



RESEARCH ARTICLE

Geostatistical variability of soil properties of Jajmau tannery industrial zone of Kanpur, Uttar Pradesh

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Abstract

In the present study, different soil properties such as pH, electrical conductivity (EC), organic carbon (OC) and the heavy metals chromium (Cr), lead (Pb) and zinc (Zn) were mapped spatially using geostatistical methods. Geostatistical tools including ordinary kriging interpolation technique were utilized to investigate the variability. Accurate and rapid assessment of soil properties is a key component of agriculture. A total of 116 surface soil samples (0–25 cm) were obtained at an interval of 250 m with GPS coordinates from the study area. The highest (93.76 %) variation was observed in the total Cr, whereas the lowest (4.75 %) was found in soil pH. The best variogram model fit in ordinary kriging was selected based on the accuracy of standardized mean error (MSE) nearest to zero, the smallest root-mean-squared prediction error (RMSE), the average standard error (ASE) nearest the root-mean squared prediction error and the standardized root-mean-squared prediction error (RMSSE) nearest one. The results indicated that soil pH, EC and Cd were best fitted to the spherical model, whereas soil OC, Pb, Cr and Zn best fitted to the Gaussian model. All the soil pollutants (Cr, Cd, Pb and Zn) were found above the permissible limits in soil, with Cr around 10 times higher than the recommended threshold. The spatial variability of important soil properties is valuable for planning remediation and management practices at regional scale.

Keywords: geostatistic; kriging; semi variogram; soil properties; spatial variability; soil pollution

Introduction

Soil is one of the most important resources in the natural environment; its health and productivity are vital for sustainable agricultural development. Decades of negligence and poor discharge of industrial and municipal waste effluents, which contain highly toxic and hazardous pollutants, have resulted in severe soil pollution in Kanpur city, India (1). The tannery industries release effluents that are extremely high in organic and inorganic toxic salt residues of Cr. A significant part of the chemicals used in leather processing is not absorbed during tanning but instead discharged into the environment. These by-products cause pollution and hamper the activities of microorganisms in soils, degrade crop and water quality and enter the food chain affecting human health. The discharge effluents are high in soil pollutants causing various adverse impacts to the ecosystem due to its long persistence and non-biodegradable nature. Cultivation of crops without knowledge of soil fertility status significantly decline soil productivity as well as soil health (2). Prolonged exposure to contaminated sites can cause various health problems such as headaches, lung infection, nausea, skin and eye irritation and can even damage some vital organs like liver. A decline in soil quality, accompanied by reduced microbial activity, negatively affects soil fertility and structure. These elevated levels of soil pollutants pose severe risks due to potential leaching into groundwater and

uptake by plants. Therefore, it is very much necessary to assess the levels of severity of soil pollutants in agricultural soils.

The conventional method of estimating soil pollutants is suitable for specific or small-scale monitoring. With the development of geographic information systems (GIS), global positioning system (GPS) and geo-statistics. Kriging is a prevalent technique used for spatial interpolation of soil properties. This method allows repetitive coverage of large-scale areas in a relatively cost-effective way, have become attractive for identifying and assessing spatial patterns of the soil properties (3, 4). Studies have shown that the properties of soil vary significantly within the same field.

Spatial variability of soil fertility is a function of intrinsic factors (soil forming factors and processes) and extrinsic factors (topography, land use and soil management practices) (5). Spatial variability and correlation among the soil properties across the topography have been deeply studied in the last decades using geostatistical methods (6). The properties of soil and their spatial pattern and observed that continuous grazing led to decrease spatial dependence of soil organic carbon and total nitrogen at sandy grassland hills (7). Hence, a proper understanding of the spatial distribution of soil pollutants at the ground level is very important for site-specific management and remediation practices (8, 9). Therefore, in this study, an attempt

was made to analyse the spatial distribution of soil pollutants near the tannery industrial area using geo-statistical tools in GIS environment rather than the conventional method of interpretation of data and assuming that the concentration of toxic pollutants decreases with distance.

Materials and Methods

Study area

Tannery industrial area, Jajmau, Kanpur situated on the banks of Ganga River lies between 26.46° N latitude and 80.35° E longitude (Fig. 1). In Northern India, this zone is the largest hub of leather tanneries and one of the biggest export centres of tanned leather in India and worldwide. It comprises of around 10 villages with a population of 423000 deriving their livelihood mainly from agriculture (rabi rice) and in patches floriculture (marigold) and vegetables (cauliflower, mustard). The slope is 1–3 % gentle sloping throughout the study area with loamy sand soil texture. The climate is humid subtropical, covering a maximum 80–85 % rainfall during the southwest monsoon periods with 800–1000 mm. Average temperature from April to June falls between 44.8 and 23.8 °C. May is the hottest month of the year when the temperature reaches 45 °C, while the minimum temperature stands at 8 °C. The maximum permissible limits in soil and plants for Cr (100 and 1.3 ppm), Cd (0.8 and 0.02 ppm), Pb (85 and 0.3 ppm) and Zn (50 and 0.6 ppm), respectively (10).

Soil sample collection and analysis

Soil samples were collected from the plough layer (0–25 cm) grid wise at an interval of 250 m with the help of GPS. A total of 116 surface soil samples were collected covering ten villages, which are adjacent to tannery industries. The samples were labelled, air-dried under shade and sieved through a 2 mm sieve for analysis of soil parameters. For OC estimation 0.5 mm sieve is used. The soil that passed through sieves is collected and stored in air-tight polythene bags for further use. Soil pH and EC through soil-suspension method, OC wet oxidation method, Cd, Cr, Pb and Zn

by micro-digestion and analysis in inductively coupled plasma optical emission spectroscopy (ICP-OES) were determined using the standard analytical methods (11–13).

Geostatistical analysis

Geostatistics uses the technique of semivariogram to measure the spatial variability of a regionalized variable and provides the input parameters for the spatial interpolation of kriging. Spatial variability of soil properties was mapped by the ordinary kriging interpolation method. For mapping the soil parameters, all the analysed data from sample sites were first imported into GIS as point-based, geo-coded data through table management. It measures the average dissimilarity between data separated by a vector h it is computed as half the average squared difference between the components of data pairs:

$$\gamma(h) = 1/2N(h) \sum_{i=1}^{n(h)} (z(x_i) - z(x_i + h))^2 \quad (\text{Eqn. 1})$$

Where, $N(h)$ is the number of data pairs within a given class of distance and direction, $z(x_i)$ is the value of the variable at the location x_i and $z(x_i + h)$ is the value of the variable at a lag of h from the location x_i .

Semivariogram models were computed using ArcGIS 10.8. The circular, spherical and gaussian models were tested for different soil parameters. Expressions for different semivariogram models are below:

Spherical

$$\gamma(h) = C + C \left(1.5 \frac{h}{a} - 0.5 \left(\frac{h}{a} \right)^3 \right), h \geq 0 \quad (\text{Eqn. 2})$$

Exponential

$$\gamma(h) = C + C \left[1 - \exp \left\{ -\frac{h}{a} \right\} \right], h \geq 0 \quad (\text{Eqn. 3})$$

Gaussian

$$\gamma(h) = C + C \left(1 - \exp \left\{ -\frac{h^2}{a^2} \right\} \right), h \geq 0 \quad (\text{Eqn. 4})$$

Where, h = lag distance, C = nugget variance, C = structural variance (partial sill) and r = range

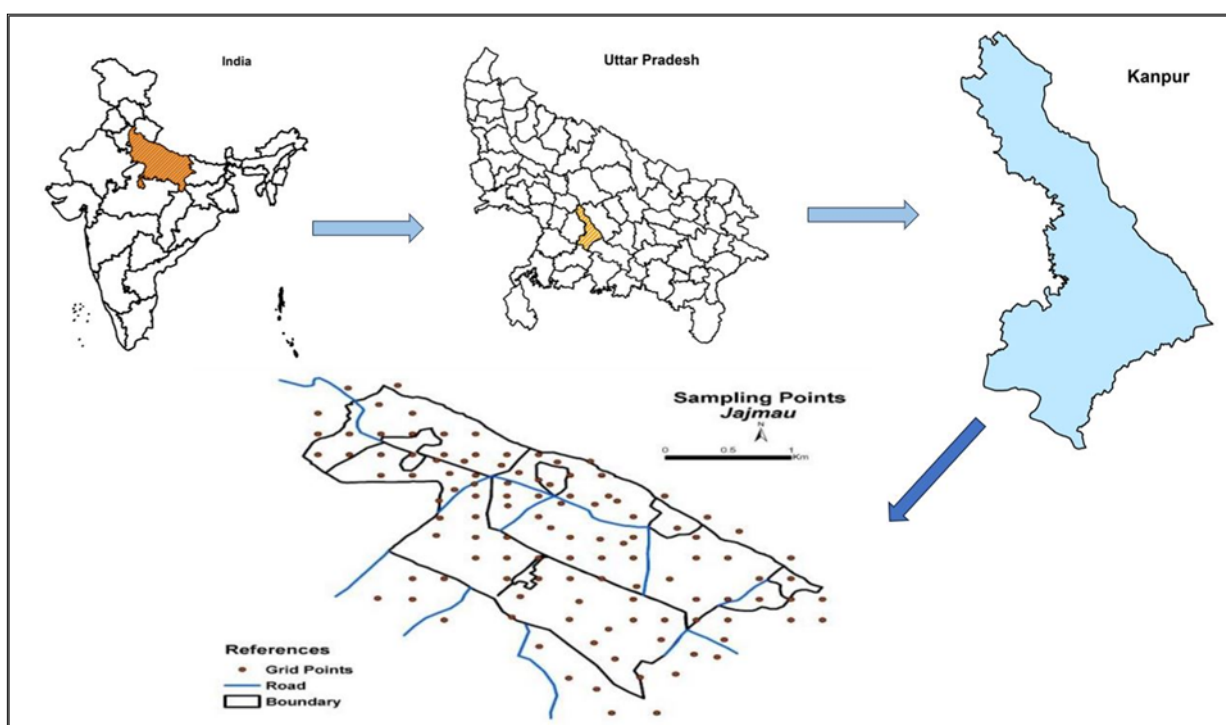


Fig. 1. Geographical area of the study area.

Statistical analysis

Descriptive statistics of analyzed soil data which are minimum, maximum, mean, median, standard deviation (SD), coefficient of variation (CV), skewness and kurtosis were determined using SPSS 16.0 (SPSS, Inc., Chicago, IL, USA). A Pearson's correlation matrix was used to reveal the relationships between different soil properties.

Accuracy analysis

Cross-validation approach was employed to assess the accuracy of model (14–16). The accuracy of prediction is measured by mean absolute error (MAE) and mean standardized error (MSE). The best fit model was computed for each parameter based on lowest MSE.

Results and Discussion

The descriptive analysis of the soil properties is presented in Table 1. The median of most soil properties was found to be lower than the mean, which indicates that the effects of abnormal data on the sampling value were not significant. The data show that the values of pH, EC and SOC ranged from 7.0–8.3, 0.32–1.32 dSm⁻¹ and 0.2 %–1.58 % with mean values of 7.57, 0.75 dSm⁻¹ and 0.8 %, respectively. The soil pollutants i.e., Pb, Cr, Cd and Zn ranged from 61.2 to 136.8, 27.2 to 4596, 3.4 to 24 and 33 to 344.6 mg kg⁻¹ with overall mean value of polluted zone of 89.04, 681.93, 9.13 and 139.88 mg kg⁻¹, respectively, without removing outliers.

The concentration of most of the pollutants particularly Cr, was at an alarming level and many times higher than the permissible limit. Tannery industries are the primary source of Cr and other heavy metals, which are used in the chrome tanning process. Other heavy metals are often found in tannery waste and enter the environment through wastewater and from the use of various chemicals and dyes. The spatial variability was interpreted using the coefficient of variation (CV) expressed in percentage. The criteria was used to classify the parameters into highly variable (CV > 35 %), moderately variable (CV 15–35 %) and least variable (CV < 15 %) variable classes (17). The CV values of soil parameters SOC, total Cr and total Zn were found greater than 35 %, indicating a higher degree of dispersion around the mean, EC, total Pb and total Cd were within the 15–35 % range and only pH was observed in the least variable class (< 15 %), indicating limited data dispersion.

The highest (93.76 %) variation was observed in the Total Cr, whereas the lowest (4.75 %) was found in soil pH (Table 1). Soil pH is considered to be the stable soil parameter (18). Skewness is the most common form of departure from normality (4). If a variable has positive skewness, the confidence limits on the variogram are wider than they would otherwise be and

consequently, the variances are less reliable. All the studied soil properties had kurtosis values more than zero, which indicates that the data distributions are non-normal, representing values that are far from the mean in the extreme ends (19). The results demonstrate that the selected study area has higher concentrations of all pollutants (Cr, Cd, Pb and Zn) than the permissible limit according to the World Health Organization, with levels increasing near the industrial zone compared to locations farther away; Cr concentration were more than ten times higher in contaminated soil.

The spatial distributions of pH, EC, OC, Pb, Cr, Cd and Zn in agricultural soil, which are continuously for more than two decades are irrigated by contaminated effluents were estimated using various interpolation techniques and ArcGIS software and the variability are indicated in Fig. 2. The three semivariogram models spherical, exponential and Gaussian models were computed and the best fit model to predict the parameters were evaluated. The best is selected based on four criteria: the standardized mean error (MSE) nearest to zero, the smallest root-mean-squared prediction error (RMSE), the average standard error (ASE) nearest the root-mean squared prediction error and the standardized root-mean-squared prediction error (RMSSE) nearest one (3, 20, 21). According to four criteria semivariograms showed that soil pH, EC and Cd were best fitted for spherical model whereas soil organic carbon, Pb, Cr and Zn were best fitted for the Gaussian model (Table 2).

However, soil properties displayed differences in their spatial dependence. The evaluation indices resulted from cross-validation of spatial maps of soil properties. The spatial distribution maps of soil properties using ordinary kriging interpolation technique (Fig. 2a, b). The availability of soil pollutants varies with the distance from the industrial zone. In tannery industries, the biproducts generated is rich in chromium therefore, a very high concentration much higher than the permissible limit is noted near industrial zone. Any interpolation techniques are used to decide how discrete data from a map are transformed into continuous data.

Conclusion

The agricultural soil of Jajmau industrial area, irrigated with contaminated effluents for more than two decades has been studied to estimate the concentration level and spatial distribution pattern of important soil properties namely pH, EC, OC, Cr, Cd, Pb and Zn. The effectiveness and error predictions of different interpolation methods were evaluated to identify the best model. The results indicate that spherical model was found best fitted for soil pH, EC and Cd while for soil organic carbon, Pb, Cr and Zn, the Gaussian model was found best for interpolation based on the accuracy criteria. The spatial variability maps of soil

Table 1. Descriptive analysis of soil properties of the study area

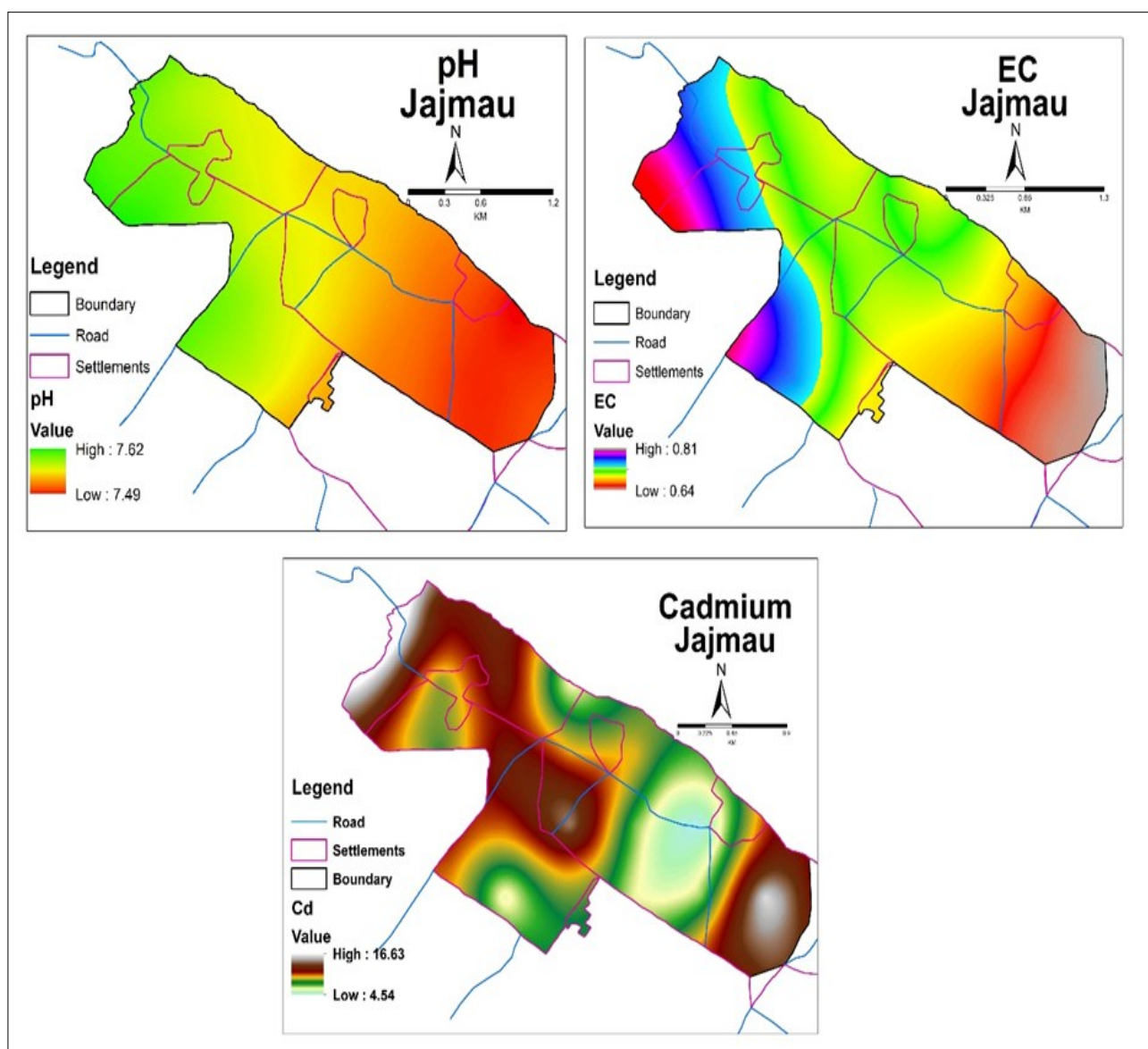
Soil parameters	Distribution	Minimum	Maximum	Mean	Median	SD ^a	Skewness	Kurtosis	CV ^b
pH (1:2.5)	Log	7	8.3	7.57	7.6	0.36	0.076	1.81	4.75
EC (dS/m)	Normal	0.32	1.32	0.75	0.72	0.23	0.395	2.21	30.66
SOC (%)	Normal	0.2	1.58	0.80	0.79	0.29	0.367	2.82	36.25
Pb (mg kg ⁻¹)	Log	61.2	136.8	89.04	87.8	15.05	0.62	3.63	16.90
Cr (mg kg ⁻¹)	Log	27.2	4596	681.93	520	639.41	2.79	14.74	93.76
Cd (mg kg ⁻¹)	Log	3.4	24	9.13	8.6	2.97	1.579	7.967	32.53
Zn (mg kg ⁻¹)	Log	33	344.6	139.88	130.8	67.36	1.05	4.07	48.15

^a standard deviation; ^b coefficient of variation.

Table 2. Modeling precision of ordinary kriging

Soil parameters	Semivariogram Model	RMSE ^a	RMSSE ^b	MSE ^c	ASE ^d
pH (1:2.5)	Spherical	0.322	0.976	0.029	0.329
	Gaussian	0.321	0.9769	0.027	0.328
	Exponential	0.324	0.9767	0.026	0.331
EC (dS/m)	Spherical	0.2093	0.952	0.035	0.2207
	Gaussian	0.2087	0.950	0.034	0.2207
	Exponential	0.210	0.955	0.0297	0.221
SOC (%)	Spherical	0.265	1.019	0.031	0.261
	Gaussian	0.289	1.06	0.024	0.27
	Exponential	0.269	1.034	0.031	0.262
Pb (mg kg ⁻¹)	Spherical	14.03	1.068	0.007	13.05
	Gaussian	13.79	1.045	0.001	13.62
	Exponential	14.20	1.089	0.009	12.96
Cr (mg kg ⁻¹)	Spherical	582.65	1.352	0.052	509.22
	Gaussian	591.51	1.376	0.059	493.40
	Exponential	587.45	1.388	0.069	473.55
Cd (mg kg ⁻¹)	Spherical	2.89	1.074	0.002	2.64
	Gaussian	2.86	1.053	0.001	2.66
	Exponential	2.92	1.095	0.012	2.62
Zn (mg kg ⁻¹)	Spherical	57.12	1.035	0.009	55.56
	Gaussian	57.72	1.034	0.011	55.12
	Exponential	57.13	1.076	0.018	53.08

^a root mean square error; ^b root mean square standardized error; ^c mean standardized error; ^d absolute standardized error.

**Fig. 2(a).** Spatial variability of soil pH, soil EC and cadmium of tannery industrial area, Kanpur.

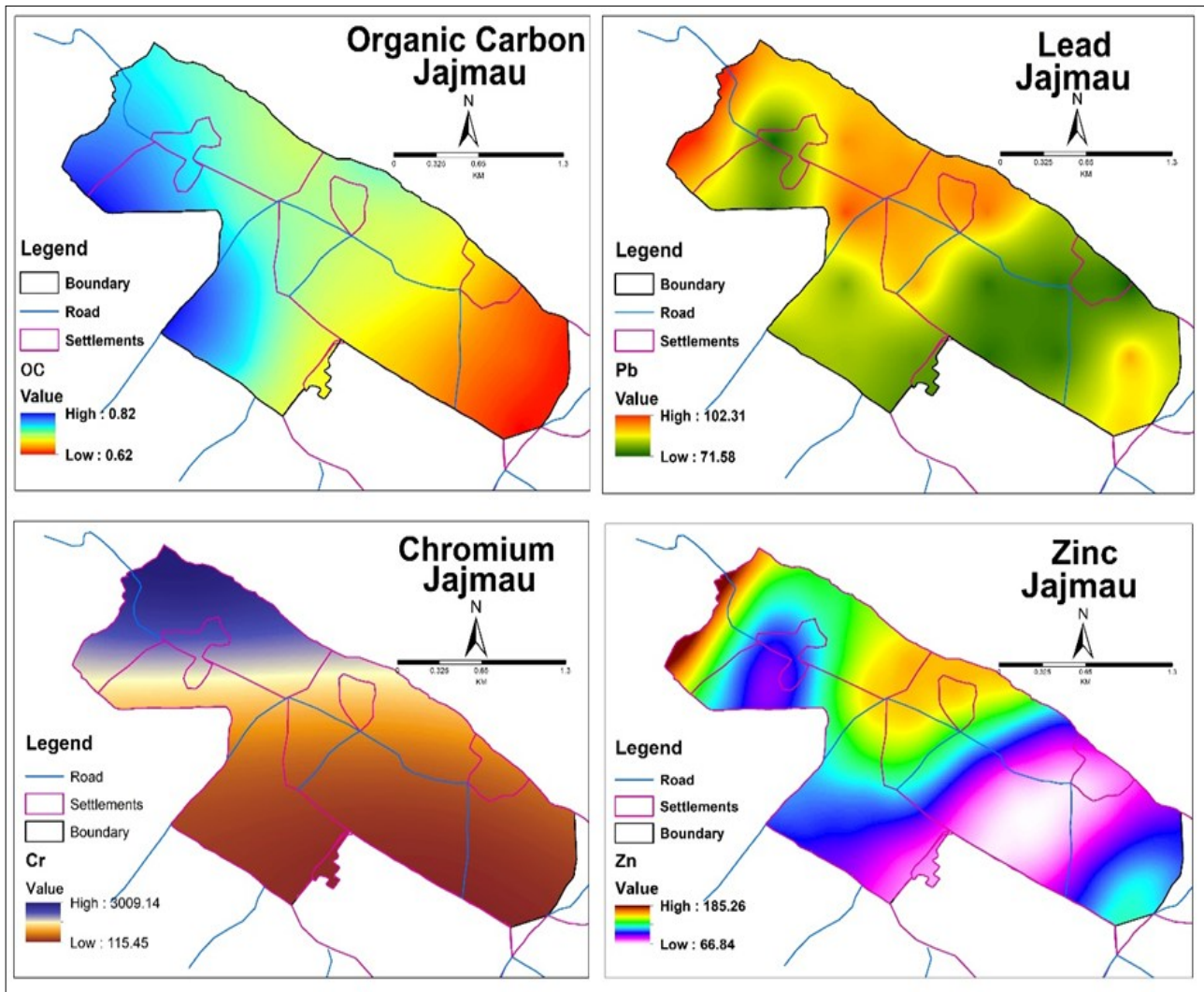


Fig 2(b). Spatial variability of soil organic carbon, lead, chromium and zinc of tannery industrial area, Kanpur.

properties were developed using the best fit semivariogram models. The concentration of all soil pollutants (Cr, Cd, Pb and Zn) were found higher than the permissible limits namely chromium was found more than 10 times the reference concentration. The variability maps can be used for delineating risk zones based on the higher concentration of pollutants. It indicates that the region is highly toxic and the crops grown in such contaminated zone are dangerous for human consumption. Therefore, it is necessary to take immediate action to prevent further accumulation of toxic pollutants and to increase public awareness about their harmful effects. The spatial distribution and status of soil pollutants in industrial area and nearby villages will help in precise the management of soils.

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Authors' contributions

NS, JKS and NKS planned the experiments. RM and MK analysed the samples and performed the statistical analysis. NS wrote the manuscript. NL helped to collect soil samples. HB and TA

contributed to the final correction of the manuscript. All authors read and approved the final manuscript.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interest to declare.

Ethical issues: None

References

1. Tiwari KK, Singh NK, Patel MP, Tiwari MR, Rai UN. Metal contamination of soil and translocation in vegetables growing under industrial wastewater irrigated agricultural field of Vadodara, Gujarat, India. *Ecotoxicol Environ Saf.* 2011;74:1670–7. <https://doi.org/10.1016/j.ecoenv.2011.04.029>
2. Gandhi G, Savalia SG. Soil-site suitability evaluation for mustard in calcareous soils of Girnar toposequence in Southern Saurashtra region of Gujarat. *J Oilseed Brassica.* 2014;5:128–33.
3. Sahu N, Pipalade D, Jain RC, Gupta SC. Geo-statistical analysis of soil pollutants of tannery industrial area, Kanpur. *Indian J Ecol.* 2024;51(1):113–7.
4. Divya A, Josphineleela R, Jaba Sheela L. A machine learning based approach for prediction and interpretation of soil properties from soil spectral data. *J Environ Biol.* 2024;45(1):96–105. <https://doi.org/10.22438/jeb/45/1/MRN-5134>
5. Ramzan S, Wani MA, Bhat MA. Assessment of spatial variability of

- soil fertility parameters using geostatistical techniques in temperate Himalayas. *Int J Geosci.* 2017;8:1251–63. <https://doi.org/10.4236/ijg.2017.810072>
6. Li GS, Wang XZ, Zhang ZY, Zhang CH. Spatial variability of soil properties in a tobacco field of Central China. *Soil Sci.* 2008;173(9):659–67. <https://doi.org/10.1097/SS.0b013e3181847ea0>
 7. Yong ZS, Yul L, Halin Z. Soil properties and their spatial pattern in a degraded sandy grassland under post-grazing restoration, Inner Mongolia, northern China. *Biogeochemistry.* 2006;79:297–314. <https://doi.org/10.1007/s10533-005-5273-1>
 8. Nogiya M, Moharana PC, Meena R, Yadav B, Jangir A, Malav LC, et al. Spatial variability of soil variables using geostatistical approaches in the hot arid region of India. *Environ Earth Sci.* 2024;83:432. <https://doi.org/10.1007/s12665-024-11737-5>
 9. Usowicz B, Lipiec J. Spatial variability of soil properties and cereal yield in a cultivated field on sandy soil. *Soil Tillage Res.* 2017;174:1–9. <https://doi.org/10.1016/j.still.2017.07.015>
 10. World Health Organization. Permissible limits of heavy metals in soil and plants. Geneva: WHO; 1996.
 11. McLean EO. Soil pH and lime requirement. In: Page AL, editor. *Methods of Soil Analysis. Part 2. Agronomy Monograph No. 9.* 2nd ed. Madison (WI): ASA; 1982. <https://doi.org/10.2134/agronmonogr9.2.2ed.c12>
 12. Walkley A, Black IA. An examination of the Degtjareff method for determining soil organic matter and a proposed modification of the chromic acid titration method. *Soil Sci.* 1934;37(1):29–38. <https://doi.org/10.1097/00010694-193401000-00003>
 13. Hutton M, Symon C. The quantities of cadmium, lead, mercury and arsenic entering the UK environment from human activities. *Sci Total Environ.* 1986;57:129–50. [https://doi.org/10.1016/0048-9697\(86\)90018-5](https://doi.org/10.1016/0048-9697(86)90018-5)
 14. Erxleben J, Elder K, Davis R. Comparison of spatial interpolation methods for estimating snow distribution in the Colorado Rocky Mountains. *Hydrol Process.* 2002;16(18):3627–49. <https://doi.org/10.1002/hyp.1239>
 15. Robinson TP, Metternicht G. Testing the performance of spatial interpolation techniques for mapping soil properties. *Comput Electron Agric.* 2006;50:97–108. <https://doi.org/10.1016/j.compag.2005.07.003>
 16. Kerry R, Goovaerts P, Rawlins BG, Marchant BP. Disaggregation of legacy soil data using area to point kriging for mapping soil organic carbon at the regional scale. *Geoderma.* 2012;170:347–58. <https://doi.org/10.1016/j.geoderma.2011.10.007>
 17. Wilding LP. Spatial variability: Its documentation, accommodation and implication to soil surveys. In: Nielsen DR, Bouma J, editors. *Soil Spatial Variability.* Wageningen: Pudoc; 1985.
 18. Bouma J, Pinke PA. Soil specific crop management. In: Robert PC, Rust RH, Larson WE, editors. *Soil Specific Crop Management.* Madison (WI): ASA, CSSA, SSSA; 1996. p. 207.
 19. Cohen JE, Davis RA, Samorodnitsky G. Heavy-tailed distributions, correlations, kurtosis and Taylor's law of fluctuation scaling. *Proc R Soc A.* 2020;476(2244):20200610. <https://doi.org/10.1098/rspa.2020.0610>
 20. Hegde R, Bardhan G, KV, Bhaskar NB, BP, Singh SK. Spatial variability and mapping of selected soil properties in Kaligaudanahalli microwatershed, Gundlupet Taluk, Chamarajanagar District, Central Karnataka Plateau, India. *SN Appl Sci.* 2019. <https://doi.org/10.1007/s42452-019-0486-4>
 21. Kumar P, Sharma M, Butail NP, Shukla AK, Kumar P. Spatial variability of soil properties and delineation of management zones for Suketi basin, Himachal Himalaya, India. *Environ Dev Sustain.* 2023. <https://doi.org/10.1007/s10668-023-03181-5>

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