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EVALUATION OF SPATIAL INTERPOLATION METHODS FOR MAPPING THE DEGRADED SOILS OF XANTHI (GREECE)

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Abstract: *Soil surveys employ interpolation of point measurements that provides spatial distribution of information for the full study area. However, no specific interpolation method is determined for each soil parameter. The aim of this work was to identify the optimum interpolation method and its parameterization to improve mapping of degraded soils of Xanthi agricultural land. Electrical conductivity (EC), exchangeable sodium percentage (ESP), cation exchange capacity (CEC) and pH measurements from 598 soil samples were used. Inverse distance weighted (IDW) and spline interpolation, as well as the power of IDW were evaluated. IDW with power 3 was proved as the most accurate method. Using thresholding, we identified the spatial distribution of saline, sodic, and acidic soils of the study area. Furthermore, degradation sources were identified, including parent material and inappropriate fertilization for acid soils and irrigation with saline water for alkaline soils. The results enabled us to propose amelioration measures and agricultural practices, according to degradation types and levels. The data was provided by the project "Soil Map of Eastern Macedonia and Thrace".*

Keywords: *Spatial interpolation, degraded soils, acidic, saline, sodic.*

Introduction

Soil degradation is one of the main causes of reduction of yield and consequently loss of sustainability in agricultural production, and in the long run, desertification. Among the several types of degraded soils in Greece, this work focuses on three of them: saline, sodic and acidic soils. Saline soils are soils that contain excessive soluble salts. The formation of sodic soils is caused by sodium which tends to be the prevailing ion in the exchangeable phase. The results of this process can lead to the destruction of the soil structure and the severe degradation of the soil surface, which may lead to desertification. Lastly, acidic soils have pH below 5.5, which plays an important role in regulating the availability of plant nutrients (Misopolinos, 1991).

Soil degradation is usually caused by inappropriate agricultural practices and application of low quality of irrigation water (Misopolinos, 1991). Soil degradation has a severe impact on the quantity and quality of agricultural production, on environmental sustainability and consequently on socio-economic conditions of local communities. In order to minimize the negative effects, we need to manage existing degraded soils and prevent further expansion, which requires mapping and soil surveys.

Soil mapping and surveys are achieved by using geographic information systems (GIS) and are mostly based on point measurements from selected locations, usually formed by sparse sampling schemes. They are organized in the graphical interface of the GIS program in layers, and after processing, are presented in thematic maps (Silleos, 1990). Spatial interpolation methods fill in information of the entire study area, taking into account the spatial location of a few sampling points and the assumption that locations are close together tend to have similar characteristics (Robinson and Metternicht, 2006). Some of the many interpolation techniques are IDW (Inverse distance weighted), kriging and spline.

Geoinformation specialists collaborating with soil scientists have examined the application of several interpolation techniques on the relevant soil properties. However, no specific interpolation method is determined for each parameter for each test site. The aim of this work was to improve the mapping of degraded soils and the specific objectives were to identify the optimal interpolation method for several soil parameters associated with degraded soils and to identify the optimal parametrization of the selected interpolation method.

Materials and methods

Study area

The study area is the agricultural area of the Prefecture of Xanthi, administratively belonging to the region of Eastern Macedonia and Thrace, located in the northeastern part of Greece.

As seen in table 1, most of the land is covered by forests, especially the mountainous area in the north, while the agricultural land is about 25% of the whole area, located in the southern part of the Prefecture.

Table 1.
Land use of the prefecture of Xanthi

Land use	Area (ha)
Forest land	113.000
Agricultural land	48.500
Arid land	8.600
Pastures	5.250
Settlements	4.350
Industrial Land	700
Total area of the county	180.400

Agricultural production involves mainly annual crops, with corn, cereals and cotton being the most important. In the past, sugar beet and tobacco were widespread crops contributing to the farmer's income. Nowadays tobacco (Basmas variety) is rain fed and located mainly in the hilly areas of the prefecture. The most important vegetables grown in the prefecture of Xanthi are industrial tomatoes and green beans, mainly due to the existence of the respective manufacturing industries. Tree crops that exist in a limited area are pomegranate, kiwi, apple and walnut (http://www.agroepiloges.gr/NomosKsanthis.aspx).

The sources of irrigation water are multiple, such as rivers, lakes, and wells. As a result, irrigation water quality varies depending on the state of the source. Especially groundwater, is affected by the chemical composition of rocks and minerals of the vadose zone.

The climate in Xanthi is continental with mean annual precipitation of 540mm. The average temperature ranges from 0 to 28°C throughout the year, based on 21 years of data (www.wunderground.com).

Datasets and data collection

All data used in this work were collected within the project "Recording of nutrients, heavy metals and hydrodynamic properties of soils for the rational use of fertilizers and water and the production of safety products in the Region of Eastern Macedonia and Thrace" (Misopolinos, 2010).

The main dataset for this work consists of 598 surface soil samples of the agricultural area, as shown in Figure 1.

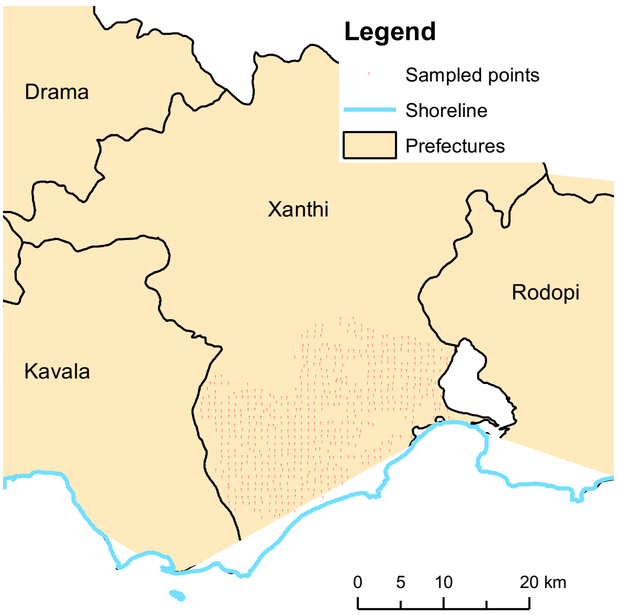

Figure 1. Spatial distribution of sampling points in the study area

Soil sampling, as part of mapping the agricultural land of Eastern Macedonia and Thrace, was performed by specialized teams of agronomists and experts in soil science using dedicated equipment (GPS tablets, hydraulic soil samplers, digital cameras, etc.).

Soil sampling procedure included excavation and studying of soil profiles, soil auger boreholes and description of soil layers based on international standards for ensuring compatibility with the European Soil Database.

In the frame of the above-mentioned project, 22 soil parameters were measured in the laboratory by analyzing soil samples according to ISO standards. In this work, four of them were selected (Table 2) that are key soil properties for identifying and characterizing soil degradation due to acidity and salinity.

Table 2.

Soil parameters determined and methods of analysis

Parameter	Method	Reagents	Bibliography
pH	pH-meter	water	Amended Extraction with water 1: 5 based on "Method of Soil Analysis 1982", American Society of Agronomy p.451
EC	Electromagnetic	water	Internal Method of saturated aqueous solution
CEC	Ammonium acetate	1M CH_3COONH_4, pH 7.0	Modified method AFNOR NFX 31-130
Exchangeable Na^+	Ammonium acetate	1M CH_3COONH_4, pH 7.0	Modified internal method Doll and Lucas, 1973

Spatial interpolations

Each spatial interpolation method serves a specific use, depending on the purpose of the study (Robinson and Metternicht, 2006). In the present work, IDW was chosen to create thematic maps of soil parameters: pH, CEC, ESP and EC (Tuncay et al., 2013). In addition, spline interpolation was applied for electrical conductivity (EC) for comparison.

The standard IDW method of ArcMap / Spatial Analyst was applied on the sampling points of soil properties to create continuous surfaces. IDW configuration included: Output cell size = 30 m, minimum number of points = 12, no maximum distance. In particular, for the power of the distance function, which controls the influence of nearby points, three options were used: the minimum value (0.5), an average value (2), and the maximum value (3).

In a similar manner, the standard spline method of ArcMap / Spatial Analyst was applied on the sampling points of EC.

Evaluation of interpolation results

Following map creation, the assessment for the selection of the most representative map (of the three created by spatial interpolation method IDW) for each of the four soil parameters (pH, ESP, CEC and EC) was performed. As a criterion, the absolute difference from the reference maps was used (Equation 1).

$$abdifference = \left|\frac{(ref - image)}{ref}\right| 100\%, \quad (1)$$

where *ref* is the reference maps, *estim* is the estimated from this work value of the respective parameter.

Finally, the assessment for the final maps selected was made, based on the lowest abdifference percentage (Schloeder et al., 2001).

As reference maps in this work were considered the thematic maps produced within the above-mentioned soil mapping project (Misopolinos et al., 2010), using mainly kriging by the expert team employed.

Classification for the delineation of degraded soils

In order to map the degraded soils, the final interpolation maps of each soil parameters were used. These maps were based on threshold values for each parameter that determine saline, sodic, and acidic soils (Table 3). The implementation of the threshold values was performed through ArcMap / Spatial Analyst Tools.

This process resulted in the spatial distribution of the degraded soils of the study area.

Table 3.

Threshold values for the determination of degraded soils

	EC_e ($dS.m^{-1}$)	pH	ESP (%)
Saline	> 2	< 8.5	< 15
Saline - sodic	> 2	< 8.5	> 15
Sodic	< 2	> 8.5	> 15
Acidic	-	<5.5	-
High risk for acidification	-	5.5<pH<6.5	-

Results and discussion

Soil parameter maps

IDW spatial interpolation method was used to estimate four soil parameters pH, EC, CEC and ESP of the study area and to create the corresponding interpolation maps (thematic maps). Three values of the power parameter used by the IDW method were tested, for each soil parameter mentioned. These were power values of 0.5, 2 and 3, which gave different accuracy of spatial information and consequently different levels of accuracy of the produced maps. The choice of power for the equation that gave the most representative situation is important for the interpretation of soil data so that measures can be taken to improve degraded land and adapt agricultural practices.

Figure 2 shows the three thematic maps created for pH. The selected colour palette is consistent across the three maps, and covers the range from the lowest value of 4.3 (acidic soil-red color) to the highest value 9 (alkaline values - blue color).

From figure 2 we infer that soils with low pH values are located in three areas: on the north-eastern side in a small extent, on the north-west side and in the central and southern area where is the largest area of acidic soils.

Figure 3 displays the three thematic maps created for electrical conductivity (EC). The selected colour palette is consistent across the three maps, and covers the range from the lowest value of 0 mS / cm (red color) to the highest value of 10 mS / cm (excessive soluble salts).

In figure 3, it is evident that the soils with low EC values cover almost the entire area. However, small areas appear on the north-eastern side of the study area where the soil has electrical conductivity ECe>2mS/cm (yellow color), causing salinity problems.

Figure 4 shows the three thematic maps created for the CEC - Cation Exchange Capacity. The selected colour palette is consistent across the three maps, and covers the range from the lowest value of CEC which is 2 meq/100g (red color) to the highest value of 44 meq/100g (blue color).

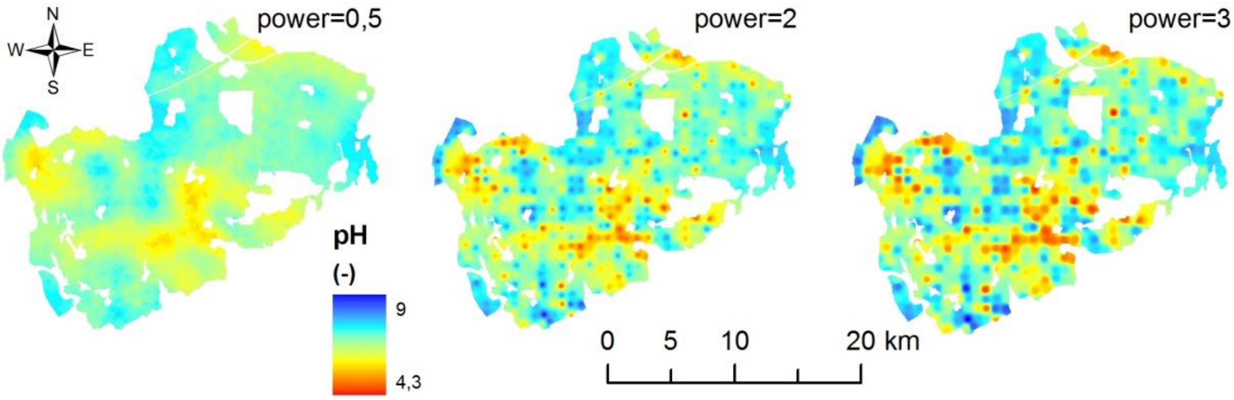

Figure 2. Thematic maps of soil parameter pH created with IDW method for three power values of 0.5, 2 and 3

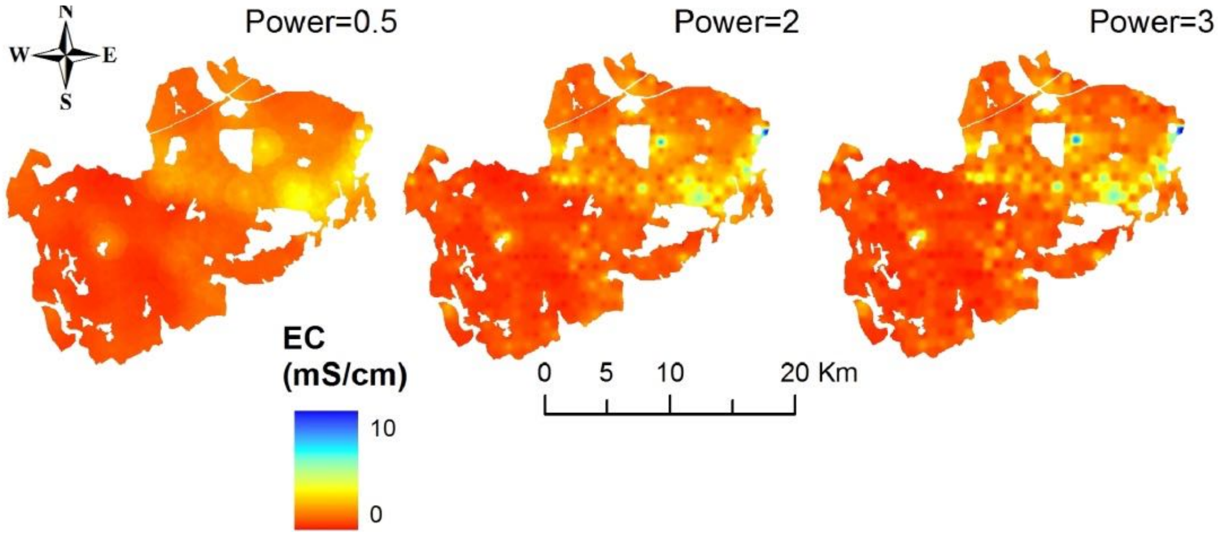

Figure 3. Thematic maps of soil parameter EC created with IDW method for three power values of 0,5, 2 and 3

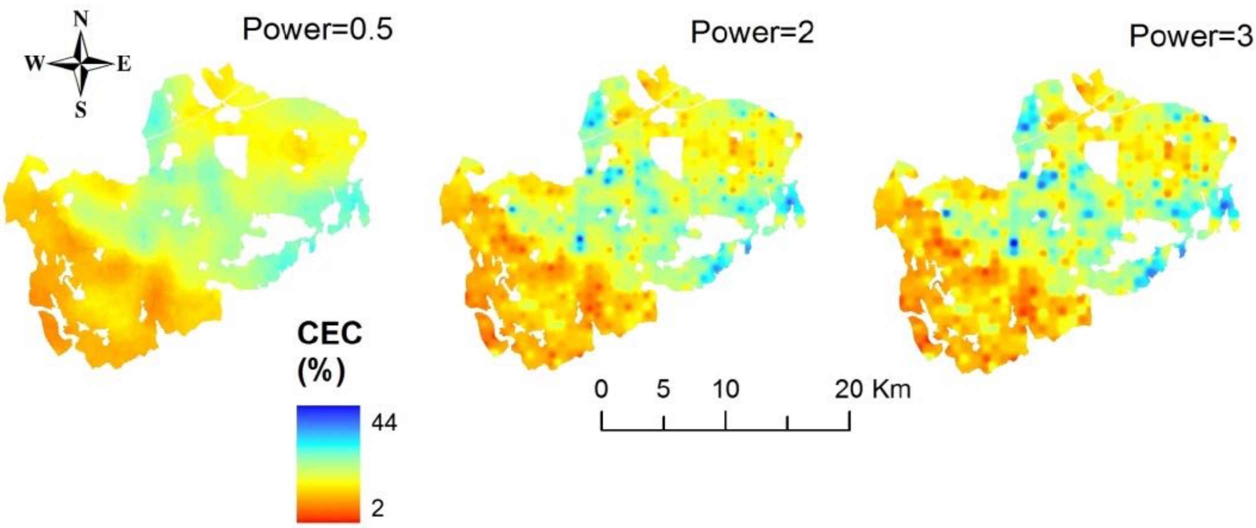

Figure 4. Thematic maps of soil parameter CEC created with IDW method for three power values of 0.5, 2 and 3

It is evident in figure 4 that the soils with low CEC values are located in two areas. On the northeastern side in a small extent and on the southwest side of the county where appears to be the largest extent of degraded soils. Larger values appear in the center of the study area.

Figure 5 represents the three thematic maps created for the exchangeable phase Na + (ESP) in the soil. The color gradient is uniform and includes ESP values from 0% (red) to 80% (blue color).

It is evident from figure 5 that the soils with high ESP values (blue color) are located in the southern region and on the southeastern side of the prefecture.

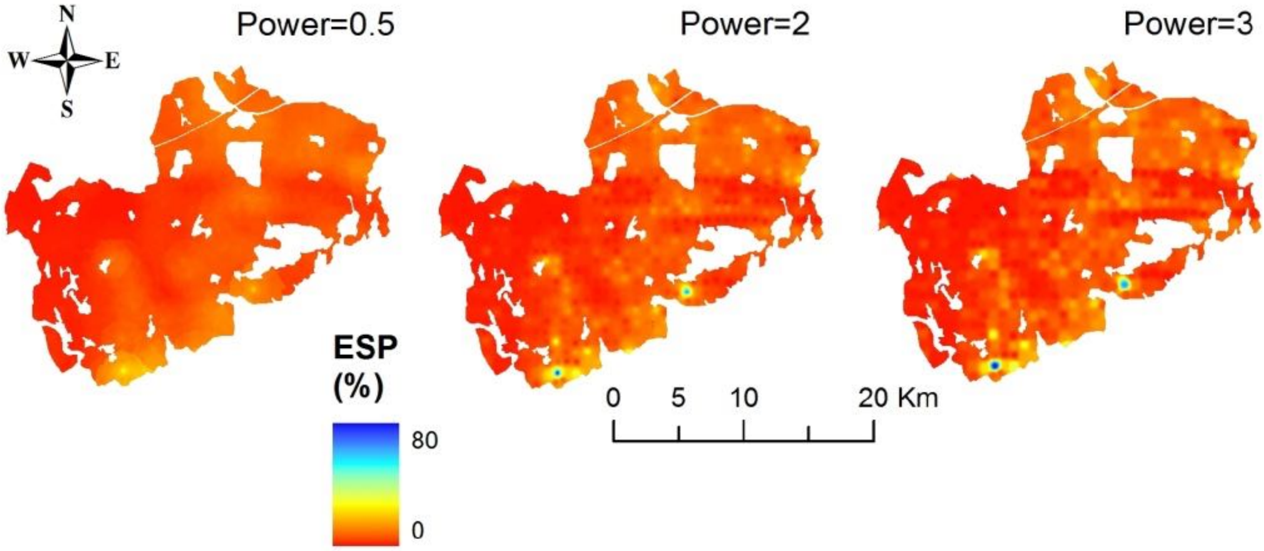

Figure 5. Thematic maps of ESP created with IDW method for three power values of of 0.5, 2 and 3

Accuracy of interpolation

The evaluation of the thematic maps, that were produced using the IDW method for different parameterizations, and different power values for the equation, was achieved by comparing them with the reference maps, which were the interpolation maps created within the soil mapping project.

Table 4 presents the absolute differences (based on equation 1) of spatial information derived from IDW method (for the three power values) versus the reference level for all four soil parameters. It is evident that all soil parameters had the highest accuracy when IDW power of 3 was used, having the lowest difference from the reference maps.

Table 4.

Absolute difference (%) of the IDW method for the three power values compared with the reference maps for all parameters examined

Soil Parameters	Power		
	0.5	2	3
pH	7,55%	4,122%	3,59%
CEC	19,9%	12,4%	11%
EC	47,5%	27,6%	23,3%
ESP	95%	55,6%	43,7%

Maps of degraded soils

Figure 6 represents the acidic soils after applying the thresholds (Table 3). It is obvious that the areas with acidic soils are located in the central and northern parts of the prefecture. The red areas are acidic, meaning pH is below 5.5 and the yellow areas show that the soil has a high risk for acidification where pH value is 5.5 ≤ pH <6.0 thus deeper investigation should be performed by measuring soil ANC (Acid nurturing capacity). Finally, the rest of the area seems to have no problem with pH values> 6.

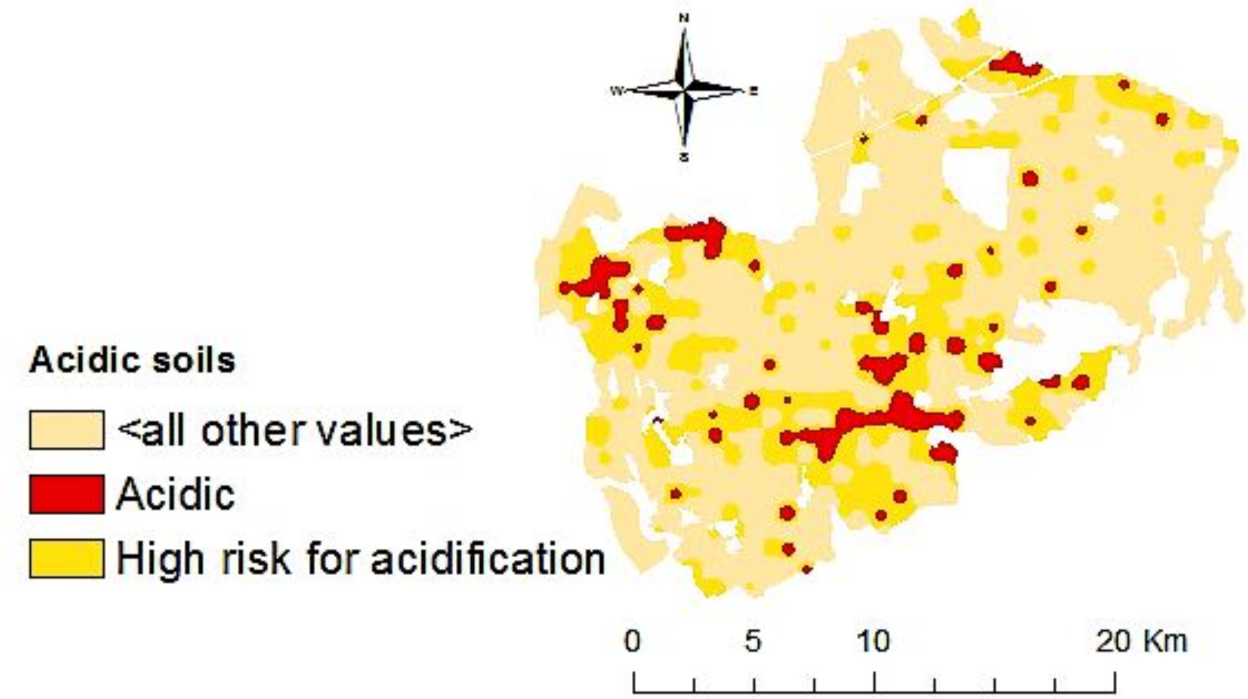

Figure 6. Map of acidic soils of the prefecture of Xanthi (Greece)

Figure 7 represents the degraded soils due to salinity, based on the thresholds of table 3 for ECe and ESP. It appears that saline soils are located in the center of the area (blue color - EC> 2mS / cm). Sodic and saline soils (red color - EC> 2mS / cm and ESP> 15) are a small percentage and are mainly located in the eastern part of the area nearby the sea, as well as two other disconnected areas around the center of the study area. Sodic soils, which are non saline (orange color - EC <2mS/cm and ESP>15) are located on the coastal front to the south part of the study area, mostly degraded due to sea proximity and salt water intrusion in the aquifers.

Conclusions

Interpolation maps were created for the soil parameters pH, EC, CEC and ESP using spatial analysis techniques and GIS.

We evaluated the effect of the power value on the generated map, which is the key feature in the parameterization of the IDW spatial interpolation method.

Comparison with the reference maps, showed that a small difference exists for soil parameters pH, CEC and EC, while for ESP the difference was significant.

It was found that the optimal interpolation method was IDW, and the best parameterization for the interpretation of soil data, was power 3, resulting in the most representative depiction of the actual soil conditions.

Acidic soils of the study area and soils that have a high risk for acidification have been identified and accordingly agricultural practices have to be applied for restoring or maintaining soil quality. Similarly, for soils which are degraded due to salinity or have a high risk of secondary salinization were identified providing a tool to farmers and regional authorities to counter-act in farm or catchment area level respectively.

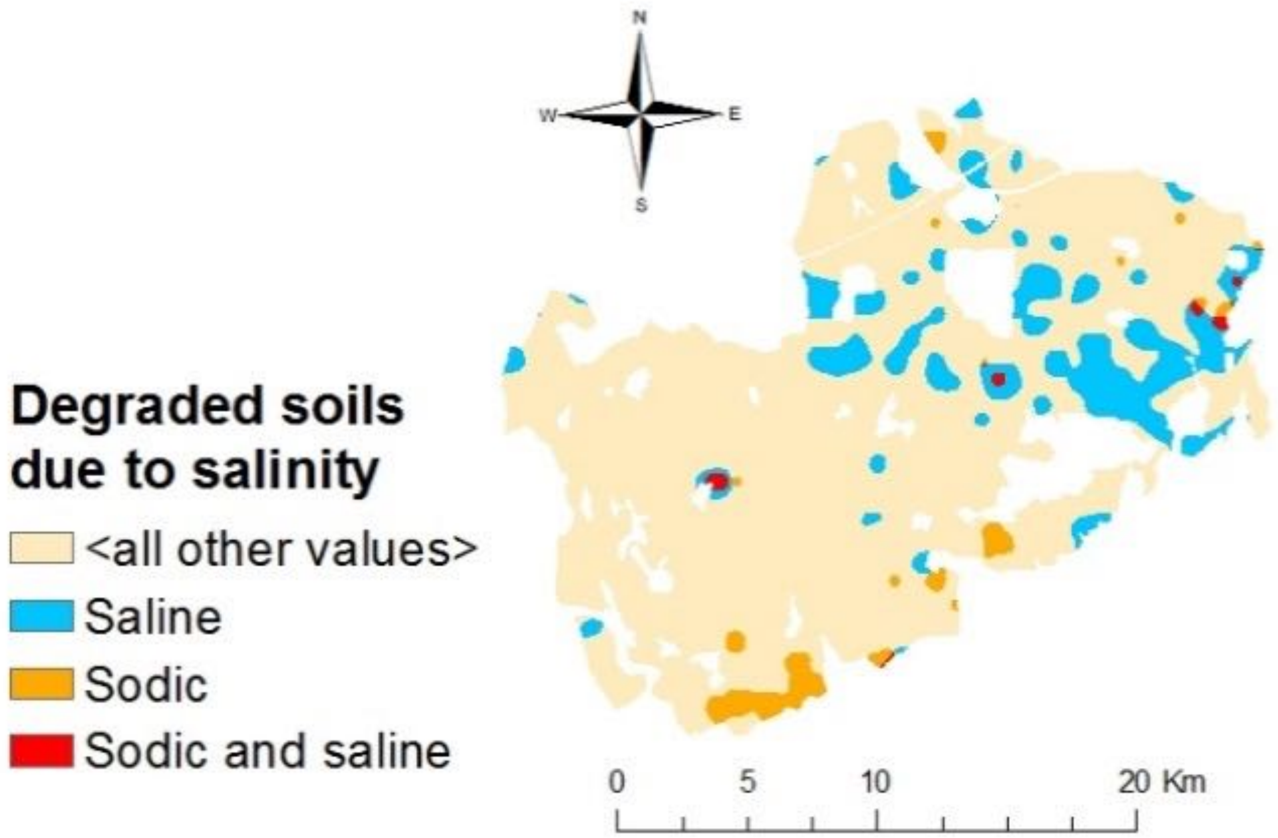

Figure 7. Map of degraded soils due to salinity of the prefecture Xanthi (Greece)

It is obvious that this process, including the identification of degraded soils in high productivity agricultural land, is the first and most decisive step in the implementation of agricultural practices and remediation measures in the context of the protection and improvement of agricultural production.

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ОЦЕНКА МЕТОДОВ ПРОСТРАНСТВЕННОЙ ИНТЕРПОЛЯЦИИ ДЛЯ КАРТОГРАФИРОВАНИЯ ДЕГРАДИРОВАННЫХ ПОЧВ В КСАНТИ (ГРЕЦИЯ)

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Аннотация: *При исследовании почв используют интерполяцию точечных измерений, которая обеспечивает пространственное распределение информации. Однако для каждого параметра почвы не определен конкретный метод интерполяции. Цель этой работы заключалась в определении оптимального метода интерполяции и его параметризации для улучшения картирования деградированных почв сельскохозяйственных земель Ксанти. Использовали электропроводность (EC), обменное процентное содержание натрия (ESP), катионообменная емкость (CEC) и измерения pH из 598 образцов почвы. Были оценены взвешенные по обратному расстоянию (IDW) и интерполяция сплайнов, а также мощность IDW. IDW с мощностью 3 был подтвержден как наиболее точный метод. Используя пороговое значение, мы определили пространственное распределение содовых и кислых почв исследуемой области. Кроме того, были обнаружены причины деградации, включая неправильное удобрение для кислых почв и орошение соленой водой для щелочных почв. Результаты позволили предложить мероприятия по мелиорации в соответствии с типами и уровнями деградации. Данные были предоставлены проектом «Почвенная карта Восточной Македонии и Фракии».*

Ключевые слова: *пространственная интерполяция, деградированные почвы, кислотность, засоленность.*