OPEN ACCESS
International Journal of Innovations in Science & Technology

Assessment of Soil Fertility in Jhelum, Punjab, Pakistan, using Geospatial Technologies

Israr- ul- Haq, Hafiza Huma Haider, and Kashif Mahmood*
Department of Geography, Government College University, Faisalabad, Pakistan
***Correspondence**: kashif.mahmood@gcuf.edu.pk

Citation | Haq. I. U, Haider. H. H, Mahmood. K, "Assessment of Soil Fertility in Jhelum, Punjab, Pakistan using Geospatial Technologies", IJIST, Vol. 07 Issue. 04 pp 2236-2246, September 2025

Received | August 10, 2025 **Revised |** August 30, 2025 **Accepted |** September 03, 2025 **Published |** September 07, 2025.

Soil fertility is a key factor influencing agricultural productivity and sustainability. This study evaluates the spatial distribution of essential soil chemical properties-pH, electrical conductivity (EC), available phosphorus (P), available potassium (K), organic matter (OM), and saturation percentage in Tehsil Jhelum, Pakistan. A total of 160 topsoil samples (0–15 cm depth) were collected using random sampling, with GPS coordinates recorded for each site. Laboratory analysis was conducted to assess the nutrient status of the soils, and Ordinary Kriging interpolation was used within a GIS framework to generate spatial distribution maps. The findings revealed notable variability across the region. Soil pH ranged from 4.3 to 7.8 (mean: 7.44), indicating mostly neutral to slightly alkaline conditions. EC values ranged from 0.49 to 1.40 dS/m, suggesting low to moderate salinity. Available phosphorus varied between 1.2 and 7.8 mg/kg, while available potassium ranged from 60 to 180 mg/kg, showing moderate fertility levels. Organic matter content was uniformly low (0.20–0.66%), with a mean of 0.42%, highlighting poor organic inputs. Saturation levels varied from 22% to 72%, displaying a layered spatial pattern. The spatial heterogeneity observed in soil nutrients underscores the need for site-specific nutrient management and precision agriculture practices. The generated maps serve as valuable tools for farmers, agronomists, and policymakers to make informed decisions aimed at improving crop productivity and maintaining soil health in the region.

Keyword: Soil Fertility, Spatial Variability, Kriging Interpolation, Geographical Information System (GIS), Jhelum, Pakistan

Introduction:

Crop yields are strongly influenced by soil fertility [1]. Understanding and evaluating the fertility status of soils across different regions is crucial for promoting sustainable and cost-effective agricultural practices [2]. An effective way to tackle these challenges is through the creation of soil fertility maps using Geographic Information Systems (GIS). Soil testing provides essential information about the availability and concentration of nutrients within the soil, which is crucial for informed decision-making. Assessing soil fertility levels is vital to achieving higher yields and profitability in Tehsil Jhelum. Balanced nutrient management supports higher yields and preserves soil health over the long term. While numerous investigations have examined soil fertility in South Asia [3][4][5][6], this study specifically evaluates the fertility status of soils in Tehsil Jhelum. Agriculture accounts for nearly 24% of Pakistan's Gross Domestic Product (GDP), with District Jhelum encompassing about 274,771 acres of cultivated land [7]. The region supports both irrigated and rain-fed farming systems. However, a majority of farmers lack formal education and awareness of modern agricultural techniques, including appropriate fertilizer application and irrigation management. Consequently, fertilizers are frequently applied without soil testing, which can result in crop damage and considerable economic losses. This study hypothesizes that soil properties vary significantly across Tehsil Jhelum, thereby affecting soil fertility status and nutrient distribution patterns. Recognizing the importance of spatial variability in soil properties, this study primarily aims to assess soil fertility status and its spatial distribution in Tehsil Jhelum. This analysis aims to support site-specific soil management practices that enhance agricultural productivity and promote sustainable land use. This research presents a novel approach by employing kriging interpolation techniques to assess and map the spatial variability of soil fertility in Tehsil Jhelum. Unlike conventional soil fertility assessments, kriging enables the estimation of unknown values and generates a continuous surface, offering a more precise and visual representation of fertility distribution across the region. This method enhances decision-making for site-specific nutrient management and contributes to precision agriculture practices in the study area.

Objective of the Study:

Given the critical importance of spatial variation in soil properties, the primary objective of this study is to analyze the soil fertility status and its spatial distribution patterns in Tehsil Jhelum. This analysis aims to support site-specific soil management practices that enhance agricultural productivity and promote sustainable land use.

Novelty Statement:

This research presents a novel approach by employing kriging interpolation techniques to assess and map the spatial variability of soil fertility in Tehsil Jhelum. Unlike conventional soil fertility assessments, kriging enables the estimation of unknown values and generates a continuous surface, offering a more precise and visual representation of fertility distribution across the region. This method enhances decision-making for site-specific nutrient management and contributes to precision agriculture practices in the study area.

Material and Methods:

The study was conducted in Tehsil Jhelum, located at 32.9271° N latitude and 73.7314° E longitude. According to the 2023 population census, the total population of Tehsil Jhelum is 507,788, with a population density of 866.53 persons per square kilometer and an urban population proportion of 61.53% [8]. District Jhelum comprises four tehsils and 44 union councils [9]. The location of the study area is illustrated in Figure 1.

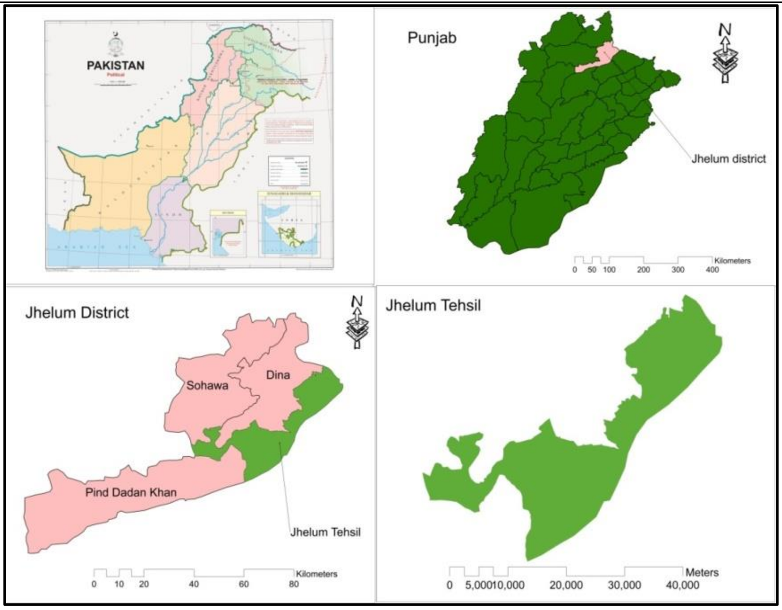


Figure 1. Study Area-Jhelum location in Pakistan

Soil samples were collected through a field survey conducted during October and November using a random sampling technique to ensure unbiased representation across different agricultural zones. A total of 160 topsoil samples were collected at a depth of 0–15 cm, which is the most active root zone and critical for nutrient uptake. Each sample site was geo-referenced using a Global Positioning System (GPS) device to facilitate spatial mapping. The spatial distribution of the sampling points is shown in Figure 2. Soil was extracted using a standard iron auger, placed into labeled polyethylene bags, and sealed properly to prevent contamination during transport to the laboratory.

All soil samples were air-dried, crushed, and passed through a 2 mm sieve before analysis. The following physicochemical parameters were analyzed:

Soil pH is determined using a pH meter in a 1:1 soil-to-water suspension, indicating the soil's acidity or alkalinity. Electrical Conductivity (EC) is measured to assess soil salinity, which can affect plant growth and nutrient availability. Organic Matter (OM) content was estimated using the Walkley–Black method, a chemical oxidation technique that quantifies the amount of decomposed plant and animal residues in the soil. Available Nitrogen (N) was determined through the Kjeldahl method, which measures the total nitrogen content accessible for plant uptake. Available Phosphorus (P) is measured using the Olsen method, a procedure suitable for neutral to alkaline soils that extracts Phosphorus in a form available to plants. Finally, Available Potassium (K) is extracted with ammonium acetate and analyzed via flame photometry, allowing for the quantification of potassium essential for various plant physiological processes. Together, these analyses provide a comprehensive understanding of soil fertility and nutrient status.

Spatial analysis was performed in ArcGIS, where the kriging interpolation technique was applied to generate continuous surface maps of soil fertility parameters. Kriging is particularly effective in predicting values at unsampled locations based on the spatial autocorrelation of measured data points. It also provides estimation variance, which helps in understanding the reliability of predicted values. Due to the unavailability and limited reliability of secondary data, this study primarily relied on field-based primary data collection. Following data collection, soil samples were analyzed in the laboratory, where their physical and chemical properties were tested at the Rawalpindi Soil and Water Testing Laboratory. Standard soil testing procedures were used to analyze selected physicochemical properties. Several researchers have employed Geographic Information Systems (GIS) for soil data analysis.

The spatial variation of soil chemical properties was demonstrated by Ilagan using DIVA-GIS [10]. The Inverse Distance Weighting (IDW) method was applied by Kumar and his team to map soil fertility [11]. Karajanagi used the Geostatistical Analyst tool to depict the soil nutrients [12]. Georeferenced points were first plotted on Google Earth, and the resulting KML file was then converted into a point shapefile for further analysis. Spatial distribution maps of soil fertility variations were generated using geostatistical kriging analysis in ArcGIS 10. The Ordinary Kriging method was applied as an interpolation technique, based on Tobler's first law of geography: "everything is related to everything else, but near things are more related than distant things The Ordinary Kriging method was used as the interpolation technique according to Tobler's law "everything is related with everything else but nearest things are more related than distant things" [13]. Ordinary kriging is the most widely used form of kriging. Constant mean values are assumed in this, but with a specific prominence on the spatial location of the sample points within the nearest neighborhood for estimating unknown values [14]. Many soil scientists and scholars have utilized kriging to study soil variations [15][16][17][18][19][20][21][22]. Chaudhary and his fellows explored the use of perceptible near-infrared (vis-NIR) spectroscopy as a fast and non-destructive substitute for forecasting soil properties and Soil quality indices [23]. Hammad and his fellows used a geostatistical approach based on ordinary kriging to produce soil property and fertility maps [24].

Figure 2 illustrates the spatial distribution of 160 soil sampling sites across Tehsil Jhelum. Each point on the map represents a location where a topsoil sample (0–15 cm depth) was collected for fertility analysis. Sampling points were systematically distributed across the tehsil, encompassing both irrigated and rain-fed agricultural areas to achieve comprehensive spatial representation. The map includes key spatial elements such as administrative boundaries, river networks, a scale bar, and a north arrow to aid in geographic orientation. Such spatial distribution is essential for geostatistical analysis and for producing accurate soil fertility maps through kriging interpolation.

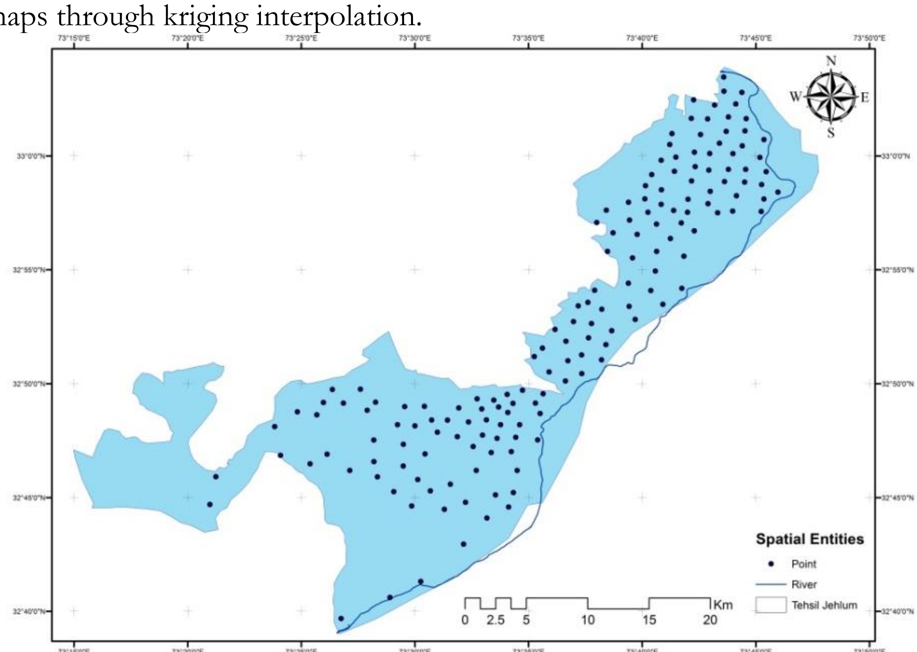


Figure 2: Spatial distribution of soil sampling sites in Tehsil Jhelum.

Results:

Figure 3 presents the spatial distribution of a key soil fertility parameter in Tehsil Jhelum, interpolated using the Ordinary Kriging method. The colored raster surface represents the concentration gradient of the nutrient, with values ranging from 1.0 to 4.4. The legend categorizes values into nine intervals: blue and green tones (1.0–1.9) denote low concentrations, yellow to orange shades (2.0–3.4) represent moderate levels, and red tones (3.5–4.4) indicate high nutrient availability. The black dots overlaid on the map represent the 160 soil sampling locations, which were used to generate the interpolated surface.

The spatial pattern indicates significant variability in nutrient concentration across the tehsil. The central and southern parts of Tehsil Jhelum exhibit higher concentrations, as shown by the dense red and orange areas. In contrast, northern and northeastern regions demonstrate lower levels, reflected in blue and light green zones. This variation may be attributed to differences in land use, cropping intensity, organic input, irrigation practices, or topographical influences. The histogram and boxplot included at the top of the figure further depict the distribution characteristics of the data, revealing a slightly right-skewed distribution with a mean value of 2.54 and a standard deviation of 0.78, suggesting moderate variability. The kriging model, based on spatial autocorrelation, enables precise estimation of nutrient levels in unsampled locations, providing a valuable decision-making tool for site-specific fertilizer application and sustainable nutrient management in the region.

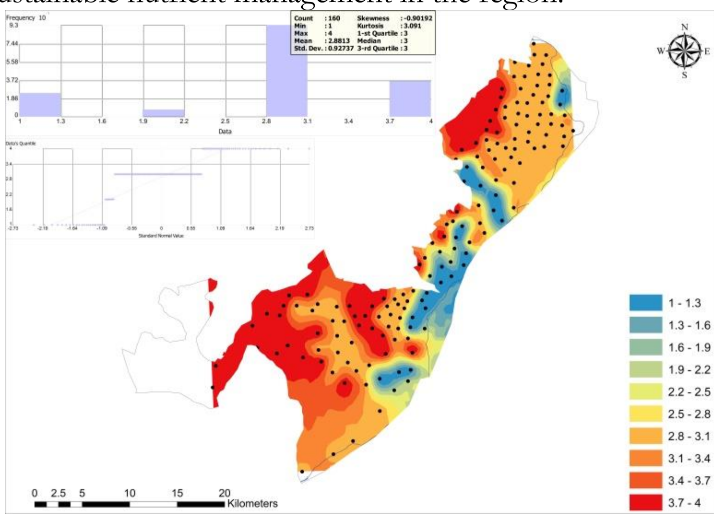


Figure 3. Spatial distribution of a selected soil fertility parameter in Tehsil Jhelum using Ordinary Kriging interpolation.

Since soil texture is a qualitative variable, it was converted into a quantitative form for kriging analysis. The coding scheme used was: clay loam = 1, clay = 2, loam = 3, and sandy loam = 4. The kriging analysis reveals that a major portion of the tehsil Jhelum is covered with sandy loam and loamy soils. 22.5% of the soils are classified as sandy loam, and 58.12% of % soils are categorized as loamy soils. These two classes cumulatively make a major portion that is 80.62% of the total sampling sites in Jhelum. Clay loam accounted for 15% of the total samples, whereas clay soils represented only 4%.

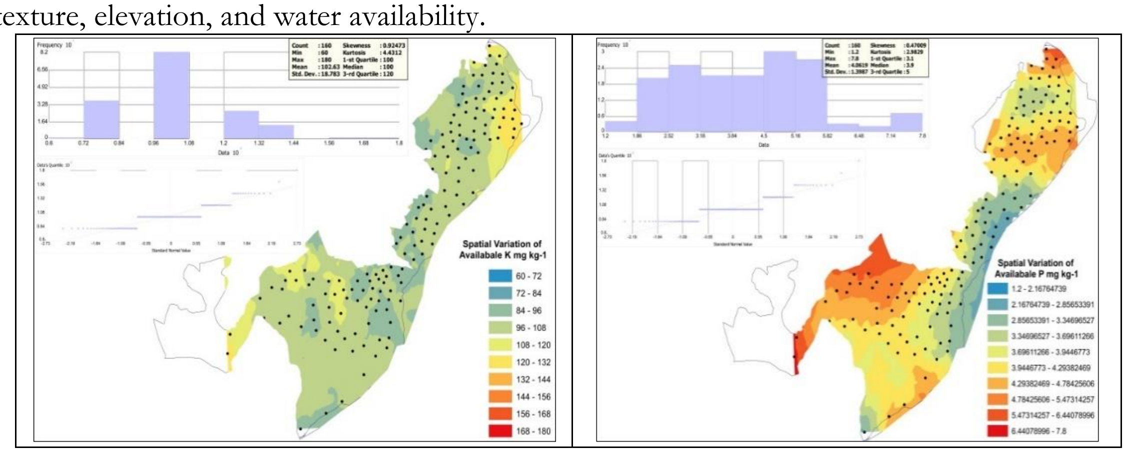
Table 1 presents the summary statistics of key soil properties in Tehsil Jhelum based on 160 topsoil samples. The saturation percentage ranged from 22% to 72%, with a mean of 39.11%, indicating moderate water-holding capacity in most areas. Soil pH values ranged from 4.3 to 7.8, with an average of 7.44, suggesting that the majority of soils are slightly alkaline, though some acidic patches exist. Electrical conductivity (EC) values were relatively low (0.49–1.40 dS/m), with a mean of 0.76 dS/m, indicating non-saline to slightly saline conditions suitable for crop production. The availability of phosphorus varied from 1.2 to 7.8 mg/kg, averaging 4.06 mg/kg, which reflects a generally low to moderate P status across the region. The concentration of available potassium ranged from 60 to 180 mg/kg, averaging 102.63 mg/kg, which is generally sufficient to meet crop requirements. Organic matter content was very low, ranging from 0.2% to 0.66%, with a mean of 0.43%, indicating poor organic inputs and the necessity of organic amendments to enhance soil health and fertility. Table 1. Salient Soil Properties of the Study Area (Tehsil Jhelum)

Sr. No	Soil Characteristic	Range	Mean
1	Saturation (%)	22 – 72	39.11
2	pH	4.3 – 7.8	7.44
3	Electrical Conductivity (dS/m)	0.49 – 1.40	0.76
4	Available Phosphorus (mg/kg)	1.2 – 7.8	4.06
5	Available Potassium (mg/kg)	60 – 180	102.63
6	Organic Matter (%)	0.2 – 0.66	0.43

Data Source: Primary data collected through field survey (2024).

Figure 4 depicts the spatial distribution of major soil chemical properties in Tehsil Jhelum, including potassium, phosphorus, organic matter, pH, electrical conductivity (EC), and saturation percentage. The available potassium content ranges from 60 to 180 mg/kg, with an average value of 102.62 mg/kg. The inset map reveals that the majority of the agricultural land is dominated by the 96–108 mg/kg potassium class (fourth class color), indicating moderately sufficient K levels. Isolated patches with higher potassium concentrations (120–132 mg/kg) are visible in the northeastern region, suggesting localized nutrient accumulation.

The available phosphorus content varies between 1.2 and 7.8 mg/kg, with an average of 4.06 mg/kg, indicating low to moderate P availability across most areas. The spatial pattern of organic matter shows concentrations ranging from 0.20% to 0.66%, with a mean of 0.42%, highlighting generally poor organic matter content in the soils of Tehsil Jhelum. Although marginally higher levels were observed in the central zones, organic matter across the region is generally low, suggesting poor organic input or residue incorporation. The soil pH ranges from 4.3 to 7.8, with an average of 7.44, indicating mostly neutral to slightly alkaline conditions. Spatially, the pH is relatively uniform across the tehsil, with values mostly falling between 7.3 and 7.6, except for a small localized acidic patch in the central region. Electrical conductivity (EC) values range from 0.49 to 1.40 dS/m, with an average of 0.76 dS/m, suggesting non-saline to slightly saline soils, which are generally suitable for crop cultivation. The saturation percentage varies between 22% and 72%, with a mean of 39.11%. The saturation pattern reveals a gradual, layered increase from west to east, likely influenced by soil texture, elevation, and water availability.



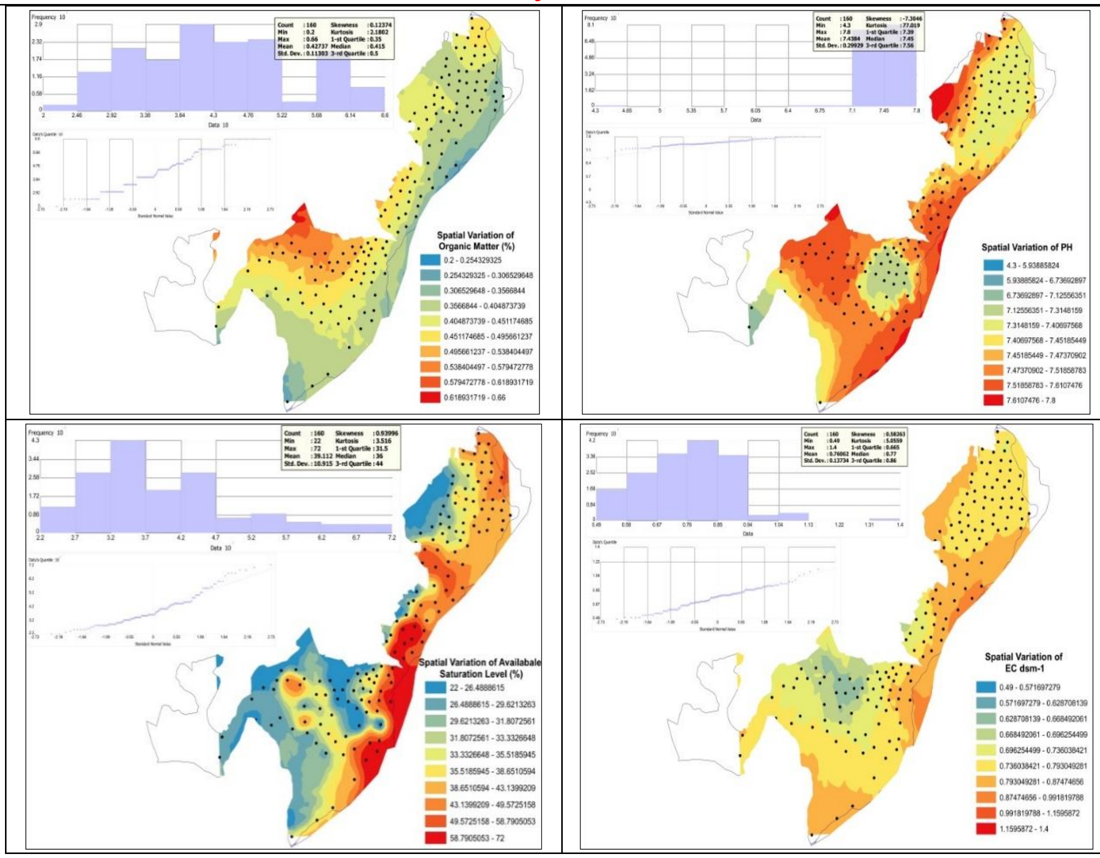


Figure 5. Spatial patterns of soil physico-chemical properties in Tehsil Jhelum based on kriging interpolation

Discussions:

Soil textural classes of Jhelum tehsil were found to be sandy loam, loam, clay loam, and clay. Mostly loam-structured soils are present in Jhelum, as about 58% soils are loam. As per the saturation level, it varies from 30% to 60 % and it is suitable for agricultural production. All soils were found to be free from salinity and are suitable for the cultivation of all crops. Mostly, soils of the study area lie in the natural category of pH value (6.6 to 7.5), which is good for agriculture. Organic matter content is below 0.86% across the area, indicating a widespread deficiency in soil organic matter. The low organic matter content in the tehsil can be attributed to extremely high summer temperatures (often exceeding 45 °C in June and July), which accelerate decomposition, along with farmers' practices of not applying farmyard compost and completely removing crop residues, leaving soils fallow. The trend of green compost is also not observed. Soils are poor in Available P, but mostly soils are in satisfactory condition in Available K. Phosphorus is a very important element for agriculture. If the available phosphorus content in the soil is too low, plant and crop growth are adversely affected [25]. Soil in the study area was characterized as weakly to strongly alkaline and generally low in organic matter. Severe deficiency of bioavailable zinc and foliar zinc was found in the studied area. Bioavailable zinc exhibited strong site-dependence in the surface layer (0–15 cm) and moderate site-dependence in the subsurface layer (15–30 cm), while foliar zinc exhibited only moderate site-dependence [26]. Variations in soil in the district of Jhelum were studied. It was concluded that an increasing extent of erosion due to slope effect can further deteriorate soil properties [27]. A comparative study of the Jhelum district based on soil fertility and characterization was conducted. The findings revealed that 89.76 % soil samples had pH levels 7.5-8.5while 56.441 % were within acceptable salinity and sodicity levels (EC < 4 dS/m. 76.363% of % samples showed a medium texture. Soil samples were significantly deficient in organic matter (88.493% had less than 0.86% OM) and available phosphorus (99.012% had less than 7 mg P/kg soil). While more than 99% soils were under the satisfactory range of K (80-180 mg/Kg) [28]. The findings of this research are quite similar to those of the present study. This study can be further expanded by using temporal data and adding comparative analysis by comparing soil fertility variations with other districts to suggest a suitable cropping pattern for agricultural regions in Pakistan.

One of the primary challenges faced during the study was the potential for contamination of soil samples during collection and handling. To minimize this risk, each sample was collected using a clean iron rod, placed in separate, labeled polyethylene bags, and sealed properly to avoid cross-contamination. However, despite these precautions, the possibility of minimal contamination during fieldwork cannot be entirely ruled out.

The vast geographical expanse of Tehsil Jhelum posed logistical and financial challenges in collecting a large number of samples uniformly across the region. To address this, a random sampling technique was adopted to ensure spatial representativeness while remaining within budgetary and time constraints. Additionally, due to limited local facilities, all soil samples were analyzed at the Soil and Water Testing Laboratory in Rawalpindi, which involved added cost and coordination.

Recommendations:

Based on the spatial analysis of soil chemical properties in Tehsil Jhelum, the following suggestions and recommendations are proposed to improve soil health and agricultural productivity in the region:

The observed spatial variability in nutrient availability—particularly potassium and phosphorus—suggests that a blanket approach to fertilizer application is inefficient. Farmers should adopt site-specific nutrient management (SSNM) based on localized soil fertility maps to optimize input use and reduce costs.

The consistently low organic matter content indicates poor soil structure and reduced microbial activity. It is recommended to increase the use of farmyard manure, compost, and green manuring to improve organic carbon content and overall soil fertility.

Soil testing facilities at the tehsil or union council level should be made more accessible and affordable. Awareness campaigns and training workshops can encourage farmers to regularly test their soils before applying fertilizers.

Farmers, especially in rain-fed areas, often lack knowledge of modern soil and nutrient management practices. Capacity-building programs focusing on sustainable soil fertility management, pH balancing, and EC monitoring should be introduced through agricultural extension services.

The spatial maps generated through kriging interpolation can serve as the foundation for decision support systems to guide crop planning and resource allocation at the farm and policy levels.

Government policies should support the adoption of precision agriculture technologies and GIS-based farm advisory systems by offering incentives and integrating them into national agricultural development plans.

Continuous monitoring of soil properties through periodic surveys and spatial mapping should be institutionalized to track changes in soil health and evaluate the effectiveness of interventions over time.

Conclusion:

This study highlights the spatial variability of key soil chemical properties—pH, electrical conductivity, available phosphorus, available potassium, organic matter, and saturation percentage—across agricultural lands in Tehsil Jhelum. Using geostatistical kriging and GIS-based mapping, the findings reveal significant heterogeneity in soil fertility, with certain regions showing nutrient deficiencies and others exhibiting relatively optimal conditions. The overall low levels of organic matter and phosphorus emphasize the urgent need for improved organic inputs and balanced fertilizer use. The spatial distribution maps produced in this research serve as practical tools for implementing site-specific nutrient management and promoting precision agriculture in the region. By adopting tailored soil management practices, farmers and agricultural planners can enhance crop productivity while preserving long-term soil health. The approach and findings of this study can also be extended to other regions facing similar soil fertility challenges.

Acknowledgement:

The authors express their sincere gratitude to the Soil and Water Testing Laboratory, Rawalpindi, for their valuable support in conducting the soil sample analysis. Their assistance in testing and interpretation of results, as well as their guidance in suggesting suitable cropping patterns based on soil fertility data, was instrumental to the success of this research.

Conflict of Interest:

The authors declare that there is no conflict of interest regarding the publication of this research.

Author's Contribution Statements:

Israr-ul-Haq executed field work and wrote a literature review. Hafiza Huma Haider did write up and applied spatial analysis, whereas Kashif Mahmood conceptualized the methodology and concluded the results.

References:

[1] M. D. P. P. Vijayakumar R., Arokiaraj A., "Micronutrients and their Relationship with Soil Properties of Natural Disaster Proned Coastal Soils," *Res.J.chem.sci*, vol. 1, no. 1, pp. 8–12, 2011, [Online]. Available: https://isca.me/rjcs/Archives/v1/i1/3.php

[2] R. and S. M. Singh, "Available macro nutrients (N, P, K and S) in the soils of Chiraigaon block of district Varanasi (UP) in relation to soil characteristics.," *Indian J. Sci. Res.*, vol. 3, pp. 97–101, 2012, [Online]. Available: https://www.semanticscholar.org/paper/Available-macro-nutrients-(N%2C-P%2C-K-and-S)-in-The-of-Singh-Mishra/16d3519a5c578f55853e72f40cf4c39a8d0bba21

[3] Q. J. Aamer, Muhammad Iqbal, Eng. Faheem Iqbal, Dr. Mohsin, "Physico-Chemical Properties and Fertility Status of District Rahim Yar Khan, Pakistan," *J. Environ. Earth Sci.*, vol. 5, no. 19, 2015, [Online]. Available: https://core.ac.uk/download/pdf/234664406.pdf

[4] Z. Akram, S. Hussain, M. Mansoor, M. Afzal, A. Waqar, and I. Shabbir, "Soil Fertility and Salinity Status of Muzaffargarh District, Punjab Pakistan," *Univers. J. Agric. Res.*, vol. 2, no. 7, pp. 242–249, Oct. 2014, doi: 10.13189/UJAR.2014.020703.

[5] R. S. Belurkar and M. S. Yadawe, "A survey of soil fertility status of cashew nut gardens of South Goa, India.," *Int. J. Appl. Biol. Pharm. Technol.*, 2011, Accessed: Oct. 02, 2025. [Online]. Available: http://imsear.searo.who.int/handle/123456789/162222

[6] et al. Hassan, I., "Determination of optimum cropping patterns in the Faisalabad division (Pakistan)," *Int J Agric Biol*, vol. 6, no. 5, pp. 901–903, 2004, [Online]. Available: https://www.researchgate.net/publication/237535862_Determination_of_Optimum_Cropping_Pattern_in_the_Faisalabad_Division_Pakistan

[7] GOP, "Land Use Statistics, P.I.T. Board, Editor," *Crop Report. Serv. Gov. Punjab*, 2021.

[8] GOP, "7th Population and Housing Census - Detailed Results ," Government of Pakistan: Islamabad. Accessed: Oct. 02, 2025. [Online]. Available: https://www.pbs.gov.pk/digital-census/detailed-results

[9] GOP, "District Profile, P.I.T. Board, Editor," *Gov. Punjab*, 2017, [Online]. Available: https://pc.gov.pk/uploads/archives/DEPIx_Updated-Final-Report.pdf

[10] et al Ilagan, L.A., "Soil Fertility Evaluation For Rice Production In Catanduanes

Province, Philippines," *Int. J. Sci. Technol. Res.*, vol. 3, no. 12, pp. 81–87, 2014.
[11] A. Kumar, "Evaluations of soil Fertility Status of Available Major Nutrients (N, P & K) and Micro Nutrients (Fe, Mn, Cu & Zn) in Vertisol of Kabeerdham District of Chhattisgarh, India," *Int. J. Interdiscip. Multidiscip. Stud.*, vol. 1, no. 10, pp. 72–79, 2014, [Online]. Available: https://www.ijims.com/uploads/8ae6072f8d73f2d1acb7OC13.pdf
[12] M. A. Ravikumar, PARAMESHGOUDA L PATIL, "GIS Mapping of available nutrients status of Dundur village under Malaprabha command area in Karnataka," *J. Farm Sci*, pp. 37–40, 2016, [Online]. Available: https://www.researchgate.net/publication/259492810_Mapping_of_Nutrients_Status_of_48A_Distributary_of_Malaprabha_Right_Bank_Command_of_Karnataka_by_GIS_Technique_I-Major_Nutrients
[13] T. I. S. Aatira Hilal, Shabir Ahmed Bangroo, Nayar Afaq Kirmani, Javaid Ahmed Wani, Asim Biswas, Mohammad Iqbal Bhat, Khushboo Farooq, Owais Bashir, "Chapter 19 - Geostatistical modeling—a tool for predictive soil mapping," *Remote Sens. Precis. Agric.*, pp. 389–418, 2024, doi: https://doi.org/10.1016/B978-0-323-91068-2.00011-4.
[14] N. Waters, "Tobler's First Law of Geography," *Int. Encycl. Geogr.*, pp. 1–13, Mar. 2017, doi: 10.1002/9781118786352.WBIEG1011.
[15] Chong-Yang Shen, Yue-Fei Xu, Jing-Wei Jin, "Effect of land use and soil management practices on soil fertility quality in North China cities' urban fringe," *African J. Agric. Res.*, vol. 6, no. 9, pp. 2059–2065, 2011, [Online]. Available: https://www.researchgate.net/publication/228422035_Effect_of_land_use_and_soil_management_practices_on_soil_fertility_quality_in_North_China_cities'_urban_fringe
[16] M. K. W. Wei Ouyang, Yushu Shan, Fanghua Hao, Siyang Chen, Xiao Pu, "The effect on soil nutrients resulting from land use transformations in a freeze-thaw agricultural ecosystem," *Soil Tillage Res.*, vol. 132, pp. 30–38, 2013, doi: https://doi.org/10.1016/j.still.2013.04.007.
[17] Guangrong Shen, Zhenhua Qian, "Spatial analysis and assessment of soil fertility by using GIS and kriging method," *IEEE World Autom. Congr.*, 2010, [Online]. Available: https://www.researchgate.net/publication/251969251_Spatial_analysis_and_assessment_of_soil_fertility_by_using_GIS_and_kriging_method
[18] R. C. Gouri Sankar Bhunia, Pravat Kumar Shit, "Assessment of spatial variability of soil properties using geostatistical approach of lateritic soil (West Bengal, India)," *Ann. Agrar. Sci.*, vol. 16, no. 4, pp. 436–443, 2018, doi: https://doi.org/10.1016/j.aasci.2018.06.003.
[19] B. M. Dinesh Panday, "Digital soil mapping in the Bara district of Nepal using kriging tool in ArcGIS," *PLoS One*, 2018, doi: https://doi.org/10.1371/journal.pone.0206350.
[20] M. J. K. Nazia Tahir, "Analysis of soil fertility and mapping using geostatistical information system," *Pure Appl. Biol*, vol. 5, no. 3, pp. 446–452, 2016, [Online]. Available: https://www.thepab.org/files/2016/September-2016/PAB-MS-160047.pdf
[21] M. H. G. Nastaran Pouladi, Anders Bjørn Møller, Salman Tabatabai, "Mapping soil organic matter contents at field level with Cubist, Random Forest and kriging," *Geoderma*, vol. 342, pp. 85–92, 2019, doi: https://doi.org/10.1016/j.geoderma.2019.02.019.
[22] Z.-M. L. Peng-Tao Guo, Mao-Fen Li, Wei Luo, Qun-Feng Tang, Zhi-Wei Liu, "Digital mapping of soil organic matter for rubber plantation at regional scale: An

application of random forest plus residuals kriging approach," *Geoderma*, vol. 237–238, pp. 49–59, 2015, doi: https://doi.org/10.1016/j.geoderma.2014.08.009.
[23] H. B. V. Hiba Chaudhry, "Evaluating the Soil Quality Index Using Three Methods to Assess Soil Fertility," *Sensors*, vol. 24, no. 3, p. 864, 2024, doi: https://doi.org/10.3390/s24030864.
[24] J. A. Hammad, S. M'nassri, B. Chaabane, A. H. I. Al-Bayati, and R. Majdoub, "Assessing agricultural potential of abandoned land in the Euphrates basin: soil fertility modeling and geostatistical analysis," *Model. Earth Syst. Environ.*, vol. 10, no. 4, pp. 4627–4639, Aug. 2024, doi: 10.1007/S40808-024-01982-9/METRICS.
[25] H. F. Boyd Ellis, "Soil Fertility," *Oxford Companion to Wine Fifth Ed.*, 2023, [Online]. Available: https://www.taylorfrancis.com/books/mono/10.1201/9780203739341/soil-fertility-boyd-ellis-henry-foth
[26] S. M. G. Ghulam Nabi, Humair Ahmed, Ijaz Ali, "Spatial variability and digital mapping of Zn content in soil and foliage of wheat producing area in district Jhelum-Pakistan," *Int. J. Biosci. | IJB |*, vol. 14, no. 3, pp. 72–81, 2019, [Online]. Available: https://innspub.net/wp-content/uploads/2022/04/IJB-V14-No3-p72-81.pdf
[27] Z. . Tarar, "Variations in Soil Characteristics along Slope Positions of Eroded Sloppy Lands of Tehsil Sohawa, District Jhelum," *Jammu Kashmir J. Agric.*, vol. 4, no. 2, pp. 213–218, 2024, [Online]. Available: https://www.researchgate.net/publication/387107804_VARIATIONS_IN_SOIL_CHARACTERISTICS_ALONG_SLOPE_POSITIONS_OF_ERODEDSLOPPY_LANDS_OF_TEHSIL_SOHAWA_DISTRICT_JHELUM
[28] and A. W. Afzal, S., M.S. Aslam, "Soil Analysis and Characterization of Jhelum District: A Comparative Study.," *J. Med. Life Sci.*, vol. 7, pp. 169–176, 2024, doi: https://doi.org/10.31580/hga22906.