SPATIAL VARIABILITY MAPPING OF SOIL-EC IN AGRICULTURAL FIELD OF PUNJAB PROVINCE (PAKISTAN) USING GEOGRAPHIC INFORMATION SYSTEM (GIS) TECHNIQUES

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ABSTRACT

In this research, the agricultural land of Punjab Province was evaluated with respect to spatial distribution of soil Electrical Conductivity (EC) by using some interpolation techniques such as Kriging with the implementation of models like Spherical, Gaussian, and Exponential etc. For research purpose, the study area was divided in three zones of Punjab province which included Upper Punjab, Central Punjab & Southern Punjab respectively. 72,294 soil samples were collected and analyzed during 2010-13 through the soil and water testing laboratories under the Directorate of Soil Fertility Research Institute, Agriculture Department Punjab, Lahore (Pakistan). To analyze the spatial variability of soil EC, the geo-statistical approach (Ordinary Kriging) was utilized and compared with respect to mean error (ME), root mean square error (RMSE), Average standard error (ASE), Mean standardized error (MSE) and root mean square standardized error. The results showed that Kriging had higher accuracy with the spherical & exponential model than the others. It was the best method to measure soil EC because it showed highest precision and minimum error. Generating prediction maps of soil parameters were conceptualized to correct conventional practices of growing crops .Based on the predicted map, electrical conductivity is found higher in Southern Punjab than in the Upper and Central Punjab areas. Almost all the agriculture land in southern Punjab is faced a lot of salinity related problems. The central Punjab represented a moderately saline soil with respect to EC and upper Punjab represented almost a non-saline soil in all agricultural fields within this area.

Key words   GIS Mapping, Interpolation, Ordinary Kriging, Punjab Agricultural Land, Salinity, Semivariogram, Soil EC

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INTRODUCTION

The Punjab province is food basket for Pakistan. Economic yields can only be achieved if crops are grown in the environment that is optimum for specific crops. Improving awareness level about given soil and environmental conditions can be of great help to improve crop production. This idea can be easily achieved by using recent IT innovations and by making information public. It is imperative that through use of GIS in agriculture as a tool for spatial data integrated with actual soil data to produce soil fertility / crop suitability maps that are informative for progressive farmers, landowners, policy makers, planners, researchers & extension workers. Conventional-ly, crops are grown irrespective of the plants' preferred ecological niche and farmers are taking the farming just as their "way of life". No better alternate of using their resources is available to them. As a strategic measure there is need of transformation of traditional agriculture from "way of life" to "mean of life" which implies growing of crops keeping in view the soil and environment conditions of that particular area. By means of this study, processed, systematic and easily understandable information would be made public through application of recent developments in IT for the farmers, policy makers & other stakeholders. Soil electrical conductivity

assessment and water provision practices are the main com-

map soil electrical conductivity, soil sampling and measurement of EC demands a considerable effort. Knowledge of the spatial variability of soil and its salinity related problems is used to evaluate the proper field management practices and the extent to increase yield of crops. Soil salinity decreases food production in different regions of the world. Soil salinity is divided into two main categories: naturally occurring dry land salinity and human-induced salinity caused by low quality of water. In both cases, the growth of plants and soil organisms are limited leading to low yields [3]. For optimum management of salted lands, it needs to map and monitor as well. To predict soil maps based on their attributes, geo-statistical approaches are used to interpolate the analyzed data of soil. A French mathematician & geologist, Georges Matheron, was the founder of Geostatistics techniques and methods, he invented that Kriging, interpolate and predict the unknown values on the bases of measured values. Ordinary Kriging is a spatial interpolation method of geo-statistical technique which plays an important role in order to find out the spatial distribution of soil parameters, their prediction and to map the soil properties as well. Effectively assess the spatial distribution of soil and its variability with respect to parameters, geo-statistic techniques are most commonly used in recent years. It provides statistical tools in order to find out soil spatial variability and interpolation. Not only the prediction maps are produced by using these techniques but it also finds error or surfaces which are uncertain. This research output would help a lot to bridge over the gap between existing and potential yield level through exploration of scope of area-wise crop specialization. Poshtmasari et al.[9] used Ordinary Kriging method with different models to find out the EC & pH on agricultural fields in research.IDW and RBF methods were also used for this purpose. They found that Kriging was proved optimum method to measure pH and based on exponential model had highest precision and minimum error for EC in their study area. Nawar et al. [8] explored the spatial variability of soil EC in their study area. They used two types of Kriging (OK, UK) with the models like Exponential, Gaussian and Spherical. Mean error, mean standardized errors and root-mean-square standardized errors were used to evaluate the results. Robinson and Metternicht [1] used the different interpolation methods like Kriging. IDW, RBF to compare the accuracy between them for estimating the soil EC, pH etc. They conclude that many parameters would be better identified from the RMSE statistic obtained from cross-validation after an exhaustive testing. Wilson et al. [12]) found that for best measurement of pH, OK performed optimum for pH and with log transformation, it gave the best results in case of electrical conductivity (EC).They also conclude that soil parameter estimation would be better understand by applying the cross-validation test and RMSE statistics. Johnston et al. [4] used statistical

ponent in agricultural lands of Punjab province. In order to analysis, models and tools for statistical analysis of data. A large choice of semi-variogram models and spatial dependency of data is provided by geo-statistical tools. In order to choose the best model, geo-statistical analyst provides the validation/cross-validation procedures to find the accuracy of dataset. Mohamed and Abdo [7] discussed the soil properties for agriculture with respect to surveying, sampling and mapping point of view. Soil surveying includes GIS and sampling methodology with the help of GPS was found to be effective tool. Zandi et al. [13] used different interpolation methods to find out the spatial variability of soil with specific models and techniques. In order to generate prediction maps, these renowned interpolation techniques characterized the spatial variability with respect to soil parameters in different contexts. Kastens and Staggenborg [6] discussed interpolation method Kriging with the Semivariogram studies, prediction accuracy, and generalizing these results with respect to the dataset. For Kriging, the choice between a spherical and an exponential variogram probably is inconsequential. Both behave similarly in terms of predictive accuracy.

MATERIALS AND METHODS

Study Area

The study area of the research work was Punjab province, in the Islamic state of Pakistan, and is confined between east longitudes 69° 15' 0.7158" and 75° 19' 15.0888" and north latitudes 27° 41' 42.3636"and 33° 58' 29.0526". The research's total area of about is 205,344 km2 (79,284 square miles).The study area was divided in three zones of Punjab province which are Upper Punjab, Central Punjab & Southern Punjab respectively. Soil survey regarding different parameters like soil classification, soil properties, and primary data regarding soil analysis was collected from Directorate of Soil Fertility Research Institute, Agriculture Department, Punjab Lahore. The department is served as input in the ongoing research activities, required for the characterization of the standard chemical and physical properties and the general properties of the soil of Punjab province.

Data Sampling and Analysis

Soil samples were collected at 6cm depth, geo-referenced using Global positioning System (GPS) with an accuracy of ±5m and analyzed for soil electrical conductivity (EC). 3km × 3km spacing was planned for grid sampling scheme. This was required to explore the spatial soil variability in the study area. The total no. of soil samples taken in the study area were consisted of 72,294 sample points. These geographical locations were recorded through use of GPS navigator and the analytical results were linked to these locations, so that spatial distribution of EC of Punjab province made easily available in understandable form of maps, was the main output of this research.
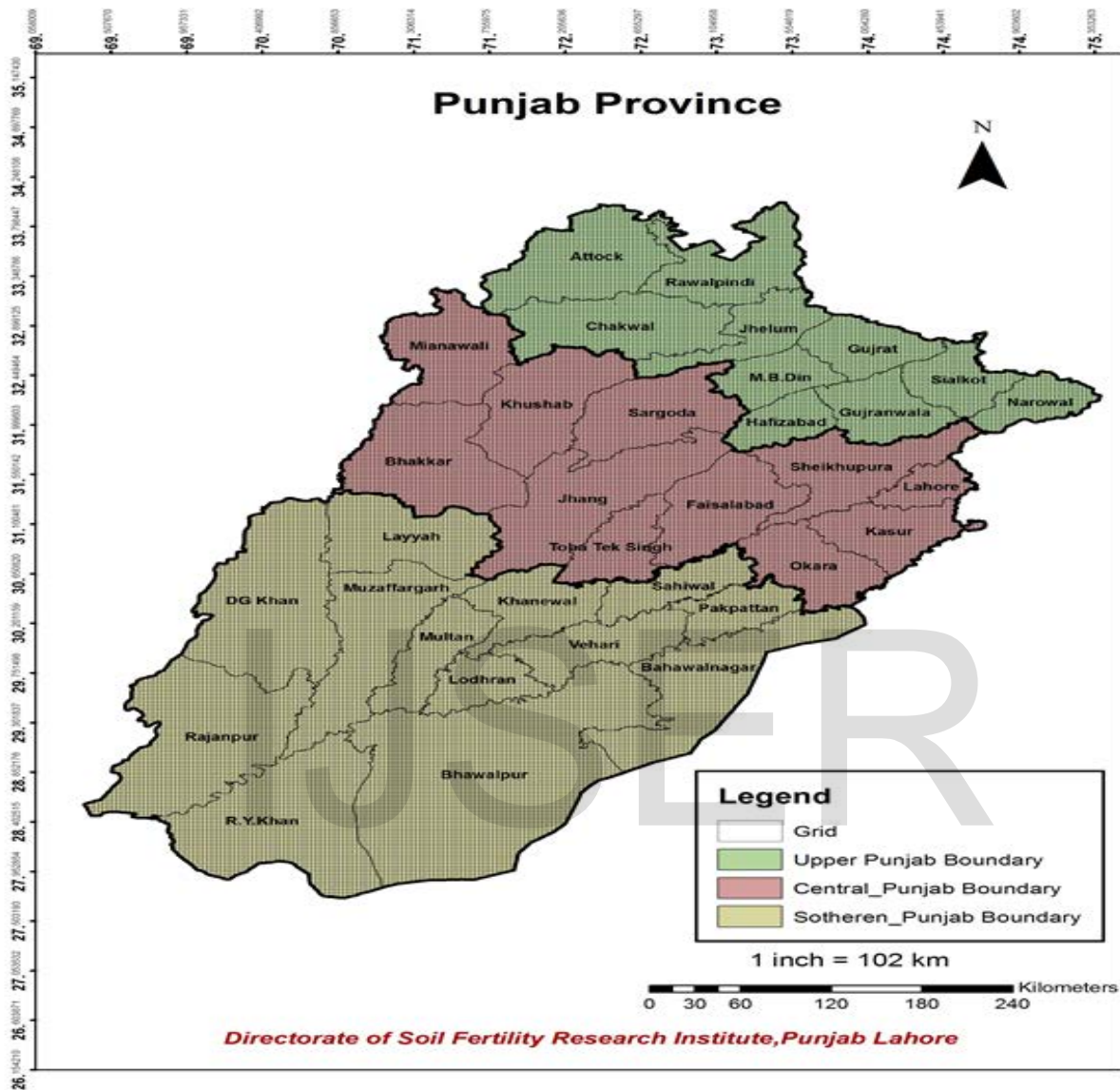
Figure 2.1 Grid Map of Study Area for soil sample location

Geo-statistical Analysis

Generally, geo-statistical estimation methods were exercised to explore and map the agricultural land. It was based on the theory of regionalized variables which were disseminated in space with spatial coordinates and show spatial autocorrelation such that samples close together in space are more alike than those that are further apart.

Spatial Dependence

Explores the tendency among the observations that are close together in space consider more correlated/interrelated with each other than those that were at distant. It is also called spa-

tial autocorrelation. Two locations with different observations that up to some extent apart from each other are not statistical independent.

Semi- Variance

Describes function of distance between the two observations is a measure of the spatial dependence.

Semi-Variogram

Represents a graph that shows how distance between the observations changes as the semi variance changes. As a function of distance between observations is used to measure the degree of dissimilarity is semi-variogram. It is based on "Rule of

Geography" that things close together are more alike than things that are at a distant. Two observations/locations are close to each other, semi- variance generally behaves low. Similarly, semi- variance increases as the distance between the Mathematically, semi-variogram $\gamma(h)$ is descirbed as a function below:

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

Where N (h) is the total number of data pairs separated by a distance h; Z represents the measured value for soil property, and x is the position of soil samples. Before the geo-statistical estimation, a semi-variogram is calculated for classes of distance between sample pairs. Standard models are used to fit the experimental semi-variogram, e.g., spherical, exponential, gaussian in this study.

Variogram

Method or semi-variogram technique describe the measure of spatial variability of a soil with regionalized variable that provides the input parameter like electrical conductivity (EC), for the spatial interpolation of kriging.
A variogram is generally characterized by three phases.

Nugget

The inconsistency/variability in the field data refers nugget that cannot be described with respect to distance among the observations. Variability of the field data which is being measured and imprecision in sampling techniques influences the magnitude of nugget. The nugget can also be influenced by the minimum distance between the observations, because if they are not located close to each other, then the spatial dependence among observations cannot be estimated.

Sill

Maximum observed variability/inconsistency in the field data refers sill. The amount of observed variation that can be described by distance among observations is the main difference between sill and nugget. A small nugget and a large sill would be an ideal situation (i.e., there is a lot spatial dependence and an unpredicted location could be inferred much based on its distance from an observed location).

Range

The range is that saturation point at which the semi-variance stops growing. The distance at which two observations are unrelated/dissimilar (i.e., independent) represents range.

Interpolation Method

Spatial distribution pattern of soil EC was determined using the geo-statistical technique providing the interpolation methods such as Kriging.

Kriging

In geo-statistical techniques, Ordinary Kriging is one of the most optimal tools that provide an estimate at an unsampled point based on the weighted average of observed adjacent points within a respective area. It is best linear unbiased estimation for quantities which vary in space.

locations grow until a saturation point comes where these locations are considered independent of each other and semi-variance no longer increases.

The weights in the kriging method are based on the distance between the measured points and the prediction points and the overall spatial arrangement of the measured points. Spatial prediction defines optimally by using this method.
Mathematically, kriging $\hat{Z}(x_0)$ is described as a function below:

$$\hat{Z}(x_0) = \sum_{j=1}^{n} \lambda_i z(x_j)$$

Where
$\hat{Z}(x_0)$=Value to be predicated at location x_0
$z(x_i)$=Observed value at sampling location x_i
n =number of locations within the search neighborhood area used for the prediction [1, 2 and 14]

Criteria for Comparison of Best Fitted Model

In order to find out the best fitted model in ordinary kriging interpolation method, Spherical, Exponential, Gaussian and K-Bessel functions are used in this study. Model selection for semi-variograms is done by comparing the deviation of estimated value from the observed/measured data and performing a cross-validation test over the entire dataset. The cross-validation technique is used to choose the best variogram model among candidate models and to select the search radius and lag distance that minimises the kriging variance. The values of mean error (ME), root mean square error (RMSE), Average standard error (ASE), Mean standardized error (MSE) and root mean square standardized error are estimated to check the results/performance of the best fitted theoretical models.

$$\text{Mean Error} = \frac{1}{N} \sum_{i=1}^{N} [Z(x_i) - \hat{Z}(x_i)]$$

$$\text{Root Mean Square Error} = \sqrt{\frac{1}{N} \sum_{i=1}^{N} [Z(x_i) - \hat{Z}(x_i)]^2}$$

$$\text{Average Standardized Error} = \sqrt{\frac{1}{N} \sum_{i=1}^{N} \sigma^2(x_i)}$$

$$\text{Mean Standardized Error} = \frac{1}{N} \sum_{i=1}^{N} \frac{ME}{\sigma(x_i)}$$

Root Mean Square Standardized Error $= \sqrt{\dfrac{1}{N}\sum_{i=1}^{N}(\dfrac{ME}{x_{i}^{2}})^{2}}$

the kriging variance for location x_i

Where $\hat{Z}(x_i)$ is the predicted value, $Z(X_i)$ the observed (known) value, N the number of values in the dataset and σ^2 is

The following rules should be implemented in order to get best fitted model:

- The mean error (ME) should ideally be zero.
- An accurate model would have a mean standardized error (MSE) close to zero.
- If the model for the variogram is accurate, then the root mean square error (RMSE) should equal to the average standard error (ASE).
- Root mean square standardized (RMSP) should equal 1.
- Standard deviation should be greater than Average standard error (ASE).

If the RMSS is greater than 1, then the variability in the predictions is being underestimated, and vice versa. Similarly if the average standard errors (ASE) are greater than the root mean square standardized errors (RMSS), then the variability is overestimated, and vice versa [4, 6, 10 and 11]

Data Analysis

Statistical results indicated that soil EC was fitted for normal logarithmic distribution .GIS software packages were used to analyze different data sets. Maps were developed with GIS software ArcGIS and its extension of Spatial Analyst and Geostatistical Analyst extention. The geostatistical analysis and the probability calculations were carried out with geostatistic extension of ArcMap.

RESULTS AND DISCUSSION

Tables below summarize EC datasets, which includes descriptive statistics such as minimum, maximum, mean, median, mode, standard deviation, skewness and kurtosis. Before performing geostatistical analysis, the raw dataset was logarithmically transformed to make the dataset normally distributed of soil EC.

Table 3.1: Descriptive Statistics of EC (Upper Punjab)

Div.	District	Mean	Median	Min.	Max.	S.D	Skewness	Kurtosis
Rawalpindi	Rawalpindi	0.9034	0.82	0.11	3.69	0.3411	2.60628	13.8049
	Attock	0.8822	0.86	0.47	2.97	0.1613	2.75811	22.1363
	Chakwal	0.8921	0.86	0.38	6.87	0.2624	9.98423	210.815
	Jehlum	1.3305	1.12	0.5	6.57	0.7550	1.76002	4.41494
	Mandi Bahauddin	1.1702	1.16	0	18.42	1.1388	4.67421	58.6990
Gujranwala	Gujranwala	1.2767	0.99	0.04	10.8	1.1045	4.45409	26.7578
	Gujrat	1.6044	1.35	0.16	8.76	1.0186	3.16906	15.4258
	Hafizabad	1.4307	1.0075	0.13	93.98	3.8323	21.5406	493.432
	Narowal	1.4246	1.11	0.2	11.88	1.1314	3.61552	21.707
	Sialkot	1.4706	1.21	0.2	71.09	2.0709	27.3719	911.456

Table 3.2: Descriptive Statistics of EC (Central Punjab)

Div.	District	Mean	Median	Min.	Max.	S.D	Skewness	Kurtosis
Sargodha	Bhakkar	0.99	0.84	0.20	8.01	0.6081	5.5542	43.3369
	Sargodha	2.47	1.71	0.15	25.07	2.1605	3.0431	13.8565
	Mianwali	1.23	1.00	0.29	9.00	0.9238	3.3440	16.3630
	Khushab	1.65	0.85	0.07	23.80	2.1798	3.9145	20.4205
Faisalabad	Faisalabad	2.51	1.83	0.69	37.44	2.6251	5.0767	36.0382
	Jhang	2.14	1.75	0.45	31.06	1.9414	5.3791	46.8809
	TobatekSingh	3.20	2.41	0.71	50.31	2.7673	6.5282	78.8317
Lahore	Lahore	2.12	1.80	0.80	8.90	1.2413	2.6423	8.48518
	Kasur	2.53	2.00	0.50	99.80	3.6043	16.111	358.001
	Sheikhupura	2.91	2.30	0.00	89.10	3.0434	11.3453	241.667
	Okara	3.20	2.60	0.00	36.00	2.7419	4.5111	30.2469

Table 3.3: Descriptive Statistics of EC (Southern Punjab)

Div.	District	Mean	Median	Min.	Max.	S.D	Skewness	Kurtosis
Multan Div.	Multan	5.50	2.86	1.00	75.40	6.9400	3.7088	19.75
	Lodhran	6.91	3.26	1.01	40.00	7.8980	2.2199	5.25
	Khanewal	2.68	1.95	0.45	19.16	2.1973	3.2989	14.11
	Vehari	2.93	2.03	0.00	42.55	3.5898	7.1906	64.32
	Sahiwal	2.51	2.10	0.88	16.54	1.5325	3.0391	15.92
	Pakpattan	2.49	2.18	0.00	14.01	1.2818	2.1521	8.055
DG Khan	DG Khan	4.75	3.10	0.30	71.40	4.4622	2.8589	20.31
	Layyah	2.24	1.42	0.40	25.60	1.8586	3.0768	25.46
	Muzaffargarh	6.65	3.65	1.00	133.38	9.4773	4.6153	30.39
	Rajhanpur	8.18	5.31	0.80	96.10	9.5800	3.8594	20.49
Baha-walpur	Bahawalnagar	5.15	2.70	0.60	97.80	8.0631	5.1987	35.68
	Bahawalpur	3.56	2.10	0.27	60.00	4.5145	4.7686	34.44
	Rahim Yar Khan	7.08	3.60	0.40	120.2	10.6702	5.9000	60.51

Based on this statistics, the upper Punjab that includes Rawal-pindi & Gujranwala divisions represent average soil EC of about less than 4 (ds/m) or non-saline. In contrast, the southern Punjab that includes Multan, DG Khan & Bahawalpur represent high EC zone on the average due to concentration of salt. And central Punjab that includes Sargodha, Faisalabad & Lahore division lied in the category of highly saline in some tehsils and on the average it was moderately saline.

Log Transformation of Soil-EC

Transformation was done to normalize dataset of soil-EC for three sampled zone of Punjab province, which was proposed as Upper Punjab, Central Punjab and Southern Punjab.
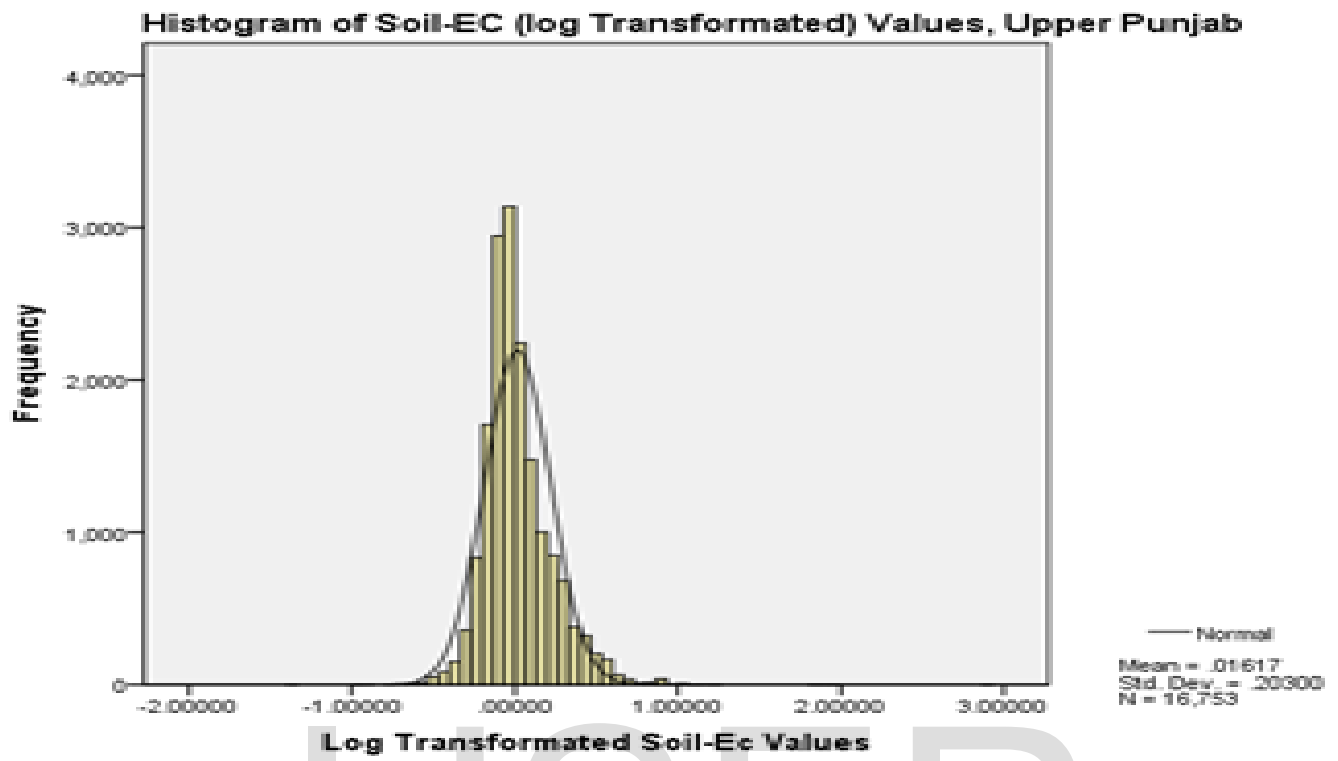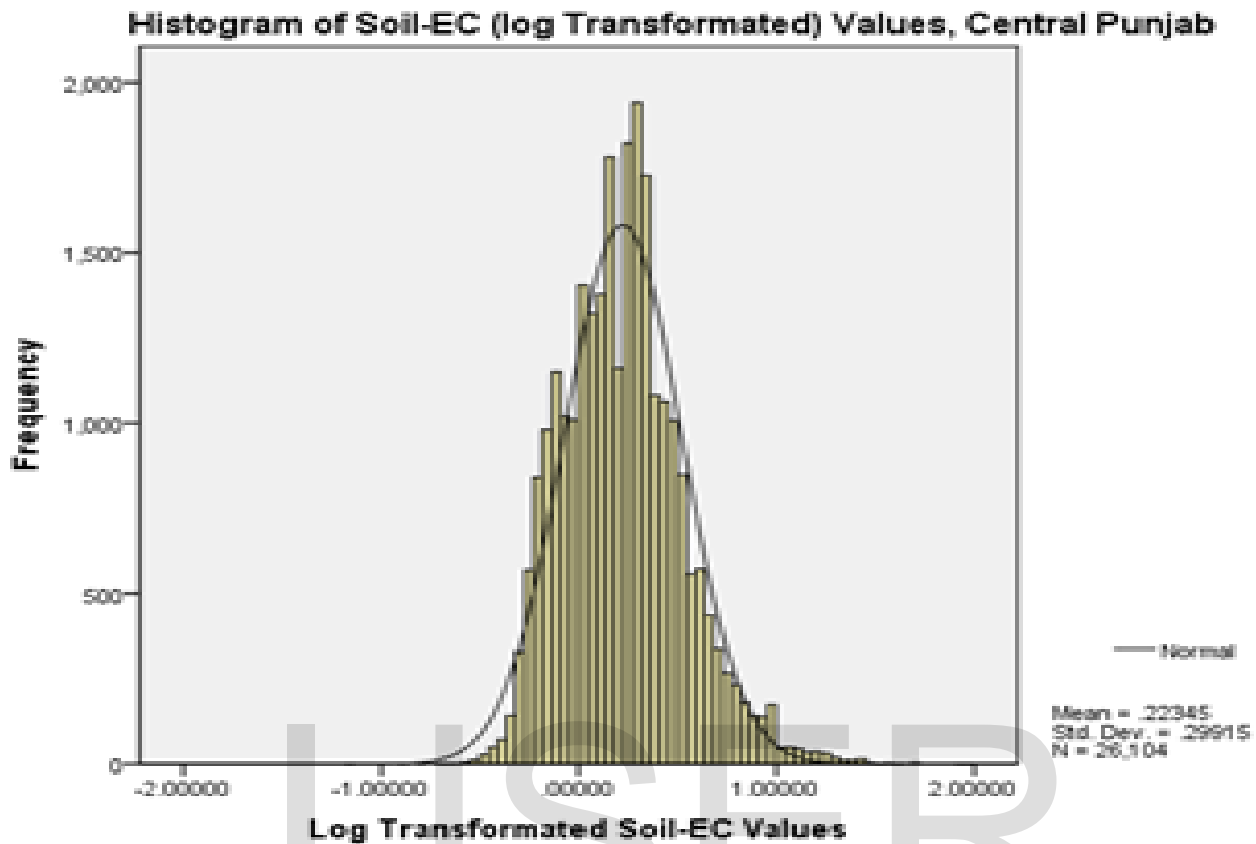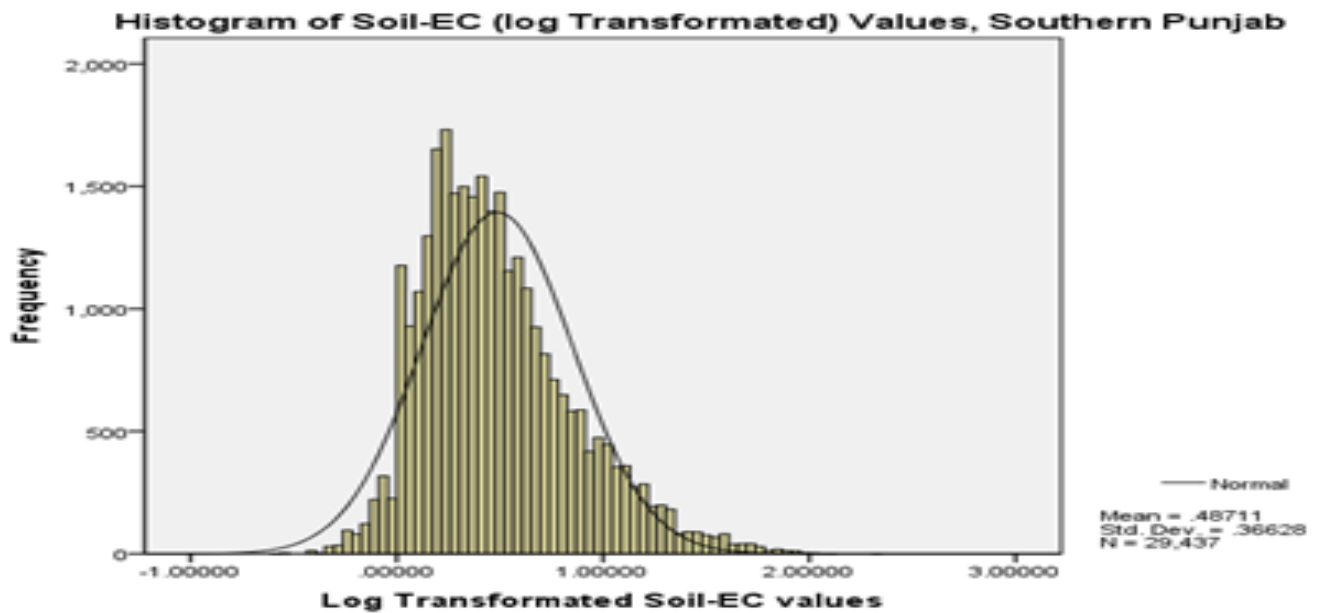
Figure 3.1

Figure 3.2

Figure 3.3

Normal distribution in statistics is described by the continuous line of histogram with mean and standard deviation, which were estimated from the data by applying log transformation.
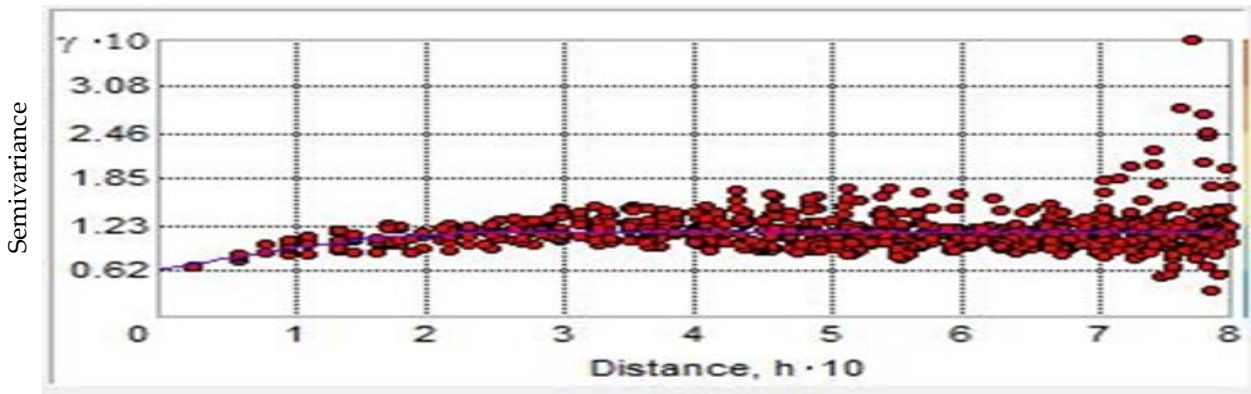
Semi-Variogram

Figure 3.4 Semivariogram for Log-transformed EC values

A semi-variogram of soil EC is shown in figure given below to find out the behavior of spatial dependence of data by using geostatistical wizard, which shows strong spatial dependence in right by using spherical model and weak spatial dependence in left by using circular model.
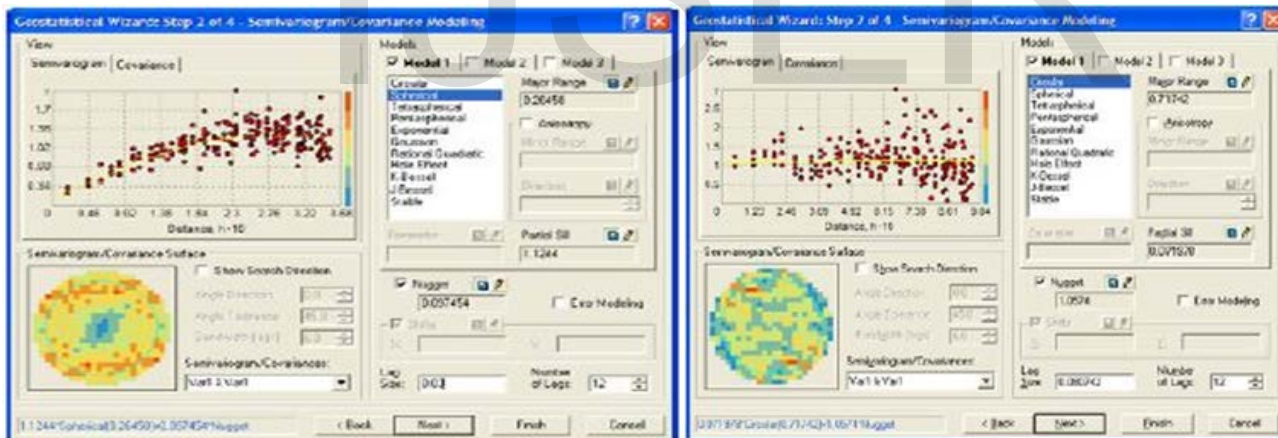
Figure 3.5

EC-Geostatistical analysis results were presented in tables below. It showed that to predict Soil EC, Spherical, Gaussian and Exponential models of Kriging method were chosen for its estimation. The highest precision and minimum error were the basic reason for the prediction of soil EC. The models spherical, exponential and Gaussian has been analyzed and compared with each other to get the optimum results of best fitted model.

Table 3.4: Results of geostatistical analyses of Soil EC in Upper Punjab

Method	Model	Trans.	ME	RMS	ASE	MS	RMSS
	Spherical	Log	-0.005698	0.333	0.3451	-0.01793	0.9677

Kriging	Gaussian	Log	-0.004893	0.3269	0.3663	-0.0147	0.9008
	Exponential	Log	-0.006358	0.3235	0.3752	-0.01792	0.8674

Table 3.5: Results of geostatistical analyses of Soil EC in Central Punjab

Method	Model	Trans.	ME	RMS	ASE	MS	RMSS
Kriging	**Spherical**	**Log**	**0.001656**	**3.045**	**3.178**	**0.0008324**	**0.9527**
	Gaussian	**Log**	**0.003724**	**3.078**	**3.208**	**0.001408**	**0.9589**
	Exponential	**Log**	**0.0004908**	**3.021**	**3.148**	**0.0005502**	**0.9592**

Table 3.6: Results of geostatistical analyses of Soil EC in Southern Punjab

Method	Model	Trans.	ME	RMS	ASE	MS	RMSS
Kriging	**Spherical**	**Log**	**-0.1459**	**4.599**	**4.517**	**-0.03307**	**1.023**
	Gaussian	**Log**	**-0.1412**	**4.601**	**4.494**	**-0.0323**	**1.029**
	Exponential	**Log**	**-0.1173**	**4.591**	**4.55**	**-0.02675**	**1.014**

By performing the cross- validation of Soil EC, the spherical& exponential models were best to choose to estimate the soil EC. To validate the accuracy of interpolation, we implemented the cross validation in soil dataset .During this process, a small subset of actual dataset is removed which consist of a few soil samples. And the predicted value of this subset in its location is observed with the remaining observation of the actual dataset. By comparing the measured and predicted results, we also found out the average difference between measured and predicted values as well. These are the cross validation graphs for the dataset used to create the semi-variogram above.
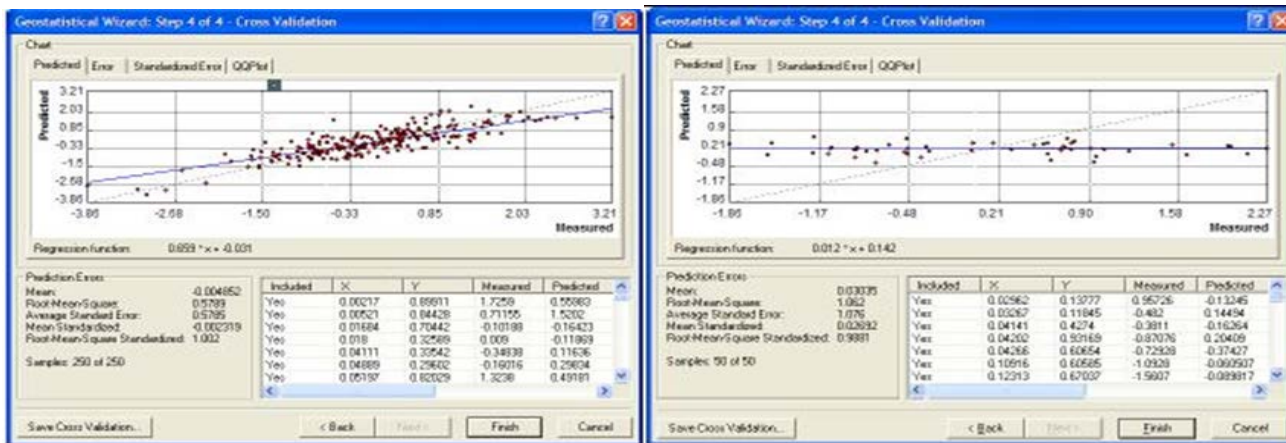

Figure 3.6

If data is correlated, then get a similar value which is predicted at that location by removing sample for cross-validation as shown in right above. But if spatial dependence is weak in dataset, then it is not possible that the predicted value of any removed sample will approximately equal to the arithmetic average value of dataset. In order to find out spatial variation of Soil EC, a predicted map was provided by kriging method for agricultural land of Punjab province. The confined area had different types of soil with respect to EC, Which was mainly defined with respect to some ranges as described below:

Soil Classification of EC (d S/m)	Remarks
≥ 4	Non- Saline
4 - 8	Slightly Saline
8 - 16	Moderately Saline
≥ 16	Highly Saline

Based on these maps, the upper Punjab that includes Rawalpindi & Gujranwala divisions represented soil EC of about 8 or slightly saline. In contrast, the southern Punjab that includes Multan, DG Khan & Bahawalpur represented high EC zone. And central Punjab that includes Sargodha, Faisalabad & Lahore represent EC less than 16 almost which is less than the mean EC in other agricultural land in Punjab province.
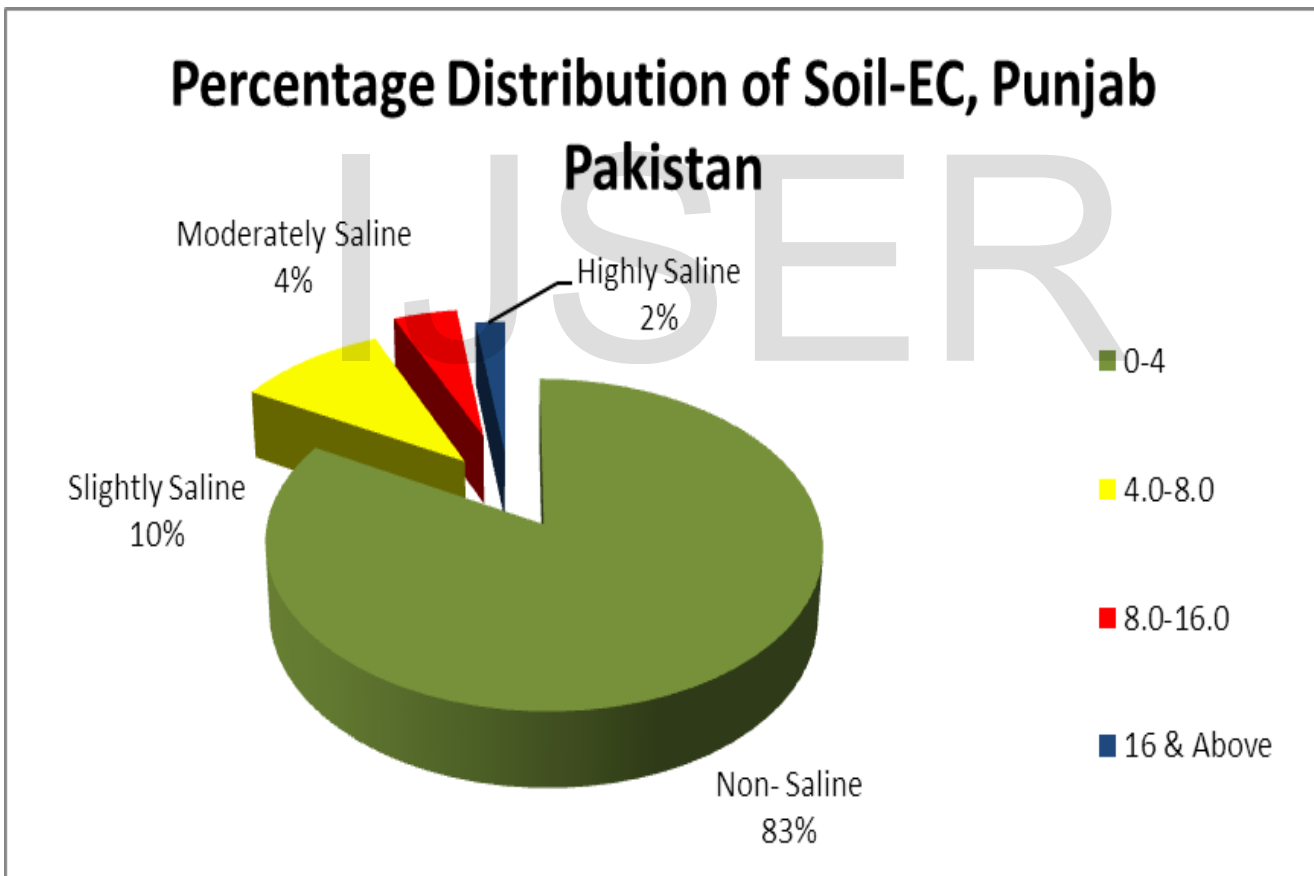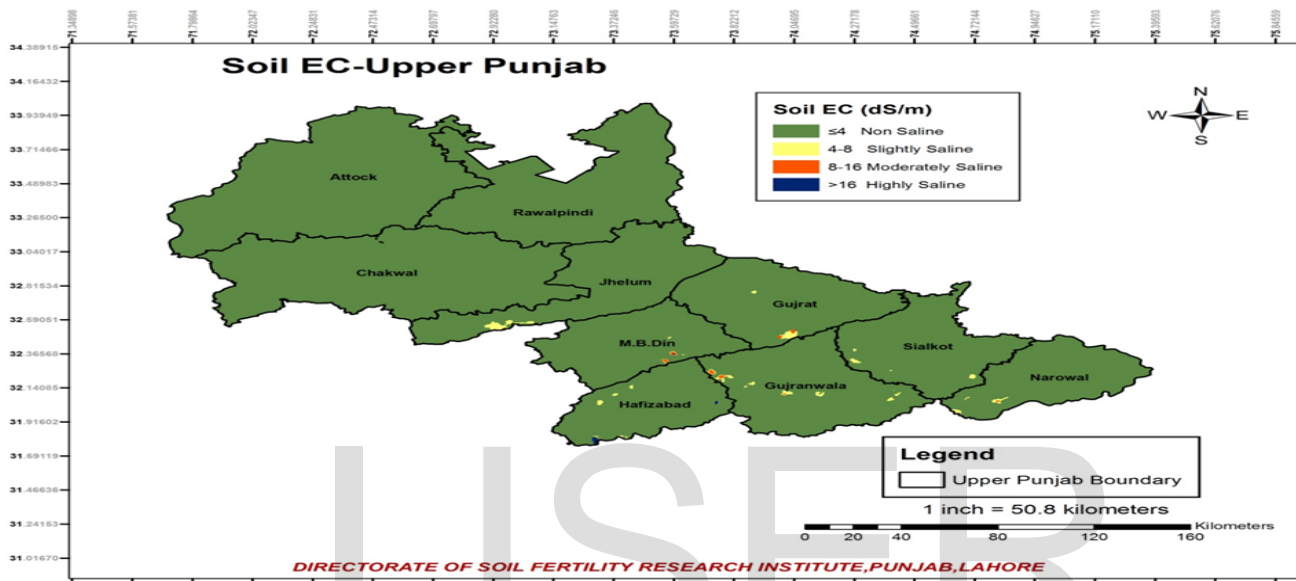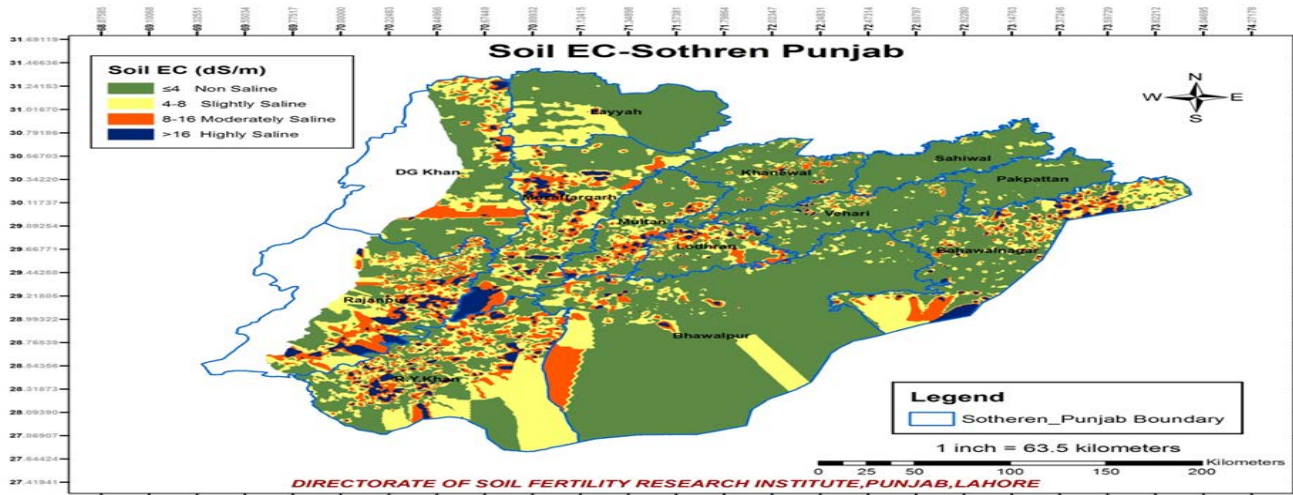

Figure 3.7

According to given study, EC of Soil Punjab represented 83% area of Punjab were Non-Saline, 10% were slightly saline, remaining 4% were Moderately saline and only 2% of agricultural land was highly saline.
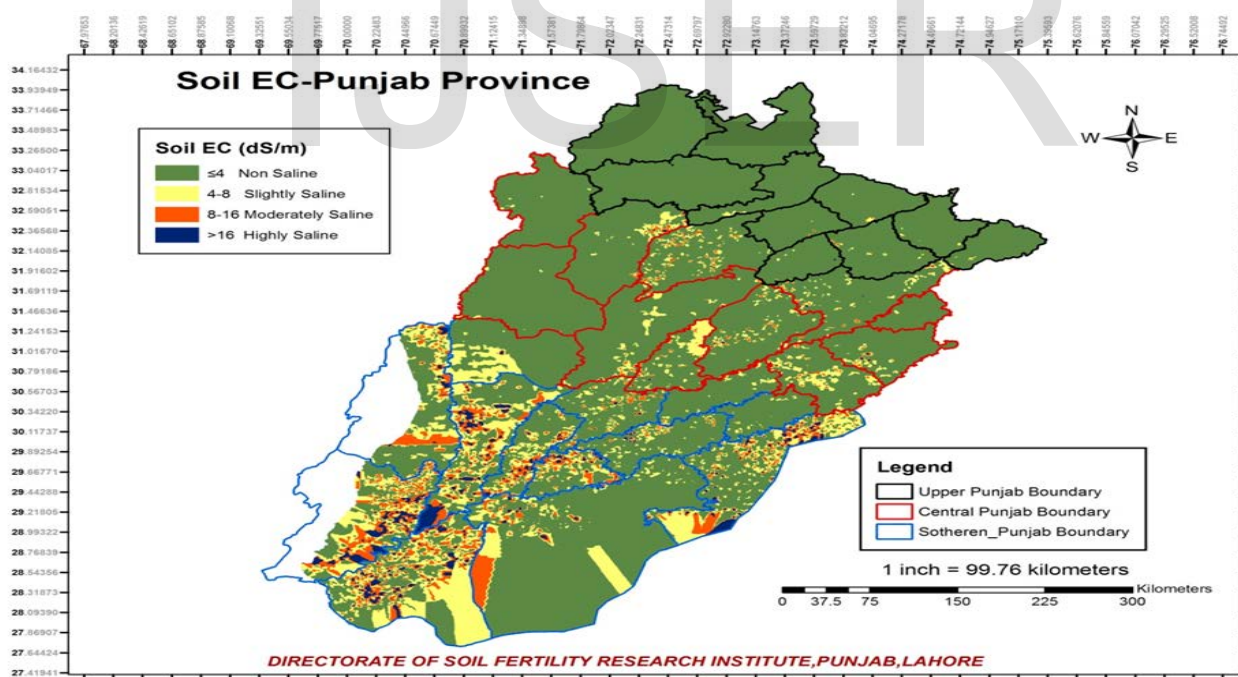
3.3 Interpolated Map of Soil EC of Upper Punjab

3.4 Interpolated Map of Soil EC of Central Punjab

3.5 Interpolated Map of Soil EC of Southern Punjab

3.6 Interpolated Map of Soil EC of Punjab Province

CONCLUSION

1. Kriging is most suitable method found, other than any interpolation methods and spherical and exponential variogram probably is inconsequential.
2. Both behave similarly in terms of predictive accuracy in order to find out spatial variability of EC in agricultural land of Punjab province.
3. Based on the predicted map of soil EC in Punjab Province, electrical conductivity is found higher in Southern Punjab than in the Upper and Central Punjab areas.
4. Almost all the agriculture land in southern Punjab is faced a lot of salinity related problems.

5. The central Punjab represents a moderately saline soil with respect to EC.
6. upper Punjab represents almost a non-saline soil in all agricultural fields within this area.
7. One of the main challenges in agriculture land of Punjab province is salinity, its reduction and control.

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