ISSN 2229-5518

MODELING OF SURFACE SOIL pH USING GEOSTATISTICAL METHODS IN PUNJAB PROVINCE, PAKISTAN

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ABSTRACT

The objective of this study was to evaluate the spatial variability of soil pH by using some interpolation methods such as Kriging, IDW, RBF and splines with the several models and techniques. Soil of the Punjab Province was sampled with respect to the five major crop zones which were Cotton Zone, Rice Zone, Central Zone, Thal Zone and Barani zone. Fom these zones 72,294 soil samples were collected and analyzed. Generating prediction maps of soil pH were conceptualized to correct conventional practices of growing crops .The range of pH in cotton Zone was relatively high as compared with other zones. Muzaffargarh and DG Khan Districts showed high range of pH 4.75 (6.10 to 10.85) and 4.65 (5.65 to 10.30), respectively. The minimum range of pH showed in Attock District which was 1.22 (7.0 to 8.22). The interpolated maps by applying Ordinary Kringing showed the optimum variability of soil pH at small scale as compared to other methods and were found that kriging is most suitable method for the estimation of soil pH due to the semi-variogram analysis and it showed highest precision and minimum error. Approximately all districts showed 5% or less CV which showed good method performance.

Keywords: GIS Mapping, Interpolation, Alkaline Soil, Ordinary Kriging, RBF, IDW, Splines, Punjab Agricultural Land, Semivariogram, Soil pH.

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INTRODUCTION

Spatial variability of soil pH plays a central role in the development and management of farming. “Soil pH may vary dramatically over very small distances (millimeters or smaller), (Brady & Weil, 2010)”. The utility of geostatistics as it relates to farming can be very impressive. “Initially, the main objective of geostatistics in soil science was to enhance the quality of spatial prediction of soil properties” Kuzyakova et al. [6] Variations in soil are recognized for centuries and taken into account of farmer for the maintenance and quality control for getting an optimum yield of suitable crops. In recent times, there is a need to get realize that the variations in soil are substantial. For better management of land and make optimum use of fertilizers and other agrochemicals, modern techniques and methodologies can be used in order to increase the yields. This realization has lead to better understand the agricultural land precisely and the need to map the soil variations with respect to its different attributes.

As we cannot measure the soil everywhere, there is a need to measure the soil with planned sampling scheme for getting quantitative information from these measurements. 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 spatial dissemination of soil and its prediction. Not only the interpolated 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. [11] used the geostatistical techniques and methods such as Kriging, Radial basis function, Inverse distance weighted to estimate the soil EC & pH in agricultural land of their study area. It was found that kriging (spherical method) performed well and give optimum results to find out pH because it had lowest error and highest precision. Also RBF was found the most unsuitable method for the estimation of these soil properties. Webster and Oliver [13] discussed the logarithmic transformation techniques to make the respective data normal in behavior. He also described the descriptive statistics and interpolation techniques for the estimation of different properties or parameters. Goovaerts [2] described the recent innovation in geostatistics domain and implemented it on the soil scienes. To find out spatial patterns of soil properties, he described descriptive tools to characterize the semivariogram.

Lark [7] described the study of variogram with distinct lag to estimate the soil properties. He also suggested appropriate models that best fitted for the measurements. McDonnell [9] described the phenomena of neighboring measured points that the predicted values get high weights when they are closer to its surroundings as compared to the un-sampled values that are far away to its neighborhood. Johnston et al. [3] described the geostatistical techniques with different methodologies to explore and evaluate the data statistically. They also conclude that soil parameter estimation would be better understood by applying the cross-validation test and RMSE statistics. Robinson and Metternicht (2006) 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. Mohamed and Abdo [10] 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. Kastens and Staggenborg [4] 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. Zandi et al. [14] 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 paprmeters in different contexts. Bradley and Weil [1] described the soil properties and the principles that can be used to overcome the degradation of soil for getting a better yield or productivity of natural resources than the existing phenomena.

2 MATERIALS AND METHOD

Study Area

The study area based on the land of Punjab Province of Islamic state of Pakistan between 69° 15' 0.7158" to 75° 19' 15.0888" in eastern longitude and 27° 41' 42.3636" to 33° 58' 29.0526" in northern latitude. The total study area of research work was about 205,344 km2 (79,284 square miles). It was divided with respect to five major crop zones of Punjab Province; such as Rice zone, Central zone, Cotton zone, Thal zone and Barani zone. These Crop Zones consisted of 34 districts of Punjab Province.

Grid Sampling Design & Soil Analysis

The soil data regarding sample analysis were taken from Directorate of Soil Fertility Research Institute, Agriculture Department, Punjab Lahore with 72,294 sample locations during 2010-13.Grid based sampling plan were designed with 3km × 3km spacing. Soil samples were collected at 6cm depth to analyze the pH of soil having an accuracy of about ±5m, geo-referenced by using a Global Positioning System (GPS).These analytical results were linked with the geographical location of samples so that an understandable form of maps are developed for a meaningful purpose such as to find out the spatial dissemination of pH in agricultural land of Punjab province, Pakistan.

Research Methodology

Visualization and Exploratory Data Analysis

In order to find out the spatial prediction of soil property such as pH on the bases of measured values and for a comparative assessment, methods and techniques were summarized in Figure 2. A manual analysis was conducted to identify outliers spatially and incorrect data information by visual interpretation and follow ups. Spatial autocorrelation of soil sampled data were also assessed efficiently by this visualization. Descriptive analysis was also found such as mean, median, minimum, maximum, standard deviation, skewness, kurtosis and Coefficient of variation in this research. It was also explored with histograms and normal plots. For an efficient assessment of the outlier related values, which were unfavorable for spatial forecasting of pH, these tools are useful. In particular, the variogram is very sensitive to detect outliers because it is based on the squared differences among data Lark [7]. If the outlier is closer to the centre of the study area, many times it badly affects the average for each lag.

ISSN 2229-5518

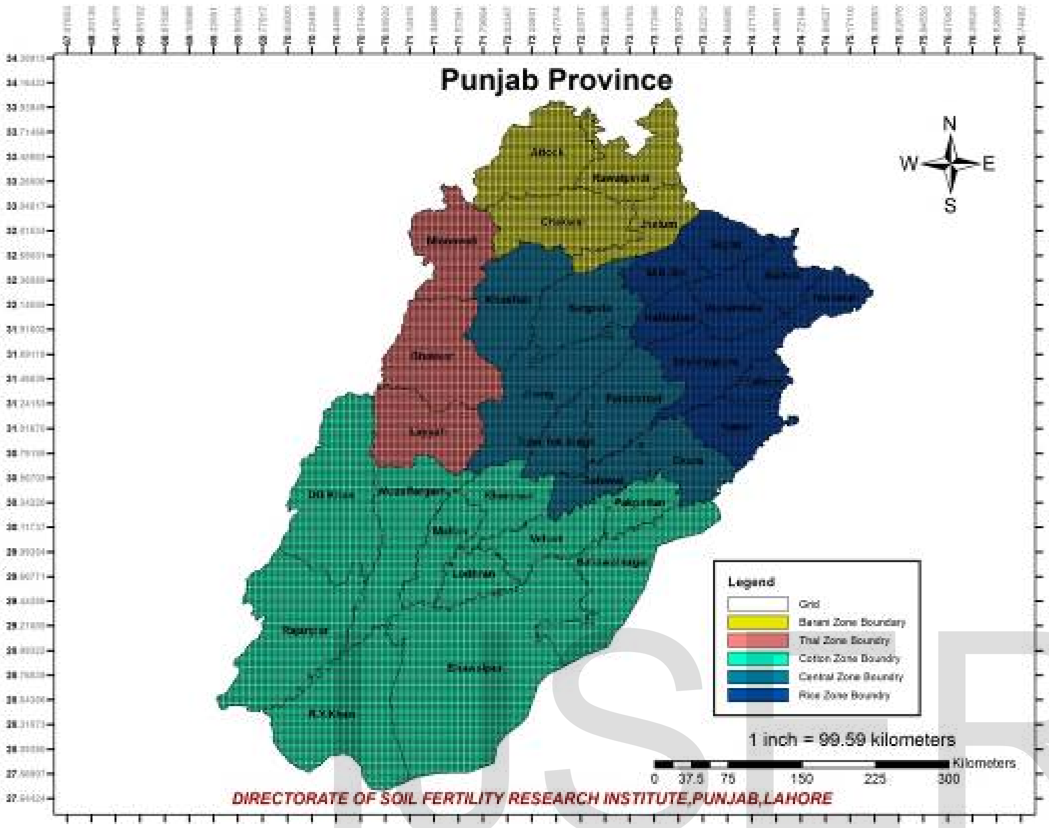


Figure 2.1 Grid Map of Study Area for soil sample location

Data Transformation and Interpolation

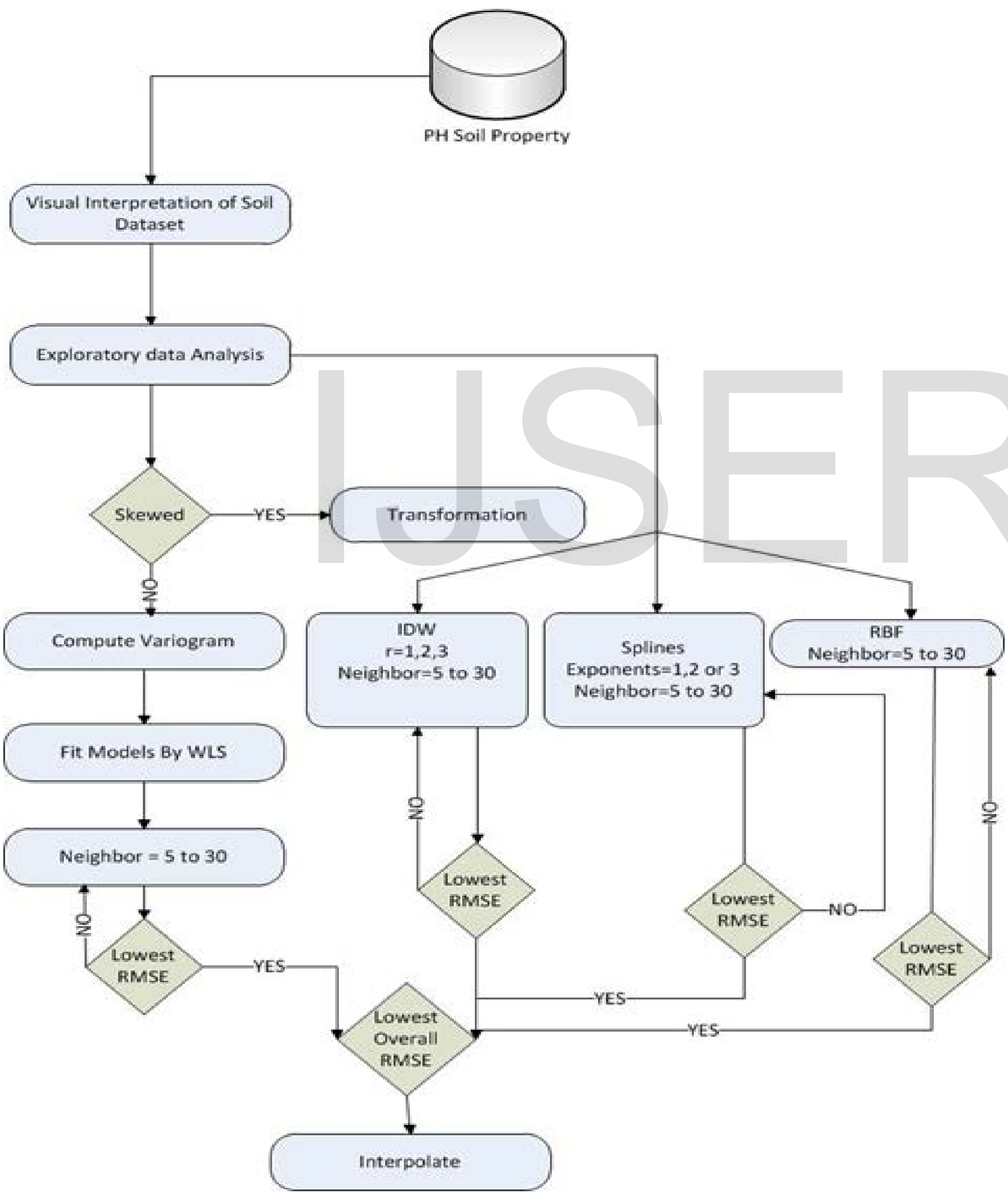
Apparently, when data tends to behave abnormal, there is a need to transform sampled data to make it normal to some extent. Geostatistical techniques and methods are utilized to get optimum results in this respect.

A logarithmic transformation is considered where the coefficient of skewness is greater than 1 and a square-root transformation if it is between 0.5 and 1 Webster and Oliver [13]

Two steps are included in Geostatistical prediction;

1. Identification and modeling of spatial structure Geostatistical Prediction
2. Variogram is used to study data continuity, its homogeneity and the identification of structure spatially.

Conceptual model for spatial prediction of soil pH



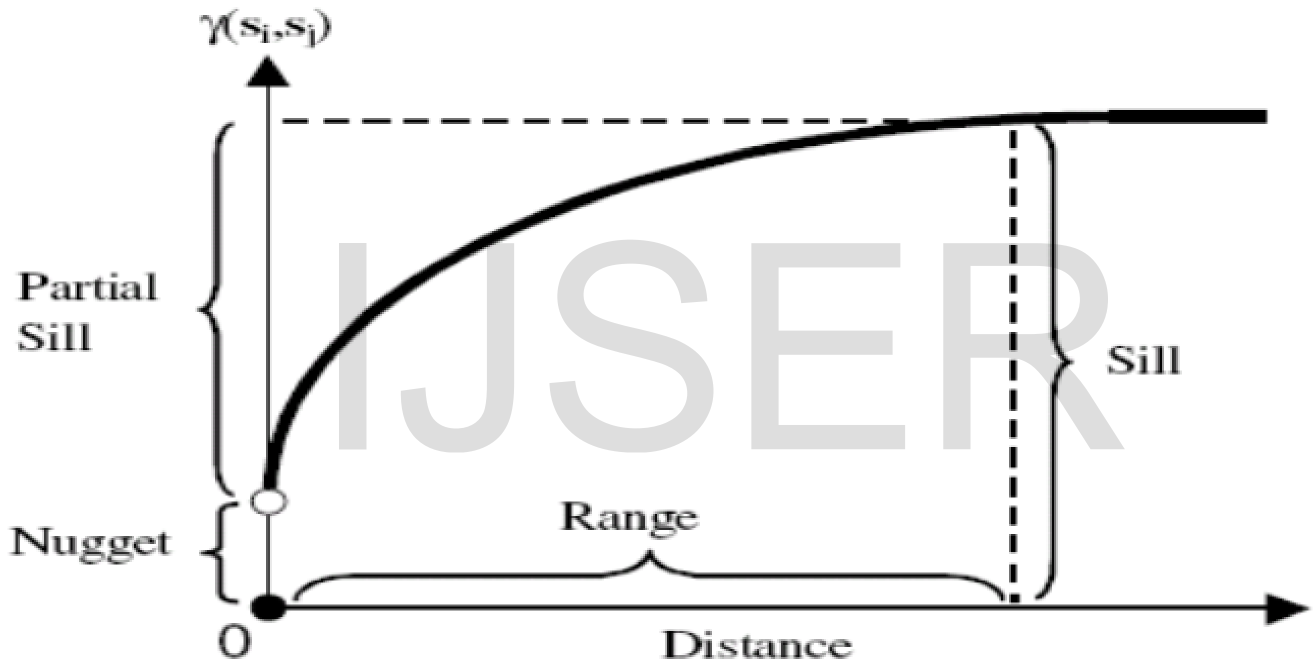
Spatial prediction methods

Kriging

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 Goovaerts [2]. The degree of measuring the average difference between the un-measured value and a observed value which is closer or in neighborhood to that un-sampled location is described by experimental variogram. And thus autocorrelation can also be described among sampled data at various distances. The value of the experimental variogram for a separation distance of h (referred to as the lag) is half of the average squared difference between the value at z(xi) and the value at z(xi + h) Lark [8];

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

where N(h) is the number of data pairs within a given class of distance and direction. If there exist autocorrelation between the values at z(xi) and z(xi + h),the results of above equation will be less with respect to uncorrelated data pair of points.



Through the evaluation of experimental variogram, the best fitted model is then chosen such as spherical, exponential etc with respect to weighted least squares and the parameters like sill, range, nugget in this method.

Inverse distance weighting

Within a local neighborhood, the average of total weight of measured data points surrounding the un-measured location is actually the value of attribute at that un-sampled location. The equation of this prediction method is given below McDonnell [9];

points within a chosen neighborhood. The weights (r) are related to distance by dij, which is the distance between the predicted point and the measured points. The estimated points that are closer to neighboring measured points get large weights while those has less influence which are far away.

Splines

Splines consist of polynomials, which describe pieces of a line or surface, and they are fitted together so that they join smoothly Webster and Oliver [13]. With the small data variations, the predicted surfaces produce good results but splines are not appropriate for the data that represent high variations within it.

Radial Basis Functions (RBF)

RBF based on the five interpolation techniques which are deterministic exactly.

1- Thin-plate spline
2- Spline with tention
3- Completely regularized spline
4- Multi quadratic function
5- Inverse multi quadratic function

These interpolators estimate values with respect to measured values that are identical and surfaces are produced by passing through each measured point. These predicted values can vary with respect to the measured values. Total curvature of surface is minimized and generation of quite smooth surfaces is based on the predicted values of these methods.

Comparison between the different methods

In cross validation mode, mean error and root mean square error is calculated for each model to check the performance of predicted results. Most accurate predictions are shown with the least RMSE.

The Root Mean Square Error was derived according to formula;

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

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

[3, 13, 5 and 12]

Cross validation is a technique used to evaluate and validate the developed model of variogram. By removing a subset from the original dataset is required for the prediction or estimation of cross validation .This technique is utilized to get the awareness of dataset that which was the best model to be implemented in which interpolation method with the appropriate neighborhood. These predicted values are compared with measured values to get the least square errors during interpolation.

Data Analysis

GIS software packages were used to analyze and explore soil sampled data. Maps were developed with ArcMap. Spatial Analyst and Geostatistical Analyst extention are also utilized in this respect. The geostatistical analysis and the statistical approches were carried out using geostatistical extension of ArcMap.

RESULTS & DISCUSSION

Descriptive Data Analysis

The descriptive statistics of soil pH data such as mean, maximum, minimum, standard deviation, skewness, kurtosis and coefficient of variation is described with respect to the divided zones of Punjab province. Maximum value of soil pH in Rice zone was 10.9 in Hafizabad District.

Table 3.1: Soil-pH statistics of Rice zone

District	Min	Max	Mean	Median	S.D	C.V	Kurtosis	Skewness
Lahore	7	10.4	8.04	8.00	0.31	3.87	6.79	1.54
Kasur	7	9.9	8.07	8.10	0.27	3.29	5.00	1.13
Sheikhupura	6.2	10.3	7.96	7.90	0.34	4.33	8.53	1.58
Gujranwala	6.37	10.04	7.77	7.71	0.45	5.75	3.51	1.11
Hafizabad	7	10.9	8.60	8.50	0.47	5.44	2.36	0.73
Narowal	6	9.65	7.69	7.77	0.53	6.91	0.62	-0.38
Gujrat	7.09	8.67	8.08	8.09	0.20	2.50	1.67	-0.78
M.B.Din	7.02	9.1	7.85	7.90	0.28	3.59	0.10	-0.02
Sialkot	6.27	9.73	7.74	7.80	0.43	5.52	1.69	-0.57

Approximately mean and median values of soil pH were same in rice Zone of Punjab Province whereas the minimum value was 6 in Narowal District. Coefficient of variation 5% or less showed good method performance.

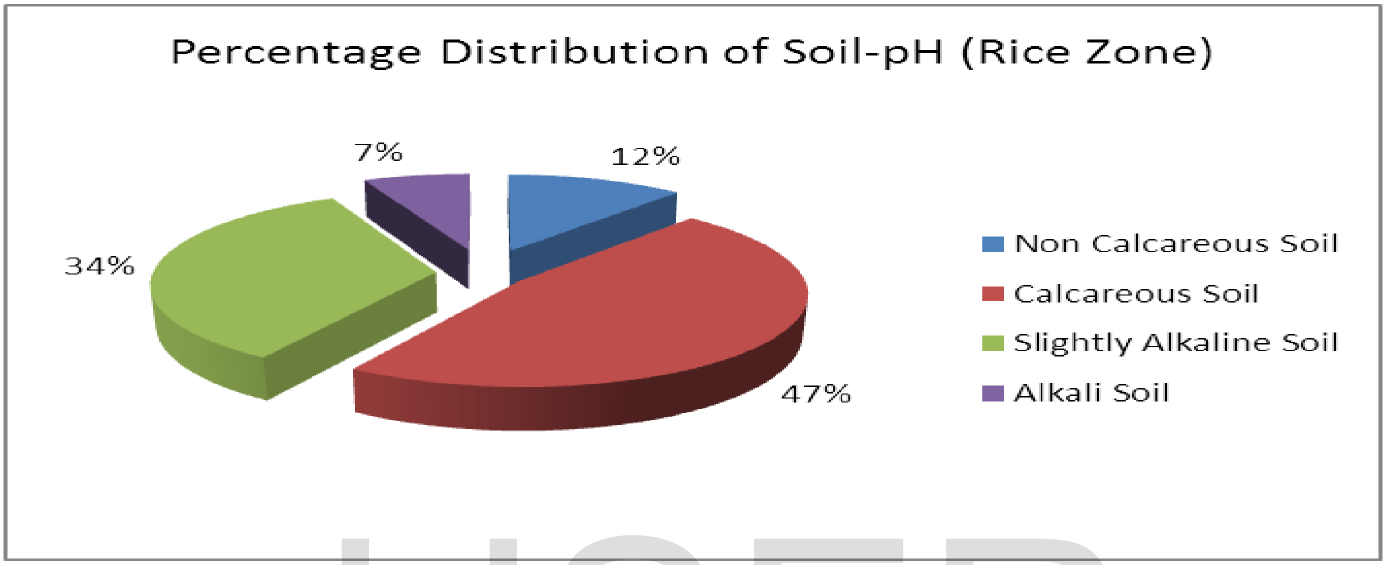


Table 3.2: Soil-pH statistics of Central zone

District	Min	Max	Mean	Median	S.D	C.V	Kurtosis	Skewness
Faisalabad	7.1	10.6	7.94	7.90	0.29	3.66	14.26	2.79
Jhang	7.1	10	8.03	8.00	0.37	4.56	0.62	0.57
T.T.Singh	7.2	9.7	7.88	7.90	0.23	2.97	13.46	2.19
Sahiwal	7.2	9.6	8.33	8.30	0.29	3.44	1.38	0.11
Okara	7	10.3	8.03	8.00	0.23	2.85	11.61	1.20
Sargodha	7	10.1	7.93	7.90	0.28	3.48	6.99	1.44
Khushab	6.3	10.3	7.90	7.90	0.39	5.00	1.66	0.23

The range of soil pH in central Zone was relatively high in Khushab and Faisalabad Districts that was 4 and 3.5 respectively. Maximum value of soil pH in Central zone was 10.6 in Faisalabad District. Approximately mean and median values of soil pH were same in Central Zone of Punjab Province.

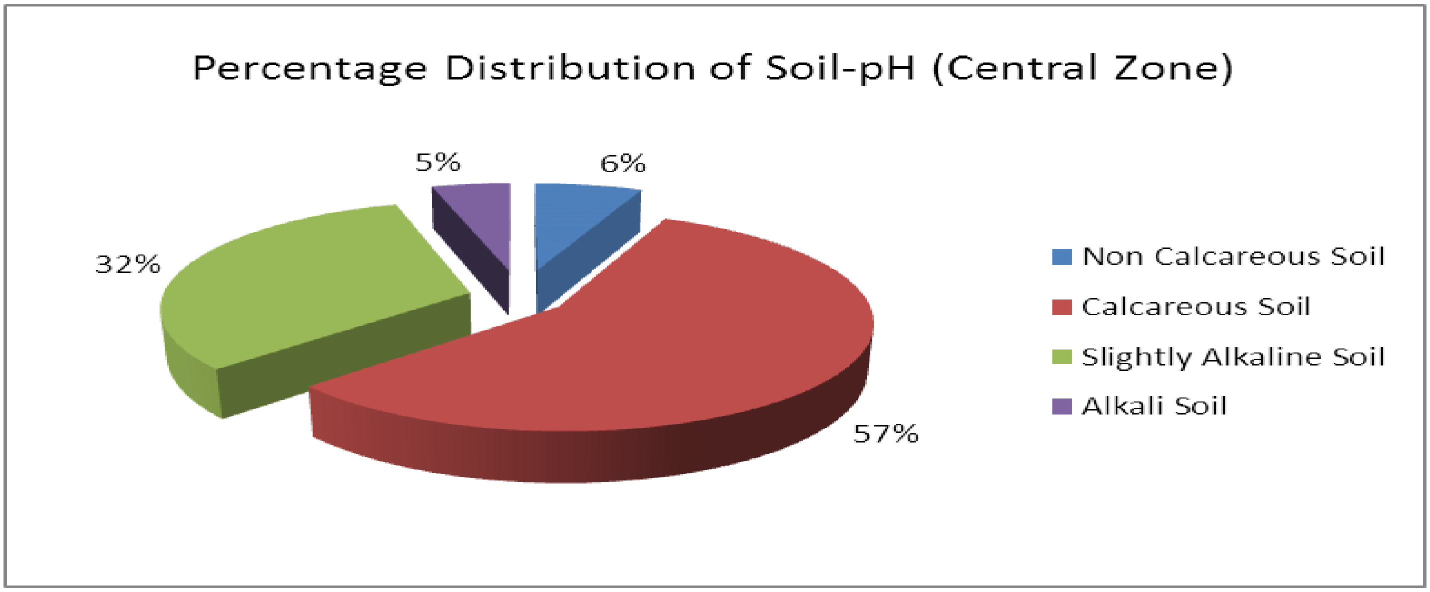


Table 3.3: pH statistics of Thal zone

District	Min	Max	Mean	Median	S.D	C.V	Kurtosis	Skewness
Mianwali	6.8	9.8	7.74	7.70	0.27	3.50	2.46	0.23
Bhakkar	7.09	9.5	7.76	7.70	0.19	2.48	5.46	0.93
Layyah	6.29	9.46	8.14	8.16	0.27	3.30	1.32	-0.53

Approximately mean and median values of soil pH were same in Thal Zone of Punjab Province. The range of soil pH in Thal Zone was relatively high in Layyah District that was 3.17 and the minimum value of soil pH was 6.29.

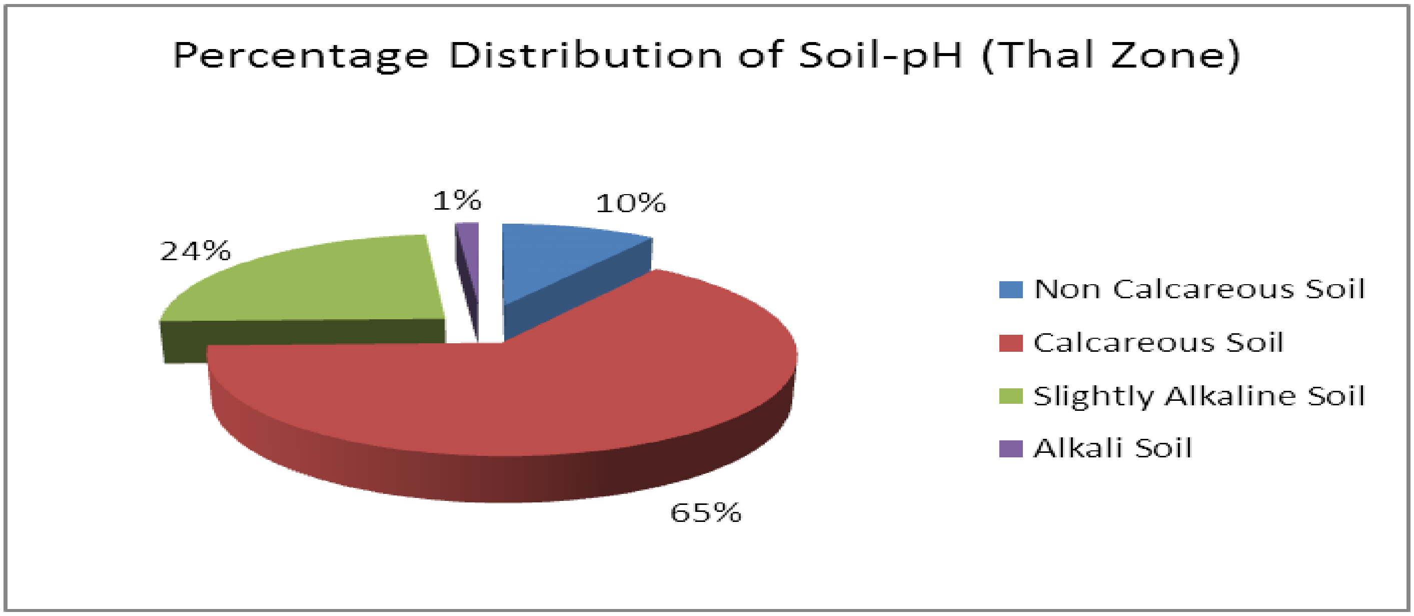


Table 3.4: pH statistics of Barani zone

District	Min	Max	Mean	Median	STD	CV	Kurtosis	Skewness
Rawalpindi	6.3	8.56	7.50	7.50	0.27	3.56	2.58	-0.63
Attock	7	8.22	7.32	7.29	0.21	2.91	1.97	1.31
Jhelum	6.1	9.2	7.46	7.40	0.32	4.26	5.61	1.46
Chakwal	7.03	8.96	7.80	7.88	0.26	3.34	0.00	-0.58

On the average, the chakwal district had the highest value of soil pH and that was 7.8 and coefficient of variation was 3.34. The minimum range of pH showed in Attock District which was 1.22 (7.0 to 8.22).

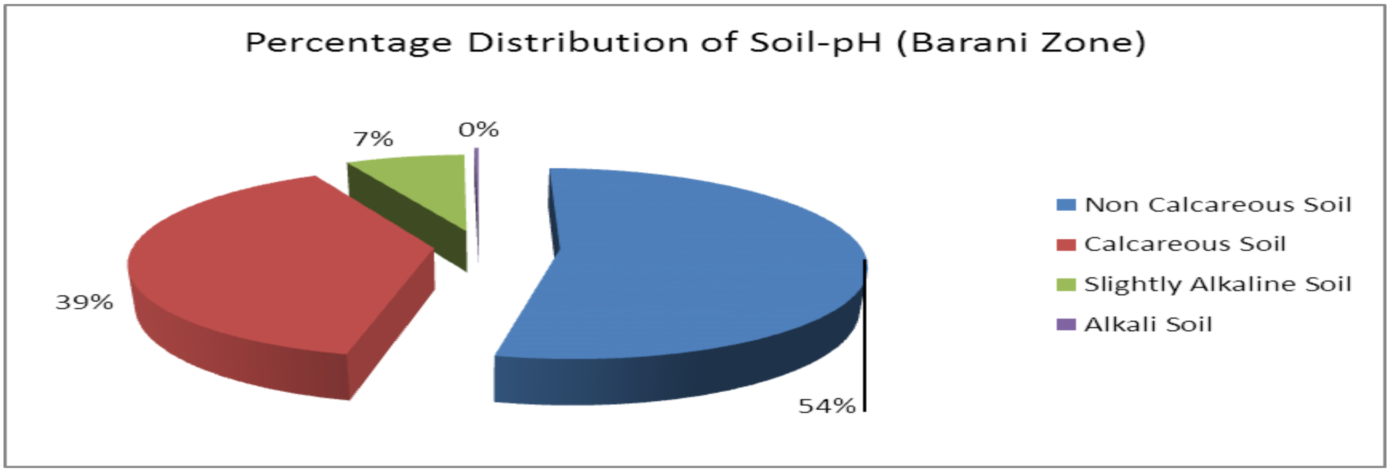
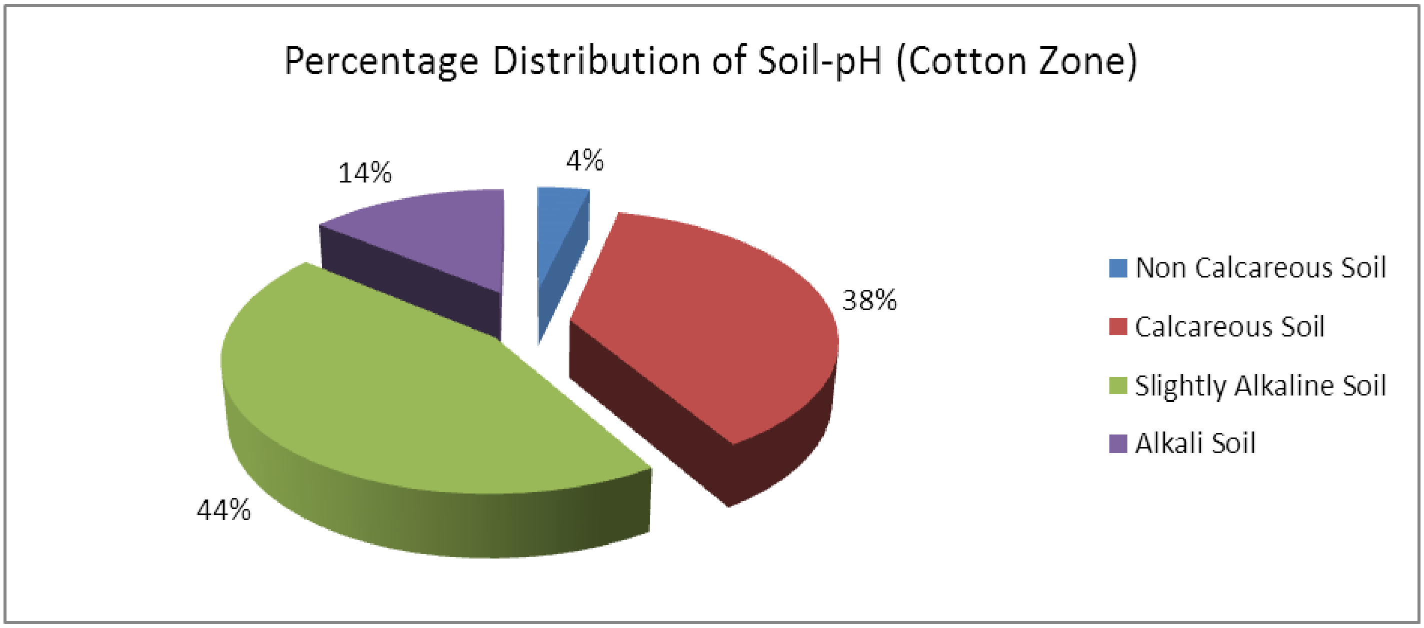


Table 3.5: pH statistics of Cotton zone

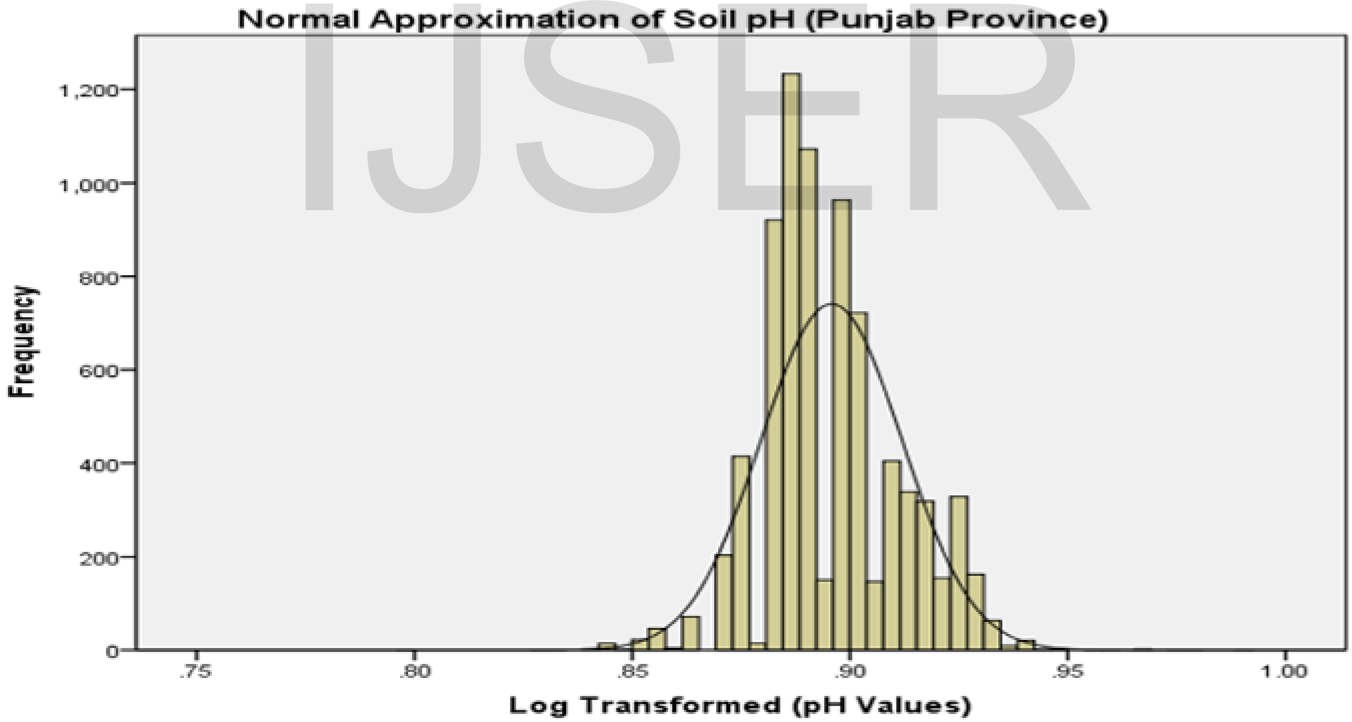
District	Min	Max	Mean	Median	STD	CV	Kurtosis	Skewness
Multan	7.8	10.7	8.62	8.60	0.33	3.81	2.02	0.36
Khanewal	7.2	10.3	8.55	8.50	0.37	4.37	0.76	0.47
Vehari	7	10	8.31	8.30	0.33	3.94	2.93	0.94
Lodhran	7.4	10	8.36	8.30	0.38	4.50	1.44	0.91
Pakpatan	7	8.9	8.26	8.30	0.25	2.99	0.93	-0.63
D.G. Khan	5.65	10.3	7.96	7.92	0.40	5.03	5.93	1.36
Muzaffargarh	6.1	10.85	8.28	8.20	0.47	5.69	1.51	0.82
Rajanpur	6.52	8.78	7.87	7.89	0.37	4.70	-0.04	-0.25
Bahawalpur	7.1	9.9	8.09	8.10	0.28	3.51	1.92	0.51
Bahawalnagar	6.1	9.8	8.06	8.00	0.27	3.31	2.68	0.46
R.Y.Khan	7	10.8	8.04	8.00	0.40	4.91	9.13	2.27

The range of pH in cotton Zone was relatively high as compared with other zones. Muzaffargarh and DG Khan Districts showed high range of pH 4.75 (6.1 to 10.85) and 4.65 (5.65 to 10.30), respectively.



Log-Transformation of Soil pH

Transformation was done to normalize the values of soil pH of mentioned crop zones of Punjab province. Exploratory Data Analysis (EDA) of soil pH consisted of statistics and graphical representation of data dissemination. The frequency distribution of soil pH is shown as histogram



These results indicated that the soil pH data distributed, approximately normal after log transformation. Skewness and kurtosis results were reduced or controlled with the help of logarithimic transformation.

ISSN 2229-5518

Geostatistical analysis of soil pH results were presented in tables below.

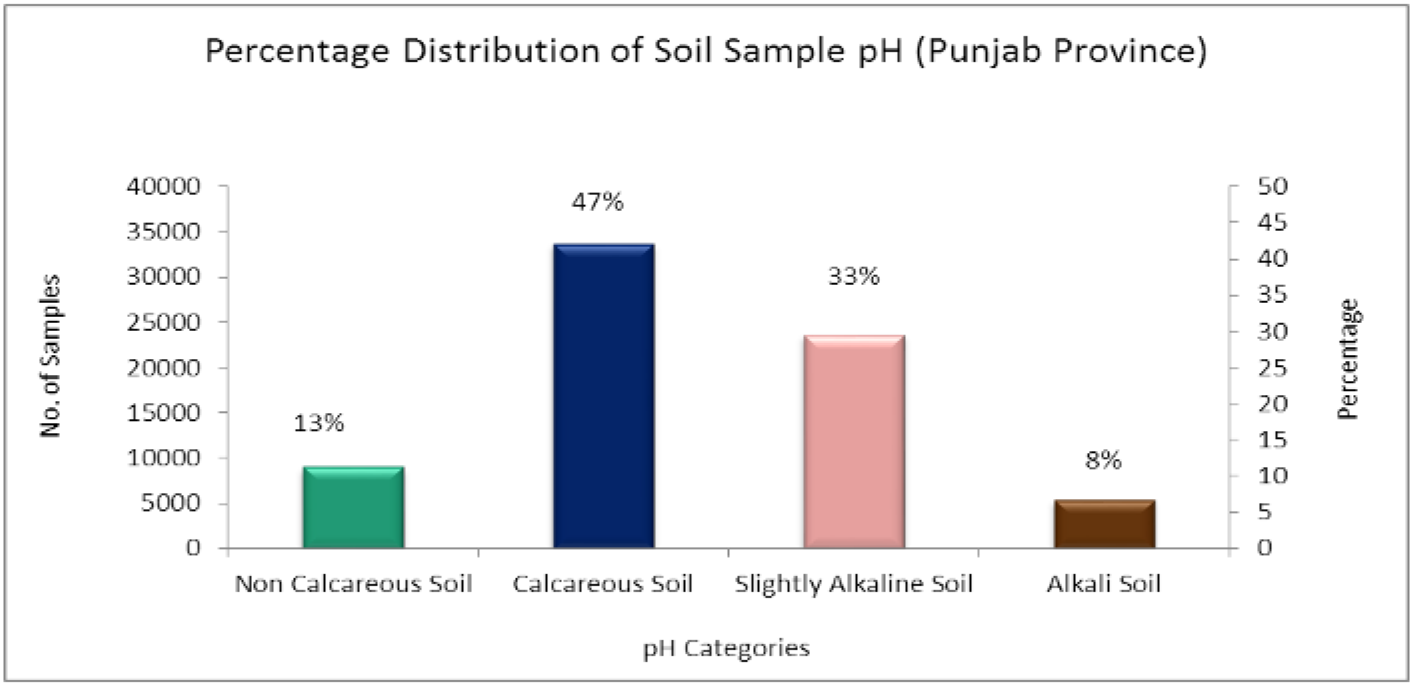
Method	Model	RMSE
Ordinary Kriging	Spherical	0.00217
	Exponential	0.00215
	Gaussian	00.0216
Inverse Distance Weighted (IDW)	Multiquardatic	0.00237
	Inverse Multiquardatic	0.00214
	Thin Plate Spline	0,00274
Radial Basis Function (RBF)	Power 1	0.00297
	Power 2	0.00214
	Power 3	0,00263
Splines	Power 1	0.00321
	Power 2	0.002987
	Power 3	0.00314

It showed that to predict soil pH, Spherical, Gaussian and Exponential models of Kriging (OK) method were chosen for its estimation. And multi-quardatic, inverse multi-quardatic, thin plate spline models of Radial bases function (RBF) were utilized. And inverse distance weighted (IDW) method with suitable first, second and third order polynomial equations were also applied. The highest precision and minimum root mean square error are the basic reason for the prediction of soil pH. These models were analyzed and compared with each other to get the optimum results for best fitted model.

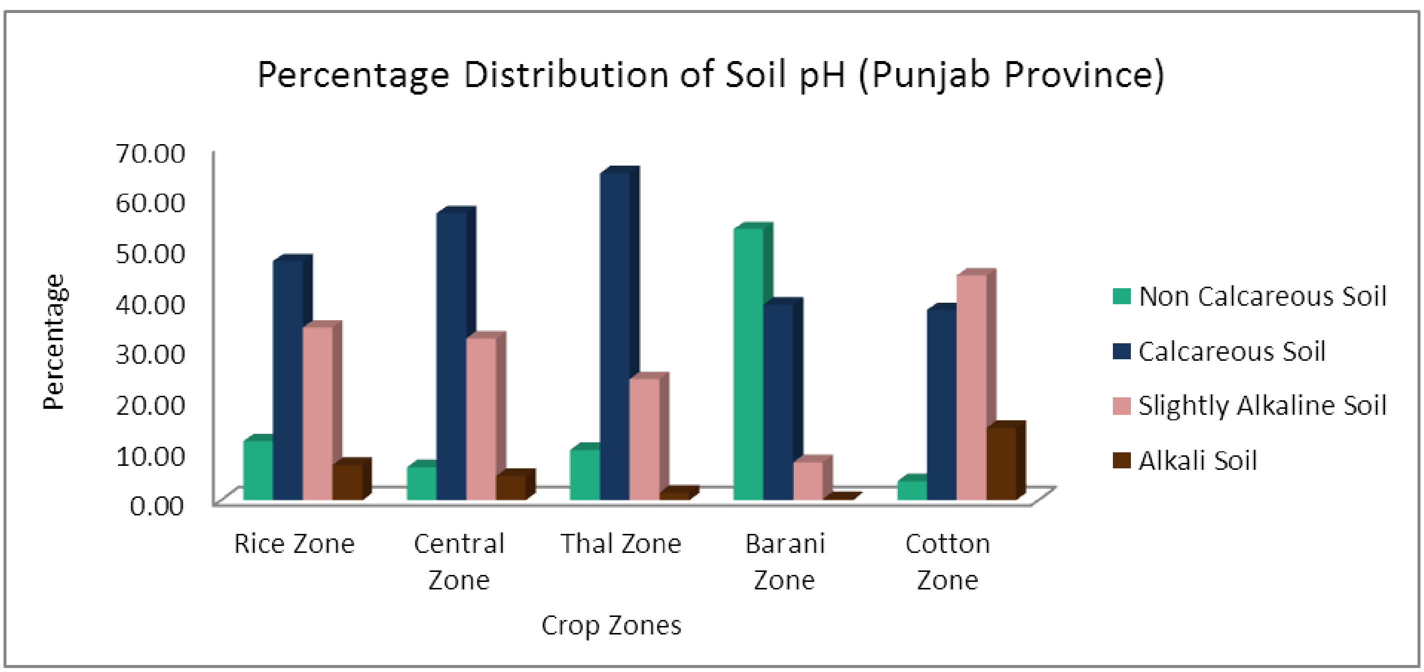
Classification of Soil pH

The study area had different types of soil with respect to pH, which is mainly defined with respect to some ranges as described below:

Soil Classification of pH	Remarks
≤7.5	Non- Calcareous Soil
7.5 - 8	Calcareous Soil
8 – 8.5	Alkaline Soil
≥ 8.5	Alkali Soil

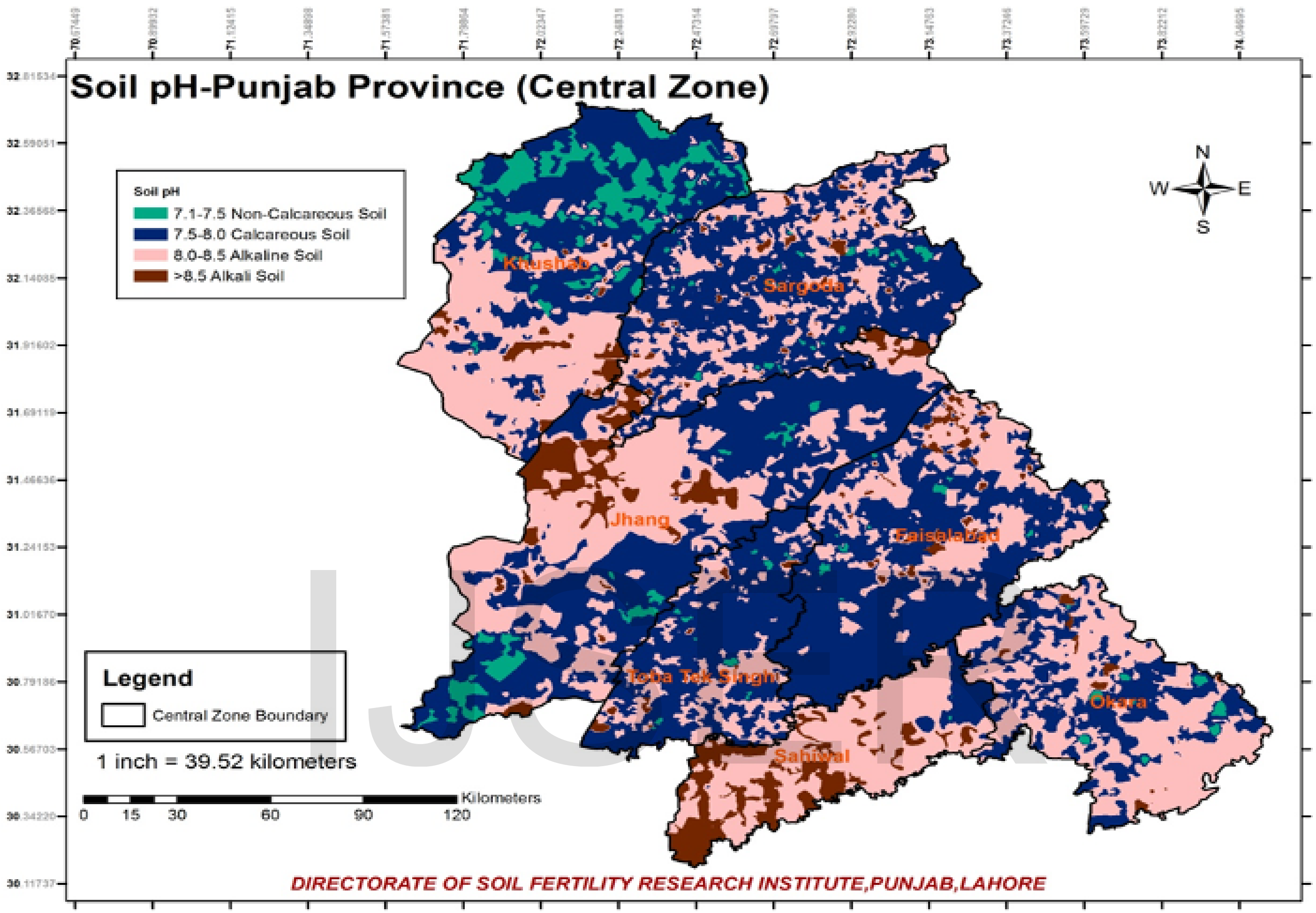


Distribution of soil with respect to pH not only serves as the maintenance and utilization of agricultural land but also provides the quantitative evaluation of soil. Categorically, soil is spatially distributed as shown in table above. Alkaline soil and alkali soil were the major types of soil, which includes 33% and 8% of total surveyed samples, respectively. The soil samples for calcareous soil were relatively higher 47% in Punjab Province than others and non-calcareous were 13% of study area respectively.

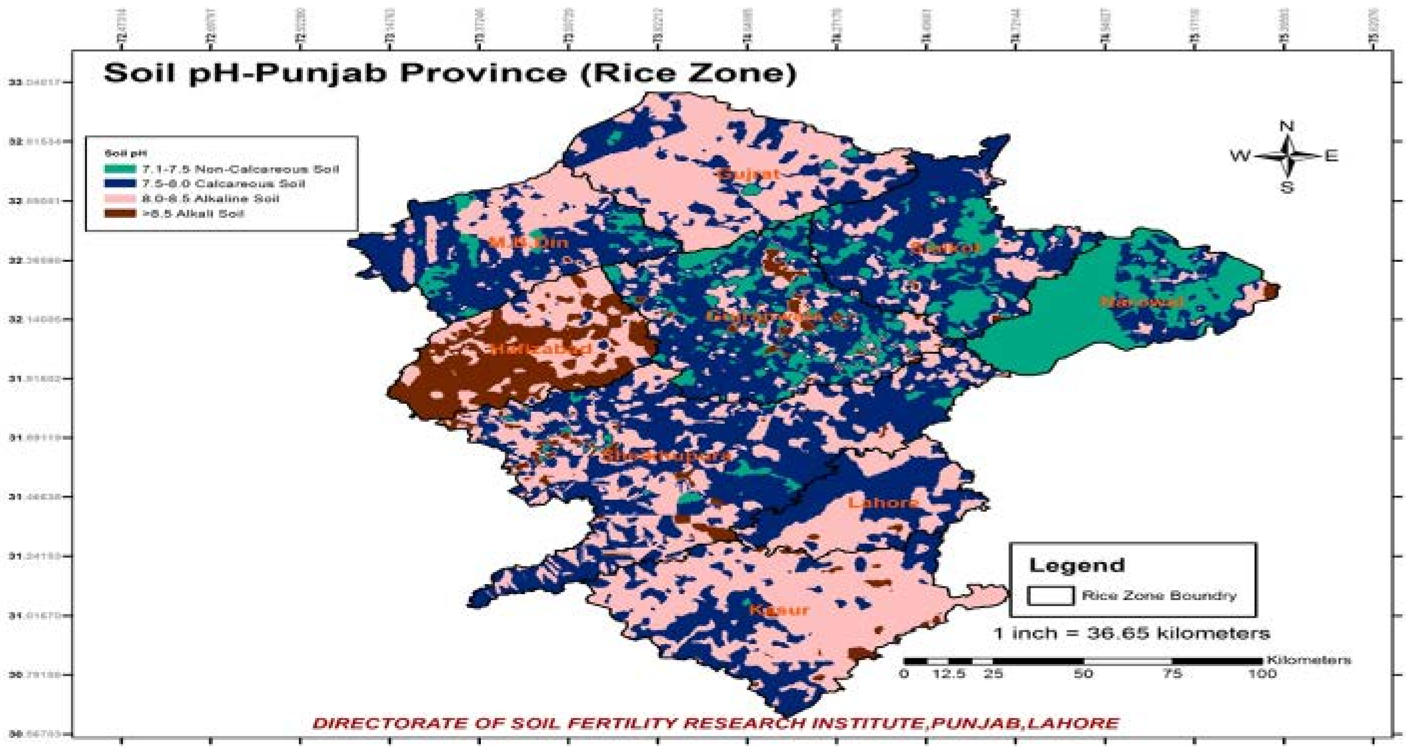


The predicted map of soil pH provides a considerable approach to the agricultural community for the suitable allocation to get a better yield. Because the agricultural land is degrading due to unawareness of soil and salt concentration problems.

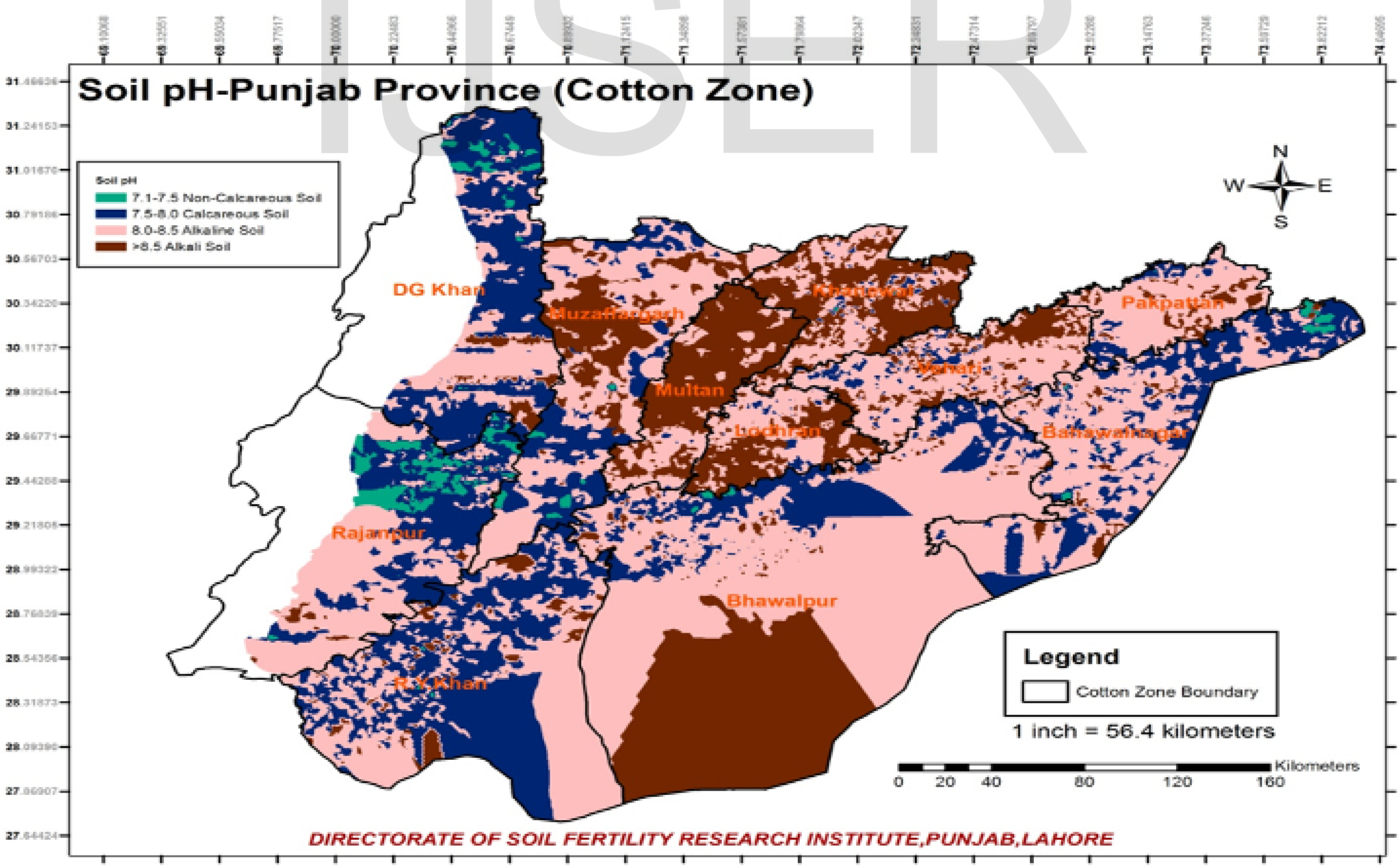
3.4 Predicted Map of Soil pH of Central Zone of Punjab Province



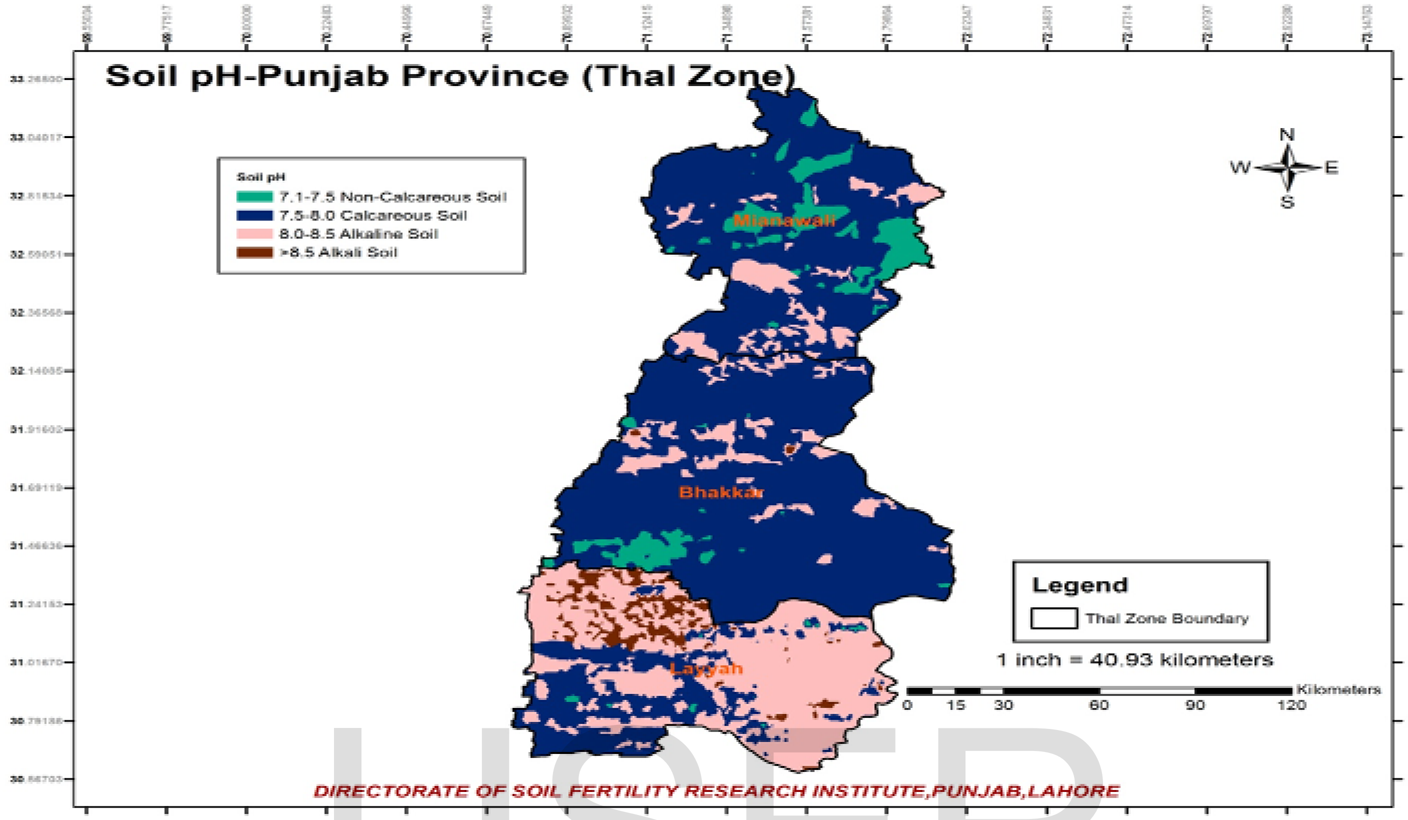
3.5 Predicted Map of Soil pH of Rice Zone of Punjab Province



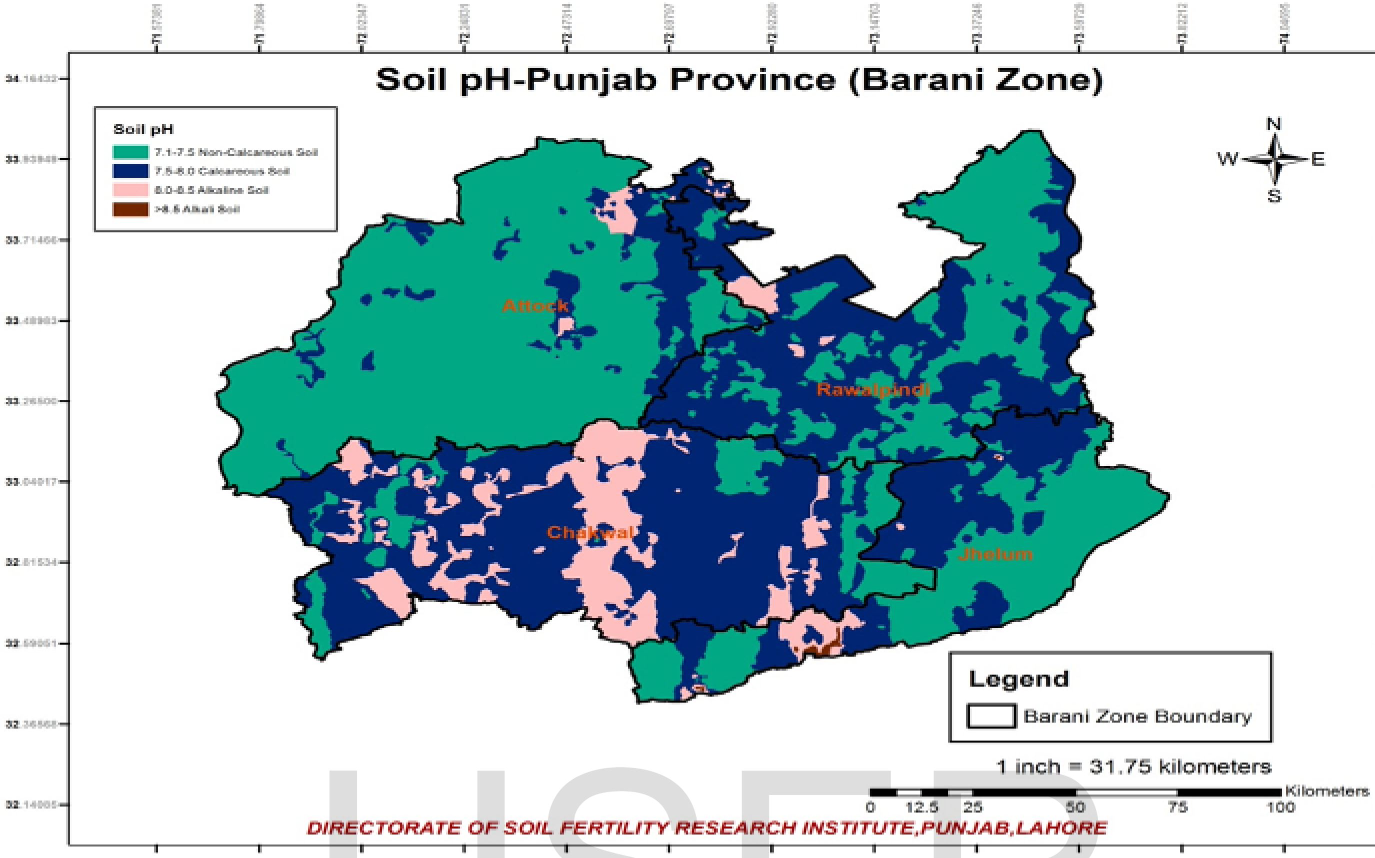
3.6 Predicted Map of Soil pH of Cotton Zone of Punjab Province



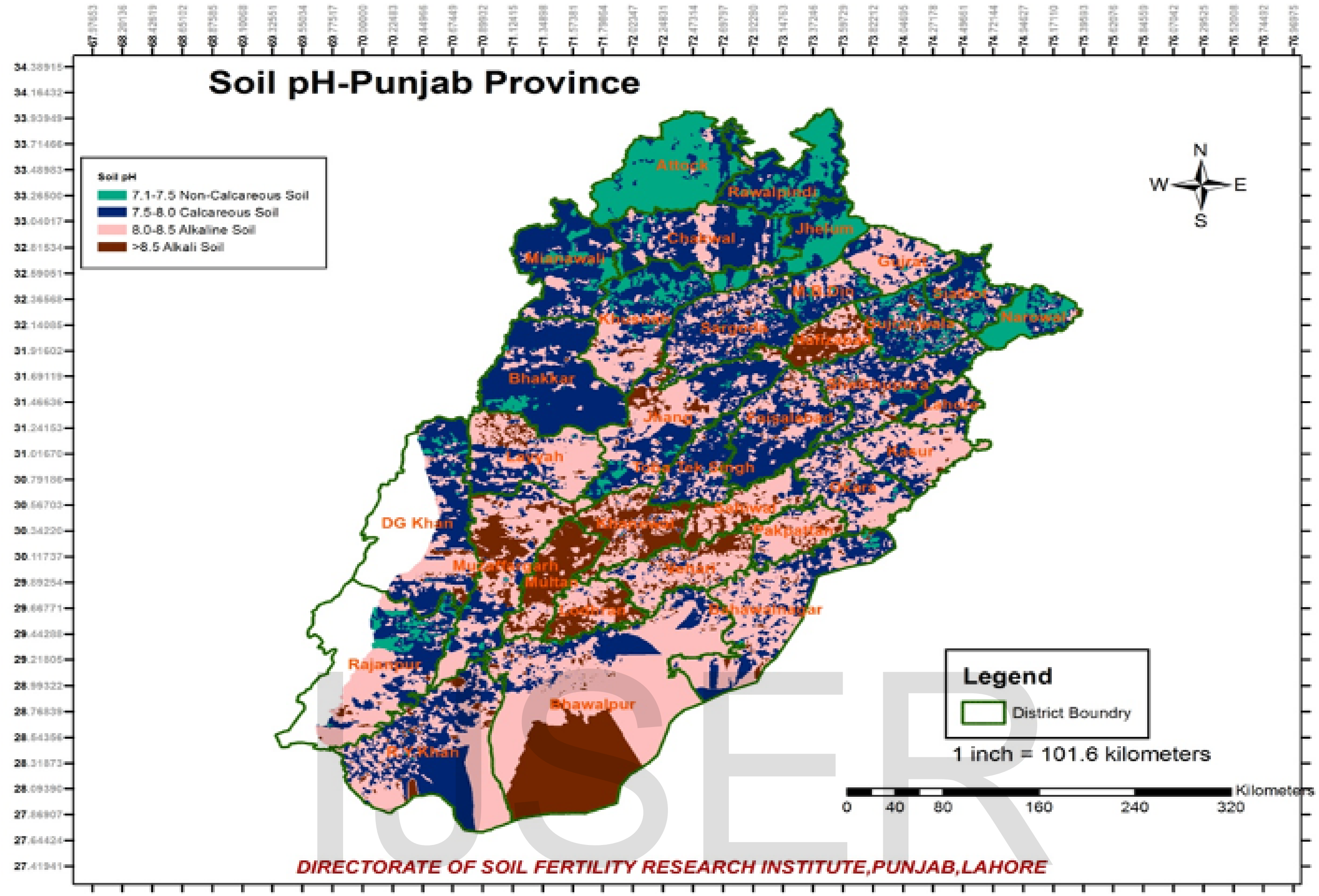
3.7 Predicted Map of Soil pH of Thal Zone of Punjab Province



3.8 Predicted Map of Soil pH of Barani Zone of Punjab Province



3.9 Predicted Map of Soil pH of Punjab Province



Kriging as a spatial interpolation technique provided the soil structure of pH with unbiased measurements with minimum variance of data. Based on the all zones of pH map,it showed the different concentration of pH. Agricultural land of Punjab province is highly dependent on this soil property. In contrast with other interpolation methods, kriging (Spherical model) provides better estimations approaches for pH soil than the other methods.

Generally kriging is superior with respect to IDW as it gives no assumption about spatial relation and estimated values are incapable of exceeding the value range of sample data. IDW uses a simple algorithm based on distance, but kriging weights come from a semivariogram that was developed by looking at the spatial structure of the data.

It is important to remember that there is no single interpolation method that can be applied to all situations. Some are more exact and useful than others but take longer to calculate. They all have advantages and disadvantages. In practice, selection of a particular interpolation method should depend upon the sample data, the type of surfaces to be generated and tolerance of estimation errors. Generally, a three step procedure is recommended:

1. Evaluate the sample data to get an idea on how data is distributed in the study area, as this may provide some approach of which interpolation method would be used.
2. Apply an interpolation method which is most suitable in both conditions such as surveyed data and study objectives.
3. Comparitive analysis of results would help to find out the best suitable method.

Conclusion

1. Geostatistical analyst provides different interpolation methods with their respective models and techniques for the estimation of soil properties like pH.
2. The predicted measurements using kriging, radial basis function and IDW were compared and evaluate with root mean square error to each other and found that kriging was most suitable for the spatial variability of soil pH due to the semivariogram analysis.
3. The interpolated maps may help to understand the soil related problem of agricultural land of Punjab provice, Pakistan.

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