# Digital Soil Mapping of Residual Lateritic Soils in Kerala using Interpolation Methods

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**Abstract.** Soil is considered to be a highly heterogeneous material whose properties vary from place to place and at a particular place with respect to depth. For carrying out any kind of geotechnical analyses on a regional scale, geotechnical soil properties are required which is possibleonly after drilling large number of boreholes, which is both time consuming and uneconomical. Digital Soil Mapping is a process by which soil properties are predicted on a regional scale from a known limited number of point observations. Digital soil map consists of pixels in a grid wherein each pixel has a unique geographic location and soil data. Different interpolation techniques can be used for the development of a digital soil map. Various studies have shown mixedconclusions about the accuracy of the different interpolation methods. In this paper, two commonly used interpolation methods namely IDW and ordinary kriging were applied to develop a digital soil map of the residual lateritic soils in Kerala. The results were validated using the com- monly used leave one out cross validation (LOOCV) technique. The accuracy was also checked by comparison of predicted soil properties with an independent soil dataset which was not used in the interpolation process. The results showed that ordinary kriging outperformed the IDW method and therefore, it can be used for development of digital soil map of residual lateritic soilsof Kerala.

**Keywords:** Digital Soil Mapping; Residual Lateritic Soils; Interpolation

## 1 Introduction

Geotechnical engineers require the properties of soil for the design of various types of engineering structures. There is a lack of literature about the availability of thematic soil maps containing geotechnical soil properties which otherwise can prove very handy in the design of structures which concern the geotechnical engineers. Field investigations for the purpose of obtaining geotechnical soil properties is a very costly, time consuming and sometimes an impossible process in case of inaccessible areas. According to Tobbler (1970), everything is related to everything else and near things are more related to each other than far things. Digital mapping is a process of combination of GIS and various interpolation techniques for predicting various parameters like soil moisture (Srivastava et al., 2019), hydraulic and shear strength properties (Rahardjo & Satyanaga, 2019; Ip et al., 2021; Satyanaga & Rahardjo, 2022), tree density and wood species (Munyati & Sinthumule, 2021), particulate matter (Choi & Chong, 2022) etc. Digital Soil Mapping is being performed for the purpose of predicting soil properties at an un-sampled locations from the data obtained through limited field observations. There are many types of interpolation techniques utilized in GIS environment for the generation of digital maps of various parameters (Eldrandaly and Abu-Zaid, 2011; Munyati & Sinthumule, 2021; Choi & Chong, 2022). A few examples of interpolation methods include trend surface interpolation, kriging interpolation, IDW interpolation, splines interpolation etc. Kriging and IDW interpolation methods are the most widely used methods found in literature (Srivastava et al., 2019; Rahardjo & Satyanaga, 2019; Ip et al., 2021; Munyati & Sinthumule, 2021; Choi & Chong, 2022). Kriging is a geo-statistical method of interpolation wherein spatial distribution of samples is also taken into account while assigning weightage to the surrounding points for the prediction at an un-sampled locations (Akkala et al., 2010) apart from the consideration of autocorrelation between the sample points based on distance between them. Ordinary kriging being the most robust among all other types of kriging models (Rahardjo & Satyanaga, 2019), it is the most widely adopted method (Li and Heap, 2011). IDW interpolation technique on the other hand is a deterministic method of interpolation wherein only the distance between the target location and the known data location is given importance. The underlying principle behind the IDW method is that nearer locations have greater similarity than farther locations with each other (Isaaks and Srivastava, 1989). After a thorough literature review, it was found that there are mixed conclusions about IDW and kriging interpolation techniques. Sometimes kriging interpolation outperforms the IDW and vice-versa (Eldrandaly and Abu-Zaid, 2011; Shahbeik et al., 2014; Gong et al., 2014; Hodam et al., 2017) which implies that no interpolation technique seems to be absolute but its performance mostly depends on the type of variable involved. Moreover, there are a very limited studies about the applicability of kriging and IDW interpolation methods in the prediction of geotechnical soil properties. Hence, in this study we applied the different kriging models to investigate its potential in the prediction of index properties of soil including liquid limit and plastic limit. Index properties of soil help in the classification of soil into plastic and non-plastic categories. In order to compare the performance between IDW and kriging, we also utilized the IDW in the prediction of above-mentioned properties.

## 2 Study area and data acquisition

The study area falls in a highly landslide prone district ‘Idukki’ in Kerala where for performing landside susceptibility analyses on a regional scale, interpolation of soil properties would be needed for the development of a digital soil map. The study area considered was lying between latitudes of (9°53′15′′ and 10°1′44′′) and longitudes of (77°2′41′′ and 77°11′5′′) as shown in **Fig. 1**. The total study area is equal to 64 Square Kilometres. The major lithological formations present in the area are pink granite gneiss, acid to intermediate charnockite and hornblende-biotite gneiss.

Detailed site investigations and laboratory experiments were performed for obtaining various geotechnical properties of soil in accordance with relevant IS codes. However, for brevity we presented only liquid limit (LL) and plastic limit (PL) of the soil for the comparison study presented in this paper. Prediction capability of two commonly used interpolation techniques; ordinary kriging and IDW were compared. In total, 165 samples were collected from the study area.

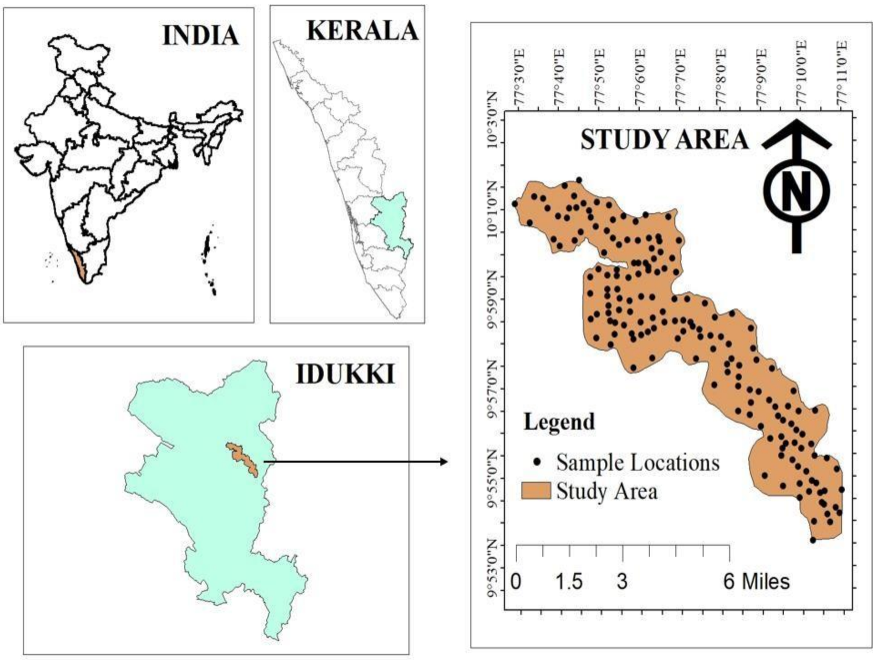


**Fig. 1.** Study area and location of soil samplings

## 3 Methods

In this study, two interpolation techniques including IDW and ordinary kriging with different types of semi-variogram models were used for the prediction of index properties of soil at an unsampled locations from the limited observed borehole data.

### 3.1 Inverse Distance Weighing (IDW)

The assumption behind the IDW interpolation method is that the things nearer to each other are similar and this similarity fades away as the distance between them increases (Isaaks and Srivastava, 1989). Therefore, the predicted value by IDW interpolation at an unmeasured location will be more affected by the nearer observations as compared to farther observations and hence the name inverse distance weighing. The equation of IDW is given by Roberts et al. (2004) as:

$$Z_{x_0} = \Sigma_{i=1}^{n} \lambda_i Z_{x_i} \quad (1)$$

Where, $Z_{x_0}$ is a value to be predicted, $Z_{x_i}$ is a known value and $\lambda_i$ is a weightage factor given by Roberts et al. (2004) as:

$$\lambda_i = \frac{[1/d_{x_{i,0}}]^p}{\sum_{i=1}^{n}[1/d_{x_{i,0}}]^p} \quad (2)$$

Where, $d_{x_{i,0}}$ is the distance between the measured and the unmeasured locations and $p$ is a power value, often assumed equal to 2 in literature.

### 3.2 Kriging Interpolation

Kriging is a geostatistical method of interpolation which takes into account the spatial arrangement of the observations also besides the distance between them. Semivariograms are used to determine the extent of dependence among the measured observations. The degree of spatial dependence is given in terms of semi-variance as:

$$(h) = \left(\frac{1}{2n}\right)\sum_{i=1}^{n}[z(x_i) - z(x_i + h)]^2 \quad (3)$$

where, h is the lag; $z(x_i)$ and $z(x_i + h)$ are the observations at two different locations; n is number of pairs of observations. The semivariance varies inversely with the distance and is modelled by semivariogram. There are different models available where a semivariogram can be best fitted in order to determine the semivariance at any given location. In this study, we used an ordinary kriging method and tried to fit a semivariogram in popular kriging models like spherical, exponential, gaussian, circular, stable which are inbuilt in ArcGIS software. Prior to interpolation, the data was checked for its suitability in kriging interpolation. Histograms and Normal QQ plots were examined for normal distribution of the data. Trend analyses was also performed to check if any trend in the data. However, no trend was seen in the data.

### 3.3 Assessment of interpolation results

The results of the interpolation can be assessed by leave one out cross validation (LOOCV) technique. In LOOCV, one observation is removed and its value is predicted from the rest of the data. This procedure is repeated for all of the data values.

The accuracy of the different models can be checked by popular statistical metrics like root mean square error (RMSE), the mean prediction error (ME) etc. However, root mean square error (RMSE) has been generally adopted in many literatures (Yao et al., 2013; Chai & Draxler, 2014; Munyati & Sinthumule, 2021; Satyanaga et al., 2022) for the evaluation of interpolation results.
The equation for RMSE is given as:

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}[z_{x_i} - z'_{x_i}]^2} \quad (4)$$

where $z_{x_i}$ is the actual value, $z'_{x_i}$ is the predicted value at location $x_i$ and n is the sample size.

## 4 Results and discussion

The spatial distribution of liquid limit and plastic limit of soil predicted by IDW method of interpolation method is shown in **Fig. 2.**

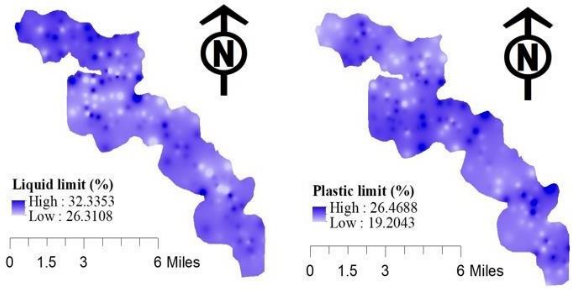


**Fig. 2.** Results of IDW interpolation a) Liquid limit b) Plastic limit

The spatially predicted values of liquid limit and plastic limit by ordinary kriging interpolation is shown in **Fig. 3 and Fig. 4,** respectively**.**

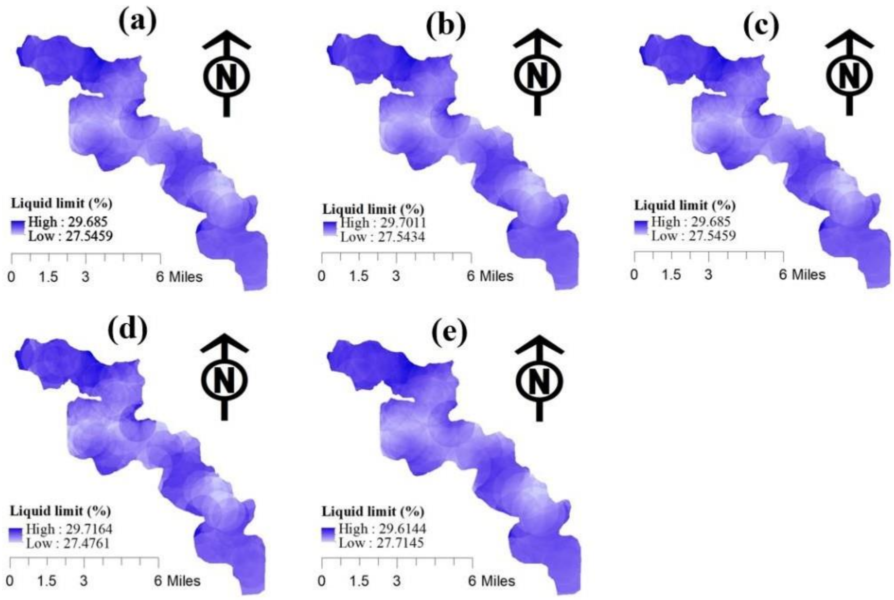


**Fig. 3.** Maps show distribution of liquid limit of soil predicted by ordinary kriging interpolation using a) Stable b) Circular c) Gaussian d) Exponential and e) Spherical models

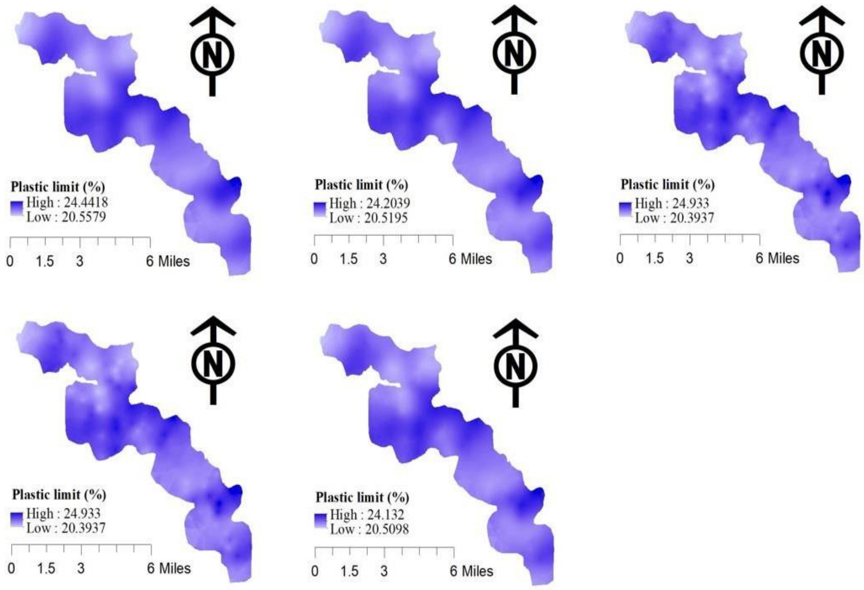


**Fig. 4.** Maps show distribution of plastic limit predicted by ordinary kriging interpolation using a) Stable b) Circular c) Gaussian d) Exponential and e) Spherical models

In order to validate the prediction by IDW and ordinary kriging interpolation methods, leave one out cross validation (LOOCV) technique was used. During cross validation one data point is deleted and then it is predicted from the remaining data set. Next this predicted value is compared with the actual measured value to evaluate the accuracy of prediction by the models. The results of LOOCV for IDW method for both liquid limit and plastic limit are shown in shown in **Fig. 5** and are summarized in **Table 1.**

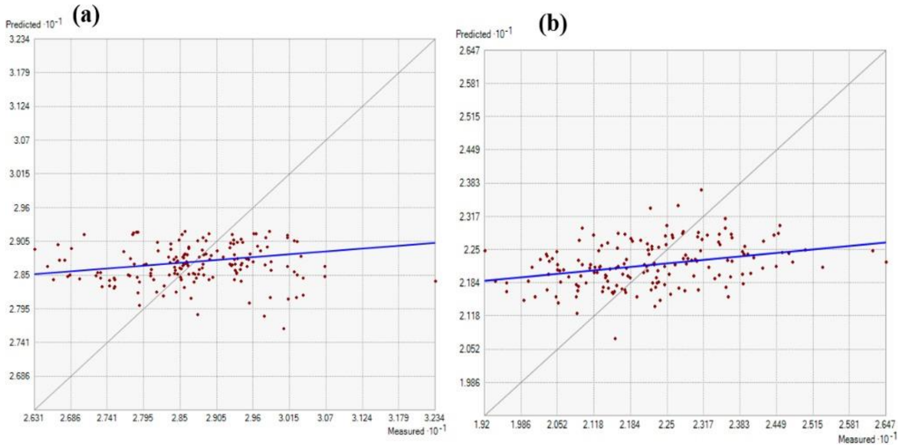


**Fig. 5.** Results of cross validation of IDW interpolation a) liquid limit b) plastic limit

**Table 1.** Summary of cross validation results of IDW interpolation method

| | LL | PL |
|---|---|---|
| *Mean* | -0.03342 | 0.03095 |
| *Root Mean Square* | 1.01144 | 1.27633 |

The results of LOOCV for ordinary kriging interpolation is shown in **Fig. 6** and summarized in **Table 2** for liquid limit**.**

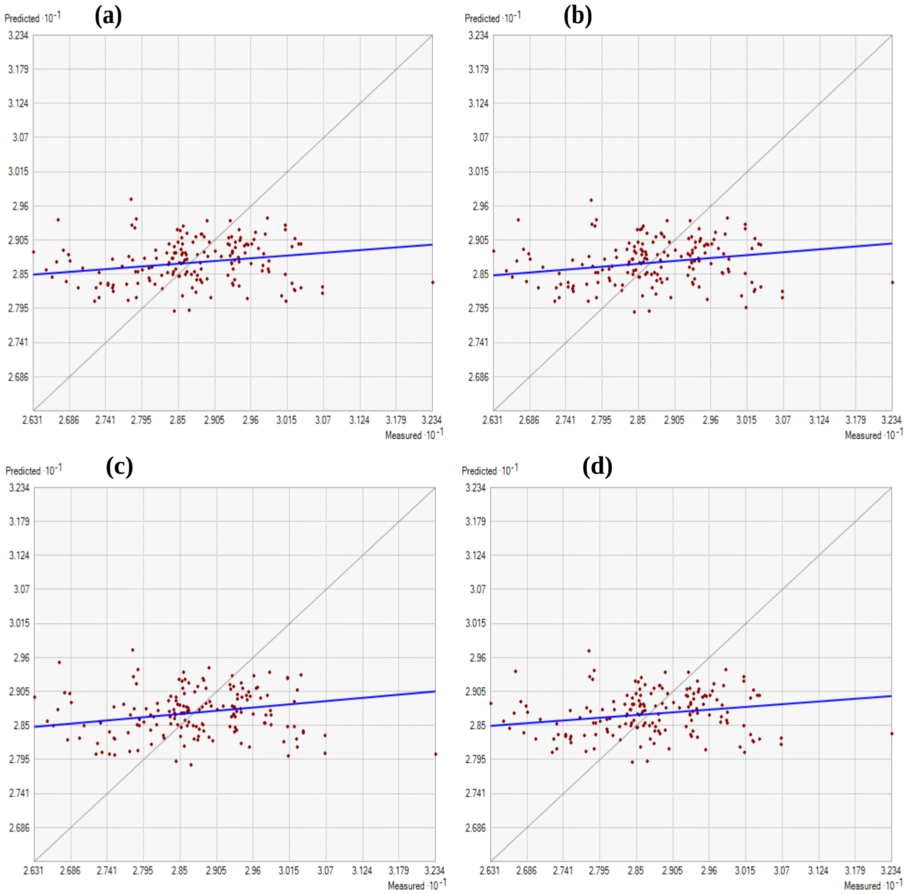


**Fig. 6.** Results of cross validation of ordinary kriging interpolation for liquid limit using a) Stable b) Circular c) Gaussian d) Exponential and e) Spherical semivariogram models

Similarly, the results of LOOCV for ordinary kriging interpolation is shown in **Fig. 7** and summarized in **Table 3** for plastic limit.

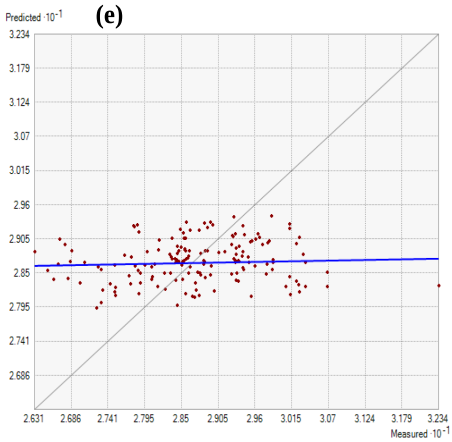


**Fig. 6.** Continued.

**Table 2.** Summary of cross validation results of ordinary kriging semivariogram models for liquid limit

| | Stable | Circular | Gaussian | Exponential | Spherical |
|---|---|---|---|---|---|
| *Mean* | -0.00940 | -0.01473 | -0.00940 | -0.00781 | -0.01571 |
| *Root Mean Square* | 1.00255 | 1.00936 | 1.00255 | 1.02733 | 0.99421 |
| *Mean standard-ized* | -0.00840 | -0.01298 | -0.00840 | -0.00697 | -0.01300 |
| *Root Mean Square Stand-ardized* | 0.96520 | 0.97033 | 0.96520 | 0.96615 | 0.96595 |
| *Average Stand-ard Error* | 1.04571 | 1.04654 | 1.04571 | 1.06795 | 1.03547 |

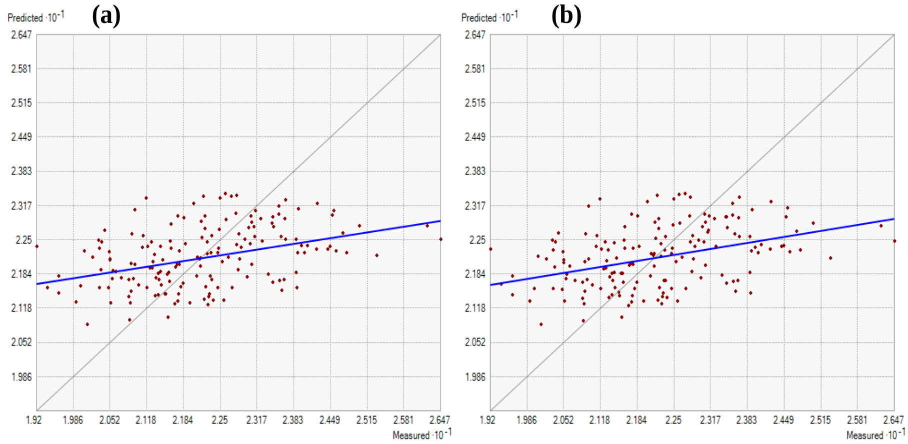


**Fig. 7.** Results of cross validation of ordinary kriging interpolation for plastic limit using a) Stable b) Circular c) Gaussian d) Exponential and e) Spherical semivariogram models

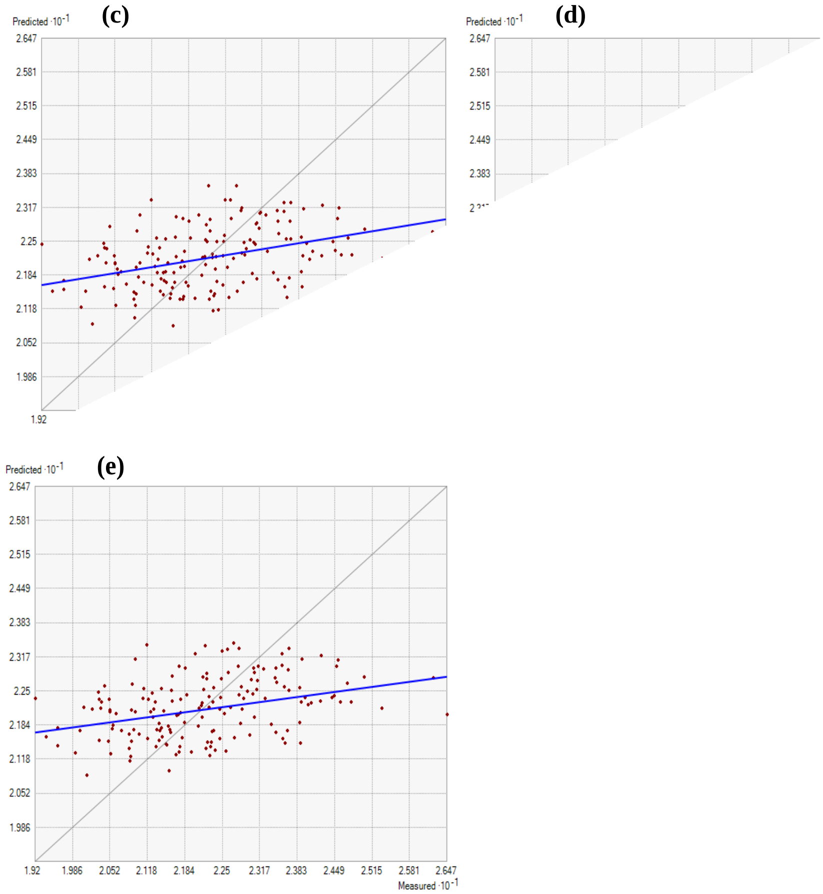


**Fig. 7.** Continued.

**Table 3.** Summary of Cross validation results of ordinary kriging semivariogram models for plastic limit

| | Stable | Circular | Gaussian | Exponential | Spherical |
|---|---|---|---|---|---|
| *Mean* | 0.00974 | 0.01183 | 0.00974 | 0.01083 | 0.00942 |
| *Root Mean Square* | 1.24323 | 1.24318 | 1.24323 | 1.25037 | 1.25914 |
| *Mean standardized* | 0.00588 | 0.00733 | 0.00588 | 0.00588 | 0.00558 |
| *Root Mean Square Standardized* | 0.96654 | 0.96858 | 0.96654 | 0.96883 | 0.97990 |
| *Average Standard Error* | 1.28578 | 1.28303 | 1.28578 | 1.29242 | 1.28255 |

The cross validation for the case of ordinary kriging interpolation would result in five different statistical metrics including mean error (ME), root mean square error (RMSE), mean standardized, root mean square standardized, average standard error. Generally, the perfect model will have mean standardized close to zero, minimum RMSE, the average standard error close to RMSE and root mean square standardized equal to 1. Root mean square error (RMSE) has been generally used in many literatures for the comparison of interpolation methods in terms of deviation of predicted values from the measured values ( Yao et al., 2013; Chai & Draxler, 2014; Munyati & Sinthumule, 2021; Satyanaga et al., 2022). Therefore, RMSE was used for the comparison between IDW and kriging prediction capability.

In the case of liquid limit, lowest RMSE value equal to 0.99421 was obtained with spherical model of kriging and for the case of plastic limit, circular model of kriging provided the lowest RMSE value equal to 1.24318. In case of IDW, the RMSE values for liquid limit and plastic limit were 1.01144 and 1.27633, respectively. Thus, in both the cases, kriging interpolation performed better than IDW.

The results of IDW and kriging interpolation were also validated against the independent soil data which was not used in the interpolation process. It was observed that ordinary kriging provided the best possible prediction when compared with the actual independent dataset. Therefore, kriging performed better than IDW in terms of validation with the independent dataset also.

Thus, the results of this study suggest that the ordinary kriging can be used for the prediction of various soil properties such as cohesion, angle of internal friction, unsaturated soil properties etc. at unsampled locations from the limited set of observed data for the development of a digital soil map.

## 5 Conclusions

Regional geotechnical analyses of any kind would also require soil properties on regional scale. Therefore, this study tried to compare the prediction capability of two commonly used interpolation techniques namely IDW and ordinary kriging. A study area in the district of Idukki (Kerala) was considered for the analyses. Geotechnical properties of soil determined from 165 sampling locations were used for the present study. IDW and different semivariogram models in case of ordinary kriging including stable, circular, gaussian, exponential and spherical were tried to come up with a best possible interpolation method. Leave one out cross validation (LOOCV) was performed to compare the results of the different methods of interpolation in terms of RMSE. Results from the present study indicated that kriging interpolation performed better than IDW. The predicted soil properties were also validated against the independent dataset which was not used in the interpolation process and it was observed that ordinary kriging outperformed the IDW interpolation method. Hence, it can be concluded that for the prediction of soil properties on regional scale from limited number of known observed borehole data, ordinary kriging can provide reliable results.

## References

1. Akkala, A., Devabhaktuni, V., Kumar, A.: Interpolation techniques and associated software for environmental data. Environ. Prog. Sustain. Energy 29 (2), 134–141 (2010).
2. Chai, T., Draxler, R. R.: Root mean square error (RMSE) or mean absolute error (MAE)?–Arguments against avoiding RMSE in the literature. Geoscientific model development, 7(3), 1247-1250 (2014).
3. Choi, K., Chong, K..: Modified Inverse Distance Weighting Interpolation for Particulate Matter Estimation and Mapping. Atmosphere, 13(5), 846 (2022).
4. Isaaks, E.H., Srivastava, R.M.: An Introduction to Applied Geostatistics. Oxford University Press, New York (1989).
5. Eldrandaly, K. A., Abu-Zaid, M. S.: Comparison of Six GIS-Based Spatial Interpolation Methods for Estimating Air Temperature in Western Saudi Arabia. Journal of Environmental informatics, 18(1) (2011).
6. Gong, G., Mattevada, S., O'Bryant, S. E.: Comparison of the accuracy of kriging and IDW interpolations in estimating groundwater arsenic concentrations in Texas. Environmental research, 130, 59-69 (2014).
7. Hodam, S., Sarkar, S., Marak, A. G., Bandyopadhyay, A., Bhadra, A.: Spatial interpolation of reference evapotranspiration in India: comparison of IDW and Kriging Methods. Journal of the Institution of Engineers (india): Series A, 98(4), 511-524 (2017).
8. Ip, S. C., Rahardjo, H., Satyanaga, A.: Three-dimensional slope stability analysis incorporating unsaturated soil properties in Singapore. Georisk: Assessment and Management of Risk for Engineered Systems and Geohazards, 15(2), 98-112 (2021).
9. Li, J., Heap, A. D.: A review of comparative studies of spatial interpolation methods in environmental sciences: Performance and impact factors. Ecological Informatics, *6*(3–4), 228–241 (2011).
10. Munyati, C., Sinthumule, N. I.: Comparative suitability of ordinary kriging and Inverse Distance Weighted interpolation for indicating intactness gradients on threatened savannah woodland and forest stands. Environmental and Sustainability Indicators, 12, 100151 (2021).
11. Rahardjo, H., Satyanaga, A.: Sensing and monitoring for assessment of rainfall-induced slope failures in residual soil. Proceedings of the Institution of Civil Engineers-Geotechnical Engineering, 172(6), 496-506 (2019).
12. Roberts, E.A., Sheley, R.L., Lawrence, R.L.: Using sampling and inverse distance weighted modeling for mapping invasive plants. West. N. Am. Naturalist. 64, 312–323 (2004).
13. Satyanaga, A., Lim, A., Gofar, N.: Interpolation method for spatial distribution of clay content within residual soil. Indonesian Geotechnical Journal, 1(1), 15-24 (2022).
14. Satyanaga, A., Rahardjo, H.: Role of unsaturated soil properties in the

development of slope susceptibility map. Proceedings of the Institution of Civil Engineers-Geotechnical Engineering, 175(3), 276-288 (2022).

15. Shahbeik, S., Afzal, P., Moarefvand, P., Qumarsy, M.: Comparison between ordinary kriging (OK) and inverse distance weighted (IDW) based on estimation error. Case study: Dardevey iron ore deposit, NE Iran. Arabian Journal of Geosciences, 7(9), 3693-3704 (2014).
16. Srivastava, P. K., Pandey, P. C., Petropoulos, G. P., Kourgialas, N. N., Pandey, V., Singh, U.: GIS and remote sensing aided information for soil moisture estimation: A comparative study of interpolation techniques. Resources, 8(2), 70 (2019).
17. Tobler, W.R. (1970) A Computer Model Simulation of Urban Growth in the Detroit Region. Economic Geography, 46, 234-240.
18. Yao, X., Fu, B., Lü, Y., Sun, F., Wang, S., Liu, M.: Comparison of four spatial interpolation methods for estimating soil moisture in a complex terrain catchment. PloS one, 8(1), e54660 (2013).