GIS-BASED ASSESSMENT OF LAND SUITABILITY FOR AGRICULTURAL PRODUCTION IN GIA BINH, BAC NINH PROVINCE, VIETNAM

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ARTICLE INFO

Received: **04/4/2025**
Revised: **13/5/2025**
Published: **13/5/2025**

KEYWORDS

Land suitability classification
LUT
LMU
Agricultural production
GIS

ABSTRACT

This study presents a GIS-based assessment of land suitability for agricultural production in Gia Binh, Bac Ninh province. Based on land characteristics and land use requirements, 6,209.38 hectares of agricultural land were classified into four main land use types. The results indicate that 3,999.55 hectares are currently classified as having low suitability for agricultural production, emphasizing the need for soil quality improvement and more effective land use planning. Only 4.46% of the agricultural area is considered highly suitable for rice production, the local's main crop. While land use types 1, 2, and 4 have over 90% of their area classified as suitable, land use type 3 has a slightly lower suitability at 88.27%. Additionally, 271.82 hectares are deemed unsuitable for agricultural production, including 259.21 hectares specifically unsuitable for rice cultivation. Fifteen land mapping units were identified through the overlay of thematic maps, including soil type, terrain, texture, fertility, and irrigation. The land suitability classification map shows that 95.62% of the agricultural land is suitable for cultivation, although the majority falls into the low suitability category. To enhance agricultural productivity and ensure sustainable land use, it is essential to improve soil fertility, upgrade irrigation systems, and optimize fertilization practices. Moreover, local authorities should implement appropriate land use policies and consider reallocating areas unsuitable for agriculture to alternative, more productive land uses.

ĐÁNH GIÁ THÍCH HỢP ĐẤT SẢN XUẤT NÔNG NGHIỆP Ở GIA BÌNH, TỈNH BẮC NINH, VIỆT NAM SỬ DỤNG GIS

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THÔNG TIN BÀI BÁO

Ngày nhận bài: **04/4/2025**
Ngày hoàn thiện: **13/5/2025**
Ngày đăng: **13/5/2025**

TỪ KHÓA

Phân hạng thích hợp đất
Đơn vị bản đồ dất
Loại hình sử dụng đất
Sản xuất nông nghiệp
GIS

TÓM TẮT

Nghiên cứu này đánh giá mức độ thích hợp đất cho sản xuất nông nghiệp tại huyện Gia Bình, tỉnh Bắc Ninh bằng công nghệ GIS. Trên cơ sở các đặc điểm đất đai và yêu cầu sử dụng đất, tổng diện tích 6.209,38 ha đất nông nghiệp được phân loại thành bốn loại hình sử dụng đất chính. Kết quả cho thấy 3.999,55 ha thuộc nhóm đất có mức độ thích hợp thấp, phản ánh nhu cầu cải thiện chất lượng đất và quy hoạch sử dụng hiệu quả hơn. Chỉ 4,46% diện tích đất nông nghiệp được xếp vào nhóm rất thích hợp cho sản xuất lúa – cây trồng chủ lực của địa phương. Trong khi các loại hình sử dụng đất 1, 2 và 4 có hơn 90% diện tích đạt mức độ thích hợp trung bình trở lên, thì loại hình 3 chỉ đạt 88,27%. Ngoài ra, trong 271,82 ha đất không thích hợp cho nông nghiệp, có 259,21 ha không phù hợp trồng lúa. Mười lăm đơn vị bản đồ đất đã được xác định bằng cách chồng lớp các bản đồ chuyên đề như loại đất, địa hình, kết cấu, độ phì và thủy lợi. Bản đồ phân loại cho thấy 95,62% diện tích có thể canh tác, tuy nhiên phần lớn thuộc nhóm thích hợp thấp. Do đó, cần cải thiện độ phì đất, nâng cấp hệ thống thủy lợi và có chính sách phù hợp nhằm sử dụng đất hiệu quả và bền vững hơn.

DOI: https://doi.org/10.34238/tnu-jst.12485

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1. Introduction

Land evaluation involves assessing the potential of land for specific uses [1]. In the context of land use planning, particularly for agriculture, land evaluation provides a scientific and practical basis for determining optimal crop placement to fulfill various economic, social, and environmental goals [2]. In recent years, Vietnam has placed significant emphasis on investing in land classification, land mapping, and land suitability assessments. These efforts have made a substantial contribution to enhancing the quality of agricultural land-use planning strategies and serve as a foundation for synthesizing and formulating crop restructuring orientations in alignment with agricultural land restructuring. Empirical evidence from local production practices indicates that the implementation of crop restructuring plans, when based on land suitability assessments at the production area level, tends to demonstrate high feasibility [2].

The Food and Agriculture Organization (FAO) has developed a comprehensive methodology for land suitability assessment to guide sustainable agricultural practices and land-use planning [3]. This approach evaluates the potential of land for agricultural production based on a combination of biophysical, environmental, and socio-economic factors. Key criteria include climate conditions, soil characteristics, topography, water availability, and land management practices. FAO's land suitability classification system categorizes land into varying degrees of suitability -ranging from highly suitable (S1) to not suitable (N) - providing essential insights for decision-makers. By incorporating these criteria, FAO’s methodology ensures that agricultural land is used effectively while promoting long-term sustainability, minimizing degradation, and supporting food security objectives. A key aspect of the FAO framework is the use of limiting factors, which identify constraints on land productivity. These are classified as permanent (e.g., slope, soil texture) or manageable (e.g., fertility, drainage) [4]. Recent studies have applied Geographic Information Systems (GIS) and remote sensing to enhance the accuracy and efficiency of FAO-based land suitability assessments, making it a widely used methodology in sustainable land-use planning [5] - [13].

Gia Binh district, located in Bac Ninh province, has traditionally been an agricultural area with a significant portion of its land dedicated to rice cultivation. However, like other parts of Bac Ninh, the rice production area in Gia Binh has been decreasing due to urbanization, industrial development, and land-use conversion. Consequently, it is essential to evaluate the suitability of land for agricultural production, serving as a foundation for proposing land-use adjustments and identifying potential areas for future agricultural development. This study aimed to assess the land suitability for sustainable agricultural production in Gia Binh district, providing data for informed land-use planning and crop restructuring in response to ongoing land-use changes.

2. Methodology

2.1. Data collection and processing

This study compiled comprehensive information and relevant documents concerning the natural conditions, socio-economic characteristics, and statistical data on land inventory, land use distribution, crop structure, productivity, and yields across different agricultural land use types in Gia Binh district, Bac Ninh province, during the period 2015–2024. The data was sourced from the Department of Science and Technology of Bac Ninh province. Additionally, other relevant land resources data were collected to support the research proces. This information formed the foundation for analyzing and evaluating land use trends and agricultural practices in the region.

2.2. Land unit mapping

The collected data was processed and utilized to develop thematic maps, including those depicting land use, soil types, soil texture, relative terrain, irrigation conditions, and soil fertility. Each thematic layer was standardized to a common spatial reference system to ensure accurate alignment and integration within a GIS environment. A land unit map was then constructed through the overlaying of these thematic layers, enabling a comprehensive spatial analysis of the landscape. Specific land units were delineated on the maps according to their unique characteristics, ensuring consistency in land use types (LUTs), management conditions, and potential for improvement. These land units were compiled into a comprehensive land suitability map for the study area. This integrated approach provides a robust foundation for evaluating land suitability for agricultural production. This process was schematically illustrated in Figure 1. Additionally, QGIS software (version 3.40) was used to establish maps.

2.3. Land suitability classification based on FAO Guidelines

To establish a scientific basis for selecting optimal agricultural land use types, this study has applied the FAO land evaluation framework to classify land suitability. The limiting factor approach has been employed to assess land suitability, taking into account the economic, social, and environmental effectiveness of land use. Limiting factors have been classified into two categories based on their characteristics and the possibility of improvement through management interventions:

▪ Major limiting factors — These are inherent and relatively unchangeable site characteristics that have a significant influence on land suitability and are difficult or economically unfeasible to improve. In this study, soil type, relative terrain, and soil texture have been identified as major limiting factors because they directly affect crop growth potential and land management practices but cannot be easily modified.

▪ Moderate limiting factors — These are factors that can be improved or mitigated through appropriate agricultural management measures. Parameters such as soil pH, organic carbon content, and irrigation capacity have been classified as moderate limiting factors, as they can be adjusted or enhanced through interventions like soil amendment, fertilization, or irrigation system improvement.

The final land suitability classification has been categorized into four levels: High suitability (S1), moderate suitability (S2), low suitability (S3), and Non suitability (N).

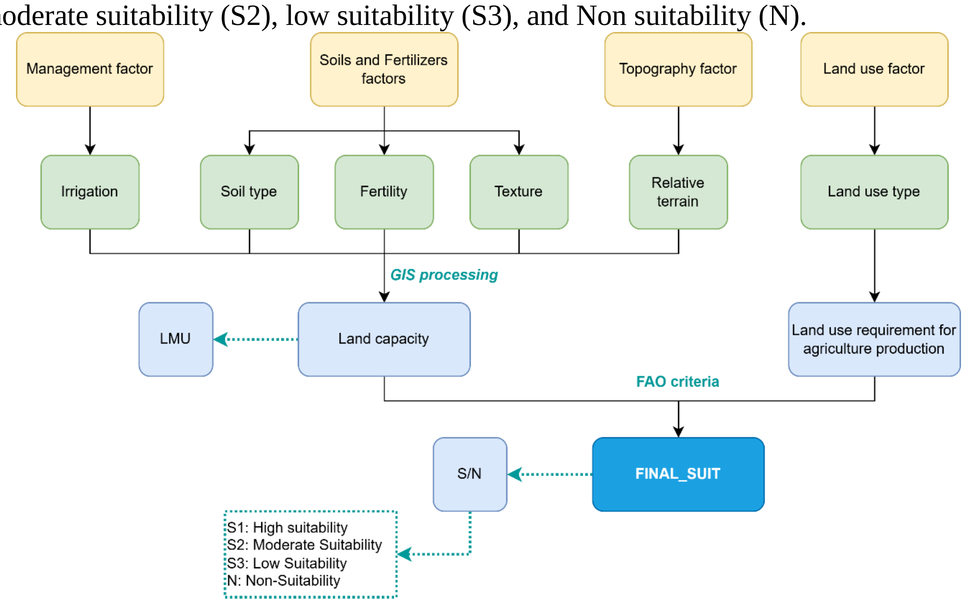

Figure 1. *Workflow of Land Suitability Classification for Agricultural Production*

3. Results and discussion

3.1. Study area

Gia Binh is one of the eight administrative units of Bac Ninh province, located in the southeastern part of the province. The district lies within the coordinates from approximately

21°02'N to 21°09'N and from 106°05'E to 106°15'E. Gia Binh shares borders with Que Vo district to the north, Luong Tai district to the south, Thuan Thanh district to the west, and Hai Duong province to the east (Figure 2).

The topography of Gia Binh is generally flat, sloping from northwest to southeast, directing water flow into the Duong river and Thai Binh river. The district consists primarily of lowland fields, with elevations ranging from 3 to 7 masl. Like the rest of Bac Ninh province, Gia Binh has shallow depressions along dykes, particularly in low-lying agricultural areas. The district does not have significant mountainous terrain, as hills and mountains are largely concentrated in other parts of the province.

Gia Binh has a total land area of approximately 108 km², with agricultural land accounting for a significant portion of the district's total area (Table 1). The district is part of Vietnam's Red River Delta region, benefiting from fertile alluvial soil suitable for various agricultural activities, particularly rice cultivation, vegetable farming, and fruit tree plantations (Figure 3).

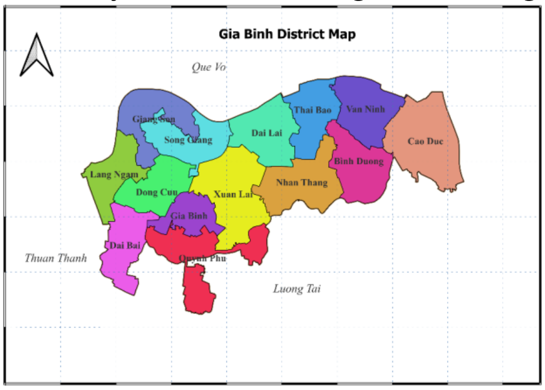

Figure 2. *Gia Binh map*

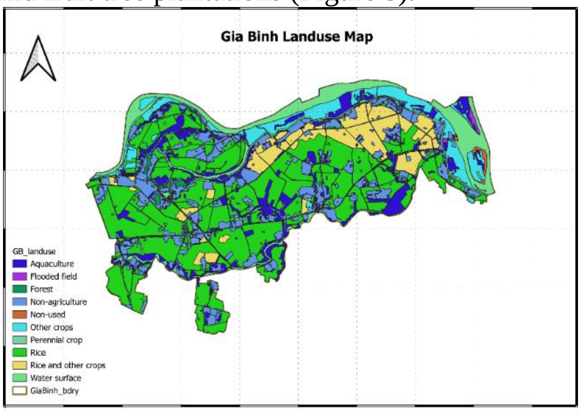

Figure 3. *Land use map*

Located in a tropical monsoon climate zone, Gia Binh experiences a humid subtropical climate with distinct hot, humid summers and cool, dry winters. The annual average temperature is around 24 °C, with the highest temperatures reaching 30–35 °C in July and the lowest dropping to 14–16 °C in January. The district receives abundant annual rainfall, which supports agricultural production but also makes the area susceptible to seasonal flooding.

Table 1. *Land use in Gia Binh*

Land use type (LUT)	**Notation**	**Area** (ha)	**Rate**
Rice	LUT1	4495.08	41.37%
Rice and other crops	LUT2	1020.81	9.40%
Perennial crop	LUT3	18.2	0.17%
Other crops	LUT4	793.67	7.31%
Forest		47.67	0.44%
Non-use		33.22	0.31%
Aquaculture		1049.24	9.66%
Flooded field		22.74	0.21%
Water surface		1463.20	13.47%
Non-agriculture		1920.43	17.68%
Grand Total		**10864.25**	**100%**

As shown in Table 1, the land use distribution in Gia Binh district, Bac Ninh highlights the dominance of rice cultivation, which occupies 41.37% of the total area, reflecting the region's suitability for rice farming due to its fertile soils. Aquaculture follows with 9.66%, indicating its significant role in the local economy, especially in areas with abundant water resources. The category "Rice and other crops" accounts for 9.40%, suggesting the practice of intercropping, while other crops make up 7.31%, indicating agricultural diversity. Non-agricultural land occupies 17.68% of the area, likely including urban development and industrial zones, signaling the district's ongoing urbanization. Smaller areas are dedicated to flooded fields (0.21%), forests (0.44%), and non-used land (0.31%). Water surfaces cover 13.47%, representing rivers and lakes crucial for irrigation and aquaculture. This distribution shows that agriculture, particularly rice and aquaculture, is central to Gia Binh's economy, though urban expansion is gradually increasing. Future planning should balance agricultural productivity with urban growth to ensure long-term sustainability.

3.2. Land suitability influencing factors

Soil type

Soil type is a fundamental criterion that characterizes the properties of a land unit, including its physical, chemical, and biological characteristics, all of which influence the land's suitability for various uses, particularly for supporting plant growth [14]. In the study area, the soil types have been classified based on soil analysis and divided into eight distinct soil types, grouped into four primary classes. The soil type map, in alignment with the current land use patterns, reveals a varied distribution of these soil types, as shown in Figure 4. Among the soil types, Eutric Fluvisols (G4) cover the largest area, followed by Gleyic Fluvisols (G1). Both belong to the Fluvisols group, typically found in floodplains and river valleys. Eutric Fluvisols are fertile, well-drained soils with a neutral to slightly alkaline pH, ideal for crops like rice, vegetables, and fruits. In contrast, Gleyic Fluvisols are found in poorly drained or flood-prone areas, leading to waterlogging and reduced aeration. Despite their high clay content, these soils can support rice cultivation when managed with proper drainage [15]. The dominance of Eutric Fluvisols and Gleyic Fluvisols in Gia Binh emphasizes the potential for both intensive farming in well-drained areas and specialized agriculture in wetland conditions, although effective land management practices are crucial for optimizing agricultural productivity [2].

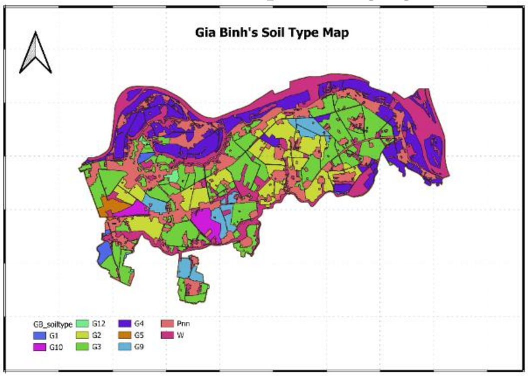

Figure 4. *Soil type map*

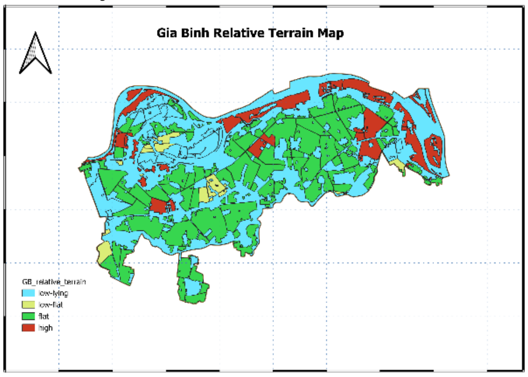

Figure 5. *Relative terrain map*

Relative terrain

The study site, located in the Red River Delta, features relatively flat terrain and is classified into four types of relative terrain: high, flat, low-flat, and low-lying (Figure 5). Flat terrain (4,132.39 hectares) is ideal for large-scale agriculture, particularly rice, due to its uniformity, facilitating irrigation and drainage. High terrain poses challenges for conventional farming but can support crops that require better drainage. Low-flat terrain is slightly depressed, needing efficient drainage to prevent waterlogging but still suitable for intensive farming. Low-lying terrain is prone to flooding and waterlogging but offers fertile soils ideal for water-intensive crops like rice, given proper drainage. Understanding these terrain types is crucial for optimizing farming practices and infrastructure in the region.

Soil fertility

Soil fertility in the study area is assessed based on pH, organic carbon content, and absorption capacity [16]. The pH scale categorizes soil as neutral (pH 6-7), slightly sour (pH 4-5 or 5-6), or acidic/alkaline (pH <4 or >7). Organic carbon content is classified as rich (≥2%), moderate (1-2%), or poor (<1%). Absorption capacity is rated as high (≥25), moderate (10-25), or low (<10). The results of the soil fertility mapping, as shown in Figure 6, indicate the distribution of soils with varying absorption capacities. Soils with high absorption capacity are effective at retaining water and nutrients, supporting a wide range of crops and promoting sustainable agricultural practices. Soils with moderate absorption capacity have a balanced ability to retain nutrients, which can still support productive farming, although additional management may be needed to optimize fertility. Soils with low absorption capacity are less efficient at retaining water and nutrients, which could limit crop growth and require more intensive management practices, such as irrigation and fertilization, to maintain productivity. The mapping results offer valuable insights into the distribution of these soil categories, aiding in agricultural planning and land management strategies.

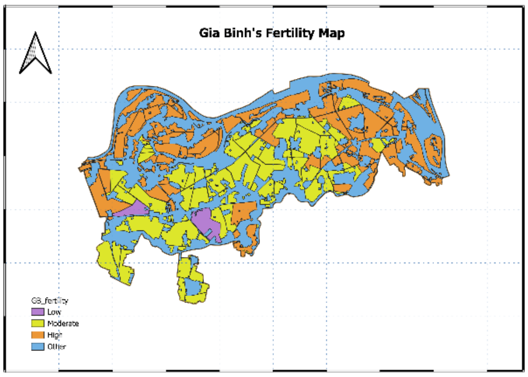

Figure 6. *Fertility map*

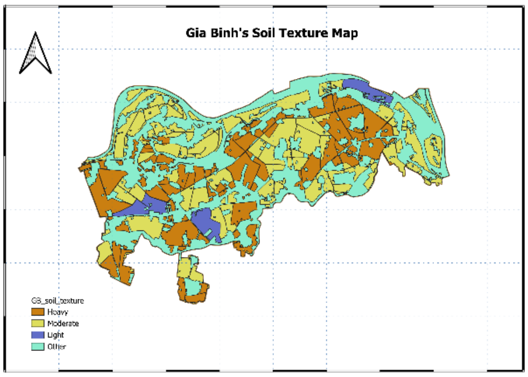

Figure 7. *Soil texture map*

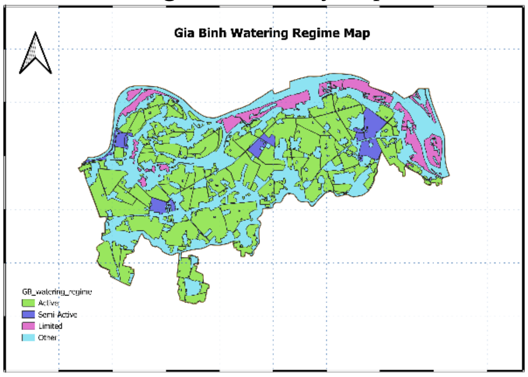

Figure 8. *Watering regime map*

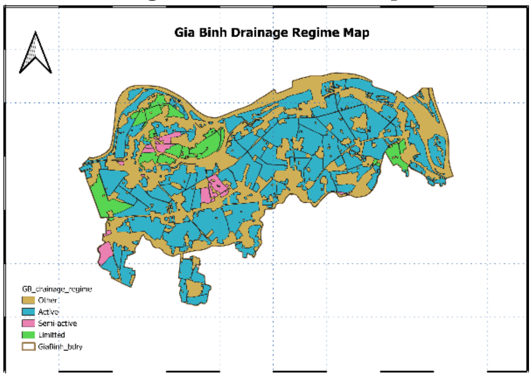

Figure 9. *Drainage regime map*

Soil texture

Soil texture refers to the relative proportions of sand, silt, and clay particles that form the mineral component of the soil. For instance, light soils are characterized by a higher sand content, while heavy soils have a greater clay content. Soil texture is crucial as it influences various factors such as water retention, the rate at which water moves through the soil, and the soil's workability and fertility. In the study area, the majority of the soil falls under moderate texture, followed by heavy and light soils (Figure 7). Soils with a moderate texture are generally well-balanced, allowing for adequate water retention and drainage, which supports a wide range of agricultural activities. Heavy soils, with higher clay content, tend to retain more water but can be prone to poor drainage, requiring careful management to prevent waterlogging. In contrast, light soils, being sandier, drain quickly and are more easily worked, but they may require more frequent irrigation and nutrient management to maintain fertility. These variations in soil texture across the study area highlight the need for tailored land management practices to optimize agricultural productivity.

Irrigation regime

The irrigation and drainage regimes are essential factors influencing agricultural productivity. In the study area, the majority of the land falls under the "Active" irrigation and drainage regimes (Figure 8 and Figure 9), indicating that most of the area benefits from sufficient water supply and effective water removal. These conditions are conducive to healthy crop growth and support consistent agricultural production. Areas with "Semi-active" and "Limited" irrigation and drainage regimes may face challenges such as insufficient water availability or poor water drainage. These conditions require careful management, including supplementary irrigation and improved drainage systems, to ensure optimal soil health and crop performance. Proper management of both irrigation and drainage is critical to preventing issues like waterlogging, salinity, and erosion, which can negatively impact yields.

3.3. Land suitability for agricultural production

3.3.1. Land mapping unit

The land unit map for Gia Binh district was generated through the integration of multiple thematic layers, including soil type, soil texture, soil fertility, relative terrain, and irrigation and drainage conditions. This overlay analysis resulted in the identification of 15 distinct Land Mapping Units (LMUs), each representing a unique combination of these biophysical and management-related attributes (Table 2). Among these, LMU 7, characterized by Eutric Fluvisols with moderate soil texture, medium fertility, flat terrain, and favorable irrigation and drainage conditions, occupies the largest area at 1,350.2 hectares. This comprehensive classification provides a critical foundation for evaluating land suitability and guiding agricultural planning in the region.

Table 2. *Land mapping units*

No.	**LMU**	**Soil_ID**	**Re_t**	**Soil_t**	**Soil_f**	**W_r**	**D_r**	**Area** (ha)
	Group I (Fluvisols)							
1	G1E3T2N2I1F2	1	3	2	2	1	2	70.29
2	G1E4T2N2I1F3	1	4	2	2	1	3	30.10
3	G2E1T2N2I2F1	2	1	2	2	2	1	49.39
4	G2E2T2N2I1F1	2	2	2	2	1	1	1114.83
5	G2E3T2N2I1F2	2	3	2	2	1	2	68.29
6	G3E1T3N2I2F1	3	1	3	2	2	1	23.28
7	G3E2T3N2I1F1	3	2	3	2	1	1	1350.20
8	G3E3T3N2I1F2	3	3	3	2	1	2	72.85
9	G4E1T1N1I2F1	4	1	1	1	2	1	0.0004
	Group II (Plinthosols)							
10	G9E1T1N2I2F1	9	1	1	2	2	1	53.83
11	G9E1T2N2I3F1	9	1	2	2	3	1	1.58
12	G9E2T1N2I1F1	9	2	1	2	1	1	22.20
13	G9E2T2N2I1F1	9	2	2	2	1	1	406.23
	Group III (Acrisols)							
14	G10E2T1N3I1F1	10	2	1	3	1	1	235.51
15	G12E2T2N2I1F1	15	2	2	2	1	1	46.67

Notice: Re_t: relative terrain; Soil_t: soil texture; Soil_f: soil fertility; W_r: watering regime, D_r: drainage regime.

3.3.2. Land use requirements classification

According to the local government report, the study area is primarily used for four main types of agricultural land use: rice, rice combined with other crops, other crops, and perennial crops. The land suitability requirements for these crops are outlined in Table 3. The suitability levels are categorized into four types: S1, indicating 'high suitability'; S2, representing 'moderate suitability'; S3, denoting 'low suitability'; and N, signifying 'non-suitability'. In all factors considered for land suitability classification, if the dominant factor has the highest threshold (the most significant limiting factor), the land unit is classified according to this highest threshold. In cases where a normal factor is at its highest threshold, while all other dominant and normal factors are at lower thresholds, the classification is elevated by one level. Specifically, if one normal factor is at S3 and all other factors are at S2 and S1, the land use type (LUT) is classified as S2 (or from N to S3, or from S2 to S1). If two normal factors are at S3 but all dominant factors are at S1, the LUT is also classified as S2 (or from N3 to S3, or from S2 to S1). If three or more normal factors are at this highest threshold, the LUT classification remains unchanged.

Table 3. *Land use types' requirement* [14], [16]

Criteria	Notation	Suitability			
		S1	S2	S3	N
1. LUT 1 (Land use of rice)					
Soil type	G	1,2,3,4	5,9	8,10,11,12,13	6,7
Relative terrain	E	2	3	4	1
Soil texture	T	2	1	3	
Soil fertility	N	1	2	3	
Watering regime	I	1	2	3	
Drainage Regime	F	1	2	3	
2. LUT 2 (Land use of rice & other crops)					
Soil type	G	2,3,4	1,10,11,12	8,9,13	5,6,7
Relative terrain	E	2	3	1	4
Soil texture	T	1	2	3	
Soil fertility	N	2	1	3	
Watering regime	I	1	2	3	
Drainage Regime	F	1	2	3	
3. LUT 3 (Land use of perennial crop)					
Soil type	G	2,3,4,8,10	9,11	1,12,13	5,6,7
Relative terrain	E	1	2	3	4
Soil texture	T	1	2	3	
Soil fertility	N	1,2		3	
Watering regime	I	1	2	3	
Drainage Regime	F	1	2		3
4.LUT 4 (Land use of other crops)					
Soil type	G	2,4,10,11	3,6,7,12	1,8,9,13	5
Relative terrain	E	1	2	3	4
Soil texture	T	1	2	3	
Soil fertility	N	1	2	3	
Watering regime	I	1	2	3	
Drainage Regime	F	1	2		3

Notice: G1: Gleyic Fluvisols; G2: Cambic Fluvisols; G3: Dystric Fluvisols; G4: Eutric Fluvisols; G5: Dystric Gleysols; G6: Dystric Arenosols; G7: Haplic Arenosols; G8: Albic Plinthosols; G9: Dystric Plinthosols; G10: Plinthic Acrisols; G11: Arenic Acrisols; G12: Hyperdystric Acrisols; G13: Haplic Acrisols.

3.3.3. Land suitability classification

Table 4. *Land suitability classification*

LUT	**Area** (ha)							
	S1	**S2**	**S3**	**Total**	**%**	**N**	**%**	**Grand total**
LUT 1	276.92	1438.69	2386.56	4102.17	94.06%	259.21	5.94%	**4361.38**
LUT 2		116.62	897.11	1013.73	100%			**1013.73**
LUT 3		5.68	10.03	15.71	88.27%	2.09	11.73%	**17.80**
LUT 4		100.11	705.85	805.95	98.71%	10.53	1.29%	**816.48**
Total	**276.92**	**1661.09**	**3999.55**	**5937.56**		**271.82**		**6209.38**
%	**4.46%**	**26.76%**	**64.40%**	**95.62%**		**4.38%**		

Notice: S1: high suitability; S2: moderate suitability; S3: low suitability; N: Non suitability

The land suitability classification for agricultural production in Gia Binh district was conducted based on land characteristics and land use requirements, covering a total of 6209.38 hectares of agricultural land (Table 4, Figure 10). The results indicate that a significant portion of the land, approximately 64.4%, falls into the S3 category (low suitability), highlighting the need for soil quality improvements and appropriate land management strategies. High suitability (S1) areas account for only 4.46% of the total agricultural land, suggesting limited optimal conditions for cultivation.

Rice production, the dominant agricultural activity in the region, benefits from the highest proportion of suitable land compared to other land use types. However, a notable portion of land remains classified as unsuitable (N), emphasizing the necessity for land use adjustments to enhance productivity. LUT 1, LUT 2 and LUT 4 show relatively higher suitability, with a combined suitable area exceeding 90%, whereas LUT 3 has lower proportion of suitable land. These findings underscore the importance of targeted interventions, such as soil fertility enhancement and improved irrigation infrastructure, to maximize agricultural productivity and promote sustainable land use in Gia Binh.

From a socio-economic perspective, efficient land use planning based on this classification can enhance farm productivity, increase incomes, and reduce production risks. Prioritizing investments in infrastructure, irrigation, and soil improvement for low-suitability areas can significantly improve agricultural efficiency. Additionally, reallocating non-suitable land to alternative uses such as agroforestry or aquaculture can promote economic diversification.

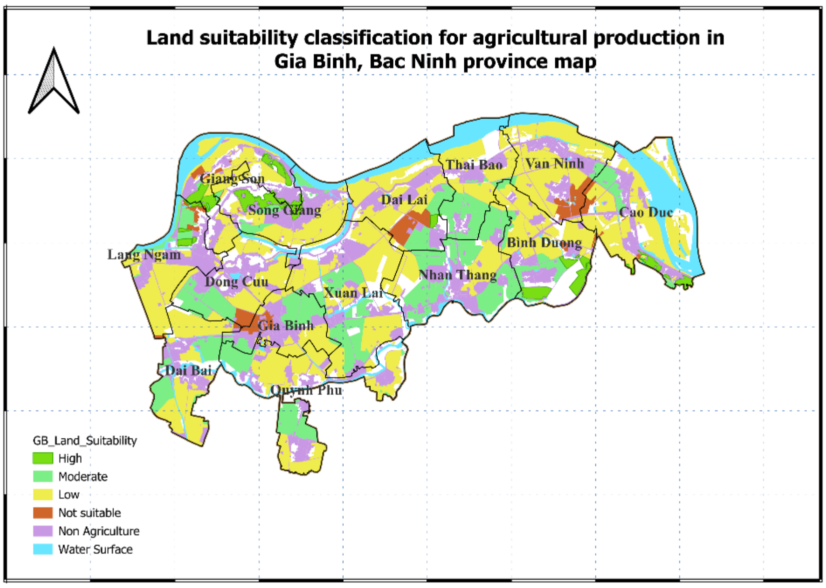

Figure 10. *Land suitability for agricultural production map*

Land suitability classification in Gia Binh provides valuable insights for sustainable agricultural planning and economic development. By optimizing land use decisions, improving soil management, and adapting agricultural practices, this classification supports long-term food security, rural development, and environmental sustainability in the region

4. Conclusion

The land suitability classification conducted for Gia Binh has provided a crucial foundation for sustainable agricultural planning and socio-economic development. The analysis has revealed that while a significant portion of agricultural land has been moderately to highly suitable for cultivation, there have remained areas with low suitability or unsuitability, necessitating targeted interventions. Efforts to enhance soil fertility, improve irrigation infrastructure, and adopt appropriate land management practices have been essential in increasing productivity in these lower-suitability regions. Given the dominance of rice production in the region, the classification results have highlighted the need for strategic land use planning to optimize high-potential areas while exploring alternative agricultural practices for less suitable lands. Additionally, reallocating non-suitable land to other productive uses, such as agroforestry or aquaculture, has contributed to economic diversification and environmental sustainability. This study has underscored the importance of integrating scientific land evaluation with policy-making to ensure efficient land use and long-term agricultural sustainability. By leveraging land suitability classification, local authorities and farmers have been able to make informed decisions that enhance productivity, improve livelihoods, and promote balanced rural development. Future research and continuous land monitoring have been recommended to refine classification methods and adapt to changing environmental and socio-economic conditions.

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