Al-Qadisiyah Journal For Agriculture Sciences (QJAS)
ISSN : 2618-1479 Vol.12, Issue. 2 ,(2022), pp. 12-18
https://jouagr.qu.edu.iq/

Evaluation of Arid Soil Landscapes Permeability in Algerian Sahara

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Received : 12/6/2022
Acceptance : 26/7/2022
Available online: 30/12/2022

Abstract. The hydro-edaphic environment of arid ecosystems in Ouargla is endangered. To the sustainability of this fragile ecosystem, detailed knowledge of geomorphology, surface characteristics, vegetation, and hydrodynamic characteristics of the soil is required. Soil permeability is an important hydrodynamic parameter for the assessment of infiltration, structure design, drainage, and groundwater vulnerability, but it has not been studied in Ouargla. In order to ensure better management of the irrigation-drainage and to better characterize the variability of the water dynamics in the soils of this region, we have measured the permeability of these soils by Porchet's method, taking into consideration the pedo-landscapes of the region: Plateau, Glacis, Erg, Reg, and Sabkha. Soils of Ouargla are semi-permeable with 4.58 m/d, which gives them good drainage capacity and facilitates the transfer of pollutants to groundwater. A difference in the mean permeability of the soils from one pedo-landscape to another is noticed, but only the difference in mean between the soils of Erg and those of Glacis is statistically significant according to the ANOVA and Tukey test.

Keywords. Arid soil, Permeability, Pedo-landscapes, Ouargla.

1. Introduction

Climate change causes severe and rapid changes in environmental conditions, such as soil degradation. This degradation is a serious ecological problem that leads to the disruption of ecosystem functions and a decrease in soil productivity and the agricultural land sustainability [1]. However, we know that the soil is a special ecosystem in which plants find the appropriate environment for rooting and receive the nutrients they need to thrive. This ensures high productivity. On this foundation, knowledge of the soil's physical and chemical properties is necessary to specify the soil's capacity to meet the plant's needs, to determine the possibility of improvement required for certain specific production factors in order to obtain the best possible yield and to ensure the preservation of groundwater [2,3].

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Ouargla, one of the largest and oldest oases in the south-east of Algeria, is now suffering from the degradation of its hydroedaphic resources and the decline in agricultural productivity caused by the lack of sufficient information on soil characteristics, neglect of palm groves, irrational exploitation of natural resources, poor water management, poor exploitation and lack of land planning [4-9]. This situation requires a study of the region's soils and the determination of their physical and chemical properties. Soil permeability is one of these proprieties that has a significant impact on agricultural productivity by influencing soil irrigation and drainage, and on groundwater by influencing water and pollutant transport [10,11]. Studies carried out on Ouargla soils have focused on their physicochemical and microbiological characteristics, and on the effects of various agricultural methods on these soils [12,13]. However, soil hydrodynamics, which play an extremely important role in near-surface water balances and the associated responses in water-limited ecosystems, have not been studied at Ouargla. This was the reason for choosing these research axes. The present study was undertaken with the objectives as: (a) to measure the permeability, the particle size, electrical conductivity, pH and total limestone of soil in different pedo-landscapes; (b) to use GIS for mapping the permeability; (c) to draw soil profiles and to present their morphological description; (c) to compare the soil permeability between the different pedo-landscapes using statistical tests in order to known if there is a difference in mean permeability between the different soil landscapes.

2. Material and Methods

2.1. Field Work and Lab Experiments

The work was carried out in Ouargla, which is located in the South-east of Algeria between longitudes 5° 17 '4" and 5° 13' 30" East and latitudes 31° 55 '25" and 31° 58' 46" North. Different pedo-landscapes are present in this region, namely: Plateau, Reg, Erg, Glacis, Sabkha (playa) [4], [14]. A total of 23 soil samples were collected from a depth of 0-20 cm ,using an auger , from different pedo-landscapes in the study area.

The particle size of soil was analyzed without decarbonation on samples of fine earth (less than 2 mm), dried in the open air, by wet sieving (under a water jet) [15]. Electrical conductivity and pH were Measured on extracts of the ratio (soil / water) 1/5 by multi-parameter type HI 931000, and the soil humidity was obtained by the difference in weight of a soil sample before and after passing in an oven at 105°C for 24 hours [16]. Total limestone present in soil was evaluated using the gasometric method by Bernard's Calcimeter [17].

Permeability was measured in situ, in 45 point (P1, P2, … P45) in the study area (Fig 1), by a constant head permeability test using the Porchet method [18]. The coefficient of soil permeability was determined by the following equation deduced from the Darcy low:

$$K=V/A.t \quad (1)$$

Where, K= soil permeability (m/d), V= volume of water infiltrated into the soil over time t (m^3), A= cross sectional area of soil (m^2), t= time (day).

2.2. Soil Permeability and Profiles Cartography

To construct the permeability map, three steps were followed: Collecting data, Data processing (digitization), Map creation: using the GIS Arc-GIS 10.0 software.

Eight soil profiles were originated, based on the optimal orientation and spacing to represent the subterranean horizons in the study area and linear position. Graphic depictions of soil lithologic logs provided the visual basis for interpreting soil morphology. The graphic logs were produced automatically for selected profiles using Cross View integrated with GIS.

2.3. Statistical Analysis

IBM SPSS Statistics 25 was used to execute the statistical analysis. Statistics used are: descriptive statistics, box plots, ANOVA followed by Tukey test, applied at a probability level of P= 0.05 to test for significant differences between the means.

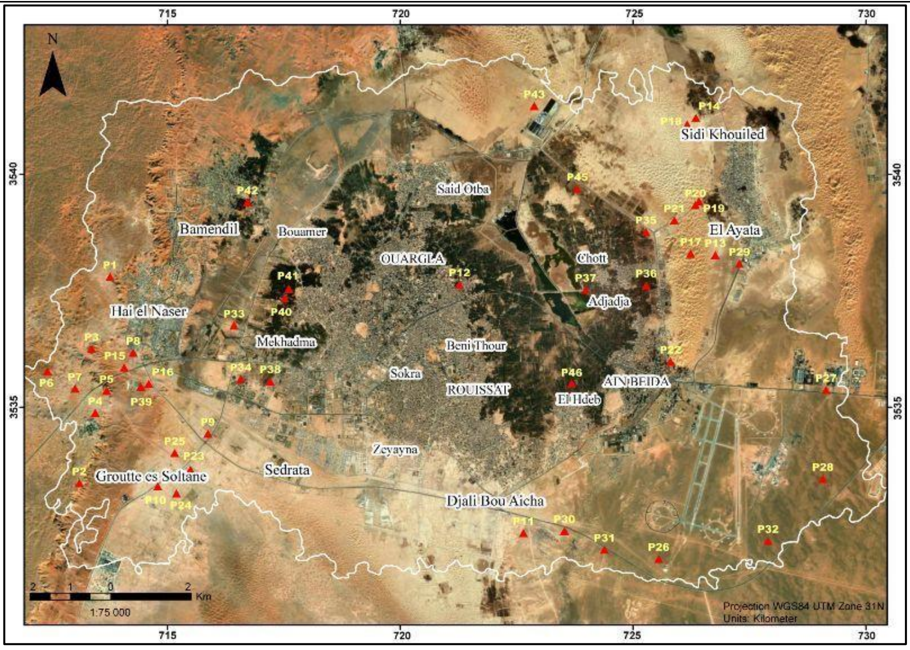

Figure 1. Spatial distribution of sampling points.

3. Results and Discussions

3.1. Morphological Description

The ability to identify and correlate subsurface units is limited by the highly variable soil horizons. The west-east cross section shows the presence of ten soil horizons (Fig 2). Small surficial geologic units are depicted on the cross sections. These deposits include polygonal surface gypsum crust (A) in P2 andP3, saline surface crust (D) in P4, P5, P6, P7 and P8 and gravelly horizon with calcareous pedorelic (I) in P1. The detrital sand (E) is only present in P1 from the surface to a depth of 200 cm. The Mio-Pliocene sandstone bedrock (J) is 10 cm to the surface in P2, 20 cm in P3 and 120 cm in P7. The crumbly crystalline gypsum crust (G) is the horizon which is present in all the profiles except for P1 and P2 at different depths. The black spotted crystalline gypsum crust (reductic) (B) is under the moderately hard crystalline gypsum crust (C) in P4 and P6. The crust of indurated crystalline gypsum (F) and the calcareous petro-calcaric crust (H) are only present in P5.

Logs reveal relatively straightforward stratigraphy under Ouargla. Logs are spaced closely enough in this area to trace most soil morphology variation. As a result, the stratigraphy may show no apparent correlation among adjacent profiles.

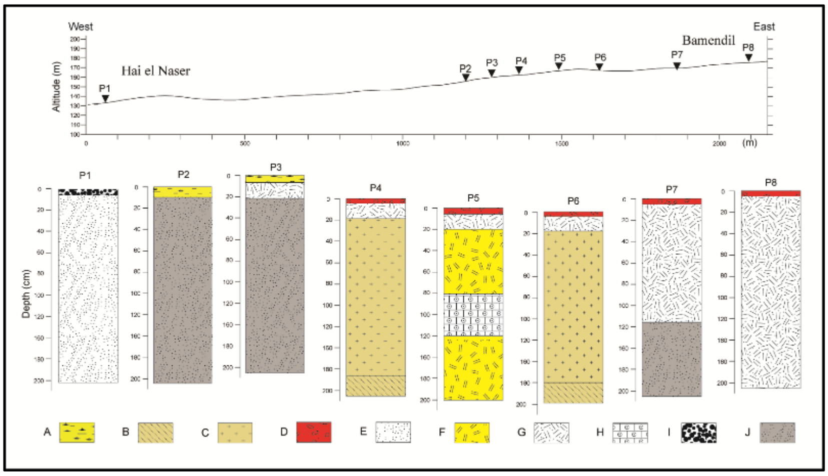

Figure 2. Lithologic cross section of Ouargla.

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3.2. Physicochemical Properties

Descriptive analyzes (Table 1) show that the Ouargla soils are sandy with 96.88% sand and 2.70% silt and clay. They are slightly alkaline (pH= 7.69), little humid, non-calcareous and salty (electrical conductivity= 447.22 mS/m) This result is consistent with the conclusions of several previous studies such as [13,19], [20].

Table 1. Statistical details of data. (EC: Electrical conductivity).

Value	K (m/d)	Sand (%)	Silt and Clay (%)	EC mS/m	Total limestone (%)	Humidity (%)	pH
Mean	4,58	96,88	2,70	447,22	2,52	21,78	7,69
Median	4,24	97,85	1,73	432,00	1,60	23,90	7,80
Std. Deviation	2,27	3,43	3,38	327,88	2,34	7,917	0,28
Variance	5,15	11,81	11,43	107511,08	5,49	62,67	0,08
Minimum	0,34	84,21	0,00	116	0,37	7,60	7,31
Maximum	10,96	99,91	15,72	1554	11,67	35,81	8,14

3.3. Soil Permeability

The soil permeability map (Fig 3) shows that in Ouargla, the soil permeability oscillates between 0 to 10 m/d. It is between 0 and 2 m/d at the places where the soils are surmounted by a very compact gypsum slab.

In the west of the region, soils are used for agriculture. They are fine and extremely fine-sandy, with organic materials such as animal dung added to increase its characteristics, resulting in their permeability ranging from 2 to 4 m/d. Going east, the permeability increases to up to 8 m/d, according to [4,14], this is explained by the texture of the soil, which is sandy because the soils become dune and at El-hdeb and Groutte es-Soltane, permeability reaches its maximum with 10m / d where the soils are stony.

The mean permeability of Ouargla soils is 4.58 m/d (Table 1), this allowed us to classify them as semi-permeable soils, sandy with gravel according to [21] which is confirmed by our results of particle size analysis (table 1).

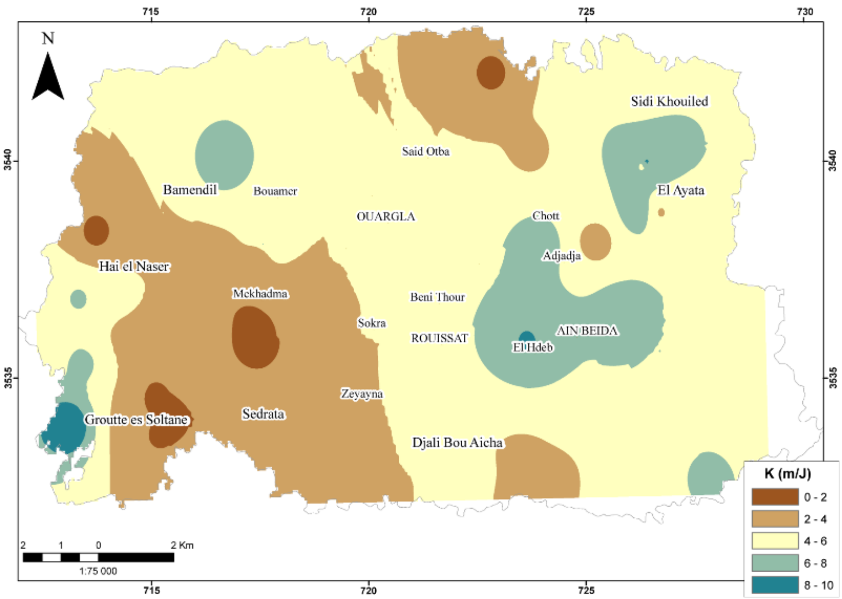

Figure 3. Ouargla soil permeability map.

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3.4. Comparison of Pedo-Landscapes Soil Permeability

The Shapiro-Wilk test shows that P > 0.05 for all pedo-landscapes, which implies a normal distribution for our data. An analysis of variance (ANOVA) was carried out in order to compare the soil permeability in the different landscapes studied (table 2). In these results, because the P < 0.05, we reject the null hypothesis and conclude that some of the pédopaysages have different means. This difference can be explained by the difference of soil texture and structure.

Table 2. ANOVA results.

K (m/J)	Sum of squares	df	Mean square	F	P
Intergroup	61,430	4	15,357	3,714	0,012
Intra-group	165,412	40	4,135		
Total	226,842	44			

To show the permeability of different pedo-landscapes, the box plots were used (Fig 4). They show great variation in soil permeability from one pedo-landscape to another. Permeability in the Plateau ranges from 1.35 to 10.95 m/d, in Glacis from 1.21 to 5.75 m/d, in Reg from 3.08 to 6.37 m/d, in Erg from 5.28 to 8.49 m/d, and in Sabkha from 0.33 to 8.16 m/d. In all cases, the whiskers are asymmetrical. The distribution is high in the plateau case, and it becomes increasingly less important in the cases of Sabkha, Glacis, Erg, and Reg, respectively.

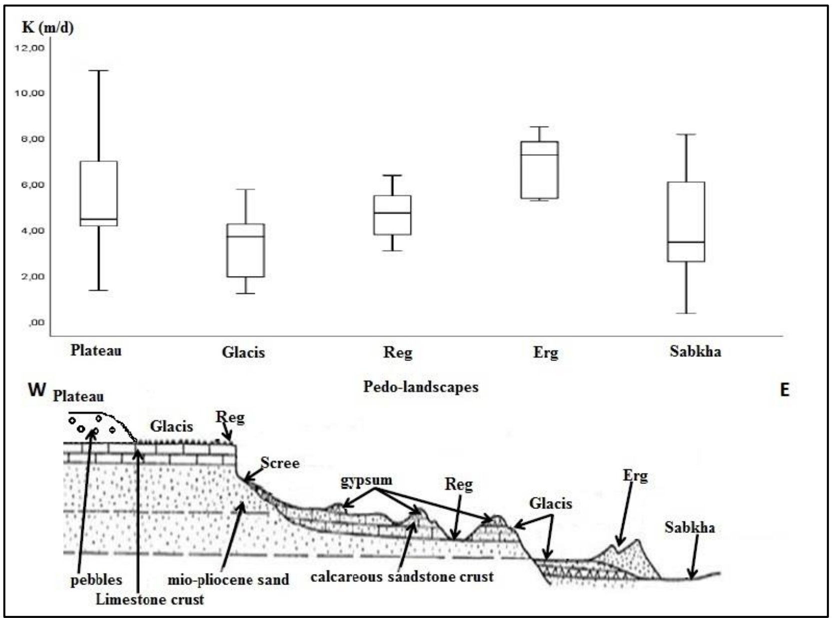

Figure 4. Permeability of Ouargla soil topo-sequence.

To determine whether the mean difference between specific pairs of groups are statistically significant and to estimate by how much they are different we have used the Tukey test (Table 3 and Table 4).
The table shows that group A contains Glacis, Sabkha, Reg and Plateau, and group B contains Reg, Plateau and Erg. Reg and Plateau are in both groups so differences between means are not statistically significant. Glacis, Sabkha and Erg do not share a group, which indicates that Erg soils have a significantly higher mean than Sabkha and Glacis soils.
According to the values of the mean permeability of each pedo-landscape, we are able to observe the following decreasing classification: Erg (6.92 m/d), Plateau (5.58 m/d), Reg (4.68 m/d), Sabkha (4/06 m/d), Glacis (3.35 m/d).

Table 3. Grouping Information Using the Tukey Method and 95% Confidence.

K (m/d)			
Pedo-landscape	**N**	**Subset for alpha = 0.05**	
		A	**B**
Glacis	12	3,35	
Sabkha	13	4,06	
Reg	7	4,68	4,68
Plateau	7	5,58	5,58
Erg	6		6,92

In the Tukey results, the confidence intervals indicate the following:

- The confidence interval for the difference between the means of Glacis and Erg is -6.47 to -0.66. This range does not include zero, which indicates that the difference is statistically very significant (P = 0.009). Glacis soils are sandy-gravelly formations of alluvial-aeolien origin, composed of 42.94% of fine sand with the presence of gypsum, which makes them more compact and less permeable than Erg soils, which are aeolien accumulations, composed mainly of 55.12% of medium sand and 38.48% of fine sand with a particulate structure.
- The confidence intervals for the remaining pairs of means all include zero, which indicates that the differences are not statistically significant. This is due to the homogeneity of the soils of these pairs in terms of structure and texture, which are generally predominantly sandy with different percentages of coarse sand, fine sand, medium sand, silt and clay.
- The 95% simultaneous confidence level indicates that we can be 95% confident that all the confidence intervals contain the true differences.

Table 4. Tukey Simultaneous Tests for Differences of Means.

Difference of levels	**Difference of mean**	**95 % CI**	**P**
Plateau - Glacis	2,22	(-0,54 ; 4,99)	0,166
Plateau - Reg	0,9	(-2,20 ; 4,00)	0,920
Plateau - Erg	-1,34	(-4,57 ; 1,89)	0,760
Plateau - Sabkha	1,52	(-1,20 ; 4,24)	0,510
Glacis - Reg	-1,32	(-4,09 ; 1,44)	0,650
Glacis - Erg	-3,56*	(-6,47 ; -0,66)	0,009*
Glacis - Sabkha	0,70	(-3,03 ; 1,62)	0,907
Reg - Erg	-2,24	(-5,47 ; 0,99)	0,294
Reg - Sabkha	0,62	(-2,10 ; 3,34)	0,966
Erg - Sabkha	2,86	(-0,01 ; 5,73)	0,051

Conclusion

Although this study did not include all Ouargla pedo-landscapes, our results show the importance of permeability, which may have profound impacts on ecosystem function in this arid system. It concluded that the soils of the region, despite the difference in pedo-landscape, are semi-permeable with an average permeability of 4.58 m/d, which gives them good drainage capacity and facilitates the transfer of pollutants to groundwater by influencing the transfer time, which will be short. To protect groundwater, which is the only source of water in arid ecosystems, and to ensure better management and use of agricultural soils, permeability must be considered in every future agricultural project or environmental study.

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