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Using Pedotransfer Functions to Assess Aggregate Stability: Application to the Lower Cheliff Soils, Algeria

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Authors' contributions

This work was carried out in collaboration between all authors. All authors read and approved the final manuscript.

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ABSTRACT

Soil physical properties have been subjected to a growing number of studies in recent decades. Although, these parameters can be measured directly, their measurement is difficult and expensive, especially in terms of time, sampling date, storage and cost of measurement. Overcoming these difficulties is through the development of pedotransfer functions (PTFs), which predict soil physical properties from other soil parameters. The main objective of this study was the establishment of PTFs through more easily accessible soils parameters, in order to predict soil aggregate stability by using the mean weight, diameter (MWD) and provide information about the behaviour of soil aggregation under the impact of rainfall or irrigation. PTFs selected according to various classifications were applied to the lower Cheliff soil. Results showed the existence of diverse classes of aggregate stability in the study area, varying from unstable to highly stable soils and also a varying relationship between measured and estimated aggregate stability according to soil classification and predicting model with a coefficient of determination varying from 0.67 to 0.94, the highest relationships were shown by clayey soils and soils containing a high organic matter percentage.

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1. INTRODUCTION

Soil physical properties are key aspects in determining soil quality [1]. Among the diverse soil properties, soil structure is of great importance, it has a major influence on most soil functions, such as root development, water retention, infiltration capacity and soil porosity [2,3,4], consequently affecting soil productivity and environmental quality ([5,4]. Soil structure is a complex soil property, related to inherent characteristics of particle size and clay mineralogy. According to [6] soil structure can be described in terms of structural form (arrangement of pores and solids), aggregate stability (ability of soil to retain its structural form after exposure to stress) commonly estimated by the mean weight diameter (MWD) [7] and structural resilience or vulnerability (ability of soil to recover its structural form through natural processes). However, although the soil structure can be measured directly, data collection is difficult, time consuming and rather costly, also soil properties can be highly variable spatially and temporally, so there is a continuous interest in the establishment of mathematical relations that can predict soil physical properties from other more easily measured soil properties [8,9,10]. According to [11], these mathematical relations are statistical regression equations expressing relationships between soil properties. [12] proposed the term transfer functions and later pedotransfer functions PTFs [13]. These models regularly used recently in research and management have been developed to improve the understanding of important soil processes [14]. Several attempts have been made to estimate indirectly soil properties from more easily measurable and available soil properties such as particle size distribution (sand, silt and clay), organic matter, density and porosity [15]. According to [16], PTFs can be characterized into three main groups namely class PTFs, continuous PTFs and neural network. [17] distinguished between class and continuous PTFs. Class PTFs predict soil properties according to the class (textural, horizon, etc.) to which the soil sample belongs, and continuous PTFs predict soil properties as continuous functions of one or more measured variables. Finally, the neural network is an attempt to build a mathematical model that supposedly works in an analogous way to the human brain. It consists of many elements connected by communication channels carrying numeric data organized into layers [18,14]. Most PTFs have been developed to predict the hydraulic properties of the soil, while, the assessment of other soil parameters is rather poor. In this context, the aim of this study carried out in the lower Cheliff plain was the assessment of aggregate stability by using class PTFs. These functions are established on the basis of validation criteria according to various classifications, then, adjusted and applied to the lower Cheliff soils, and consequently mapping the aggregate stability along the study area by using geostatistics.

2. MATERIALS AND METHODS

2.1 Study Area

The lower Cheliff plain is one of the largest salted alluvial plains of Northwestern Algeria (Fig. 1) covering approximately 400 km^2. This plain, located between 35º 48' 03'' - 36º 05' 36'' N of latitude and 0º29' 11'' - 1º 00' 00'' E of longitude, is about 35 km inland from the Mediterranean Sea, with an average altitude of 70 m. It is a Syncline framed on the north by Dahra hills and Benziane hills on the South, both characterized by clayey silt, schist and salted marls [19]. This plain consists of non-climatic, immature and halomorphic soils with a saline efflorescence [20], mainly of Fluviosols and Salisols types according to French pedological referential [21], developed on quaternary alluvium rich in lime and clay [22]. The clay fraction (less than 2 µm) consists essentially of illite with a predominance of irregular, swelling and interbedded smectite/illite type [23,9]. These geological characteristics, accentuated by an arid climate with an average annual temperature of 20ºC, a dry period of 7 months, a high evapotranspiration rate, and a weak annual rainfall (approximately 200 mm/year), explain the high salinity conditions of the plain [24].

2.2 Data Collection

Sampling locations were selected after preliminary studies of a topographic map, a total of 183 soil samples were collected in the study area from the first horizon at a depth of 20 cm. In order to be used as statistical regressors, measured soil factors were of physical nature (C = Clay, S_L = Silt, S_A = Sand) and chemical nature (Electrical conductivity (EC), Calcium carbonate ($CaCO_3$), $pH_{soil/water}$, organic matter (OM), Metson

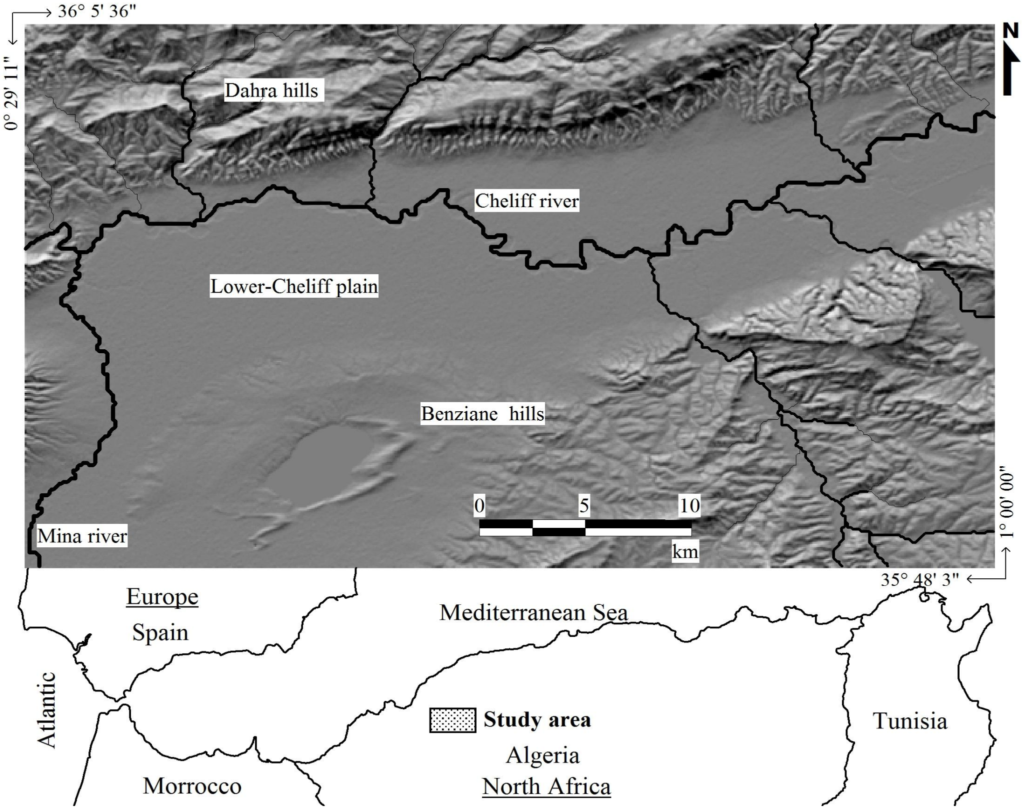

Fig. 1. Location of the study area

cation exchange capacity (CEC_m) and effective cation exchange capacity (CEC_e), analysed according to [25].

Before calculating the descriptive statistics, variables were subjected to a Shapiro-Wilk's normality test, those with non-normal distribution were log-transformed. In order to apply geostatistical analysis and map the spatial variation of the aggregate stability along the study area, the geographical position of each sample was determined by using GPS. Beside the study area samples, we also used a database containing 1248 soil samples among them 352 samples from Algerian soils and 896 international soil samples.

2.3 Model Selection and Methodology

To predict the Mean Weight Diameter (MWD) in the most reliable way, simple and multiple linear regression models were developed to explain the relationship between the explained and the explanatory variables, the general form of the resulted regression equations can be expressed as:

$$Y = b_0 + b_1 x_1 + b_2 x_2 \ldots. + b_n x_n . \quad (1)$$

Where: Y represents the dependent variable MWD, b_0 is the intercept, b_1 to b_n are the regression coefficients, and x_1 to x_n refer to the independent variables representing the basic soil properties.

The performances of the regression models, were evaluated by a set of test data using the determination coefficient (r^2), the root mean square error (RMSE) and the standard error of prediction (SEP). The RMSE (Eq. 2) is a measure of accuracy and reliability for calibration and test data sets [26], the smaller the RMSE, the better the forecasting ability of the model.

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(Y_i^0 - Y_i^p\right)^2} \quad (2)$$

Where: Y^0_i is the observed value, Y^p_i is the predicted value, n is the number of samples, σ_y is the standard deviation of the predicted scores.

The Bland-Altman plot [27,28] was used to analyse the relationship between the measured and predicted MWD.

The adopted methodology was mainly based on the relationship between the aggregate stability and the most influent physicochemical characteristics. As illustrated by Fig. 2, the most relevant physicochemical parameters such as organic-textural, salinity and texture were stratified in 4 classes according to the following pattern: low, moderately high, high and very high. Finally, as geostatistics [29] provide a powerful suite of tools such as kriging for spatial analysis [30] by producing a continuous grid of MWD values. The geostatistical approach was carried out as a second way of statistical characterization of aggregate stability in the study area using the GPS coordinates (x, y) and the MWD value of each sampled point.

3. RESULTS

3.1 Descriptive Statistics and PTFs

The data summary presented in Table 1 showed that the lower Cheliff samples were mostly characterized by slightly alkaline pH, moderate cation exchange capacity and were moderately rich in OM content. The EC along the lower Cheliff plain was relatively high with an average of 9.7 dS/m and a very high maximum value of 59.3 dS/m. The physicochemical characteristics widely vary from a sample to another as shown by the high values of the coefficient of variation (CV), Among the 9 soil properties, $CaCO_3$ showed the highest CV, while soil pH the lowest. The textural analysis revealed wide ranges of physical properties, the silt and clay content varies from 0 to 97%, with a respective mean of 42.3% and 32.4%, which indicate an inadequate drainage condition prevailing in the area, the proportion of silt and clay was followed by sand content with an average of only 25.5% meaning that the study area belong to the fine-textured soil class. The textural classification according to the USDA textural triangle indicates the dominance of the silty clay class. The aggregate stability was very variable along the lower Cheliff plain as indicated by the high CV (32%), with a mean equal to 1.01 mm the lower Cheliff plain is among the category of average soil stability. Simple linear correlation coefficients (r) between MWD and independent variables were also calculated. As illustrated in Table 2, MWD was significantly to highly significantly related to 7 of the 9 variables. The highest significant positive correlations to MWD were shown respectively by CEC_m, OM, CEC_e and clay at $P<.01$, EC showed significant positive correlations ($P<.05$), sand and silt showed significant negative correlations ($P<.05$), whereas MWD correlation with pH and $CaCO_3$ was not significant.

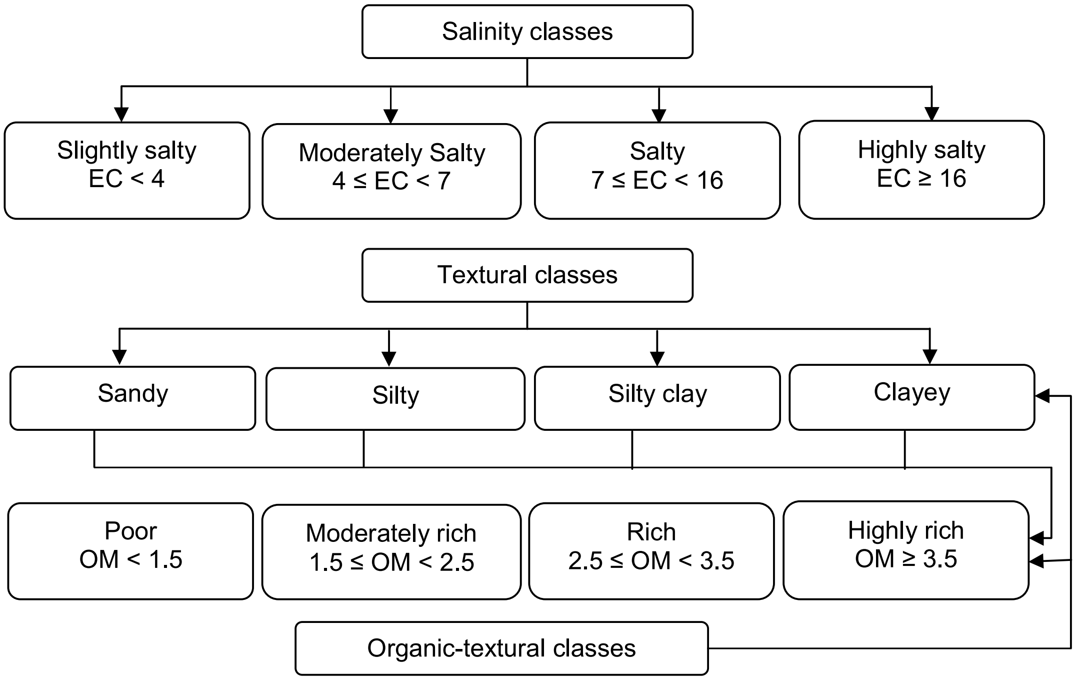

Fig. 2. Schematic representation of the classification procedure

Regarding these correlation coefficients, CEC_m, CEC_e, clay, OM, EC, sand and silt are highly suitable for developing PTFs to predict aggregate stability (MWD) in the lower Cheliff region.

Hence, with respect to these results, multivariate regression equations were developed for the studied parameters, only regression models of each class that showed a coefficient of determination (R^2) greater than 0.6 were retained. The best model in case of textural classification (Table 3) was shown by clayey and silty clay class ($R^2 > 0.9$), furthermore, the clayey class RMSE was equal to 0 which indicate the highest accuracy of this PTF in estimating aggregate stability. Regarding salinity classification (Table 4), the highly salty class showed the highest R^2 but also the highest RMSE (0.07), the lowest RMSE (0.01) was obtained in salty class. As Aggregate stability is highly dependent on OM [31-33] the lowest RMSE according to organic-textural classification (Table 5) were shown by PTFs related to rich and highly rich OM classes regardless the structural class, whereas, poor OM classes coincide always with high RMSE.

Table 1. General statistics of the training data sets (183 soil samples)

Variable	Minimum	Maximum	Mean	Standard deviation	CV%
Clay (%)	1.68	97.10	32.43	16.64	51.31
Silt (%)	0.00	91.70	42.31	19.07	45.07
Sand (%)	0.00	92.00	25.47	21.05	82.65
EC (dS/m)	0.07	59.30	09.69	07.03	72.55
OM (%)	0.06	09.50	01.52	01.15	75.66
pH	3.40	09.10	07.32	00.68	09.29
CaCO3 (%)	0.00	46.60	07.81	10.21	130.7
CEC_m ($cmol_+$/kg)	0.67	73.50	15.14	08.46	55.88
CEC_e ($cmol_+$/kg)	0.61	86.14	15.79	09.33	59.09
MWD (mm)	0.08	02.28	01.01	00.32	32.00

Table 2. Pearson correlation (r) between physicochemical characteristics and MWD, associated with significance level (P* <.05, ** *P* <.01)**

	Clay (%)	Silt (%)	Sand (%)	pH	$CACO_3$ (%)	OM (%)	EC (dS/m)	CECm ($cmol_+$/kg)	CECe ($cmol_+$/kg)
MWD (mm)	0.49**	-0.14*	-0.20*	-0.24	-0.04	0.5**	0.11*	0.72**	0.51**

Table 3. Selected PTFs and validation for textural classification (C = Clay, S_L = Silt, S_A = Sand, EC = Electrical conductivity, OM = Organic matter, $CEC_{m,e}$ = Cationic exchange capacity)

	Model	R^2	RMSE
Sandy	$MWD(mm) = 0.017 \times C(\%) + 0.004 \times S_L(\%) + 0.002 \times pH + 0.018 \times CaCO_3(\%) + 0.14 \times OM(\%) + 0.006 \times CEC_e(cmol_+/kg) + 0.052$	0.67	0.02
Silty	$MWD(mm) = 0.007 \times S_L(\%) + 0.001 \times S_A(\%) + 0.05 \times pH + 2.6E^{-4} \times CaCO_3(\%) + 0.04 \times OM(\%) + 0.04 \times EC(dS/m) + 0.02 \times CEC_e(cmol_+/kg) - 0.3$	0.71	0.03
Silty clay	$MWD(mm) = 0.005 \times C(\%) - 0.02 \times pH + 0.01 \times CaCO_3(\%) + 0.15 \times OM(\%) + 0.04 \times EC(dS/m) + 0.08 \times CEC_m(cmol_+/kg)$	0.91	0.03
Clayey	$MWD(mm) = 0.0056 \times CEC_m(cmol_+/kg)$	0.94	0.00

Table 4. Selected PTFs and validation for salinity classification

	Model	R^2	RMSE
Slightly salty	$MWD(mm) = 0.21 \times OM(\%) + 0.12 \times EC + 0.017 \times CEC_m(cmol_+/kg)$	0.81	0.02
Salty	$MWD(mm) = 0.54 + 0.018 \times C(\%)$	0.86	0.01
Highly salty	$MWD(mm) = 0.026 \times C(\%) + 1.5E^{-4} \times S_L(\%) + 6.2E^{-5} \times S_A(\%) - 0.006 \times EC(dS/m) + 0.004 \times CEC_m(cmol_+/kg) + 0.52$	0.90	0.07

Table 5. Selected PTFs and validation for organic-textural classification

Texture	OM	Model	R^2	RMSE
Sandy	Poor	MWD(mm) = 0.02 × $CaCO_3$(%) + 0.25 × OM(%) + 0.02 × EC(dS/m) + 0.007 × CEC_e(cmol$_{+}^{/}$kg)	0.90	0.23
	Mod rich	MWD(mm) = 0.02 × $CaCO_3$(%) + 0.4 × OM(%)	0.94	0.13
Silty	Poor	MWD(mm) = 0.04 × CEC_e(cmol$_+$/kg)	0.74	0.35
Silty clay	Mod rich	MWD(mm) = 0.0006 × pH + 0.14 × OM(%) + 0.03 × EC(dS/m) + 0.03 × CEC_m(cmol$^+$/kg)	0.90	0.04
	Highly rich	MWD(mm) = 0.13 × OM(%) + 0.04 × CEC_m(cmol$_+$/kg) + 0.04	0.75	0.01
Clayey	Poor	MWD(mm) = - 0.01 × C(%) - 0.004 × S_L(%) - 0.075 × pH + 0.004 × $CaCO_3$(%) + 0.06 × CEC_m(cmol$_+$/kg) + 0.5	0.81	0.33
	Mod rich	MWD(mm) = 0.06 × EC(dS/m) + 0.04 × CEC_m(cmol$_+$/kg) - 0.3	0.73	0.14
	Rich	MWD(mm) = 0.002 × S_L(%) + 0.02 × pH + 0.03 × $CaCO_3$(%) + 0.93 × OM(%) + 0.25 × EC(dS/m) + 0.04 × CEC_m(cmol$_+$/kg) - 4.04	0.88	0.09
	Highly rich	MWD(mm) = 0.05 × CEC_m(cmol$_+$/kg) + 0.009	0.8	0.13

3.2 Bland - Altman Approach

As process used to assess the relationship between measured and predicted MWD via the differences, including approximate 95% limits and based on the assumption of normal differences, the Bland-Altman (Fig. 3) plot 95% limit lines were at - 0.81 and + 0.94.

The graph also showed that the vast majority of the points were in the limits ± 0.5 with a few differences outside these limit lines. Such small differences indicate high agreement between measured and predicted MWD, furthermore, the t-test showed that the observed t (1.89) was less than the critical t (1.97) (*P*>.05) indicating no difference between the observed and predicted MWD.

3.3 Geostatistical Analysis

The cross validation, was used to estimate MWD of each sample in the lower Cheliff area through ordinary kriging, with neighbouring MWD by excluding the MWD being estimated, and to evaluate the kriging results in the main directions (0º, 45º, 90º and 135º), comparison of the 4 models (Table 6) showed that power model produced the highest coefficient of determination (R^2 = 0.94), the lowest variability (CV% = 7%) and mean square error (MSE) (0.007), consequently this model was the most appropriate to estimate MWD.

The outcome was a predictive spatial distribution map of MWD. The results of the spatial distribution (Fig. 4), showed a relatively small area of soils belonging to the stable category, only 63 km^2 among 400 km^2 were considerably resistant to slaking, runoff and diffuse erosion. The vastest area (277 km^2) was moderately stable and subject to frequent slaking and variable erosion risk depending on weather and topographical conditions according to [7] scale. Areas with a relatively low stability (< 0.8) were mainly located at the periphery of the lower Cheliff plain.

Table 6. Summary of theoretical variograms

Model	Nugget effect	CV (%)	R^2	MSE
Spherical	0.082	30%	0.3	0.074
Exponential	0.078	28.90%	0.26	0.078
Gaussian	0.082	29.30%	0.21	0.083
Power	0.085	7%	0.94	0.007

4. DISCUSSION

Although soil aggregate stability can be measured directly, data collection is difficult, time consuming and rather costly, also soil properties can be spatially and temporally highly variable. To overcome this handicap, researchers have shown in the last few years a growing interest in developing indirect approaches, the most relevant were the pedotransfer functions (PTFs). Unfortunately, most PTFs have been developed to predict soil hydraulic properties, while the assessment of other soil parameters is very poor.

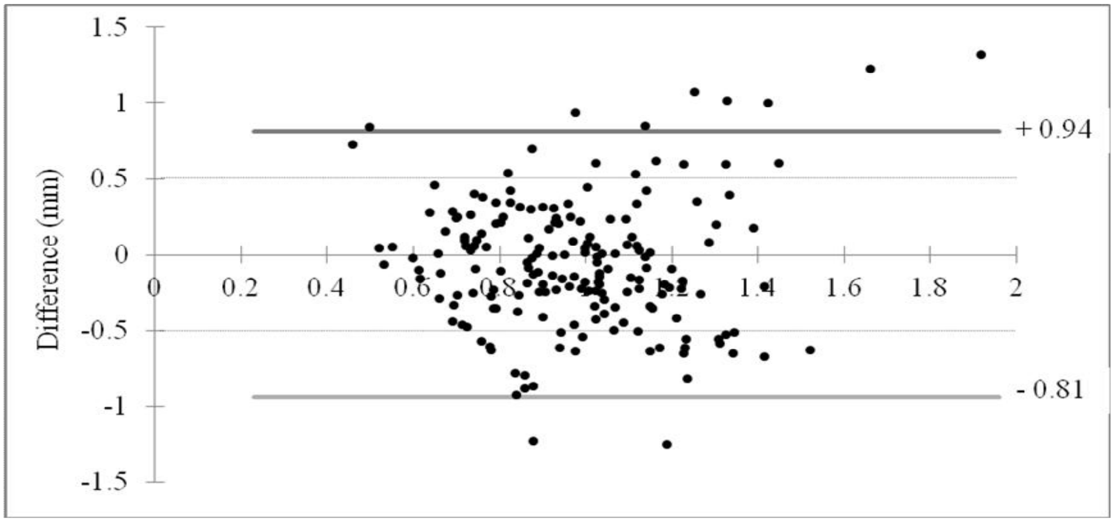

Fig. 3. Bland-Altman plot showing the agreement between measured and predicted MWD

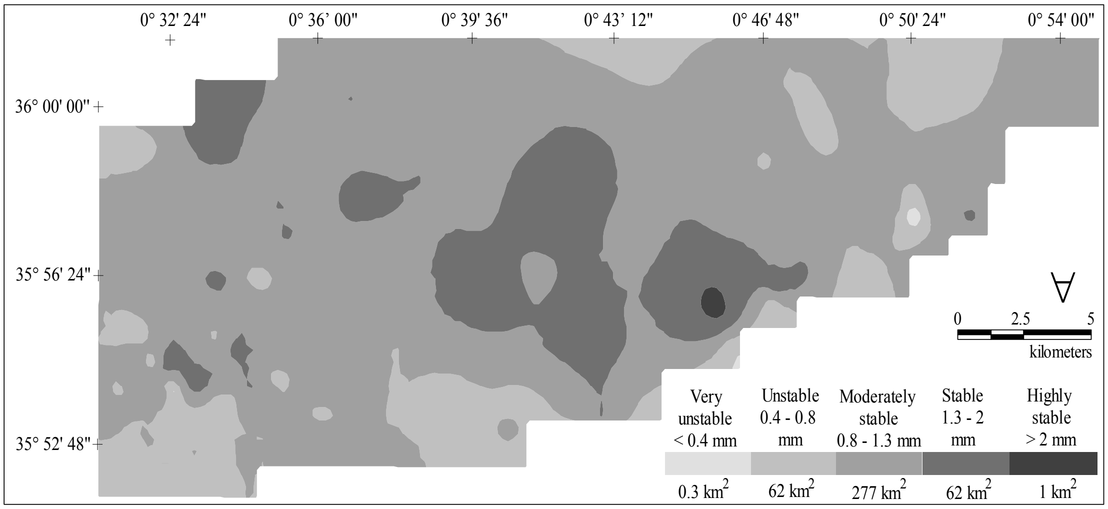

Fig. 4. Theoretical map of MWD in the lower Cheliff plain obtained by kriging

Modelling soil aggregate stability requires reliable, more easily measurable and available soil parameters describing soil physical and chemical properties. In this context, the aim of this study was the development of classes PTFs in order to predict soil aggregate stability in the salted lower Cheliff plain, one of the most vulnerable areas to the structural disintegration using easily measurable soil properties such as particle size distribution, EC, pH, OM, $CaCO_3$, pH, and cation exchange capacity. Results showed that the lower Cheliff is one of the most salted plain in northwestern Algeria, as reported by [34-36] this variable is the most important parameters affecting soil disintegration in this area. Except $CaCO_3$ and pH, the soil aggregation was significantly related to sand, silt, EC and highly significantly related to OM, CEC and clay, meaning that these variables were highly suitable for developing aggregate stability PTFs. The best model with the lowest bias were shown by clayey, silty clay, rich and highly rich OM classes, whereas, poor OM classes always coincide with a high bias. The worst PTFs with the lowest R^2 were related to sandy and silty classes. Hence, with regard to these results, we can easily attribute the variations of aggregate stability to clay and OM. Indeed, as reported by [37,31-33] aggregate stability is highly dependent on OM content and clay percentage. These two variables play a role of cementing agents influencing the aggregate stability [38]. Thus, through the different PTFs developed in this study, 95% of the differences between predicted and measured MWD lie between the limits of agreement (-0.81 and +0.94). Furthermore, the majority of the points were in the limit ± 0.5, this high agreement was also confirmed by the t-test, meaning that the differences observed were due to random errors. The geostatistical analysis another technique of MWD prediction using ordinary kriging in the main directions (0º, 45º, 90° and 135°), showed that power model produced the highest coefficient of determination, the lowest variability and the lowest bias, consequently this model was the most appropriate to estimate MWD. From an operational perspective and due to the complexity of soil properties and the spatiotemporal variability, the PTFs developed in this study can be considered as reliable methods in estimating aggregate stability according to the different classes of soil. Future plans are the prediction of aggregate stability by neural network PTFs and compare them to the class PTFs developed in this study.

5. CONCLUSION

The aim of this study was to develop PTFs to estimate soil structural stability in an arid area, through a set of local and worldwide data.

As structural stability was related to sand, silt, EC, OM, CEC and clay, these variables were used to develop aggregate stability PTFs. The best models were those related to clayey, silty clay, rich and highly rich organic matter classes, whereas, the worst PTFs were related to sandy and silty classes. Hence, we were able to conclude that aggregate stability variations in the study area were mainly attributed to clay and organic matter.

Through the PTFs developed in this study, the predicted and measured MWD were highly concordant, the observed differences were only due to random errors.

Finally, the PTFs developed in this study are very promising, but an enrichment of the database and the exploration of further soil variables are needed, to develop stronger PTFs.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Lichtfouse E. Biodiversity, biofuels, agroforestry and conservation agriculture. springer. New York. USA. 2011;400.
2. Dexter AR. Advances in Characterizations of soil structure. Soil and Tillage researches. 1988;11:199-238.
3. Neves CSVJ, Feller C, Guimaraes MF, Medina CC, Tavares J, Fortier M. Soil Bulk density and porosity of homogeneous morphological units identified by the cropping. Profile method in clayey Oxisols in Brazil. Soil and Tillage Researches. 2003;71:109-119.
4. Guber AK, Pachepsky Y, Levkowsky E. Mass-size scaling in soil aggregates as affected by aggregate water content and soil compaction. Soil Science. 2004;169:1-12.
5. Kay BD, Munkholm LJ. Management-induced Soil Structure Degradation: Organic Matter Depletion and Tillage, in Schjonning P, Elmholt S, Christensen BT. Eds. Managing Soil Quality: Challenges in Modern Agriculture, CABI Publishing, Wallingford, UK. 2004;185-197.
6. Kay BD, Angers DA. Soil Structure. In: Sumner ME, Ed. Handbook of Soil Science. CRC Press, Boca Raton, Florida, FL, USA. 2001;229-276.
7. Le Bissonnais Y, Le Souder C. Mesurer la stabilité structurale des sols pour évaluer leur sensibilité à la battance et à l'érosion. Etude et Gestion des Sols. 1995;2:43-56.
8. Bastet G. Estimation des propriétés de rétention en eau des sols à l'aide de fonctions de pédotransfert: développement de nouvelles approches. Thèse Université d'Orléans. 1999;214.
9. Saïdi D. Influence de la phase saline sur les propriétés physiques des matériaux argileux du Bas Cheliff. Alger, DZ: INA, El Harrach; 2005.
10. McKenzie NJ, Grundy MJ, Webster R, Ringrose-Voase AJ, Guidelines for surveying soil and land resources. CSIRO Publishing, 2nd Ed. Collingwood, AUS. 2008;576.
11. Feddes RA, Rooij de GH, Dam van JC. Unsaturated-zone modelling: Progress, challenges and applications. Springer, New York. USA. 2004;364.

12. Bouma J, Lanen van HAJ. Transfer functions and threshold values: From Soil characteristics to land qualities. In: Beek K, Barrough PA, McCormack DD, editors. Quantified land evaluation procedures. ITC publication, Enschede, NLD. 1986;106-111.
13. Bouma J. Using soil survey data for quantitative land evaluation. Advances in Soil Science. 1989;9:177-213.
14. Minasny B, McBratney AB. The Neuro-m Method for Fitting Neural Network Parametric Pedotransfer Functions. Soil Science Society of America Journal. 2002;66:352-361.
15. Lake HD, Akbarzadeh A, Mehrjardi RT. Development of pedotransfer functions (PTFs) to predict soil physico-chemical and hydrological characteristics in southern coastal zones of the Caspian Sea. Journal of Ecology and Natural Environment. 2009;1:160-172.
16. Schaap MG, Leij FJ, van Genuchten MT. Neural network analysis for Hierarchical prediction of soil water retention and saturated hydraulic Conductivity. Soil Science Society of America Journal. 1998;62:847-855.
17. Wösten JHM, Finke PA, Janes MJW. Comparison of class and Continuous pedotransfer functions to generate soil hydraulic characteristics. Geoderma. 1995;66:227-237.
18. Schaap MG, Bouten W. Modelling water retention curves of sandy soils using neural networks. Water Resources Research. 1996;32:3033-3040.
19. Mc Donald, B.N.E.D.E.RÉtude de l'avant projet détaillé des extensions de Guerouaou et de Sebkhat de Benziane et du réaménagement du Bas Chéliff. BNEDER (Bureau National d'Étude pour le Développement Rural), Tome I. Etude du milieu physique. 1990;192.
20. C.P.C.S. Classification des sols. Laboratoire de géologie et de pédologie de l'ENSA de Rennes, Paris – Grignon. 1967;87.
21. A.F.E.S. Référentiel pédologique. Versailles, FR: INRA Editions; 1995.
22. Boulaine J. Etude des sols des plaines du Chélif. Thèse d'Etat de l'Université d'Alger. 1957;582.
23. Daoud Y. Contribution à l'étude des sols des plaines du Cheliff. Le phénomène de salinisation, conséquences sur les propriétés physiques des sols argileux. Alger, DZ: INA El Harrach. 1993;277.
24. Ababou A, Chouieb M, Bouthiba A, Saïdi D, M'hammedi Bouzina M, Mederbal K. Spatial pattern analysis of Peganum harmala in the salted lower Cheliff plain, Algeria. Turkish Journal of Botany. 2013;37:111-121.
25. A.F.N.O.R. Qualité des sols. Recueils de normes Française. Paris, FR: AFNOR; 1996.
26. Wösten JHM, Lilly A, Nemes A, Le Bas C. Development and use of a database of hydraulic properties of European soils. Geoderma. 1999;90:169-185.
27. Bland JM, Altman DG. Statistical methods for assessing agreement between two methods of clinical measurement, Lancet. 1986;1:307-310.
28. Bland JM, Altman DG. Applying the right statistics: analyses of measurement studies, Ultrasound in Obstetrics and Gynecology. 2003;22:85-93.
29. Matheron G. Les valeurs régionalisées et leur estimation. Masson; 1965.
30. Burrough PA. GIS and geostatistics. Essential partners for spatial analysis. Environmental and Ecological Statistics. 2001;8:361-377.
31. Six J, Elliott ET, Paustian K, Soil structure and soil organic matter II. A normalized stability index and the effect of mineralogy. Soil Science Society of America Journal. 2000;64:1042-1049.
32. Saïdi D, Le Bissonnais Y, Duval O, Daoud Y, Halitim A. Effet du sodium échangeable et de la concentration saline sur les propriétés physiques des sols de la plaine du Cheliff (Algérie). Etude et Gestion des Sols. 2004;11:137-148.
33. Ababou A, Chouieb M, Khader M, Mederbal K, Saïdi D, Bentayeb Z. Multivariate analysis of vegetation in the salted lower Cheliff plain, Algeria. Boletin de la Sociedad Botanica de Mexico. 2009;85:59-69.
34. Saïdi D. Etude expérimentale de la stabilité structurale des sols des plaines du Cheliff. Alger, INA, El Harrach. DZ; 1992.
35. Saïdi D, Le Bissonnais Y, Duval O, Daoud Y, Tessier D. Estimation et signification de

la capacité d'échange cationique des sols salés du Cheliff (Algérie). Etude et Gestion des Sols. 2008;15:241-253.

36. Ababou A, Chouieb M, Khader M, Mederbal K, Saïdi D. Using vegetation units as salinity predictors in the lower Cheliff, Algeria. Turkish Journal of Botany. 2010;34:1-10.
37. Chenu C, Le Bissonnais Y, Arrouays D. Organic matter influence on clay wettability and soil aggregate stability. Soil Science Society of America Journal. 1999;64:1479-1486.
38. Goldberg S, Suarez DL, Glaubig RA. Factors affecting clay dispersion and aggregate stability of arid zone soils. Soil Science. 1988;146:317-325.

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