International Journal of Enhanced Research in Science Technology & Engineering, ISSN: 2319-7463
Vol. 3 Issue 9, September-2014, pp: (31-39), Impact Factor: 1.252, Available online at: www.erpublications.com

Characterization of soil and water quality in irrigated perimeters of Issen and El Guerdane areas in the Souss valley (Morocco)

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Abstract: The aim of this work is to conduct an assessment of the quality of agricultural soils and water in irrigated perimeters of Issen and El Guerdane in the Souss valley (southern Morocco) with the goal of describing the degree of degradation of natural resources and improve the sustainability of the environment and irrigated farming systems of the plain through optimal management of these resources. Both perimeters in question are subject to two modes of management and valorization of irrigation water. The perimeter of Issen managed by a conventional mode of public administration of Souss Massa and by the Association of Agriculture Water Users, while the perimeter of El Guerdane is under a modern management mode based on Public-Private Partnership, where the water service is delegated to a private operator. Hundred sixteen waters and soils samples were taken in based on existing soil and piezometric maps of the irrigated areas. Characterizations of the main parameters of soil and irrigation water quality were made. Irrigation water salinity varies between 0.30 and 1.33 dS/m and the dams water which present the lowest salinity values. Soils irrigated from groundwater have shown a risk of degradation and higher salinization than soils irrigated by the waters of the dams in both perimeters. Texture dominant soil in the area is silty and sandy loam with occupancy of 59%. Within the perimeter of Issen cultivated soils has salinity reached 8.80 dS/m in some areas. Also within the perimeter of El Guerdane salinity values which can reach up to 6.13 dS/m were obtained in the soil. The Sodium Adsorption Ratio (SAR) shows a minimal risk to accumulate sodium in the soil of both perimeters. The soils are moderately to strongly basic and represent respectively 57% and 35% of the study area. 71% of the soils are low in organic matter and have an average value of 1.25% showing a high risk of degradation of the structure of the soil. Potassium and available phosphorus have very high values in the majority of soils which will have a negative impact on the environment. The spatialization of these parameters was performed by geostatistical probabilistic models. This is in order to delineate areas that are a priori subject to environmental degradation in order to understand the effect of agricultural intensification on the sustainability of natural resources, taking into account the type of management (public vs. private) water irrigation in the arid region.

Keywords: Characterization, Soil, Water, quality, Issen area, El Guerdane area, Souss valley.

Introduction

Located in Africa and with a large Mediterranean coast, Morocco is a country subject to a semi-arid to arid Mediterranean climate characterized by alternating wet years and sequences of severe droughts that can extend over several years. According to the fourth assessment report of the Intergovernmental Panel on Climate Climate Change **IPCC [1]**, Morocco is highly vulnerable to climate variability and land resources are severely affected leading to the degradation of their qualities. Agriculture, which contributes up to 19% of GDP and about 80% of direct rural employment, contribute significantly to the deterioration of soil quality due to intensive farming. Responding to the increasing population, food security is a priority in Morocco face the deterioration of soil quality as well as the scarcity of water resources. With the growing interest of the public to determine the effects of land use and management practices of soil resources, focus has increased on soil quality and it has been recognized as crucial for sustainable agriculture **(Zhanjun Liu et al. [2]).**

Recognizing the great need for knowledge of our soil resources and low map coverage at appropriate scales, scientists from National Institute of Agriculture Research of Morocco have started since the 70s to the soil mapping, the establishment of agricultural suitability maps and most recently in 2009 to develop cultivated soils fertility maps. As regards the characterization of soil quality in Morocco, although studies on the northern part of the country exist, such as those made by **M. Badraoui [3], M. Baaki [4]; M. Badraoui and A. Merzouk [5] ; A. Farhat [6] ; M. Badraoui et al [7] , M. Badraoui et al [8] ,** very little work has been done in the southern part of the country, Theoretical

advances are also limited. This work will contribute to the characterization of soil and water quality in a southern region qualified as an agricultural lung of the country and where resources are subject to intense exploitation. The use of geostatistics allows the perception of the spatial variability of indicators at the regional level and to assist in better targeting of basic and applied research.

Study area

The study was conducted in the Souss valley in Morocco. This area was chosen because it was never about a study of quality of its soil, it also presents an ideal context to address such a study. The Souss valley is characterized by an arid to semi-arid Mediterranean climate. The temperatures are moderate with an average of 19 °C with the maximum average of 27 °C and the minimum average of 11 ° C (**A. Baroud [9]**). The average annual rainfall is low and erratic and amounted to 280 mm. The average annual potential evapotranspiration is 2000 mm. The average annual wind speed is of the order of 5 km/h. Agriculture is the main economic activity of the region. Irrigated area, mainly located in the Souss Basin, covers 134,300 ha. Two juxtaposed perimeters in the Souss valley are subject of this study. The first one is the perimeter of Issen with an area of 50,195 ha. This perimeter has an irrigable area of 11,560 ha and is supplied from the diversion dam of Dkhila and regulated by the Abdelmoumen dam (**Souss Massa river basin Agency [10]**). It is composed of a modern sprinkler irrigated sector of 8,560 ha and a traditional gravity equipped sector of 4,440 ha of which 3,000 ha irrigated. This perimeter has an annual endowment of 65 Mm3. The second one is El Guerdane perimeter and the study was conducted over an area of 44 927 ha instead of 59 903 ha, due to absence of a cover soil map at 1: 100,000. Affected by drawdown of groundwater level due to the severe intensification of water withdrawals for agricultural purposes and those of drinking water, this perimeter is the only operational experience in Morocco where exploitation is supported by a private operator under an agreement of public-private partnership for the delegated management of irrigation water service. This experience concerns an irrigated area of 10,000 ha and is served by the Mokhtar Essoussi dam of Aoulouz with an extra endowment of 46 million m3 per year.

Materials and Methods

Hundred and sixteen samples of soil and water, and representing 58 plots of different sizes and spatially distributed on both perimeters, were collected. The choice of sample points is based on the soil map of 1: 100 000 drawn up by **Staimesse et al [11],** and on the map of irrigated areas defined by the agriculture office of Souss Massa (**Tagma [12]**). For each group of soil, samples from cultivated plots to a depth of 30 cm have been made. The performed soil analyzes were soil texture, moisture, the rate of limestone, infiltration rate, the rate of organic matter, electrical conductivity, pH_{H2O}, pH_{Kcl}, sodium, available phosphorus and potassium. Parameters are analyzed according to the convenient analysis used in soil science (**Baize [13]**). Samples of irrigation water were also made. Water analyzes concern the electrical conductivity, pH, Ca, Na, Mg, Cl, K, CO_3, HCO_3 and turbidity. The result of laboratory analyzes, data record of the soil map of 1: 100,000 scale, as well as information collected by surveys of farmers are treated and fed into a GIS database. The questionnaires include: sampling date, GPS coordinates, the crop grown, the number of years of operation, rotation practiced, the amount and type of fertilizer used, irrigation system practiced, and the source of irrigation water. After the evaluation of the soil and irrigation water quality by interpreting data, maps are produced to describe and visualize the spatial distribution and evolution of soil quality parameters in the study area. The optimal spatial interpolation method used, ordinary kriging, is described in a simplified way in the article published by **Yves Gratton [14].** The implementation of the Kriging method involves a step of analyzing data. From the analysis of frequency histograms of data distribution, identify global trends and exploring directional influences, anisotropy by semivariogram, adjustments and changes were made to improve the model interpolation for better data representation. The maps presented in this article relate to electrical conductivity, organic matter, available phosphorus, potassium, sodium and water pH. The projection used is Lambert Conformal Conic South Morocco, Ellipsoid Clarke 1880.

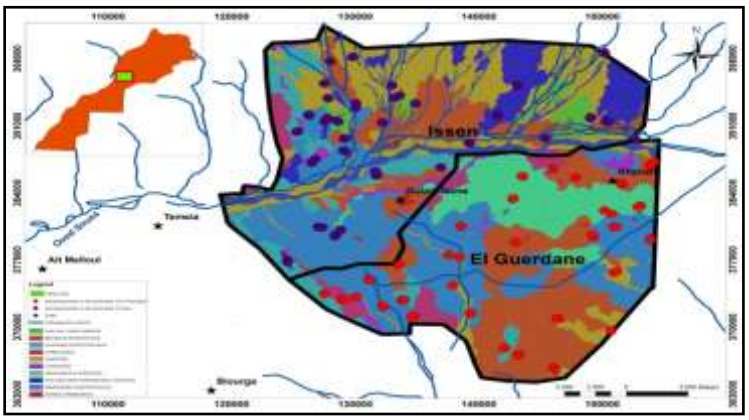

Figure 1. Soil and water sampling sites in the Issen and El Guerdane area.

A. Characterization of irrigation water quality

1) The perimeter of Issen

Water used for irrigation in Issen is either dam waters, to the west and center of the perimeter, or groundwater to the East. The quality characteristics of these waters are given in **Table 1.** According to the standards of quality of irrigation water given by the **United States Department of Agriculture (USDA) [15],** water used for irrigation in this area has a moderate salinity and varies between 0.53 to 1.33 dS/m. This means that water can be used to irrigate soils with good drainage and plants with moderate salt tolerance can be developed in these waters without any practical salinity control. The Sodium Absorption Ratio (SAR) has values ranging from 0.35 to 6.21 (mEq/L) ½. Water characterized by a SAR greater than 10 will tend to produce an accumulation of sodium in the soil. According to **Richard [16]**, sodium acts on the clay deflocculation leading to a decrease of the macro-porosity and the infiltration rate of water. In our case the water can be used on practically any type of soil with minimal risk to accumulate sodium to damaging levels. Some wells present undesirable chlorine levels, greater than 250 ppm, for irrigation of crops sensitive to salts. These levels can cause burns on the tips of leaves and even cause the death of irrigated plants.

Table 1: Characterization of irrigation water quality parameters in the perimeter of Issen

	Underground water									
	Ca meq/l	**Mg meq/l**	**Cl ppm**	**HCO_3 meq/l**	**Na meq/l**	**K meq/l**	**pH**	**CE mS/cm**	**Turbidity NTU**	**SAR $meq/l^{1/2}$**
Min	2,20	1,40	37,63	1,95	0,51	0,70	6,58	0,52	0,28	0,35
Max	5,40	10,40	999,68	7,30	17,46	2,30	7,66	1,33	2,24	6,21
Avg	3,53	3,43	198,45	4,08	3,67	1,59	6,97	0,75	0,76	1,64
SD	1,02	3,00	331,41	1,63	5,66	0,55	0,33	0,27	0,64	1,91
	Dam Water									
Min	2,40	1,40	86,62	1,50	2,20	2,80	7,87	0,61	0,17	1,52
Max	2,60	1,60	89,46	2,15	2,24	4,10	7,99	0,62	0,70	1,58
Avg	2,53	1,53	88,51	1,83	2,22	3,23	7,92	0,61	0,39	1,55
SD	0,12	0,12	1,64	0,33	0,02	0,75	0,06	0,01	0,27	0,03

2) The perimeter of El Guerdane

Concerning El Guerdane perimeter, irrigation water, especially for groundwater, present a moderate salinity risk (**Table** 2). The SAR presents minimal risk to accumulate sodium in the soil. The risk of precipitation of calcium and magnesium ions is higher in the groundwater with bicarbonate content up to 3 meq/l. The concentrations of chlorine ion are not an issue in the two sources of irrigation. Turbidity values show that the water is clear (NTU <5). It plays a very important role in water treatment and can provide information on the probability of presence of pathogens recirculated by agricultural runoff. It can also reduce the effectiveness of chlorine disinfection and disrupts water treatment by ultraviolet.

Table 2: Characterization of irrigation water quality parameters in the perimeter of El Guerdan

	Underground water									
	Ca meq/l	**Mg meq/l**	**Cl ppm**	**HCO_3 meq/l**	**Na meq/l**	**K meq/l**	**pH**	**CE mS/cm**	**Turbidity NTU**	**SAR $meq/l^{1/2}$**
Min	1,20	2,60	45,44	3,70	0,55	1,50	6,77	0,67	0,14	0,31
Max	4,20	4,40	106,50	8,40	2,55	12,10	7,99	1,22	2,19	1,38
Avg	3,25	3,62	77,33	5,05	1,47	2,80	7,27	0,87	0,42	0,80
SD	0,79	0,54	18,25	1,22	0,61	2,94	0,48	0,16	0,57	0,32
	Dam Water									
Min	1,49	0,34	7,23	2,00	0,68	0,08	7,65	0,30	0,17	0,48
Max	2,17	2,40	29,82	3,00	2,00	1,90	9,00	0,39	0,70	1,65
Avg	1,67	1,37	20,84	2,36	1,41	0,37	8,24	0,34	0,33	1,17
SD	0,23	0,69	7,57	0,40	0,47	0,67	0,63	0,03	0,17	0,41

B. Characterization of soil quality

1) Effect of irrigation on soil quality

a) The perimeter of Issen

The effect of irrigation on soil quality is illustrated by their salinization. In the perimeter of Issen plots electrical conductivity varies from 0.28 to 8.80 dS/m (**Table 3**). Knowing that a soil is saline when the value of electric conductivity is more than 4dS/cm, so we can say that a significant portion of the soils in this area are saline. This salinity changes according to the source (quality) of irrigation water. Soils irrigated by the dam waters present electric conductivity values lower than those of the soil irrigated by groundwater.

Table 3: characterization of soil quality parameters within the perimeter of Issen

Cultivated soil characteristics											
	PH $_{H2O}$	**PH $_{Kcl}$**	**Na (meq/100g)**	**K2O (ppm)**	**P2O5 (ppm)**	**MO (%)**	**CE (ms/cm)**	**CaCO3 %**	**H2O %**	**A %**	**S %**
Min	7,23	6,91	0,14	81,34	4,86	0,13	0,28	0,00	0,50	5,03	4,36
Max	9,12	8,60	4,81	991,11	232,20	2,80	8,80	24,51	5,50	62,21	86,03
Avg	8,47	7,82	0,88	242,04	47,15	1,12	2,02	8,00	1,89	21,59	45,96
SD	0,54	0,56	1,13	186,76	62,49	0,63	2,35	7,87	1,10	13,27	17,86

b) The perimeter of El Guerdane

Within the perimeter of El Guerdane we note that the plots do not exhibit electrical conductivities as high as noticed in Issen (**Table 4**). Irrigation with groundwater caused secondary salinization. Values that can go up to 6.13 dS / m were obtained. This can be explained by the moderate salinity waters and the quantities of water used for irrigation. For soil irrigated with dam water, variations are not very significant. The interpretation of the variation of physical and chemical parameters such as pH, OM, P, K, and Na did not detected the effects of irrigation on this parameters. However, their values and their spatial distributions may beings characterized.

Table 4: characterization of soil quality parameters within the perimeter of El Guerdane

Cultivated soil characteristics											
	PH $_{H2O}$	**PH $_{Kcl}$**	**Na (meq/100g)**	**K_2O (ppm)**	**P_2O_5 (ppm)**	**MO (%)**	**CE (ms/cm)**	**$CaCO_3$ %**	**H_2O %**	**A %**	**S %**
Min	7,26	6,87	0,14	69,29	7,83	0,45	0,37	0,00	0,00	0,00	6,73
Max	8,97	8,36	1,52	1111,61	232,20	2,85	6,13	41,25	3,00	34,48	83,72
Avg	8,38	7,65	0,40	315,42	50,32	1,46	1,22	11,56	1,31	14,91	42,87
SD	0,36	0,38	0,34	230,45	53,57	0,59	1,20	9,99	0,86	9,50	22,95

2) Characterization of soil quality parameters in the study area

a) Soil texture

Following the results, loamy and sandy loam that are dominant with an occupancy of 54% within the perimeter of Issen. Within the perimeter of El Guerdane 50% of the soils are loamy and silty. The soils of these textural classes show a risk of crusting slaking and water erosion. Degradation of soils can be reduced if it contains enough organic matter which reduces the risk of crusting and stabilizes soil structure. It should also implement appropriate agricultural practices such as avoiding soil compaction and working in good conditions of humidity.

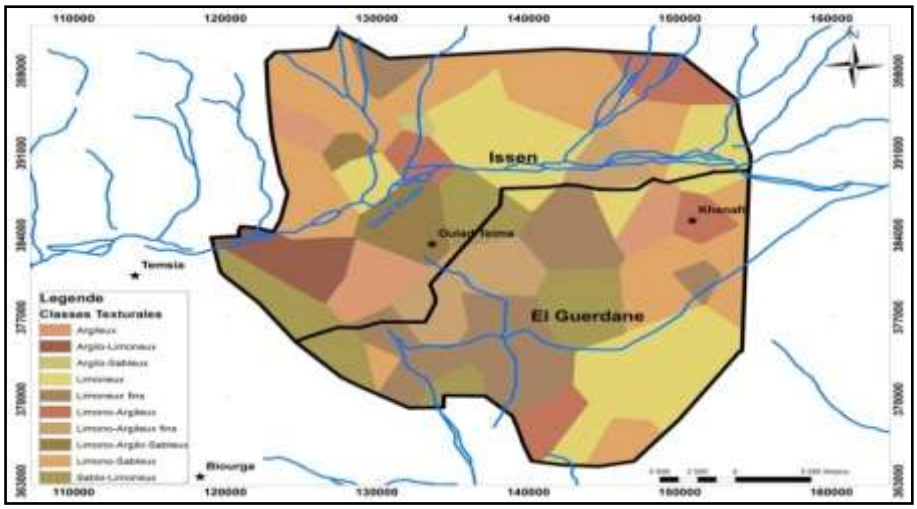

Figure 2. The soil texture map of the study area

b) Infiltration rate

Measurements of the soil infiltration rates were conducted by the double ring method. These measures involved three main soil types in the region. Three replicates for each measurement were made. **Table 5** below shows the interpretation of obtained results.

Table 5: The infiltration rate of the three main soil types in the study area

Soil Type	Texture	Infiltration rate (mm/h)	Interpretation	Risk
Isohumique brun subtropicaux	Silty clay	2,55	slow infiltration	Waterlogging and salinization risk
Isohumique Sierozems subtropicaux	sandy clay	153,57	rapid infiltration	Risk of groundwater pollution by transport of solutes
Sols à sesquioxydes	loamy	103,89	Average to fast infiltration	Risk of groundwater pollution by transport of solutes

c) Soil pH

Hydrogen potential of soils varies between 7.23 and 9.12 with an average of 8.42. The soils are moderately to strongly basic and represent respectively 57% and 35% of the study area. There is no significant difference in terms of value and spatial distribution of these values between the two perimeters El Guerdane and Issen.

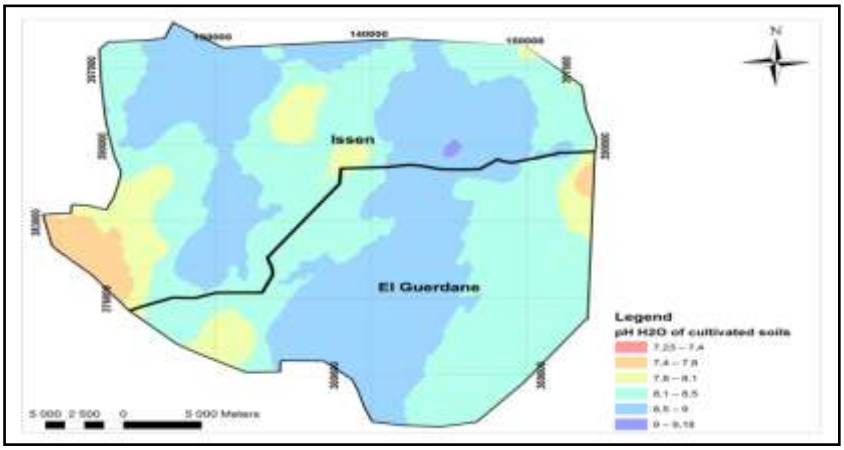

Figure 3. The distribution map of soil pH of the study area

d) Electrical conductivity

According to the maps obtained (**Figure 4**) we observe that the soil at the perimeter Issen are more saline than the El Guerdane area. Viewpoint salinity degree we can assign the saline character to the soils in the eastern part of the area. We have previously explained the difference in soil salinity by the effect of different sources of water used for irrigation. Indeed currently ground waters are used for irrigation in the eastern part of Issen and the dam water in the remainder of the perimeter. On the perimeter of El Guerdane soils are not yet saline but a risk of secondary salinisation still present after the use of underground water with moderate salinity in some area of the perimeter.

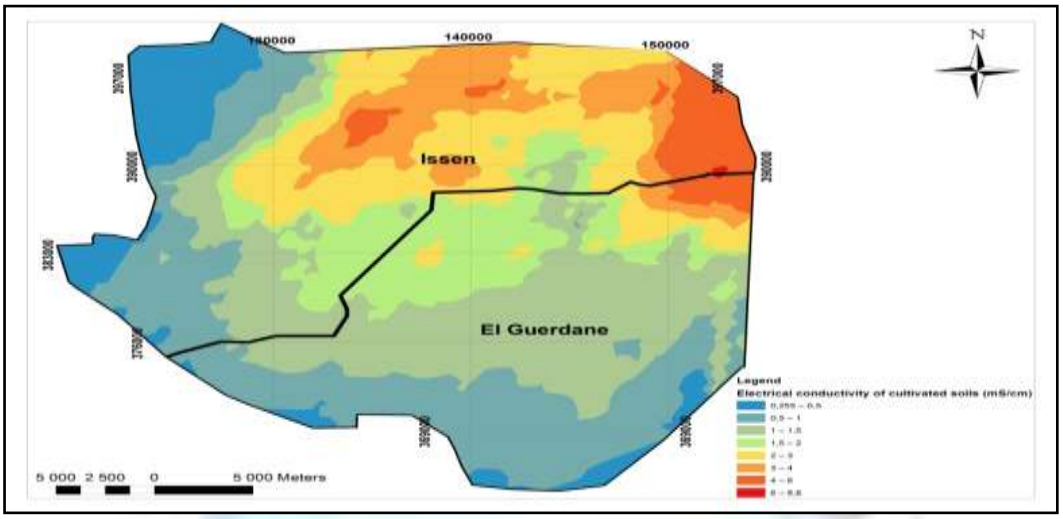

Figure 4. The distribution map of the electrical conductivity of the soil of the study area

e) Organic matter

Concerning organic matter, **Figure 5**, we note that the spatial distribution of different classes of soil organic matter is almost the same in both perimeters. The rate of organic matter ranged from 0.13% to 2%. A high value went up to 2.85% was observed and involves a small central portion of the study area. An average organic matter content of 1.29% has been calculated for the study area. This low average conforms to the average recorded by the Office of Agricultural. Generally the organic matter content of soils in arid regions is low in pristine condition, but expected to increase under irrigation water and crop management. In our situation the application of manure or preferably compost by farmers is required.

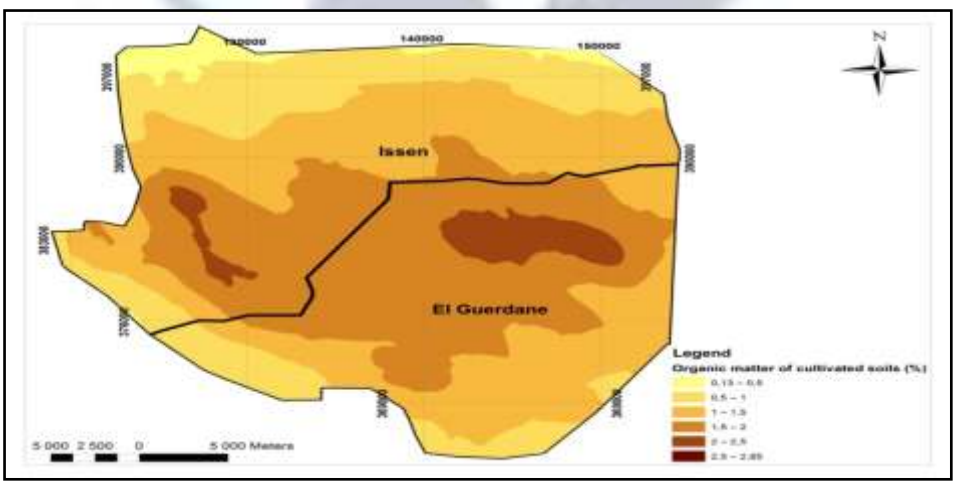

Figure 5. The distribution map of soil organic matter in the study area

f) Available phosphorus

Knowledge of the content of soil available phosphorus is necessary to optimize and maintain sustainable fertilization according to the needs of the soil and crop. The content of the soil varies between 4 and 232 ppm. 61% of

soils have very high levels of phosphorus. Gradient levels increases from west to east of the work area and it is the perimeter of Issen having the highest values. Additional amendments of this element are indispensable in Western parts of the two perimeters.

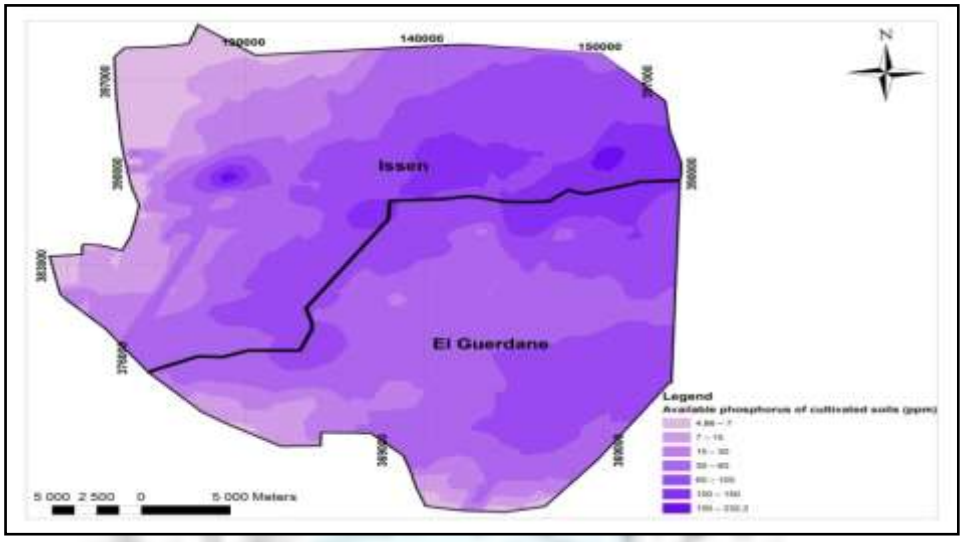

Figure 6. The distribution map of soil available phosphorus in the study area

g) Exchangeable potassium

The exchangeable potassium is a mandatory element in plant growth. The interpretation of the levels of this element is depending on the soil CEC. In our case, whatever the value of the CEC of the soils of the study area, the equivalent levels are high for 73% of lands and moderate for 10% of lands of the perimeter. These are the soils of the northern part of the perimeter of Issen which have the lowest values while the highest values are obtained in the perimeter of El Guerdane.

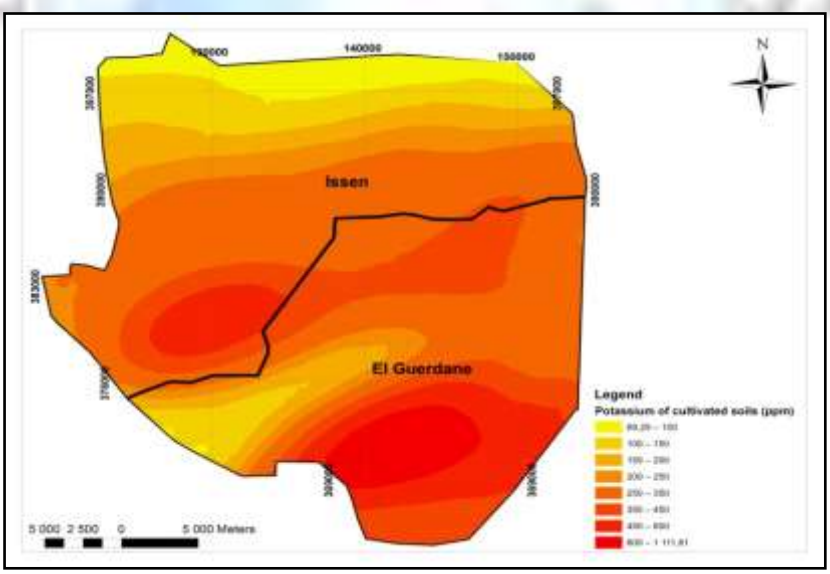

Figure 7. The distribution map of exchangeable potassium in soils of the study area

h) Sodium

The sodium content in the soils of the two perimeters is low to moderate. This content is less than 0.62 meq/100 g for 76% of soils but still sufficient for the needs of the crop. Only 3.2% of the area of the work which has an excess of sodium and a risk of deterioration of the soil structure causing a disturbance of the growth of the culture and a soil pH which rises. The distribution of this high value is located within the perimeter of Issen. In El Guerdane the risk of destabilization of the structure of the soil is minimal.

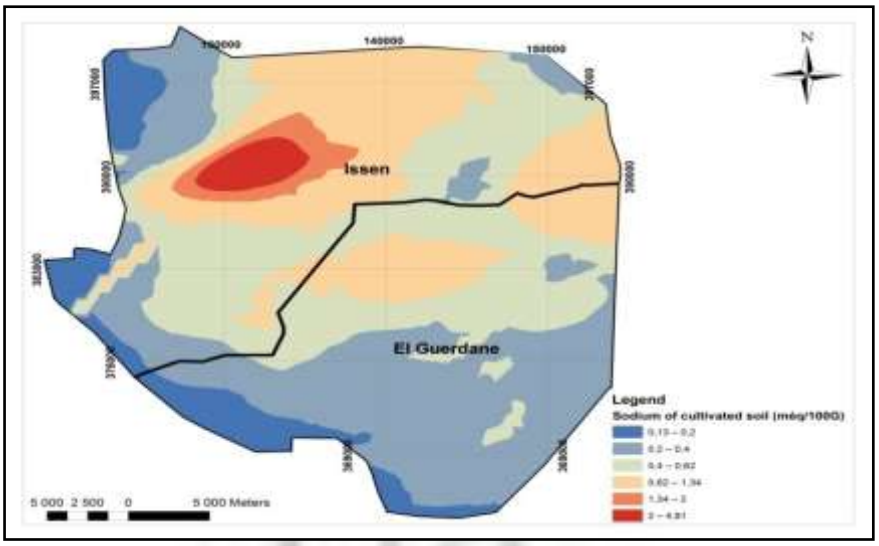

Figure 8. The distribution map of exchangeable sodium in soils of the study area

Conclusion

To assess soil quality in the perimeters of Issen and El Guerdane, quality parameters were determined. Soil Salinity, organic matter content, exchangeable sodium and the infiltration rate of cultivated soils are a good indicator for measuring the sustainability of the soil resource. Continuous monitoring of soil quality is required to avoid excessive degradation of this resource. The present work is a first step for the study of soil quality in the region of Souss Massa. The results obtained were introduced into a GIS database and constitute a first step towards the creation and implementation of a database at the regional level. More refined studies should be conducted in the study area affecting aspects and disciplines related to soil quality to better interpret the results in the context of land management strategy. In fact, we should know that the soil is a dynamic and living system, and measuring the response of a quality parameter of any soil disturbance is not sufficient. The assessment of soil quality as a means to increase agricultural production in the region of Souss Massa is irrefutable for national sustainable food security. Other perimeters in the region missing similar studies on the quality of their land must be surveyed in order to respond more effectively to the needs of the region. The methodology used in this work can be used to conduct the proposed studies

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