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GIS AND STATISTICAL EVALUATION OF SOIL QUALITY OF SIDI YAHYA, GHARBPLAIN (MOROCCO)

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SidiYahya perimeter

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ABSTRACT

The study of soil quality in irrigated areas is necessary to evaluate the sustainability of the agricultural production system. Indeed, the assessment of this quality is based on the physicochemical and biological characterization of soil parameters, as well as the knowledge of their spatial distribution and their evolution over time. This work aims to make a diagnosis of the current situation of soil quality of SidiYahya in the Gharb plain, Morocco. For this, sampling was carried out from 33 sites distributed over the studied plain during 2019. In this study, different soil properties including specifically texture, pH, electrical conductivity (EC), organic matter (OM), phosphorus (P_2O_5), and potassium (K_2O) were measured while exchangeable sodium percentage (ESP) was calculated using the standard formula. Based on the observed soil properties a map was prepared by using a geographic information system (GIS), which was based specifically on the inverse distance weighted (IDW) spatial interpolation method. Data were processed using different statistical tools like descriptive statistics, correlation, and principal component analysis (PCA). Results of the study revealed that 70% of the soils have a heavy clayey texture with a predominance of vertisols (55%). Further, the study area soil is mainly alkaline (70%), poor in organic matter (61%) and phosphorus (52%), while very rich in potassium (70%), and non-saline (88%) contents. Soil pH was reported to be the least variable whereas sand, phosphorus, and salinity

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were the highest variable. IDW allowed mapping the soil properties by moving from punctual information to whole extent information. Furthermore, correlations were found between various soil properties by using PCA, 3 principal components (PCs) were able to extract 76% of the information from the 9 initial soil properties. Collected soil samples were grouped into 3 groups, based on their scores on the 3 PCs. Based on these two kinds of information, delineation of management zones can be established for a site-specific supply of agricultural inputs leading to better management of soil and water resources for securing their sustainable use.

1 Introduction

Environmental quality encompasses three different compartments i.e. air, water, and soil. The quality of the two first components means mainly pollution whereas soil quality is more general and goes beyond pollution as it includes, in addition, fertility, salinity, and more (Bunemann et al., 2018). Soil quality is an essential element for assessing the sustainability of intensive agricultural development. Soil management can only be sustainable if it maintains or improves soil and water quality (Larson & Pierce, 1991). Soil quality has been defined as the resultant of the physical, chemical, and biological properties of the soil, allowing crop growth and development, water flow regulation and partitioning through the environment, and acting as a pollutant filter (Karlen et al., 1997). Soil quality reflects its ability to retain and release water and nutrients, maintain biodiversity and resist the effects of practices that can lead to degradation. Soil quality mainly depends on its intrinsic properties, its geochemical and climatic environments, and its use by humans. In addition, as soil-forming factors vary with space and time, soil quality will not be uniform for a given area and its spatial and temporal variability could be assessed by using GPS, remote sensing, GIS, and field and laboratory data (Douaik et al., 2005; 2011).

Soil quality has been well evaluated for rainfed (Santos-Frances et al., 2019; Nehrani et al., 2020) as well as irrigated environments (Abd-Elwahed, 2019; Jahany & Rezapour, 2020). Also, it has been assessed for the different land uses like crop-livestock farming (Viaud et al., 2018), intensive agriculture (Zeraatpisheh et al., 2020), citrus production (Cheng et al., 2016), olive grove production (Calero et al., 2018), rice production (Sione et al., 2017), sugarcane production (Cherubin et al., 2016); vineyard production (Dogan & Gulser., 2019), and forests ecosystem (Andres-Abellan et al., 2019; Shao et al., 2020). Further, soil quality was also evaluated in different topographical situations like plains (Bilgili et al., 2017; Moharana et al., 2018) and mountainous lands (Chandel et al., 2018; Nosrati & Collins, 2019).

In Morocco, several studies showed that agricultural intensification under irrigation frequently leads to soil degradation (Dakak et al., 2014; Zouahri et al., 2015; El Khodrani et al., 2017; ElOumlouki et al., 2018). The quality of irrigation water, soil texture, and drainage potential of the soil greatly influence the rate of soil degradation.

The Gharb plain is among the perimeters that are most affected by agricultural intensification in Morocco. It is an important citrus fruit production zone that includes the SidiYahya perimeter, where this study was carried out. It is recognized as a technically modern, professionally organized, highly productive, and export-oriented sector. The irrigation system in the area is essentially based on pumping from the aquifer. The importance of water withdrawals, given the scarcity of inputs, has led to a continuous decline in the water table level (1.5 to 2 m/year). At this decline rate, around 10,000 ha of citrus is threatened in the medium to long term. The main purpose of this study was to assess the soil quality of the irrigated perimeter of Sidi Yahya, Gharb plain (Morocco) using a geographic information system (GIS), in particular, the spatial interpolation method of inverse distance weighted (IDW) and the multivariate statistical method of principal component analysis (PCA).

2 Materials and methods

2.1 Study area

Sidi Yahya is a municipality within the province of Sidi Slimane. It is a part of the Rabat-Salé-Kénitra region of the North-West of Morocco. The study area has as geographic coordinates 34°18′33" N for latitude and 6°18′41" W for longitude. Sidi Yahya is located on the South-East of the Gharb plain, on the transition zone between the Maamora and the Gharb water tables; it has a very low but wide basin that covers an area of 616000 ha (Fathallah et al., 2014). The region is characterized by a climate that is mainly influenced by the Atlantic Ocean, specifically regarding humidity and temperature.

2.2 Soil sampling and laboratory analyses

Soil samples were taken at a depth of 20 cm from the 33 sites using an auger (Figure 1). These soil samples were air-dried, crushed, sieved, and labeled for laboratory physical and chemical testing. The main soil properties used for assessing its quality were texture, pH, electrical conductivity, organic matter, available phosphorus, and exchangeable potassium. In this, the particle size of the collected samples was determined by sedimentation according to the Stokes law (Petard, 1995). It allows to determine the soil texture based on the diameter of their mineral constituents (clay: < 2µm, silt: 2-50 µm, and sand: > 50µm). While the soil pH was

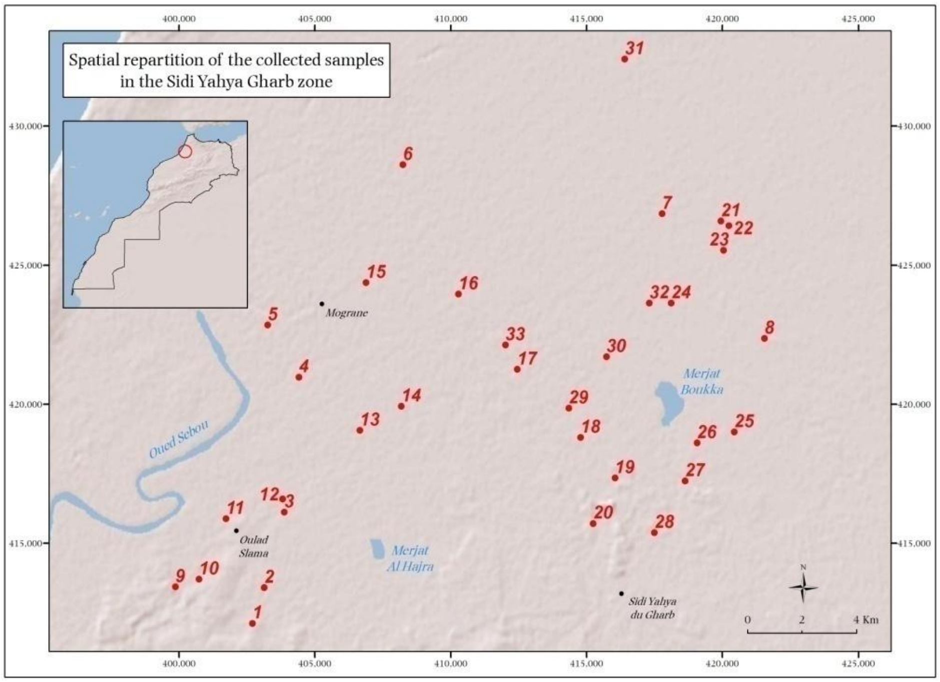

Figure 1 Study area and distribution of soil samples.

determined using the potentiometric method (Van Ranst et al., 1999) using a Mettler Toledo Seven Easy-728 Metrohm pH meter. Further, electrical conductivity (EC)(dSm^{-1}) was measured by applying the saturated paste method (USSLS, 1954) using an ORION brand conductivity meter, model 162. Organic matter (OM) (%) was determined following the organic carbon oxidation by potassium dichromate ($K_2Cr_2O_7$ to 1N) (Walkley & Black, 1934).

Further, available phosphorus (P_2O_5) (ppm) was determined using the Olsen method (Olsen, 1954) in which the extraction is made by sodium hydrogen carbonate at pH 8.5. This method is based on the formation and reduction of a complex of orthophosphoric acid and molybdic acid (sky blue). A JENWAY 6405 Visible-model UV spectrophotometer, at a wavelength of 825 nm, was used to read phosphorus content. Exchangeable potassium (ppm) is extracted using the ammonium acetate CH_3COONH_4 1N at pH 7 (Van Ranst et al., 1999). Its levels were determined using a flame photometer model CL 378. To evaluate soil alkalinity, Exchangeable Sodium Percentage (ESP) was calculated as the ratio between sodium (Na) content and Cation Exchange Capacity (CEC).

2.3 Mapping

Thematic maps were elaborated using spatial interpolation within Geographic Information System (GIS) (Tambassi, 2019; Mitran et al., 2021). The interpolation algorithm was the Inverse Distance Weighting (IDW) (Bernardi et al., 2017; Ozsahin et al., 2017; Kalambukattu et al., 2018). For this, a geostatistical analysis extension of the ArcGis 10 software was used.

2.4 Statistical analysis

The multivariate statistical method of principal component analysis (PCA) was performed on the basis of Pearson correlation matrix between the different pairs of soil properties and using the varimax rotation (Khlosi et al., 2013; Moutassem et al., 2019; Aboutayeb et al., 2020). It is an exploratory method that can be used to describe the structure of variables taken simultaneously, reduce the number of variables to be measured for similar future studies, and visualize the distribution of samples in the reduced dimension and see how they are grouped. SPSS software was used for statistical analysis.

3 Results and discussion

Descriptive statistics of both observed and calculated physical and chemical proprieties of soils are summarized in Table 1.

3.1 Physico-chemical parameters of soils

Results of the Shapiro-Wilk test of normality show that all soil properties, except organic matter and ESP, did not follow a normal distribution (Table 1). The lack of normality is confirmed by skewness and/or kurtosis values higher than 1 and also by the discrepancy between mean and median values (Table 1) which indicate the presence of a few exceptionally low or high values.

Table 1 Descriptive statistics of soil properties (n=33 samples)

Parameter	Clay (%)	Silt (%)	Sand (%)	pH	OM (%)	P_2O_5 (ppm)	K_2O (ppm)	EC (dS m^{-1})	ESP
Min.	9.8	2.4	0.7	6.0	1.0	4.3	54.2	0.3	5.9
Max.	76.7	31.5	87.7	8.6	5.1	195.6	1024.4	5.8	92.5
Mean	50.0	19.1	30.9	7.9	2.8	43.4	347.3	1.2	51.5
Median	58.7	23.4	11.6	8.1	2.8	29.7	361.6	0.6	53.5
Skew.	-0.7	-0.8	0.8	-1.9	0.2	1.8	1.2	2.3	-0.4
Kurt.	-1.2	-0.8	-1.0	4.5	-0.6	4.0	2.9	5.5	-0.7
CV (%)	46.3	49.6	103.2	6.9	38.5	99.4	61.9	110.8	48.0
P(SW)	0.000	0.000	0.000	0.000	0.673	0.000	0.000	0.000	0.086

Min: Minimum; Max: Maximum; Skew: Skewness; Kurt: Kurtosis; CV: Coefficient of variation; P(SW): p-value corresponding to the Shapiro-Wilk test of normality.

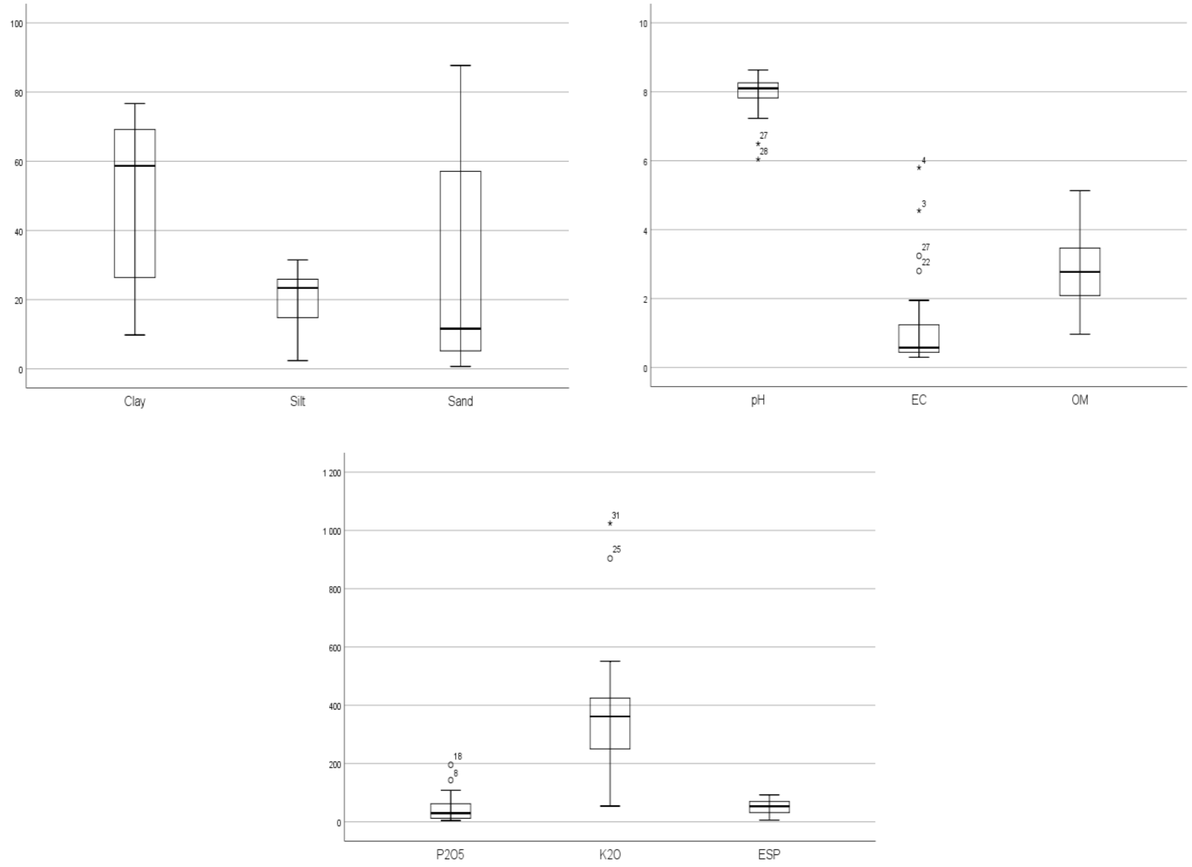

Figure 2 Boxplot of soil properties

3.1.1 Soil texture and types

The clay content of the collected samples ranged from 9.8 to 76.7% with a mean value of 50%, a median value of 58.7%, and a coefficient of variation (CV) of 46.3% while the sand content varied between 0.7 and 87.7% with a mean value of 30.9%, a median value of 11.6% and a CV of 103.2% (Table 1). Further, silt content has intermediate values between clay and sand contents (Figure 2). These particle size distributions resulted in variable soil texture with 70% of soils having a heavy clay texture while 6% have a clayey sand texture whereas 24% are considered having a sandy texture. The main soil type is primarily vertisols (55%), followed by gleysols (14%), cambisols (12%), arenosols (10%), luvisols (7%), and chernozems (2%) (Figure 3).

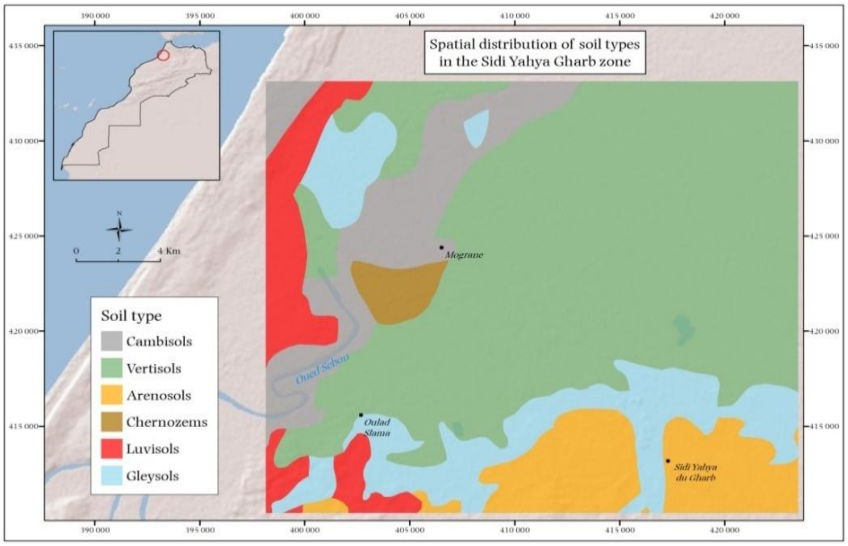

Figure 3 Pedological map of the perimeter of SidiYahya, Gharb plain

Table 2 Distribution of soil pH classes according to the Moroccan standards (DIAEA/DRHA /SEEN, 2008).

Class of soil	pH	Number of sites	% of sites
Slightly acid	6.0 - 6.5	2	6.0
Neutral	6.5 - 7.3	1	3.0
Slightly alkaline	7.3 - 7.8	4	12.2
Moderately alkaline	7.8 - 8.5	23	69.7
Strongly alkaline	8.5 – 9.0	3	9.1

Table 3 Distribution of the organic matter classes according to the Moroccan standards (DIAEA/DRHA /SEEN, 2008)

Class of soil	OM (%)	Number of sites	% of sites
Poor	0.7 - 1.5	6	18.2
Moderate	1.5 – 3.0	14	42.4
Rich	3.0 – 6.0	13	39.4

3.1.2 pH

Soil results showed that pH values ranged from 6.0 to 8.6 with a mean value of 7.9 and a median of 8.1 (Table 1). This soil parameter is the least variable with a CV of 6.9%. Further, there are two abnormally low pH values with 6.0 at site 28 and 6.5 at site 27 (Figure 2).

Almost 70% of the studied soils are moderately alkaline, with a pH value ranging from 7.8 to 8.5 (Table 2). The dominance of this class is illustrated by the spatial distribution map (Figure 4) showing that it is found in almost the whole study area except the South-East and South-West parts. From Figure 4, it can be seen that the pH of the soils is moderately alkaline. This is probably because of low rainfall in the region and the low soil organic matter slow down the process of natural soil acidification (Kamprath & Smyth, 2005; Goulding, 2016).

3.1.3 Organic matter

Soil organic matter (OM) contents varied from 1 to 5.1% with the same mean and median values (2.8%), and a CV of 38.5% (Table 1). Results of the study revealed that 60.6% of the studied soils have low to medium levels that cover most of the study area (Figure 5; Table 3). On the other hand, 39.4% of soils are rich in OM. These results are obtained due to the inputs of organic fertilizer (compost or manure), or by the residue of the roots which remain in the soil after the crops. These results are following the general trend in Morocco as soils have low organic matter content due to low rainfall, limited crop cover (vegetation), and use of crop residues as feeds for animals (Mrabet, 2008).

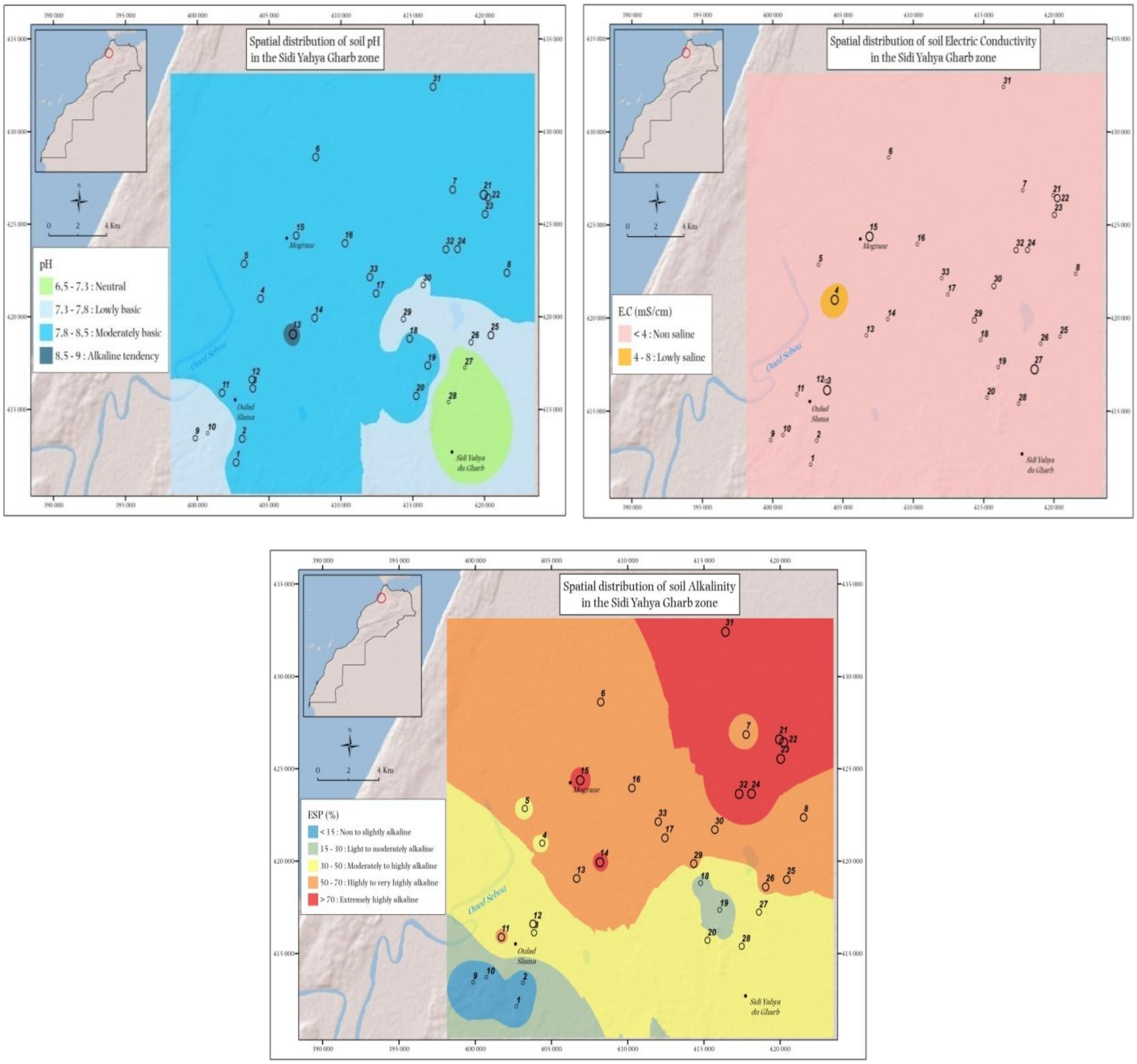

Figure 4 Spatial distribution of soil pH(top), electrical conductivity (middle), and exchangeable sodium percentage (bottom)

Table 4 Distribution of the phosphorus classes according to the Moroccan standards (DIAEA/DRHA /SEEN, 2008)

Class of soil	P_2O_5 (ppm)	Number of sites	% of sites
Very low content	< 15	11	33.3
Low content	15 - 30	6	18.2
Good content	30 - 45	5	15.2
High content	45 - 100	8	24.2
Very high content	> 100	3	9.1

3.1.4 Phosphorus

Phosphorus contents ranged from 4.3 to 195.6 ppm with a mean value of 43.4 ppm, a median value of 29.7 ppm, and a CV of 99.4% (Table 1). There were two sites i.e. 8 (143.1 ppm) and 18 (195.6 ppm) that have excessively high phosphorus content (Figure 2). Most of the studied soil samples (51.5%) are characterized by low phosphorus content whereas only 33.3% have high content (Table 4).

The spatial distribution map of phosphorus shows that there is a general North-South gradient, with the highest values located in the South (Figure 2). This element comes mostly from farming practices and is not highly mobile in the soil; it can also be easily carried by runoff thus contributing to the pollution of the environment by promoting the eutrophication of surface water. Several studies have been focused on the agricultural impact of this phenomenon (Coale et al., 2002). Phosphorus represents a risk of degradation of soil quality in the case of excessive input, which can have repercussions on the quality of groundwater or surface water (risk of eutrophication). So the analysis of the soil can contribute to a better rationalization of the contribution of this element.

3.1.5 Potassium

Potassium (K_2O) content varied from 54.2 to 1024.42 ppm, with a mean value of 347.3 ppm, a median value of 361.6 ppm, and a CV of 61.9% (Table 1). There were two sites with excessively high (31 with 1024.4 ppm) potassium content (Figure 5). This indicates that these soils are very rich in potassium, especially since their sand-loamy texture with a low colloid percentage cannot fix this element. Almost 70% of the samples have a very high potassium content (Table 5). The excess of potassium can be converted into salt and thus pollute the groundwater by infiltration and percolation, which can also cause magnesium deficiency for crops (Koné et al., 2009).

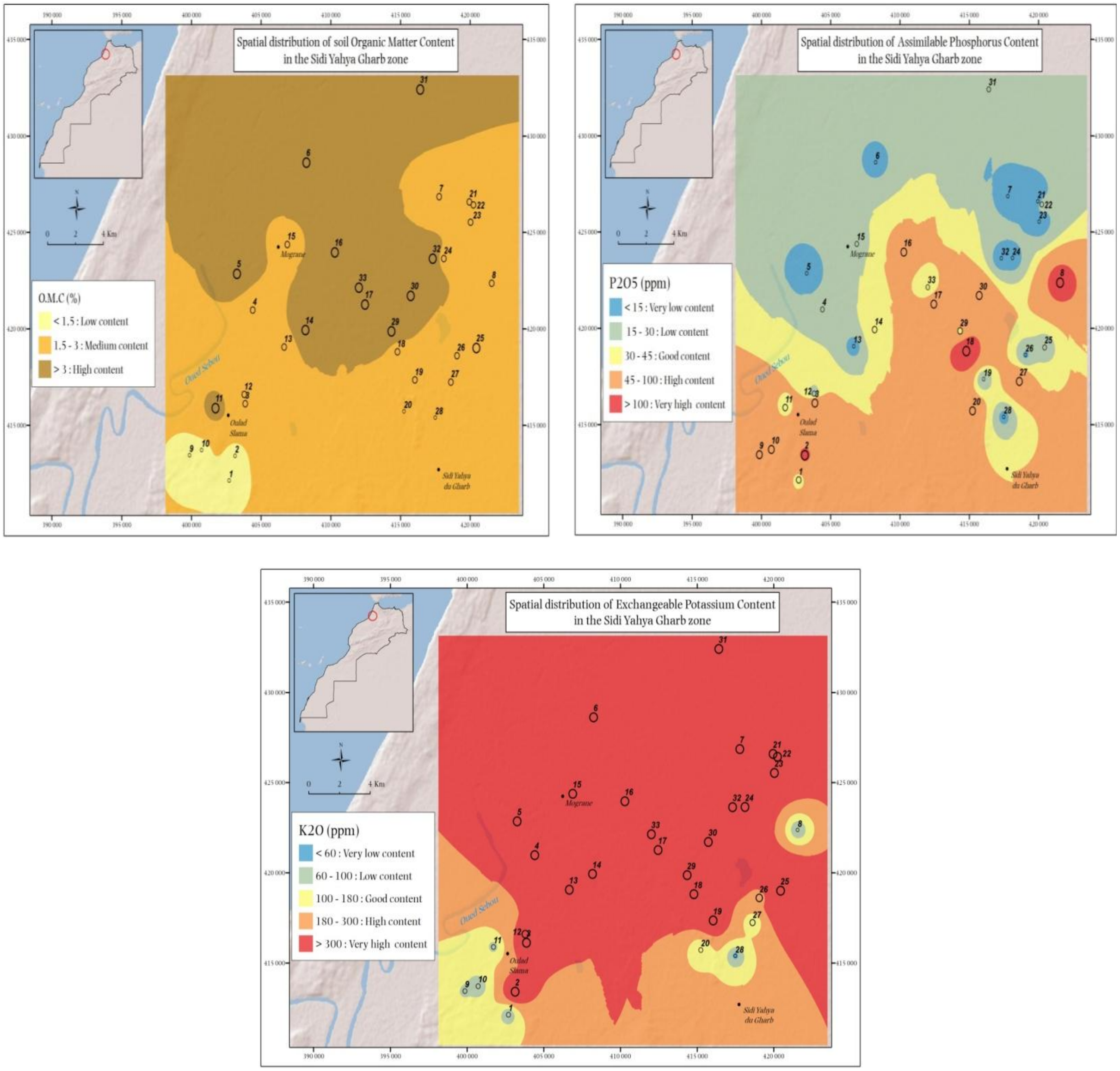

Figure 5 Spatial distribution of soil organic matter (top), phosphorus (middle), and potassium (bottom).

Table 5 Distribution of exchangeable potassium classes according to the Moroccan standards (DIAEA/DRHA /SEEN, 2008)

Class of soil	K_2O (ppm)	Number of sites	% of sites
Very low content	< 60	2	6.1
Low content	60 - 100	5	15.1
Good content	100 - 180	1	3.0
High content	180 - 300	2	6.1
Very high content	> 300	23	69.7

Table 6 Distribution of electrical conductivity (EC) classes according to the american standards (USSLS, 1954)

Class of soil	EC (dS m^{-1})	Number of sites	% of sites
Non saline	< 2	29	87.8
Slightly saline	2-4	2	6.1
Moderately saline	4-8	2	6.1

Table 7 Distribution of soil alkalinity classes according the FAO norms (FAO, 1988)

Class of soil alkalinity	ESP	Number of sites	% of sites
Non to slightly alkaline	< 15	4	12.1
Slightly to moderately alkaline	15 - 30	2	6.0
Moderately to highly alkaline	30 - 50	6	18.2
Highly to very highly alkaline	50 - 70	15	45.5
Extremely highly alkaline	> 70	6	18.2

The spatial distribution map shows that high potassium levels cover most of the study area (Figure 5). This high potassium content seems beneficial for plant growth but proves to be disastrous for areas close to surface waters, where it can be the cause of the appearance of the eutrophication phenomenon.

3.1.6 Soil salinity

Electrical conductivity (EC) values ranged between 0.3 and 5.8 dS m^{-1} with a mean value of 1.2 dS m^{-1}, a median value of 0.6 dS m^{-1}, and the largest CV (110.8%). There are two abnormally high EC values (2.8 dS m^{-1} at site 22 and 3.2 dS m^{-1} at site 27) and two outliers (4.6 dS m^{-1} at site 3 and 5.8 dS m^{-1} at site 4) was reported (Figure 2). Most of the soils (87.8%) are not saline; on the other hand, only 12.2% are slightly or moderately saline (Table 6).

The spatial distribution map shows that majority of the study area has the lowest salinity levels (Figure 4). Therefore, the soil of the sites does not present any salinity problem since only two soil samples have values higher than the 4 dS m^{-1} threshold which distinguishes nonsaline from saline soils (USSLS, 1954).

3.1.7 Exchangeable Sodium Percentage

Accumulation of soluble salts in the soil, especially Na, can contribute to the increase of soil alkalinity (higher pH) (Day & Ludeke, 1993). This is evaluated using exchangeable sodium percentage (ESP). In the current study, ESP extreme values were minimum as 5.9 and maximum as 92.5, with 51.4 as a mean value and 53.5 as a median value. It had a moderate variability (CV of 48%). ESP values higher than 10% indicate sodic soil where the excess of exchangeable sodium may contribute to the deterioration of soil structure by dispersing soil colloids and, consequently, decreasing aeration and infiltration rate (Badraoui & Merzouk, 1994). The main contributing factors to sodicity are sodium intake from irrigation water (high Sodium Adsorption Ratio) and capillary upwelling of groundwater charged with Na.

A small portion of soil samples (12.1%) is non-alkaline and just 6 % can be considered either lightly or moderately alkaline (Table 7). On the other hand, 63.7 % of soil samples are high to extremely highly alkaline. There is a clear trend of decreasing ESP from North-East to South-West (Figure 4).

Table 8 Correlation matrix for soil properties

Parameter	pH	EC	OM	P2O5	K2O	ESP	Clay	Silt	Sand
pH	1								
EC	-0.02								
OM	0.19	0.02							
P2O5	-0.14	-0.05	-0.18	1					
K2O	0.39*	0.07	0.48**	-0.14	1				
ESP	0.39*	0.08	0.68**	-0.44**	0.44**	1			
Clay	0.46**	0.12	0.60**	-0.39*	0.39*	0.81**	1		
Silt	0.37*	0.16	0.69**	-0.35*	0.47**	0.80**	0.89**	1	
Sand	-0.44**	-0.13	-0.64**	0.39*	-0.43*	-0.83**	-0.99**	-0.94**	1

**: Correlation coefficients are significant at the 0.01 level; *:Correlation coefficients are significant at the 0.05 level.

Table 9 Eigen values, variances, and cumulated variances of the principal components

Principal Component (PC)	Eigenvalues		
	Eigen values	% Variance	% Cumulated variance
1	4.9	54.0	54.0
2	1.0	11.5	65.6
3	0.9	10.5	76.1
4	0.8	9.3	85.4
5	0.7	7.6	92.9

3.2 Correlation and Principal Component Analysis (PCA)

The matrix of the correlation coefficients between the different pairs of soil physic-chemical properties is given in Table 8. There are many highly significant (p-value <0.01) correlation coefficients. The highest ones are reported between the soil texture elements (-0.99 between sand and clay, -0.94 between sand and silt, and 0.89 between clay and silt). ESP has also a very high correlation with soil texture (negative with sand and positive with clay and silt). In addition, OM has a relatively high correlation with soil texture and ESP. Other interesting correlations are between K_2O and ESP, silt and OM, pH and clay + sand, and P_2O_5 and ESP. In addition, there were also some significant (p-value < 0.05) correlation coefficients such K_2O / sand (-0.43), pH / K_2O, pH / EPS, P_2O_5 / sand, and K_2O / clay (0.39), P_2O_5 / clay (-0.39), pH / silt (0.37), and P_2O_5 / silt (-0.35). All the remaining correlation coefficients were not significant (p-value > 0.05). In particular, EC is not correlated to any of the other soil properties. This will appear clearly in the PCA results as a separate principal component.

Based on the Kaiser criterion (eigenvalue > 1), only two principal components have to be kept. The extracted information would amount to 65.6% (Table 9), which is not enough. Also considering the third principal component which has an eigenvalue near one (0.9), the total extracted information increased to 76.1%, which seemed enough. The first principal component (PC1) kept 54% of the total information that was contained in all of the 9 initial soil properties while the second component (PC2) kept 11.5% of this information and the third principal component kept 10.5% (Table 9).

The first principal component (PC1) was positively correlated to ESP, clay, and silt (from 0.71 to 0.76) and negatively correlated with P_2O_5 (-0.81) and sand (-0.76) (Table 10, Figure 6). It opposes fine textured and alkaline soils with low P_2O_5 content to those with coarse textured, nonalkaline with high P_2O_5 content. The second principal component (PC2) was positively correlated with K_2O (0.78), pH (0.67), and OM (0.60). It contrasts alkaline soils with high K_2O and OM content to acid soils with low K_2O and OM content. Finally, the third principal component (PC3) is only and positively correlated with EC (0.97) (Table 10). It differentiates between saline and non-saline soils. This is in agreement with what was found in the correlation analysis above.

Table 10 Loadings of soil physico-chemical properties on the principal components

Soil properties	Principal Components (PC)		
	PC1	PC2	PC3
pH	0.12	0.67	-0.16
EC	0.05	-0.03	0.97
OM	0.46	0.60	0.08
P_2O_5	-0.81	0.19	0.09
K_2O	0.07	0.78	0.07
ESP	0.74	0.52	0.06
Clay	0.76	0.55	0.11
Silt	0.71	0.59	0.19
Sand	-0.76	-0.57	-0.14

Bold values are loadings higher than 0.6.

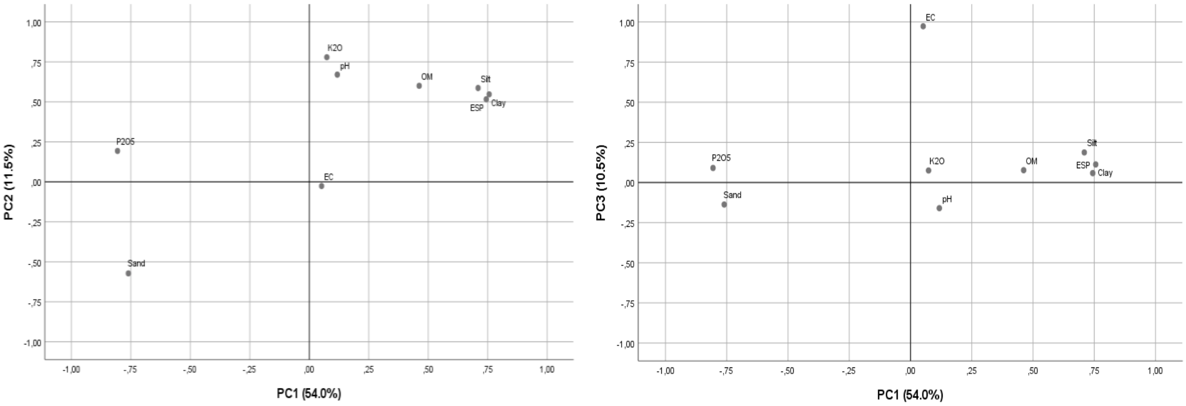

Figure 6 Loading plot for the principal component analysis: PC1–PC2 (left) and PC1-PC3 (right) plans.

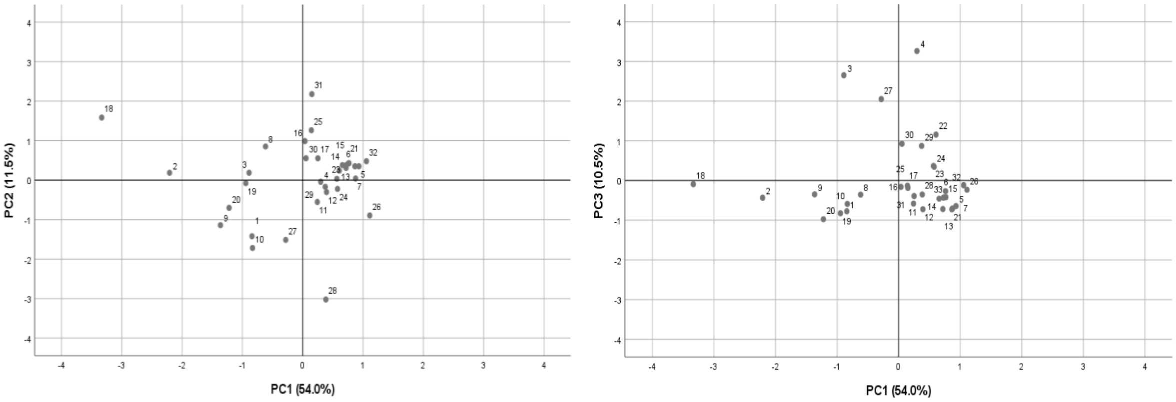

Figure 7 Score plot for soil samples in the PC1–PC2 (left) and PC1-PC3 (right) plans.

Some specific soil samples appeared (Figure 7). For example, samples 2 and 18 have the highest levels of P_2O_5 (108.1 and 195.6 ppm) and among the highest levels of sand (80.7 and 80.4%) as well as the lowest levels of clay (14.4 and 14%), silt (4.8 and 5.6%), and ESP (7.3 and 20.5). So, these two samples are sandy soils, rich in P_2O_5, and non-alkaline. In addition, samples 28 and 31 are particular as the first one is characterized by the lowest levels of pH (6.0), K_2O (54.2 ppm), and OM (1.2%) whereas the second one is characterized by the opposite: the highest levels of pH (8.3), K_2O (1024.4 ppm), and OM (5.1%). Therefore, sample 28 has acidic soil, poor in K_2O and OM whereas sample 31 is an alkaline soil, rich in K_2O and OM. Also, samples 3, 4, and 27 are characterized by the highest levels of EC (3.2 to 5.8 dSm^{-1}). They are among the most saline soils in the study area. Finally, many samples are found around the origin of the PC plans (8, 11, 12, 13, 17, 24, 29, 30, etc.).These soil samples are characterized by intermediate levels of the different soil properties. Such soils have a medium texture (neither fine nor coarse), with neutral pH, and medium salinity and fertility.

Conclusion

Based on 33 samples taken at the 0-20 cm depth in the SidiYahya, Gharb plain (Morocco), some soil physical and chemical properties were measured to assess soil quality. Most of the soil samples had a heavy clayey texture with a predominance of vertisols. In general, the soils had an alkaline pH, low organic matter and phosphorus levels, and high potassium content. They were predominantly non-saline and had moderate to high ESP levels. There were few samples with extremely low or high levels for some soil properties. Soil properties varied differently with the geographical localities and among the tested various parameters; the pH is the least variable parameter whereas sand and phosphorus were the most variable parameters. This spatial variability was used in GIS, in particular using IDW, for interpolating soil properties to the whole extent of the study area, thus establishing soil maps. Soil properties were correlated and PCA allowed reducing the initial 9 dimensions to only 3 principal components. A multivariate statistical method such as PCA and spatial interpolation method such as IDW are useful tools to delineate homogeneous soil resources for their better and sustainable management.

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Conflict of interest

No potential conflict of interest was reported by the authors

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