Research Article

Spatial and seasonal assessment of physico-chemical characteristics of soil in Wadi El-Rayan lakes using GIS technique

Asmaa Nasser Mohamed Eid[1] [iD] · C. O. Olatubara[1] · T. A. Ewemoje[1] · Mohamed Talaat El-Hennawy[2] · Haitham Farouk[3]

Abstract

Wadi El-Rayan wetland is an inland Egyptian Ramsar site of international importance, due to its rich biodiversity. The wetland constitutes two man-made lakes. The lakes size, particularly the Lower Lake, is in continuous reduction, and the vegetation productivity pattern is changing as result of deteriorating water and soil quality, domestic and industrial activities. This research was carried out to map the spatial and seasonal distribution of certain physico-chemical parameters of geo-referenced soil samples covering the two lakes parts using ordinary kriging GIS technique. The study utilized ArcGIS ver.10.7 software, and 76 soil samples collected from representative sites; 38 samples during winter and 38 samples during summer seasons. Soil data were analyzed statistically and geo-statistically based on best fitted semivariogram model. The results indicated high concentrations of some soil physical and chemical parameters, especially in summer and in the Lower Lake of Wadi El-Rayan. The summary statistics for soil parameters had shown that the median of some soil parameters is higher than the mean which indicated the presence of abnormal data. This finding has been approved through the spatial distribution mapping which clearly showed the differences in spatial and temporal distribution between the upper and lower lakes of Wadi El-Rayan. The study concluded that the generated spatial distribution maps using ordinary kriging method can be used as an effective tool in Wadi El-Rayan wetlands' soil management.

Keywords Ordinary kriging · Geo-statistics · Semivariogram · GIS

1 Introduction

Sustainable wetland management generally requires increased management ability and input [25]. Water, soil and vegetation are among the main components of any wetland ecosystem. Soil quality is a reflection of water quality, and it determines the soil capacity to produce biomass [10]. Soil physical and chemical parameters play an important role in wetlands functions as they influence their vegetation productivity and indirectly their biodiversity. Numerous previous studies concluded that there is a significant correlation between wetlands vegetation productivity and soil quality [23, 29, 44, 55]. However, those parameters are characterized by high spatial and temporal variability depending on climate, season, topography, land use, water quality, anthropogenic activities (e.g., grazing), as well as management. Hence, understanding spatial and temporal variability of soil physical and chemical parameters are essential for devising site specific parameter management strategies with the aim of better wetlands management and increased sustainability in wetlands vegetation productivity.

Geo-statistical methods are used to interpolate the spatial variability of soil parameters and also to predict an unknown soil parameters value at a certain locations. Geo-statistical methods are based on [51] low, which states

✉ Asmaa Nasser Mohamed Eid, asmaaa.an@gmail.com | [1]Environmental Management Department, The Pan African University for Earth and Life Sciences including Health and Agriculture, University of Ibadan, Ibadan, Nigeria. [2]Nature Conservation Sector, Ministry of Environment, Cairo, Egypt. [3]Computer Science Department, Faculty of Computers and Information, Suez University, Suez, Egypt.

that "everything is related to everything else, but near things are more related than distant things." They have been applied since 1970s, and many methods have been developed through the time such as; Inverse Distance Weighting (IDW) [49], Ordinary Kriging (OK) [12, 57], Simple Kriging (SK) [54], Co-Kriging (CK) [37], pedo-transfer functions [43] and artificial neural network [53]. Recently, OK has been most widely used in many studies that map spatial distribution of soil physical and chemical parameters in different soils of Egypt [26, 16, 17, 15, 36] due to its efficiency in predicting and interpolating specific soil parameter on spatial distribution maps [50].

Wadi El-Rayan wetlands are part of Wadi El-Rayan Protected Area (Ramsar site) which covers an area of 1759 km^2 [31]. Wadi El-Rayan wetland constitutes two man-made connected lakes formed during 1970s. One of the reasons behind there formation was to slow-down the increase in the water table in El-Fayoum main depression in Egypt. The construction of the two Lakes led to restoration of the severely affected biodiversity of Wadi El-Rayan Protected Area and attraction of large populations of birds (e.g., water fowl) which came after vegetation cover; mainly common reeds; distributed along the shores of the two lakes (Saleh 1987). Wadi El-Rayan lakes get their water through around 9 km length tunnel from El-Wadi drain. The tunnel was receiving about 8 m^3/s in 1999, and this amount decreased to about 4.5 m^3/s in 2008 [19]. Based on the reduction in total received drainage per year and the rainfall pattern, besides the fact that the Lower Lake is a closed basin with no outflow, these all led to the accumulation of salts in Wadi El-Rayan Lakes, particularly the Lower Lake [1]. Soil salinity is the most soil limitation factor for vegetation productivity [36]; however, other soil physical and chemical characteristics can also influence it. Wetland's cover classification is an important tool in wetlands management [14]. According to land cover classification performed on selected two Landsat imageries for the years 1990 and 2020, the total area of the wetlands' surface water and vegetation cover are in continuous reduction and open soil is becoming more exposed. The water body class in Wadi El-Rayan wetland has declined by 30.98 km^2 at an annual rate of 1.03 km^2/year. While, the vegetation cover have lost over 80% of its area over the past three decades (Table 1).

Therefore, diagnosis of soil physical and chemical parameters-related limitations assumes a greater significance to assess the degree of impact of Wadi El-Rayan wetlands water quality on their soil. Assessment of spatial variability of different soil parameters is a viable option to identify the most affected sites. This will enable Wadi El-Rayan wetlands mangers to delineate the most productive sites and identify the critical impact zones.

Table 1 Area (km^2) of water body and vegetation classes of Wadi El-Rayan wetlands for the years 1990 and 2020

Class name	1990	2020	Total loss
Water Body (km^2)	101.9	70.92	30.98
Vegetation (km^2)	3.17	0.6	2.57

There have been few studies and insufficient data on the physico-chemical characteristics of the study areas' soils. Those studies include the work of [2], who studied the 16 physical and chemical soil variables in order to evaluate the soil-vegetation relationship in Wadi El-Rayan wetlands and found that soil salinity, pH, calcium carbonate, organic matter and the relative concentration of the major cations were the most important variables affecting the distribution of the vegetation pattern. El-Hennawy [20] studied the soil physical and chemical characteristics of the two lakes and found that the salinity level is particularly higher in the Lower Lake comparing to the Upper Lake. He also revealed that the wetland vegetation productivity in a certain site is correlated with its correspondent environmental variables. Sayed [47] studied the soil chemical properties of Wadi El-Rayan lakes and revealed that chlorides, sulfates, sodium and magnesium were the major ions concentrations recorded during the study and that the Lower Lake recorded higher concentrations than those of the Upper Lake. He also said that the rate of evaporation and the decreased water flow rate from the Upper Lake are the major factors controlling these concentrations. Abdou[4] studied six chemical concentrations of soil samples collected from Wadi El-Rayan Lakes and found that the two lakes soil nitrites content was the highest recorded concentration among the selected samples, and he also attributed his results to non-point sources soil pollutants such as agricultural and industrial wastes and runoff.

However, up to this date, no studies were reported on the spatial and/or temporal distribution of soil physical and chemical parameters of Wadi El-Rayan wetlands. In this study, we attempt to use ordinary kriging method (OK) to address this knowledge gap by mapping variety of soil physical and chemical parameters spatialy according to their standard soil classification. The objectives of this study are, to assess the spatial variations in soil physical and chemical parameters in different seasons as well as study their status.

2 Materials and methods

2.1 Description of the study area

The area under investigation belongs to Wadi El-Rayan protected area located in a depression about 140 km southwest of Cairo, in El-Fayoum Governorate, Egypt [31]. It is located between longitude 29°00'00" and 29°24'11" E, and latitude 30°00'00" and 30°34'00" N. Wadi El-Rayan is located in hyper-arid Saharan climate zone with hot summers and mild winters [56]. The mean elevation of the area is 43 m below sea level. According to metrological data recorded by the nearest station to the protected area in El-Fayoum over the past fifty years, the mean temperature during winter and summer is 28.5 °C and 13.7 °C, respectively, and the average precipitation rate is 10.1 mm per year, whereas the highest rainfall occurs in winter and there is zero rain fall precipitate in summer. The mean annual aridity index is 0.004, which is due to the high evapotranspiration rate throughout the year [46]. The main habitats in protected area are desert, lakes, oasis and wetlands [24]. Hawela and El-Khatib [27], classified the soils in Wadi El-Rayan as Typic Torriorthents, Typic Torripsamments and Typic Salorthids and a number of sub-land types.

Wadi El-Rayan Protected Area was declared a Protected Area by Prime Ministerial Decree (No. 943) in1989 according to the law No. 102/1983 of the protected areas in Egypt. In 2012, the protected area was declared one of the four Egyptian RAMSAR sites of international importance [13]. The area has drawn the attention of national and international visitors due to its natural landscapes, biodiversity, sand beaches, bird watching, camping, waterfalls and the Valley of Whales in Wadi El-Hitan which was designated by the UNESCO as the first World Heritage Site of natural category located in Egypt. Wadi El-Rayan Protected area is visited by over 200 thousands visitors annually [24].

2.2 Soil sampling

Seventy-six soil samples were collected from 18 representative sites covering Wadi El-Rayan Lakes' parts (upper and lower lakes) during the year of 2019 for two times. Thirty-eight samples were collected during winter, and 38 samples were collected during summer from the same locations. SW-GIS data collector android application used to record a track of each sampling point, which helped us to take the second season samples from the same locations with the same coordinates. All the soil samples were collected at depth of 0–30 cm in duplicate in labeled plastic bags and carried out in the Ecology Laboratory, Department of Botany and Microbiology, Faculty of Science, Al-Azhar University, Cairo, Egypt.

2.3 Laboratory analysis

Sand/Silt/Clay Content was determined using hydrometer method according to Estefan et al. [22]. Samples were dried in an oven at 40 °C for 72 hours, sieved with a 2 mm sieve and stored for further analyses. Water Holding Capacity was determined after Estefan et al. [22]. Soil pH was determined in soil extract for each sample (1 g soil: 5 ml distilled water) using digital portable pH meter Adwa® AD11. Organic Carbon (OC) and Organic Matter (OM) were determined using titration method according to Piper [39]. Total Dissolved Salts (TDS) and Electrical Conductivity (EC) were both measured using digital portable TDS meter Adwa® AD201, in soil extract (1 g soil: 5 ml distilled water). Calcium Carbonate ($CaCO_3$) was determined using titration method described by Estefan et al. [22]. Chlorides (Cl) and Bicarbonates (HCO_3) were determined by titration method according to Jackson (1967). Sulfates (SO_4) were determined using the turbid metric method after Estefan et al. [22]. Calcium (Ca) and Magnesium (Mg) were determined by titration method according to Page, Miller and Keeney (1982). Potassium (K) and Sodium (Na) were determined using Flame photometer at 767nm wavelength and Flame photometer at 589 nm wavelength, respectively, according to Estefan et al. [22]. Nitrates (NO_2) and Nitrites (NO_3) were determined using UNICO 2100 UV Visible Spectrophotometer according to Greenberg, Clesceri, and Eaton (1995). Phosphorous (P) was determined using UNICO 2100 UV Visible Spectrophotometer according to Allison et al. [5].

2.4 Statistical analysis

Minitab ver.18 was used to produce descriptive statistics (mean, median, standard deviation, range, minimum and maximum) for different soil parameters during both winter and summer seasons.

2.5 Geo-statistical analysis

Geo-statistical methods, including Ordinary Kriging (OK), semivariogram and cross-validation, were used to assess the spatial and temporal distribution of 17 selected soil physical and chemical parameters. Geo-statistical analysis was done using geo-statistical analyst tool in ArcGIS ver.10.7 software through application of ordinary kriging method.

OK is the major widely used type of kriging in spatial distribution researches [33]. It is expressed as;

$$z * (u) = \sum_{a=1}^{N} \lambda_a z(u_a)$$

where $z * (u)$ is the measured value of z at location (u); λ_a is the weight associated with the estimated value of z at location a and N is the number of estimated values used in measurement in the neighborhood of a.

According to ESRI [21], the semivariogram is defined as

$$Y\left(s_i, s_j\right) = \frac{1}{2}\text{variance}\left(Z\left(s_i\right) - Z\left(s_j\right)\right),$$

Where s_i and s_j are pair of points close to each other in terms of the distance and $Z\left(s_i\right) - Z\left(s_j\right)$ are the difference in their values. The semivariogram assumes that when the distance between two pair of point is small, the difference in their values is expected to be similar and vice versa. There are 11 models can be fitted to the experimental semivariogram, from which we chosen three models; circular, exponential and Gaussian models in order to select the best fit model with Mean Standardized (MS) close to zero and Root Mean Square Standardized (RMSS) close to 1 [41]. The cross-validation method was then applied to validate the model parameters using three major parameters; nugget, sill and range, which assessed the selection of most appropriate model to interpolate and predict the different soil physical and chemical parameters in the study area [36].

3 Results and discussions

Results of soil texture analysis of Wadi El-Rayan wetlands during winter and summer showed that the main soil textures that can be found are mainly sandy loam, loamy sand (distributed around the Upper Lake) and sand (distributed around the Lower Lake), and these results are in accordance with Abbas and Afefe [1].

3.1 Descriptive statistics

The median of some soil parameters, sand, water holding capacity, pH, total dissolved salts, sulfates and calcium during winter and sand, pH, calcium carbonate and sodium during summer, were higher than the mean, which indicates that the effects of abnormal data were significant (Table 2). Soil water holding capacity (WHC) ranged from 10.4–60.56% to 20.7–56.7% during winter and summer, respectively. The mean value of soil WHC during summer was higher during winter, and it showed a trend with soil texture. These results agreed with Bandyopadhyay [7], who said that the soil WHC has direct relation with the soil texture and the higher the soil silt and clay percentages; the higher the soil WHC. During winter, pH values of

Table 2 Descriptive summary statistics of the soil physico-chemical parameters analysis results of the 76 soil samples during winter and summer seasons collected from Wadi El-Rayan Lakes

Variable	Winter season			Summer seasons		
	Mean ± SD	Range (Min–Max)	Median	Mean ± SD	Range (Min–Max)	Median
Sand	73.48±22.46	74.72 (23.27–98)	76.7	79.7±11.98	48.6 (42.05–90.65)	83.08
Silt	18.65±19.78	67.98 (0.17–68.15)	12.82	9.05±10.08	41.55 (0.4–41.95)	5.8
Clay	7.86±8.5	28 (0.8–28.8)	2	11.17±2.85	10.8 (8.4–19.2)	10.8
WHC	34.85±15.73	50.15 (10.4–60.56)	40	41.38±9.79	36 (20.7–56.7)	39.7
pH	8.48±0.27	1 (8–9)	8.5	7.68±0.18	0.7 (7.3–8)	7.7
OC	0.813±0.81	2.76 (0.12–2.88)	0.480	0.74±0.49	2.16 (0.12–2.28)	0.60
OM	1.27±1.32	4.74 (0.2–4.95)	0.826	1.32±0.86	3.71 (0.206–3.92)	1.03
TDS	2051±1480	4374 (186–4560)	2070	2861±2109	6837 (533–7370)	2560
EC	3.47±2.7	9.05 (0.29–9.34)	3.23	4.47±3.29	10.68 (0.833–11.51)	4.00
CaCO$_3$	11.64±8.52	21.6 (0.30–21.9)	10.5	16.55±7.12	21.7 (0.3–22)	20.1
Cl	334.7±253.1	680 (20–700)	250	484.2±359.5	1200 (100–1300)	450
HCO$_3$	0.353±0.11	0.305 (0.305–0.61)	0.305	3.05±0.00	0.00 (3.05–3.05)	3.05
SO$_4$	114±45.7	129 (49.6–178.7)	121.1	96.68±38.26	142.28 (43.4–185.7)	91.8
Ca	789±483	1400 (200–1600)	800	605.3±432.7	1800 (200–2000)	400
Mg	320±278.1	960 (120–1080)	120	1063±962	3332 (250–3582)	856
K	541.3±34.5	104.9 (484.5–589.5)	537.9	946.8±314.3	926.3 (529–1455.3)	908
Na	906±466	1455 (305–1760)	550	1454±625	2260 (603–2863)	1550
No$_2$	16.43±19.08	68.77 (2.4–71.17)	6.54	11.94±5.78	19.5 (5.8–25.3)	9.5
No$_3$	1.03±1.38	4.47 (0.01–4.48)	0.470	1.129±1.35	4.5 (0.1–4.6)	0.7
P	12.5±4.36	18.66 (7.8–26.46)	11.41	34.56±21.19	73.99 (4.31–78.3)	29.81

the soil water extract ranged from 7.2 to 8.1, while during summer they ranged from 7.4 to 7.8. According to Proffitt [40], the mean value of pH of soil extract of Wadi El-Rayan wetlands was strongly alkaline during winter and slightly alkaline during summer, and these agree with the study of El-Hameed et al. [18]. The soil organic carbon (OC) and organic matter (OM) varied from 0.12 to 2.88%, 0.2–4.95% during winter and from 0.12 to 2.28%, 0.2–3.92% during summer, respectively. Organic carbon and organic matter play a very important role in soil fertility in Egypt [3]. According to Proffitt [40] classification, most studied soil samples had low OC and OM percentages. These results agreed with Dregne [11], who reported that soil of arid areas usually have low level of organic matter. Soil total dissolved salts (TDS) and Electrical conductivity (EC) ranged from 186 to 4560 ppm, 0.29–9.34 mS/cm during winter and from 533 to 7370 ppm, 0.83–11.51 mS/cm during summer. According to [42] classification, the mean value of TDS of soil extract of Wadi El-Rayan wetlands was moderately saline during winter and summer and the mean value of EC of soil samples was slightly saline during winter and moderately saline during summer. However, salinity concentration was higher during summer season compared to the winter season; this result is in accordance with [48], who said that the concentration of TDS in hot period (summer) is much higher than cold period (winter). Generally, the high soil salinity concentration could be attributed to reduction rate of drainage water inflow for reclamation projects and the high evaporation rate [19, 47]. Soil calcium carbonate content ranged from 0.3–21.9% to 0–22% during winter and summer, respectively. The mean value of soil calcium carbonate during winter (11.64%) was lower than during summer (16.55%). The high percentages of soil calcium carbonate could be attributed to the accumulation of large amounts of shell remains. The results of soil calcium carbonate and pH analysis indicate that the soil is calcareous, and this is according to 58], who said that the calcareous soils normally have pH values between 7.5 and 8.5 and calcium carbonate between 5 and 8% or greater. Generally, the concentration of major anions, sulfates and chloride, reflect that of TDS because they also tend to increase in the direction of flow; however, bicarbonate does not show the same trend relative to other anions. The mean value of soil sulfates content was higher during winter (114 mg/L) than during summer (96.68 mg/L). According to [30] classification, soil sulfates during winter and summer were very high (> 20). Sulfate is an indication of pollution, and this pollution could be due to industrial discharge, treated sewage release and K-sulfates fertilizers. Results of soil chlorides analysis revealed that the soil chlorides content ranged from 20–700 mg/L to 100–1300 mg/L during winter and summer, respectively. According to [38] guidelines, most of the studied sites ranged from

low during winter to moderate during summer and these results are in accordance with [1].

The four most abundant cations in soils are Calcium (Ca^{+2}), magnesium (Mg^{+2}), Potassium (K^+) and sodium (Na^+). The cations zinc (Zn^{+2}), manganese (Mn^{+2}), iron (Fe^{+2}), aluminum (Al^{+3}) and copper (Cu^{+2}) are usually present in amounts that do not contribute significantly to the cation complement. Therefore, it is common practice to measure only the concentration of the four abundant cations [28]. The soil calcium content range was between 200–1600 mg/L and 200–2000 mg/L during winter and summer, respectively. According to [35] classification, the mean values of soil calcium content were low during the two seasons. Soil magnesium content ranged from 120–1080 mg/L to 250–3582 mg/L during winter and summer, respectively. According to [30], the mean value of soil magnesium content ranged from high during winter to very high during summer. Soil potassium content ranged from 484.57–589.53 mg/L to 529–1455.33 mg/L during winter and summer, respectively. The mean values of soil potassium ranged from high during winter (541.3 mg/L) to excessive during summer (946.8 mg/L) [30]. Soil sodium content ranged from 305–1760 mg/L to 602.5–2862.5 mg/L during winter and summer, respectively. The mean values of soil sodium were very high (> 480 mg/L) during the two seasons [35].

According [34], the mean values of soil nitrites and nitrates content were low (< 20 mg/L) and (< 10 mg/L) during winter and summer, respectively. Soil phosphorous content ranged between low and moderate during winter, and low and excessive during summer [34]. The mean values of soil phosphorous content during summer was much higher than during winter, these could be attributed to the accumulation of deposits containing dead planktons which increase the phosphorous percentage in the soil and according to [24], WadiEl-Rayan Protected Area is visited by over 200 thousands visitors annually who come to the area for recreational activities (boats, cafeterias and camping) around the Lower Lake especially during summer season which contribute to the increase in the pollution rate in the lake.

3.2 Semivariogram analysis

Semivariogram parameters of the soil physical and chemical data of the winter and summer seasons and their validation information that used to evaluate the goodness of fit are showed in (Table 3). These semivariogram parameters are the nugget value, sill (summation of nugget and partial-sill), nugget/sill ratio, range and lag size. Generally, positive nuggets were observed for all the soil data and this could be explained by short range variability, random and inherent variability and sampling error.

For bicarbonates, the variance of the input data was too small to be calculated; however, the rest of the soil physical and chemical parameters recorded lag size less than half of the range (Table 3). According to [32], the sampling interval (lag size) should not exceed the half of the range. Hence, using this sampling design was appropriate for the current study, and it is foreseeable that good spatial structures will be shown on the interpolated maps. According to [45], the nugget/sill ratio is used to classify the spatial dependence of soil parameters and to quantify short distance autocorrelation. Low (< 25%), Moderate (25–75%) and High (> 75%) nugget/sill ratios indicate strong, Moderate and weak spatial dependence or spatial autocorrelation, respectively [9]. In the present study, the nugget/sill ratio during winter showed that TDS, Cl, SO_4, Ca, Mg, Na, NO_2 and NO_3 were strong spatially dependent (0.26–20.45 %),

and pH, OC, OM, EC and $CaCO_3$ were moderate spatially dependent (34.62–69.41 %). The nugget/sill ratio during winter also showed that K and P were weak spatially dependent (82.3–95.5 %). The nugget/sill ratio during summer showed that pH, OC, OM, TDS, EC, CaCO3, Cl, SO4, Ca, K , Na and NO_3 were strong spatially dependent (1.72–23.01 %), and WHC, Mg and NO_2 were moderate spatially dependent (25.31–53.68 %). The nugget/sill ratio during summer also showed that P was weak spatially dependent (93.83%).

The strong and moderate spatially dependence of total dissolved salts, electrical conductivity and their correspondent anions and cations during winter and summer seasons could be attributed to the high evaporation rate and reduction in the inflow rate of the Lower Lake of Wadi El-Rayan wetlands; however, the strong and moderate spatial dependence of nitrates and nitrites during the

Table 3 Geo-statistical parameters (nugget, sill, nugget/sill ratio (%), range and lag size) and best fitted semivariogram model for each soil physical and chemical parameter of Wadi El-Rayan Lakes during winter and summer seasons

Parameter	Season	Model	Nugget	Sill	Ratio	Range	Lag size
WHC	Winter	Exponential	89.42	323.3	27.6	0.9	0.12
	Summer	Exponential	58.91	109.72	53.68	0.8	0.08
pH	Winter	Circular	0.0376	0.0796	47.23 %	0.74	0.083
	Summer	Gaussian	0.004	0.045	10	5	0.64
OC	Winter	Exponential	0.293	0.519	56.49	5	0.58
	Summer	Circular	0.032	0.24	13.3	5.6	0.74
OM	Winter	Exponential	0.722	1.663	43.41	7.2	0.75
	Summer	Circular	1.88	0.817	23.01	6.2	0.62
TDS	Winter	Circular	8375.19	3207591	0.26%	1.23	0.14
	Summer	Exponential	681589	4262835	15.98	9	0.78
EC	Winter	Circular	3.04	8.78	34.62	1.06	0.12
	Summer	Exponential	1.66	10.4	15.96	9.3	0.78
$CaCO_3$	Winter	Gaussian	62.13	89.51	69.41	1.8	0.15
	Summer	Gaussian	6.152	69.26	8.88	4.8	0.54
Cl	Winter	Circular	9606	119139	8.06	1.8	0.15
	Summer	Exponential	4485	144171	3.11	9.9	0.82
SO_4	Winter	Circular	137	2959	4.64	1.2	0.15
	Summer	Exponential	277.7	1972	14.04	1.8	0.15
Ca	Winter	Exponential	47430	307126	15.44	1.3	0.11
	Summer	Gaussian	3514	204135	1.72	4.8	0.54
Mg	Winter	Exponential	5265	75563	6.96	7.8	0.65
	Summer	Exponential	464520	942048	49.30	1.009	0.086
K	Winter	Circular	1140	1193	95.5	0.48	0.15
	Summer	Circular	30055	1771160	17.55	1.8	0.15
Na	winter	Exponential	27679	302889	9.13	1.7	0.15
	Summer	Circular	15037	396218	3.79	0.5	0.09
NO_2	Winter	Gaussian	67.37	535.44	12.58	4.8	0.54
	Summer	Exponential	9.56	37.77	25.31	5	0.7
NO_3	Winter	Circular	0.54	2.64	20.45	5	0.56
	Summer	Circular	0.44	2.33	18.88	4.8	0.5
P	Winter	Exponential	17.76	22.79	82.3	0.9	0.09
	Summer	Gaussian	438.03	466.81	93.83	1.8	0.15

two seasons could be attributed to the fact that the source of the two Lakes is agricultural drainage water which is rich with fertilizers. The strong and moderate spatially dependence of organic carbon and organic matter during the study period could be attributed to the grazing activities particularly, around the Upper Lake' shores. The weak spatially dependence of phosphorous during winter and summer and weak spatially dependence of potassium during winter season indicated that the spatial patterns of this soil parameters were not influenced by those parameters, however, influenced by factors such as evaporation rate, inflow rate, quality of drainage water and anthropogenic activities such as grazing, aquaculture Fig. 1.

Among selected three models, there was no best fitted model for all the soil parameters; however, the model varied according to the soil parameter and season. Exponential model was best fitted to WHC, OC, OM, Ca, Mg, Na and P during winter, and WHC, EC, CL, SO4, Mg, NO$_2$ during summer. Similarly, circular model was best fitted to pH, TDS, EC, Cl, SO$_4$, K and NO$_3$ during winter, and OC, OM, K, Na and NO$_3$ during summer. Furthermore, Gaussian model was best fitted to CaCO$_3$ and NO$_2$ during winter, and CaCO$_3$, Ca and P during summer Fig. 2.

3.3 Spatial, seasonal distribution and spectrum

Ordinary kriging method was applied to estimate the value of the different soil physical and chemical parameters at un-sampled sites using three semivariogram models. The soil parameters data showed normal distribution and did not require any transformation before computing the spatial distribution maps. Raster maps (30 * 30 m) of different soil parameters were generated for the study area during winter and summer seasons (Figs. 3, 4, 5, 6 7 and 8). Spectrum of different soil physical and chemical parameters according to some soil interpretation guidelines is shown in Table 4.

Spatial maps of WHC during winter and summer seasons showed that the WHC value was mainly low, which reflects the soil sandy texture nature of Wadi El-Rayan wetlands. The spatial maps of the soil pH showed that the soil pH was alkaline and was significantly higher in winter than summer. This alkalinity may be due to the exchangeable cations, which increase the soil pH. The spatial maps of soil organic carbon showed that the OC value in the Lower Lake ranged from very low during winter to low during summer, while in the Upper Lake it ranged between low and moderate during the two seasons. Similarly, the spatial maps of soil organic matter showed that the OM value
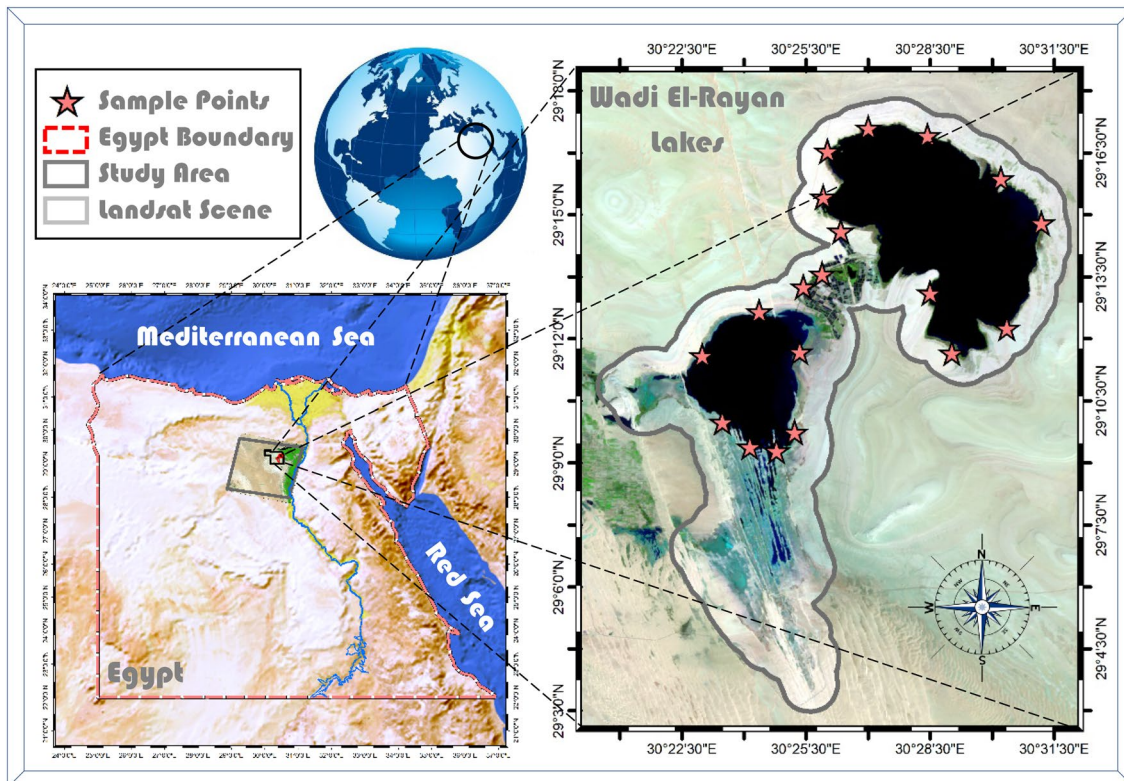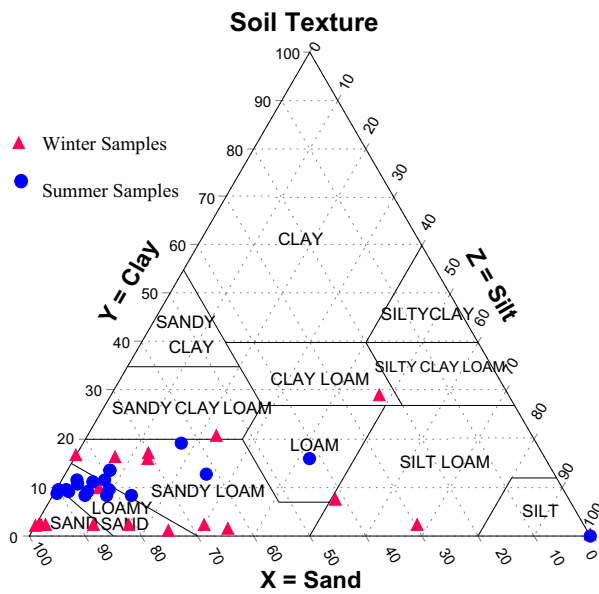

Fig. 1 Landsat Scene of Rayan Lakes in Egypt, and sampling points' locations map

Fig. 2 Textural distribution of soil samples collected from Wadi El-Rayan wetlands during winter and summer seasons plotted on USDA textural triangle

in the Lower Lake was low during the two seasons, while in the Upper Lake it ranged between low to moderate and did not differ significantly between the two seasons. The spatial maps of TDS and EC showed that the Lower Lake salinity is much higher than the Upper Lake, which showed low to moderate salinity levels during the two seasons. Spatial maps of soil Cl showed that the Lower Lake soil chloride content was higher than the Upper Lake and did not differ significantly between the two seasons. Spatial maps of soil SO_4 showed that soil sulfates content in the two lakes during the two seasons was very high. The spatial maps of the soil exchangeable cations (Mg, K and Na) showed that the soil magnesium, potassium and calcium content of the two lakes ranged between high and very high and did not show significant difference between the seasons; however, spatial maps of soil Ca showed that the soil calcium content in the Lower Lake was higher than the Upper the Lake during the two seasons. The spatial maps of soil NO_2 and NO_3 content showed that there were no significant spatial and temporal deference of soil nitrites and nitrates content between the two lakes and that their values were mainly low. The spatial maps of soil P content showed that the soil phosphorous content in the two lakes was moderate during winter, while it was high during summer.

3.4 Cross-validation results

Evaluation of performance of the ordinary kriging method was done through cross-validation procedures using mean prediction error (MPE), mean standardized prediction error (MSPE) and root mean square standardized prediction error (RMSSPE) of the spatial maps of soil parameters (Table 5). Some parameters showed high MPE which explain the high spatial difference of those parameters between the two lakes of Wadi El-Rayan wetlands. This agreed with the overall research findings which showed that soil of the Lower Lake is much deteriorated comparing to the Upper Lake. However, MSPE and RMSSPE values were low as they ranged from (0.075–0.103) to (1.37–0.822), respectively, indicating that OK provided superior prediction and mapping accuracy for Wadi El-Rayan soil parameters.

4 Conclusion

This study provides the first comprehensive analysis of physical and chemical parameters of Wadi El-Rayan wetlands' soils. The results indicated high concentrations of some soil physical and chemical parameters, especially in summer and in the Lower Lake of Wadi El-Rayan. The summary statistics for soil parameters had shown that the median of some soil parameters is higher than the mean which indicated the presence of abnormal data. This finding has been approved through the spatial distribution mapping which clearly showed the differences in spatial and temporal distribution between the upper and lower lakes of Wadi El-Rayan. Semivariogram models were fit for all soil properties, and the best fitted semivariogram model for each parameter was identified through cross-validation procedures. Exponential, Gaussian and Circular models performed well in analyzing the spatial variability of the 17 soil physical and chemical parameters contents. A strong and moderate spatial dependence of soil parameters was observed, indicating that the soil parameters were controlled by evaporation rate, inflow rate, quality of drainage water and anthropogenic activities such as grazing, aquaculture. Cross-validation of semivariogram models through ordinary kriging showed that the spatial prediction and interpolation of soil parameters is preferred than assuming the mean of the observed values at any unstamped site. Finally, the generated spatial distribution maps using best fitted semivariogram models and
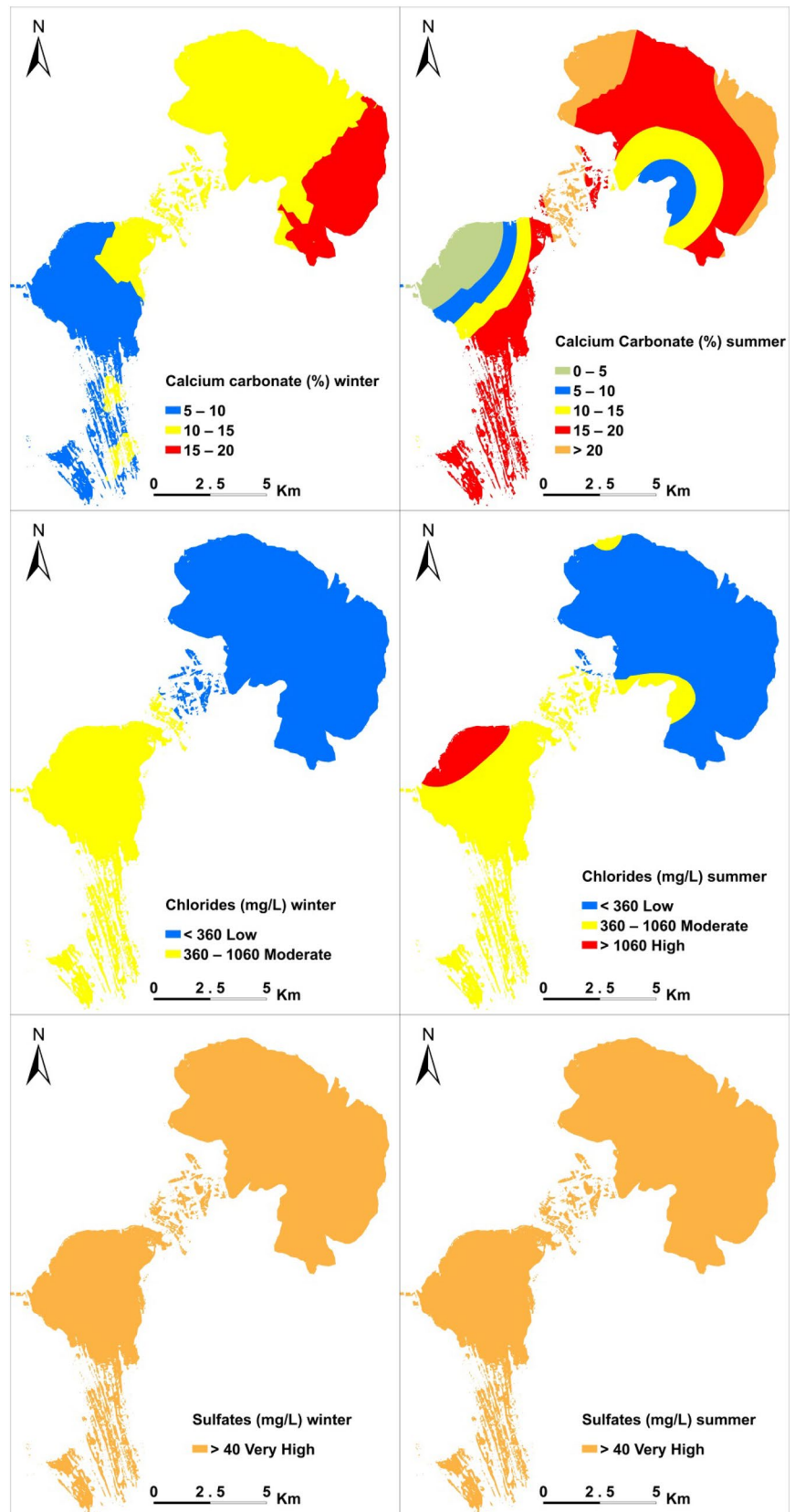
Fig. 3 Spatial distribution and spectrum of soil parameters (WHC, pH and OC) in Wadi El-Rayan Lakes during winter and summer seasons, respectively using GIS technique
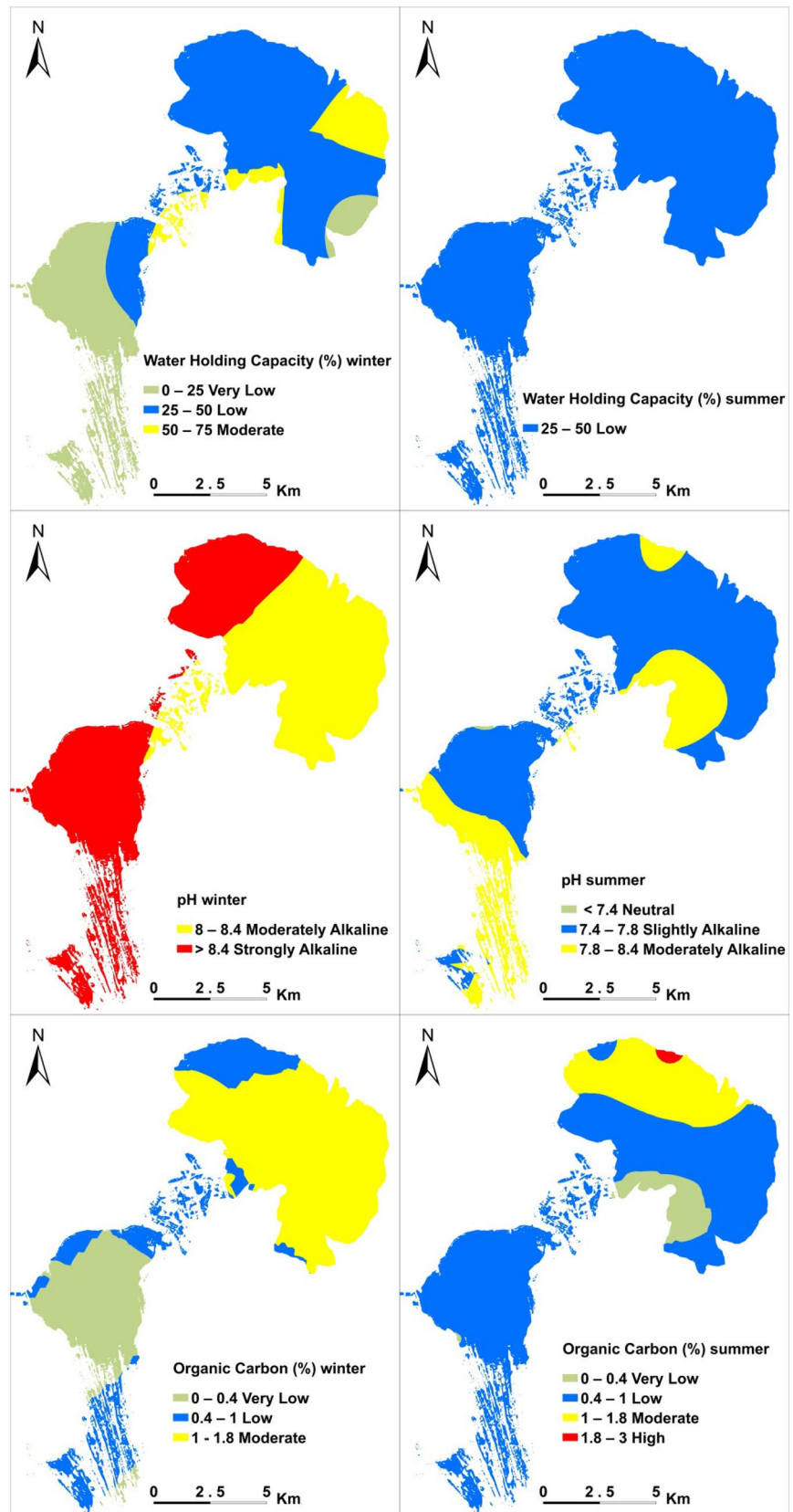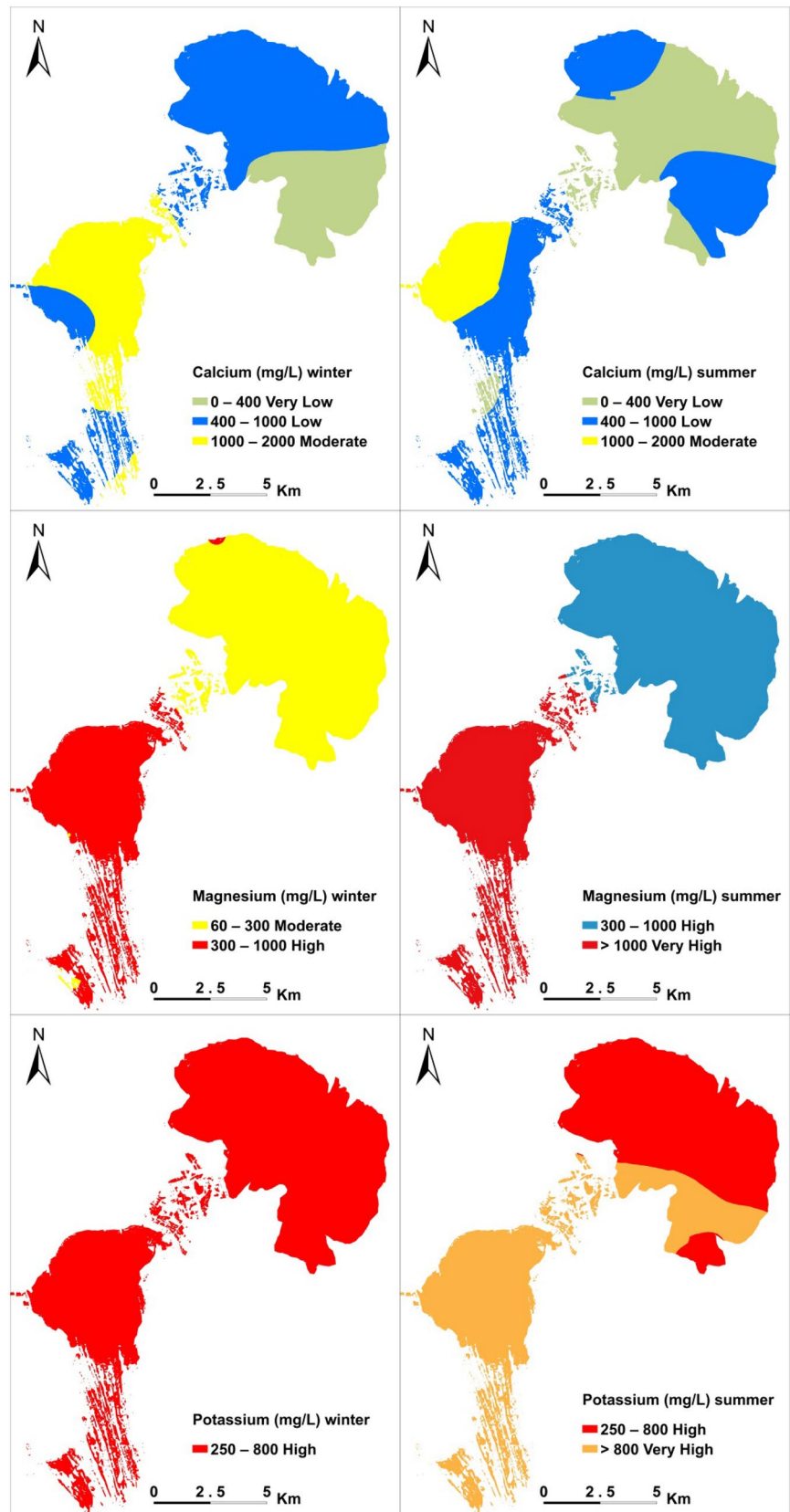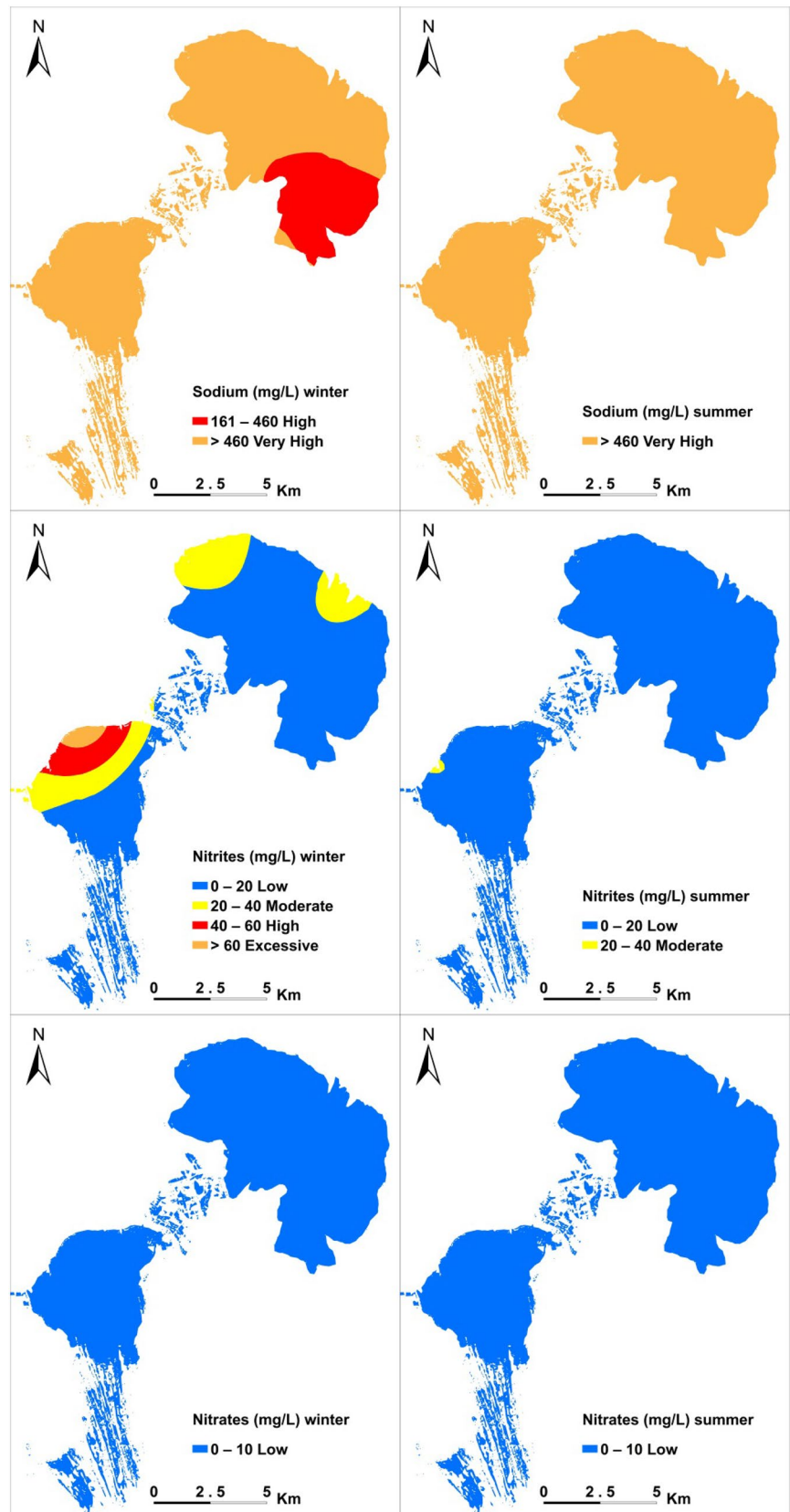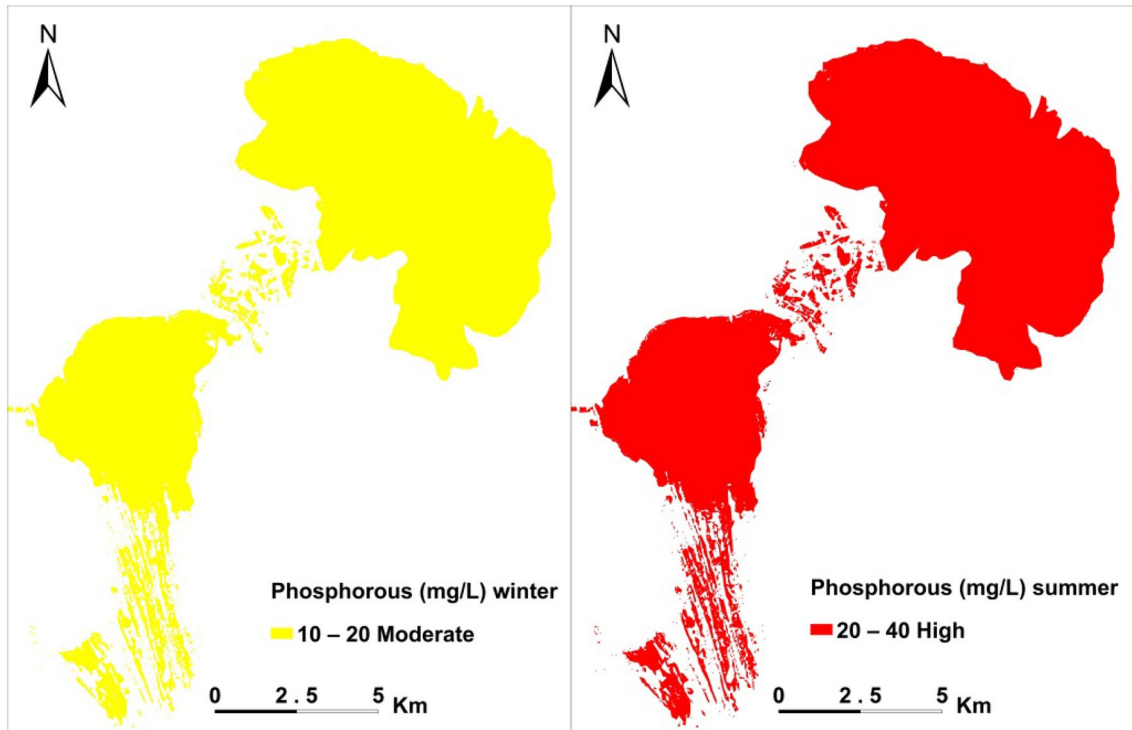
Fig. 4 Spatial distribution and spectrum of soil parameters (OM, TDS and EC) in Wadi El-Rayan Lakes during winter and summer seasons, respectively using GIS technique
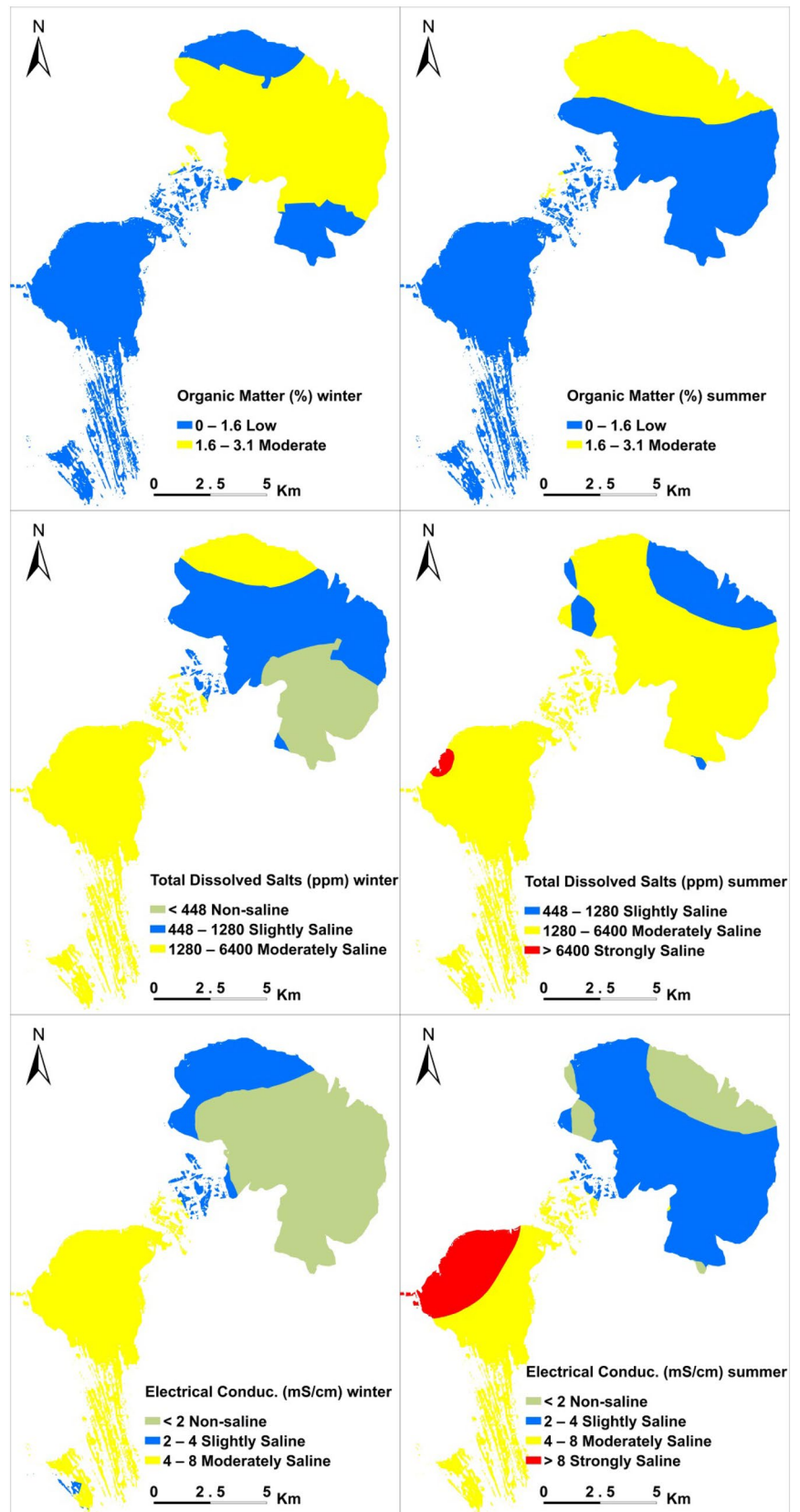
Fig. 5 Spatial distribution and spectrum of soil parameters (CaCO$_3$, Cl and SO$_4$) in Wadi El-Rayan Lakes during winter and summer seasons, respectively using GIS technique

Fig. 6 Spatial distribution and spectrum of soil parameters (Ca, Mg and K) in Wadi El-Rayan Lakes during winter and summer seasons, respectively using GIS technique

Fig. 7 Spatial distribution and spectrum of soil parameters (Na, NO$_2$ and NO$_3$) in Wadi El-Rayan Lakes during winter and summer seasons, respectively, using GIS technique

Fig. 8 Spatial distribution and spectrum of soil parameter (P) in Wadi El-Rayan Lakes during winter and summer seasons, respectively, using GIS technique

Table 4 Spectrum of different soil physical and chemical parameters according to some soil interpretation guidelines

Parameter	Spectrum					Reference
	Very Low	Low	Moderate	High	Very High	
WHC (%)	0–25	25–50	50–75	75–100	–	[7]
pH	<7.4 Neutral	7.4–7.8 Slightly alkaline	7.8–8.4 Moderately alkaline	>8.4 Strongly alkaline	–	[40]
OC (%)	0–0.4	0.4–1	1–1.8	1.8–3	>3	
OM (%)	–	0–1.6	1.6–3.1	> 3.1	–	
TDS (ppm)	<448 Non-saline	448–1280 Slightly saline	1280–6400 Moderately saline	>6400 Strongly saline	–	[42]
EC (mS/cm)	<2 Non-saline	2–4 Slightly saline	4–8 Moderately saline	> 8 Strongly saline	–	
Cl (mg/L)	–	<360	360–1060	> 1060	–	[38]
SO$_4$ (mg/L)	–	0–2	2–20	20–40	> 40	[30]
Mg (mg/L)	–	1–60	60–300	300–1000	> 1000	
K (mg/L)	–	<150	150–250	250–800	> 800	
Ca (mg/L)	0–400	400–1000	1000–2000	2000–4000	> 4000	[35]
Na (mg/L)	–	21–96	96–161	161–460	> 460	
NO$_2$ (mg/L)	–	0–20	20–40	40–60	> 60	[34]
NO$_3$ (mg/L)	–	0–10	10–20	20–30	> 30	
P (mg/L)	–	<10	10–20	20–40	< 40	

Table 5 Evaluation performance of ordinary kriged maps of soil physical and chemical parameters of Wadi El-Rayan Lakes during winter and summer seasons through cross-validation

Parameter	Season	MPE	MSPE	RMSSPE
WHC	Winter	−0.12	0.017	1.03
	Summer	0.70	0.061	1.09
pH	Winter	−0.012	−0.050	1.017
	Summer	−0.003	0.015	1.35
OC	Winter	0.022	0.030	1.028
	Summer	0.004	0.010	1.370
OM	Winter	0.006	0.005	1.033
	Summer	0.010	0.012	1.26
TDS	Winter	−16.38	−0.010	0.987
	Summer	−54.42	−0.024	0.909
EC	Winter	0.003	−0.002	0.830
	Summer	−0.098	−0.026	0.932
$CaCO_3$	Winter	0.336	0.037	1.026
	Summer	0.634	0.075	1.065
Cl	Winter	−1.38	−0.006	0.865
	Summer	−11.9	−0.02	0.948
SO_4	Winter	−0.085	−0.001	0.96
	Summer	−0.149	−0.009	0.822
Ca	Winter	0.715	−0.003	0.894
	Summer	−33.37	−0.103	0.935
Mg	Winter	−11.63	−0.039	0.931
	Summer	−23.48	−0.021	0.923
K	Winter	−2.11	−0.047	1.07
	Summer	−1.61	−0.005	0.978
Na	Winter	−3.91	−0.008	0.872
	Summer	−20.41	−0.031	1.09
NO_2	Winter	−0.08	−0.048	0.88
	Summer	−0.26	−0.034	1.07
NO_3	Winter	−0.005	−0.003	1.016
	Summer	−0.037	−0.025	1.067
P	Winter	0.33	0.063	0.935
	Summer	0.326	0.012	1.023

ordinary kriging method can be used as an effective tool in Wadi El-Rayan wetlands' soil management.
Recommendations

- The amount of water inflow into the two lakes should be measured and controlled in order to solve the high salinity problem, particularly the Lower Lake.
- Regular monitoring of the soil quality of the Wadi El-Rayan Lakes is important for sustainable wetlands management.
- Great efforts and cooperation between wetland managers, decision makers and other concerned authorities are needed in order to keep the wadi El-Rayan wetlands' biodiversity.

- Application of GIS and geo-statistical mapping, spatial distribution of soil and water physical and chemical parameters is helpful in wetlands management.

5 Future work

The authors are currently working on evaluation of vegetation productivity of Wadi El-Rayan and correlation of distinctive productive sites to their correspondence environmental gradients. Furthermore, the authors are also working on monitoring wetland change detection of Wadi El-Rayan Protected Area in Egypt (RAMSAR site) over the past three decades using remote sensing and GIS.

Data Availability The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Compliance with Ethical Standards

Conflict of interest The authors declare that they have no conflict interest.

Ethical approval and consent to participate A research site permission letter was obtained from the concerned institution. An effort was made to conduct the research in an ethical manner.

Consent for publication All authors agreed and approved the manuscript for publication in Environmental Systems Research.

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