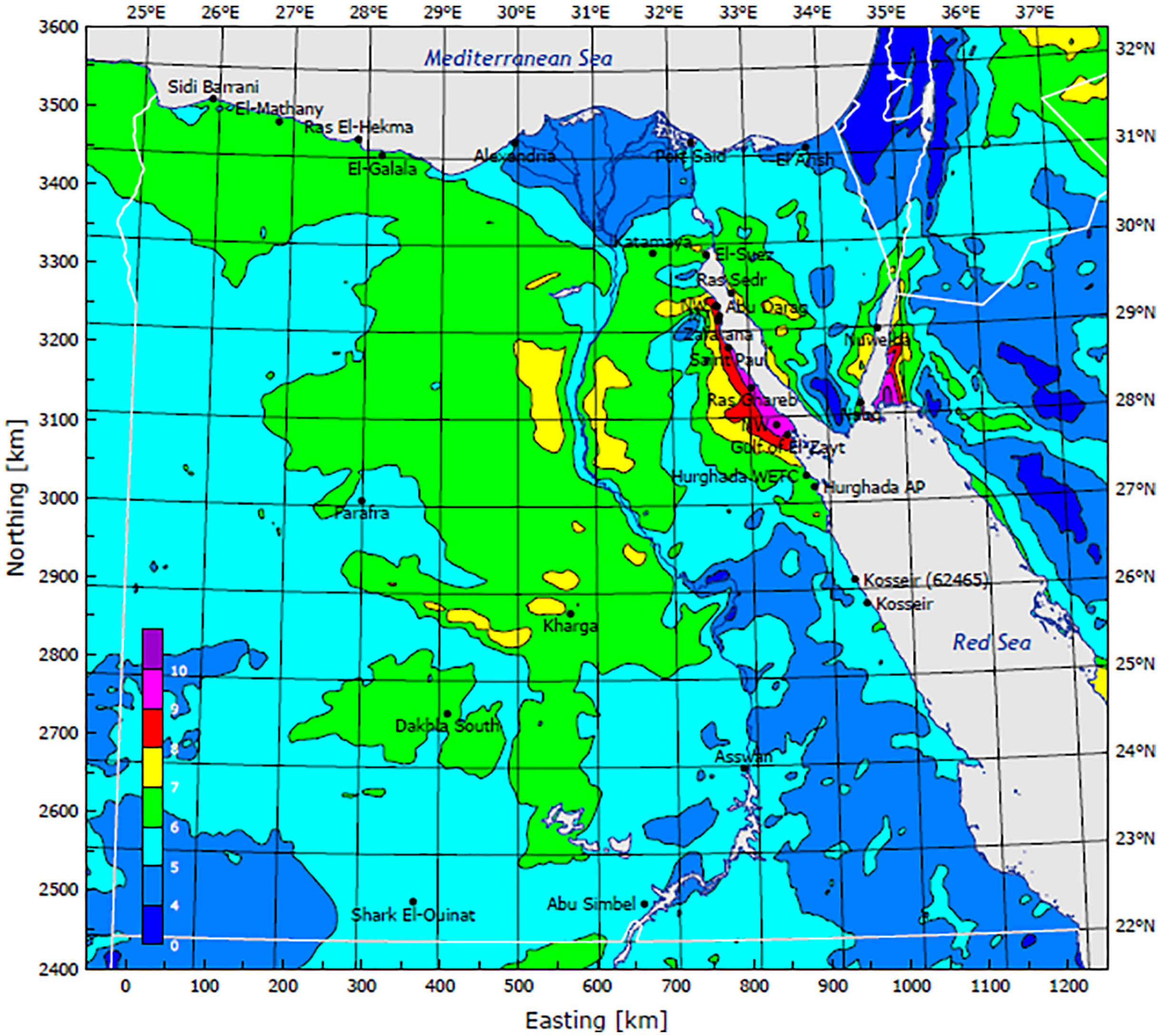

Fig. 4. Wind resource map of Egypt: Mean wind speed (m/sec) (Mortensen, et al., 2006).

hence food crisis (Omran and Negm, 2020). Sand dunes in the Western Desert are classified into sand seas and dune fields. Sand seas cover more than 5000 km^2 compared with dune fields that cover an area of less than 5000 km^2. In the Western Desert, there are five sand seas and four dune fields (Fig. 5). Linear dunes extend in a parallel direction and they might encroach on cultivated lands, villages, and cross highways and railways (Embabi, 2020).

2.2.3. Flash floods

Flash floods are natural disasters which impact vast areas, mainly in arid/semi-arid regions. There are areas of the Egyptian territory that are more exposed to floods than others, and this depends on a number of factors including: amount of rainfall, rainfall duration, areas of drainage basins, degree of steepness of waterways and surface runoff flow, types of rocks that make up the valley basins, and their geological structure (El Desouki, 1998).

2.2.4. Topography

The elevation of the country ranges from −133.0 masl in the Qattara Depression to 2629 masl in Sinai Peninsula (Said, 1990) (Fig. 6).

The Western Desert (more than 681,000 km^2) stretches from the Nile Valley towards the Libyan border in the Western direction. In the northern and central parts of the Western Desert, the plateau is intersected by large depressions and oases. Due to topography and after securing the required water for irrigation, agricultural expansion is oriented towards the Western Desert, which has several depressions such as Qattara and Fayum Depressions (Omran and Negm, 2020).

3. Case studies for evaluating some expansion areas in the Egyptian deserts using GIS

(GOPP) classified Egypt into seven regional units (GOPP, 2010). The case studies presented in the current review paper will focus on Assiut, North Upper Egypt and Alexandria Regional Units. Remotely sensed data integrated with GIS are the main tools in addressing the presented case studies.

Some Land Reclamation Projects in Egypt

- **The Four Million Acres Development Project aims** to build an integrated society within new lands by supporting the SDG goal of the sustainable development strategy (SDS): Egypt Vision 2030 related to increasing the urban area by about 25% of its present total area by the year 2030. Implementation of the first project stage is based on development of one and a half million

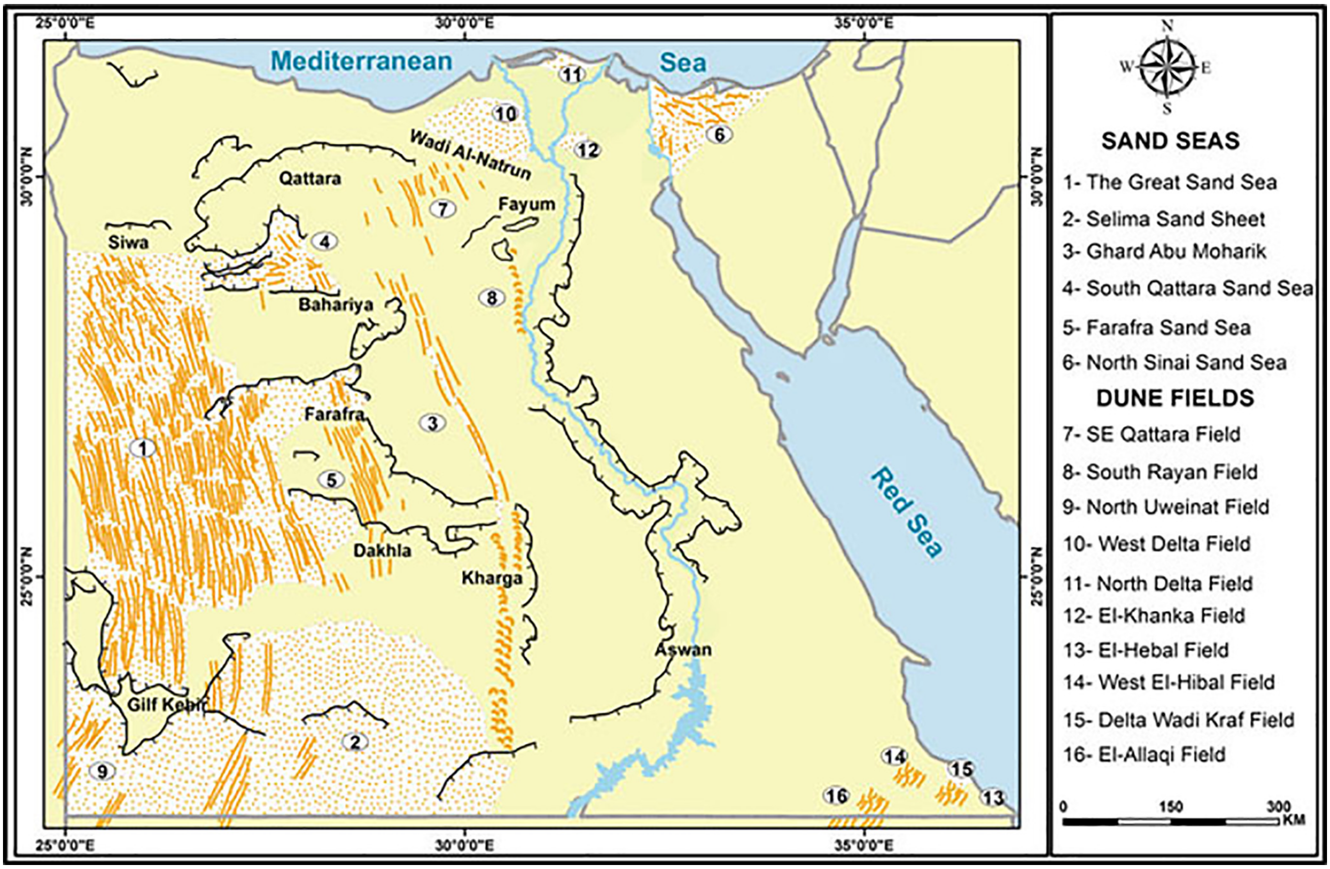

Fig. 5. Sand seas and dune fields distribution in Egypt (Embabi, 2020).

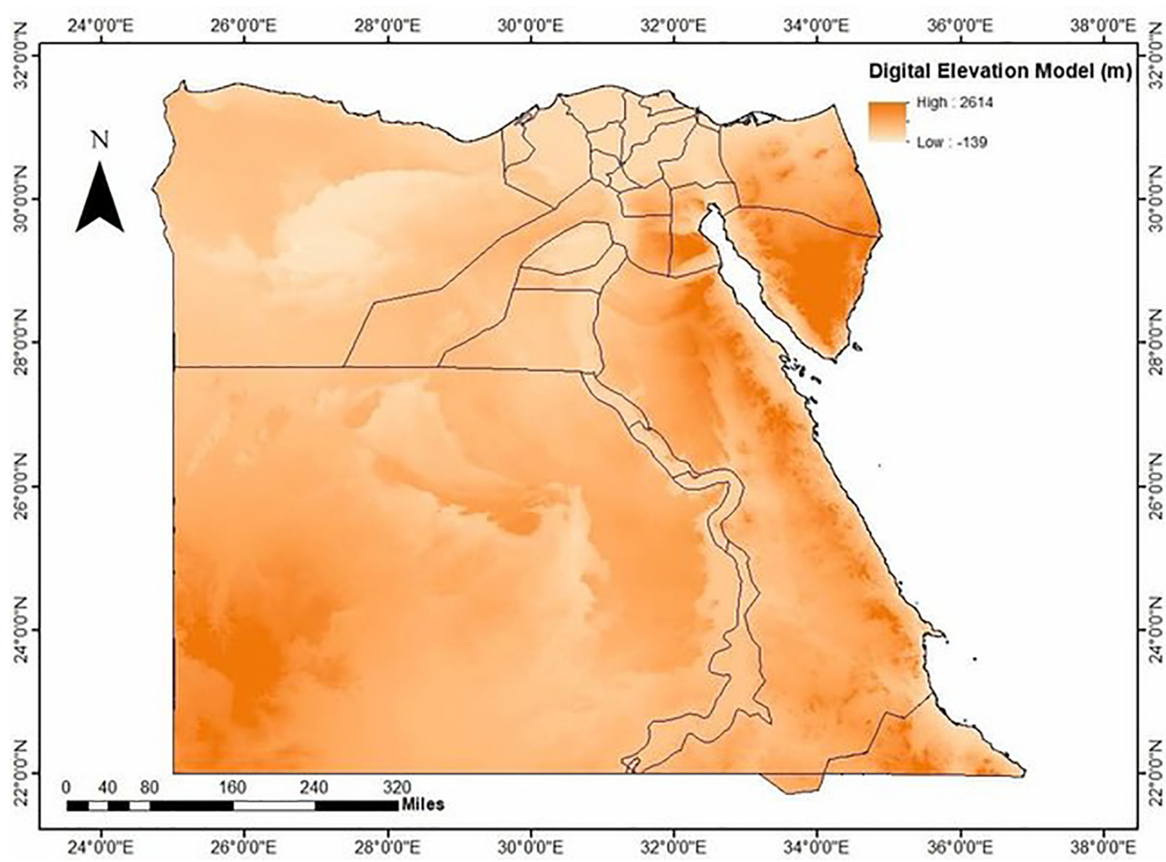

Fig. 6. Digital elevation model (DEM) of Egypt (Kim et al. (2018)).

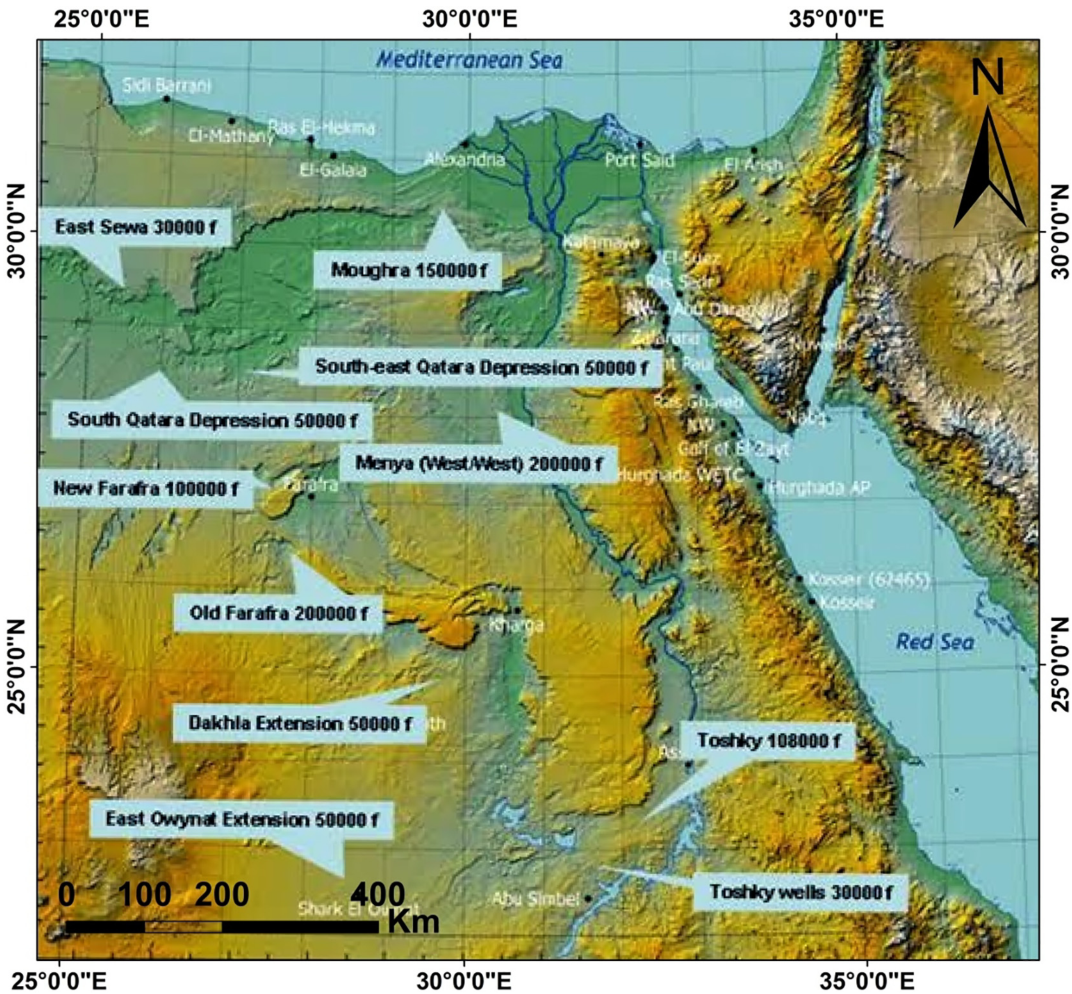

Fig. 7. 1.5 Million Feddan promising land reclamation projects in Egypt: Modified after (Elreef-elmasry, 2017).

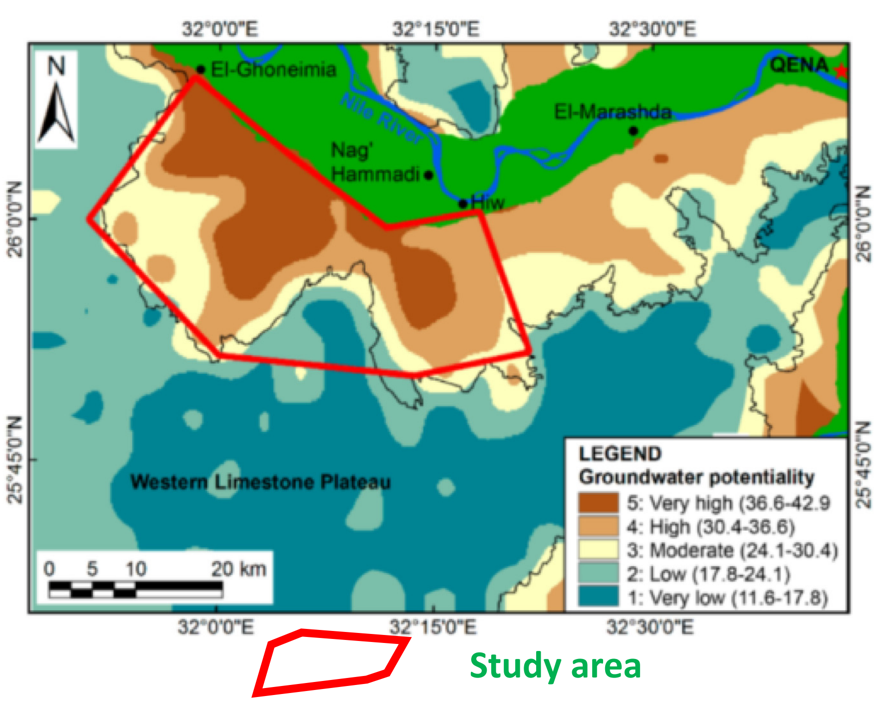

Fig. 8. Groundwater recharge potentiality of West Qena (Gaber et al., 2020).

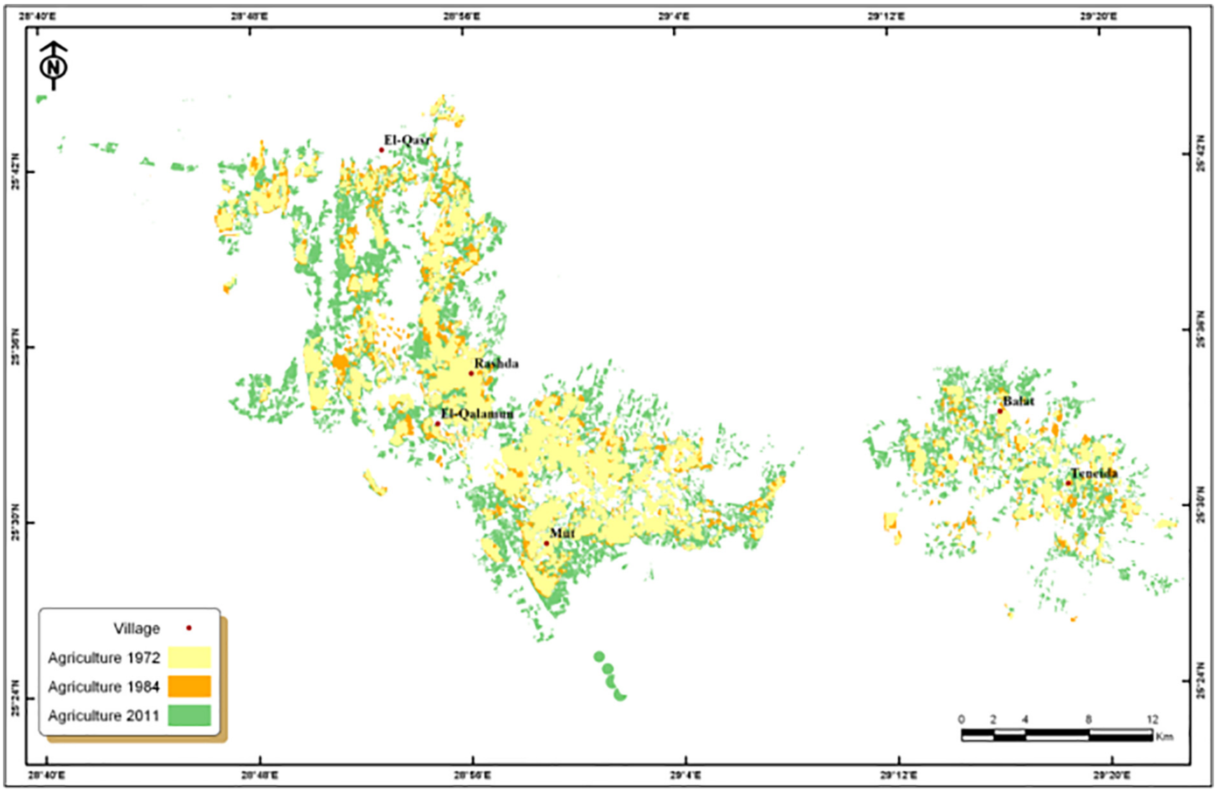

Fig. 9. Distribution of agricultural lands in Dakhla Oasis villages between 1972 and 2011 (Kato et al. 2014).

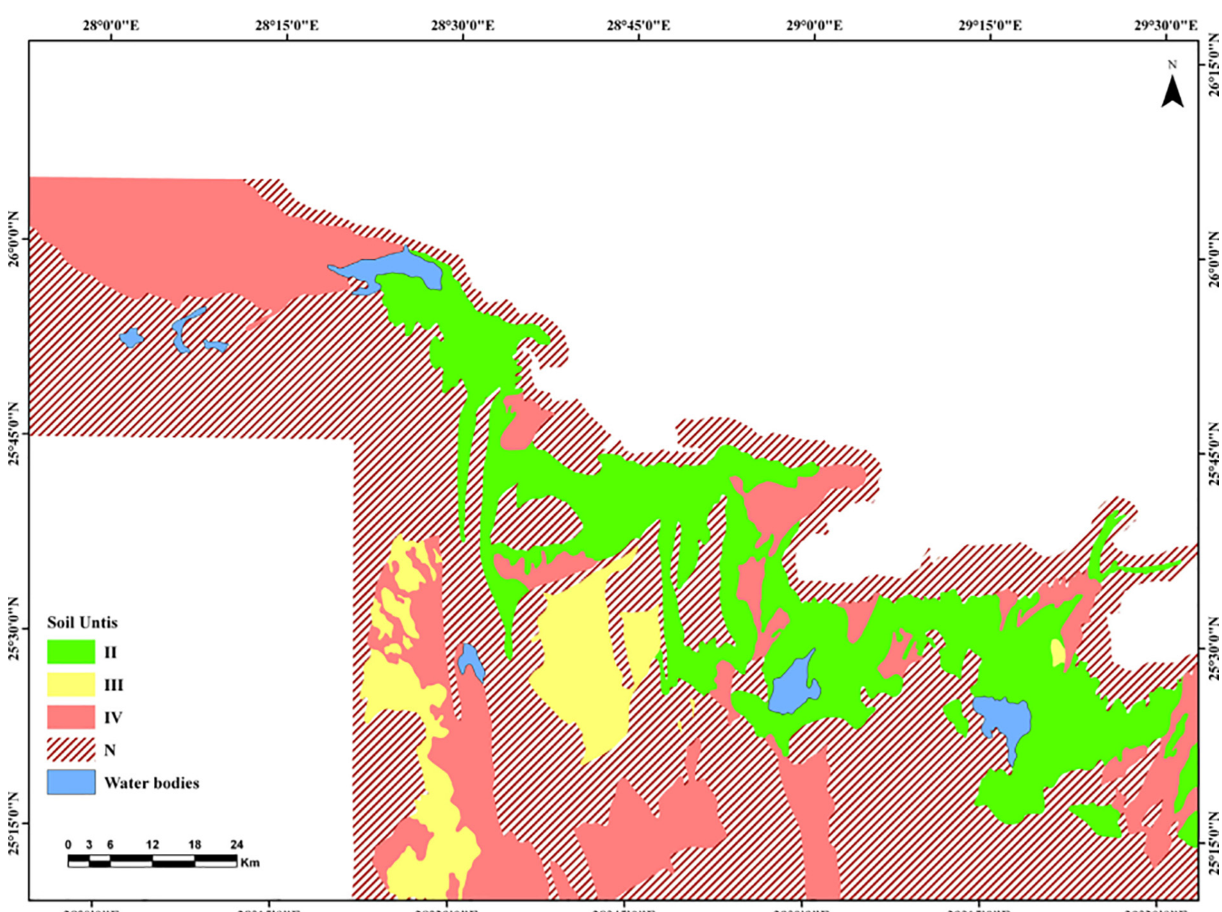

Fig. 10. Dakhla Oases Land capability classes (Gad, 2015).

acres has begun (MCIT, 2020). Fig. 7 shows the planned reclamation sites in the first stage of the project and irrigated using groundwater.

- **Northwest Coast Development Project** aims to develop the northwestern coast by constructing a number of roads and transverse and longitudinal corridors that connects that area with the rest of the governorates. The project includes cultivation of approximately 1,000,000 acres and land reclamation due to the available groundwater resources in the area and the availability of coastal ranges with excessive rainwater. This project contributes to supporting agriculture and reclamation of these lands through cultivation of wheat, barley and the establishment of agro-industries clusters

The present section divides the case studies into: Assiut Regional Unit that includes Assiut and New Valley Governorates; North Upper Egypt Region that includes Minia, Fayoum and Beni Sueif Governorates; and Alexandria Regional Unit that includes Alexandria, Beheira and Matruh Governorates

3.1. Assiut regional unit

Gaber et al. (2020) integrated remote sensing with geoelectric resistivity and aeromagnetic techniques for exploring the groundwater potentiality of west Qena area, West Nile Valley, Egypt (one of 1.5 Million Acres project), as an alternative water source to the River Nile. This will allow for establishing new agricultural communities to accommodate the demands of population growth in this area. The remote sensing data sets used include: (SRTM DEM, Landsat-8, ALOS/PALSAR-1, Sentinel-1, and TRMM). The thematic maps of: slope, faults, rock permeability, drainage patterns, rainfall, lithology, and soil types were overlaid and integrated using the weighted overlay method in a GIS framework to obtain a groundwater potentiality map. The thematic maps were ranked on a scale of 1–5 based on the relative influences of the factors on the infiltration. Based on the model output, the area was classified into five zones based on the recharge capabilities as shown in Fig. 8.

Kato et al. (2014) integrated Remote Sensing (RS) and Geographic Information Systems (GIS) to study the dynamic relation between groundwater resources, Land Use (LU)/Land Cover (LC), and population distribution in Dakhla Oasis. One Landsat Multispectral Scanner System image, two 1984 Landsat Thematic Mapper images and Six 2011 SPOT4 satellite images were used for LULC. In addition, a detailed database of groundwater extraction from 1960 to 2005 was available. This integration enabled mapping the spatial distribution of land cover changes and its impact on agricultural lands. The analysis revealed that Dakhla Oasis has clear land cover changes represented in an increase in urban settlements and in agricultural lands, due to recent land reclamation projects and population growth. The total population showed a growth rate of about 34% which is a clear basis for increase in urban land cover and area of agricultural lands (Fig. 9). In addition, groundwater abstraction and exploitation increased between 1976

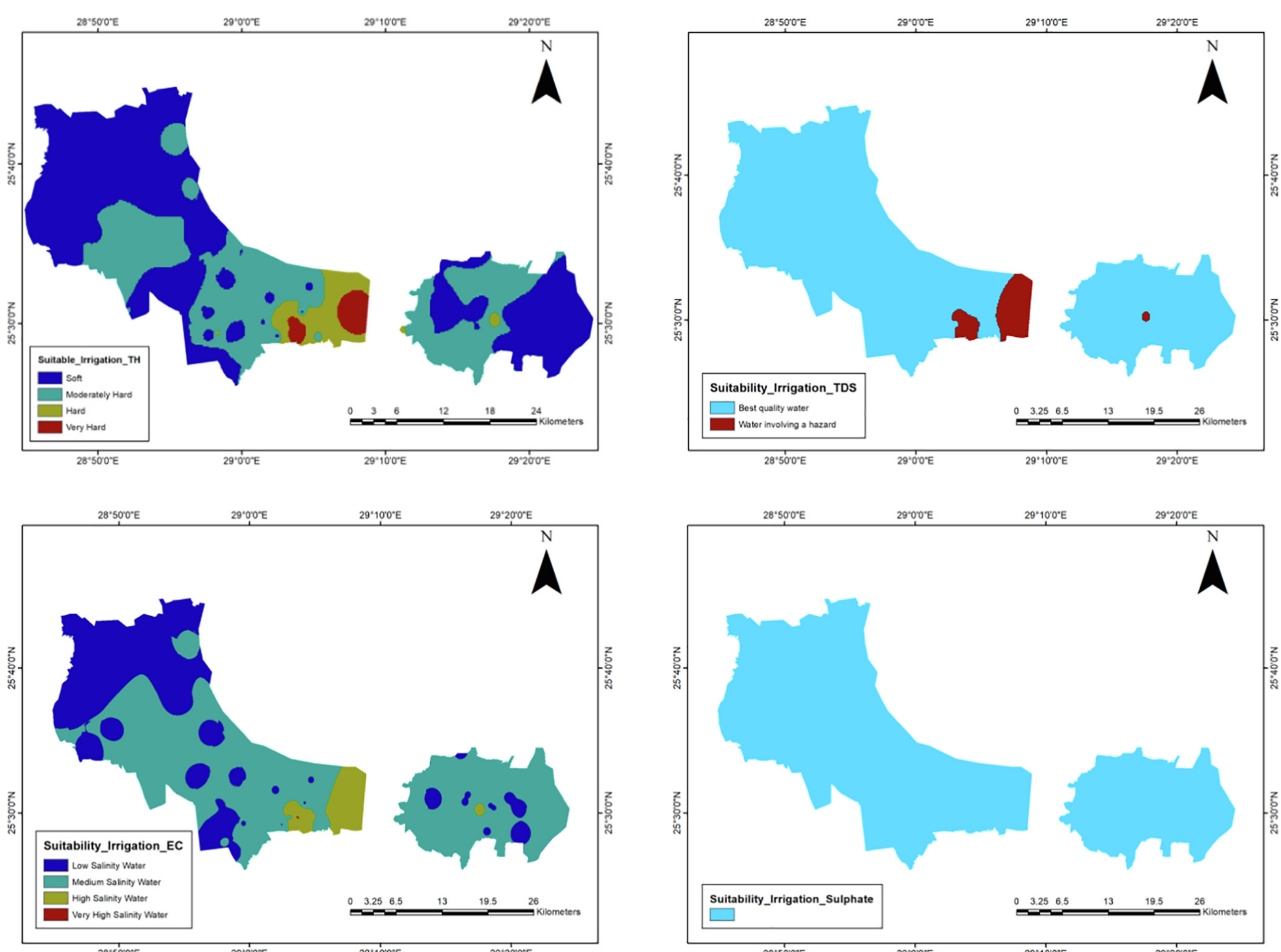

Fig. 11. Groundwater suitability for irrigation in Dakhla Oasis (El-Zeiny and Elbeih, 2019).

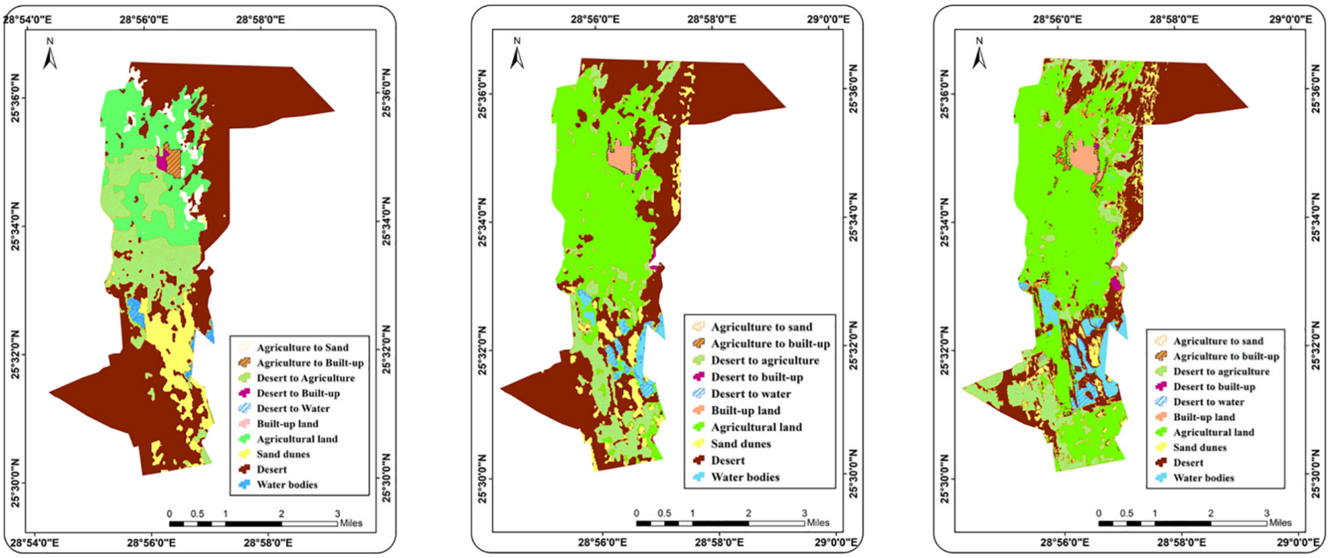

Fig. 12. Land use/cover classes in Rashda Village (Dakhla Oasis): a from 1968 to 1988, b from 1988 to 2003 and c from 2003 to 2018 (Iwasaki et al., 2020).

and 2006 by 54% to 62% in different regions. This increase in water abstraction is associated with the increase in the population, which ranged between 8.5 and 150% in the same period.

Gad (2015) created a land resources database for Dakhla Oasis that aims to assess and map land capabilities based on (FAO, 1985) methodology. Soil samples, Landsat satellite images, databases of climate and landscape, were integrated in a GIS model. A Digital Elevation Model (DEM) was produced using SRTM satellite images with the aid of topographic maps. The results revealed that 19.2 % of the Oasis are highly capable soils (Class II), and are found in the northern parts of the Oases. On the other hand, 6.1 % of the Oasis area are moderately capable soils (Class III) and exhibits some small areas in the western side of the depression. In addition, low capable soils represent 20.3% of the total area are mainly found close to the depression margins or adjacent to the active sand dunes. 54.5 % of the total area of the Oases is considered non capable soils, rock land or active sand dunes (Fig. 10).

In the Western Desert, groundwater is the main source for agricultural purposes, and the quality of groundwater is greatly affected by the related human activities. Accordingly, in Dakhla Oasis, (El-Zeiny and Elbeih, 2019) used GIS techniques to assess the spatial distribution of groundwater quality and its suitability for irrigation. Landsat 8 OLI satellite images were used to produce Land Use Cover map (LULC) to assess agricultural and human activities in the study area. In addition, eight groundwater quality parameters for irrigation were used in a Geographic Information System (GIS) for 71 wells using the Inverse Distance weighting (IDW) method. Results revealed that most of the groundwater wells are of the best suitable type for irrigation with salinity levels not more than 2000 mg/l and excellent quality based on sodium absorption rate (less than 10) (Fig. 11). This spatial assessment of the groundwater resource in Dakhla Oasis explained the extent of its deterioration and the areas that are more suitable. Taking onto account the international recommendations for irrigation, most of the wells characteristics are suitable to be used in irrigation.

Iwasaki et al. (2020) analyzed the changes in land use of Rashda Village - Dakhla Oasis and linked these land use changes with the

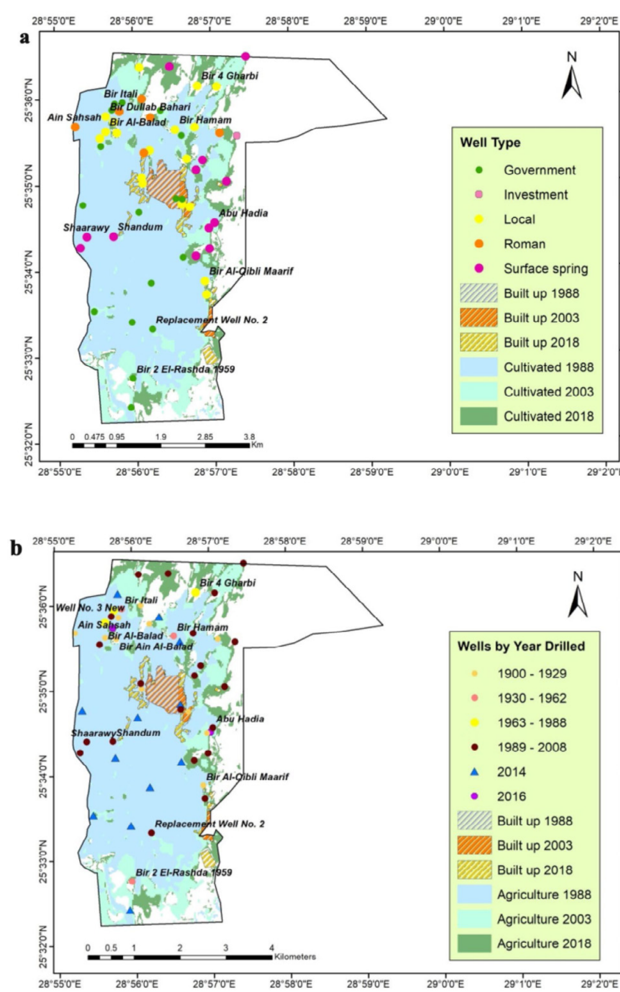

Fig. 13. Well llocation by a type, b drilling date, overlaid by land use (1988–2018), in Rashda Village (Dakhla Oasis) (Iwasaki et al., 2020).

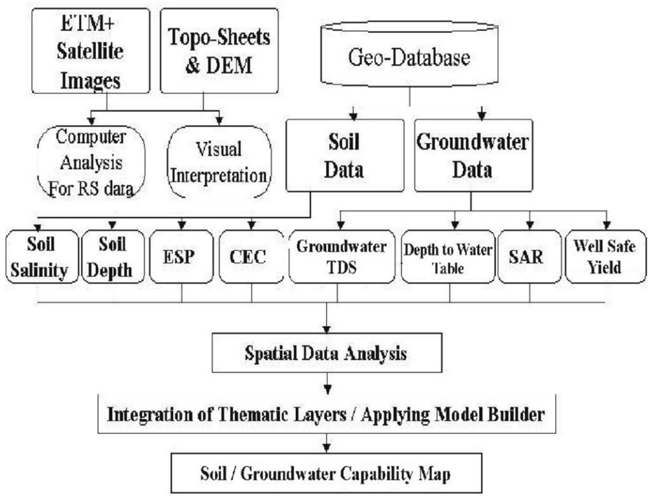

Fig. 14. A flow chart of the methodology used for soil/groundwater mapping in East Oweinat (El Nahry et al., 2010).

groundwater wells and changes of water quality and levels over time. This study documents the expansion of the agricultural land area as a result of the development of well drilling techniques. Satellite images were used from 1968 to 2018 including: Landsat, Sentinel-2 and Corona images. In addition, a 2008 ALOS PALSAR image was used to produce high-resolution (DEM) and groundwater well data from field checks and governmental reports.

Results showed significant land use/cover changes in the past 50 years where the largest expansion of agricultural lands occurred between 1988 and 2003 due to the acceleration in well drilling and operation (Fig. 12). From 2003 to 2018, the increase in agricultural lands occurred at an average rate of 33.3 ha/year. However, agricultural lands area increased at a rate of 40.0 ha/year from 1988 to 2003, which was considerably faster than during the period 1968–1988 (8.1 ha/year) (Fig. 12). One of the phenomena that emerged from 1968 to 2018 was the increase in drainage basins from 15.6 ha to 194.4 ha, where their growth was associated with the rapid increase in cultivated lands during the past 50 years (1988–2003) (Fig. 12).

The period between 1988 and 2008 witnessed the highest annual expansion in cultivated lands coinciding with the emergence of new well types on the outskirts of the village (surface springs and investment wells), where the land cahnged from desert to agricultural (Fig. 13).

El Nahry et al. (2010) applied a Weighted Spatial Capability Modeling (WSCM) technique using hydrogeological and soil capability data to determine soil/groundwater capability areas in East Oweinat. The study used the hydrogeological, hydrogeochemical and pedological characteristics of the Nubian Sandstone Aquifer System (NSAS) as an input for a multi-decision criteria model (Fig. 14). The layers used were: depth to water as a measure of accessibility, total dissolved solids (TDS) as a suitability factor for water in agriculture, well safe yield as a measure for water quantity available for agricultural activities, sodium adsorption ratio (SAR) that measures sodium hazard in irrigation water, soil salinity that influences crop productivity, soil depth that reflects soil thickness, soil exchangeable sodium percentage and cation exchange capacity that indicates soil capacity to hold cation nutrients. These layers were integrated into a (GIS) model as shown in (Fig. 14).

The output model classes showed the availability of the moderate soil/groundwater capability class, which emphasizes the success of the land use pattern in East Oweinat area in the last years. The WSCM soil/groundwater capability map showed three classes; high, moderate and low. 65.87 % of the total mapped area is classified to be moderately capable, whereas the high capability class represents 23.31 % of the studied area. The low capability class (80.94 km^2), encounters only a small zone at the southern zone (Fig. 15).

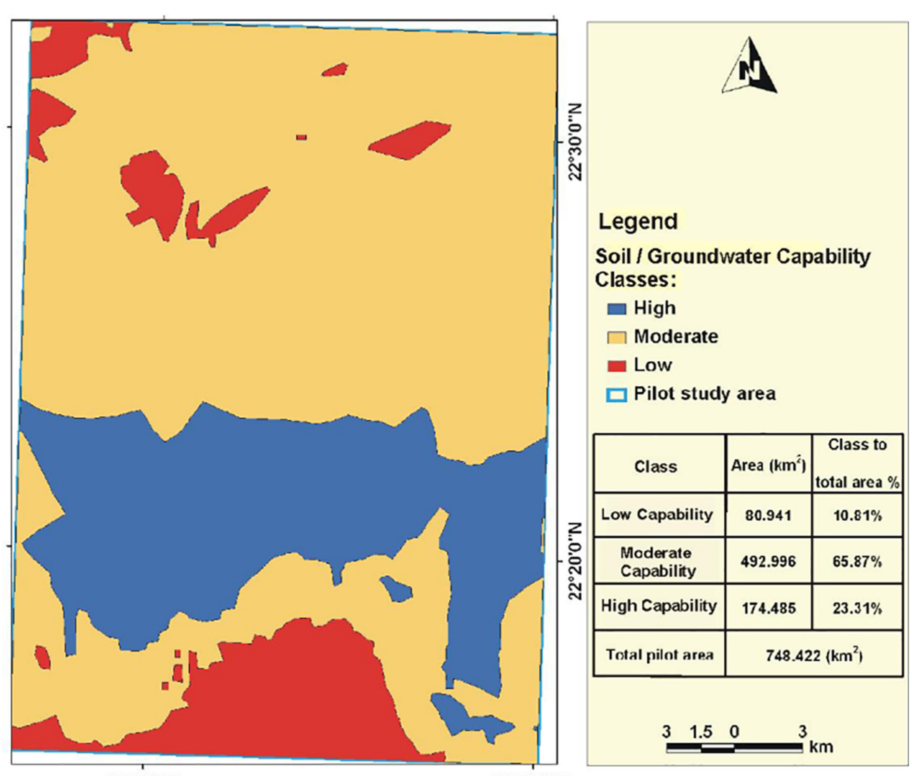

Fig. 15. Soil/groundwater capability map constructed using the WSCM technique in East Oweinat (El Nahry et al., 2010).

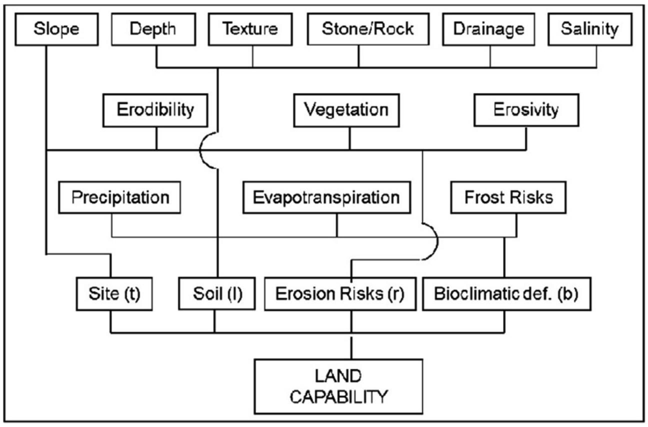

Fig. 16. Flowchart of Cervatana model for predicting land capability in El-Galaba basin (Saleh et al., 2015).

Saleh et al. (2015) investigated the potentiality of West Aswan soils (mainly El-Galaba basin) for agricultural expansion and the optimum agricultural use. Terrain units were identified using Landsat 8 satellite image over Digital Terrain Model (DTM) to express the landscape and the soil mapping units. Fifteen mapping units were identified and grouped and the land capability was performed using Cervatana capability model as shown in (Fig. 16). Prediction of land use capability is a qualitative evaluation process based on several factors including: slope, soil, climate, and current use or vegetation. The results of the study showed the potentiality of El-Galaba basin for agricultural uses.

3.2. North Upper Egypt region

- **West Minya**

AbdelRahman et al. (2018) studied the area of "West Minya Governorate" according to the government development plans. The study produced a land capability map for West Minia using soil information based on the USDA criteria and a new added parameter to determine the capability index for soil suitability to different irrigation methods. Landforms were mapped using SRTM combined with Sentinel satellite images of the studied area. The Fuzzy-Multi-Criteria spatial model was used to quantitatively assess land evaluation based for sustainable land use planning. In respect to drip and sprinkle irrigation, soil suitability is moderate to high for the entire area except for sand dunes and rock lands (Fig. 17). Modern irrigation methods should replace the surface irrigation system in the cultivated lands of the studied area.

3.3. Alexandria regional unit

- **Moghra Oasis, Wadi El-Farigh and Wadi El-Natroun**

Sayed et al. (2019) produced a map of the best sites to establish photovoltaic (PV) panels to generate solar energy to exploit groundwater in Moghra Oasis, by applying a Multi-Criteria Analy-

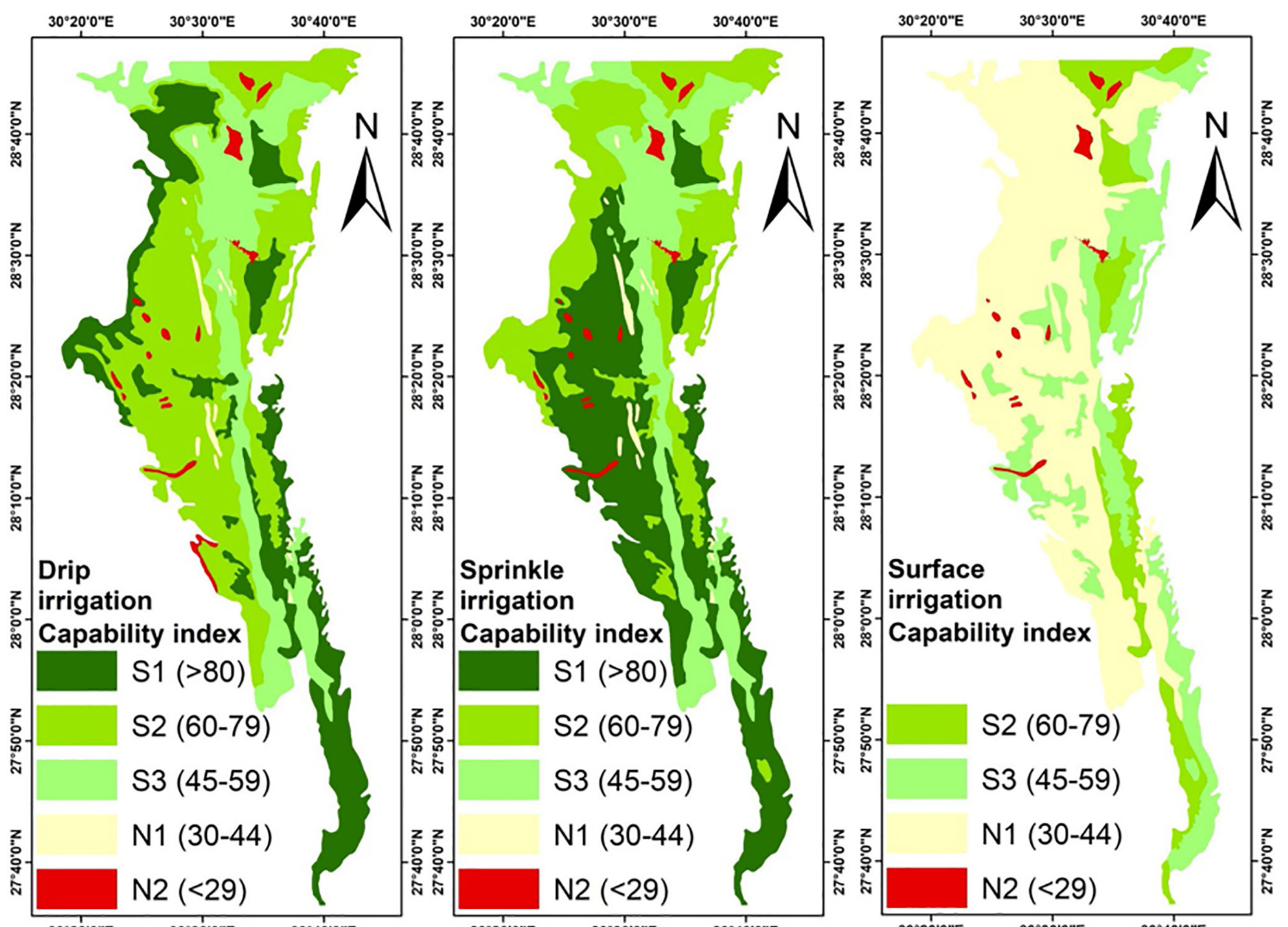

Fig. 17. Capability index for soil suitability to different irrigation methods in West Minia (AbdelRahman et al., 2018).

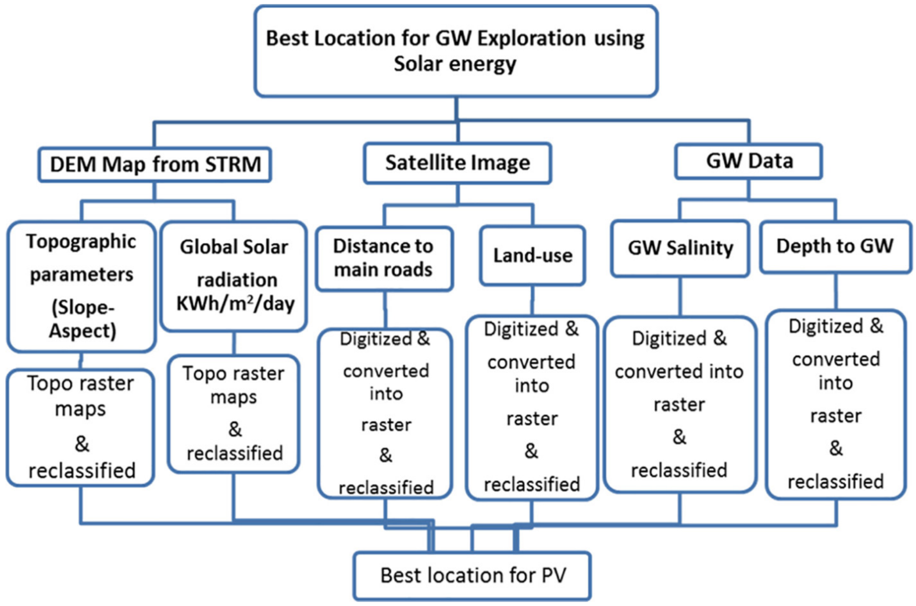

Fig. 18. Flow chart for the layers of the MCA GIS model input data in Moghra Oasis (Sayed et al., 2019).

Table 6
Weights for the input criteria for the MCA GIS model in Moghra Oasis (Sayed et al., 2019).

Rank	Criteria	Weight $(n - rj + 1)$	Normalized weight wj
1	Groundwater Salinity	7	0.25
2	Depth to groundwater	6	0.21
3	Land-cover	5	0.18
4	Distance to roads	4	0.14
5	Slope	3	0.11
6	Aspect	2	0.07
7	Solar radiation	1	0.04
Sum		**28**	**1**

sis model (MCA) based on GIS technology. SRTM data was used to model land elevation, land slope, aspect angles and area solar radiation maps. The criteria applied to the layers include the following factors: depth of groundwater, salinity, solar brightness, topography, proximity to transportation routes and land use (Fig. 18) and (Table 6).

The model outputs showed that the best sites for setting up photovoltaic panels for solar energy utilization stations are near the Nile River delta and outside the boundaries of the Qattara Depression and Moghra Lake, the oil fields areas close to the study area, and the areas where the salinity of the groundwater is more than 5000 ppm. The resulting map showed that the best sites for the establishment of solar stations have the salinity of the groundwater less than 5000 ppm and depth of less than 100 m from the ground surface (Fig. 19).

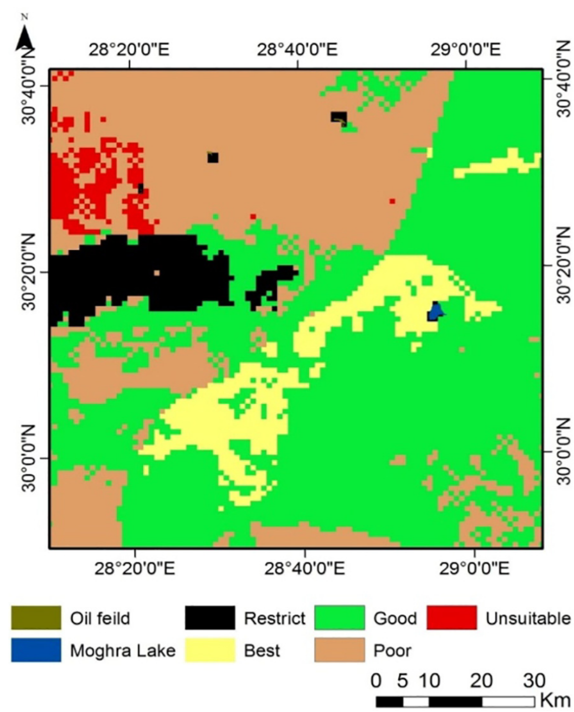

Fig. 19. Suitability map for groundwater extraction using solar energy in Moghra Oasis (Sayed et al., 2019).

4. Egypt future vision for scientific and applied advancement

The sustainable development strategy: Egypt Vision 2030 adopted the sustainable development as a general framework to improve the quality of life without prejudice to the future generations' rights for a better life. Hence, the concept of development adopted by the Egypt Vision 2030 is based on three main axes (dimensions); economic, social and environmental dimensions (MCIT, 2020)

The economic axis includes the agricultural, water and irrigation sectors. The main challenges that face the agricultural sector include: high rates of infringements on agricultural lands(more

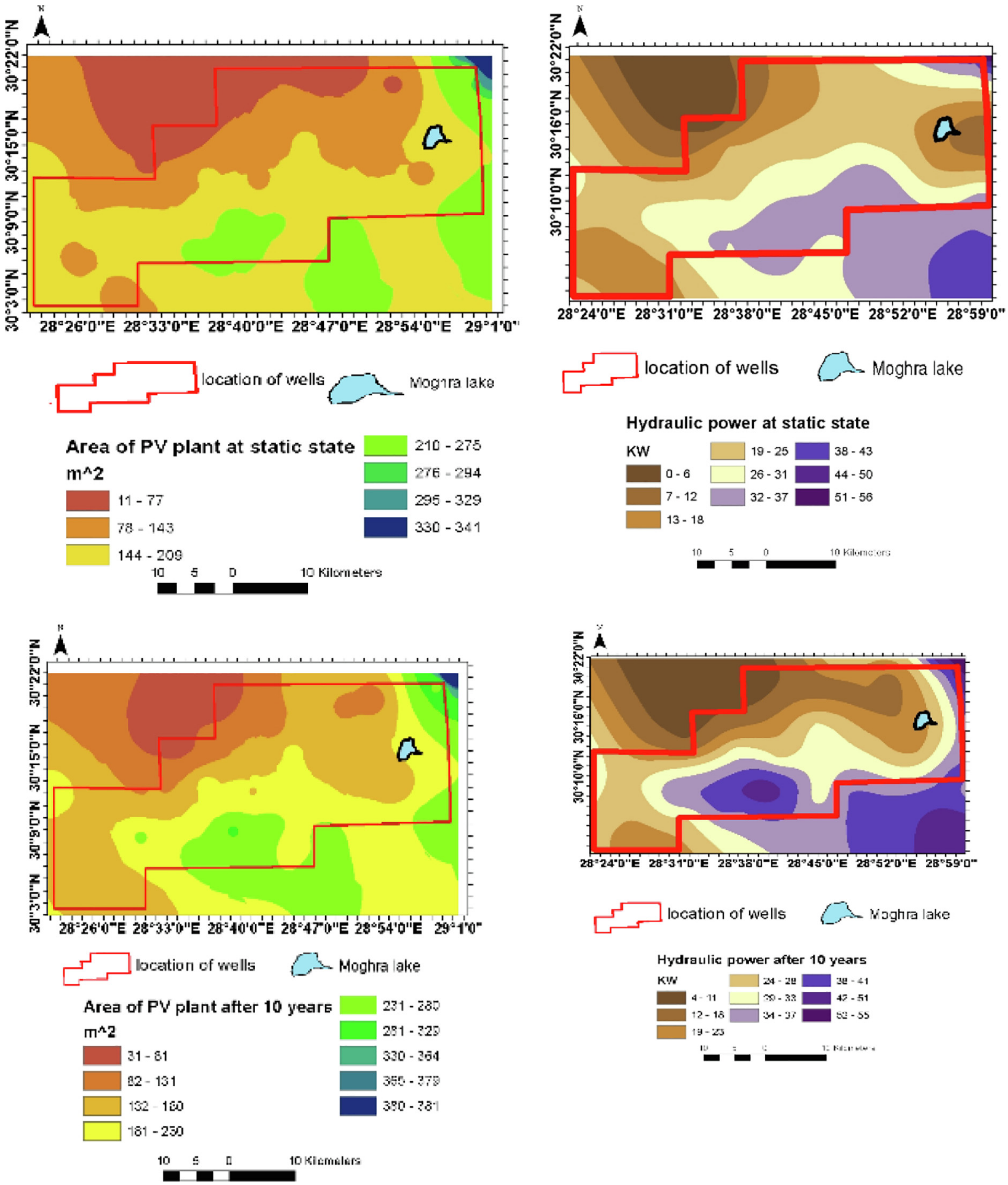

Fig. 20. Surface area of the Photo Voltaic plant and the required hydraulic power required at the beginning of pumping and after 10 years in Moghra Oasis (Sayed et al., 2020).

than 20,000 acres/year), limited agricultural investments, changing of irrigation systems from flood to modern irrigation (that rationalize the water consumption), lack of water resources due to limited revenue from the River Nile, in addition to the deterioration of the water quality in the Nile and waterways due to pollution. The main challenges that face the water and irrigation sector include: Water quality deterioration due to pollution and limited spatial and temporal distribution of water resources. In the programs and projects for economic development until 2030, two themes were given to agriculture; theme number 40 "Developing agricultural areas and supporting agro-industry" and theme number 43 "Establishing Agriculture Modernizing Center". It is important for the government and decision makers to encourage and benefit from recent and up to date technologies to successfully fulfill Egypt vision 2030 towards the sustainable development of old and newly reclaimed lands (MCIT, 2020).

Sustainable Development Goals (SDGs) Goal 2 that aims to end hunger, achieve food security and improve nutrition and promote sustainable agriculture: addresses many issues involved in doubling the agricultural productivity, increase the percentage of agricultural areas under productive and sustainable agriculture, increase investment, including enhanced international cooperation, in rural infrastructure, agricultural research and extension services. Moreover, SDG Goal 7 that ensures access to affordable, reliable, sustainable and modern energy: focuses on increasing the share of renewable energy, expanding infrastructures and upgrading technology for supplying modern and sustainable energy services (United Nations (UN), 2020).

The Egyptian Government highly indicates towards the expansion of agricultural projects in the New Valley and the related food industries and establishing logistical areas, (New Valley Governorate, 2020). In conjunction with the government plans to utilize solar energy for groundwater exploitation in promising areas in the Western Desert, (Sayed et al., 2020) constructed a groundwater model using MODFLOW/GMS software. One of the main aims of this model was to calculate the area of the Photo Voltaic (PV) plants and the required power for water pumping in Moghra aquifer, North Western Desert. The study was based on topographic, climatic, geological and hydrological data processed within a GIS environment. The area and power required was calculated at the static head (initial water level) and after 5, 10, 50 and 100 years. The results showed that the needed power (the potential electrical energy) and the area of the PV solar panels needed for abstraction will increase after 5, 10, 50 and 100 years (referred to the beginning of pumping) by about 48 %, 60%, 140% and 200 % respectively, due to the continuous abstraction and the expected drawdown in the groundwater levels. These percentages may be lower in case of better usage of the aquifer, reasonable pumping rates and increasing distance between wells (Fig. 20).

5. Conclusions and recommendations for future research

This review paper covers different remote sensing and GIS applications in the field of evaluating newly agricultural expansion areas in the Egyptian Deserts. Generally speaking, most of these applications aim at providing a support for decision makers and urban planners.

The main criteria and constraints considered in evaluation of agricultural lands in deserts are based on "The Environmental Perspective for Urban Development". The sustainable development strategy within the Egypt Vision 2030 takes into account the main challenges that face the development process in Egypt represented in the scarcity of natural resources such as energy, land, water, and environmental degradation. To protect the cultivated and newly reclaimed lands in the Egyptian deserts and conserve them for the future generations, the following recommendations should be considered;

- Rationalize water consumption by changing irrigation systems from flooding to sprinkling or drip irrigation. This will reduce water losses and the amount of wastewater received in the drains and hence avoid water logging problems
- Recharging the groundwater aquifer with low to medium salinity water or in case of low quality water to use it in cultivation of wooden trees
- Rely more on solar energy, establish PV panels for generating solar energy to exploit the groundwater and consider wind energy as an alternative of renewable sources
- Study the possibility of desalination of brackish groundwater using solar energy in areas of high groundwater salinity
- Cultivating kinds of tolerant crops to high temperatures
- Upgrading drainage systems to prevent water logging and appearance of drainage ponds.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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