

Assessing Groundwater–Soil Interactions for Sustainable Water Resource Management in the Mostaganem Plateau, Algeria

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Abstract: *Groundwater characteristics and their impact on soils and the environment in the Mostaganem Plateau, Algeria, depend on additional data and aggregate analyses. This interdependence highlights the importance of considering a variety of parameters such as bicarbonates, calcium, chlorine, electrical conductivity, magnesium, sodium, sulfates, potassium and pH to understand the impact overall.*

These studies highlight a significant relationship between groundwater and its impact on the environment, thus highlighting the importance of closely monitoring water quality in the Mostaganem region. This correlation also suggests a possible association between water salinity and environmental problems, raising critical questions in water resource management and environmental conservation.

Furthermore, the impact of groundwater on soils and the environment is also influenced by agricultural practices such as continuous irrigation, which is common in the region due to its status as an important agricultural center.

By highlighting these links between groundwater, soils and the environment, this research highlights the urgency of implementing sustainable and effective water resources management measures. This requires close collaboration between local authorities, researchers and farmers to develop water and land conservation strategies that take into account the environmental and socio-economic realities of the region.

Groundwater quality management in the Mostaganem Plateau is crucial to ensure long-term environmental and agricultural sustainability. This

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approach requires an integrated and collaborative approach that takes into account the multiple factors at play and aims to promote judicious use of water resources while preserving the health of the soil and the ecosystem as a whole.

Keywords: Groundwater , soil, Water quality, Mostaganem plateau, Agricultural practices.

Abbreviations : SO₄ - sulfate ; PH - pontetial hydrogen ; P - calcium; Na - sodium ;EC - electrical conductivity ; K – potassium ; Mg – magnésium ; Ca – calcium ;Rstd – standardized reseduals ; PCA - principal compoment analysis; S.S - sample size; DOF - degrees of freedom; MS - mean Square ; SS - sum of squares ; INSID - National Institute of Soil, Irrigation and Drainage

Introduction

The Mostaganem Plateau, located in Algeria, is considered an area of great agricultural activity, and is characterized by its dependence on groundwater for irrigation. This region has The region experiences a harsh semi-arid climate, characterized by hot summers, cold winters, and long dry periode. The mean yearly precipitation amounts to approximately three hundred and seven millimeters, while the annual evaporation and transpiration reach up to one thousand millimeters. (Nassira Salhi et al 2014). The quality of this groundwater participate a vital function not solely in upkeep agricultural productivity additionally in shaping the overall environmental health of the region. Understanding the interplay between groundwater properties, soil quality and environmental impact is essential for effective water resource management and sustainable agricultural practices. Environmental stewardship efforts are closely tied for the concept of enviromental sustainnability. Amidst this regard, substrate stands out compared to other environmental components such Life forms, atmosphere, and water reservoir due up to the crucial role in both productive and the environmental operation. (Brevik & Sauer, 2015).

In this context, comprehensive studies were conducted to evaluate the agro-environmental impacts of groundwater quality in the Mostaganem Plateau. These studies used complementary data and pooled analyzes to explore the relationships between different factors, such as bicarbonate, calcium, chlorine, electrical

conductivity, magnesium, sodium, sulfate, potassium, and pH, and their collective impact on soil and environment.

Furthermore, heightened wind erosion can exacerbate salinization in regions previously unaffected by saline soils. In practical terms, salinization predominantly results from inadequate irrigation practices involving the use of Substandard quality, saline rich water insufficient Water flow measures. (Ruto et al., 2018).

By studying these connections, researchers aim to shed light on the complex dynamics at play within the groundwater-soil-environment continuum. These insights are critical for guiding policy decisions and implementing management strategies that enhance agricultural productivity and environmental sustainability in the Mostaganem Plateau. "The escalation of salinization poses threats to agriculture and the environment, raising concerns for agricultural production systems. This prompts researchers to conduct further studies to better understand this phenomenon and search for solutions to address it. profoundly impacting land utilization and natural resource management. (Negacz et al., 2022). This paper discusses the results of these studies, and highlights the main relationships between groundwater characteristics and their effects on the soil and the environment. Through comprehensive Through data analysis, our objective is to enhance comprehension of the challenges and opportunities linked to water resource management in this significant agricultural region.

Material And Methods

STADY AREA

The Mostaganem plateau represents one of the hardest hit ecosystems in Algeria by the Deterioration of its water reserves. This plateau is part of the sandy areas located between Mostaganem and Ténès along the western flank of the country which have more than fifty kilometers of coastal length and where wind transport is very active (baiche A.et al 2002). These can remain active for several months a year. Additionally for this purpose. The plateau suffers from a relatively high urban concentration, leading to diverse economic activities such as agriculture and industry. These activities consume large quantities of water, especially groundwater, threatening its resources and fundamental ecological balances. (Lorne, 1959) Thus, it is in high demand and continually undergoes degradation (Larid, 2014), despite being relatively under-researched (Gorine et al 2019).

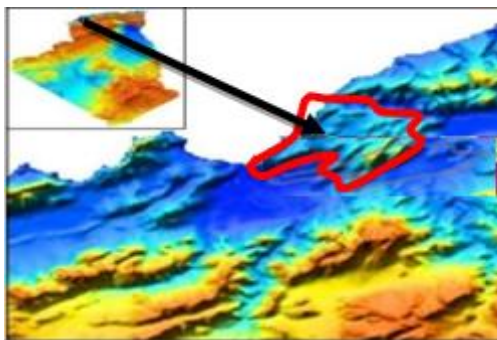


Figure.1 Digital Elevation Model of the Mostaganem Plateau.



Figure.2 Water Sampling Point Mapping (Ouabel 2024)

Methods of Analysis :

We automatically sample 1-liter quantities of water extracted from each well, based on surveys conducted with farmers, to collect accurate data. Sampling can cause changes in the properties of the collected water. Some changes remain constant over time, while others, such as temperature, conductivity, pH, and dissolved gases, can change rapidly. Samples must be representative of the water to be analyzed. Field measurements of temperature are essential to obtain accurate data. Field analysis methods can vary depending on the parameters being measured. Groundwater quality studies are divided into three stages : sampling, analysis, and interpretation. Sampling is crucial because it determines the accuracy of the analyses. The containers used must be clean, rinsed several times with the water to be analyzed, and then tightly sealed to avoid any change in the sample. The choice of material for the sampling bottle is also critical, as it should not react with the water to be analyzed. Samples are taken directly to the water and soil analysis laboratory located in Relizane.

Selecting the materials and methods for water analysis is crucial for obtaining reliable results. Portable electrochemical probes are used to measure pH, conductivity, sodium, potassium, calcium, magnesium, and other ions. These probes are user-friendly and enable quick measurements within the laboratory. Photometry (spectrophotometry) is employed to measure parameters such as chlorides, phosphates, sulfates, nitrates, iron, manganese, fluorides, and other chemical compounds. This method relies on measuring light absorption by substances in the water. Titration or colorimetry is a method used to measure certain parameters like

alkalinity, nitrate, nitrite, and other substances. Titration involves adding a titrant to the sample until a color change or other indicator reveals the end of the reaction. Interpreting analysis results involves examining fundamental factors such as pH, conductivity, and temperature, along with assessing the impact of pollutants on water quality. For instance, studies by Ruto et al. (2018) have demonstrated that inadequate irrigation practices using low-quality water can significantly increase soil salinity, affecting agricultural productivity and environmental health. Qadir et al. (2014) also emphasize the importance of managing soil salinity to maintain agricultural production and ensure food security, highlighting the global scale of saline lands and their detrimental effects.

Statistical analyses :

including Principal Component Analysis (PCA), ANOVA, and polynomial tests, were meticulously conducted on the measured indicators using XLstat, a robust statistical software seamlessly integrated with Microsoft Excel Office 2016. These analyses were performed to extract meaningful insights, unravel complex relationships, and derive comprehensive conclusions from the collected data.

Results and Discussion

COMPONENT ANALYSIS (PCA) PRINCIPAL

The findings from the “PCA” indicated that the initial five principal components (F1 to F5) collectively explain 82.827% of the total variability in the data, which is considered significant for representing the entirety of information contained within the dataset. Essential factors F1 and F2 were the most influential in explaining the variance, with eigenvalues of 3.092 and 1.911 respectively, highlighting their importance in structuring the data. While the other components (F3 to F5) provided additional information, their contribution to the total variance was lesser. PCA helped reduce the complexity of the data while preserving their informative content, facilitating their interpretation and use for subsequent analyses (tab1).

Table.1 Explained Variability by Principal Components (F1 to F10)

	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10
Eigen value	3,092	1,911	1,321	1,036	0,923	0,638	0,606	0,376	0,092	0,005

Variabili	30,9	19,1	13,2	10,3	9,23	6,38	6,06	3,76		
ty (%)	17	10	05	62	3	4	2	2	0,918	0,048
Cumulat	30,9	50,0	63,2	73,5	82,8	89,2	95,2	99,0	99,95	100,0
ive %"	17	27	32	94	27	10	73	35	2	00

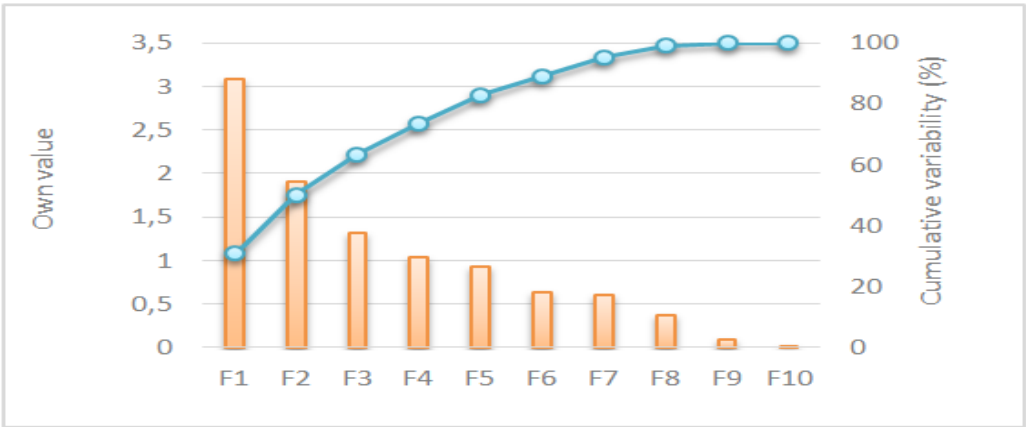


Figure.3 Scree Plot, Evaluating Principal Components

EC (dS/m) and Clen Meq/lare most influential at F1.
The number of wells and Na are major contributors to F2, indicating a trade-off.
SO4 Meq/lt mainly affects F3.
k and Mg are important for F4.
Bicarbonate (meq/L) has a strong effect on F5.
In the context of principal component analysis (PCA), (Tab2) the eigenvectors depict the directions of greatest variance within the dataset, with their respective eigenvalues signifying the extent of this variance.
Each eigenvector (or principal component) can be thought of as a new axis in the transformed space that best captures the variance in the data.

Table.2 Vecteurs propres :

	F1	F2	F3	F4	F5
N° of well	-0,058	-0,653	-0,097	-0,065	-0,041
pH	-0,307	-0,218	-0,245	-0,328	0,127

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EC (dS/m)	0,518	0,043	-0,091	0,268	0,072
Clen Meq/l	0,510	0,046	-0,081	0,333	0,021
Bicarbonet(meq/L)	0,217	-0,041	-0,444	-0,201	0,711
SO4Meq/lt	0,017	0,103	0,714	-0,090	0,297
k	-0,193	-0,348	0,111	0,553	0,382
Mg	-0,395	-0,030	0,025	0,501	0,141
Ca	-0,244	0,296	-0,438	0,313	-0,264
Na	-0,273	0,548	-0,058	-0,045	0,384

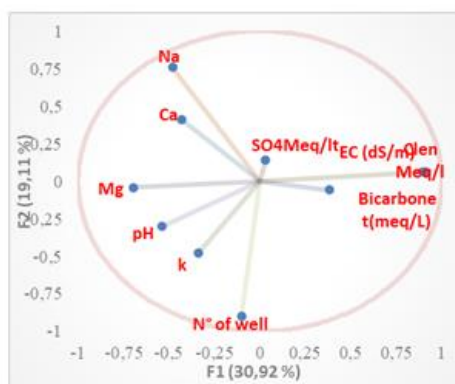


Figure.4 Variables (axes F1 and F2: 50,03%)

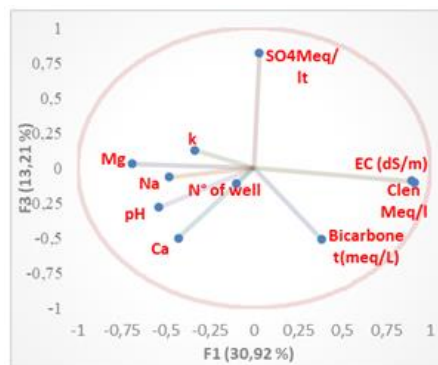


Figure.5 Variables (axes F1 and F3 : 44,12 %)

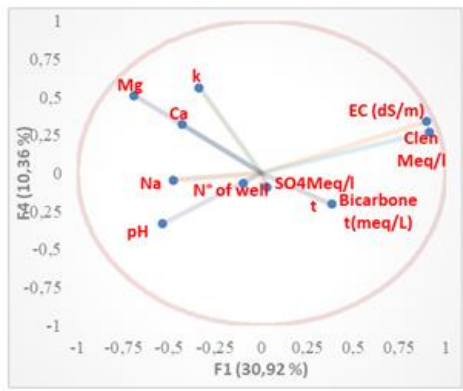


Figure.6 Variables (axes F1 and F4 : 41,28 %)

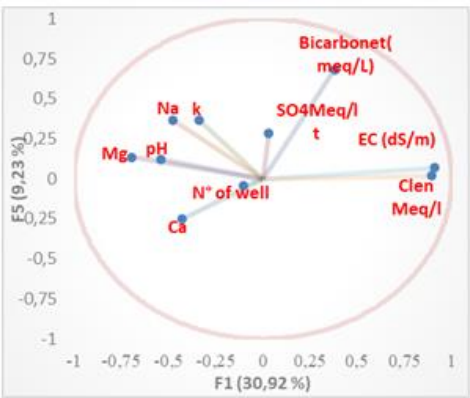


Figure.7 Variables (axes F1 and F5 : 40,15 %)

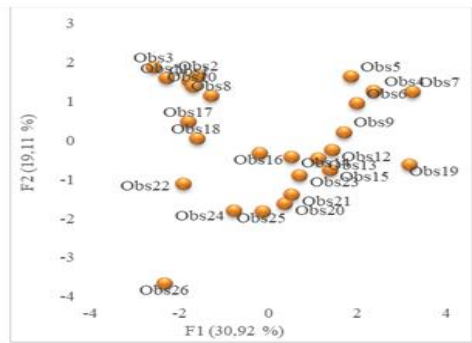


Figure.8 Observations (axes F1 and F2 : 50,03 %)

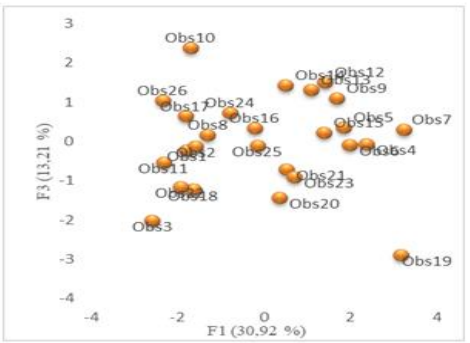


Figure.9 Observations (axes F1 and F3 : 44,12 %)

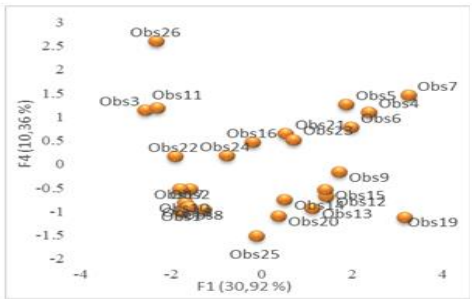


Figure.10 Observations (axes F1 and F4 : 41,28 %)

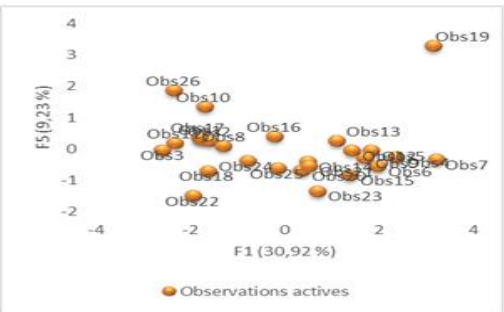


Figure.11 Observations (axes F1 and F5 : 40,15 %)

The following is a detailed interpretation of the eigenvectors given for the first five principal components (F1, F2, F3, F4, F5):

The first principal component has high positive loadings for (EC (dS/m)) (0.518) and (Clen Meq/l (0.510)), indicating that these variables contribute significantly to this component.

It indicates that F1 is largely driven by these variables, meaning that differences in these variables explain much of the variance captured by F1.

The second principal component has a high negative loading for (well number) (-0.653) and a high positive loading for (Na (0.548)).

This indicates that F2 contrasts wells with higher N° values with those with higher Na values, suggesting a trade-off between these variables along this component.

The third principal component has a high positive loading for SO₄ Meq/l (0.714), indicating that it plays a major role in this component.

This indicates that variations in (SO₄ Meq/l) are the primary contributors to the variance captured by F3.

The fourth principal component has a high positive loading for k(0.553) and Mg(0.501).

This component is mainly affected by changes in these variables, indicating that their common variance is captured by F4.

The fifth principal component has a high positive loading for (Bicarbonate (meq/L)(0.711)), indicating that this variable is the primary contributor.

This indicates that the variation in Bicarbonate (meq/L) is a major factor captured by F5.

Classification Indices :

The indices provided make it possible to evaluate the quality of the different classification solutions for an increasing number of classes (from 2 to 5). Here is the interpretation of each index and their evolution:

Optimal number of classes : According to all the indices, the 3-class model seems the most optimal. The silhouette index remains relatively high, the Hartigan index

and the evolution $H(k-1) - H(k)$ clearly justify the addition of a third class, and the Calinski & Harabasz index reaches its maximum.

Minimum number of classes : If we favor simplicity and very good cohesion, 2 classes* may be sufficient, as indicated by the silhouette and Hartigan index. These interpretations help choose the optimal number of classes for good cluster separation and cohesion, while avoiding unnecessary complexity.

Table.3 Evolution of Clustering Indices by Number of Classes

N° of Classes	2	3	4	5
Silhouette Index	0,485	0,480	0,404	0,419
Hartigan index (H)	24,809	5,763	7,366	7,187
$H(k-1) - H(k)$	15,183	19,046	-1,603	0,179
Calinski & harabasz index	39,992	52,237	43,958	44,350

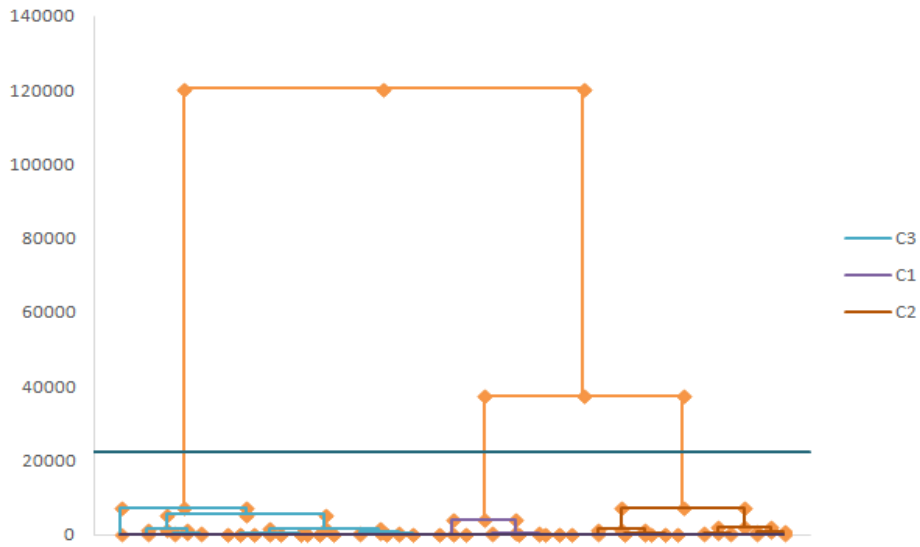


Figure.12 Hierarchical Agglomerative Clustering (HAC) / Number of Classes = 3:

Calculate the power of the test :
Hypotheses and Statistical Parameters
 $H_0: (R^2) = 0.$
 $H_a: (R^2) \neq 0.$

0.263 is the risk of not rejecting the null hypothesis H_0 when it is false. Given the parameters entered, with an alpha value of 0.05 and a sample size of 20 observations, the Type II error rate (beta) is 0.263, and the power is 0.737.

These results indicate that while the test has a moderate sample size and effect size, maintaining a good balance between Type I and Type II errors enhances the quality and reliability of the results, with a reasonably high power of 73.7%. This implies that the study is well-designed to detect true effects when they exist.

Table.4 Number of predictors tested2

Parameters	Results
Sample Size	20
Significance Level	0,05
Effect Size	0,500
(Beta)	0,263
(1 - Beta)	0,737

One-sample correlation test (Student's approx.)

H_0 : the difference between the correlations = 0.

H_a : the difference between the correlations $\neq 0$.

The risk of not rejecting the null hypothesis H_0 Equals 0, even if it's false.

When the alpha value is 0.05 and the sample size is 20 observations, the Type II error is 0, and the power is 1. These results indicate that the test has an exceptionally low Type II error rate (Beta) of less than 0.0001, and a perfect power of 1.000. here, the suggestion is that test is very productive in detecting valid effects when they exist, making it extremely unlikely to fail to reject a false null hypothesis. Additionally, the significance level and effect size used are appropriate for ensuring reliable and robust results.

Table.5 Statistical Analysis Parameters and Results

Paramètres	Résultats
Significance Level	0,05
Effect Size	0,500
(Beta) type 2 error rate	<0,0001
(1 - Beta) power	1,000

Test on a proportion (Normal Approx.)

H0 : the difference between the correlations = 0.

Ha : the difference between the correlations $\neq 0$.

The probability of failing to reject the null hypothesis H0 despite its falsity is 0.86. For the given parameters, with a significance level of 95% and a sample size of 20 observations, the Type2 error rate is 0.86, while the power is 0.14. These parameters are often used in hypothesis testing to assess the strength of evidence against the null hypothesis and the likelihood of detecting a true effect if it exists. The lower power value suggests that the study might not have enough statistical power to detect a difference if it truly exists, given the specified significance level and effect size.3.5

Table.6 Statistical Analysis Parameters and Results

Paramètres	Résultats
Significance Level	0,05
Proportion	0,4
Theoretical proportion	0,5
Beta	0,860
Power	0,140

Test on two variances

H0 : the difference between the correlations = 0.

Ha : the difference between the correlations $\neq 0$.

The probability of failing to reject the null hypothesis H₀ despite its falsity is 0.692. For the specified parameters, with a significance level of 95% and a sample size of 20 observations, the Type II error rate is 0.692, while the power is 0.308..

These parameters provide information about the sample sizes, the threshold for significance, the size of the effect being tested, and the likelihood of making Type II errors or correctly detecting true effects.

Table.7 Statistical Analysis Parameters and Results Summary

Paramètres	Results
S.S 1	20
S.S 2	20
Significance Level	0,05
Effect Size	0,500
(Beta) type2 error rate	0,692
(1 - Beta) power	0,308

One-sample t-test :

H0 : the difference between the correlations = 0.

Ha : the difference between the correlations $\neq 0$.

The probability of failing to reject the null hypothesis H_0 despite its falsity is 0.435. For the specified parameters, with a significance level of 0.05 and a sample size of 20 observations, the Type II error rate is 0.435, while the power is 0.565.

At a significance level of 95%, with a moderate effect size, a Type II error rate of 0.435, and a power of 0.565, the interpretation suggests that there is a reasonable chance of correctly detecting a true difference between the averages if it exists, but there's also a notable chance of failing to detect it (Type II error).

Table.8 Alternative hypothesis: Average 1 $\neq$ Theoretical average

Paramètres	Résultats
Significance Level	0,05
Effect Size	0,500
Bêta	0,435
Power	0,565

ANALYSIS OF VARIANCE (Y) :

The model accounts for a substantial portion of the data's variability, evident from the remarkably low p-value (<0.0001). Consequently, we reject the null hypothesis suggesting equal means and infer significant differences among at least some of the groups.

Table.9 Calculated against the model $Y = \text{Average}(Y)$

Source	DOF	SS	MS	F	Pr > F
Model	8	275556,831	34444,604	40,504	<0,0001
Error	225	191341,621	850,407		
Corrected total	233	466898,452			

STANDARDIZED COEFFICIENTS (Y) :

Variables with p-values below 0.05 are typically Deemed statistically significant. In my table, the (N° of well-Ca) and (N° of well-Mg) variables have p-values less than 0.05, indicating that the number of wells of calcium and magnesium has a statistically Substantial impact on the outcome. being studied.

The coefficient estimate (Valeur) for each variable representing the estimated variation in the outcome variable associated with a one-unit change in the predictor variable, while holding all other variables constant.

Confidence intervals provide a range of plausible values for the true population parameter. If the interval includes zero, it suggests that the variable may not have a significant effect on the outcome. The coefficient estimate for the number of wells is 0.775, indicating that each additional well of sodium increases the outcome variable by approximately 0.775 units on average, holding all other variables constant. Since the p-value is less than 0.05, this effect is statistically significant.

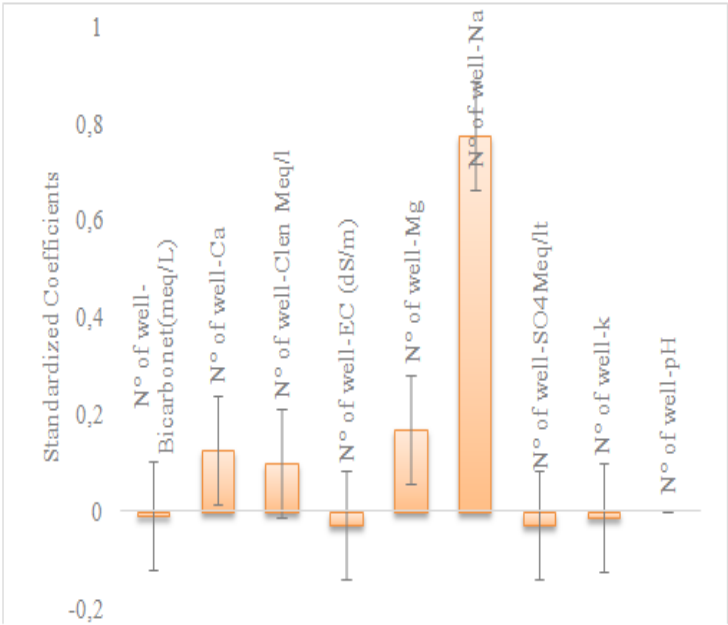


Figure.13 Y / Normalized coefficients (Conf. 95%)

Forecasts and residuals (y):

The donors will likely be interested in understanding the implications of the regression analysis results. In essence, the analysis provides insights into how effectively the regression model suits the data. Each line in the output corresponds to a different observation, and there are various statistical measures provided to assess the performance of the model.

For example, let's consider a scenario where the regression analysis was conducted to forecast the sales of a product based on different marketing variables such as spending on advertising, promotional events, and competitor pricing. In this case :

- **Y (Variable Dependency):** This represents the actual sales figures observed for each observation
- **Pred(Y) (Regression Model Prediction):** This indicates the sales figures predicted by the regression model based on the marketing variables.
- **Residual (Difference):** The residual demonstrates the variance between the actual sales and the expected sales. A positive residual signifies an underestimation of sales by the model, whereas a negative residual implies an overestimation. **RStd (Standardized Residuals):** These standardized residuals help to monitor how far each observation deviates from the overall trend of the regression model. Large standardized residuals may indicate outliers or observations that are not well explained by the model.
- **95% Confidence Interval (IC 95%) :** For both the mean and individual observations, these intervals provide a range where the true values are expected to fall with 95% confidence. For instance, if the confidence interval for a particular observation is wide, it suggests considerable uncertainty about the true value of that observation based on the model.

In interpreting these results, it's crucial to note any patterns or trends in the residuals and confidence intervals. Large residuals or wide confidence intervals may indicate areas where the model could be improved or where further investigation is needed. In the context of our example, if the model consistently underestimates sales for a particular type of promotional event, it might suggest that the model doesn't adequately capture the impact of that event on sales. Thus, the donors may want to consider refining the model or exploring additional variables to improve its predictive accuracy.

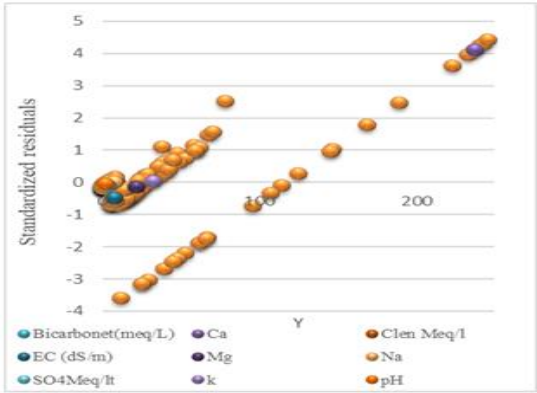


Figure.14 Y / Normalized residuals

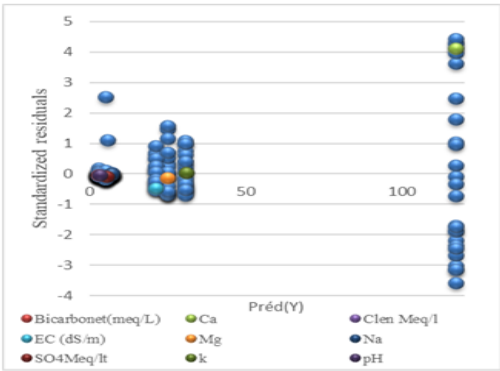


Figure.15 Préd(Y) / Normalized residuals

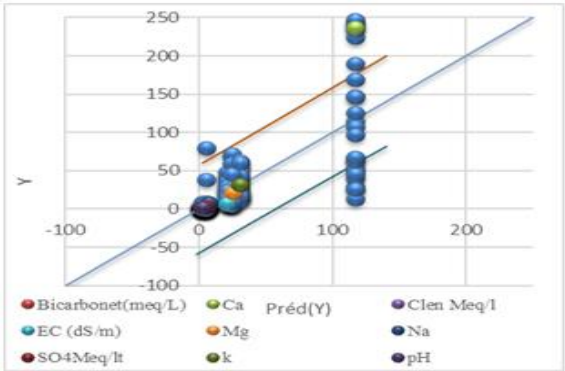


Figure.16 Préd(Y) – Y

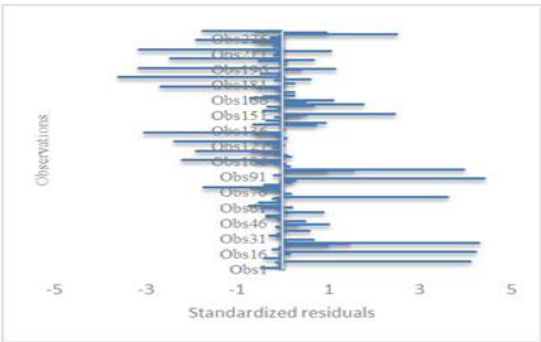


Figure.17 Standardized residuals / Y

Conclusion

The analysis of water samples from the Mostaganem Plateau reveals a concerning trend : a significant portion (77%) of the samples exhibit high salinity levels, rendering them unsuitable for irrigation, except in well-drained sandy areas. This high salinity likely stems from geological or anthropogenic factors, considering the region's sandy composition. Furthermore, downstream water samples indicate heavy pollution from agricultural, urban, and industrial activities, particularly prevalent in areas known for intensive poultry farming. This complex environmental situation demands comprehensive research involving various stakeholders and experts to address the multitude of challenges it presents.

Moreover, degradation of water quality due to erosion poses an additional threat, especially in regions like Mazagran, where evidence of erosion is prominent. In

uncultivated areas, central circles indicative of water erosion are visible in the northwest, while the southeast exhibits the formation of valleys and channels. Human activities exacerbate soil degradation, particularly through excessive irrigation, affecting municipalities like Mostaganem, Ain Nouissi, and Ain Sidi Sharif. Additionally, forest areas in the southwest are shrinking due to encroachment by agricultural fields, contrasting with relatively intact forests in the northwest. The degradation of natural vegetation around towns like Hassi Mamish and Mezgran underscores the urgent need for sustainable land management practices to mitigate further environmental deterioration.

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