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IMPACT OF PEDOLOGICAL PARAMETERS ON SOIL PERMEABILITY IN THE OUARGLA REGION: A CASE STUDY USING PORCHET'S METHOD

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ABSTRACT

Understanding the structure of the soil is the first step in studying it, as it is considered a key factor in water functioning. Determining the structure and texture of soil provides insights into its porosity, which is crucial for understanding permeability and water retention—key factors for addressing water balance, irrigation, drainage, and solute movement. Pedogenesis, the process of soil formation, is largely influenced by water and salt. In the Ouargla region, environmental challenges such as unfavorable topography and extreme climatic conditions exacerbate the degradation of shallow groundwater from both human and natural sources. This situation necessitates a comprehensive analysis and the development of new, environmentally respectful management methods for hydro-edaphic resources.

The main objective of this research is to study the impact of specific pedological parameters on the permeability of Ouargla soils. In situ permeability measurements were conducted using Porchet's method, which is suitable for sandy soils. Over five campaigns, we performed twenty-four tests and collected samples.

The results indicate that Ouargla soils have a sandy texture with a humidity level of 20.29%. The pH ranges from neutral to slightly alkaline. The average electrical conductivity (EC) is 5.13 mS/cm, attributed to the salt content in the drainage water. Total limestone is prevalent, with an average of 3.34%. Spearman and Pearson tests reveal that EC, total lime content, and humidity are inversely correlated with permeability and have an average impact on it. The pH has a minimal effect on permeability.

Keywords: hydrodynamic characteristic, soil properties, Pearson test, Spearman test, Ouargla.

1. INTRODUCTION

Soil undergoes continuous water infiltration at different depths, with lateral and vertical movement influenced by factors such as gravity, capillarity, and evapotranspiration. Permeability, defined as the intrinsic capacity of the soil to allow the passage of fluids or gases through its interstices, constitutes an essential characteristic of the geotechnical environment. It is crucial for researchers conducting subsurface geophysical exploration to gain a better understanding the specific properties of different soil layers (Jabro, 1992; Alyamani & Şen, 1993; Das *et al*., 2010; Salarashayeri & Siosemarde, 2012; Onur, 2014; Elhakim, 2016; Hussain & Nabi, 2016).

Accurate knowledge of the permeability coefficient (k) is essential for addressing challenges such as pumping seepage water from construction excavations, determining the spacing and depth of drains to lower the water table under roads and highways, carrying out analyses of the stability of structures, effectively managing irrigation, and assessing the vulnerability of groundwater to pollution (Onur, 2014; Elhakim, 2016; Hussain & Nabi, 2016; Charikh *et al.,* 2022).

Numerous elements affect soil permeability, including soil characteristics, which are the collection of the soil's chemical, physical, and biological properties. They are determined by the nature of the parent rock, the climate, vegetation, and human activity (Das *et al.*, 2010; Salarashayeri & Siosemarde, 2012; Onur, 2014; Onur & Shakoor, 2015;Hussain & Nabi, 2016; Singh *et al.*, 2020; Kumar *et al.*, 2023; Söylemez, 2023).

There is a dearth of trustworthy data since, despite its critical importance, the permeability of soils in the Ouargla region (Lower Sahara) has not been the focus of any thorough scientific investigation, save from a few pilot studies. This makes it difficult to accurately estimate the stability of soil landscapes, the rate of erosion, the needs of crops, the optimal management of irrigation and drainage, as well as the evaluation of the potential for contamination of the phreatic water.

This study aims to investigate how several soil factors affect soil permeability in the Ouargla region. The findings of this study will contribute to our understanding of the variables influencing soil permeability and to the development of techniques for estimating permeability from easily accessible soil data.

2. MATERIAL AND METHODS

The Ouargla Oasis, located in the Algerian Sahara, stands out as a vast oasis in the southeast of the country, covering an area of 20,000 km2 and being approximately 800 km from the capital, Algiers (Fig. 1). The topography of the region presents varying altitudes between 268 m and 42 m, with relatively gentle slopes oscillating between 0.6‰ and 1.8‰ (Slimani *et al.*, 2017, 2023). The geomorphological forms of this area include (i) the Hamada, a rocky plateau approximately 200 m above sea level, dating from the Quaternary to the Mio-Pliocene; (ii) the existing alluvial areas in the form of fossil alluvial terraces; (iii) the Sebkhas forming bodies of water such as Sebkhat Safionne, Sabkhet Oum Rneb, and Chott Ain Beidha; and (iv) the glacis on the slopes made up of Mio-Pliocene sandstone formations. The cartographic analysis of land use in the Ouargla region reveals a distribution including (i) areas of sand and bare soil, covering 70% of the area studied; (ii) an agricultural area encompassing palm groves and cultivated areas; (iii) an open water area occupied by Chotts and Sebkhats; and (iv) urban areas including the town of Ouargla and the main localities of the communes (Hamdi-Aïssa & Girard, 2000; Charikh *et al.,* 2022).

The climate of Ouargla is characterized by marked aridity and almost permanent drought. The monthly average temperature is around 24.59°C, with a maximum temperature recorded in July (37.9°C) and a minimum temperature observed in January (12.3°C). The annual average precipitation is about 40.44 mm, with November being the wettest month (7.7 mm) and July the driest (0.2 mm)(ONM, 2023).

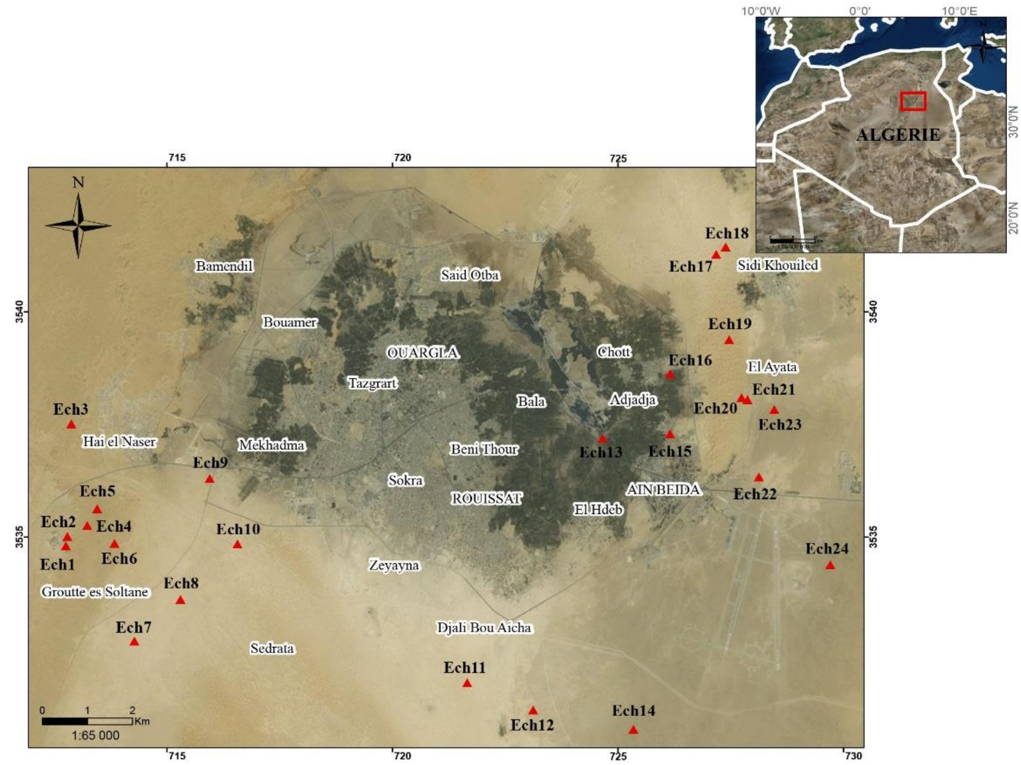

Figure 1: Study area location.

The research strategy involves examining how specific soil characteristics impact the permeability of Ouargla soil. Five campaigns were conducted, comprising 25 tests and samples. In situ permeability measurements were conducted using the Porchet method, which involves monitoring the reduction of water in a hole dug with an Auger over time. This procedure is divided into three phases, as described by various authors (Roederer, 1956; Colombani et al., 1973; Chossat, 2005; Nagy et al., 2013; Elhakim, 2016; Kącki et al., 2022).

- *Setting up the device:* This phase consists of drilling a 20-cm-deep superficial cavity in the ground manually with an auger. This is done carefully, avoiding smoothing the walls. Its diameter must be sufficient to install the regulating cell (15 cm).
- *Start of the test:* In this stage, we tried to approach the saturation conditions and, therefore, to respect the calculation hypotheses as best as possible. We systematically carried out the first filling of the hole with water to reach saturation before starting the measurements.
- *Measuring phase:* Once the imbibitions stage is completed and saturation is reached, we connect the regulator with the measuring tank and note, every 60 seconds, the height of water in the graduated tank.

$$K = V/S.t$$

With "V" is the volume of water infiltrated into the soil at time "t" and "S" is the area of the humidified zone.

$$S = \pi R^2 + 2\pi Rh$$

The pH and the electrical conductivity were measured using a multi-parameter HI 931000. Soil humidity is obtained by the difference in weight of a soil sample before and after passing through an oven at 105 °C for 24 hours (Mathieu *et al.*, 2003). The determination of total limestone is carried out using the Bernard Calcimeter method. Its principle is based on the decomposition of calcium carbonate by hydrochloric acid and the measurement of the volume of CO_2 obtained (Aubert, 1983).

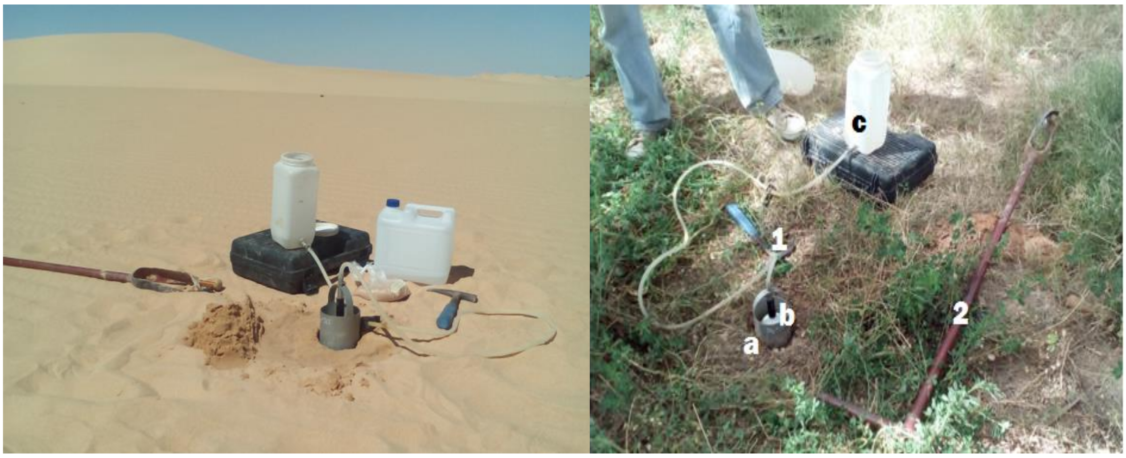

Photo 1: Viguier permeameter installed at Erg (left) and Sebkha (right): (1) stainless steel level control cell (a), suspension device (b) (float), measuring tank (c), Auger (2).

3. RESULTS AND DISCUSSION

Soil characteristics

Figure 2 presents the results of an analysis of Ouargla's soil parameters. They demonstrate that:

- Limestone soil contents vary between 0.37 and 11.67%, with an average content of around 2.53%. A significant variation in limestone content is observed from one point to another, which is confirmed by the variance, which is equivalent to 5.5.
- Soil humidity varies between 0.76 and 3.58%. The values of the standard deviation and the variance, which tend towards zero, indicate the homogeneity of the soils with respect to humidity.
- Electrical conductivity oscillates between 0.87 and 15.54 mS/cm. The average EC is 4.13 mS/cm. The standard deviation and variance are 3.22 and 10.40, respectively, which indicates a large variation in electrical conductivity from one measurement point to another.
- Ouargla soils are neutral to slightly alkaline soils. They are characterized by pH that ranges from 7.31 to 8.14, with an average pH of 7.69. The results do not show a significant variation in pH between the measurement points, which is confirmed by the variance, which is equivalent to 0.28.

Hydrodynamic characteristics

Soil permeability in the Ouargla region varies from 1.54 to 10.96 m/s (Fig. 2). The average permeability is of the order of 4.82 m/s with a standard deviation of 2.17 and zero variance, which indicates the homogeneity of the data. These values place the region's soils in the "semi-permeable" category according to the standards cited by Calvet (2003).

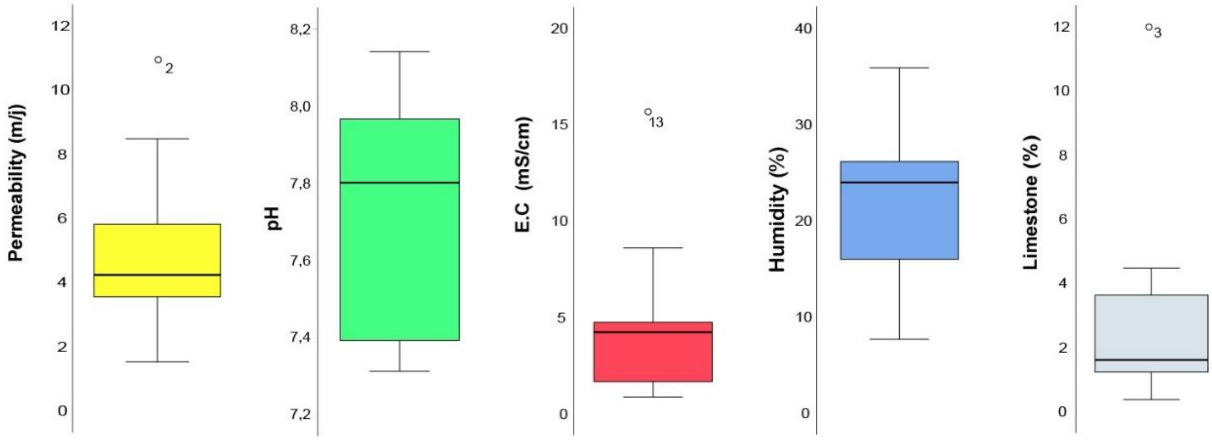

Figure 2: Statistical characteristics of the elements examined.

The effect of physicochemical parameters on permeability

To deduce the effect of the physicochemical parameters studied on the permeability of the soil in the Ouargla region, we first tested the distribution of the data for each parameter, whose results are represented in Table 1, and their distribution histograms are illustrated in Figure 3. The determination of the effect of these parameters on permeability is obtained by two correlation tests. The parametric Pearson and non-parametric Spearman tests results are illustrated in Table 2.

Table 1. Normality test results (Shapiro-Wilk).

Parameters	N	Shapiro-Wilk P
Permeability	23	0,092
E. C.	23	0,000
limestone total	23	0,000
Humidity	23	0,327
pH	23	0,005

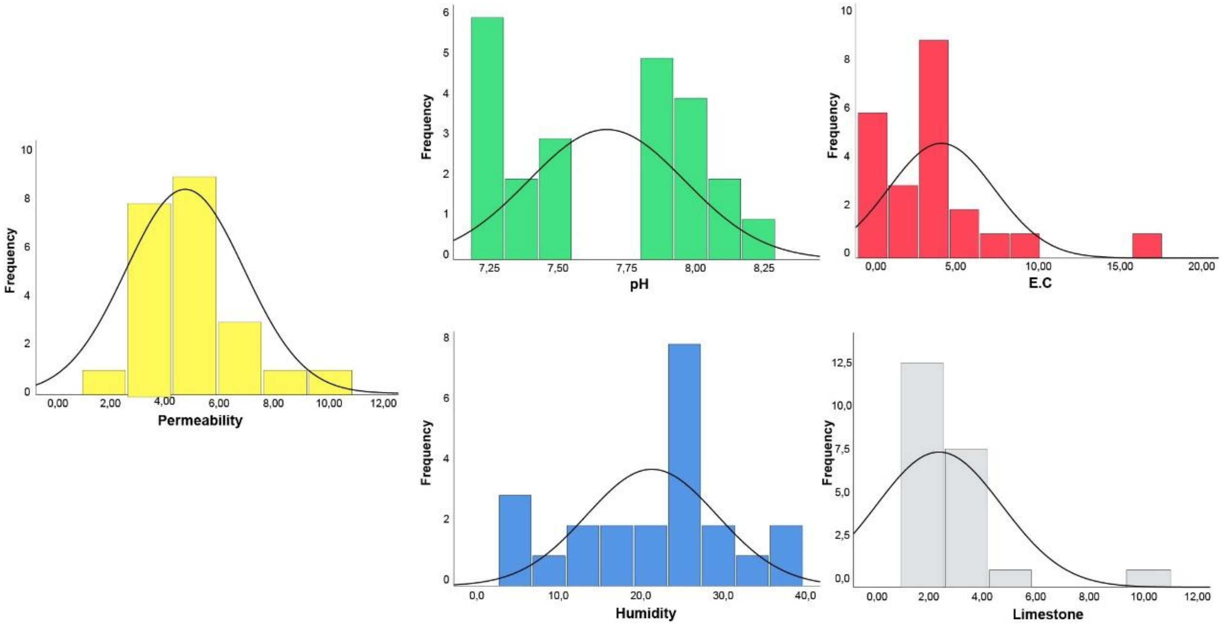

Figure 3: Histogram of distribution of the elements studied with the normality curve.

According to the results of the Shapiro-Wilk test, we deduced that:

- Permeability and humidity: P = 0.092 and P = 0.327, values greater than 0.05, which contribute to a normal distribution.
- Total limestone and electrical conductivity: P = 0 less than 0.05, which contributes to total limestone and EC, a non-normal distribution.
- pH: Figure No. 3, representing the histogram of the pH distribution associated with the normality curve, shows that the pH distribution is non-normal. This is confirmed by the P value obtained by the Shapiro-Wilk test, which is 0.005.

Table 2. Physicochemical parameter – permeability correlations

Tests	Rho de Spearman			Rho de Pearson
Parameters	CE	limestone	pH	Humidity
Correlation coefficient	-0,310	-0,352	-0,121	-0,272
P	0,150	0,099	0,584	0,210

- *Effect of electrical conductivity:* The Spearman correlation coefficient is -0.310. It indicates an average negative correlation between EC and permeability, i.e., when the EC increases, the permeability decreases. This means an effect of the average size of the EC on the permeability. Statistically, the effect of C.E. on permeability is not significant because P > 0.05.
- *Effect of total limestone rate:* The average negative correlation with a coefficient of -0.352 between total limestone rate and permeability indicates that the latter presents a medium-sized effect on permeability. The significance of the Spearman test is 0.099, which implies that the effect of the lime content on permeability does not have statistical significance.

- *Effect of humidity:* The Pearson correlation coefficient is -0.272; it indicates an average negative correlation between moisture and permeability, which shows the effect of average moisture size on permeability. That is to say, as humidity increases, permeability decreases. Statistically, the effect of humidity on permeability is not significant because P = 0.210.
- *Effect of pH:* As the Pearson coefficient is -0.039, the correlation between pH and soil permeability is almost zero and has no statistical significance.

4. CONCLUSION AND RECOMMENDATION

It is impossible to investigate the many water movement processes in the soil, plant, and atmospheric system without an understanding of the factors that allow one to forecast the dynamics of water in the soil. Characterizing the hydrodynamic behavior of the soil's surface layers is still challenging, though. This is the reason we were drawn to the in situ measuring method, which enables non-destructive determination of the hydrodynamic properties of the soil in the Ouargla region.

Our study's findings show that the pH range of Ouargla's soils is mildly alkaline to neutral, they have a high electrical conductivity, and there is a heterogeneous distribution of limestone. These soils have a high potential for infiltration and are typically porous. EC, total limestone content, and humidity have a medium-sized impact on permeability and are inversely connected with it, according to the results of the Spearman and Pearson tests. Permeability is slightly impacted by the pH and the rate of coarse elements.

This information can be used to develop soil permeability prediction models based on easily accessible soil data. The region's groundwater recharge, drainage planning, irrigation scheduling, and water conservation techniques can all be improved by using these models.

Several fundamental and applied research avenues are proposed in order to refine knowledge of the functioning of the soils of the Ouargla basin and the impact of anthropization and climate change on these soils.

1. Permeability measurements by other methods such as pumping tests and the double ring method are recommended to estimate the permeability of soils to eliminate horizontal flow.
2. The study of the variation in permeability depending on the frequency of irrigation.
3. Measurement of the permeability of different waters (fresh water, saline water, etc.)
4. Control of the management of water and soil resources is the guarantor of the sustainability of Saharan agriculture.

5. ACKNOWLEDGMENT

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