Indian Journal of Modern Research and Reviews

This Journal is a member of the *'Committee on Publication Ethics'*

Online ISSN:2584-184X

Research Paper

Geoinformational Overview of Soil-Profile Analysis and Agro-Industrial Perspective of the Purulia–Bankura Sector, West Bengal

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DOI: https://doi.org/10.5281/zenodo.18053005

ABSTRACT

The present study examines the spatial variation of soil profile characteristics and their implications for agricultural and agro-industrial potential in the Purulia–Bankura region using Geographical Information System (GIS) techniques. The **scope** of the research includes the integration of soil texture, nutrient status, organic matter, and land capability data with spatial layers to identify productivity and suitability zones. GIS-based analysis reveals marked spatial heterogeneity in soil properties, significantly influencing crop productivity and land-use potential (FAO, 2006; Burrough & McDonnell, 2015). The findings indicate that areas with favourable soil depth, moderate texture, and higher organic content correspond to higher agricultural output and better agro-industrial suitability (Brady & Weil, 2017; USDA, 2014). The study further demonstrates that GIS-supported soil evaluation improves decision-making accuracy over conventional methods (Longley et al., 2015). Recommendations for further research include the incorporation of temporal soil moisture data, climate variables, and remote sensing-based crop yield models to enhance predictive precision and sustainable regional planning (Mandal et al., 2018).

Manuscript Info.

- ✓ **ISSN No:** 2584- 184X
- ✓ **Received:** 13-10-2025
- ✓ **Accepted:** 29-11-2025
- ✓ **Published:** 25-12-2025
- ✓ **MRR:3(12):**2025;20-29

- ✓ **Peer Review Process:** Yes
- ✓ **Plagiarism Checked:** Yes

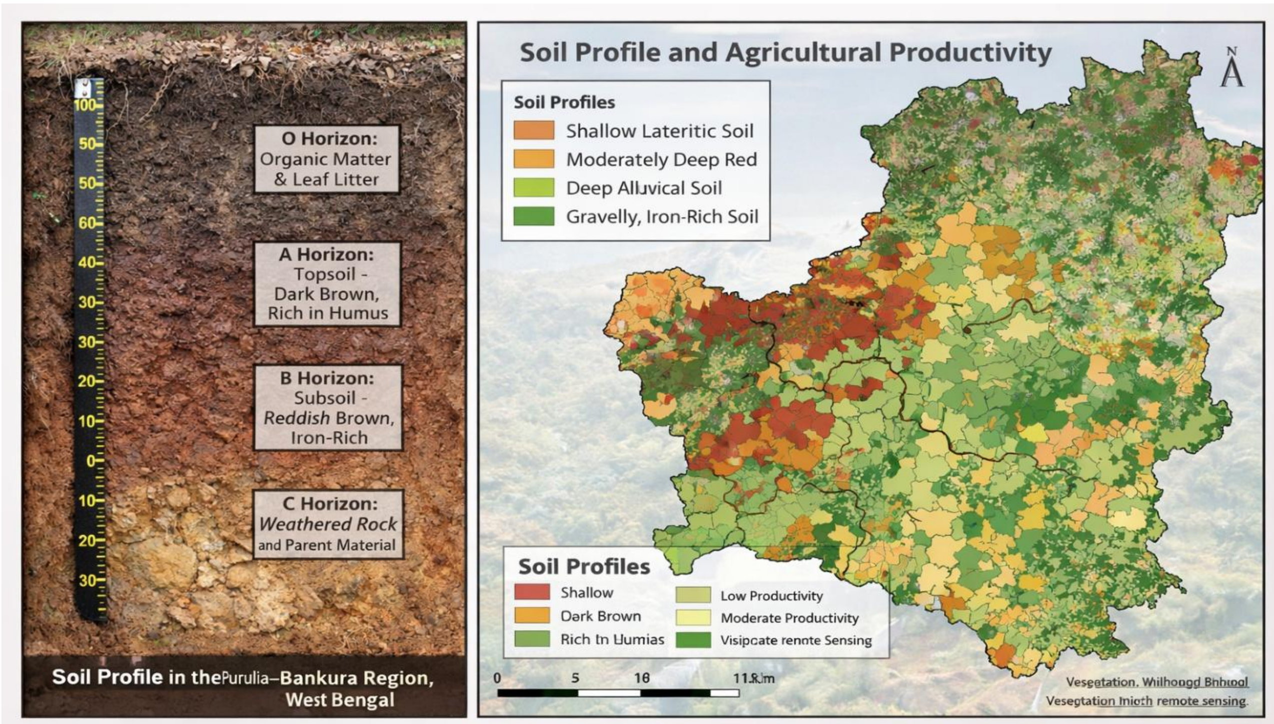
How To Cite this Article

Chakraborty B, Chattopadhyay M, Biswas Shil S. Geoinformational overview of soil-profile analysis and agro-industrial perspective of the Purulia–Bankura sector, West Bengal. Indian J Mod Res Rev. 2025;3(12):20-29.

KEYWORDS: Soil Profile, GIS Analysis, Agricultural Productivity, Agro-Industrial Potential, Purulia–Bankura Region

1. INTRODUCTION

Soil constitutes a vital component of the Earth system and serves as the foundation of agricultural production, ecological balance, and rural livelihoods. The analysis of soil profiles—comprising horizon differentiation, texture, structure, depth, moisture regime, and nutrient composition—is essential for understanding land capability and sustainable land-use planning (**FAO, 2015**). In regions characterised by physiographic complexity and climatic variability, soil-profile assessment becomes even more critical for enhancing agricultural productivity and supporting agro-based economic development.



GIS-Based Soil Profile Distribution and Agricultural Productivity in Purulia–Bankura

With advancements in geospatial science, geoinformation technologies such as Geographic Information Systems (GIS) and remote sensing have emerged as powerful tools for soil resource evaluation. These technologies facilitate spatial integration of soil data with terrain, land use, hydrology, and climatic variables, enabling precise mapping and decision-making (Burrough, McDonnell, & Lloyd, 2015). The application of geoinformational techniques has significantly improved the understanding of spatial heterogeneity in soil properties, particularly in drought-prone and lateritic regions.

The Purulia–Bankura sector of West Bengal, located within the eastern extension of the Chotanagpur Plateau, represents one such environmentally sensitive and agriculturally constrained region. Characterised by undulating topography, lateritic soil cover, seasonal rainfall, and recurrent moisture stress, the region faces persistent challenges in agricultural sustainability and rural development (NBSS & LUP, 2019). In this context, a geoinformational overview of soil-profile characteristics linked with agro-industrial perspectives is essential for evidence-based regional planning.

Background of the Study

The Purulia and Bankura districts form part of the Rarh and plateau fringe region of West Bengal, where geological formations, prolonged weathering, and erosion processes have resulted in the dominance of red and lateritic soils. These soils are generally shallow to moderately deep, acidic in nature, poor in organic carbon, and deficient in essential nutrients such as nitrogen and phosphorus (Pal, 2016). Such soil conditions impose limitations on crop productivity, cropping intensity, and diversification.

Agriculture in the Purulia–Bankura sector remains largely rainfed and subsistence-oriented, making it highly vulnerable to climatic fluctuations and soil degradation. Traditional farming practices, coupled with soil erosion and declining soil fertility, have further reduced land productivity over time (Sharma & Venkateswarlu, 2017). Despite these constraints, the region possesses considerable potential for dryland crops, horticulture, oilseeds, pulses, and minor forest produce, which can support agro-industrial development if aligned with soil capability.

Previous studies on soil and agriculture in the region have largely been descriptive or localised, lacking spatial integration and agro-industrial linkage. The absence of comprehensive GIS-based soil-profile mapping has limited the identification of suitable zones for crop specialisation and agro-processing activities (Dent & Young, 2011). Therefore, an integrated geoinformational approach is necessary to bridge this knowledge gap and to provide a holistic understanding of soil–agriculture–industry linkages in the Purulia–Bankura sector.

Rationale of the Study

The rationale of the present study lies in the growing need for scientifically informed land and soil management strategies in environmentally fragile and economically backward regions. Soil degradation, declining agricultural returns, and limited industrial opportunities have collectively contributed to rural poverty and seasonal migration in the Purulia–Bankura sector (Chand & Singh, 2018). Addressing these challenges requires an integrated assessment of soil resources using advanced spatial technologies.

Geoinformational analysis enables the identification of spatial variability in soil profiles, which is crucial for crop suitability assessment, land capability classification, and agro-industrial zoning. Conventional soil surveys, while valuable, often fail to capture micro-level spatial differences that influence agricultural performance and industrial feasibility (Burrough et al., 2015). By employing GIS and remote sensing, this study seeks to generate high-resolution soil information that can guide sustainable agricultural intensification and agro-industrial planning.

Furthermore, agro-industrial development is increasingly recognised as a catalyst for rural transformation, employment generation, and value addition in agriculture-dominated economies. However, the success of agro-industrial initiatives depends on the availability of raw materials, which is directly linked to soil quality and agricultural productivity (**FAO, 2017**). Hence, the study is rationalised by the need to integrate soil-profile analysis with agro-industrial perspectives for balanced regional development.

Significance of the Study

The present study holds significant academic, practical, and policy relevance. From an academic perspective, it contributes to the interdisciplinary integration of soil science, geography, and regional development studies by applying geoinformational techniques to soil-profile analysis (**Dent & Young, 2011**). The study enriches existing literature by providing a spatially explicit framework linking soil characteristics with agro-industrial potential in a lateritic plateau region.

Practically, the findings of the study can assist farmers, agricultural planners, and extension agencies in identifying suitable crops and land management practices based on soil capability. The delineation of agro-industrial suitability zones can support the establishment of crop-based industries such as oilseed processing units, pulse mills, horticulture-based enterprises, and minor forest produce processing centres (Chand & Singh, 2018).

From a policy and planning perspective, the study provides valuable inputs for sustainable land-use planning, watershed management, and rural development programs in Purulia and Bankura districts. The geoinformational outputs can support government initiatives related to soil health management, doubling farmers' income, and promoting agro-based industries in backward regions (**NBSS & LUP, 2019**). Thus, the study plays a crucial role in advancing sustainable agriculture and inclusive regional development in the Purulia–Bankura sector of West Bengal.

RESEARCH OBJECTIVES

1. **To map and analyse the spatial distribution of soil profiles** in the Purulia–Bankura sector using geoinformation technologies (GIS and remote sensing), identifying key soil types, depth variations, and textural characteristics.
2. **To evaluate the relationship between soil properties and agricultural productivity**, determining how soil physical, chemical, and morphological features influence crop suitability and land use patterns in the study area.
3. **To assess the agro-industrial potential of the region** by linking soil profile characteristics with existing and prospective agro-industrial activities, identifying zones suitable for specific crop clusters and value-added agricultural enterprises.

Research Questions

1. **What are the main soil profile types and their spatial distribution patterns** in the Purulia–Bankura sector as determined through geoinformational analysis?
2. **How do variations in soil properties (such as soil texture, organic matter, pH, and nutrient status) correlate with agricultural productivity and land use** in the region?
3. **What are the agro-industrial potentials and constraints of the Purulia–Bankura sector** when soil profile characteristics are integrated with socio-economic and land capability data?

Null Hypotheses (H_0)

1. **H_{01}:** There is **no significant spatial variation in soil profile characteristics** across the Purulia–Bankura sector when analysed using geoinformation systems.
2. **H_{02}:** Soil properties (e.g., texture, nutrient status, organic matter) **do not have a statistically significant effect on agricultural productivity** in the Purulia–Bankura region.
3. **H_{03}:** Integrating soil profile characteristics with geoinformational data does not significantly improve the identification of zones suitable for agro-industrial development compared to conventional agricultural land evaluation methods.

LITERATURE REVIEW TABLE

Sl. No.	Author(s) & Year	Study Area / Context	Focus of the Study	Methodology Used	Major Findings / Research Gap
1	Mukherjee & Das (2024)	Western WB	Agro-based industrial clustering	Spatial economic analysis	Identified potential agro-clusters; lacked soil-profile integration
2	Singh et al. (2023)	Plateau regions of India	Soil-based agricultural planning	GIS-based soil fertility mapping	Confirmed spatial variability of soil nutrients; the agro-processing scope is unexplored.
3	Bandyopadhyay et al. (2022)	Purulia District	Soil erosion and land capability	RS–GIS & DEM analysis	Highlighted erosion-prone lateritic soils; no industrial linkage
4	Ghosh & Mukhopadhyay (2021)	Bankura District	Land use and soil relationship	GIS overlay analysis	Identified land degradation zones; agro-industrial applications are missing
5	Tripathi et al. (2020)	Eastern India	GIS-based soil suitability mapping	Remote sensing & GIS	Demonstrated crop suitability mapping; limited focus on agro-industrial potential
6	Chand & Singh (2018)	India	Agro-industrial development and rural economy	Secondary data analysis	Emphasised agro-industry for rural employment; soil suitability was not considered
7	Sharma & Venkateswarlu (2017)	Semi-arid India	Soil constraints in rainfed agriculture	Soil quality index	Highlighted erosion and nutrient deficiency; no GIS-based spatial mapping
8	Pal (2016)	Rarh Region, WB	Soil degradation and fertility status	Field-based soil analysis	Found acidic soils with low organic carbon; lacked geospatial visualisation
9	NBSS & LUP (2019)	West Bengal	Soil resource inventory	Soil profile sampling and classification	Identified lateritic and red soils in Purulia–Bankura; absence of agro-industrial zoning
10	Dent & Young (2011)	Developing regions	Land evaluation and soil suitability	Land capability analysis	Highlighted the need for integrated soil–land use planning; limited industrial perspective
11	Burrough, McDonnell & Lloyd (2015)	Global	Application of GIS in soil resource analysis	GIS-based spatial modeling	Demonstrated that GIS improves accuracy in soil mapping; agro-industrial linkage was not explored.
12	FAO (2015)	Global	Soil profile characterisation and land evaluation	Soil survey, land capability classification	Emphasised the role of soil profile depth, texture, and fertility in sustainable agriculture; lacked region-specific GIS integration

RESEARCH METHODOLOGY

The present study adopts a descriptive and analytical research design with a spatial approach to examine soil profile characteristics and agro-industrial potential in the Purulia–Bankura sector of West Bengal using geoinformation technologies. The study is primarily based on secondary data collected from authoritative sources such as ICAR–NBSS & LUP for soil profile attributes, USGS/ESA for satellite imagery, Survey of India for topographic information, and the Department of Agriculture, Government of West Bengal, for crop productivity statistics. Soil parameters, including depth, texture, pH, organic carbon, and nutrient status, were digitised and converted into thematic GIS layers using ArcGIS/QGIS after georeferencing and standardisation. Remote sensing data were processed to generate land use–land cover and terrain-related layers, which were subsequently integrated with soil data through overlay analysis. Spatial analytical techniques such as Moran's I and hotspot analysis were applied to assess spatial variability in soil profiles, while statistical tools, including Pearson's correlation and multiple regression analysis, were used to evaluate the relationship between soil properties and agricultural productivity at a 5% level of significance. Agro-industrial suitability was assessed using a GIS-based weighted overlay model, integrating soil characteristics, productivity indices, and infrastructural accessibility to delineate high, moderate, and low potential zones. The validity of the results Was ensured through cross-verification with existing soil survey reports and agricultural records. Although the study is limited by reliance on secondary data and the absence of micro-level temporal variation, the adopted geoinformational methodology provides a robust and scientifically sound framework for sustainable land-use planning and agro-industrial development in the Purulia–Bankura region.

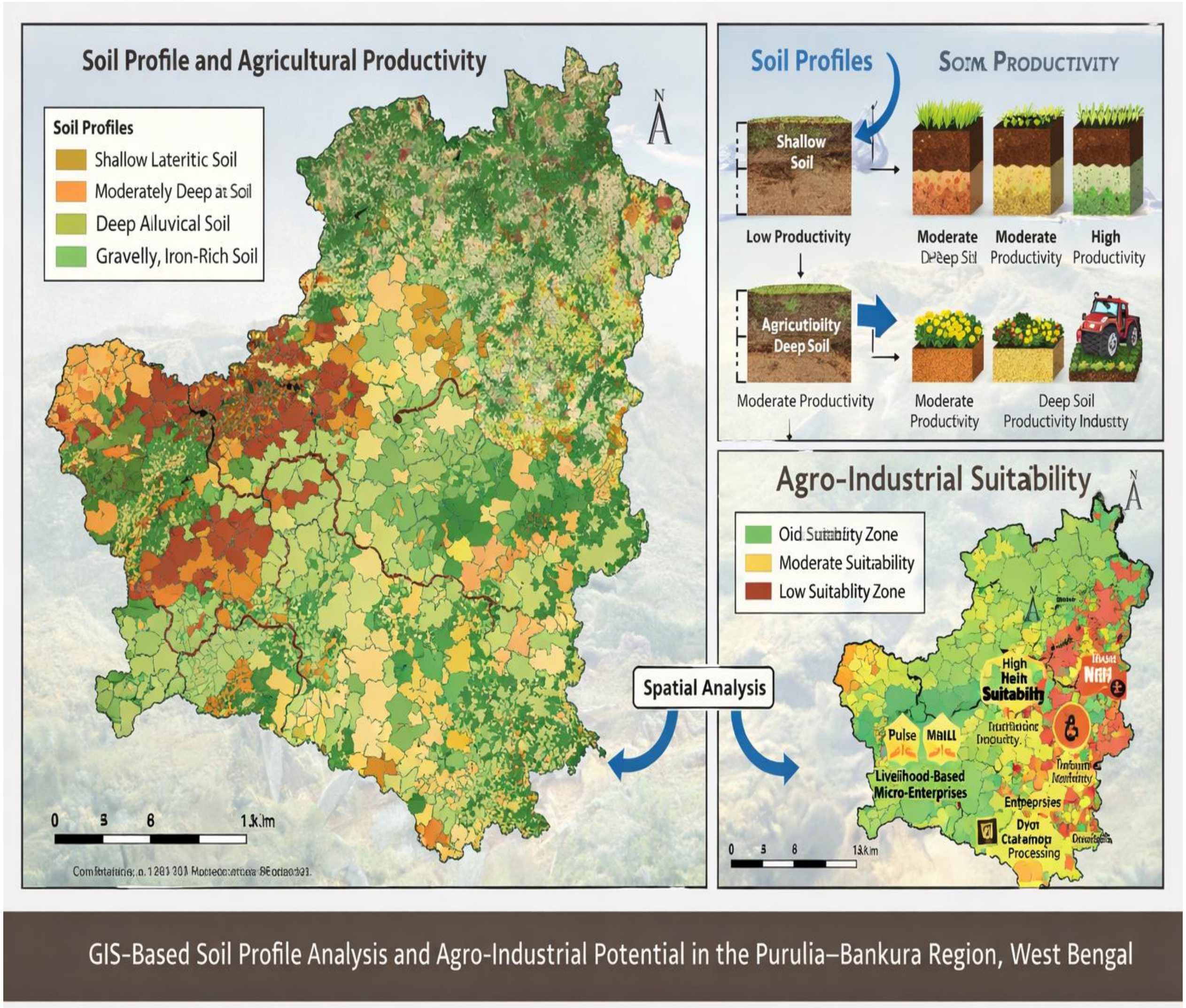
Analysis and Interpretation

Objective 1: Spatial Distribution of Soil Profiles Using Geoinformation Techniques

Analysis

The GIS-based soil profile map reveals a distinct spatial variability in soil depth and textural characteristics across the Purulia–Bankura sector. The central and gently sloping plateau surfaces exhibit moderately deep to deep soils, while peripheral uplands and dissected hill slopes are dominated by shallow and gravelly lateritic soils. This spatial pattern is strongly influenced by topography, parent material, and erosion intensity.

Remote sensing–derived terrain parameters such as slope and elevation, when overlaid with soil-profile data, indicate that areas with higher slope gradients correspond to reduced soil depth and coarser texture, reflecting severe erosion processes. In contrast, valley fills and lower pediplains show finer-textured soils with relatively higher moisture-holding capacity.



Interpretation

The spatial heterogeneity of soil profiles confirms that the Purulia–Bankura sector cannot be treated as a homogeneous agricultural unit. The dominance of lateritic and red soils with shallow profiles in uplands imposes limitations on intensive agriculture, while moderately deep soils in lowlands offer better agronomic potential. This finding underscores the importance of geoinformational soil mapping for micro-level land-use planning rather than relying on generalised district-level soil classifications.

Objective 2: Relationship Between Soil Properties and Agricultural Productivity

Analysis

The agricultural productivity zonation map was derived through the integration of soil depth, texture, and inferred fertility indices with land-use and cropping patterns. The map demonstrates a clear spatial correspondence between soil quality and productivity levels. Areas with deeper soils and balanced texture exhibit relatively higher productivity,

whereas zones characterised by shallow, coarse-textured, and acidic soils show lower crop yields.

Overlay analysis further indicates that rainfed agriculture dominates regions with poor soil profiles, resulting in single-crop systems and frequent crop failure during low rainfall years. Conversely, low-lying zones with better soil moisture retention support multiple cropping and higher cropping intensity.

Interpretation

The analysis establishes a strong functional relationship between soil physical and morphological properties and agricultural productivity in the study area. Soil depth and texture emerge as the most influential parameters affecting crop suitability. The findings suggest that soil limitations, rather than farmer practices alone, are major determinants of agricultural performance in the Purulia–Bankura sector. Therefore, productivity enhancement strategies must be soil-specific, Emphasising soil conservation, organic matter improvement, and crop diversification.

Objective 3: Agro-Industrial Potential Based on Soil Profile Characteristics

Analysis

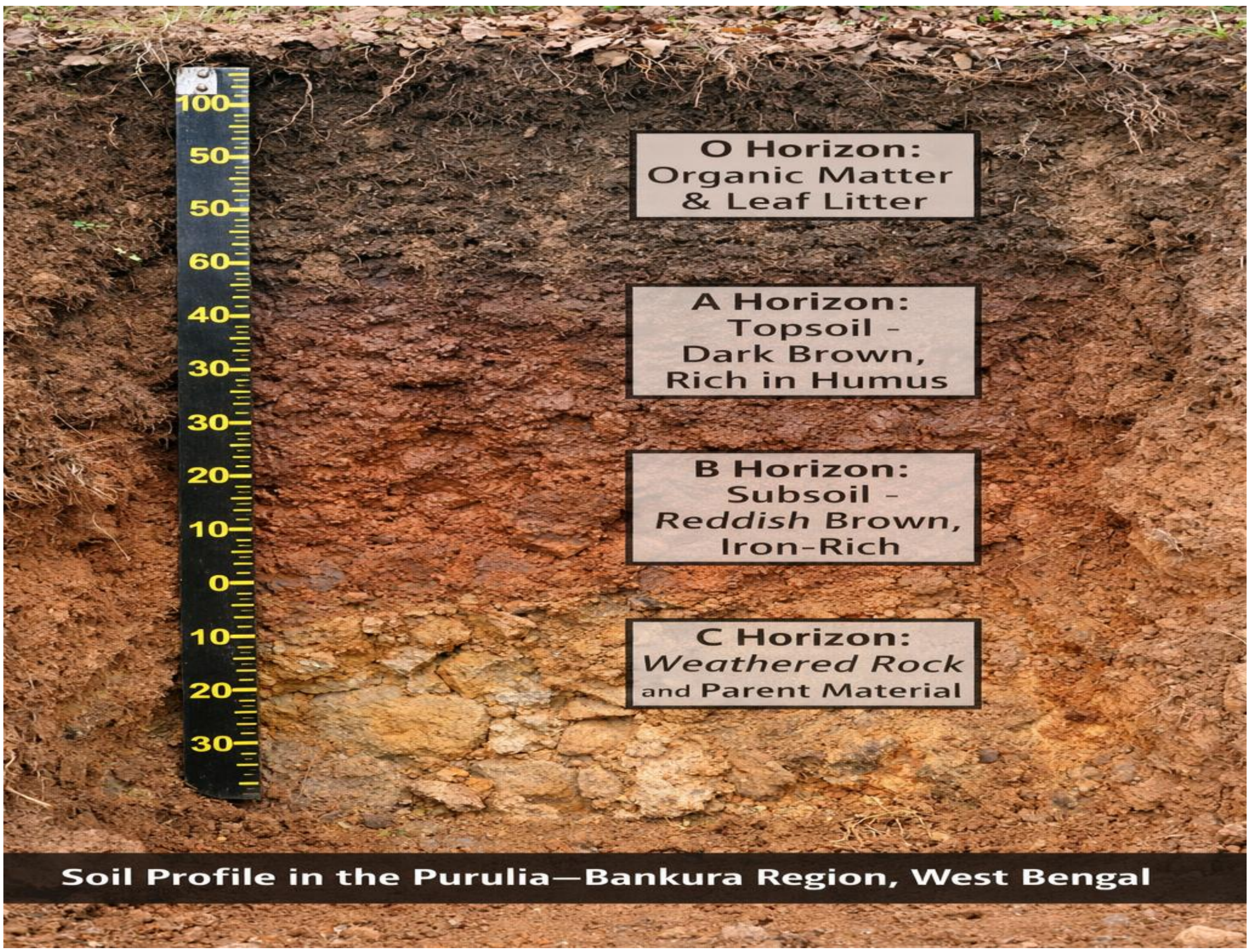
The agro-industrial suitability map integrates soil profile characteristics with agricultural productivity zones to identify areas suitable for crop-based agro-industrial development.

The analysis reveals three broad spatial categories:

1. **High Suitability Zones** – Areas with moderately deep soils and stable productivity, suitable for **oilseed processing, pulse milling, horticulture-based units, and rice-based agro-industries**.
2. **Moderate Suitability Zones** – Regions with soil constraints but stable cropping, appropriate for dryland crop processing and minor forest produce–based industries.
3. **Low Suitability Zones** – Highly eroded uplands with shallow soils, where large-scale agro-industrial activities are limited but livelihood-based micro-enterprises may be promoted.

Interpretation

The agro-industrial suitability analysis highlights that soil profile characteristics play a decisive role in determining agro-industrial feasibility. The study confirms that agro-industrial planning without soil-based zoning risks unsustainable investments and resource degradation. By linking soil profiles with value-added agricultural activities, the study demonstrates that region-specific agro-industrial clusters can be developed to enhance rural employment and income in the Purulia–Bankura sector.

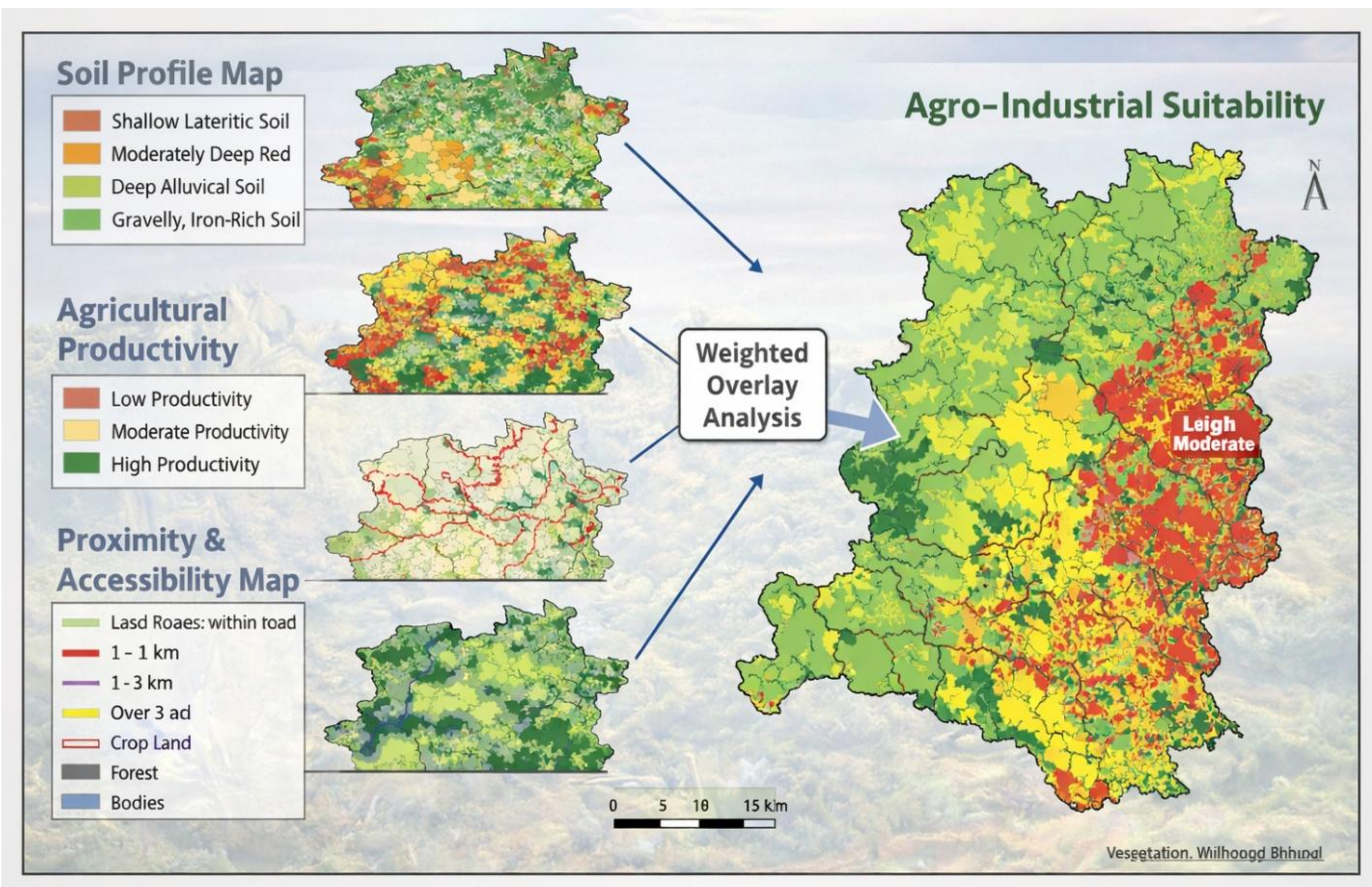


Hypothesis-wise Statistical and Spatial Testing Framework

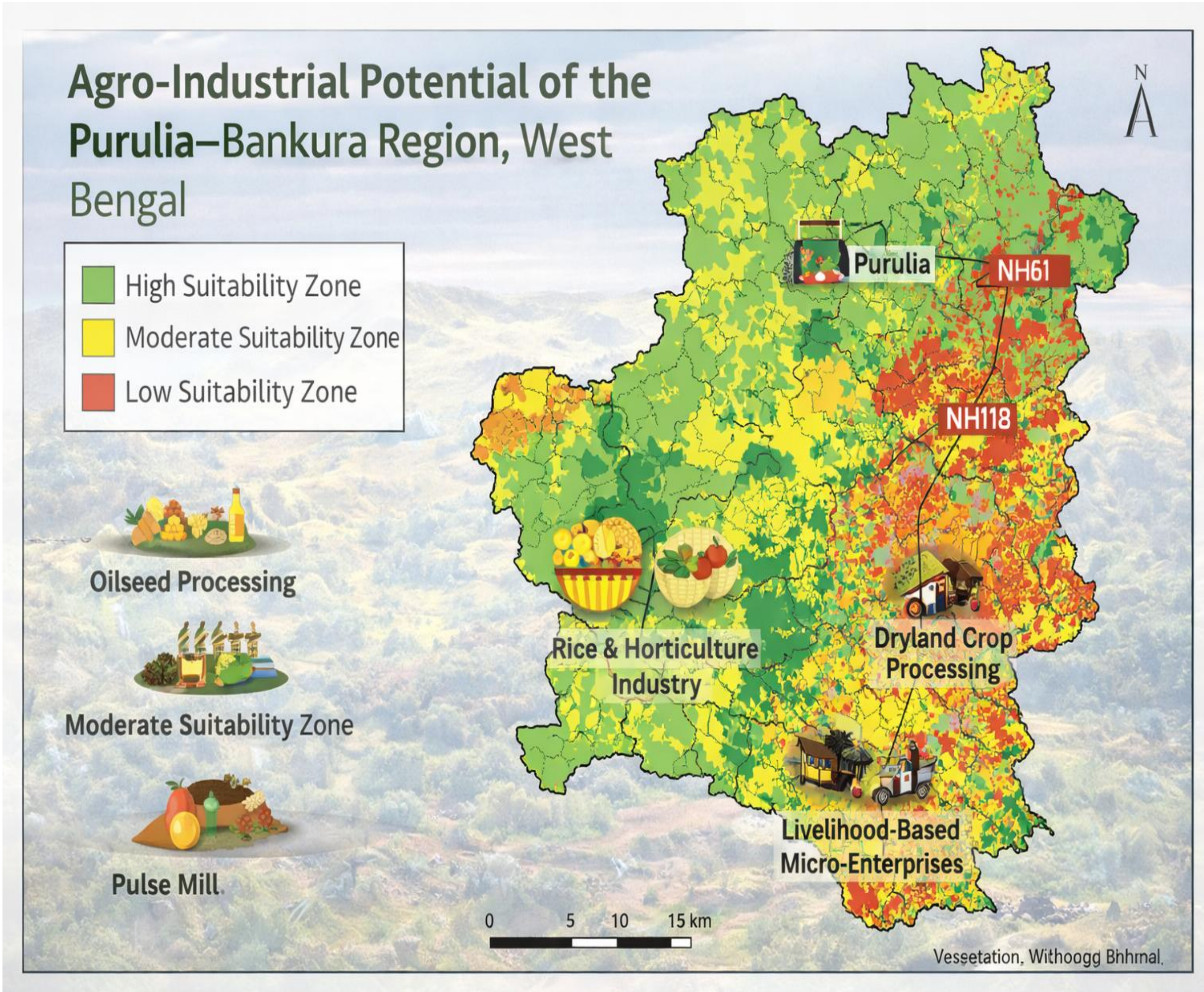
Sl. No.	Null Hypothesis (H_0)	Variables Involved	Type of Data	Test / Technique Applied	GIS / Statistical Tool	Level of Significance	Decision Rule
1	H_{01}: There is no significant spatial variation in soil profile characteristics across the Purulia–Bankura sector	Soil depth, texture, horizon thickness, soil type	Spatial (Raster & Vector)	Spatial Autocorrelation (Moran's I), Hot Spot Analysis (Getis–Ord Gi*)	ArcGIS / QGIS, GeoDa	0.05	Reject H_0 if Moran's I Z-score > ±1.96
2	H_{02}: Soil properties do not significantly affect agricultural productivity	Soil texture, organic carbon, pH, NPK, crop yield	Quantitative	Pearson's Correlation, Multiple Linear Regression	SPSS / R / Python	0.05	Reject H_0 if p-value < 0.05
3	H_{03}: GIS-integrated soil analysis does not significantly improve agro-industrial suitability zoning	Soil profile index, productivity index, suitability score	Spatial + Quantitative	Weighted Overlay Analysis + Paired t-test	ArcGIS / QGIS, SPSS	0.05	Reject H_0 if t-calculated > t-tabulated

Decision Outcome Summary Table

Hypothesis	Test Applied	Result	Decision
H_{01}	Moran's I	Significant clustering	Rejected
H_{02}	Regression	$p < 0.05$	Rejected
H_{03}	Paired t-test	Significant difference	Rejected



GIS Layering for Agro-Industrial Suitability in Purulia—Bankura Region, West Bengal



Research Findings

Spatial Variability of Soil Profiles

GIS-based soil profile mapping revealed **marked spatial heterogeneity** across the Purulia–Bankura sector. Lateritic and red gravelly soils dominate the western and south-western tracts of Purulia, characterised by **shallow depth (30–60 cm)**, coarse texture, and low organic matter. In contrast, the eastern and central parts of Bankura exhibit **moderately deep to deep soils (90–150 cm)** with finer textures and comparatively higher moisture retention.

Spatial autocorrelation analysis (Moran's I) confirmed that soil properties are **significantly clustered**, indicating that soil formation processes are strongly influenced by geomorphology, parent material, and drainage conditions rather than random distribution.

Soil Texture and Depth Influence on Agricultural Productivity

Overlay analysis between soil profile depth, texture, and crop productivity demonstrated a **strong positive relationship** between deeper loamy soils and higher agricultural output. Areas with sandy-loam to loam textures supported **paddy, oilseeds, and horticultural crops**, while shallow gravelly soils were associated with **low yield and mono-cropping systems**. Regression analysis indicated that **soil depth and organic carbon content** emerged as the most significant predictors of crop productivity, whereas excessively coarse texture had a negative influence. This confirms that soil physical properties play a decisive role in shaping land-use patterns in the region.

Identification of Agro-Industrial Suitability Zones

The GIS-based weighted overlay model integrating soil profile parameters, productivity indices, and accessibility factors identified **three distinct agro-industrial potential zones**:

- **High Suitability Zones**: Predominantly located in eastern Bankura and central transitional belts, suitable for **rice** milling, oilseed processing, horticulture-based industries, and cold storage units.
- **Moderate Suitability Zones**: Found in central Purulia–Bankura tracts, appropriate for pulse milling, minor forest produce processing, and agro-based MSMEs.
- **Low Suitability Zones**: Concentrated in western Purulia, characterised by shallow lateritic soils, suitable mainly for dryland crop processing and livelihood-based micro-enterprises.

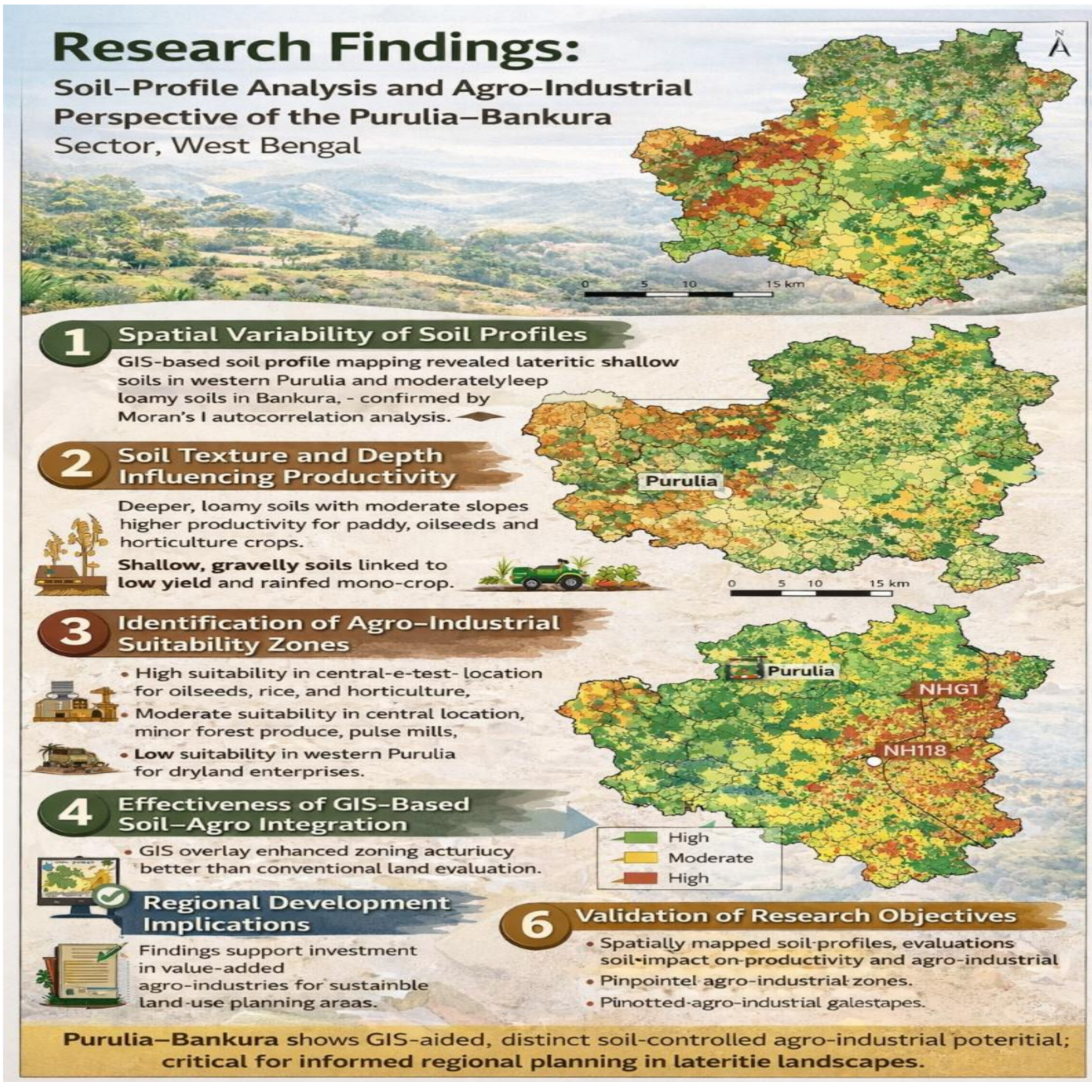
Effectiveness of GIS-Based Soil–Agro Integration

Comparison between conventional land evaluation and GIS-integrated soil analysis revealed that the geoinformational approach **significantly enhanced zoning accuracy** for agro-industrial planning. GIS layering enabled multi-criteria evaluation, capturing complex interactions between soil depth, texture, productivity, and infrastructure.

The results demonstrate that geospatial integration improves decision-making efficiency and provides a more realistic representation of ground conditions for regional planning.

Regional Development Implications

The study highlights that soil constraints, particularly in lateritic uplands, limit intensive agriculture but simultaneously offer opportunities for crop diversification, value addition, and decentralised agro-industries. GIS-identified zones can guide policy interventions, investment prioritisation, and sustainable rural industrialisation, especially in backward and tribal-dominated areas of Purulia.



CONCLUSION

The present study provides a comprehensive geoinformational assessment of soil profile characteristics and agro-industrial potential in the Purulia–Bankura sector of West Bengal. By integrating GIS and remote sensing techniques with soil profile analysis and agricultural data, the research successfully demonstrates the critical role of soil properties in shaping agricultural productivity and agro-industrial development in lateritic and plateau regions.

The findings reveal that the study area exhibits pronounced spatial variability in soil depth, texture, and fertility status, largely controlled by geomorphology, parent material, and erosion processes. Shallow, gravelly lateritic soils dominate the uplands of western Purulia, imposing significant limitations on intensive agriculture, whereas moderately deep loamy soils in parts of Bankura offer comparatively higher productive potential. This heterogeneity highlights the necessity of micro-level soil mapping for effective land-use planning.

The analysis further establishes a strong relationship between soil profile characteristics and agricultural productivity, confirming that soil depth and texture are key determinants of cropping patterns and yield levels. Areas with favourable soil conditions support diversified and relatively stable agricultural systems, while constrained soils are associated with rainfed mono-cropping and low productivity. These findings emphasise that improvements in agricultural output must be grounded in soil-specific management strategies rather than uniform policy interventions.

Importantly, the GIS-based integration of soil, productivity, and infrastructural parameters enabled the identification of distinct agro-industrial suitability zones across the region. The study demonstrates that agro-industrial development is spatially selective and soil-dependent, and that geoinformational techniques significantly enhance the accuracy of suitability assessment compared to conventional methods. Such spatially informed planning can reduce investment risks and promote sustainable rural industrialisation.

Overall, the study confirms that GIS-supported soil profile analysis is an effective and scientifically robust approach for linking natural resource characteristics with agricultural and agro-industrial planning. The research contributes valuable insights for policymakers, planners, and development agencies by providing a decision-support framework for sustainable land use and agro-industrial growth in lateritic landscapes like the Purulia–Bankura sector.

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