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MAPPING SOIL ELECTRICAL CONDUCTIVITY AS AN INDICATOR OF SOIL SALINITY IN THE CITY OF NOUAKCHOTT (MAURITANIA)

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ABSTRACT

The city of Nouakchott faces challenges linked to soil salinity, rising water tables and the absence of a sewerage system, leading to flooding during the rainy season. These conditions are disrupting urbanization and the greening of the city. All these phenomena inhibit plant growth and development due to soil hydromorphy and salinity. To remedy this situation, the Nouakchott region carried out a study to characterize soils and assess the adaptability of ornamental plants. The approach involves soil mapping. The parameters analyzed are: electrical conductivity (EC), pH, Calcium (Ca^{2+}), Magnesium (Mg^{2+}) and Chloride (Cl^-). A total of 104 samples were collected from various representative sites in the city. GPS coordinates are well defined. Two spatial interpolation methods, Ordinary Kriging (OK) and Inverse Distance Weighting (IDW), were used to estimate unmeasured values. The results show that Nouakchott's soils are saltier in the west and more alkaline in the east. Calcium predominates in the west, while magnesium is evenly distributed but more present in the east. Chlorides are also concentrated in the west. The IDW method proved to be the most effective for characterizing soils in the city of Nouakchott, with a very high correlation coefficient (R^2= 0.99) and low errors (RMSE and MAE).

Key-words: *Nouakchott, Mapping, Electrical conductivity, pH, Ions.*

1. INTRODUCTION

Soil mapping is widely regarded as a rapid and reliable tool for diagnosing soil health (Tripathi et al. 2015; Abidine et al. 2018; Zarco-Perello et Simões 2017; Seyedmohammadi, Esmaeelnejad, et Shabanpour 2016; Poshtmasari et al. 2012). In the urban environment, soil salinization is a major factor not only in the deterioration of buildings but also in the creation of green spaces (Czaja, Kołton, et Muras 2020). The city of Nouakchott lies on the Atlantic Ocean coastline (Sidi Cheikh et al. 2007) ; it is separated from the ocean by a dune cordon dotted with preaches. Climate change has accentuated these effects (Mohamed et al. 2017). Global warming as the polar ice caps melt threatens to flood the city with ocean water. Estimates show that these floods could occur between 2050 and 2100. Thus, the city is subject to the combined effect of groundwater outcrops, soil salinization and flooding (Dubois et al. 2024). Over the past decade, the city has experienced several floods due to intense rainfall and poor soil drainage (Dubois et al. 2024).

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To alleviate these problems, the Nouakchott region has embarked on approaches based on physical and biological systems. The biological approach aims to mitigate the rise in the water table by using adapted species. The choice of such species depends on their resistance to edaphic and climatic conditions. To our knowledge, no study of soil salinization in the city of Nouakchott has been carried out. The soils of Nouakchott, like those of other coastal towns, are mainly affected by sodium chloride salt (Okur et Örçen 2020). The presence of certain cations (Ca^{2+}, Mg^{2+}, etc.) in the soil can attenuate the harmful effect of Na^{+} ions (Ismayilov et al. 2021). Cl^{-} anions are well tolerated in low concentrations (Pessoa et al. 2022).

The aim of this work is to map the distribution of Ca^{2+}, Mg^{2+} and Cl^{-} ions in soils. Soil salinity is estimated by measuring soil electrical conductivity; soil buffering capacity is defined by pH measurements. The various maps are produced using two interpolation methods: deterministic interpolation (IDW) and ordinary kriging.

2. STUDY AREA

Nouakchott, the capital of Mauritania, lies in the Sub-Saharan zone, serving as a transition between the Saharan climate to the north and the Sahelian climate to the south. The climate is dry, with low and very irregular rainfall in summer. The city's main feature is its flat topography, with areas just a few meters above sea level. The relief is almost uniform, not exceeding 30 meters above sea level. Land below sea level is therefore vulnerable to rising water tables, marine incursions and technical challenges in drainage and sanitation. The sebkha's brackish water table is sub-surface, at a depth of 2 to 4 meters, causing flooding during heavy rainfall. These conditions are generally unfavorable to the installation of trees intended for the city's green landscape. The study covered a transect (**Fig. 1**) representative of the city's three wilayas divided into Moughataa (Tevragh Zeina, Sebkha, Ksar, Teyarett, Dar Naïm, Toujounine, Arafat, Riadh and El Mina).

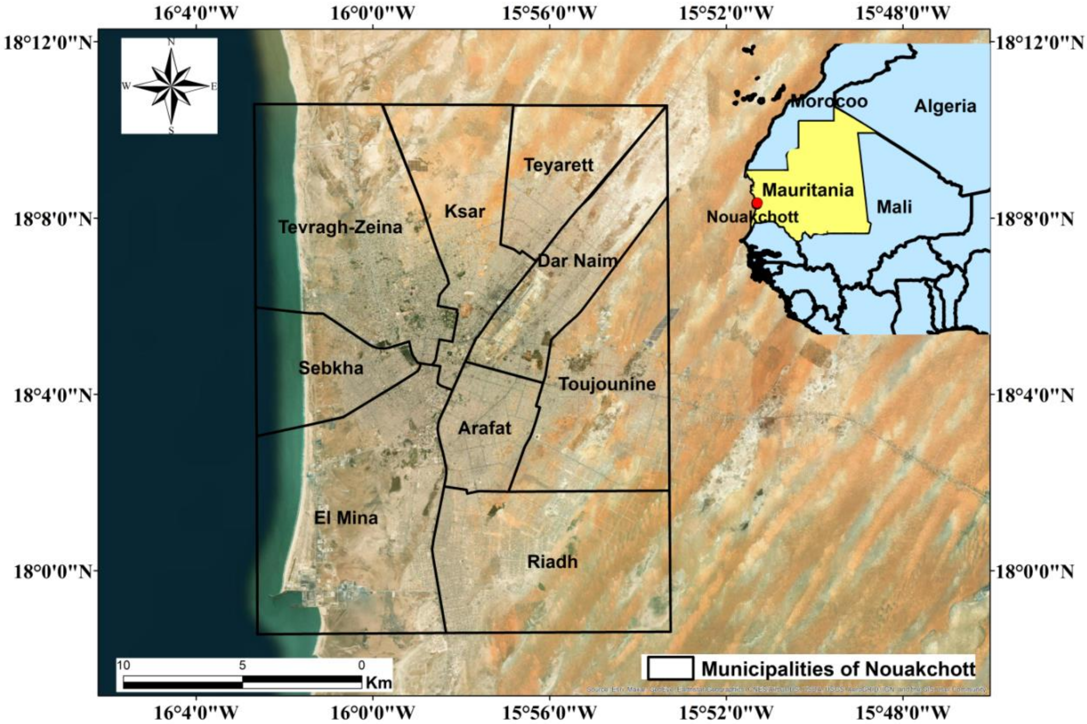

Fig. 1. Location of the Nouakchott region.

3. SOIL SAMPLING AND LABORATORY ANALYSIS

Site identification and sample collection were carried out over a two-week period. The choice of sampling sites was guided by the use of a SPOT image covering a large part of the city. The study area was sampled to a depth of 25 cm. A total of 104 samples were taken from 105 different sites. The GPS coordinates of each site were recorded. The soil samples were placed in plastic bags and kept cool. In the laboratory, they were dried in an oven at 105°C for 12 hours. They were then carefully ground in a mortar and sieved to 2 mm before the various protocols and measurements were applied. The various parameters studied are analyzed in the laboratories of the Biodiversity and Plant Resource Development Unit-Faculty of Science and Technology. pH and EC measurements were carried out using a multifunctional instrument. The protocol involves mixing 20g of crushed and sieved dry soil sample with 100ml of distilled water. The mixture is stirred for 1h30 min on a Hanna shaker, then left to settle and filtered on filter paper. The filtrate obtained is used for pH, EC and exchangeable ion measurements.

4. PREDICTION OF ELECTRICAL CONDUCTIVITY, PH AND SOIL IONS

Two spatial interpolation methods (OK and IDW) were used. They enable unknown values of electrical conductivity, pH and ions to be estimated from measured values. Correlation coefficients and performance criteria are used to validate the appropriate method for the study area.

4.1. Ok method prediction

The prediction of conductivity and pH by the ok method is calculated by the following equation (Tripathi et al. 2015)

$$y(h) = \frac{1}{2N} \sum_{i=}^{N(h)} [z(x_i) - z(x_i + h)]^2 \quad (1)$$

where: N(h) is the number of data pairs in a given distance and direction class.

4.2. Prediction using the IDW method

The prediction of conductivity and pH by the IDW method is calculated by the following equation

$$z(x_o) = \frac{\sum_{i=}^{n} \frac{x_i}{h_y^{\beta}}}{\sum_{i=1}^{n} \frac{1}{h_y^{\beta}}} \quad (2)$$

where, Z(x0) is the interpolated value, n representing the total number of sample data values xi is the measured data value, hi is the separation distance between the interpolated value and the sample data value, and β denotes the weighting power.

4.3. Performance evaluation criteria

Three types of standard statistical performance evaluation criteria were used to assess the accuracy of the predictive ability of the models developed. These criteria include correlation coefficient (R), root mean square error (RMSE) and mean error (ME). The performance evaluations in our study are determined using the following equations:

$$R = \sqrt{1 - \left[\frac{\sum_{i=1}^{n}(y_i - \hat{y}_i)^2}{\sum_{i=1}^{n}(y_i - \overline{y})^2}\right]} \quad (3)$$

$$RMSE = \sqrt{\frac{1}{n} \sum_{i=1}^{n} (y_{i-} \hat{y}_i)^2} \quad (4)$$

$$MAE = \frac{1}{n}\sum_{i=1}^{n}|y_i - \hat{y}_i| \quad (5)$$

where y_i indicates the measured value; $\hat{y}_i$ the predicted value, $\overline{y}_i$ the mean of the measured value and n the total number of observations.

5. RESULTS

5.1. Explanatory statistics

The data in **Table 1** presents the descriptive statistics for the EC, pH, major cations (Mg^{2+} and Ca^{2+}) and predominant anion (Cl^-) data sets for the 104 soil samples analyzed. The average electrical conductivity (EC) of the soil is 1.97 dS m-1. It ranges from 0.15 to 3.99, implying that the area has been affected by salinization (Richards, 1954). The average pH of the soil varies between 3.46 and 8.78, and the soils are mainly alkaline (Soltner, 1989). Calcium ranged from 16.05 to 258.11 mg/l. Magnesium ranged from a low of 15.11 to 291.6 mg/l. Soil-available chloride ranged from 23.43 to 497 mg/l.

Table 1.

Descriptive statistic for soil pH and EC data sets in the Nouakchott study area.

Soil properties	**Depth (cm)**	**Mean ± SD**	**Min**	**Max**	**CV (%)**	**Kurtosis**	**Skewness**
EC (dS m−1) (n = 104)	0–40	1,97± 1,56	0,15	3,99	79	-1,70	0,33
pH (n = 104)	0–40	7,84±0,56	3,46	8,78	8,2	34,21	-4,47
Cl^- (mg/l)(n = 104)	0–40	133,75±131,79	23,43	497	98	3,41	2,05
Ca^{2+} (mg/l)((n = 104)	0–40	89,12±81,47	16,05	258,11	91	-0,55	1,02
mg^{2+} (mg/l)((n = 104)	0–40	84,50±63,27	15,11	291,6	74	4,42	1,78

Notes: SD, standard deviation; CV, coefficient of variation.

Coefficients of variation (CV) denote the variability of properties for soil parameters (Emadi et Baghernejad 2014). According to Wilding (1985), the variability of measured electrical conductivity (EC) is significant when CV exceeds 35%. Our results show this heterogeneity. Abidine et al. (2018) found the same results for Diawling soil. In contrast, soil pH CVs show little variability (8.2). The results of the EC and pH CVs corroborate those of Tripathi et al. (2015) in Odisha, India. The coefficients of variation (CV) are 62.5% for electrical conductivity (EC), 4.43% for pH.

5.2. Cross-validation

The variograms of the various parameters studied according to the two methods used (IDW and OK) showed a lower uncertainty (RMSE, MAE) and a very high R (0.99) for IDW (**Tab. 2**). Thus, the IDW method is the most appropriate in this study. It seems that this method is more valid in arid regions (Karydas et al. 2009; Attaeian et al. 2015;. Abidine et al. 2023 ; Abidine et al. 2018).

Table 2.

Validation criteria for two methods (IDW and OK) in the study area

	CE		**pH**		**Cl-**		**Ca2+**		**Mg2+**	
	IDW	OK	IDW	OK	IDW	OK	IDW	OK	IDW	OK
R	0,99	0,55	0,99	0,56	0,99	0,99	0,99	0,03	0,99	0,81
RMSE	0,0037	1,298	-0,00011	-0,00816	0,11	1,54	0,15	61,02	0,032	40,24
MAE	0,00012	0,012	0,00011	0,0082	0,002	0,22	0,004	1,24	0,005	1,24

R^2= coefficient of determination, RMSE=root mean square error, MAE=mean absolute error.

5.3. Interpolation using IDW

Figures (2, 3, 4, 5 and **6**) show the interpolation maps for the various parameters studied using the IDW method. **Figure 2** shows the soil pH in the study area. pH values are lower in the west, in the Tevragh-Zeina region (5.31-7.65). In the other areas (Ksar and Dar Naim), values are higher (7.65-8.77). Soils in the city of Nouakchott thus seem to have an alkaline tendency.

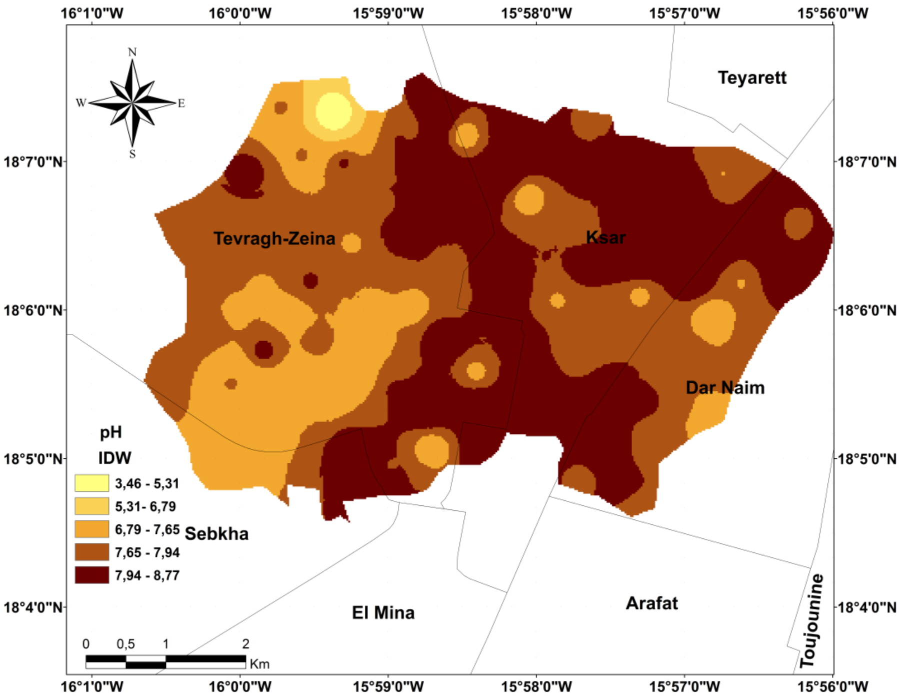

Fig. 2. IDW pH interpolation map.

Figure 3 shows that electrical conductivity (CE) follows a gradient from west to east. It is highest in the Tevragh-Zeina region (2.42-3.98 ds/m). It is lower in the Kasr and Dar Naim regions (0.15-2.42 ds/m).

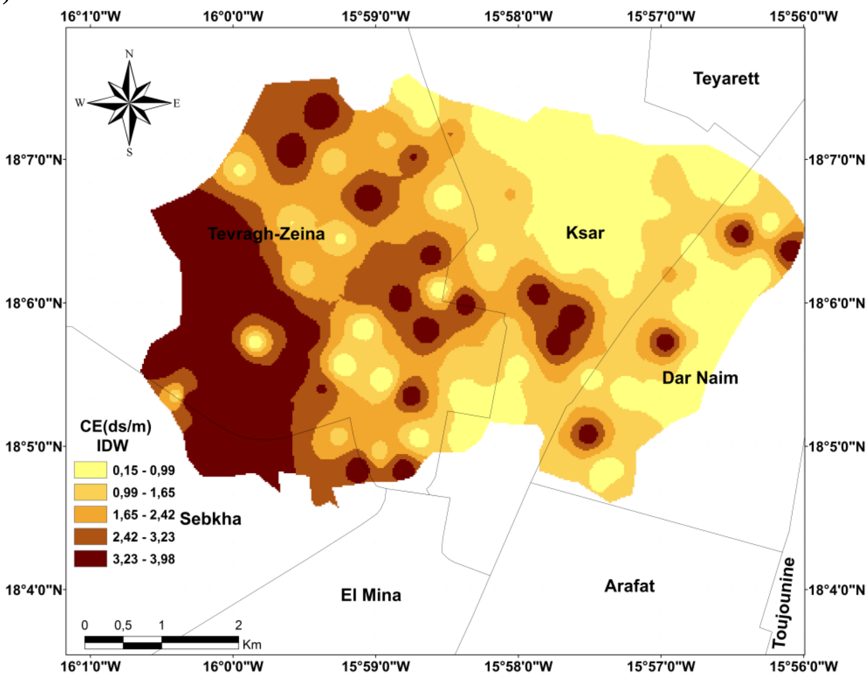

Fig. 3. CE interpolation map by IDW.

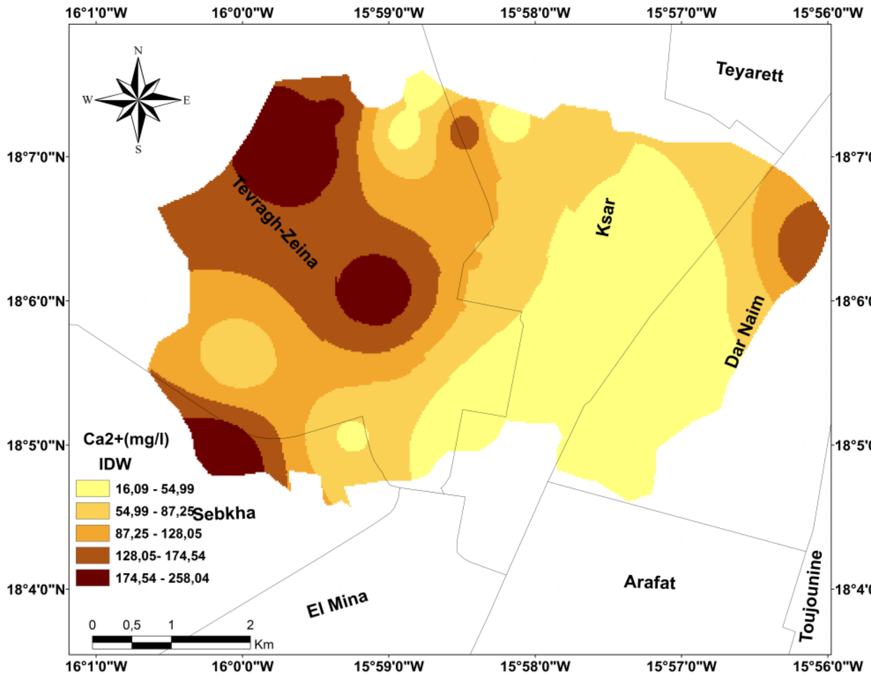

Fig. 4. IDW Calcium interpolation map.

Interpolation maps for two major cations (Ca^{2+} and Mg^{2+}) and anion (Cl^{-}) show contrasting behavior. The distribution of the Ca^{2+} ion shows a gradient from west to east. The highest concentration (87.25-258.04 mg/l) is found in Tevragh Zeina, while concentrations are only 16.09 to 54.99 mg/l in Ksar and Dar Naim (**Fig. 4**).

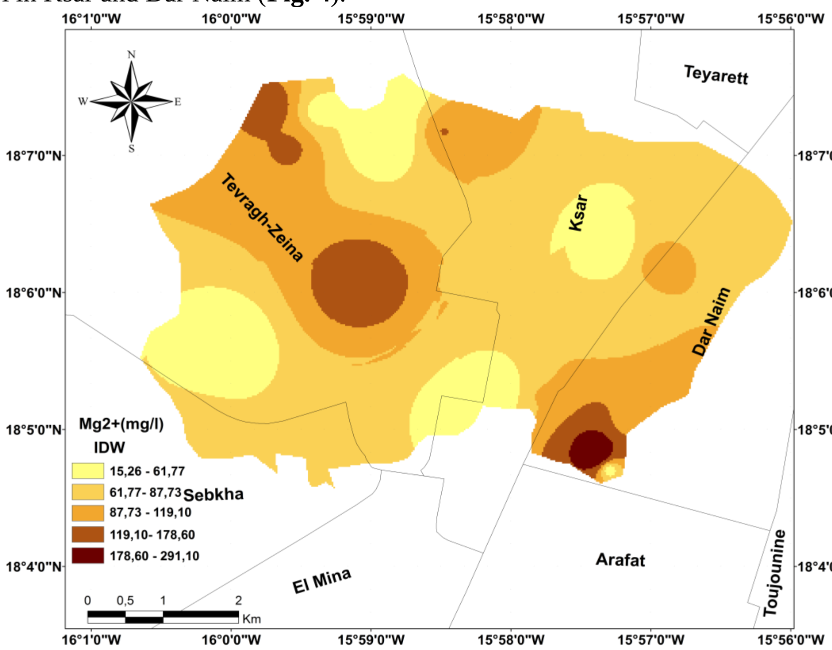

Fig. 5. IDW Magnesium interpolation map.

The Mg^{2+} cation shows a more even distribution. **Figure 5** illustrates the concentrations of this ion in the study area. Values range from 61.77 to 78.73 mg/l. No significant differences between the different zones (Tevragh Zeina, Ksar and Dar Naim).

Figure 6 shows the distribution of the anion (Cl^-). Concentrations are slightly higher in the west, in the Tevragh Zeina zone (251.82-496.89 mg/l). Ksar and Dar Naim have the lowest Cl^- concentrations (23.45-251.82 mg/l).

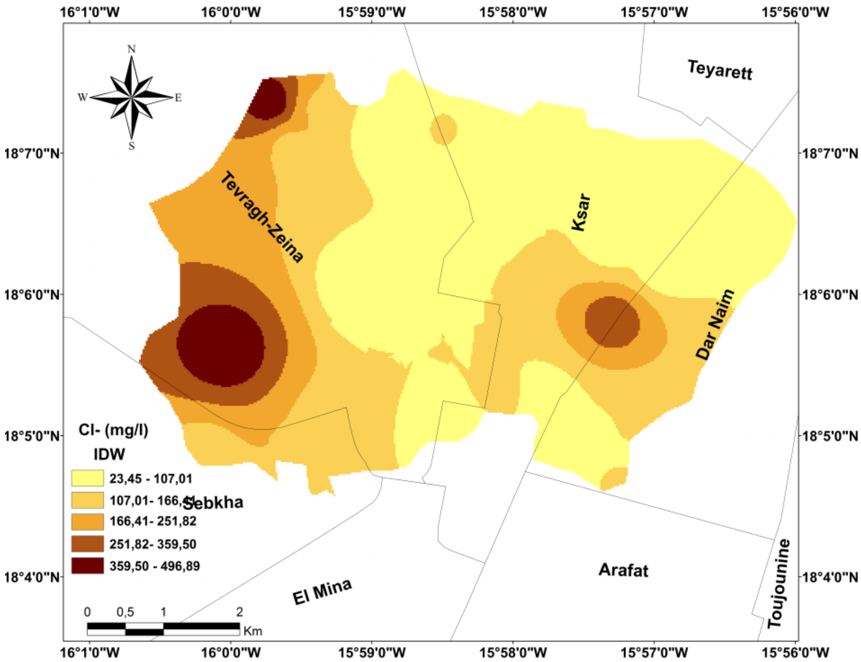

Fig. 6. IDW Chloride Interpolation Map.

6. DISCUSSION

Green spaces are considered the lungs of cities. Urban planning is heavily dependent on public gardens and street trees. The choice of species used depends on climatic and, above all, edaphic conditions. The ground in the city of Nouakchott (Mauritania) is characterized by sebkas and puddles. Salt crusts (especially NaCl) are frequently observed in certain parts of the city. The absence of sanitation infrastructures and the rising water table, which is very close to the surface, accentuate the problems of soil salinization.

Physico-chemical characterization of the soils in the city of Nouakchott is an important approach in any city vegetation program. In this study, we set out to map the distribution of salinity in the city using electrical conductivity (EC). The results show high salinity in the Tevragh Zeina area (EC=3.9 $ds.m^{-1}$). According to the scale established by Durand, (1983), this soil is considered very salty. In contrast, Ksar and Dar Naim (EC=1.6 $ds.m^{-1}$) have moderately saline soils, according to the same scale. The pH of Nouakchott soils is 8.7. According to Soltner (1989), this soil is considered alkaline.

Soil pH affects plant nutrition; certain ions are only available for absorption when the pH is basic. In alfalfa, a pH higher than 7 increases the harmful effect of Nacl 200mM on plant growth and development (Kaiwen et al. 2020). High salt concentration in alkaline soil reduces nutrient availability (He et al. 2017). Thus, plant nutrition in saline soils depends on the soil's nutritional status in terms of major and minor ions.

The beneficial effect of Ca^{2+} and Mg^{2+} on plant growth and development in saline conditions (rich in Na^+) has been well demonstrated in several studies. At soil level, Ca^{2+} competes with Na^+ at the same binding site, thus improving K^+ uptake (Taieb Tounekti et al. 2010).

K^+ ion improves plant water status (Taïeb Tounekti et al. 2011). The uptake of Ca^{2+} and Mg^{2+} by plant roots is proportional to their availability in the soil. However, the most sensitive species absorb major cations less efficiently than salinity-resistant species (Walker et al. 1955). In other species, Secale (Rajakaruna et al. 2003), Helianthus bolanderi ssp. exilis A. Gray and the sunflower (Walker et al. 1955), their ability to tolerate salinity depends on maintaining high Mg^{2+}/Ca^{2+} and K^+/Na^+ ratios.

The results observed in Lasthenia californica growing on different soils postulate that the salinity resistance of different populations is not due to a single mechanism (Rajakaruna et al. 2003). Resistance operates at several levels, including root morphology, uptake, translocation and cation interactions. One of the key elements of salinity tolerance is the ability to maintain a high level of cytosolic K^+/Na^+ independently of external concentrations of these two ions. Cl^- is a trace element, which is only toxic in relatively high concentrations (Rejili et al. 2007).

The soil of Nouakchott has a relatively homogeneous distribution of this ion. The exceptionally high content is localized in small pockets at Tevregh Zeina. We can understand its presence in such high concentrations in the context of its accompanying anion behaviour of Na^+, Ca^{2+}, Mg^{2+}. Abdelaal et al. (2021), have shown that the predominance of chloride salts in saline soils in Egypt disrupts the soil's biological processes and reduces its capacity for natural regeneration. As a result, the addition of certain cation-rich fertilizers improves soil quality to the extent that it does not lead to further soil salinization.

Halophytes are species adapted to these types of soil, where chloride salts predominate (Zhao et al. 2022). It thus seems to us that a judicious choice of halophytic species can be considered the most plausible approach in gardening programs in Nouakchott. Soil physico-chemical parameter maps for the city of Nouakchott are drawn up using the IDW method. This method showed very low error values and a high correlation coefficient, making it the most suitable for studying soils in desert regions. The effectiveness of the IDW method in arid environments has been endorsed by Lotfinasabasl et al. (2018) in Iran and Bashir et Fouli (2015) in Saudi Arabia.

7. CONCLUSION

Soil mapping in the city of Nouakchott has shown that soils tend to be basic, with Tevregh Zeina being the most saline. Chloride salt levels are very high and have a generally homogeneous distribution in the areas studied. Nevertheless, Tevregh Zeina showed pockets with exceptionally high concentrations.

The two major cations Ca^{2+} and Mg^{2+} show different edaphic behavior. Ca^{2+} ions are concentrated in the Tevregh Zeina area, while Mg^{2+} ions are more or less evenly distributed across the different regions studied. Vis the very high salinity of the soil, additional fertilizers can lead to salinization of the soil by total salts. So, the choice of species adapted to aridity conditions (salinity, heat and drought) seems to be the most appropriate strategy.

The IDW method is the most suitable for mapping soil physico-chemical parameters in these arid edaphic situations.

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