Spatial analysis of Cadmium and Lead in soils of Nagaon District of Assam, India

ABSTRACT

Aims: The study was carried outin order to find the hotspots of Cadmium and Lead accumulation in the soil due to the anthropogenic activities, so that proper management strategies can be taken on time for their remediation.
Study design: Different geospatial techniques as Normal Q-Q plot, histogram, trend analysis and semi-variogram cloud model is used.
Place and Duration of Study: The study was conducted emphasizing basically in high agricultural chemicals dependent Nagaon District of Assam, India, from 2018 to 2021
Methodology: Heavy metals were assessed using a random sampling method with a 5 x 5 km^2 grid, and a total of 160 samples were collected from a depth of 0 – 15 cm for soil. Choropleth maps were created to show the distribution and hotspots of pollution.
Results: Geospatial analyses from different thematic maps of heavy metals revealed significant vulnerable points of elevated concentrations of Pb (>24.45 mg/kg) and Cd (>0.31 mg/kg) in soil which is presumed to be due to anthropogenic factors. The three-dimensional trend over the distribution of metals throughout the district best fitted the second-order polynomial for Cd, and Pb in soils. Significant numbers of pairs of heavy metal pairs to a certain extent were found to be spatially autocorrelated and all the pairs away from X-axis towards the extreme right corner and far above the axis reflected less influence of local characteristics of the heavy metal. Co-variance cloud with search direction from North to South revealed the existence of spatial autocorrelation and a wider spatial shift of correlation towards the southern direction.
Conclusion: The current study provides baseline data to update the mitigation approaches to better manage the heavy metal contamination in soil in the entire district.

Keywords: Geospatial, Geostatistical, GIS, Spatial autocorelation, trend analysis, Assam

1. INTRODUCTION

Contamination of soil with heavy metals has become a serious problem globally, which is caused not only by industrialization and urbanization but also by natural reasons such as geological origin and other human impact e.g., agricultural activities. With the growth in development, the threat of soil contamination by the notorious heavy metals is also increasing prominently. Heavy metal pollution assessment of soil is of great significance as helps in identifying the risk-prone zones and judge the possible accumulation of these toxic metals in food chains for evaluating the fate of the metals in human health. In this context, Geographic Information System (GIS) is a powerful tool helping researchers to obtain more meaningful insights about the current pollution status and identifying the risk-prone polluted as well as unpolluted areas through maps. GIS database also helps in the decision-making process by identifying the most sensitive zones that need immediate attention. Geostatistical approaches for surface interpolations are emerging as the most sought after methods for researchers wherein the values from the measured locations are used to predict values for each location in the landscape. Evaluation of heavy metals in soil thus gives a baseline database in addressing the key issues as far as the sustainable resource productivity of the district is concerned. This study aims to provide database to the authorities in order to identify the critical vulnerable areas of heavy metal contamination helping thereby to formulate key policy decisions. Baring a study on the delineation of groundwater arsenic vulnerable zones using Geographic Information System in Nagaon district of Assam (Medhi*et al.*, 2021), no detailed study has been conducted so far.

2. MATERIAL AND METHODS

The district of Nagaon, covering an area of 3993 Km^2, lies between 25°45" and 26°45" North latitudes and 91°50" and 93°20" East longitudes. On the north, the district is bounded by the mighty Brahmaputra beyond which lies the Sonitpur district, on the south by Karbi Anglong and Dima Hasao districts, on the east by Golaghat and Karbi-Anglong districts and on the west by the Morigaon district which was originally a part of the erstwhile Nagaon District. The topography is flat plain with minor undulation and rainfall is 1726.90 mm annually with 78% (maximum) humidity. The districts consist of four numbers of Urban Local Bodies (ULB)s – the Nagaon Municipal Board having 26 wards, Kampur Town Committee having 5 wards, Raha Town Committee with 7 wards and Dhing Municipal Board with 10 wards. The headquater lies at Nagaon Sadar. As per the 2011 census, the total population of the entire district was 1,57,084.

During the study, the entire district was first divided into grids (5x5 km^2) and a total of 160 grids were demarcated to represent the whole district. One soil sample was collected from each grid as per the standard protocol and the locations of sampling sites were taken by using handheld global positioning (GPS) system unit EtrexGermin. The analysed results were then fed to the GIS environment using software ArcGIS v10.4 and base maps were drawn. Interpolation was done using IDW. The experimental area is shown in Figure 1 and the methods followed for the analyses of the samples are as follows.

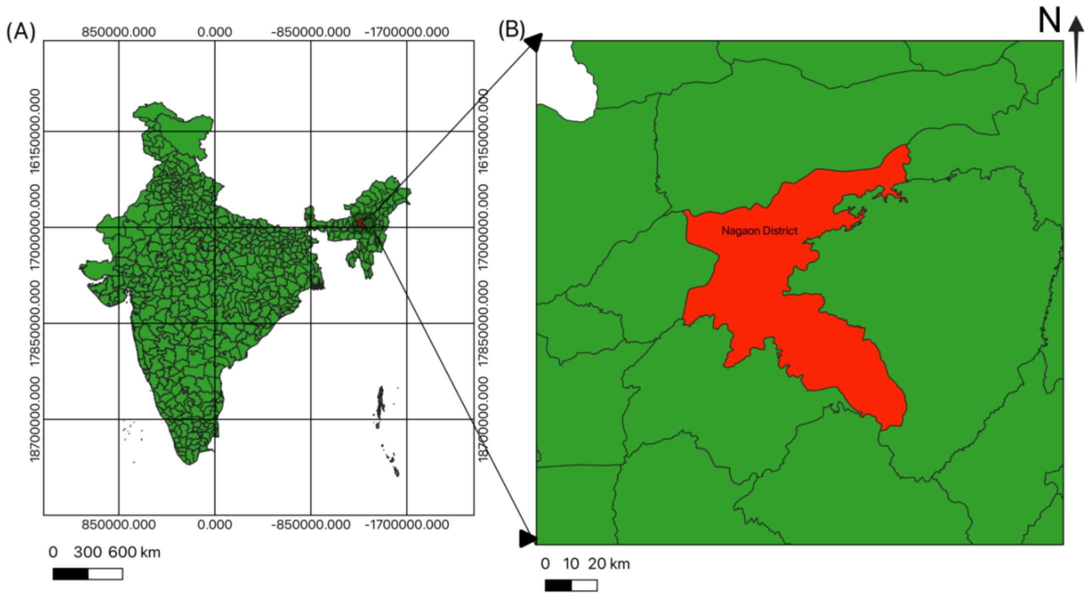


Fig 1: Experimental Area

2.1 Methods for analysis of plant and soil samples

Cadmium (Cd) and Lead (Pb) were determined by HNO_3–$HClO_4$ acid digestion and then analysis in AAS (Model iCE 3500, Thermofisher) using acetylene flame as per the procedure described by Watson and Isaac.[11]

2.2 Geo-statistical approaches

Geo-statistical approaches were taken to identify the vulnerable areas of contamination in soil are as follows: Histograms for calculation of summary statistics, Trend analysis and Semivariogram cloud model.

3. RESULTS AND DISCUSSION

The Cd concentration (mg/kg) in the soil of Nagaon district ranged from 0.13 to 1.3 with a mean value of 0.415(Fig 2). Strongest frequency was shown by 34 numbers of samples each in the frequency range of 0.228 to 0.326 mg/kg and 0.424 to 0.521 mg/kg of soil(Fig 3).

Cadmium is a natural element in the earth's crust, usually found as a mineral combined with other elements such as oxygen, chlorine or sulfur. The maximum permissible limit of Cd for soil as suggested by WHO [12] is 0.31 mg/kg, as such, 70.21% area of the entire district was found to have Cd concentration above the permissible limit (Fig 2). A total of 126 samples were found to surpass the permissible limit, indicating an alarming level of Cd in soil, as well as a threat to the environment. The distribution of Cd in the district was depicted by a positively skewed (1.72) leptokurtic curve (6.46), revealing deviations of the data from symmetrical normal distribution bell (Fig. 4) and significant numbers of samples had 1.09 standard deviations above and below the mean Cd concentration in soil (Fig. 5).

The higher values of Cd in the soil was attributed to higher and long term uses of chemical fertilizers in the soils.[13][10] Moreover, the presence of granite and gneiss along with sandstone and shales,[2]as the parent material of the soil, may be also a primary reason for the alarming rates of Cd in the soil as these rocks are regarded as parent material for Cd in the soil.[9][6]

Three dimensional analysis for the trend of Cd in the soil of the district showed that the strongest influence was from the centre of the district towards its border that depicted the highest Cd concentration in mid of the district and lowest being near the edge of in both XZ and YZ axes (Fig. 6).The centre of the district being the major municipal area, including Nagaon Sadar, the disposal of municipal waste as well as the number of industrial activities are comparatively higher in this part of the district. As Cd is highly related to municipal wastes, construction activities and increased traffic[8], this might be the possible reason for higher concentration of Cd in the central part of the district than the edges. Moreover, the rapidly changing land use pattern and higher use of agricultural chemicals towards the central part of the district mainly in the Rupohi and Samaguriarea[7] may also be the contributing reasons.

Semivariogram clouds, studying the spatial auto-correlation of Cd in the soil in one direction showed that considerable pairs of data were spatially auto-correlated and all pairs nearer to X-axis (below Y-axis) had more or less similar and closer Cd level as compared to values which were farther apart towards Y-axis and right corner of X-axis. The points were found to be auto-correlated upto a distance of about 67 km (Fig. 7). Co-variance cloud with search direction from North to South revealed the existence of spatial autocorrelation revealing a wider spatial shift of correlation towards the southern direction (Fig. 8).

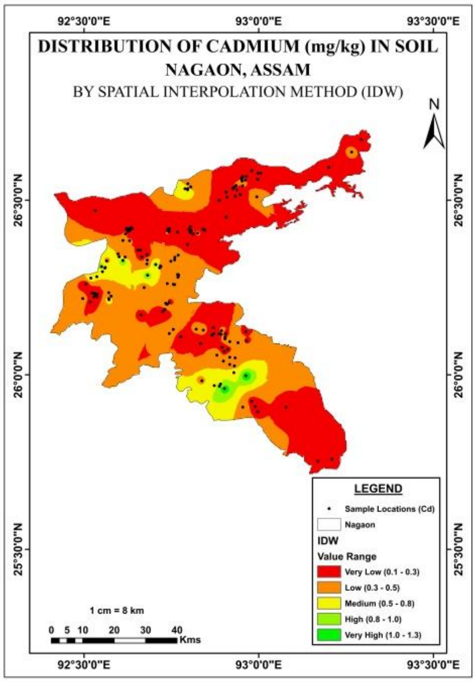


Fig 2: Soil Cadmium content (mg/kg) across the district

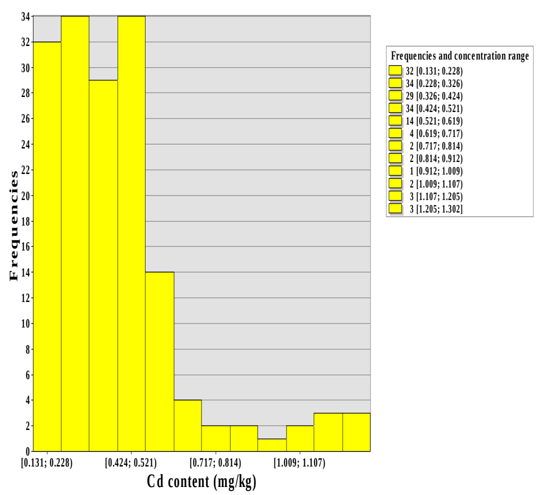


Fig 3 : Frequency and concentration range of Cadmium in

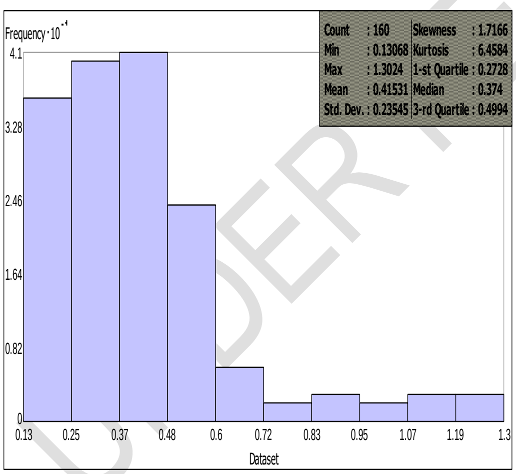


Fig 4: Histogram for lead content in soil

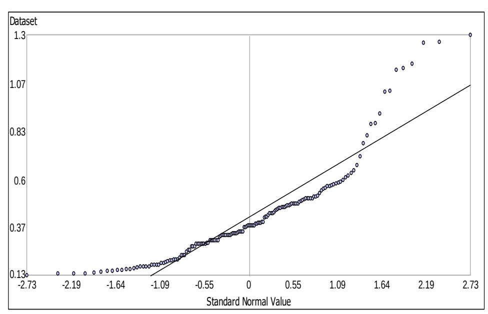


Fig 5: Normal Q-Q plot for Cadmium in soil

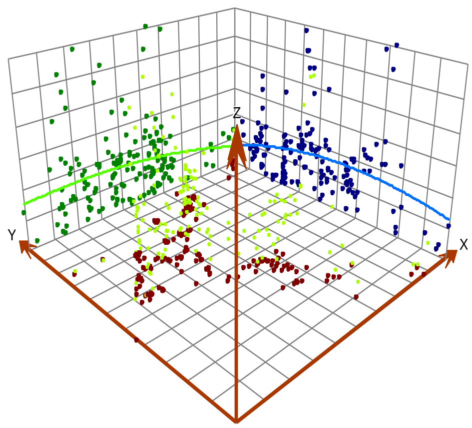


Fig 6: Trend analysis for Cadmium in soil

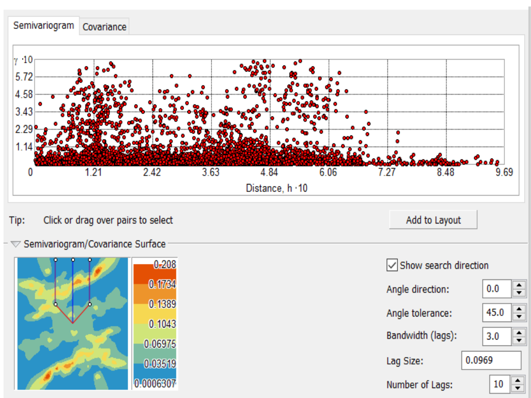


Fig 7: Semivariogram cloud of Cadmium in soil

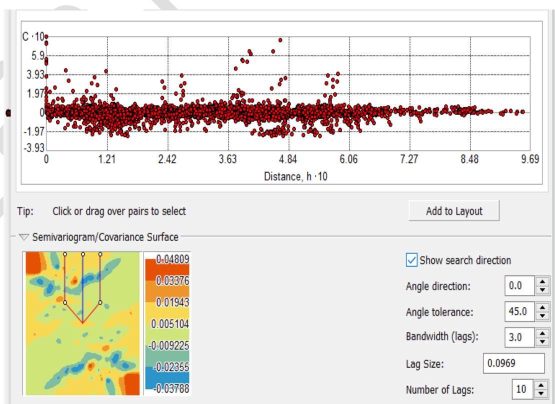


Fig 8: Covariance cloud of Cadmium in soil

The lead concentration (mg/kg) in the soil of the district ranged from 8.81 to 40.53 (Fig 9), with a mean concentration of 24.13. The maximum percentage coverage was depicted by 40.76% by concentration range of 22.51-25.73 mg/Kg of soil and the lowest percent (10.13%) contribution was by 29.72-40.53 mg/kg of soil. Pb has been listed as a hazardous heavy metal pollutant due to its high toxicity. From fig 6 it was evident that 70.21 % of the area fell above the permissible limit of Pb for soil (24.45 mg/kg), indicating a severe threat to the soil environment of the district from the metal.

According to the frequency and concentration graph (Fig 10), 70 numbers of samples were above the permissible limit for Pb in soil. The strongest frequency was given by 25 numbers of samples in the concentration range of 14.36 to 17.22 mg/kg of soil. The long term application of phosphatic fertilizer also supply Pb to the soil as they contain Pb in traces.[5]

The distribution of Pb too showed a deviation from the normal bell shape with a positive skewness of 0.2609, while the curve being platykurtic (1.9418) as shown in Fig 11. A significant numbers of samples were seen having standard deviation of 1.09 above and below the mean concentration of Pb in the soil (Fig. 12).

Lead is also abundant in the soil of those areas with marked air pollution as it is often found attached to the particulate matters. [3]Moreover, the accumulation of Pb in the soil may also be due to continuous use of pesticide as Acetochlor and Glyphosate [1].However, the primary cause of alarming levels of Pb in the soil may be due to the parent materials in the soil as Granite and gneiss.[5]

The trend of Pb in the soils of Nagaon district followed second order polynomial in both XZ and YZ axes (Fig. 13), depicting a higher concentration of Pb at the central part of the district than that at the edges. The increased concentration of Pb at the central part of the district may be due to the increased commercially cultivated areas at the mid part of the district that leads to the increased use of the agricultural chemicals leading to higher concentration of Pb in the soil as impurity and residue.[7]Moreover, the increased particulate matter in the air toward the town[3] located at the central part of the district may also be the probable reason for the accumulation of Pb in the soil.[3]

Semivariogram clouds for the study of Pb in soil in one direction showed considerable pairs of data were spatially auto-correlated and all pairs nearer to X-axis (below Y-axis) had more or less similar and closer Pb level as compared to values which were farther apart towards Y-axis and right corner of X-axis. The points were found to be auto-correlated upto a distance of about 60 km (Fig. 14). Co-variance cloud with search direction from North to South revealed the existence of spatial autocorrelation revealing a wider spatial shift of correlation towards the southern direction (Fig. 15).

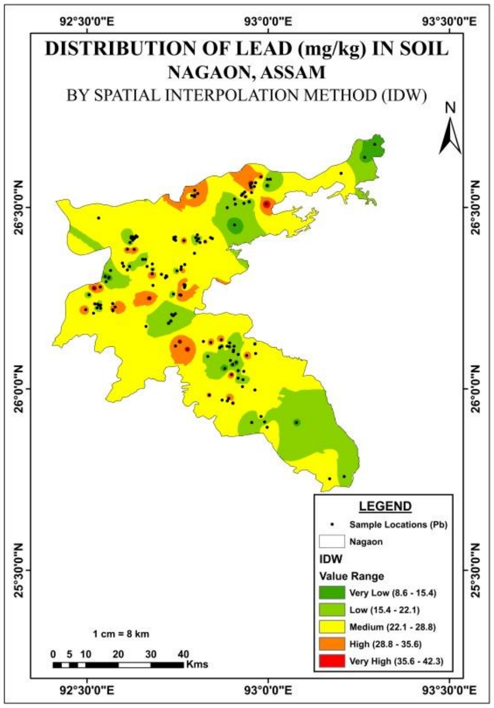


Fig 9: Soil Lead content (mg/kg) across the district

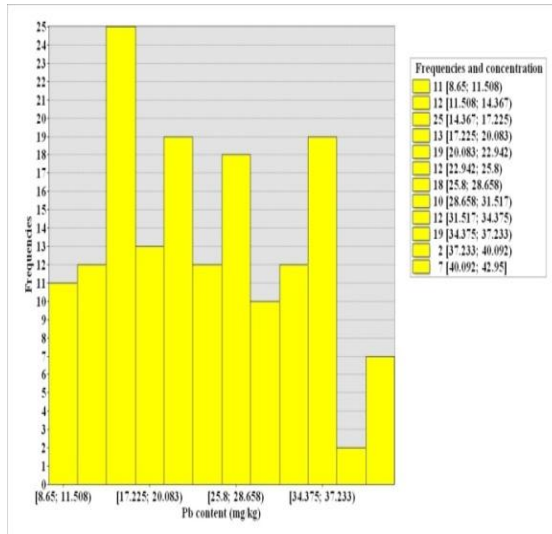


Fig 10: Frequency and concentration range of Lead in soil

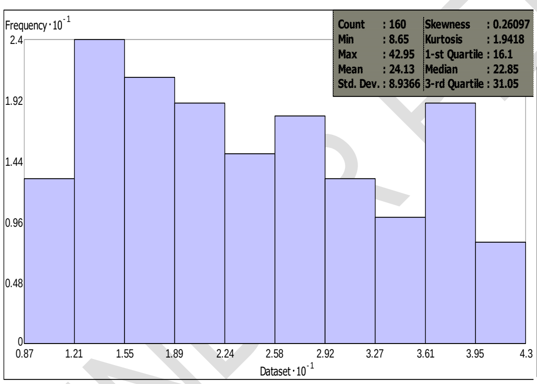


Fig 11: Histogram for lead content in soil

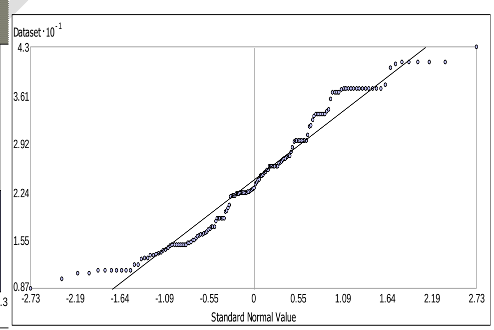


Fig 12: Normal Q-Q plot forLead in soil

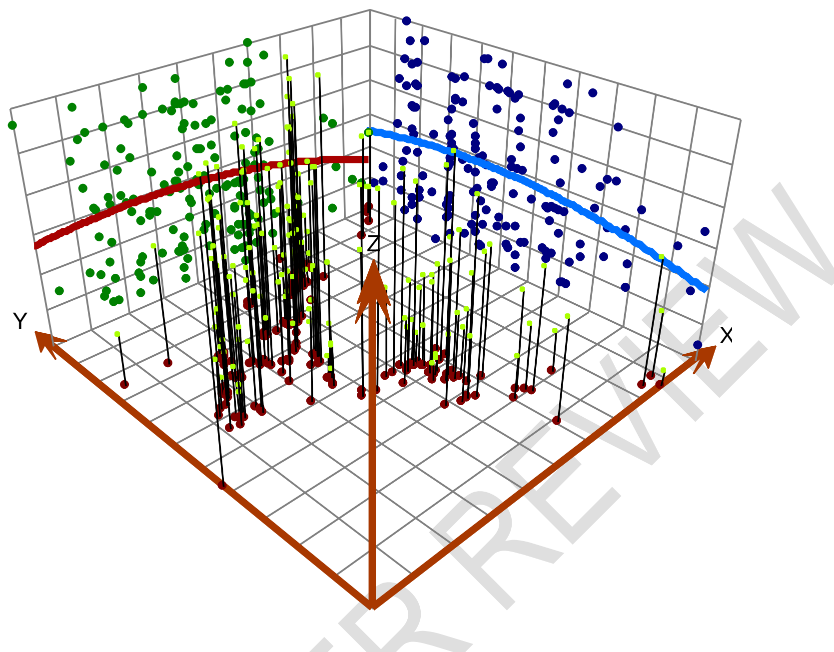
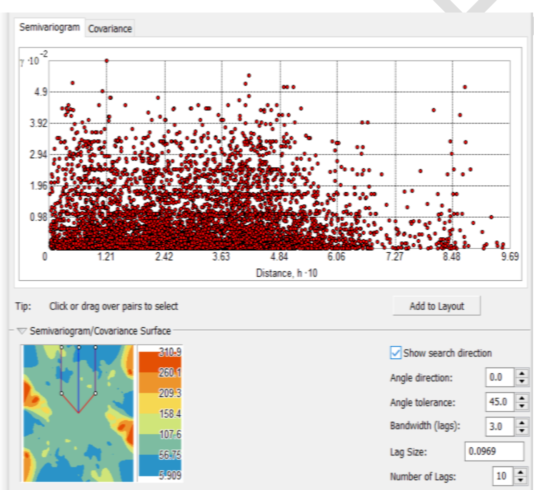


Fig 13: Trend analysis for Lead distribution in soil across the district



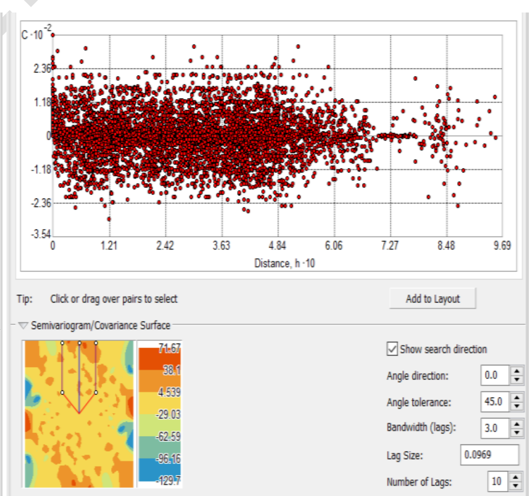


Fig 14: Semi-variogram for Lead distribution in soil **Fig 15: Co-variance cloud for Led distribution in soil**

4. CONCLUSION:

GIS aided spatial variability maps of heavy metals in soil provide a baseline database for sustainable resource productivity of the district. The concentration of Cd was found to be above the permissible limit as recommended by WHO, with much higher concentration at the centre than that at the edges of the district. Similarly, the Pb concentration too suppressed the permissible limits too, with higher concentration at the central part of the district than the edges. The district is identified as hotspot for the presence of Cd and Pb in the soil that needs immediate attention to address the issue in right forum. In this regard, however, further research and awareness is necessary along with proper scientific remedial measures.

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