Soil salinity mapping by different interpolation methods in Mirzaabad district, Syrdarya Province

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Abstract. Soil salinity is an important global issue and especially on irrigated areas due to its great impact on a crop production system. Proper soil salinity mapping can improve land use management. The goal of this study was to improve the accuracy of soil salinity mapping with the two objectives (1) to evaluate different interpolation methods during soil salinity mapping and (2) to identify of differences in soil salinity assessments in irrigated land of Mirzaabad district which is most affected by salinity in Syrdarya province of Uzbekistan. Soil salinity data measured by EC meter was obtained from Syrdarya Hydromelioration Expedition. Different four interpolation methods such as Inverse Distance Weighted (IDW) with power 1, 2, and 3, and Kriging techniques were used for the generation continuous surface of soil salinity maps. The cross-Validation method with the assessment of Root Mean Square Errors (RMSE) shows that IDW with power 2 (IDW-2) most accurate. The maximum difference reached between IDW-2 and IDW-1 on the slightly saline area where the value decreased by 55% of the total irrigated land of the district. Minimum differences reached on IDW-3 on moderated saline class and higher than IDW-2 on 408.6 ha.

1. Introduction
Soil salinity is among the common soil characteristics that affect agricultural production, and it causes severe worldwide environmental problems particularly in arid and semi-arid areas. In these regions, precipitation is inadequate to keep natural percolation of water within the soil profile, and thus, it leads to the accumulation of soluble salts in soil with a negative effect on soil structure. About 35% of the world’s production of food and fiber originates from irrigated agriculture. It is predicted that irrigated agriculture will need to produce nearly 50% by 2040 [1, 2].

According to the FAO [3] the total land area currently being cultivated is 1.6 billion hectares of which 20% (0.3 billion ha) is on marginally suitable lands. Central Asia has large expanses of salinized lands. Of this region’s 7.8 million irrigated hectares, about 50% is saline, of which 29% has a moderate to high salinity level. Indeed, soil salinity is one of the major factors in diminishing agricultural production in Central Asia [4]. In Uzbekistan, 51% of irrigated land is affected by some degree of soil salinity [5]. There are nearly 2 million hectares of highly saline areas, costing Uzbekistan some US $1 billion annually [6–10]. One of the most affected area by soil salinization is
Syrdarya province. The causes of this degradation are an insufficient operation of drainage and irrigation systems, irregular observations of the agronomic practices, and non-efficient on-farm water use.

In the Syrdarya province according to statistics for 2003 – 2008 the lands affected by salinization, especially human causes increased from 87 to 95%. Among them, more than 80% of the soils are heavy saline. All these lands being partly used as low productive gradually are out from the irrigated agricultural use and abandoned by farmers. In the Mirzachul steppe the area of arable lands has decreased from 805000 ha in 1991 to 531000 ha in 2006 [11].

Assessing soil salinity is complicated by the nature of its spatial and temporal variability [12]. Conducting soil salinity measurements at high sampling density is costly and time-consuming. Fortunately, it is possible to use quick in-situ methods of electrical conductivity (EC), which is related to soil salinity, to evaluate salinity. The relationship between EC and soil salinity is complicated. Quality of EC field measurements is influenced by several factors, such as soil texture, water content, and bulk density [13, 14]. Thus, in situ measurements of EC require calibration for a certain field case to be suitable to monitor and map soil salinity. Such calibration usually is conducted using common statistical methods of correlation and regression [15–17].

Geostatistical methods, kriging is becoming commonly used estimation techniques to generate soil maps. Kriging has been applied to quantify the variability of various spatial variables in soil science. For example, Tabor et al. [18, 19] used variograms and kriging to determine the spatial variability of nitrates in cotton petioles and analyzed spatial variability of soil nitrate and correlated variables. Several researchers have applied the kriging method to study groundwater contamination [20–22]. Yates et al. [23] used geostatistics in the description of salt-affected soils. Samra et al. [24] used kriged results to assess variations of pH and sodium adsorption ratio associated with tree growth on a sodium-contaminated soil.

Robinson et al. [25] used three different techniques including IDW, kriging methods for predicting the level of soil salinity, acidity, and organic matter in the South West of Australia. The analysis showed that the co-kriging and spline methods were the best techniques for estimation of the soil salinity level and organic matter content, where the IDW method was suitable for the prediction of soil acidity level.

The goal of this study was to improve the accuracy of soil salinity mapping with the two objectives (1) to evaluate different interpolation methods during soil salinity mapping and (2) to identify differences in soil salinity assessments in the case study area.

2. Materials and methods
2.1. Study area
The case study for this research was chosen irrigated land of Mirzaabad district which is placed in the Syrdarya province of Uzbekistan. Irrigated land in Mirzaabad District is most affected by salinity in Syrdarya province and occupies an area of 67286.7 hectares.

Mirzaabad district is part of Syrdarya Province. It was established on September 2, 1988. Originally, from October 22, 1992, Mirzaabad. The district borders with Syrdarya, Gulistan, Saykunobod, Boyavut, Mehnat-Abad, Sharof Rashidov, and Akaltyn districts and part of Kazakhstan.

Mirzaabad district is located in the Mirzachul Plain. The surface of the earth is flat (average height 250 m), covered with loamy sand and sandstones. The climate is continental. July average temperature is 28 °, January -2 ° -4 °. In a year 200-300 mm of deposits drop out. Groundwater is salty and stormy. The soils are mainly sandy soils.

The basis of the economy is agriculture the leading branch is cotton growing. Grain, vegetables, melons, fruits, grapes, and potatoes are also grown. The main cultivated area of the district is 44426 ha, including irrigated land - 24043 ha.
2.2. Sampling and mapping
In the study area, two soil samples were taken by the expedition in each field of Water Consumers Associations. Each sample was taken from about 37 ha and a total of 2496 sample points were taken for mapping.

In this article, four and geostatistical techniques were used to create a soil salinity map of the study area using point-based field measurements.

Geostatistical prediction includes two stages: (a) Identification and modeling of a spatial structure where continuity, homogeneity and spatial structure of a given variable is studied using a variogram; (b) Geostatistical estimation using kriging technique which depends on the properties of the fitted variogram which affects all stages of the process.

In interpolation with Inverse Distance Weighted (IDW) method, a weight is attributed to the point to be measured. The amount of this weight is dependent on the distance of the point to another unknown point. These weights are controlled on the bases of power of ten. With an increase of power of ten, the effect of the points that are farther apart diminishes. Lesser power distributes the weights more uniformly between neighboring points. We should keep in mind that in this method the distance between the points count, so the points of equal distance have equal weights [26].

Geostatistical Analyst uses power values greater or equal to 1. When \( p=2 \), the method is known as the inverse distance squared weighted interpolation. The default value is \( p=2 \), although there is no theoretical justification to prefer this value over others, and the effect of changing \( p \) should be investigated by previewing the output and examining the cross-validation. As \( p \) increases, the interpolated value by inverse distance is assigned the value of the nearest sample point, that is, inverse distance estimate becomes the same as estimate produced by the polygonal method [27].

The presence of a spatial structure where observations close to each other are more alike than those that are far apart (spatial autocorrelation) is a prerequisite to the application of geostatistics [25, 28]. The experimental variogram measures the average degree of dissimilarity between unsampled values and a nearby data value [29] and thus can depict autocorrelation at various distances. The value of the experimental variogram for a separation distance of \( h \) (referred to as the lag) is half the average squared difference between the value at \( Z(x_i) \) and the value at \( Z(x_i+h) \) [25, 30].

From an analysis of the experimental variogram, a suitable model (e.g. spherical, exponential) is then fitted, usually by weighted least squares, and the parameters (e.g. range, nugget, and sill) are then used in the kriging procedure. The cross-semi-variogram was used to quantify cross-spatial auto-covariance between the original variable and the covariate [2, 31]. A comparison between the different methods was done base on the results of root mean square error (RSME) which applied to evaluate
model performances in cross-validation procedure. The smallest RMSE indicates the most accurate prediction.

3. Results and Discussion

This study has been done by applying to ArcGIS 10.3.1 and the geostatistical analyst tool bar has been used to obtain root-mean-square error which gives us an opportunity to know how each interpolation method is calculated properly. IDW power 1, 2, 3, and Kriging/Co-kriging methods were used and input data obtained from the expedition was inserted in assigned places. Power values were inserted and the standard type of Neighborhood search was selected. 15 and 10 sample points were selected as maximum and minimum neighbor points respectively. From the Cross-validation window, RMSE values were obtained for each interpolation method. Some researchers claimed that the root means squared error (RMSE) should be as low as possible. RMSE values for the methods were as the following: IDW power 1=0.0321, IDW power 2=0.0312, IDW power 3=0.0313, and Kriging=1.1068. Reclassification and Extraction tools were used to calculate the areas of five classifications that show soil salinity levels. The soil salinity levels’ areas were given in Table 1 below.

![Figure 2. Mapping IDW (power 1)](image)

![Figure 3. Mapping IDW (power 2)](image)
Table 1. Results of cross-validation assessment of interpolation methods salinity areas

| №   | Interpolation methods | RMSE  | Areas under different salinity classes | Total area, (ha) |
|-----|-----------------------|-------|----------------------------------------|-----------------|
|     |                       |       | Non-saline, (ha) | Slightly saline (ha) | Moderate saline (ha) | Highly saline (ha) | Very high saline (ha) |
| 1   | IDW (power 1)         | 0.0321| 0.09 | 43134.57 | 14683.59 | 6564.42 | 2904.03 | 67286.7 |
| 2   | IDW (power 2)         | 0.0312| 12956.67 | 6082.56 | 22282.11 | 21008.43 | 4956.93 | 67286.7 |
| 3   | IDW (power 3)         | 0.0313| 10011.42 | 4305.51 | 21873.51 | 24398.91 | 6697.35 | 67286.7 |
| 4   | Kriging               | 1.1068| 19642.59 | 12922.2 | 18255.6 | 13454.1 | 3012.21 | 67286.7 |
|     | Differences IDW2 vs   | +12956.5 | -37052.01 | +7598.52 | +14444.01 | +2052.9 |
|     | IDW1                  | 8     |          |          |          |          |          |          |
|     | Differences IDW2 vs   | +2945.25 | +1777.05 | +408.6 | -3390.48 | -1740.42 |
|     | IDW3                  |       |          |          |          |          |          |          |
|     | Differences IDW2 vs   | -6685.92 | -6839.64 | +4026.51 | +7554.33 | +1944.72 |
|     | Kriging               |       |          |          |          |          |          |          |

Interpolation method IDW with power 2 calculated more accurately than three other methods. RMSE with IDW power 2 was 0.0312 and the maximum RMSE was with the Kriging method which accounted as 1.1068. The study of the most accurate interpolation method in our case IDW with power 2 (IDW-2), show that salinity classes have quite essential differences in saline areas. Comparison of area results for five ordinal soil salinity classes between IDW-2 as the most accurate interpolation method in our case with lowest RMSE value and IDW-1 show that maximum differences reached on slightly saline areas, where this class value decreased on 37052.01 ha (which is 55% of district irrigated land). Minimum differences reached on IDW-3 on moderated saline class and higher than IDW-2 on 408.6 ha. Absolute differences $|\max| - |\min|$ results in areas between IDW-2 interpolation method with IDW-1, IDW-3, Kriging show 51496.02 ha, 3799.08 ha, and 14393.97 ha, respectively. The Sum of differences in the same comparison mode shows 74104.02 ha, 10261.8 ha, and 27051.12
ha, respectively. Compare, this results in relation to total irrigated areas of the district show differences as 110.1%, 15.3%, and 40.2%, respectively.

4. Conclusion

For the study, the Mirzaabad district was chosen because this area was one of the most important districts of Syrdarya province regarding soil salinity. In the district, there were shown much more salinized soils and all soil salinity levels were available which enabled us to work on interpolation methods’ calculations and finding soil salinity areas. The assessment of different interpolation tools was done by the cross-validation method. The Root-mean-square errors of the interpolation methods were obtained as they show the accurateness of those methods. Different RMSE values were gained: IDW power 1 = 0.0321, IDW power 2 = 0.0312, IDW power 3 = 0.0313, and Kriging = 1.1068. The analysis reveals that the deterministic interpolation method like IDW power 2 can be successfully used to generate exact continuous surface for soil salinity mapping. Properly define the interpolation method for example IDW with power 2 compare to IDW with power 1 (commonly used method) can be important for accurate measurements of soil salinity areas. The cross-Validation method with an assessment of Root Mean Square Errors (RMSE) shows that IDW with power 2 (IDW-2) most accurate. The maximum difference reached between IDW-2 and IDW-1 on a slightly saline area where the value decreased by 55% of the total irrigated land of the district. Minimum differences reached on IDW-3 on moderated saline class and higher than IDW-2 on 408.6 ha.

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