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ORIGINAL PAPER

Soil quality analysis and mapping of various land uses using geospatial technology: a case study

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Abstract

This manuscript presents a comprehensive study on soil quality analysis and mapping across various land uses in the city of Madurai, India, leveraging advanced geospatial technology. Soil quality assessment is crucial for sustainable land management and informed decision-making in urban planning and agriculture. The study integrates geospatial data, remote sensing imagery, and ground-truthing techniques to evaluate soil properties and categorize land uses, facilitating a holistic understanding of the city's soil health. The research begins by collecting soil samples from multiple locations representing diverse land uses, including urban, peri-urban, and agricultural areas within Madurai. Laboratory analyses are performed to measure various soil attributes such as pH, organic matter content, nutrient levels, and texture. Simultaneously, high-resolution satellite imagery and geographic information system (GIS) data are employed to create detailed land use maps, identifying distinct patterns and spatial distributions. The pH, amount of organic matter, amount of nutrients, and texture of the soil were all examined. Based on the significance of these characteristics in determining soil quality, a soil quality index was devised, and maps of soil quality were made for each type of land use. The consistency index map is created to gauge the level of soil contamination. Using statistical and geospatial analyses, the manuscript highlights significant variations in soil properties across different land use types. It explores the impact of urbanization on soil quality, revealing areas of soil degradation and pollution in urban zones. Furthermore, the study identifies regions with fertile soils suitable for agricultural purposes and suggests potential areas for soil improvement and sustainable land management practices.

Keywords GIS · Soil quality index · Kriging · Landuses

Introduction

Soil, a fundamental component of the Earth's ecosystem, plays a pivotal role in supporting life and ensuring food security. It serves as the foundation upon which cities are built and the cradle from which agriculture springs forth. In the context of urbanisation and rapid land use changes, understanding the quality and health of soil becomes imperative for sustainable urban development, agricultural productivity, and environmental preservation (Asadi 2008; Ray 2014). The concept of soil quality refers to the ability of the soil and its ecosystem to provide plants with the nutrients they require at all phases of growth in order to maintain agricultural output. Soil quality encourages sustainable soil management because it is connected to soil productivity; hence, a reliable evaluation needs accurate, comprehensive quantification. In order to sustain agricultural production and food security, soil quality is a crucial element of ecosystem health and productivity. There has been a considerable global decline in soil quality as a result of the fast development of urban and agricultural land use. Hence, in order to make informed judgements about land use planning and management, it is crucial to evaluate the effects of various land uses on soil quality (Chand 2010).

Rapid industrialization causes a large amount of garbage to be produced in developing nations like India, which makes land for the safe disposal of hazardous waste scarcer. When liquid trash is created from solid waste, it seeps into the ground and causes issues including groundwater contamination, vegetation decline, altered soil characteristics, etc. (Abuzaid et al. 2021). Soil contamination contributes to collapsed structures, land subsidence, landslides, poor groundwater quality, and other problems. Geospatial technology, a dynamic amalgamation of satellite imagery, geographic information

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systems (GIS), and ground-truthing techniques, offers a powerful toolkit for understanding the complex relationship between land use patterns and soil quality (Şenol, et al. 2020).

As urban sprawl continues and agricultural landscapes evolve, it is crucial to comprehensively assess the state of the soil that underlies these diverse land uses. The quality of soil not only affects agricultural productivity but also plays a significant role in determining the sustainability and resilience of urban areas (Moore, et al. 2016). The soil samples are subjected to rigorous laboratory analyses, where parameters such as pH levels, organic matter content, nutrient concentrations, and soil texture are meticulously examined. Simultaneously, high-resolution satellite imagery and GIS data are harnessed to create detailed land use maps, which serve as critical inputs for understanding the spatial distribution of land use. Recent advancements in GIS technology and the availability of digital georeferenced data have substantially increased the potential that is available, encouraging the use of multi-criteria spatial analysis to support land planning (Li, et al. 2005).

This study aims to unravel the spatial variations in soil quality and their relationship with different land use types. This manuscript delves into the realm of soil quality analysis and mapping within the vibrant and culturally rich city of Madurai, India, harnessing the power of geospatial technology (Ozsahin et al. 2017). Madurai, located in the southern state of Tamil Nadu, is a city that beautifully intertwines its historical heritage with modern urbanization. This research encompasses the collection of soil samples from various land use categories, including urban, peri-urban, and agricultural areas, scattered across the city. By discerning how urbanisation influences soil health, the regions were identified where soil degradation and pollution are most pronounced (de Paul Obade, Vincent, and Rattan Lal. 2013; Zhu, A-Xing,, et al. 2001; Vilas and Ghosal 2015; Balamurugan and Balakumaran 2015; Dengiz 2013; Alaboz et al. 2017; AbdelRahman and Tahoun 2019). The insights gained from this research will inform urban planners, environmentalists, and farmers, aiding them in making informed decisions related to land use planning, pollution mitigation, and sustainable agriculture. Ultimately, this manuscript underscores the importance of harnessing geospatial technology to unravel the intricate relationship between land use and soil quality, with the ultimate goal of fostering sustainable urban development and ecological resilience within the vibrant tapestry of Madurai.

Details about the study area

The study area of this project is a district of Madurai. The location map of the study area is depicted in Fig. 1. There are more than 18,000 industries in this area. Four industrial regions, three residential regions, and two agricultural regions are selected for the analysis of soil contamination. The various regions have industries like the Perungudi dyeing industry, Villapuram's electroplating business, Kappalur's plastics industry, and an Arappalayam workshop. The physical, chemical, index, and engineering qualities of soil can be used to infer its contamination characteristics.

Methodology

Geospatial information systems (GIS) are used in the approach for the GIS-based soil quality study to evaluate the effects of various land uses on soil quality by using the Arc GIS 10.3 software. The interpolation method used by this software determines the chemical characteristics of the vicinity where the sample was taken. The process entails several steps, beginning with the choice of the study area, data collection, analysis of the soil, and the creation of a soil quality index. The study area within Madurai was classified into urban, peri-urban, and rural regions. Identify the types of land uses that will be examined, such as urban, agricultural, forested, and aquatic bodies. Soil quality maps are generated for each kind of land use using GIS-based analysis, providing a comparison of the soil quality of various land uses. ("Application of GIS in general soil mapping of Bangladesh." 2017). This study will yield valuable insights into soil quality variations across different land uses in Madurai, enabling informed decision-making for urban development, agriculture, and environmental conservation. The workflow of this research work is depicted in Fig. 2.

Experimental analysis of soil quality

To provide precise and accurate results, testing processes for soil quality analysis should be methodical. The protocols should also be customised for the particular study area and research goals. A soil auger or a soil sampling tube should be used to gather soil samples. The depth of the plant's root zone should be used to gather the samples. To generate a representative sample, the samples should be collected from several sites within the land use type and well mixed (Ochola and Kerkides 2004).

Determination of soil pH

A significant determinant of soil quality is the pH of the soil. 20 g of soil are weighed and then added to 40 ml of distilled water. Using a glass rod, thoroughly stir it, and then let it stand for 30 min while stirring occasionally. With the buffer solution, adjust the pH meter. The electrodes should then be thoroughly washed and dried with a piece of filter paper. Place the electrodes in the beaker containing the soil water suspension and set the pH range on the switch (0 to 7 or 7 to 14). The pH level of the samples will be automatically shown

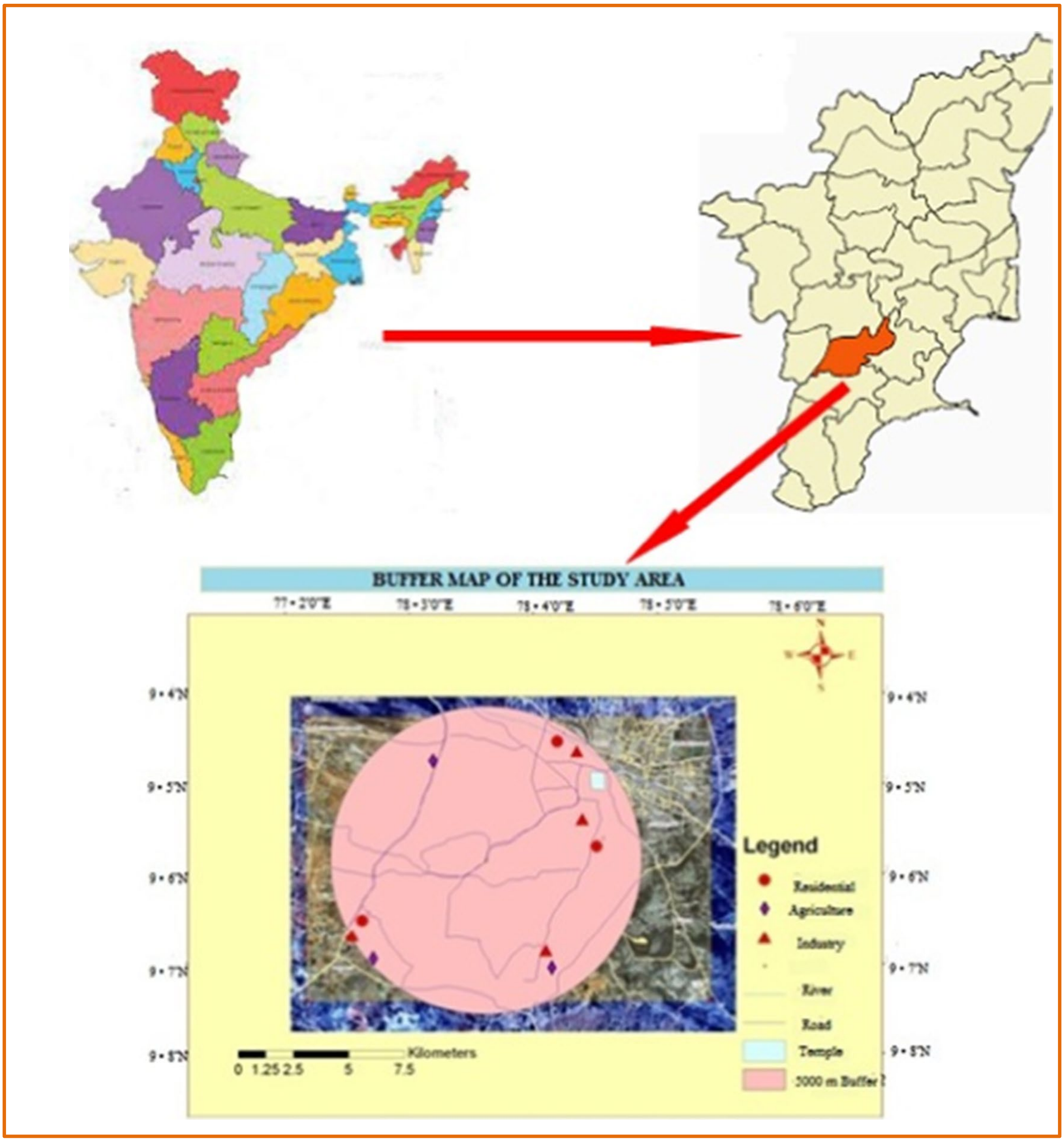

Fig. 1 The GIS based location map of the soil sampling site

by the metre reading. The optimal pH range for most plants is between 6.0 and 7.5. A soil pH outside of this range may lead to toxicities or nutritional shortages.

Determination of electrical conductivity

Transfer 20 g of soil to a 100-ml beaker after weighing it. Add 40 cc of water, stir it thoroughly, and then leave it alone for 30 min. Switch on the conductivity bridge. Use saturated 0.1N KCl solutions to test the instrument. Set the multiplier switch to an intermediate position, submerge the electrodes in the soil suspension, or, if the electrode is a pipette, suction the supernatant solution into the electrode bulb, and then rotate the main dial control until the magic eye of the null indicator is at its widest. Set the multiplier switch to a different position and repeat if no shadow angle is achieved or if the shadow angle is only at either extreme of the scale. The electrical conductivity is indicated by the scale readings multiplied by the multiplier switch position value. To determine the precise conductivity, multiply this by the cell constant listed on the cell itself.

Determination of nitrogen level in soils

Transfer 20 g of soil to a distillation flask after weighing it. Add 20 ml of distilled water and 1 ml or 1 g of liquid paraffin (to control frothing). To avoid bumping, put a few glass beads

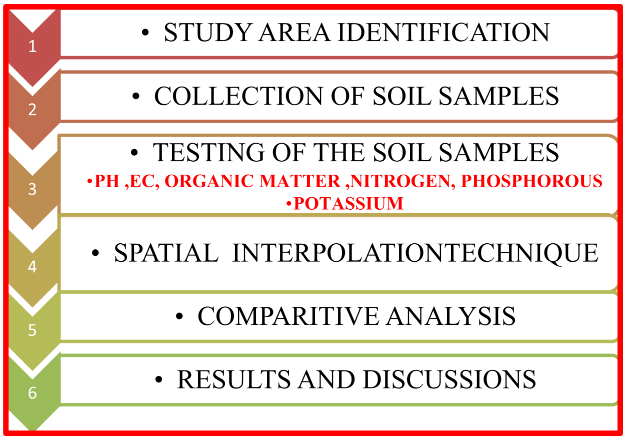

Fig. 2 Workflow of the Analysis

with holes before adding 100 ml of the 0.32% KMn04 solution and 100 ml of the 2.5 NaOH solution. Concentrate the mixture at a steady rate, collecting the freed ammonia in a 500-ml ice tumbler with 20 ml of boric acid and a double indicator. Once 100 ml of distillate has been gathered in the beaker, the distillation should continue for another 80 min. Calculate the available nitrogen content by titrating the ammonia obtained against the reference acid.

Determination of organic matter in soil

A vital sign of soil fertility is the amount of organic matter present. One gramme of soil sample (finely powdered and sieved via a 0.2-mm sieve) was collected into a 500-ml conical flask. Stir in 10 ml of potassium dichromate. Keep the flask on a wire gauge or an asbestos pad. Swirl the flask after adding 20 mL of concentrated sulfuric acid. Let it stand for 30 min. And 200 ml of distilled water, 10 ml of orthophosphoric acid, and 1 ml of diphenylamine indicator should all be added. Titrate until the blue colour turns green using ferrous ammonium sulphate or ferrous sulphate solution. Run a blank (soil-free) at the same time (Aslam, et al. 2021; Lovett, et al. 2009).

Determination of phosphorous level in soil

Fill a 50-mL Erlenmeyer flask with 2 g of soil, tapping the scoop on the funnel or flask to remove all of the soil. Each flask should contain 20 mL of the extracting solution, which should be shaken at 200 or more rpm for five minutes at a temperature of 24 to 27 °C. Use Whatman No. 42 filter paper or a paper of a comparable grade to filter extracts. If the extracts are unclear, refilter. Add 2 mL of the mixture to a test tube (or remove quantitatively all but 2 mL from the filter tube if colour is to be developed in the filter tube). Add 8 mL of the working solution to ensure thorough mixing and agitation (Gao et al. 2003; Hammam, et al. 2022; Jiang, et al. 2019). Check the optical density or percentage transmittance using a colourimeter or spectrophotometer set at 882 nm. For around 2 h, the colour remains steady. Aliquot 2 mL of each working standard to create a standard curve, then read and develop colour and intensity the same way with soil extracts. Convert the ppm concentration in the filtrate to the concentration in the soil by using the standard curve to determine the ppm P in the extracts:

ppm P in soil = ppm P in filtrate *10.

Lb/acre P in soil = ppm P in filtrate *20.

Determination of potassium level in soil

A 100-ml polythene shaking bottle should contain 5 grammes of soil. In a mechanical reciprocating shaker, add 25 ml of neutral nitrogen ammonium, and shake for 5 min. Dry test tubes, beakers, or injection vials should be used to filter through Whatman number 40 filter paper before collecting the filtrate. Use a flame photometer to determine the potassium content of the filtrate (Panday, et al. 2018).

Result and discussions

Tested results

According to the tested results of the soil quality analysis, the use of the land has a big impact on the quality of the soil. Significant disparities in soil quality between the various land use categories were indicated by the tested results. Decisions about land use that prioritise soil protection and restoration can be made using the findings (Abdellatif, et al. 2021; Rezaee, et al. 2020). The computed soil quality values are listed in Table 1.

By giving each soil property a weight based on how crucial it is to assessing soil quality, it is possible to create a soil quality index. The weight can be established via statistical analysis or assessment. The index can be used to compare the quality of the soil for various types of land uses. For the determination of variations in soil quality among the various land use categories, the data on soil quality should be evaluated using statistical tools. Land use planning and management decisions might be based on the findings of the analysis.

Kriging interpolation techniques for soil quality analysis

Spatial distribution of soil properties

The complex spatial patterns and changes in essential soil characteristics found throughout the study area illuminate the dynamic interaction between soil quality and land uses. The

Table 1 Result of Soil quality parameters of various landuses

Land uses	Location	pH	EC	Org mat	Nitrogen	Phosphorous	Potassium
Industrial regions	Site 1	8.58	0.19	0.261	56.4	3.45	45.2
	Site 2	4.2	0.12	0.26	63.8	4.22	501
	Site 3	7.48	0.57	0.26	56.35	2.43	98.34
	Site 4	7.13	0.97	0.25	56.1	3.2	249
Residential regions	Site 1	5.65	1.3	0.262	55.7	3.3	213.2
	Site 2	5.33	0.24	0.32	63.2	4.5	439.6
	Site 3	7.15	0.61	0.34	64	3.12	431.2
Agricultural regions	Site 1	6.12	1.96	0.27	55.8	3.32	212
	Site 2	8.4	0.34	0.31	51.4	3.22	75.6
	Site 3	6.67	1.86	0.22	52.8	3.16	221.2

utilisation of advanced GIS techniques, coupled with Kriging interpolation methods, empowers us to portray a detailed and nuanced picture of the distribution of soil properties essential for informed land management decisions. To analyse the soil quality in the study area, a methodology for soil quality evaluation using products was advanced by the creation of the soil quality map, which displayed the spatial variations in soil quality and could be used to direct the improvement of low-yield farmland and the reorganisation of agricultural structure. Kriging is a powerful geospatial interpolation technique commonly used in soil quality analysis and mapping to estimate values at unsampled locations based on the spatial autocorrelation of data points. GIS-based Kriging interpolation techniques are used to analyse soil quality and create spatially explicit maps for various land uses in Madurai, providing valuable insights for sustainable land management and urban planning (Maleki, et al. 2022).

Kriging maps unveiling the landscape of soil quality

Through the meticulous application of Kriging interpolation techniques, a series of informative maps are generated, each dedicated to a specific soil property. These maps, adorned with a rich palette of colours representing varying property values, offer a visual narrative of soil quality across the study area. The ArcGIS software's interpolation tools can be used to perform kriging after the interpolation grid and kriging parameters are defined. The result is a raster or vector layer that depicts the interpolation grid's estimated values for the variable of interest at each cell or point. Before applying Kriging, conduct a variogram analysis to assess the spatial autocorrelation of soil properties. Determine variogram parameters, including range, nugget, and sill, and then add them to the Kriging interpolation. Based on the variogram-assisted Kriging interpolation method used to interpolate soil property values at unsampled locations within the study area, once the Kriging model is established, it can be used to predict values at unsampled locations within the study area. These predictions are typically accompanied by estimates of prediction error or uncertainty. By examining the spatial arrangement of colours and gradients, readers can readily discern areas of high and low soil quality and identify regions where specific soil attributes exhibit pronounced spatial patterns (AbdelRahman and Tahoun 2019; Samaei et al. 2022; Nabiollahi et al. 2018).

The symbiosis of land use and soil properties

This research extends beyond simple soil property maps and cleverly superimposes the land use categories onto the Kriging maps to allow for the comparison of soil quality distributions and land use patterns. This symbiotic representation highlights the complex connections between soil health and land use. The results of kriging must be carefully examined to assess the precision, accuracy, and spatial distribution of the estimated values. In addition to a visual examination of the output maps, this can be accomplished using statistical metrics like mean error, root mean square error, or cross-validation. The computed values of soil quality parameters as well as the kriging methods for various land uses are listed in Table 2. Soil contamination maps developed using kriging techniques in GIS can provide useful insights into the distribution of contaminants in a particular area. These maps could enhance efforts to prevent or remediate soil pollution issues in Madurai city by assisting in identifying potential problem locations (Zeraatpisheh, et al. 2020; Taghipour, et al. 2022).

Table 2 Comparative analyses of estimated values of soil quality parameters with Kriging method

TESTS	MANUAL	KRIGING
pH	6.1	5.5
ELECTRICAL CONDUCTIVITY	0.5	0.43
ORGANIC MATTER	0.3	0.25
NITROGEN	61.3	67.34
PHOSPHOROUS	3.7	3.87
POTASSIUM	373.13	370.84

Interpreting the landscape of soil quality

The generated maps can be used to demonstrate the contamination's spatial distribution and help pinpoint regions that pose a higher or lower risk (Rahmanipour, et al. 2014; Borgogno-Mondino et al. 2015; Nael et al. 2004). Kriging maps for each soil property (e.g., pH, organic matter content, nutrient concentrations, soil texture) across various land use categories in the study area. The kriging thematic maps were generated using Arc GIS software based on various soil quality parameters, as depicted in Figs. 3, 4, 5, 6, 7 and 8. The experimental values and results obtained from the GIS interpolation technique are indicated in Table 2. These findings show that most of the industrial sector in the study area has an alkaline pH. According to the findings, the industrial area of the research site has been found to be a highly contaminated area. The obtained thematic map was

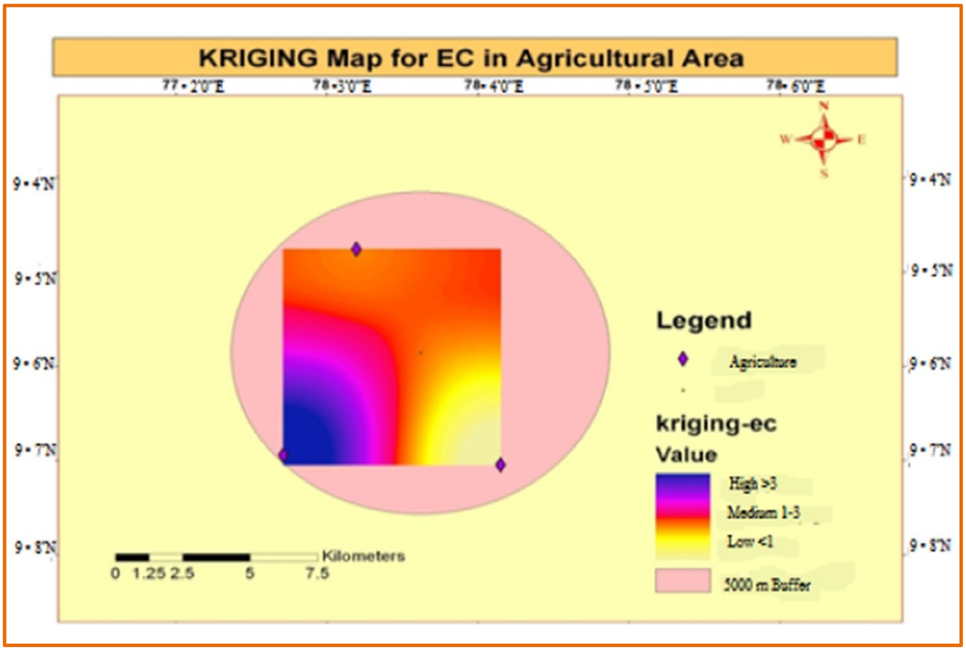

Fig. 3 Kriging map for agricultural area based on electrical conductivity

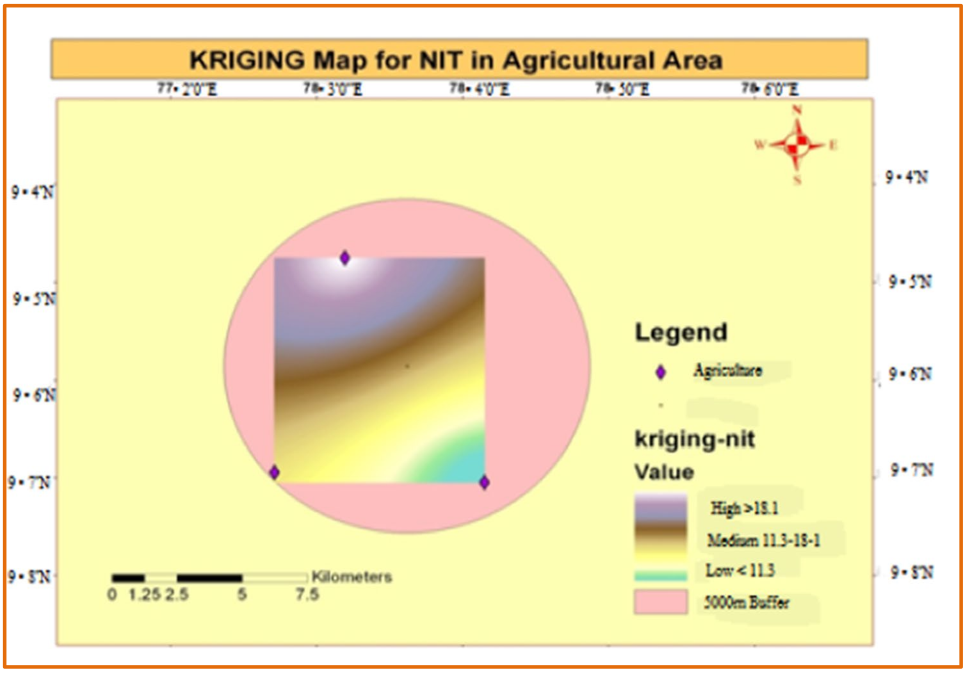

Fig. 4 Kriging map for agricultural area based on nitrogen

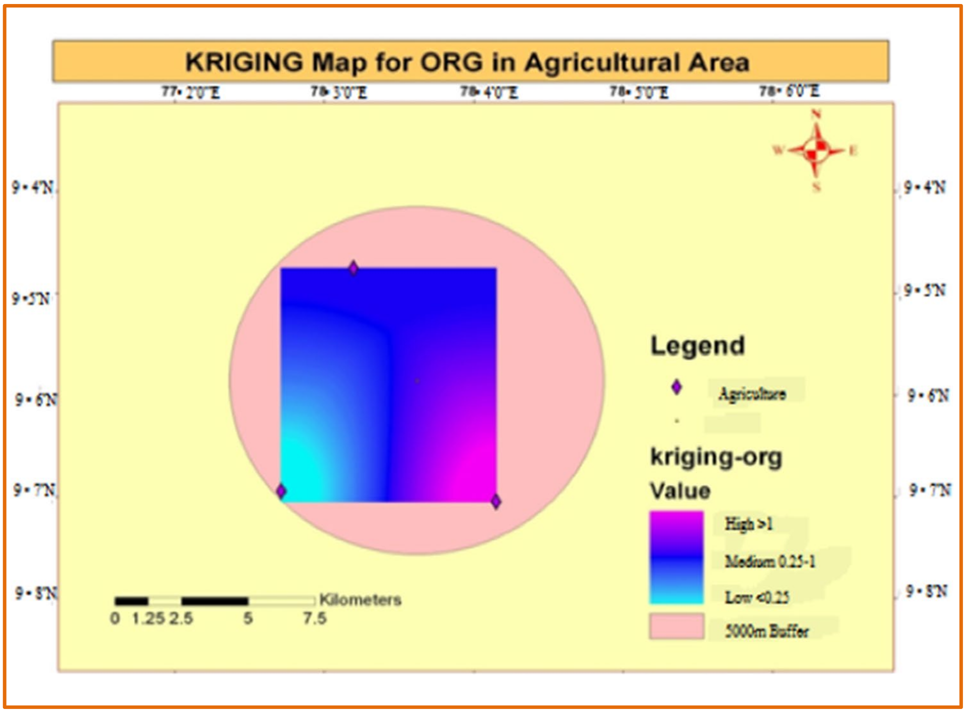

Fig. 5 Kriging map for agricultural area based on organic matter

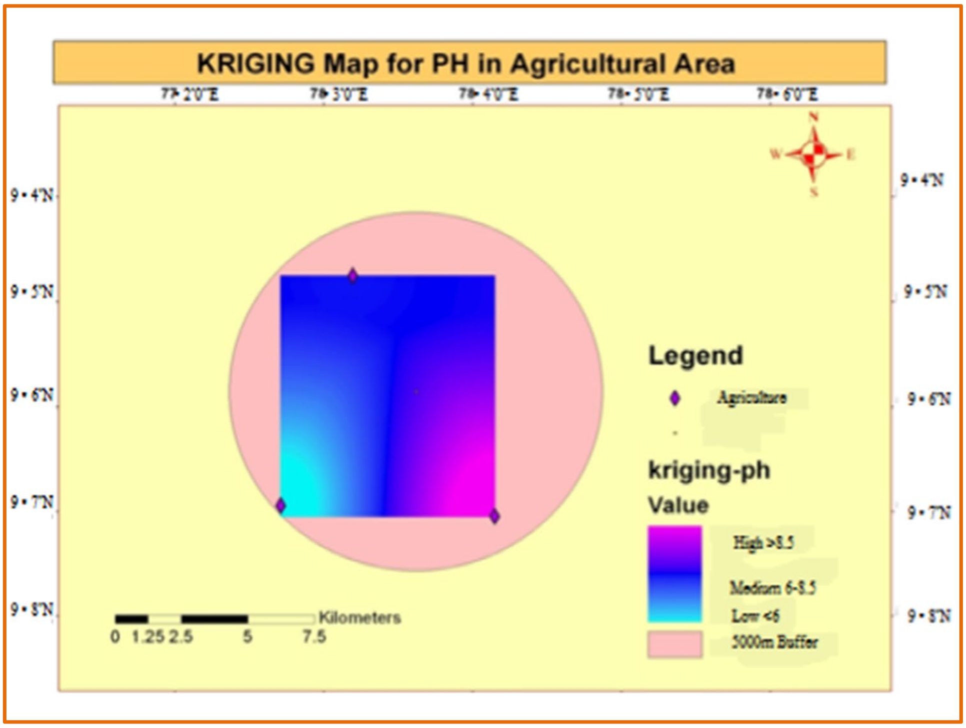

Fig. 6 Kriging map for agricultural area based on Ph

divided into low- to high-level risk zones based on the amount of contamination. The quality and quantity of the data used for interpolation affect the accuracy of the contamination maps, which is crucial to remember.

The observed patterns explore the effects of high- and low-quality soil regions on decisions regarding land management. Additionally, it investigates how environmental conditions, urbanisation, and land use

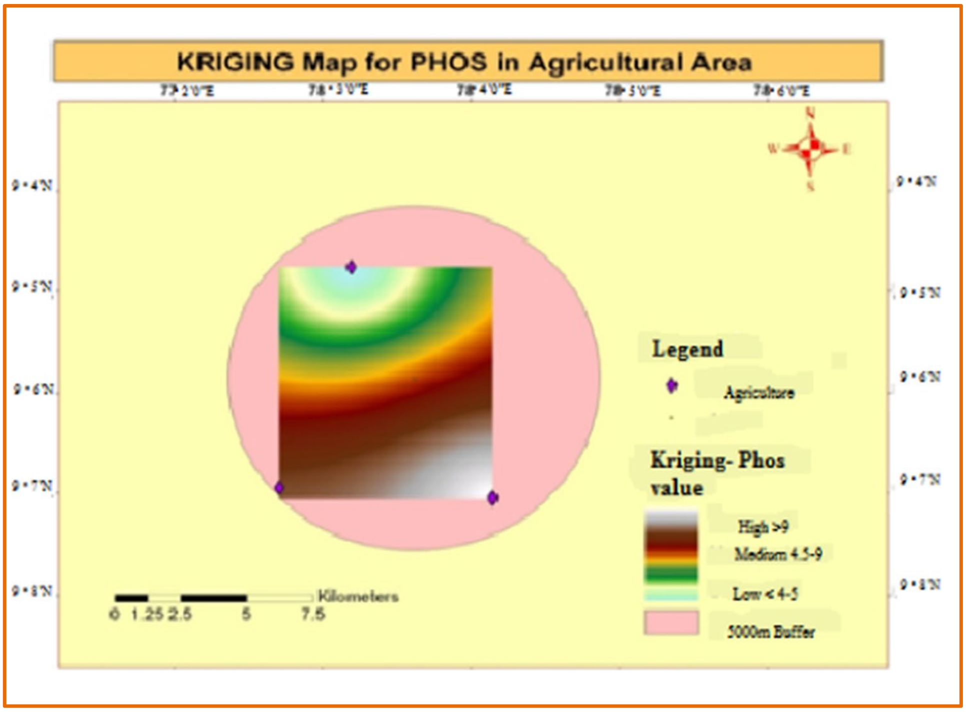

Fig. 7 Kriging map for agricultural area based on phosphorus

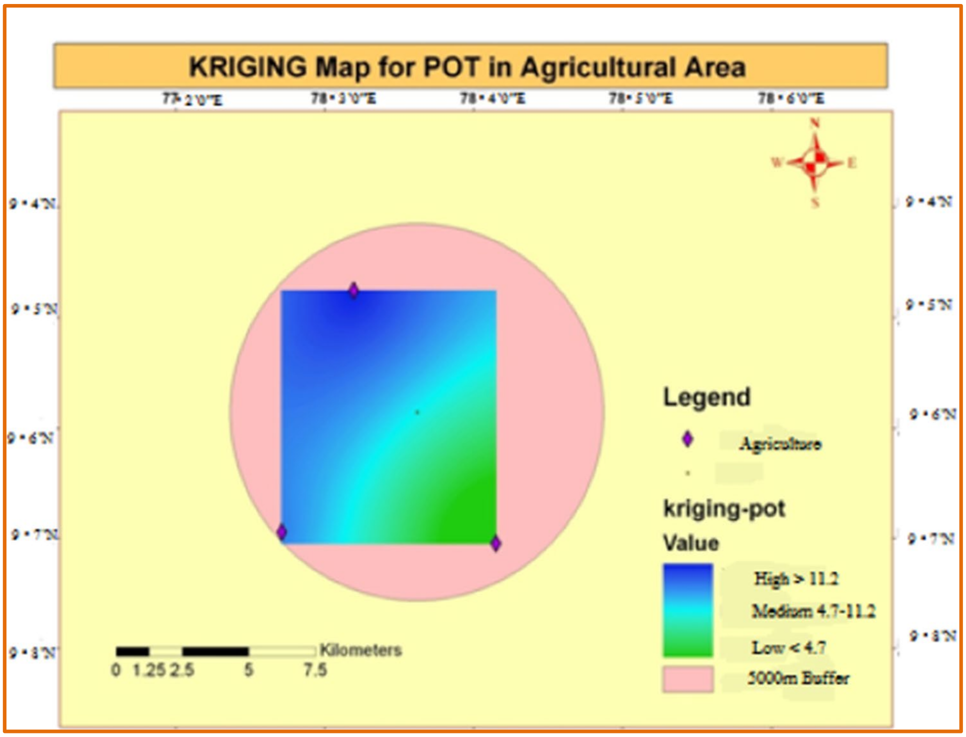

Fig. 8 Kriging map for agricultural area based on pottasium

practices affect the observed spatial variances. In essence, the “Spatial distribution of soil properties” section serves as a cartographic journey where GIS techniques, Kriging interpolations, and informed spatial analysis converge to unravel the intricate tapestry of soil quality across diverse land uses. It is within this section that readers will gain a profound understanding of the spatial dimensions of soil health, empowering them with knowledge essential for sustainable land management and environmental stewardship. To ensure the credibility and applicability of the maps, additional data and site-specific information should be used to evaluate them. Numerous studies have been done to evaluate soil quality with the use of various mathematical techniques for analysing strategy, indicator preference, weight optimism, and model design. Along with the approaches outlined above, the development of spatial scientific research has led to the development of geospatial technologies that provide robust tools for data processing and information collection [34–37].

Conclusion

GIS techniques were used to monitor and analyse the chemical characteristics of the soil. Using GIS to analyse soil quality can reveal important details about the condition and production of the soil in a specific area. GIS can assist in identifying regions that may need targeted interventions to improve soil quality, such as fertilisation or erosion control measures, by combining data on soil parameters, topography, land use, and other factors. Moreover, GIS can be used to monitor changes in soil quality over time, giving valuable insight into the efficacy of management strategies and the effects of shifting land uses on soil health. Sustainable land use strategies and policy decisions can be guided by this knowledge. The crops that are most suitable for farming in that area are suggested based on the soil contamination. The results of the tests were acquired, and the findings were compared to identify the area with the highest level of contamination. According to the findings, the industrial area was discovered to be the most contaminated area. It also recommended the best crops for agriculture in those areas based on the chemical characteristics of the soil.

Author contribution C.T.A.: design, research, methodology, interpretation, reviewing and writing.

Data Availability The data that support the fndings of this study are not openly available and are available from the corresponding author upon reasonable request.

Declarations

Conflict of interest The authors declare no competing interests.

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