



Application of geostatistical methods for the spatial distribution of soils in the irrigated plain of Doukkala, Morocco

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Abstract

In this study conducted in the semi-arid region of the irrigated plain of Doukkala, Morocco, we evaluated the spatial variation in the soil of organic matter (OM), pH of soil, cation exchange capacity (CEC), potassium (K_2O), soil phosphorus (P_2O_5), clay, sand and silt, this investigation use conventional statistics and a geographical information system (GIS) to create a map of soil redistribution, which included a newly compiled 1:10,000 digital soil map, and using 1865 soil samples (0–20 cm), the produce maps of distribution the variability of soil physico-chemical properties and to provide information which revealed the soil quality functions of the physicochemical characteristics. Coefficient of variation (CV) indicated that OM, P_2O_5 , K_2O , CEC, and Silt indicated that high variation ($CV > 40\%$), Moreover, the Coefficient of variation the pH, the our areas value was 9, 91%, which indicated very low variation. The semivariogram model of soil physico-chemical properties [lag distance, rang, nugget (C0), partial sill (C), Sill (C0 + C) and nugget/sill ratio] indicated the diver's spatial dependency of soil properties (strongly, moderately and weakly). According to spatial variability of parameters was mapped by ordinary kriging using spherical model based on root mean square error and the interpolated methods of inverse distance weighting deterministic. In this work, we find that the kriging ordinary and deterministic methods show almost similar results with a spatial distribution and provide the heterogeneity the distribution map of four area in different soil parameters in the study areas.

Keywords Spatial variability · Geostatistics · GIS · Irrigated plain of Doukkala · Soil properties · Soil physico-chemical

Introduction

Many key environmental, economic and social functions are performed by soil as a vital non-renewable natural resource. It is a resource that has a slowly developing rate, gradually over time, which makes it possible to show a great spatial variability (Vrščaj et al. 2008). For

all that, soil quality is described as its capacity of having a biological function, to sustain plant and animal production, which aims to maintain and even enhance water and air quality and to create a human's health supportable climate (Liu et al. 2016). Spatial variability information and soil distribution properties are primordial for farmers trying their best to improve fertilization efficiency and crop diversity (Tagore et al. 2015).

Soil quality for sustainable crop production is at the foundation of soil health. Soil considered as a living being, which has the function of power include the nutrient cycle, and symbiotic relationships with plant roots, weed control and diseases, also soil structuring and aggregation soil particles that act on soil protection against erosion. Soil organic matter has multiple roles in the complex functioning of the soil ecosystem, which allows for a wide variety of organisms and constituting a reservoir of nutrients and moisture (FAO 2011).

Soil organic properties (organic matter, nutrients, pH and texture) measured as key factors in quality of soil

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(Reeves 1997; Pan et al. 2009). Specially, organic matter the product of on-site biological decomposition affects the chemical and physical properties of the soil and are essential to soil fertility. Consequently, soil organic matter could be increased by either improving C, tillage and vegetation burning, accelerate the decomposition of soil organic matter and leave the soil susceptible to wind and water erosion (Chen et al. 2009). However, there are alternative management practices that enhance soil health and allow sustained agricultural productivity (Liu et al. 2013a, b). Phosphorus (P), potassium (K), pH soil, soil organic matter (SOM) are considered as an key to soil quality which significantly contributes to the ecosystem services such as food production (Manlay et al. 2007).

Spatial variation is primordial for exploiting soils efficiently and to make decisions for land use, more details are required to set up models to simulate chemical physical, as well as for farming algorithms precision (Zhang et al. 2007). Over and above that, soil distribution is necessary when evaluating potential soil productivity and assessing current environmental pollution, aiming for a better understanding of climate change and its feedbacks (Jennings et al. 2009). Therefore, heterogeneity spatial of soil is caused by various factors as climatic factors, vegetation types, soil texture land use, among those factors, land use changes have substantial impact on soil, since land use variation could occur more frequently because of climate change and human activities (Liu et al. 2013a, b; Gami et al. 2009; Rodríguez et al. 2009; Patil et al. 2010).

In an agricultural ecosystem soil phosphorus (P), potassium (K), pH soil, soil organic matter (SOM) are the major determinants and indicators of soil fertility and quality are closely related to soil productivity (Liu et al. 2011; Reeves 1997; Susanne and Michelle 1998; Al-Kaisi et al. 2005; Badraoui and Naman 2008). In the plains Doukkala of Morocco recent studies have highlighted the existence of problems of degradation of soil fertility. These problems can limited Intensive agricultural management has affect economic and social development, this problems has also contributed to land degradation in terms of soil organic matter decline, desertification and biodiversity loss and ground and climate action and human activity play the most influential role in altering the performance characteristics of soils, irregular rainfall patterns, abiotic factors such as climate, low rainfall, agronomic practices, soil texture, fragile soils and low in organic matter and water contamination, intensified agriculture and management increased environmental degradation (Arshad and Coen 1992; Badraoui et al.

1993; Badraoui and Naman 2008; Chofqi 2004; Naman 2003; Gana 2002).

During the last 30 years, many researches have been carried out geostatistics widely to describe the spatial variability of soil qualities because it allows the study of the spatial variability of soil properties and aptitude of quantifying and decreasing sampling uncertainties and reducing investigation costs (Cambule et al. 2014a, b; Emery and Ortiz 2007). There is many studies that have been showed based on geostatistical analysis to characterize the soil spatial variability as well as physical (Li et al. 2007; Weindorf and Zhu 2010), chemical (Huang et al. 2007), biochemical properties (Šnajdr et al. 2008) and even the microbiological processes (Cao et al. 2011; Peigné et al. 2009).

In general, traditional statistics, in combination with GIS has been used extensively to characterize the spatial variability of soil attributes due to its ability of quantifying and reducing sampling uncertainties and minimizing investigation (Liu et al. 2014; Cambule et al. 2014a, b; Emery and Ortiz 2007). Furthermore, traditional statistics, in combination with geographical information system (GIS), have been widely applied to assess spatial variability of soil properties, to provide soil maps and to supply information's susceptible to help farmers and even researchers to more understand the quality of each soil the plains of Doukkala.

Therefore, the specific objectives were (1) to map the soil digitally and understand the spatial variability of soil map (2) to estimate the spatial variability soil physicochemical properties such as organic matter (OM), pH soil, cation exchange capacity (CEC), potassium (K_2O), soil phosphorus (P_2O_5), and soil texture, were analyzed using classical statistics, geostatistical method and GIS techniques, (3) to assess the spatial variation and to produce thematic maps of properties soil using geostatistical kriging ordinaire and inverse distance weighting (IDW) approaches an agricultural ecosystem in irrigated plains of Doukkala.

Materials and methods

Study area and site description

The study is performed in the irrigated perimeter of the Doukkala plains in the region of Casablanca-Settat, Morocco. The Doukkala plains irrigated perimeter cover a surface of 61,000 ha irrigated land in the Perimeter called "low service". At the end of the development of

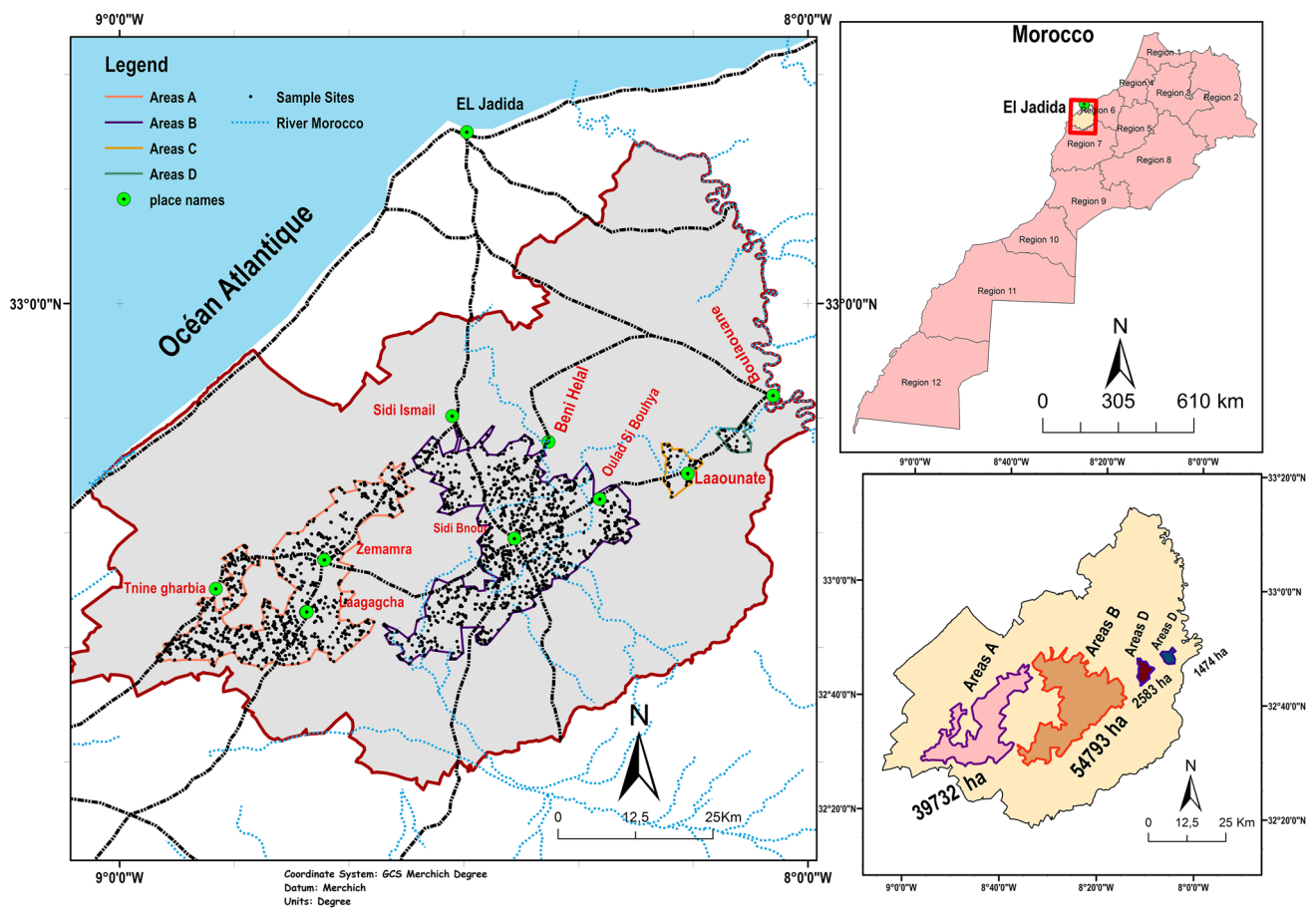


Fig. 1 Locations of the irrigated perimeter of plains the Doukkala in Morocco and the sampling sites

the Perimeter called “high service”, the total area irrigated will reach 125,000 hectares, localized between 7°55'00" and 9°15'00" West and between 32°15'00" and 33°15'00' North (Fig. 1).

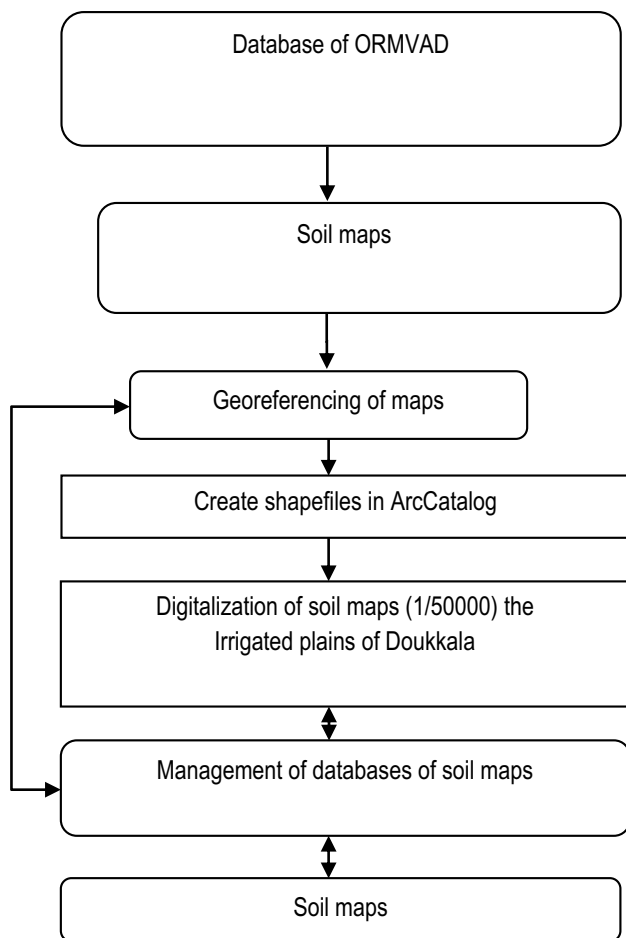
The province is characterized by a semi-arid climate, and hot in summer and relatively cold in winter, where the annual average temperature of 18.7 °C, and the annual precipitation is 300–400 mm (mean 322 mm), However, duration of sunshine average annual 3030 h (between 1000 h, winter 590 h), annual values high levels of evaporation (1700 mm), superior to the rainfall, the neighbouring hygrometry of 70–80% is important due to ocean winds and mists and of the permanent winds with average speeds ranging between 1.7 and 2.8 m/s.

The main water resource in the area comes from the rivers Oum Errabia in central Morocco. However, many farmers’ pumps water as a complementary resource from the perimeter of the plains the Doukkala groundwater system.

Data analysis

Soils of the plains of Doukkala

Georeferencing and digitizing of soil maps of the study area GIS data integration, and instrumentation has made it possible to achieve unprecedented reliability and utility in digital soil maps. In this study, the database of soil maps of the irrigated plains of Doukkala was obtained from the Regional Office for the implementation of the agricultural value of Doukkala (ORMVAD) conducted in the 1978s. However, soil maps geo-referenced and soil polygons were digitized from the 50,000 soil map, the mapping units of soils on the 50,000 soil map are soil families. In total, 27 polygons of soils were identified on the 50,000 soil map. The mapping units of soils offer opportunities to improve the prediction of the spatial distribution of nutrients. However, the methodological approach adopted is illustrated by the following chart:



Exploratory statistical analysis

The eight soil variables (OM, pH, CEC, K_2O , P_2O_5 , clay, sand and silt) under investigation were subjected to a descriptive statistical study using descriptive statistics to describe all variables, statistics estimators such as minimum, maximum, mean, standard deviation, coefficient of variation, and skewness were determined using STATISTICA 23. This can provide first-hand information to help us understand the variation of soil variables. However, normality tests, the Kolmogorov–Smirnov test was used to assess the normality of all variables, were conducted using Quantile–Quantile (Q–Q) plots and based on skewness values, was used to evaluate the normality of the data sets (Vasu et al. 2017; Goovaerts et al. 2005), of the soil physical–chemical properties of the soil fertility parameters are presented in Table 2.

Spatial variability mapping of soil with geostatistical analysis

The spatial variability of soil physicochemical properties from the Regional Office for the Implementation of the Agricultural Value of Doukkala (ORMVAD) a total of 1865 top-soil samples (0–20 cm) such as organic matter (OM), pH soil, cation exchange capacity (CEC), potassium (K_2O), soil phosphorus (P_2O_5), clay, sand and silt were estimated using geostatistical analyst in ArcGIS 10.3 for windows. The structure of the spatial variability including spatial variation modelling (variogram) was conducted to characterize the spatial distributions of parameters soil was assessed by calculating semivariograms by the formula (Goovaerts 1997; Outeiro et al. 2008; Webster and Oliver 2001; Vasu et al. 2017).

$$\gamma(h) = \frac{1}{2n(h)} \sum_{i=1}^{n(h)} [z(\chi_i + h) - z(\chi_i)]^2$$

where $\gamma(h)$ is the experimental semivariogram and $N(h)$ is the number of pairs of samplings sites $z(\chi_i + h)$ and $z(\chi_i)$ separated by h .

However, a map of the spatial distribution of the soil redistribution was produced using the ordinary kriging approach for data interpolation method. Spherical, was tested root mean square error (RMSE) technique was used to select the best kriging model (Li et al. 2011; Vasu et al. 2017). The RMSE was calculated using the following formula:

$$RMSE = \sqrt{\frac{1}{N} \sum_{i=1}^N \{\hat{z}(\chi_i) - z(\chi_i)\}^2}$$

Therefore, kriging is based on the assumption that the parameter being interpolated can be considered as a localized variable (Matheron 1963; Mabit et al. 2008). The ordinary kriging (OK) is an estimation technique known as the best linear unbiased estimator (BLUE) that has the great advantage of using the semivariogram information (Cressie 1993; Mabit et al. 2008). Concisely, the kriging is an advanced interpolation procedure generating estimated surfaces, and the interpolated methods of IDW which has one of the mostly applied and deterministic interpolation techniques in the field of soil science to determine the spatial variability (Umali et al. 2012; Choudhury et al. 2013; Li et al. 2013; Xu et al. 2013; Cambule et al. 2014a, b; Xin et al. 2016). In the inverse distance weighted (IDW), which assumes that each point has a local influence that decreases with distance (Bonham-Carter 1994; Di Virgilio et al. 2007), was also used to produce maps in order to have a comparison with the kriging method, were directly implemented using the spatial analysis module of ArcGIS 10.3, where the power

is 2 using a search radius of eight points based on the grid algorithm functions, which has been widely used to determine the spatial variability of parameters soil.

Data treatment with computer software

All the results were stored in a Microsoft Excel spread sheet. The descriptive parameters were calculated using SPSS 23.0 for Windows. All maps were produced using GIS software ArcMap 10.3 with Geostatistical analyst extension.

Results and discussions

Data analysis

Soils of the plain of the Doukkala

Georeferenced and digitizing of soil maps of the study area The georeferenced soil maps at 1:50,000 soils of the irrigated plain of the Doukkala and the map projection are of type Lambert Conic Conformal North Morocco Degree (datum: D Merchich).

The richness of the ground at a given time is not a function of the type of the soil only but depends on the history of fertilization of the parcel by against the standard of interpretation of the analysis of the soil is strongly dependent on the type of the soil. In effect, there are types of soils which set of nutrients more than another and on the other that release more than others.

In this sense, the plain of Doukkala has been the subject of several studies of soil type since 1947, all these

studies had for their objective the delineation and characterization of irrigable soils. These studies, carried out at different scales, were synthesized in 1978 by Goffroy Jean-Louis Geoffroy responsible for research ORSTOM-Soil Scientist DER in the form of map to the 1/50,000 (Badraoui et al. 1993). Our first component of this work has consisted in digitizing and assembling soil maps of the study area (Fig. 2). The main types of soils of the region are divided into six classes according to the French classification (CPCS 1967; Badraoui et al. 1993).

Area of the classes of the soils of the plain of doukkala Following the work of digitalization and assembly of soil maps, we calculated the size of each class of soils of the plains of Doukkala. The results obtained are data in (Table 1; Fig. 2) as a result.

- Aridisols:

There is specially ascendants in the Sidi Bennour of 10,800 ha, 16.5% of the total area (Fig. 3), and these types are represented by soils of low advanced input modal alluvial. In Boulaouane, Zemamra and soils advanced little are éolisés, Moreover, the maps of the Aridisols, an area in the northwest region of the study area, was observed also along both sides indicating a large patched distribution of the irrigated plain of Doukkala.

- Vertisols:

Fig. 2 Digital mapping the soil maps (1:50,000) in the plain irrigated of Doukkala

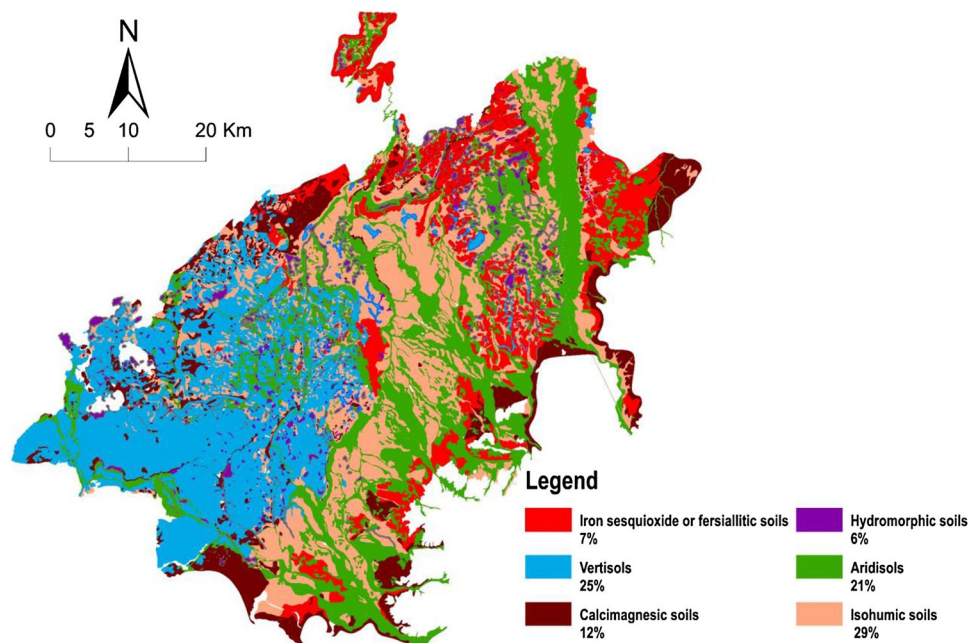


Table 1 Superficies the class of soils types in the study areas in the plain irrigated of Doukkala

| Class of soils | Area (ha) | % of total area |
|--|-----------|-----------------|
| Aridisols | 57921.92 | 20.71 |
| Vertisols | 69135.03 | 24.72 |
| Calcimagnesian soils | 33273.73 | 11.9 |
| Isohumic soils | 82806.79 | 29.61 |
| Iron sesquioxide or fersiallitic soils | 20121.37 | 7.19 |
| Hydromorphic soils | 16305.09 | 5.83 |
| Total | 279563.9 | 100 |

From the maps the Vertisols of the area the 18,250 ha, 30% of the scope of the bottom area (Fig. 3), localized mainly in the North West and South East, had also large spatial variation in the study the Zemamra and Tnine gharbia, the racks of Tnine Gharbia and Zemamra with deep shots, the firing shallow and firing sanded.

- Calcimagnesian soils:

The distribution the calcimagnesian soils represent the 5760 ha, 9.4% of the total area of the perimeter (Fig. 3). However, the maps of calcimagnesian soil showed a relatively patchy distribution the study areas, in the south and south-east area of the field, there is a relatively attributed the limit of plains irrigated the Doukkala.

- Isohumic soils:

With 21,970 ha representative of 36% the region of the study area (Fig. 3), there is a relatively attributed in the middle and

everywhere in the plain irrigated of Doukkala, but especially in the areas of Sidi Bennour, Sidi Smail and Zemamra.

- Iron sesquioxide or fersiallitic soils:

Regarding the spatial distribution of Iron sesquioxide or fersiallitic soils with the 4100 ha, or 6.7% (Fig. 3), it is found that the high distribution the soils attribute of plain in the north and northeast, were observed also in the limit South east of the study areas.

- Hydromorphic soils:

With 840 ha, they represent 1.4% of the irrigated plain of Doukkala (Fig. 3). Although, the spatial distribution of soil maps of the hydromorphic soils is not homogenous it was found that there was low spatial variation in the all study area.

Descriptive statistics and distribution the variability of soil physico-chemical properties

The descriptive statistics for the 1856 soil quality parameters are presented in Table 2. the variability was interpreted using the coefficient of variation (CV). However (Hillel 1980; Nielsen and Bouma 1985) classified the variability based on the coefficient of variations (CVs) of soil properties, as weak (lower 10%), moderate (10–100%) and strong (superior 100%) variability (Rosemary et al. 2017). as indicated by the coefficient of variation (CV), the our areas value for soil pH was 9, 91%, which indicated very low variation. Soil pH has often been found to be less variable than other soil properties (Liu et al. 2013a, b, 2016). However, the CV for soil P₂O₅, K₂O, CEC, and Silt, were 117.21; 45.84; 42.62 and 41.01 respectively, indicating

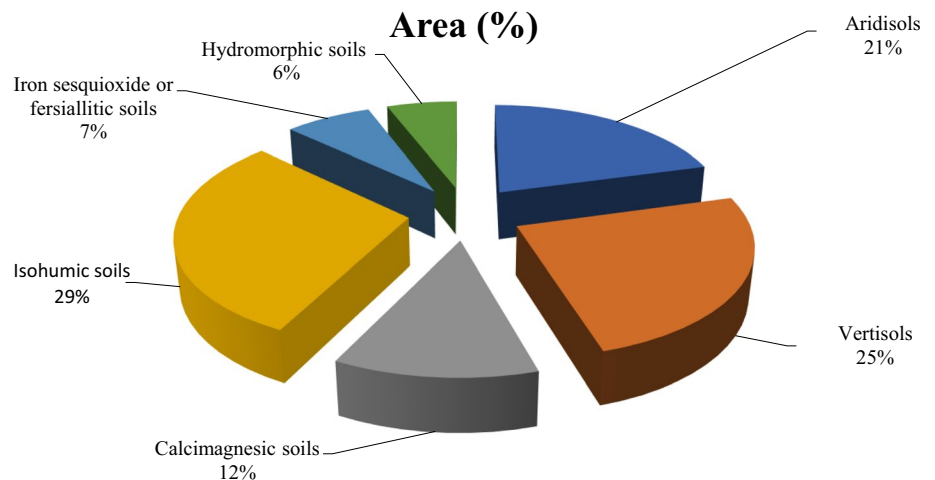
Fig. 3 Variation of soils types in the study areas in the plain irrigated of Doukkala

Table 2 Descriptive statistics of soil quality parameters

| Properties | OM | pH | CEC | K ₂ O | P ₂ O ₅ | Clay | Sand | Silt |
|------------------------|-------|--------|-------|------------------|-------------------------------|--------|-------|-------|
| N | 1856 | 1856 | 1856 | 1856 | 1856 | 1856 | 1856 | 1856 |
| Minimum | 0.35 | 4.8 | 2.8 | 41 | 2 | 5.5 | 19.4 | 2.00 |
| Maximum | 4.32 | 9.9 | 42.4 | 1133 | 809 | 54.8 | 91.4 | 76.00 |
| Mean | 1.46 | 8.15 | 22.40 | 190.40 | 45.27 | 29.31 | 56.40 | 14.25 |
| Median | 1.43 | 8.3 | 23.1 | 176 | 32 | 31 | 54.4 | 13.80 |
| Std. deviation | 0.48 | 0.81 | 9.55 | 87.28 | 53.06 | 10.25 | 13.21 | 5.84 |
| CV (%) | 33.08 | 9.91 | 42.62 | 45.84 | 117.21 | 34.96 | 23.43 | 41.01 |
| Skewness | 0.959 | −0.771 | −0.22 | 2.398 | 6.18 | −0.353 | 0.409 | 1.70 |
| Std. error of skewness | 0.057 | 0.057 | 0.057 | 0.057 | 0.057 | 0.057 | 0.057 | 0.06 |

high variation (Naman and Badraoui 2008). High variation in P₂O₅ may result from various planting patterns and the amount of fertilizer used in different areas, thus showing the great wealth of the soil phosphorus in all the plain irrigated Doukkala. However, Spatial variation was also remarkable for OM and the CVs of textural fractions, it implied a considerable variation. (CV higher than 30%). The larger variation of available P₂O₅, K₂O, CEC, OM and the texture of soil may be the result of extrinsic factors being more of an influence on these soil properties. The results also indicate high that is a consequence of the high heterogeneity of soil in the study area (Soudi et al. 1999).

In On other hand, descriptive statistical of the soil quality parameters are presented in Table 2, Mean values of the organic matter, pH, CEC, K₂O, P₂O, clay, sand and silt of the studied in the soil environment within the research area the irrigated of Doukkala were 1.46, 8.15, 22.40, 90.40, 45.27, 29.31, 56.40 and 14.25 respectively. This indicated a remarkable concentration of K₂O, sand and P₂O₅. Hence, the mean organic matter indicated the lowest organic matter percentage was observed in the soil irrigated of the plain of Doukkala. However, the organic matter content of a soil is a function of the relative rates at which organic materials are added to the soil and lost from it through decomposition (Oleschko et al. 1996). All of the irrigated plains of Doukkala have suffered from intensive agricultural cultivation, failure of management of crop residues and conditions of temperature and irrigation ensuring conditions thermal and water are optimal for mineralization. Which has resulted in relatively lower OM, both in terms of content and variability (Gana 2002).

The normal distribution was estimated on skewness base: for a skewness range between −1 and 1 data were considered normally distributed (Table 2). Hence, the skewness (<0.5) of soil properties indicated the approximate normal distributions of data (Rosemary et al. 2016), the positive skewness of Organic matter, K₂O, P₂O₅, sand and silt were 0.95, 2.39, 6.18, 0.40 and 1.70 respectively, and with negative coefficient varying between −0.77 and −0.22 (Table 1) these results may be associated with massive fertilizer applications

in recent decades in the irrigated plain of Doukkala (Liu et al. 2014).

Test the normality for the whole data set In this test the normality for database, we will briefly discuss the following tools to determine if our data is “normal”: Histogram for data, Normal quantile–quantile (Q–Q) plots were produced for identification of probability and obvious outliers (extreme values) (Fu et al. 2010). However, the Normal Q–Q plots were produced for database for the organic matter, pH, CEC, K₂O, P₂O, Clay, sand and silt (Fig. 4). In other hence, CEC, sand, clay, silt and pH, followed a straight diagonal line except for a few samples slightly deviated from the majority at both ends, Should visually indicate that our data are approximately normally distributed, in terms of histograms and normal Q–Q plots and box plots (Figs. 4, 5) which was confirmed by test of the Kolmogorov–Smirnov (K–S) significance value (0.005) method was applied to evaluate the normality of data sets, as asymmetry in the distribution of data has an important effect on the geostatistical analysis (Kerry and Oliver 2007; Fu et al. 2010) and the degree to which a given data set follows a specific theoretical distribution (such as normal, uniform, or Poisson). It is based on the largest absolute difference between the observed and the theoretical cumulative distribution functions (Zhang et al. 2005) the organic matter, K₂O and P₂O This data does not fit the normal distribution it fits a different distribution.

Semi variance analysis and spatial dependence of the variables with geostatistical analysis

In this study, geostatistical methods consists of analyze this spatial structure and spatial autocorrelation and has been useful to determine spatial distribution of soil by the variogram (Mabit et al. 2008). Accordingly, ordinary kriging was used to assess the spatial variability of various soil of 8 variables for parameters at irrigated plain of Doukkala (organic matter, pH, CEC, K₂O, P₂O₅, clay, salt and silt).

Based on the lowest RMSE value and r² (Table 3) discusses R-squared and the regression standard error to assess

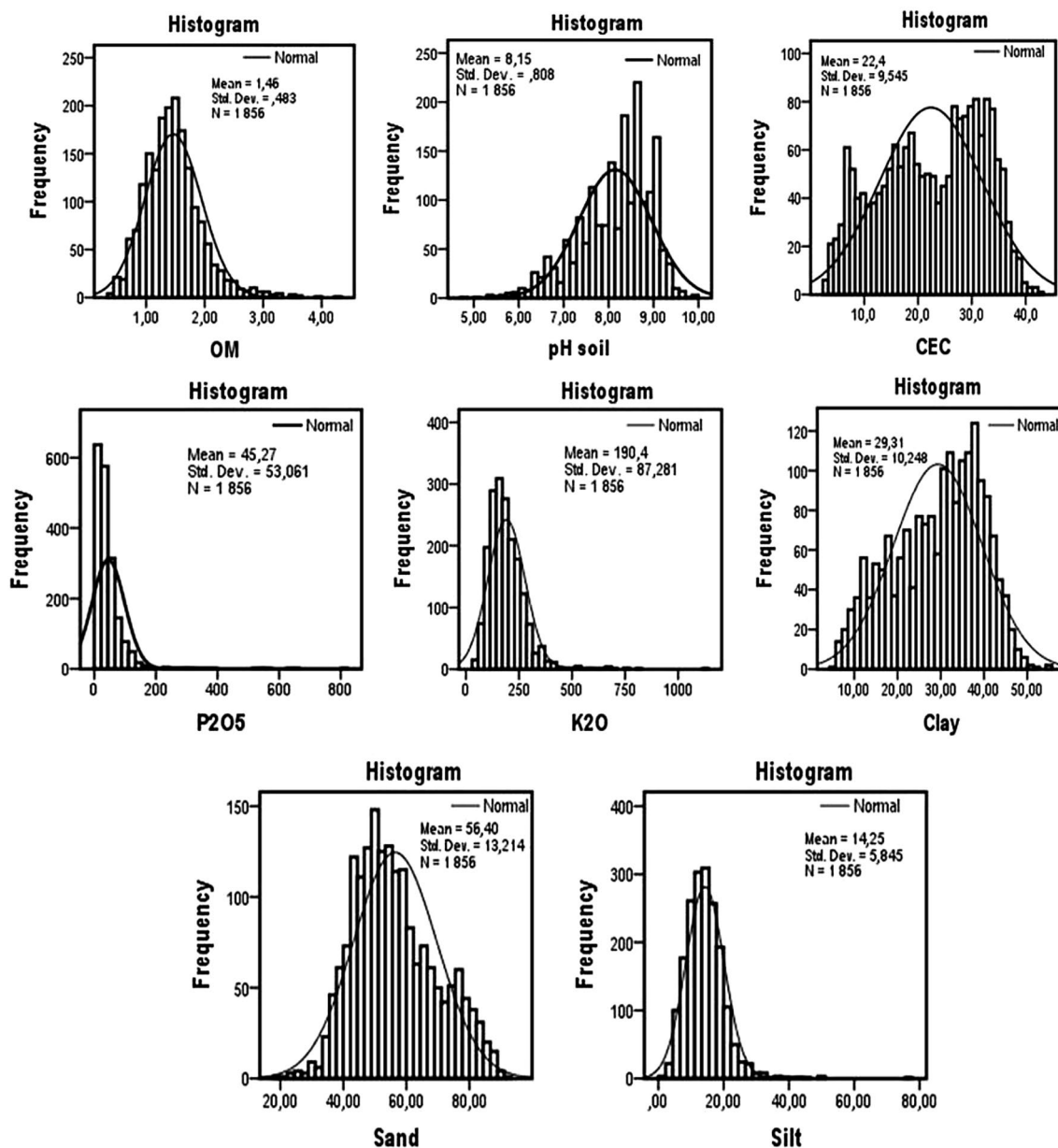


Fig. 4 Histogram the database 8 of soil variables (N = 1856)

model fit, the model's ability to explain the variance in the dependent variable, thus properties of calculated semivariograms are presented in Fig. 6 for fertility parameters to indicate different degree of spatial dependence. However, geostatistical methods were used in this study to characterize spatial variability by Spherical model the most commonly used (Di Virgilio et al. 2007) (Table 3), on the other hand, the sill represents the variance of the variable and Nugget could represent the measurement error or some variation at small scale this classes used to define spatial dependence of variable, the nugget: sill ratio indicates what percent of the overall variance is found at a distance smaller than

the smallest lag interval, and gives a sense of how much variance you have successfully accounted for in the model. However, when there is a pattern present in the distribution, variance will increase with comparisons of close, autocorrelated samples, but will level off to form a sill when samples become independent. the nugget to sill (N:S) ratio, low ratio (<25%) means that a large part of the variance is introduced spatially, implying a strong spatial dependence (S) of the variable, ratio was between 25 and 75%, the parameter was considered moderately spatially dependent (M). A high ratio (>75%) often indicates weak spatial dependency (W) (Cambardella et al. 1994; Dai et al. 2014).

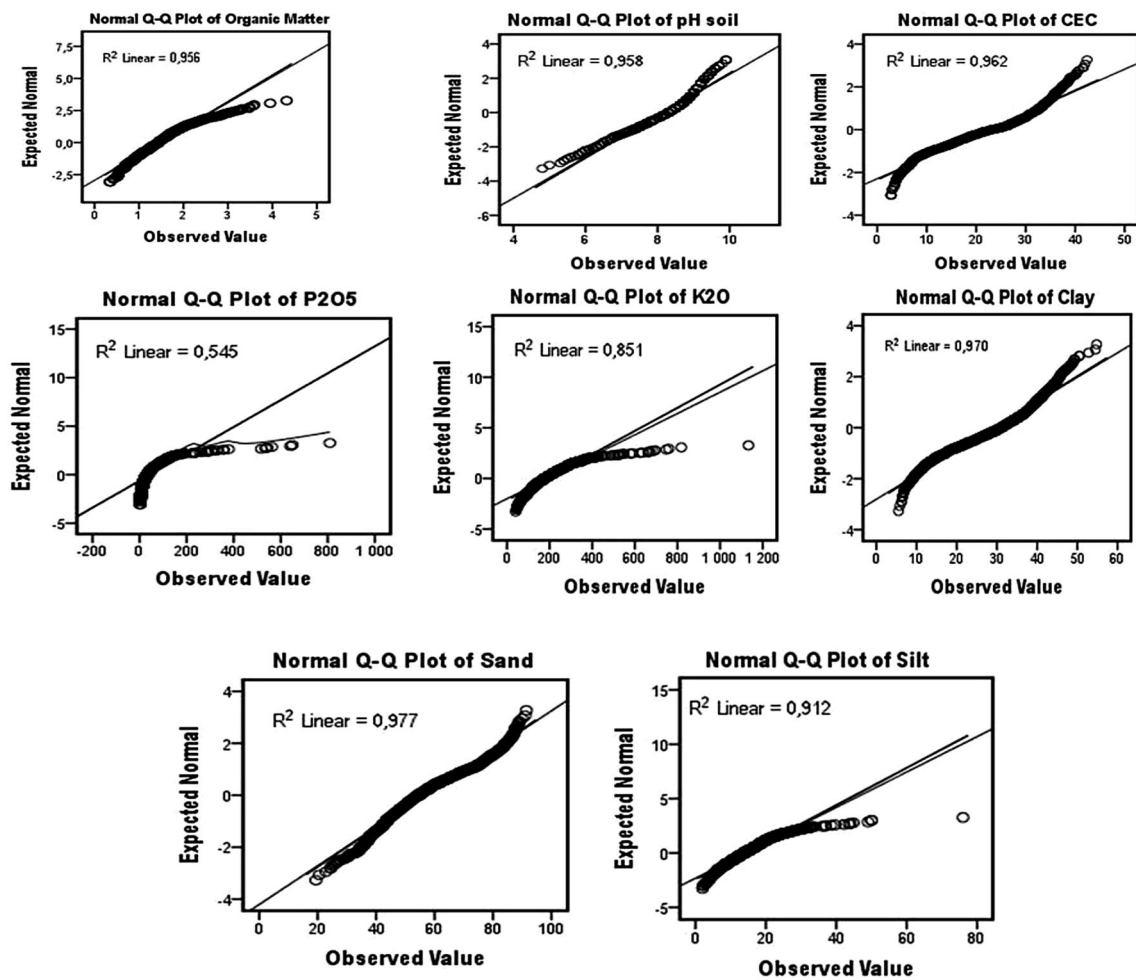


Fig. 5 Normal Q–Q plots the database 8 of soil variables (N = 1856)

The semivariogram in first case is a linear trend with positive slope in all the cases, which means spatial structure analysis indicated spatial variability across the study area showed that semivariance organic matter, pH, CEC, K₂O, P₂O₅, clay, sand and silt in areas A and Areas B, respectively, increased with distance to a constant value (sill). For the other areas C and D for eight variables for parameters (organic matter, pH, CEC, K₂O, P₂O₅, clay, salt and silt). However, this provides a set of semivariance values for distance lags, h, increasing to value somewhat less than the greatest distance, that representing that a severe variety value could be identified outside the field scope, or that the number of samples were too few to extrapolate the spatial dependence (Cambardella and Karlen 1999; Di Virgilio et al. 2007).

Based on nugget/sill ratio (Cambardella et al. 1994), heterogeneity observed in the distribution of area, in different classes the spatial dependence of eight variables for parameters may be evaluated. All these parameters were considered to have between moderate, weak and strongly spatial

dependent (Table 4). Their spatial dependence for organic matter, pH, CEC, clay sand and silt in areas A and areas B, respectively, was moderate and the weakly spatial dependence for organic matter, pH in area C and D. There are many possible causes for spatial variability included extrinsic and intrinsic causes of variability of soil, also environmental heterogeneity and the spatial climatic variability (Zhang et al. 2007). However, sand and silt was the moderate spatial dependence for the four areas, strong spatial dependence for silt in areas D, P₂O₅ was considered moderately spatially dependent for areas A and areas D, and weakly spatially dependent for areas B and areas C. Which the first is that it would probably be assigned to a variable rates of fertilization during the growing season (Rüth and Lennartz 2008). However, their spatial dependence is very likely due to multiple factors, such as may be attributed to both intrinsic factors, soil properties and extrinsic factors and anthropic disturbances activities (Liu et al. 2013a, b). As a consequence, the spatial variability of soil properties fire must be affected by intrinsic factor such as, soil formation factors and soil

Table 3 Summary statistics of models of ordinary kriging for parameters

| Soil property | Areas | Semivariogram model | r^2 | RMSE |
|-----------------------------------|---------|---------------------|-------|-------|
| OM | Areas A | Spherical | 0.954 | 0.297 |
| | Areas B | Spherical | 0.934 | 0.306 |
| | Areas C | Spherical | 0.879 | 0.321 |
| | Areas D | Spherical | 0.883 | 0.260 |
| pH | Areas A | Spherical | 0.958 | 0.593 |
| | Areas B | Spherical | 0.961 | 0.728 |
| | Areas C | Spherical | 0.956 | 0.794 |
| | Areas D | Spherical | 0.973 | 1.006 |
| Log CEC | Areas A | Spherical | 0.926 | 0.76 |
| | Areas B | Spherical | 0.970 | 0.72 |
| | Areas C | Spherical | 0.944 | 0.57 |
| | Areas D | Spherical | 0.971 | 0.37 |
| Log K ₂ O | Areas A | Spherical | 0.874 | 1.84 |
| | Areas B | Spherical | 0.832 | 1.94 |
| | Areas C | Spherical | 0.851 | 1.76 |
| | Areas D | Spherical | 0.768 | 1.82 |
| Log P ₂ O ₅ | Areas A | Spherical | 0.812 | 1.45 |
| | Areas B | Spherical | 0.494 | 1.80 |
| | Areas C | Spherical | 0.812 | 1.59 |
| | Areas D | Spherical | 0.835 | 1.73 |
| Log clay | Areas A | Spherical | 0.943 | 0.80 |
| | Areas B | Spherical | 0.979 | 0.84 |
| | Areas C | Spherical | 0.965 | 0.72 |
| | Areas D | Spherical | 0.956 | 0.52 |
| Log sand | Areas A | Spherical | 0.962 | 0.92 |
| | Areas B | Spherical | 0.977 | 0.94 |
| | Areas C | Spherical | 0.966 | 1.01 |
| | Areas D | Spherical | 0.927 | 0.50 |
| Log silt | Areas A | Spherical | 0.99 | 0.55 |
| | Areas B | Spherical | 0.853 | 0.67 |
| | Areas C | Spherical | 0.949 | 0.80 |
| | Areas D | Spherical | 0.970 | 0.16 |

parent material. Aside from this, soil would be substantially affected by soil texture, precipitation, temperature, vegetation and human activities (Liu et al. 2013a, b) and extrinsic (soil management, such as fertilization) factors (Rüth and Lennartz 2008). Usually, strong spatial dependence of soil properties can be attributed to intrinsic factors, and weak spatial dependence can be attributed to extrinsic factors (Cambardella et al. 1994) (Table 4).

Generally, strongly spatially were determined following properties likely to be controlled by both intrinsic factors, soil characteristics, while extrinsic factors may control the variability of these weakly spatially dependent parameters (Cambardella et al. 1994).

Spatial pattern of soil properties in such agricultural soils may be partly attributed to the manipulations of intensive management practices such as increased amounts of fertilizers, different management practices adopted by farmers that have been designed to reduce spatial pattern of soil, including type, the increased amounts of pesticides and saline waters (Jalali 2007). In other hand, Semivariogram was calculated to examine the spatial correlation within the spatial correlation between soil properties and the range of variogram be used to indicate the degree of spatial correlation of soil properties (Ayoubi et al. 2007; Rosemary et al. 2017), therefore, the range of the semi-variograms was the distance (h) of spatial dependence were of values the Organic matter varied from 3891 m to 2243 m for 4 areas, 7658 m to 1142 m, 3871 to 618, 9356 m to 2338 m, 9755 m to 771 m, 2462 m to 1409 m, 2907 m 1836 m, 5163 m to 88 m of pH, CEC, K₂O, P₂O₅, clay, sand and silt, respectively, the ranges of their spatial correlation were small (Table 4), were relatively small, 9755 m and 618 m, the ranges of spatial dependence were the highest for pH, K₂O and P₂O₅. Accordingly, soil spatial variability is present over a long range indicates that mechanisms by which these factors may have affected soil property of large spatial dependence factors such as vegetation, the greater the frequency over distances than soil properties that have the smaller range and the estimates of the range has revealed much about nature on the largest scales (Dai et al. 2014).

Generally, this spatial heterogeneity of range indicating that greater heterogeneity in the upper soil layers, this could be suggesting that environmental heterogeneity and human disturbances that mainly affected the surface soil layer (Cambardella et al. 1994).

Spatial variability mapping

In the distribution map of various soil parameters, the organic matter (a), pH soil, CEC, P₂O₅, K₂O, Clay, Sand, and Silt derived by kriging ordinaire (KO) and IDW is shown in Figs. 7 and 8. The mean contents of OM, pH, CEC, P₂O₅, clay, sand and silt were 1.46, 8.15, 22.40, 190.40, 45.27, 29.31, 56.40, 14.25 respectively. Moreover, the heterogeneity observed in the distribution map of 4 area in different soil parameters (Figs. 7, 8). the results indicate that the values of organic matter in the north an area A, areas B, and areas C of content the range from 2.2 to 3.1 and high content in the south areas D. low content of organic matter was observed south east of areas A, areas B, and areas C and low content for areas D in the study area. However, the frequency distribution of organic matter in the study areas was very low, generally, the ranged content in soil organic matter is low in the order of 1.3%, the majority of the soils are very poor in organic matter (< 1.5%) (Naman 2003; Badraoui 2006).

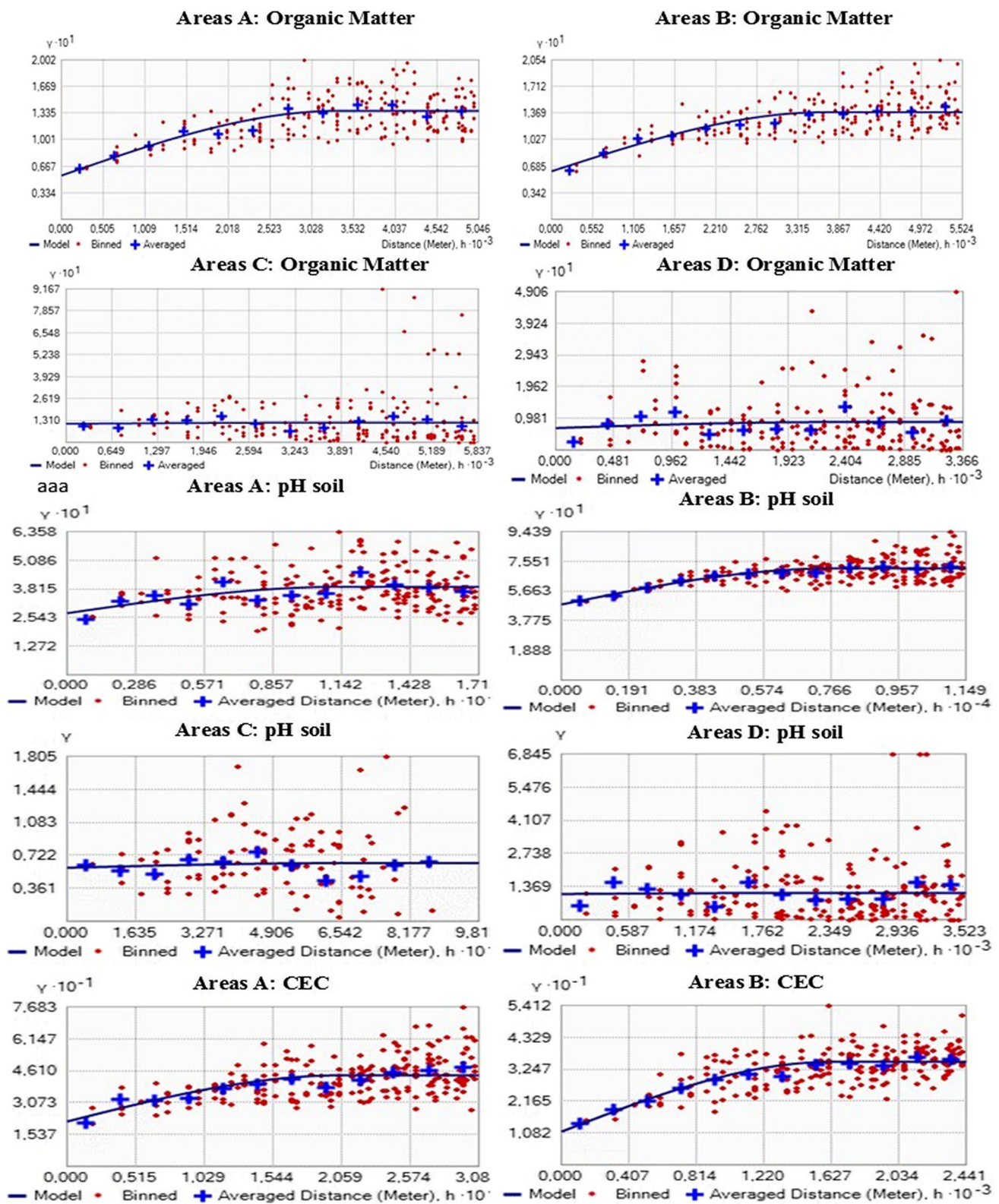


Fig. 6 Calculated semivariograms of soil properties based on RMSE and r^2 values

The spatial distribution of pH in the study area indicates that the pH soil the range from 8.2 to 9.2 was observed for

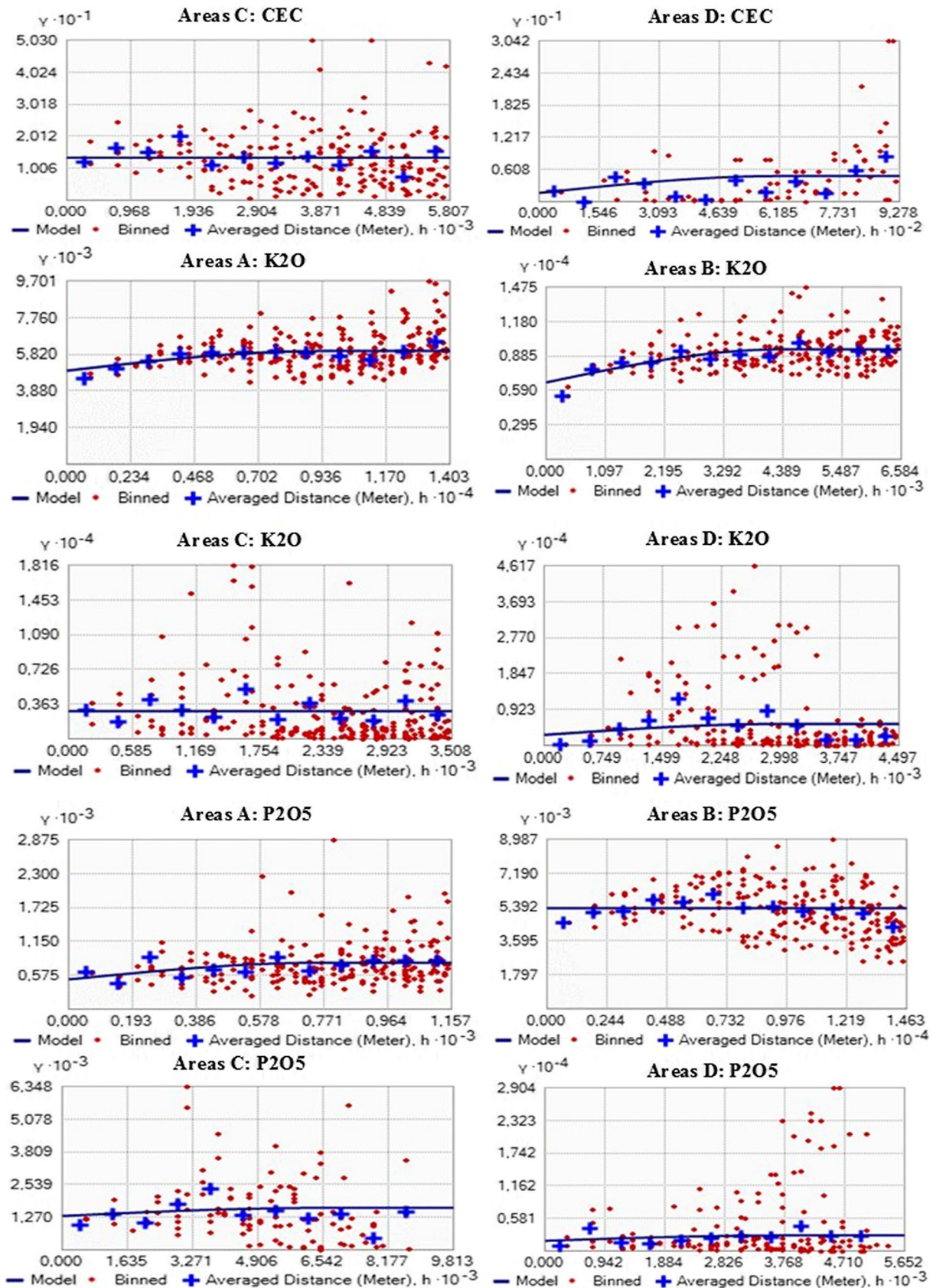


Fig. 6 (continued)

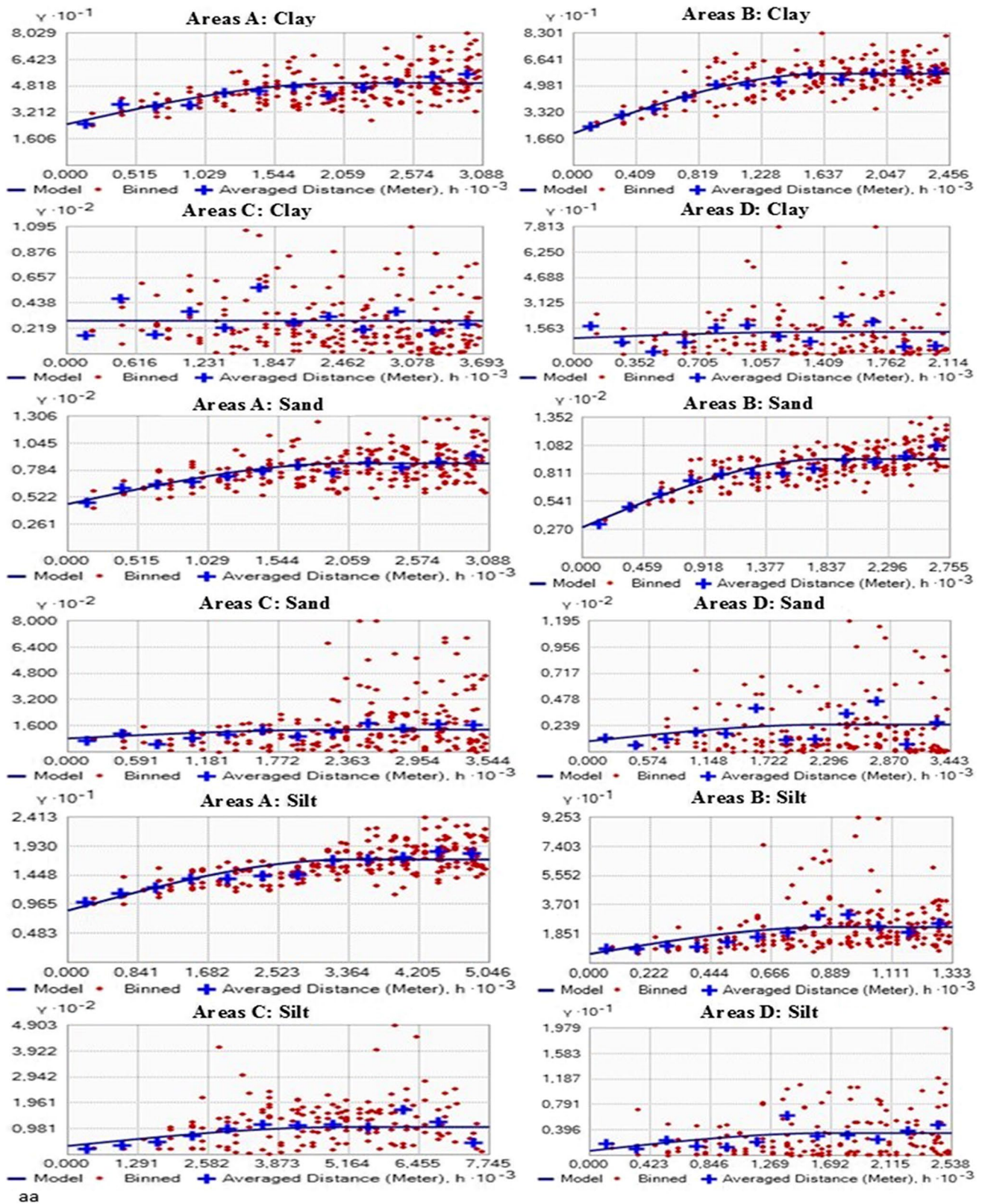


Fig. 6 (continued)

Table 4 Semivariogram model the parameters of soil properties

| Soil property | Areas | Semi-variogram model | Lag distance (m) | Rang(m) | Nugget (C0) | Partial sill (C) | Sill (C0+C) | Nugget/sill ratio | Spatial dependency |
|-------------------------------|---------|----------------------|------------------|---------|-------------|------------------|-------------|-------------------|--------------------|
| Organic Matter | Areas A | Spherical | 420.521 | 3364 | 0.055 | 0.081 | 0.136 | 0.404 | Moderately |
| | Areas B | Spherical | 460.374 | 3682 | 0.062 | 0.076 | 0.138 | 0.449 | Moderately |
| | Areas C | Spherical | 486.422 | 3891 | 0.111 | 0.006 | 0.117 | 0.949 | Weakly |
| | Areas D | Spherical | 280.466 | 2243 | 0.068 | 0.018 | 0.086 | 0.791 | Weakly |
| pH | Areas A | Spherical | 142.789 | 1142 | 0.273 | 0.117 | 0.390 | 0.700 | Moderately |
| | Areas B | Spherical | 957.306 | 7658 | 0.481 | 0.229 | 0.710 | 0.677 | Moderately |
| | Areas C | Spherical | 817.738 | 6541 | 0.585 | 0.051 | 0.636 | 0.920 | Weakly |
| | Areas D | Spherical | 293.595 | 2348 | 1.064 | 0.049 | 1.113 | 0.956 | Weakly |
| CEC | Areas A | Spherical | 257.373 | 2058 | 21.633 | 22.265 | 43.898 | 0.493 | Moderately |
| | Areas B | Spherical | 203.416 | 1627 | 11.283 | 23.680 | 34.963 | 0.323 | Moderately |
| | Areas C | Spherical | 483.927 | 3871 | 13.390 | 0.000 | 13.390 | 1.000 | Weakly |
| | Areas D | Spherical | 77.313 | 618 | 1.659 | 3.192 | 4.851 | 0.342 | Moderately |
| K ₂ O | Areas A | Spherical | 1169.509 | 9356 | 4951.000 | 1039.000 | 5990.000 | 0.827 | Weakly |
| | Areas B | Spherical | 548.670 | 4389 | 6590.000 | 2830.000 | 9420.000 | 0.700 | Moderately |
| | Areas C | Spherical | 292.334 | 2338 | 2912.000 | 0.000 | 2912.000 | 1.000 | Weakly |
| | Areas D | Spherical | 374.726 | 2997 | 2719.000 | 2818.000 | 5537.000 | 0.491 | Moderately |
| P ₂ O ₅ | Areas A | Spherical | 96.409 | 771 | 505.000 | 284.000 | 789.000 | 0.640 | Moderately |
| | Areas B | Spherical | 1219.424 | 9755 | 5325.000 | 0.000 | 5325.000 | 1.000 | Weakly |
| | Areas C | Spherical | 817.738 | 6541 | 1320.000 | 312.000 | 1632.000 | 0.809 | Weakly |
| | Areas D | Spherical | 471.038 | 3768 | 1841.000 | 983.000 | 2824.000 | 0.652 | Moderately |
| Clay | Areas A | Spherical | 257.373 | 2058 | 24.977 | 24.922 | 49.899 | 0.501 | Moderately |
| | Areas B | Spherical | 204.650 | 1637 | 20.170 | 37.250 | 57.420 | 0.351 | Moderately |
| | Areas C | Spherical | 307.763 | 2462 | 28.520 | 0.000 | 28.520 | 1.000 | Weakly |
| | Areas D | Spherical | 176.150 | 1409 | 9.685 | 3.860 | 13.545 | 0.715 | Moderately |
| Sand | Areas A | Spherical | 257.373 | 2058 | 45.660 | 39.240 | 84.900 | 0.538 | Moderately |
| | Areas B | Spherical | 229.582 | 1836 | 29.220 | 65.670 | 94.890 | 0.308 | Moderately |
| | Areas C | Spherical | 295.357 | 2362 | 82.420 | 53.470 | 135.890 | 0.607 | Moderately |
| | Areas D | Spherical | 278.335 | 2907 | 9.120 | 17.760 | 26.880 | 0.339 | Moderately |
| Silt | Areas A | Spherical | 420.521 | 3364 | 8.600 | 8.440 | 17.040 | 0.505 | Moderately |
| | Areas B | Spherical | 111.077 | 888 | 5.880 | 16.980 | 22.860 | 0.257 | Moderately |
| | Areas C | Spherical | 645.454 | 5163 | 33.060 | 71.550 | 104.610 | 0.316 | Moderately |
| | Areas D | Spherical | 211.523 | 1692 | 0.718 | 2.750 | 3.468 | 0.207 | Strongly |

all the study areas and the mean value of soil (8.15–8.5) was found in study areas, low pH values were located along the east boundary in areas A, and Areas B, the west part of the areas C and areas D the study site. Accordingly, the pH soil of Doukkala is weak to moderately basic on their surface horizons. However, in deep Horizons, pHs are moderately alkaline (Gana 2002). These results are also comparable with those of El Bouzaoui (2006). Another high soil CEC area of the range 32–40 was found in the areas A, north west and south east of areas B in the range 25–34, in the areas C were the high value also in the north and south in the areas D. Cation exchange capacity (CEC) is a key parameter indicating soil nutrient conservation and buffering capacity (Liu et al. 2014; Tang et al. 2009), and its decrease always

results in soil degradation for acid paddy fields (Noble et al. 2000). High soil K₂O concentrations were observed in the southern in the areas A and north part of the areas B in the study area and the high concentration also east area C and the middle areas D, while low soil K was located in the northern and east, areas A, areas D and areas C part of the study area. While low soil K was located in the study area. For the low soil K₂O area, appropriate K fertilizer is also needed to improve soil fertility (Fu et al. 2010).

The distribution map of P₂O₅ showed high concentrations in southeast in areas A, areas B, areas C and areas D and low concentrations in South in the study areas, Additionally, the most of the area is characterized by P₂O₅ ranging from 6 to 32 (mg/kg) for areas A, 17–46 (mg/kg) for

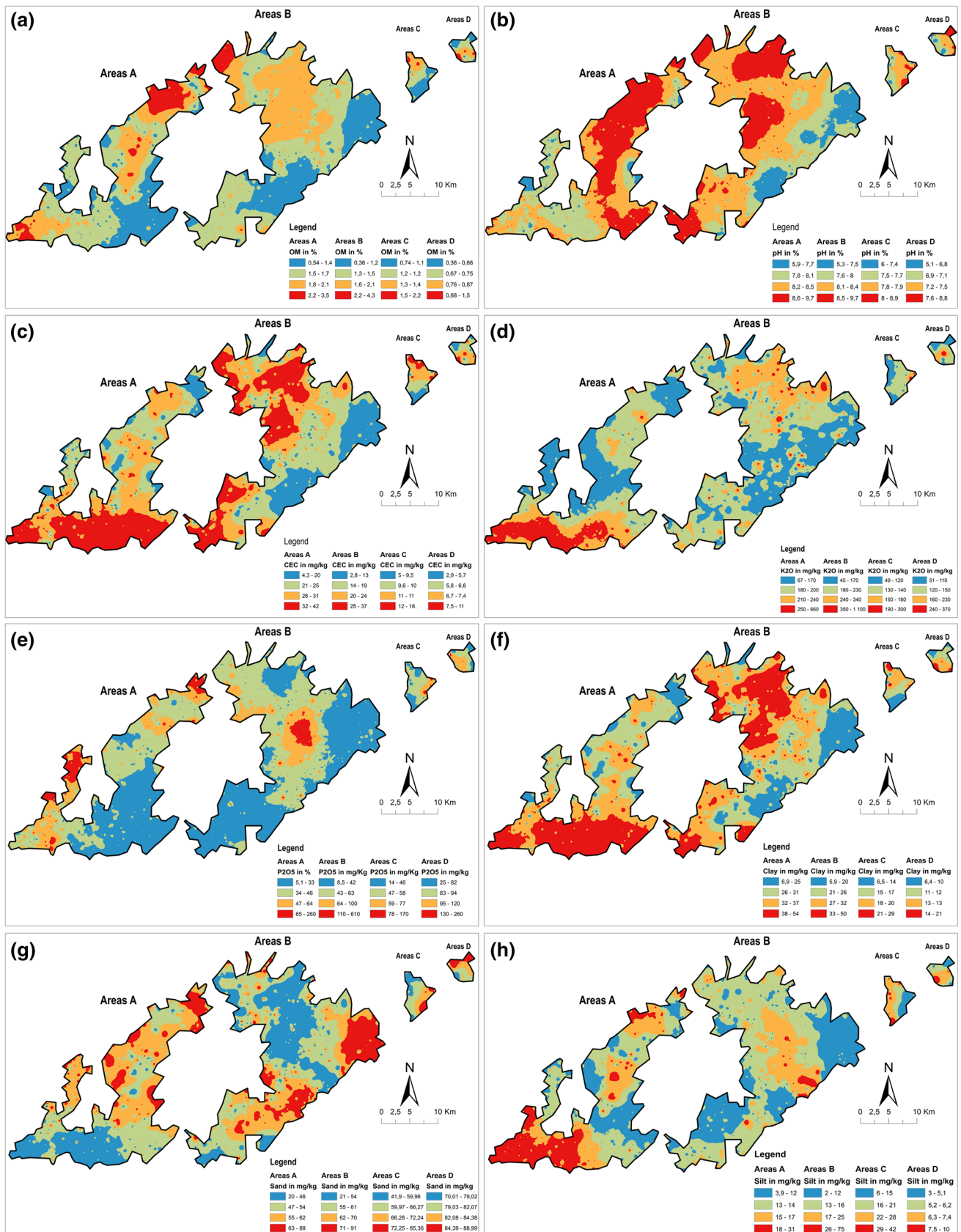


Fig. 7 Spatial variability maps of organic matter (a), pH soil (b), CEC (c), K₂O (d), P₂O₅ (e), clay (f), sand (g) and silt (h) derived from IDW

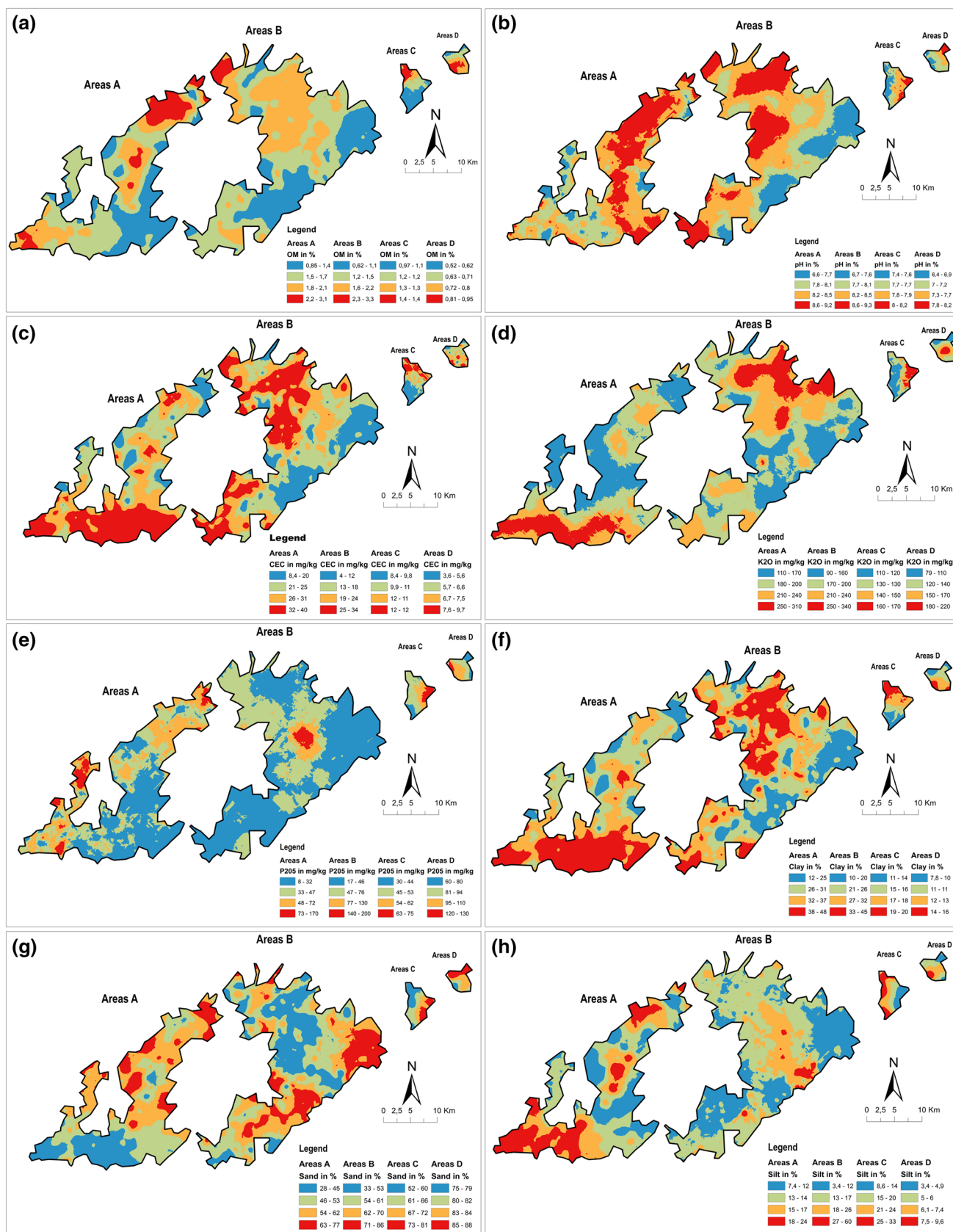


Fig. 8 Spatial variability maps of organic matter (a), pH soil (b), CEC (c), K₂O (d), P₂O₅ (e), clay (f), sand (g) and silt (h) derived by kriging ordinaire

areas B, 30–44 (mg/kg) for areas C and 60–80 (mg/kg) for areas D, attributed at the irrigated plain of Doukkala, this may be related to great wealth of the soil phosphorus in all the irrigated plain of Doukkala. This wealth can be linked to an external supply of phosphorus by the chemical fertilizers. This may be related to unbalanced P fertilizer application (Gao et al. 2001). However, the distribution map of clay indicates that clay height value the ranged from 38 to 54 (mg/kg) in the south in areas A and low to medium in north. Areas B was relatively, high value in the north and south the ranged from 33 to 50 (mg/kg) in the, also clay was low to medium in most of the areas C and areas D. Additionally, soil texture is one of the most important properties that influence most of the soil functions such as cation exchange, nutrient and water retention (Rosemary et al. 2017) and leaching of plant nutrients. In other hand, interpolated maps of sand showed that the high value in the northeast in areas A, areas B and areas D, also low value the ranged from 30 to 46 in south areas A and the north areas B and areas C. Generally, the heterogeneity observed in the distribution map of Sand for 4 areas in different with the frequency distribution de ranged from 55 to 62 (mg/kg) in areas a 66–72 (mg/kg) in areas B 79–82 (mg/kg) for areas C. Moreover, in the south areas A showed the high value of silt the ranged from 18 to 31, the frequency distribution the ranged 16–21 (mg/kg) were observed in almost the entire study for areas B, areas C, areas D indicate. Accordingly, several studies have shown that agricultural intensification under irrigation frequently leads to soil degradation (Mathieu 1996; Rullan 2003; Badraoui et al. 1998). The quality of irrigation water, depending on the texture and drainage potential of the soil greatly influences the rate of soil degradation (Umali et al. 2012).

Conclusion

In the present study, classic statistical analysis showed all distribution of soil properties (OM, CEC, P_2O_5 , K_2O , clay, sand, and silt) except pH, coefficient of variation (CV) indicated that OM, P_2O_5 , K_2O , CEC, and physical (texture) parameters indicating high variation. All properties except sand percentage did not follow normal distribution in the irrigated plain of Doukkala. Hence, it could be attributed to farm management practices such as fertilizer addition and intensive cultivation. However, geo-statistical analysis used to evaluate spatial variability, showed that heterogeneity observed in the distribution all area of parameters was considered to have between moderate, weak and strongly spatial dependent, therefore, the range of the semi-variograms chemical physical (texture) properties was the distance (h) of spatial dependence varied from 618 to 9356 m. In addition,

the distribution map of various soil parameters, the organic matter (a), pH soil, CEC, P_2O_5 , K_2O , clay, sand, and silt derived by kriging ordinaire (KO) and IDW indicate the heterogeneity observed in the distribution map of four study area. This study indicates that intrinsic factors, such as the texture, and extrinsic factors, such as soil fertilization and cultivation practices.

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Compliance with ethical standards

Conflict of interest The author declares no conflict of interest.

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