Environmental analysis of soil characteristics in El-Fayoum Governorate using geomatics approach

Ahmed M. El-Zeiny · Hala A. Effat

Abstract The present study aims at identifying the impact of wastewater irrigation on soil characteristics of El-Fayoum Governorate using Landsat images and geo-statistical techniques integrated with field investigation and soil analyses. Soil samples were collected from 40 representative sites during November/ December 2016 and analyzed for pH, electric conductivity (EC), organic carbon (OC), total nitrogen (TN), total phosphorus (TP), Ca, K, Na, and Mg. Landsat images were processed to produce spectral indices of water (MNDWI), vegetation (NDVI), salinity (NDSI), and urban areas (NDBI). Inverse distance weighting in ArcGIS 10.1 was used for mapping soil characteristics. Results refereed to a fluctuation in soil characteristics among different districts, as a result of variation and severity of activities. High levels of OC (3.5–5.21%) were recorded in several scattered parts while northern parts showed high levels of TP and TN recording 0.8–1.7 mg/g and 1.7–2.4 mg/g respectively. A great fluctuation in salinity, Ca, K, and Na levels were detected among the collected soil samples. Southern and eastern borders of the governorate showed high levels of Ca (> 17.7 mg/g). The most alkaline soil samples (> 8) were mostly recorded in El-Fayoum and Tamia districts. Variation of soil characteristics is greatly impacted by irrigation using wastewater particularly from El-Bats and El-Wadi drains. A strong positive correlation (0.94) was observed between urbanization (NDBI) and land salinization (NDSI) which ensures the negative impact of residential areas on agricultural lands. It can be concluded that the agricultural land problems have greatly been impacted by the lack of sufficient water supply. Geospatial techniques along with soil analyses facilitate studying such problems.

Keywords Soil quality · Wastewater irrigation · Soil pollution · Remote sensing · GIS · Spatial analyses

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Introduction

One of the major problems in El-Fayoum's agricultural area is land degradation. This degradation is caused by the misuse of natural resources (e.g., water, soils), poor drainage system, and inadequate soil leaching. This is magnified due to the lack of sufficient water supply to "tail end" sites of El-Fayoum basin and a lack of adequate field drainage system in low lying areas of the basin (El- Baroudy 2013). Sanitary conditions are negatively affected by the inappropriate organization of sewage and liquid waste disposal. Another problem is the presence of El-Batts and El-Wadi drains which are

the heaviest contaminated drains in El-Fayoum. These drains are discharging wastewater into Lake Qaroun and are used for irrigation in surrounding agricultural lands. Irrigation using the contaminated drainage water increases health risks (UNDP 2003).

Two sources of pollution are found along El-Batts drain, which adversely influence its quality. The first source is the municipal wastewater which can be classified as point load comes from discharges of the wastewater treatment plants. Huge amount of wastewater is directly discharged into drainage channels forming high peak of organic load. This type is considered a distributed load (i.e., non-point source). The second source is the agricultural drainage that results from the agricultural activity. The quantity and quality characteristics of drainage received from agricultural regions are highly variable. The most important contaminants found in runoff from agricultural areas are crop residues, plant nutrients, sediments, inorganic salts and minerals, chemical pesticides, and fertilizers. The industrial wastewater is not considered a scope of investigation because the majority of industries are located at Kom-Oshim area. The industrial waste is injected in the soil (Farag and Donia 2006).

On the other hand, central parts of El-Fayoum Governorate (i.e., El-Fayoum depression) were more vulnerable to expansion of urban areas on account of the vegetated lands. These conditions adversely influence the potentiality for sustainable development in the depression as well as increase the pressure on water and land resources in the governorate (Gad and El-Zeiny 2016; El-Zeiny and Effat 2017).

Water pollution has become a menace in recent times, causing a great damage to aquatic and land ecosystems. Many agricultural, urbanized, and industrial processes lead to pollution of environment and contribute to the deterioration of water resources (Goher et al. 2017). Pollution of water directly influences soil quality characteristics. Pollutants may cause damage with remarkable effects on the environment. Pollution of soil has increased dramatically in the last decades due to mobilization by human activities including industrial effluents, smelting, mining, municipal wastes, use of agricultural fertilizers, manufacturing, pesticides, traffic emissions, and industrial chemicals (Al Naggar et al. 2014; Serageldin et al. 1995).
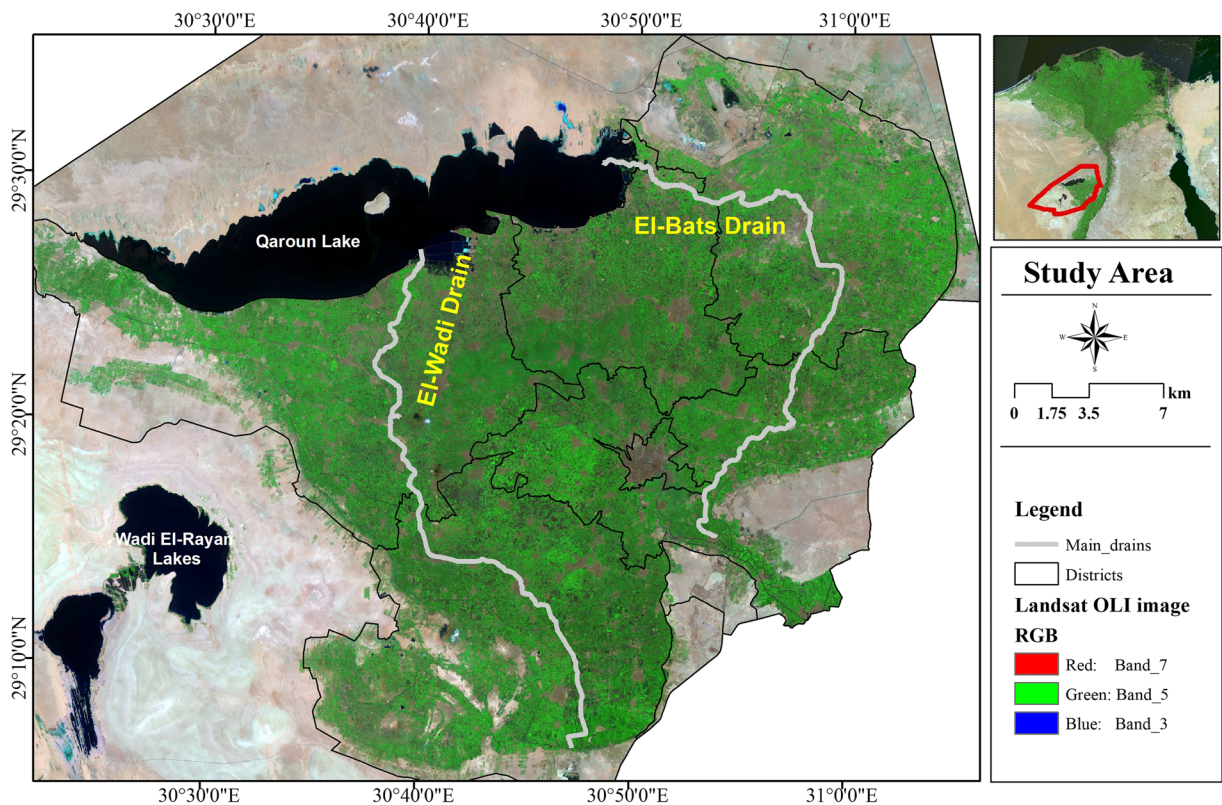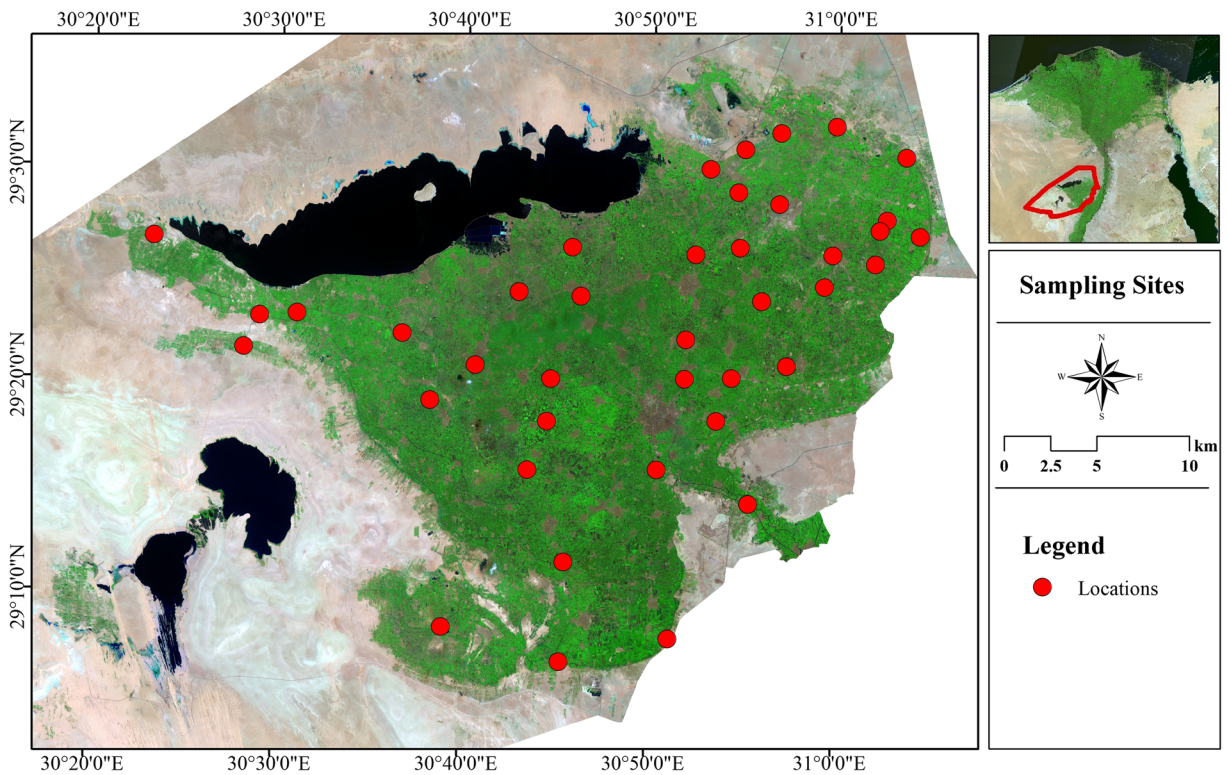

Fig. 1 Location map for El-Fayoum Governorate

Fig. 2 Topsoil sampled locations in El-Fayoum Governorate

On the other hand, anthropogenic activities have a considerable impact on surface water resources including irrigation canals. This, in addition to the natural factors, leads to a change in water quality
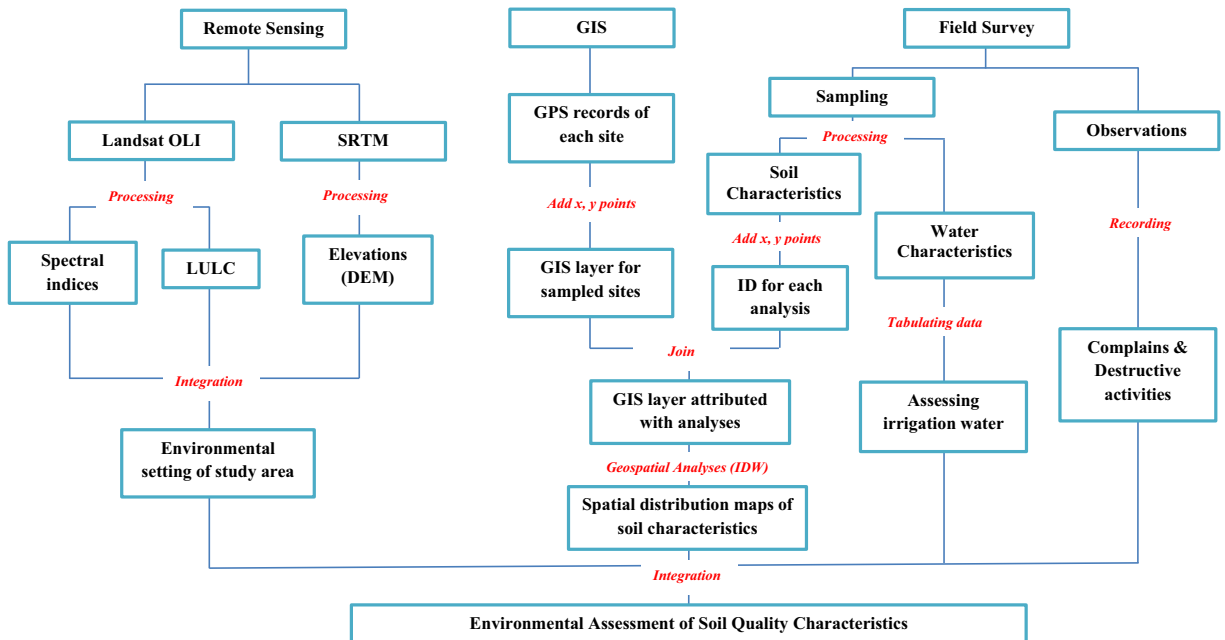

Fig. 3 Flow chart showing the methodology adopted in the present study

which might influence the suitability of water for irrigation. The criteria for assessing water quality for irrigation purposes include for instance the measurement of salinity hazard in terms of electrical conductivity (Ayers and Westcot 1994; Bauder et al. 2014). Suitability of water for irrigation purposes depends on the effect of water minerals on soil and plants (Wilcox 1958). The effects of salinity on crops could be distinguished into osmotic and specific salinity effects. A decrease in osmotic potential of the soil solution without corresponding decrease in root water potential reduces water flow from soil to root, thereby restricting water uptake by crop plants and a reduction in crop growth. The specific effects may be through nutrition and through toxicity (Sonneveld and Voogt 2009; Mandal et al. 2019).

The potential application of remote sensing data has been well recognized in assessing and mapping land attributes such as soils, physiography, and land use/land cover. Techniques of remote sensing and GIS play a major role in providing information on soil types, DEM, land use/land cover, infrastructures, NDVI, and monitoring changes to achieve the concepts of sustainable development (Uttarwar 2001; El-Zeiny and Effat 2017). Further, geospatial techniques integrated with a limited field survey could be useful to map soil and water characteristics as well as to identify the most significant sources of pollution (El-Zeiny et al. 2016; Hammam and Mohamed 2018).

Mapping soil properties is one of the important items for the sustainable management of soils. The spatial analysis helps to generate thematic layers of soil characteristic, representing a great source of data for the land use planners. The geographic variation of soils could present the connection among different soil characteristics and landforms and thus helps to understand the differences in crop yield (Ali et al. 2019; Darwish and Abd El-Kader 2008; Mohamed et al. 2018; Ali et al. 2019).
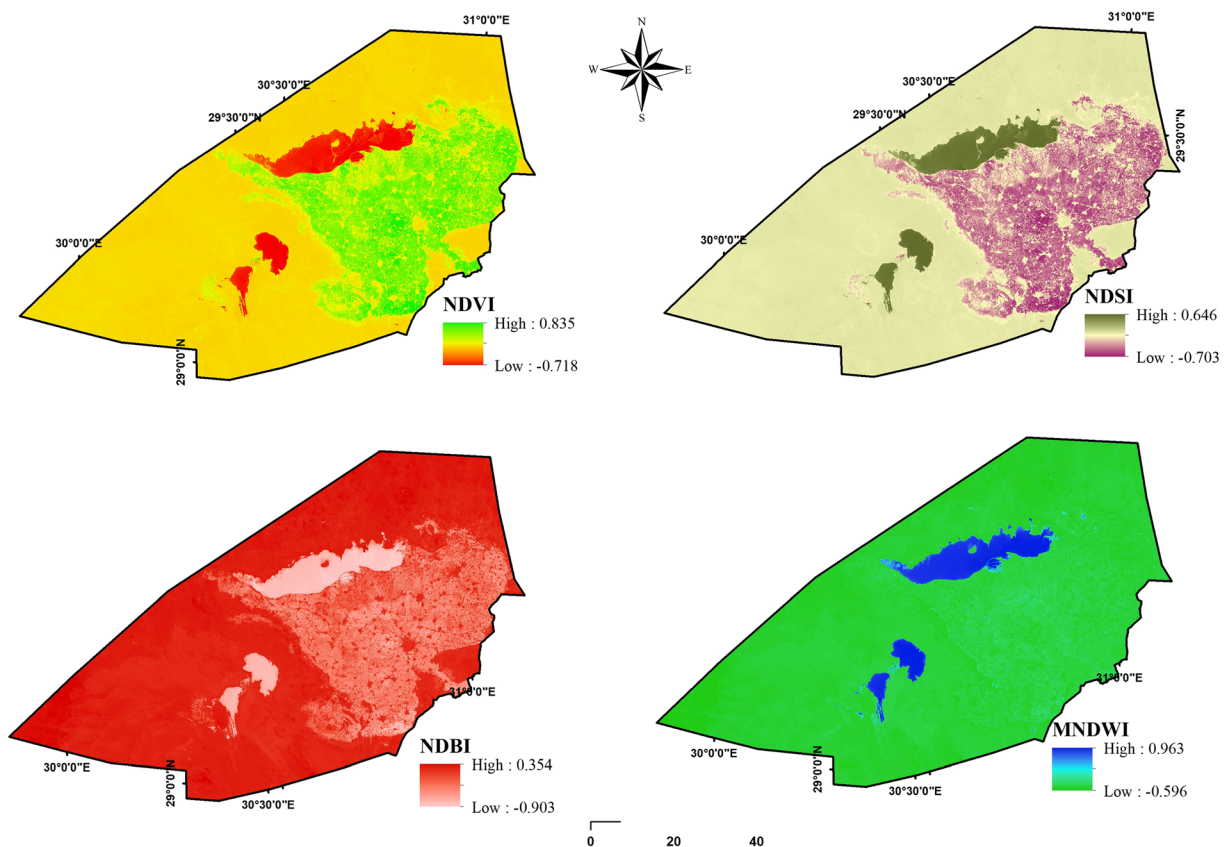

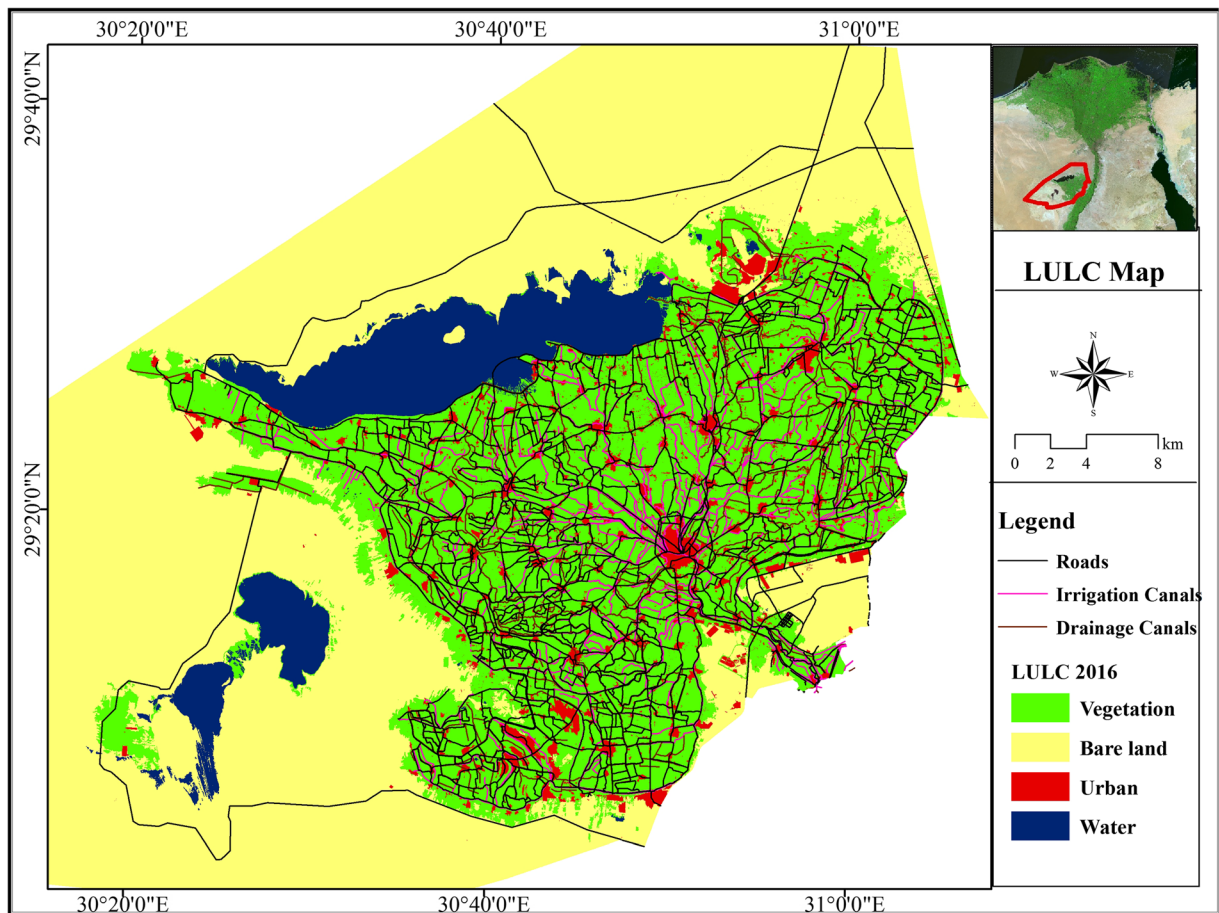**Fig. 4** Spectral indices of El-Fayoum Governorate

Fig. 5 Land use/cover map for the study area

Further, information on spatial variation of nutrient properties of topsoil becomes important for measuring fertilizing needs on site specific basis. One method for mapping topsoil properties is to sample the investigated area by grid sampling and analyzing soil properties. Then, mapping of management zone could be created through the interpolation of measured property values of each sample by either "inverse distance weighting-IDW" or "kriging" statistical techniques (Weisz et al. 1995; Abu-Hashim et al. 2016; Ali et al. 2019).

In the present study, integration between field survey and geospatial analyses of soil was utilized to investigate and assess soil characteristics in El-Fayoum Governorate taken into consideration the impacts of human activities and the contamination of irrigation water.

Materials and methods

Study area

El-Fayoum Governorate occupies, in the central parts, a depression in west of the Nile at a distance about 90 km southwest of the great Cairo between latitudes 28° 55′ N

Table 1 Areas and percentage of LULC classes

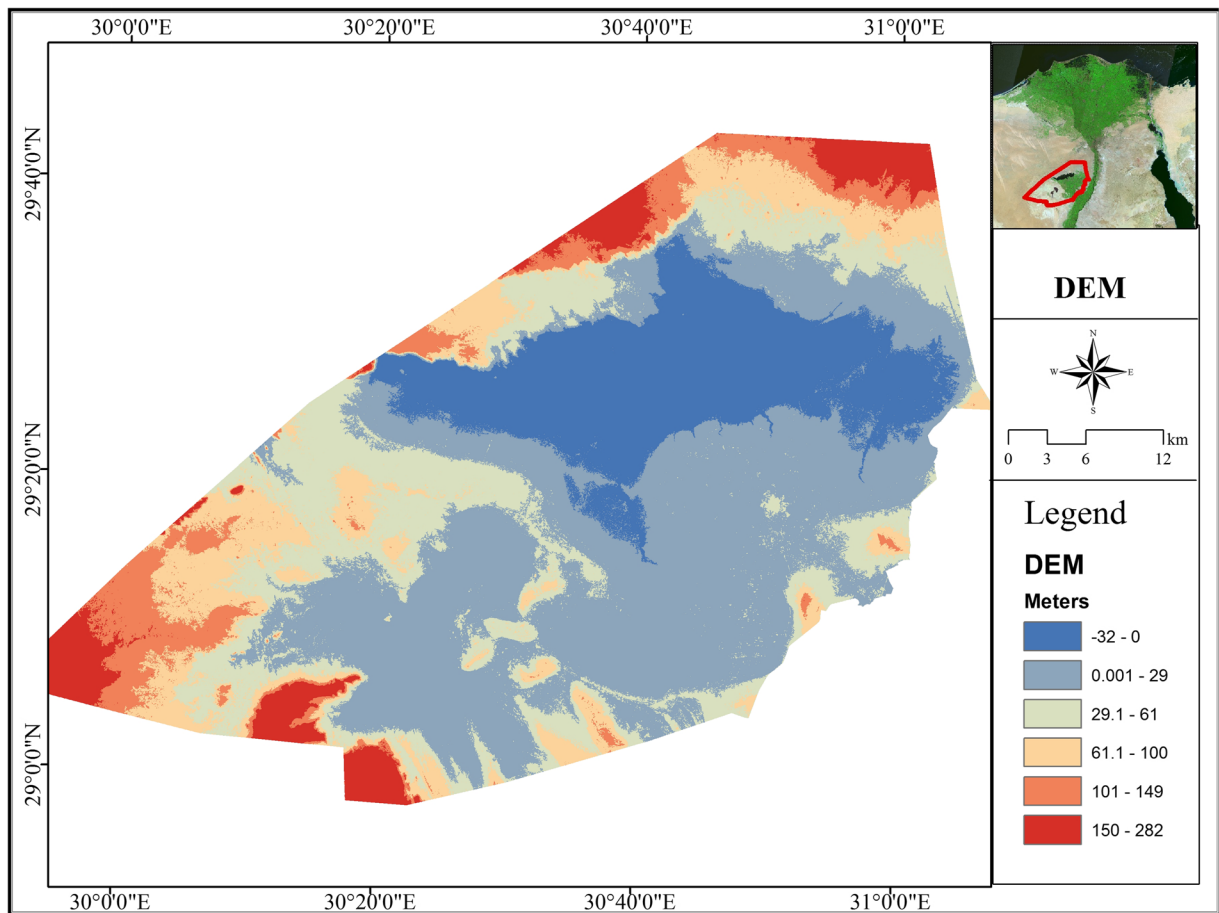| LULC	km²	Percent
Bare land	3579.33	61.77
Urban	235.94	4.07
Vegetation	1633.86	28.20
Water	345.46	5.96
Total	5794.59	100.00

Fig. 6 Digital elevation model of El-Fayoum Governorate (m asl)

and 29° 40′ N, longitude 29° 55′ E and 31° 5′ (Fig. 1). The governorate is remarkable by its nature differing from the Upper Egypt and the Delta. The differences are not only restricted to the agricultural areas but also
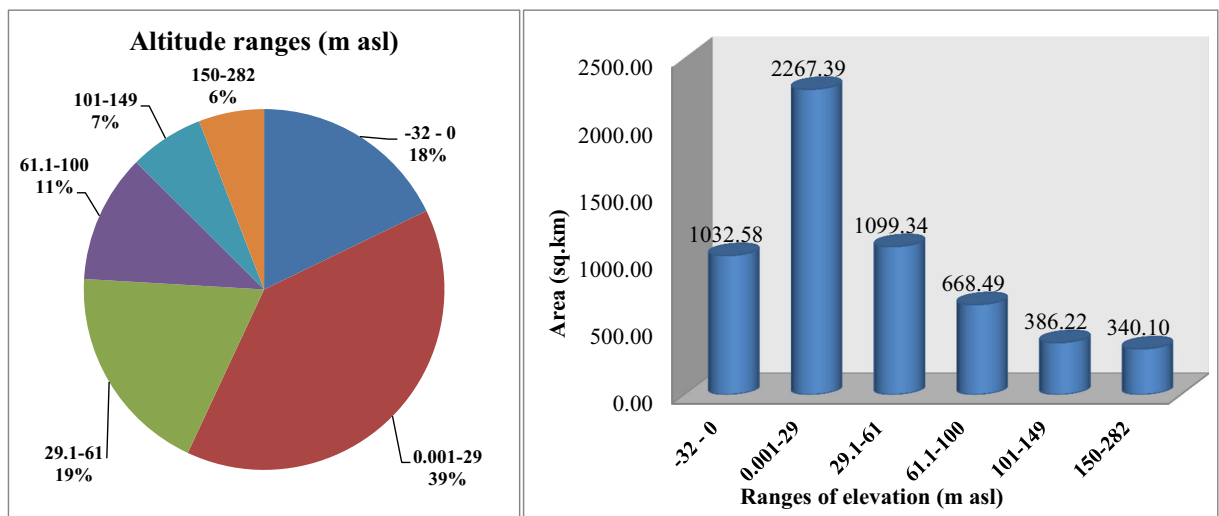

Fig. 7 Areas (left image) and percent (right image) of DEM ranges (m asl)

Table 2 Limits of EC if water suitable for irrigation (Hammad 1985)

EC (µS/cm)	Water class
Less than 250	Excellent
250–750	Good
750–2000	Permissible
2000–3000	Doubtable
More than 3000	Unsuitable

extended to topographic and geographic characteristics because the environment of the governorate is a combination of agricultural lands, lakes, and desert. Further, El-Fayoum population includes both rural and Bedouins inhabitants. El-Fayoum depression looks as an oasis which is directly connected to the River Nile through Bahr Youssef which transports water from Ibrahimiah Canal to El-Lahoon barrages. Water is spread through Bahr Hassan Wassef and Bahr Yousef. Bahr Youssef serves the central and northeastern areas, while Bahr Hassan Wassef serves the western and southern parts (ARCADIS 1999; El-Zeiny and Effat 2017).

El-Fayoum receives fresh water from one source called Bahr Youssef with a share of irrigation water amounts to approximately 2.5 (bcm) yearly. Surface areas of Wadi El-Rayan and Qaroun Lakes amount to 35,000 and 55,000 feddans, respectively. Both are considered the basic reservoirs of agricultural drainage water of El-Fayoum (Farag and Donia 2006). The climatic data of the governorate referred that the total annual rainfalls does not exceed 7.2 mm while the annual means of minimum and maximum temperatures are 14.5 and 31.0 °C, respectively (Gad and El-Zeiny 2016).

Sampling and spatial analyses

A field trip was conducted to El-Fayoum Governorate during the period November 30th–December 4th 2016. To evaluate soil and irrigation water characteristics, 40 topsoils (0–30 cm) and 40 water samples were collected (Fig. 2). The collected soil samples were analyzed for the following physical and chemical characteristic: pH, EC, Ca, K, Na, Mg, TP, TN, and OC according to Soon and Hendershot (2006). Physico-chemical parameters of
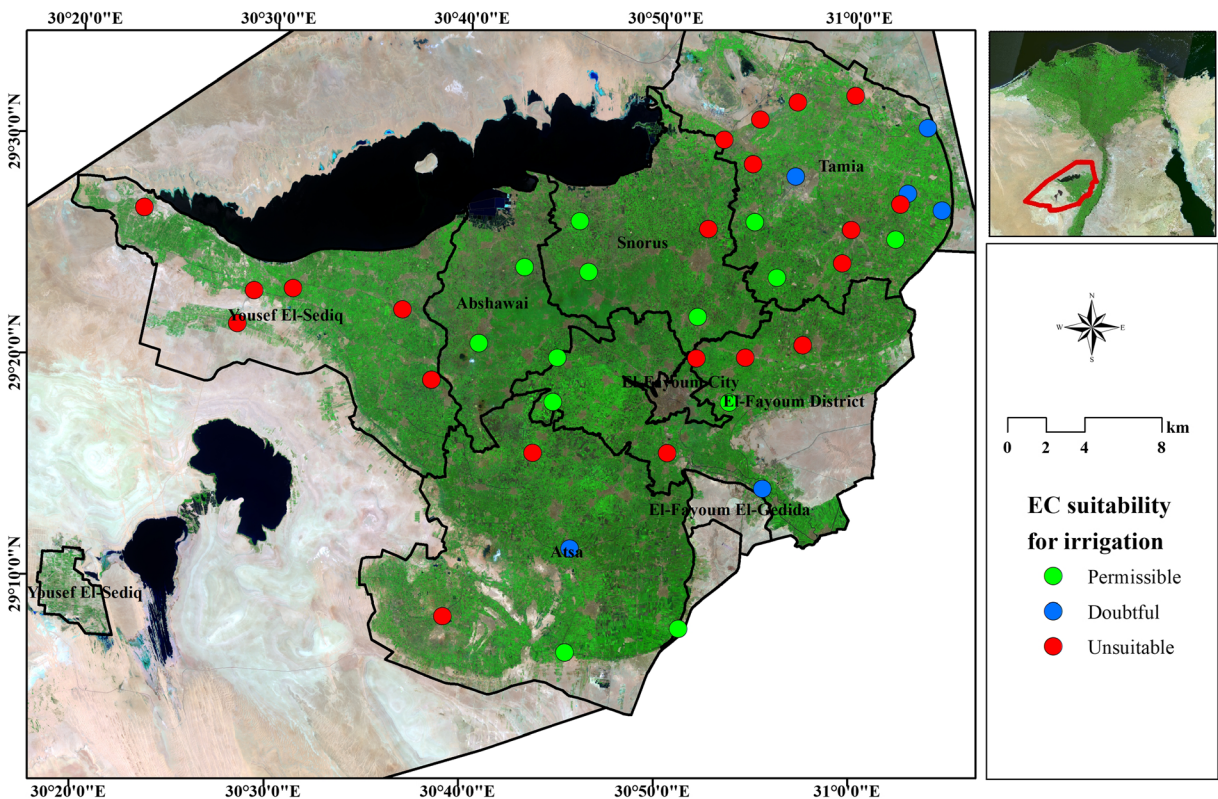

Fig. 8 Suitability of water EC for irrigation

water samples were in situ measured using Aqua meter including pH, EC, turbidity, dissolved oxygen (DO), oxidation reduction potential (ORP), and resistivity (RES).

The geographic location of each sampled site was recorded and converted into a GIS thematic layer. Spatial and non-spatial data sets were joined for mapping soil characteristics in the governorate.

Fig. 9 Water quality characteristics and spectral retrieved indices of unsuitable, doubtable, and permissible irrigation water
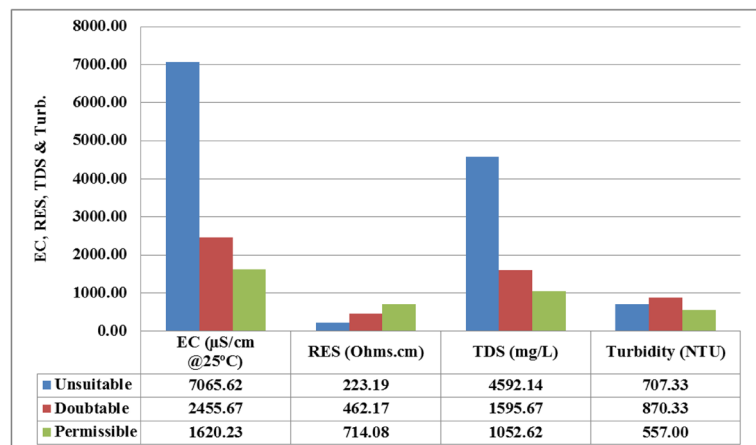

	Temp (ºC)	pH	ORP (REDOX)	DO (mg/L)
■ Unsuitable	20.64	7.60	43.61	6.28
■ Doubtable	21.60	7.71	69.68	5.11
■ Permissible	21.08	7.70	60.02	5.88

	EC (μS/cm @25ºC)	RES (Ohms.cm)	TDS (mg/L)	Turbidity (NTU)
■ Unsuitable	7065.62	223.19	4592.14	707.33
■ Doubtable	2455.67	462.17	1595.67	870.33
■ Permissible	1620.23	714.08	1052.62	557.00

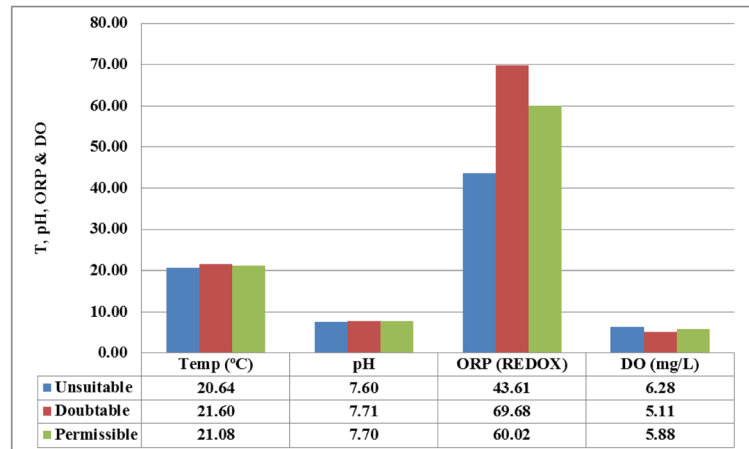|	MNDWI	NDBI	NDMI	NDSI	NDVI
■ Unsuitable	−0.27	−0.10	0.10	−0.35	0.35
■ Doubtable	−0.24	−0.11	0.11	−0.33	0.33
■ Permissible	−0.22	−0.13	0.13	−0.35	0.35

Table 3 Correlation matrix between irrigation water analyses and spectral indices

Parameters	Temp (°C)	pH	ORP (REDOX)	DO (mg/L)	EC (µS/cm @25 °C)	RES (Ohms cm)	TDS (mg/L)	Turbidity (NTU)	MNDWI	NDBI	NDSI	NDVI
Temp (°C)	1.00											
pH	−0.13	1.00										
ORP (REDOX)	−0.22	0.23	1.00									
DO (mg/L)	−0.24	0.33	0.08	1.00								
EC (µS/cm @25 °C)	0.25	−0.13	−0.03	0.05	1.00							
RES (Ohms cm)	−0.07	0.24	0.21	−0.11	−0.68	1.00						
TDS (mg/L)	0.25	−0.13	−0.03	0.05	1.00	−0.68	1.00					
Turbidity (NTU)	0.12	0.43	0.31	0.04	0.23	−0.05	0.23	1.00				
MNDWI	−0.46	0.10	0.20	−0.01	−0.34	0.37	−0.34	−0.18	1.00			
NDBI	−0.08	0.05	−0.16	0.28	0.20	−0.14	0.20	−0.06	−0.14	1.00		
NDSI	−0.24	0.09	−0.10	0.28	0.08	−0.01	0.08	−0.11	0.20	0.94	1.00	
NDVI	0.24	−0.09	0.10	−0.28	−0.08	0.01	−0.08	0.11	−0.20	−0.94	−1.00	1.00

Non-spatial data was represented by the lab analyses where ID was assigned to each analysis. Spatial data sets were represented by the geographic position of each site. Geo-statistical analyses were performed using inverse distance weighing (IDW) for mapping soil characteristics in the whole study area including the non-surveyed sites. Spatial distribution maps of soil characteristics (i.e., result of interpolation) were generated and eventually exported as a raster data layer for assessment.

Satellite image acquisition and processing

Initially, multispectral Landsat imageries (OLI) on 2nd of August 2016 covering El-Fayoum Governorate were freely downloaded. The data set was created by the US Geological Survey and was obtained in GeoTIFF format. The study area is located in two scenes: 177–39 and 177–40. The downloaded scenes were subjected to radiometric and atmospheric corrections, then a mosaic was created and cropped to resize the study area. Radiometric calibration refers to a set of methods applied during image processing which includes corrections related to topography and sun angle, sensitivity of the remote sensor, and atmospheric scattering/absorption (El-Zeiny and El-Kafrawy 2017).

The calibrated Landsat image was processed to produce 4 spectral indices based on empirical equations identified in ENVI 5.1. The investigated indices and their formulas are Modified Normalized Difference Water Index (MNDWI) = (Green-SWIR)/(Green+SWIR), Normalized Difference

Table 4 Statistics of soil characteristics in El-Fayoum governorate

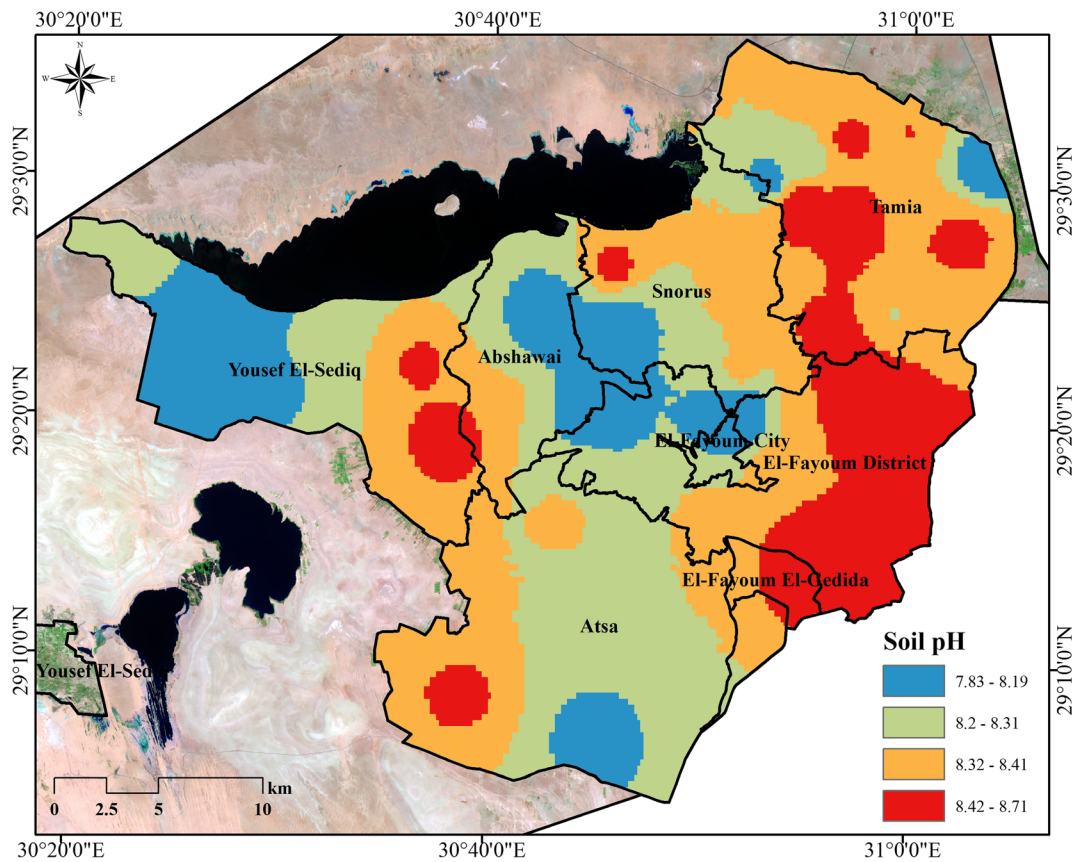| Statistics	Min	Max	Average	SD
pH	7.83	8.71	8.31	0.20
EC, mS/cm	0.04	9.59	1.71	1.78
Ca, mg/g	0.81	98.58	20.71	19.92
K, mg/g	0.50	34.38	6.07	6.82
Mg, mg/g	0.56	31.50	10.65	6.45
Na, mg/g	1.65	131.48	24.58	26.16
TP, mg/g	0.11	1.71	0.50	0.30
TN, mg/g	0.05	2.44	0.74	0.50
OC, %	0.21	5.21	1.75	1.45

Fig. 10 Soil pH map of El-Fayoum Governorate

Built-Up Index (NDBI) = (SWIR-NIR)/(SWIR+ NIR), Normalized Difference Vegetation Index (NDVI) = (NIR-Red)/(NIR+Red), and Normalized Differential Salinity Index (NDSI) = (Red-NIR)/ (Red+NIR). One of the most important types and most accurate classifiers of supervised classification is the maximum likelihood classifier (MLC). It has been widely used to produce land use and land cover maps (Lillesand and Kiefer 1987). The spectral indices along with the supervised classification were utilized to identify and assess the land use/cover in the study area. The classified image was produced with a calculated accuray of 89.59% based on the field validation points.

Correlation analysis

Correlation coefficient can be defined as a measure of the degree to which the estimated variables vary together. Value of correlation coefficient must fall between −1 and +1 (Ramadan 2003). The tool of

correlation analysis, in the Microsoft Excel analysis, was employed to study the statistical relationship between the studied characteristics: irrigation water, spectral indices, and soil parameters.

Adopted methodology

Data requirements of the present study were obtained from the field survey and the remotely sensed data processing (Fig. 3). From the field survey, the

Table 5 Impacts of soil salinity on the growth of crops (After Al-Khaier 2003)

Salinity (EC, dS/m)	Plant tolerance
0 to 2	Mostly negligible
2 to 4	Growth of sensitive plants may be restricted
4 to 8	Growth of many plants is restricted
8 to 16	Only tolerant plants grow satisfactory
Above 16	Only a few, very tolerant plants grow satisfactory

required samples were collected for further analyses in addition to reporting the anthropogenic activities and the most common complains. The remotely sensed data were processed to map the main land uses, the drains, and the DEM to assess the environmental settings of the study area. Maps of soil characteristics were generated based on the geostatistical analyses in ArcGIS 10.1. These maps along with field observations and environmental characteristics of the study area were integrated to environmentally assess soil characteristics in the study area taken into consideration the dominant anthropogenic activities.

Results and discussions

Environmental setting of the study area

Elevations and land cover characteristics of the study area were investigated by assessing land use/cover (LULC), NDVI, MNDWI, NDSI and NDBI, and digital elevation model (DEM). A recent space-borne multi-spectral Landsat image dated 2016 was integrated with archival data, field observations, and spectral indices in order to produce a more precise up-to-date land use and cover map (LULC) for El-Fayoum Governorate. Further, the spectral indices facilitated identifying the agricultural lands (NDVI), water bodies (MNDWI), urban and desert lands (NDBI), as well as indicate the lands affected by salinization (NDSI). This helped to explain the current anthropogenic activities that might impact the available resources including agricultural lands (Fig. 4).

The urban class in the produced LULC map represents all residential and industrial areas in El-Fayoum Governorate within rural areas and cities. The vegetation class represents the whole agricultural lands in the governorate including both old cultivations and newly reclaimed areas. The water class includes all surface water bodies in the governorate (i.e., irrigation and drainage
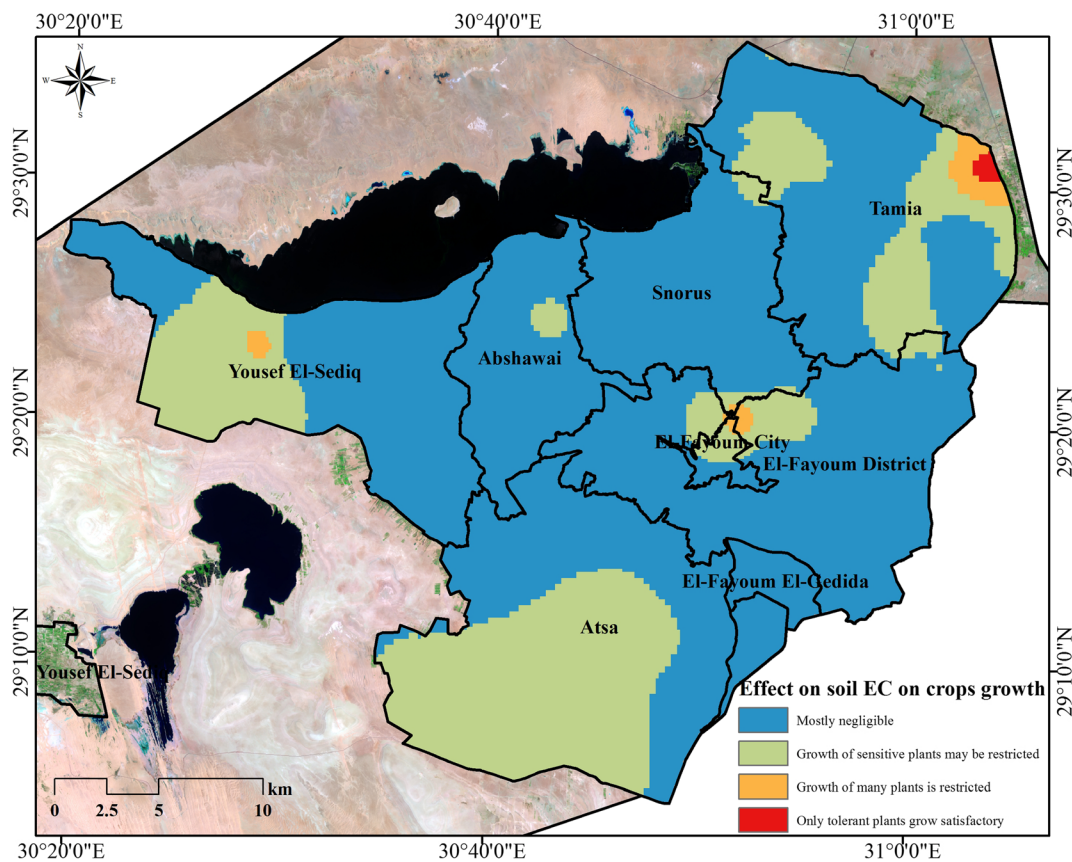

Fig. 11 Soil classfication according to EC effects on crops

canals, lakes). Desert and non-used lands were classified as "bare land" in the LULC map. Results showed that the governorate is bordered from north, south, and west by the western desert which represents the most dominant class in LULC map, exhibiting a total area 61.77% (3579.33 km^2) as shown in Fig. 5 and Table 1.

Agricultural land was the second dominant class, representing 1633.86 km^2 (28.20%), distributed in the whole area except the desert expansion of the governorate as also observed in NDVI. Urban and desert lands appeared as one class in NDBI map recording the highest positive values. The urbanized areas occupied 235.94 km^2 (4.07%) and were embedded in the agricultural lands, connected by a dense roads network as appeared in LULC map. Irrigation and drainage canals were well distributed within the agricultural area. The main drains in the governorate are El-Bats and El-Wadi which receive huge quantities of wastewater. Due to water scarcity problems, these drains are widely used for irrigation purposes.

Water bodies are mainly represented by Qaroun and Wadi El-Rayan lakes amounting 345.46 km^2 (5.96%) from the total area of the governorate as presented in LULC and MNDWI maps. NDSI showed that the northern agricultural lands (south of Qaroun Lake) are mostly affected by salinity problems which might be attributed to the impact of irrigation using polluted water due to the extreme water scarcity in this area. Although the governorate is connected by a dense roads network, they are mostly tracts with few numbers of paved roads.

Figure 6 shows DEM of the studied area based on the processed SRTM images. It is clear that El-Fayoum Governorate attains an elevation ranging between −32 and 282 m asl. Most of the depression is characterized by an altitude ranging between 0.001 and 29 m asl (39%, 2267.39 km^2) which is associated with the agricultural area. The high altitude (150–282 m asl) covered an area of 340.10 km^2 (6%) which characterize the northern and southwestern parts of the governorate (Fig. 7). The Qaroun Lake is located in the low altitude area between −32 and 0 m asl (18%, 1032.58 km^2). The
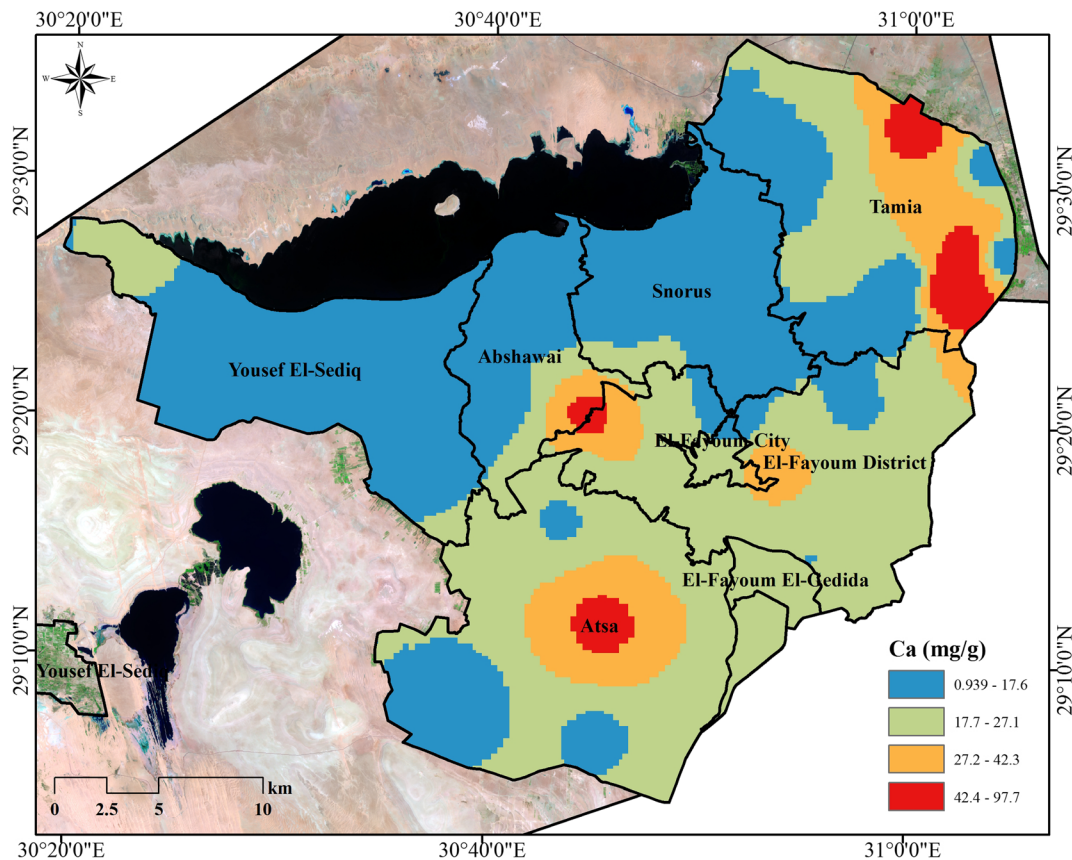

Fig. 12 Distribution of calcium in soil of El-Fayoum Governorate

sustainability is favored in the low altitude regions which are mostly located in the majority of the depression south of Qaroun Lake (Gad and El-Zeiny 2016).

Irrigation water characteristics

In the present study, EC in irrigation canals fluctuated from 1023 to 26,275 µS/cm with an average of 4604.38 µS/cm. The highest level of EC was associated with irrigation canals adjacent to agricultural lands suffering from water logging problems as observed during the field survey. Levels of EC in irrigation canals of El-Fayoum Governorate were studied in order to assess its suitability for irrigation. Based on Table 2, it was recorded that 21 of irrigation water samples were found unsuitable, 6 doubtable and 13 permissible for irrigation. The spatial distribution of these samples is shown in Fig. 8.

All irrigation canals of Youssef El-Sediq district as well as majority of Atsa and El-Fayoum canals were found unsuitable for irrigation as regards EC

levels. Various factors are probably influencing EC levels of irrigation canals such as sea water intrusion and wastewater discharges. In the northern parts of the governorate particularly in Tamia and Yousef El-Sediq, sea water intrusion from Lake Qaroun, which is currently considered as a wastewater disposal pond, might influence EC levels of irrigation canals. However, the high levels of irrigation water salinity are greatly arisen from the wastewater discharges into irrigation canals. Further, farmers are using the agricultural drainage water for irrigation in some regions. Figure 9 illustrates irrigation water quality and corresponding spectral indices of the three categories of water salinity (i.e., unsuitable, doubtable, and permissible).

The three categories of EC showed fluctuated relationships with the water quality and the spectral derived indices. No significant variation was observed in the mean values of pH, temperature, DO, turbidity, NDSI, NDVI, NDBI, and MNDWI for the three categories of EC. The obvious variation was
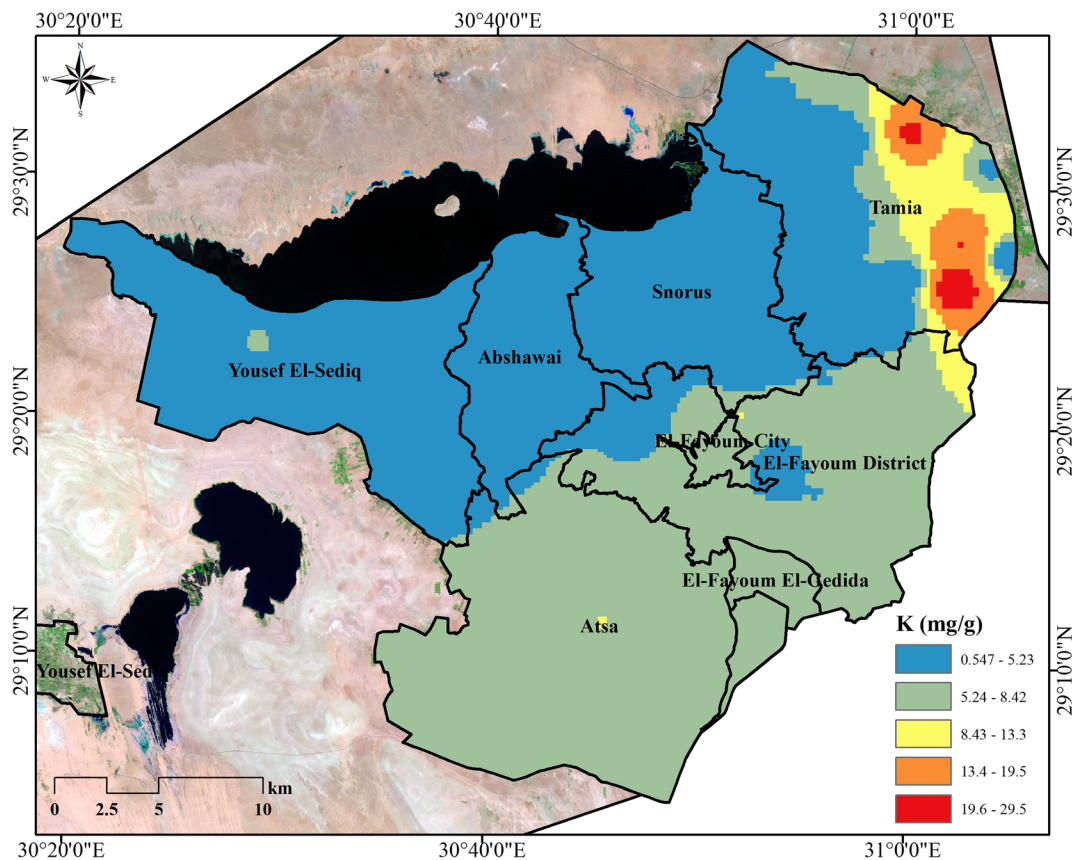

Fig. 13 Distribution of potassium in soil of El-Fayoum Governorate

observed in levels of EC, TDS, and RES. Previous results show that there is no obvious difference in water quality parameters that could define EC suitability for irrigation. In other words, no clear influence of irrigation water salinity on the studied water quality parameters was detected. This means that suitable irrigation water, as regards salinity, could possess a deteriorated water quality and vice versa. In El-Fayoum, numerous farmers are reusing the agricultural drainage water for irrigation which is highly saline rather than polluted which could explain the previous findings.

For more interpretation, the statistical relationships between the previously studied parameters are calculated (Table 3). Significant correlations were observed between EC with TDS (1.00) and resistance (-0.68). The resistance is an electrical quantity that measures how the device or material reduces the electric current flow through it which is decreased with the increase of EC and TDS.

On the other hand, a strong positive correlation (0.94) was observed between urbanization (NDBI) and land salinization (NDSI) which explains the negative impacts of residential areas on agricultural land. Both indices (NDBI and NDSI) showed strong negative correlations (> -0.9) with vegetation cover (NDVI) which means that vegetated lands decrease in urban and salinized regions.

El-Fayoum soil quality analyses

Soil quality analyses showed a noticeable fluctuation among different districts. Statistics of the investigated parameters are shown in Table 4. Weak alkaline soil samples were recorded with a pH ranging from 7.83 to 8.71 with an average of 8.31 (Fig. 10). The most alkaline soil (> 8) were mostly observed in El-Fayoum and Tamia districts. Present results of pH are coinciding with findings of Zaid et al. (2012) (7.5–8.8).
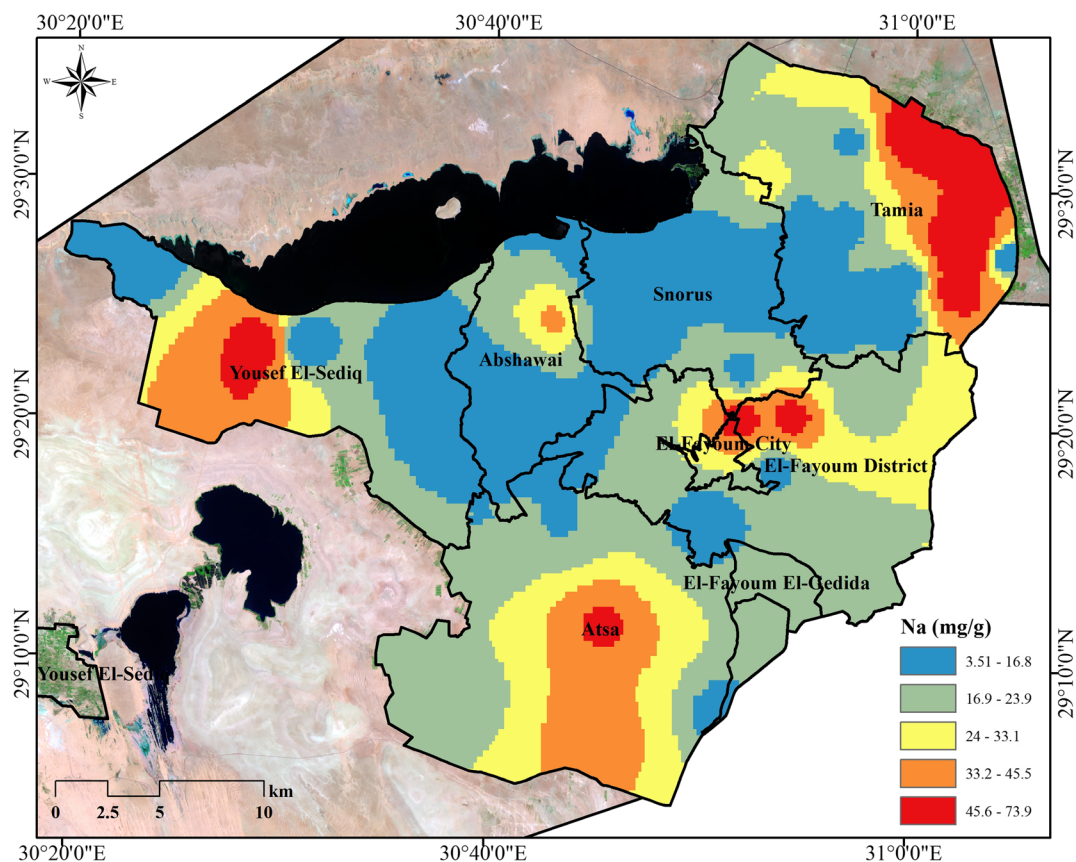

Fig. 14 Distribution of sodium in soil of El-Fayoum Governorate

A great fluctuation in salinity was detected among the collected soil samples with EC ranges from 0.21 to 9.59 mS/cm with an average of 1.75 mS/cm. Present results of EC are slightly lower than findings of Zaid et al. (2012) in El-Fayoum Governorate (0.55–10.8 mS/cm) and matching with Ali et al. (2019) in east of Qaroun lake (1.4–3 mS/cm). Based on plant tolerance with salinity (Table 5), the investigated soil samples were classified and mapped as shown in Fig. 11. Fortunately, the effect of soil EC on crops growth was mostly negligible. Few areas in Tamia, Atsa, Yousef El-Sediq, and El-Fayoum City showed restrictions for growth of sensitive plants. Three few batches in Yousef El-Sediq, El-Fayoum City, and Tamia showed restrictions for many plants growth. In Atsa district, a small area showed a growth for only tolerant plants as regards EC levels in soil.

High levels of salt in the soil have similar effects as drought since it makes water less available for uptake by plant roots. Salinization has negative impacts on the environment (land, water, vegetation, biodiversity, society, and economy of affected countries). Abd El-Hamid (2010) and Chhabra (1996) stated that some human activities can cause good agricultural lands to be salinized through the following:

- Construction of roads, dams ,and canals which block the natural surface drainage of the area and lead to water logging, rise in water table, and ultimately salinization.
- Use of saline waters for irrigation without providing adequate drainage.
- Poor management of irrigation water leading to higher seepage and secondary salinization as well as alkalization.
- Farmers sometimes tend to over-irrigate because of unsure canal water supply and ignorance about the proper depth and frequency of irrigation leading to rise in water tables.
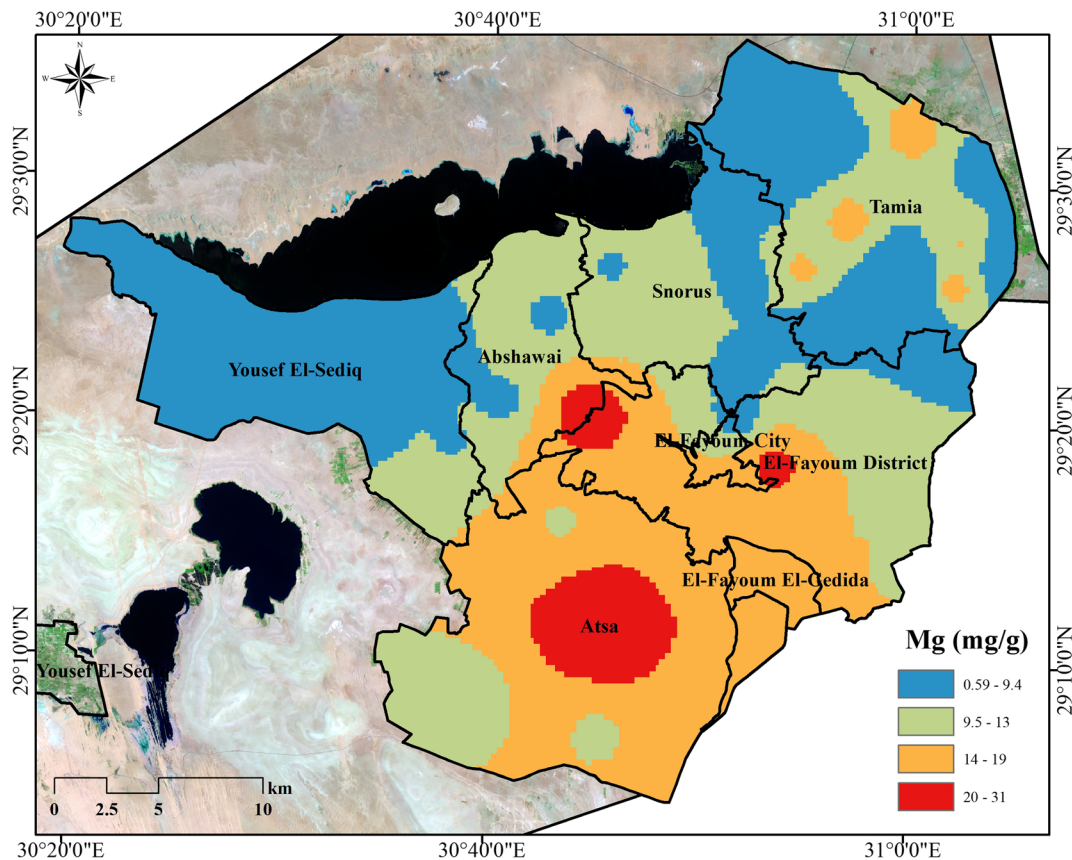

Fig. 15 Spatial distribution of Mg in soil of El-Fayoum Governorate

In the present study, irrigation water showed high levels of salinity which were classified as unsuitable for irrigation as illustrated in irrigation water quality section. Fortunately, the well distribution of adequate drainage network in some parts of El-Fayoum Governorate and the type of soil texture (particularly sand) play a significant role in reduction of soil salinity and thus elimination of salinity impacts on plant growth.

On the other hand, salts in the soil are represented by cations and anions. Spatial distribution maps of the studied cations (i.e., K, Na, Mg, and Ca) are shown in Figs. 12, 13, 14, and 15). A great fluctuation in levels of Ca, K, Mg, and Na were observed: 0.81–98.58, 0.50–34.38, 0.59–31, and 3.35–131.48 mg/g, respectively. Southern and eastern borders of the governorate showed high levels of soil calcium (> 17.7 mg/g) particularly in Atsa and Tamia districts.

Highest levels of potassium (> 13.4 mg/g) were recorded within Tamia district followed by the southern parts showing moderate levels (5.24–8.42 mg/g). The great fluctuation in the spatial distribution of Na was also recorded among different districts. Parts of Tamia, Atsa, Yousef El-Sediq, and El-Fayoum City recorded the highest levels of Na (33.2 mg/g).

According to Chhabra (1996), cations can be derived from the following origins: soil weathering process, accumulation on the surface due to irrigation, shallow water table, fossil salts, seepage from the up slopes containing salts, and ocean/Lakes. In fact, the Qaroun Lake is located in a low land area (as presented in DEM); thus, it did not show a significant impact on surrounding soils. Further, a drainage canal elongated south of the lake minimized the problems of soil salinization in the northern agricultural lands.
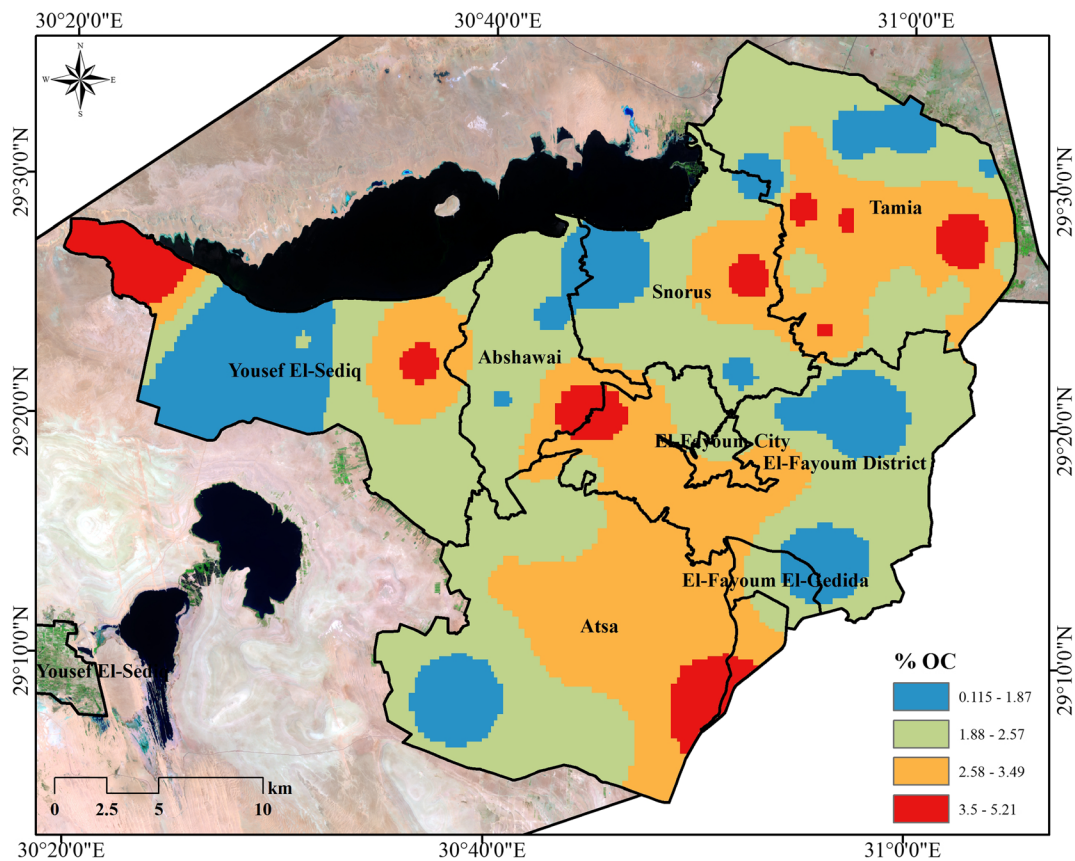

Fig. 16 Distribution of OC in soil of El-Fayoum Governorate

Three soil parameters, including OC, TN, and TP, were used to assess pollution levels in El-Fayoum Governorate and the adverse impacts of fertilizers and pesticides as well as the urban activities, represented in the wastewater irrigation, on soil (Figs. 16, 17, and 18).

OC, as an indicator for soil contamination and toxicity, showed a remarkable fluctuation within the agricultural area of El-Fayoum Governorate ranging from 0.21 to 5.21% with an average of 1.75%. High levels of OC (3.5–5.21%) were recorded in different scattered areas among the governorate districts: Tamia, Snorus, El-Fayoum City, Atsa, Abshawai, and Yousef El-Sediq. Soil OC is mainly formed from decomposition of the plants and animals or anthropogenic sources such as chemical contaminants, fertilizers, or organic-rich waste. Soil OC are strongly correlated with organic contaminants.

The northern sectors of the governorate showed high levels of TP and TN recording 0.8–1.7 mg/g and 1.7–2.4 mg/g, respectively. Water scarcity problems are magnified in the northwestern parts; therefore farmers, instead, are using the domestic wastewater for irrigation which contributes to soil pollution. The high levels of TN, TP and OC are tremendously attributed to the agricultural and domestic wastewater discharges into irrigation canals which represent the common sources of these pollutants in soil.

To confirm the previous findings, a correlation matrix among the studied parameters in soil was calculated (Table 6). Significant positive correlations were recorded between the following cations: Ca and K (0.812), Ca and Mg (0.699), Ca and Na (0.549). This may be due to that these ions are originated from the same source and are highly associated. Further, there was a positive correlation between TN and OC (0.465) which explains that number of agricultural lands suffer from pollution by organic and nitrogenous compounds. This is significantly impacted by irrigation using mixed agricultural and domestic wastewaters.
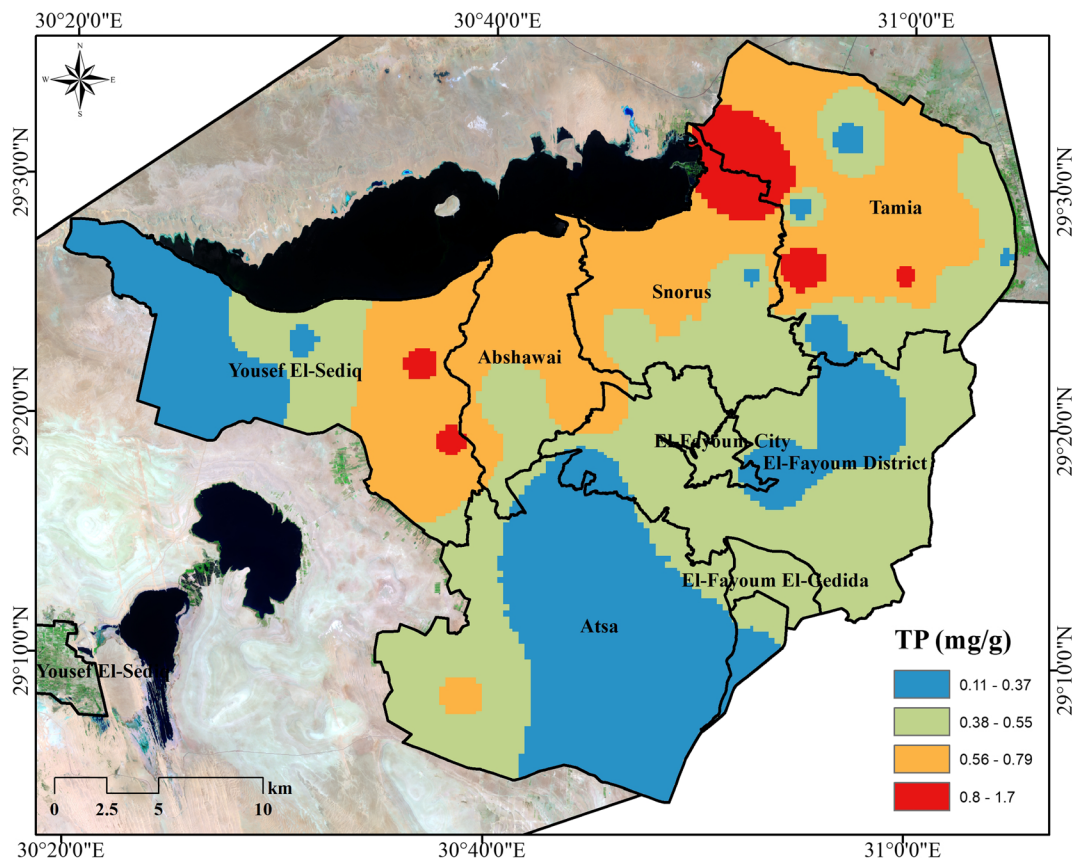

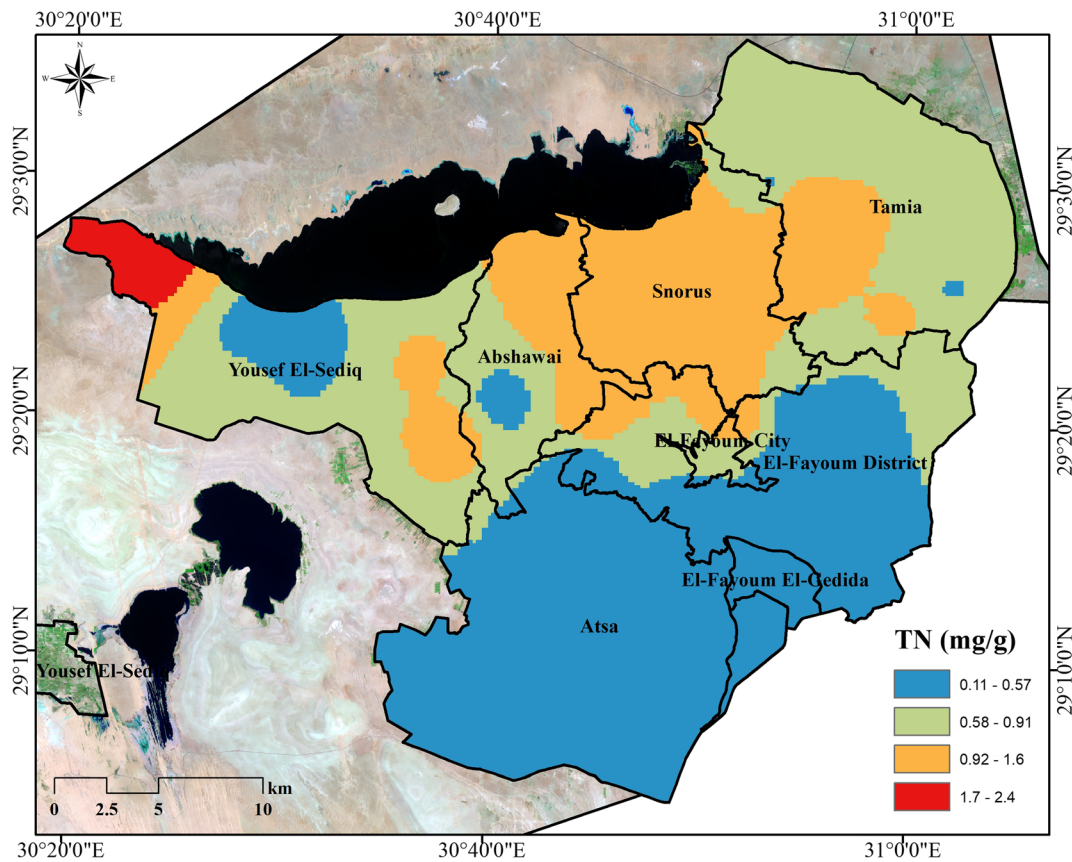Fig. 17 Spatial distribution of TP in soil of El-Fayoum Governorate

Fig. 18 Spatial distribution of TN in soil of El-Fayoum Governorate

Conclusion

The insufficient fresh water resources in El-Fayoum Governorate forced farmers to use wastewater for irrigation which tremendously affected the soil productivity. The present study is conducted on the agricultural lands of El-Fayoum Governorate to highlight the impact of land uses and wastewater irrigation on soil characteristics using integrated approach of remote sensing and GIS with a limited field study and

Table 6 Correlation coefficient between soil characteristics

Parameters	pH	EC, mS/cm	Ca, mg/g	K, mg/g	Mg, mg/g	Na, mg/g	TP, mg/g	TN, mg/g	OC, %
pH	1.000								
EC, mS/cm	−0.648	1.000							
Ca, mg/g	0.094	−0.181	1.000						
K, mg/g	0.094	−0.079	0.812	1.000					
Mg, mg/g	0.028	−0.129	0.699	0.367	1.000				
Na, mg/g	−0.248	0.386	0.549	0.798	0.297	1.000			
TP, mg/g	−0.104	0.043	−0.083	−0.094	−0.142	−0.066	1.000		
TN, mg/g	−0.096	−0.059	−0.042	−0.169	−0.167	−0.191	0.163	1.000	
OC, %	0.092	−0.182	0.175	−0.110	0.260	−0.248	−0.068	0.465	1.000

laboratory analyses. Soil salinity, alkalinity, and pollution in El-Fayoum lands were assessed and mapped through investigating pH, EC, cations, and pollution indicators (OC, TP, and TN). Soil quality investigation showed fluctuated levels in most of the studied characteristics among El-Fayoum districts as a result of soil texture, in addition to variation and severity of practiced activities. Weak alkaline soil samples were observed where pH ranged from 7.83 to 8.71. Great fluctuation in salinity levels was detected within the collected soil samples and the effect of soil EC on crops growth was mostly negligible.

Soil pollution is extended to most of the agricultural lands in the governorate as a result of anthropogenic activities particularly the uncontrolled urban expansion and the irrigation using wastewater. High levels of OC were recorded in several separate parts within the governorate districts while the northern parts showed high levels of TP and TN. The unplanned urban expansion increased the wastewater discharges into surface water bodies due to the lack of a sewage system. This creates more pressure on the available water and land resources in El-Fayoum Governorate. Further, the newly reclaimed agricultural lands in the desert extension of the governorate consume some of the water budgets assigned to the old agricultural lands in the remote lands particularly the north western parts. Water scarcity problem increases the need for wastewater in irrigation which negatively impacted the agricultural lands. These problems require more investigation and continuous monitoring programs to find effective solutions to conserve the agricultural lands of the governorate using a geomatics-based approach which is very effective in such studies.

References

Abd El-Hamid H. T. (2011). Inventory of soil salinity, alkalinity and water logging problems. M.Sc. Thesis, Faculty of Sci. Damietta, Mans. Univ. Egypt.

Abu-hashim, M., Mohamed, E. S., & Belal, A. (2016). Effect of land-use changes and site variables on surface soil organic carbon pool at Mediterranean region. *Journal of African Earth Sciences, 114*, 78–84.

Al Naggar, Y., Naiem, E., Mona, M., Giesy, J., & Seif, A. (2014). Metals in agricultural soils and plants in Egypt. *Toxicological & Environmental Chemistry, 96*(5), 730–742. https://doi.org/10.1080/02772248.2014.984496.

Ali, R. R., Abd El-Kadera, A. A., Essaa, M. E. F., & AbdelRahman, A. E. (2019). Application of remote sensing to determine spatial changes in soil properties and wheat productivity under salinity stress. *Plant Archives, 19*(1), 616–621.

Al-Khaier F. (2003). Soil salinity detection using satellite remote sensing. International Institute for Geo-Information Science and Earth Observation. M.Sc. Thesis, Michigan Technological University.

ARCADIS. (1999). Euro consult, Arnhem, the Netherlands and Darwish Consulting Engineers, "Rehabilitation Master Plan, Main Report". Fayoum Water Management Project II, Cairo, Egypt.

Ayers, R. S. & Westcot, D. W. (1994). Water quality for agriculture, irrigation and drainage. Paper no. 29. Food and Agricultural Organization of the United Nations, Rome.

Bauder, T. A., Waskom, R. M., & Davis, J. G. (2014). *Irrigation water quality criteria*. Fort Collins: Colorado State University Extension.

Chhabra, R. (1996). *Soil salinity and water quality* (p. 284). Vermont: A.A. Balkema Publishers. Brooksfield.

Darwish, K. M., & Abd El-Kader, A. A. (2008). Spatial analysis of yield and soil components in an onion field. *Journal of Applied Biological Science, 2*(2), 103–110.

El- Baroudy, A. A. (2013). Evaluating environmental sensitivity to desertification in El-Fayoum depression, Egypt. *Egyptian Journal of Soil Science, 53*(3), 445–460.

El-Zeiny, A. M., & Effat, H. A. (2017). Environmental monitoring of spatiotemporal change in land use/land cover and its impact on land surface temperature in El-Fayoum Governorate, Egypt. *Remote Sensing Applications: Society and Environment, 8*, 266–277.

El-Zeiny, A., & El-Kafrawy, S. (2017). Assessment of water pollution induced by human activities in Burullus Lake using Landsat 8 operational land imager and GIS. *The Egyptian Journal of Remote Sensing and Space Sciences, 20*, S49–S56.

El-Zeiny, A., Gad, A., El-Gammal, M., & Salem, M. (2016). Geospatial techniques for detection of vulnerable areas to contamination at Damietta coast, Nile Delta, Egypt. *ISJ, Journal of Environmental Science, 4*(12).

Farag, H. & Donia, N. (2006). Spatial modeling approach to water pollution monitoring of drainage system (El-Fayoum). Tenth International Water Technology Conference, IWTC10, Alexandria, Egypt 1163.

Gad, A., & El-Zeiny, A. (2016). Spatial analysis for sustainable development of El Fayoum and Wadi El Natrun Desert depressions, Egypt with the aid of remote sensing and GIS. *Journal of Geography, Environment and Earth Science International, 8*(3), 1–18.

Goher, M., Mahdy, E., Abdo, M., El Dars, F., Korium, M., & Elsherif, A. (2017). Water quality status and pollution indices of Wadi El-Rayan lakes, El-Fayoum, Egypt. *Sustainable*

Water Resources Management, 5, 387–400. https://doi.org/10.1007/s40899-017-0162-z.

Hammad, F. A. (1985). Hydrogeology of Chad formation. First Int. Conf. App. Sci., vol. IV, Zagazig Univ.

Hammam, A. A., & Mohamed, E. S. (2018). Mapping soil salinity in the East Nile Delta using several methodological approaches of salinity assessment. *The Egyptian Journal of Remote Sensing and Space Science. In press*. https://doi.org/10.1016/j.ejrs.2018.11.002.

Lillesand, T. M., & Kiefer, R. W. (1987). *Remote sensing and image interpretation* (2nd ed.p. 721). New York, Chichester, Brisbane, Toronto, Singapore: John Wiley and Sons.

Mandal, S. K., Kole Dutta, S., Pramanik, S., & Kole, R. K. (2019). Assessment of river water quality for agricultural irrigation. *International journal of Environmental Science and Technology, 16*, 451–462.

Mohamed, E. S., Saleh, A. M., Belal, A. B., & Gad, A. (2018). Application of near-infrared reflectance for quantitative assessment of soil properties. *The Egyptian Journal of Remote Sensing and Space Science, 21*(1), 1–14.

Ramadan, A. (2003). Heavy metal pollution and biomonitoring plants in Lake Manzala, Egypt. *Pakistan Journal of Biological Sciences, 6*(13), 1108–1117.

Serageldin, I., Cohen, M. & Sivaramakrishnan, K. (1995). *The human face of the urban environment*. Second Annual World Bank Conference on Environmentally Sustainable Development. Washington, D.C.: The World Bank.

Sonneveld, C., & Voogt, W. (2009). *Plant nutrition of greenhouse crops*. New York: Springer ISBN 9048125316.

Soon, Y. K., & Hendershot, W. H. (2006). *Soil chemical analyses* (3rd ed.). United Kingdom: Taylor & Francis Group, LLC http://www.niordc.ir/uploads%5C86_106_Binder2.pdf. Accessed 15 May 2016

UNDP. (2003). *Fayoum Human Development Report*. Cairo, Egypt.

Uttarwar, P. S. (2001). Applications of GIS and remote sensing in urban planning, implementation and monitoring of urban projects—case study of Rohini and Dwarka project, New Delhi. Proceedings of the Map India Conference, Feb. 7–9, New Delhi, India, http://www.gisdevelopment.net/application/urban/overview/urbano0015.htm accessed 6-March-2007. Accessed 15 May 2016

Weisz, R., Fleischer, S., & Smilowitz, Z. (1995). Map generation in high-value horticultural integrated pest management: appropriate interpolation methods for site-specific pest management of Colorado potato beetle (Coleoptera: Chrysomelidae). *Journal of Economic Entomology, 88*, 1650–1657.

Wilcox, L. V. (1958). Determining the quality of irrigation water. *Agriculture Information Bulletin, 197*, 1–6.

Zaid, M. S., Abd El-Rassoul, S. M., & Abdalla, I. M. (2012). Soil limitations and land capability classification of El-Fayoum Governorate. *Journal of Soil Sciences and Agricultural Engineering, 3*(8), 763–778.