Spatial Planning for Natural Resource Utilization based on an Adaptive Multifunctional Approach: Integrating Ecological Protection, Community and Business in Routa, Konawe, Southeast Sulawesi

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Abstract: - In this research, it is investigating spatial planning strategies in Routa District, a karst region of Southeast Sulawesi with high ecologic and socio-economical complexity. We aim toward building an adaptive spatial planning model that combines ecological conservation, community use and industrial growth. The study blends GIS analysis, site surveys and field interviews with participatory mapping within a mixed-method approach. The zoning strategy is a multifunctional landscape and sustainable development oriented process that takes into account karst characteristics, landscape forms (land use patterns) with socio-ecological dynamics. Successful implementation can only be achieved with an adaptive approach and includes active stakeholder participation along with local knowledge integration. Finally, spatial planning in Router must reconcile biodiversity maintenance of karst ecosystem, capacitating community and economy development through collaborative governance. In this sense, the model provides a novel framework for socio-ecological approaches to karst regions outside of Indonesia.

Key-Words: - Adaptive spatial planning, Multifunctional landscape, Collaborative management, Karst ecosystem, Routa District.

Received: October 9, 2024. Revised: April 9, 2025. Accepted: May 8, 2025. Published: May 29, 2025.

1 Introduction

The management of natural resources based on spatial planning for sustainable use has become increasingly relevant, especially for karst and other areas with sensitive ecosystems. This model strives to balance social needs, economic prosperity, and environmental protection, [1]. But the complexity of stakeholder interactions and local ecosystem dynamics often works against its implementation, [2]. A possible solution is the adaptive multifunctional approach, which provides increased flexibility and synergy between key proposition interests, [3].

A small example of spatial planning problem in karst areas is the case of Routa District, the provincial capital of Konawe Regency, Southeast Sulawesi. In a nutshell, Routa which covers 171,065.82 hotspot hectares is experiencing the "tragedy of the commons" [4] due to an overlapping interests of local communities, industrial sector and ecological conservation efforts. It is even worse in some current spatial planning policies and regulation that are insufficient to deal with the socio-ecological complexity of the place, [5].

Evolution of spatial planning thought shows a welcome from the linear models to more holistic frameworks. [4], [6] highlight that spatial planning can only be understood as a socio-ecological system in its complexity [7], [8] introduce the idea of multifunctional landscapes, while [9] highlight the need for spatial planning and management to be flexible. The adaptive multifunctional approach unites these ideas and offers a spatial planning approach which is more responsive to changing social, economic and ecological conditions, [10].

Routa is rich in biodiversity, including the Matarombeo ecosystem, the Lasampala forest, and the Hiuhiuka wetlands. This area also has historical and cultural value as a place of exchange between people and the center of ethnic resin culture, [11], [12]. These unique environmental and cultural factors are under development pressure and present unique challenges in spatial planning, [13].

Routa grows equally complex as it becomes a Regency Key Area and also part of National Key Area. Located at the nexus of nickel industry towns severely highlights the economic potential along with environmental challenge via its strategic geographical position. The number of 8 nickel mining companies and also 1 oil palm plantations operating in Routa now witness the nature of economic activities there; highlighting large scale environmental implications. Although conservation, community livelihoods and industrial development conflict with each other the main challenge in spatial planning of this region was identified by [14].

This paper contributes within this context to develop an adaptive-based spatial planning model for Routa District at regional level in the adaptive sense. This model is designed with the intention to be a guide in natural resources spatial regulation considering ecological protection (bio), community use and industrial development. This research is expected to provide new and significant ideas in the conflict management as well as sustainable development of karst regions solving method of local ecological, social and economic conditions.

This research is important on three levels: the first one comes from a theoretical perspective, this study involves constructing a new conceptual framework to explore interactions of ecological, social and economic dimensions in spatial planning for karst region, [15]. The second from the methodological part, this research creates new approaches for the assessment and quantification of multifunctionality in karst landscapes by closing gaps within existing scientific review of multifunctional landscape assessment in distinctive ecosystem types, [16]. Third, from an operational level, the outputs of this research are to be guided serving as a reference for stakeholders in karst zones conservation/development trade off management to directly benefit in support of Sustainable Development Goals (SDGs), [17].

So this research not only has to form the basis of scientific innovation, but in the physical output also might contribute to local and regional sustainable development programs in the overall process that is spatial planning of natural resources toward karst regions.

2 Research Methods

The multi-method research design blend of quantitative and qualitative to accomplish this complex research goal, [18]. This particular approach was needed to make a holistic take on the spatial complexities in Routa District reflecting the intricacy of ecological, social and economic interactions that characterize the karst landscape context, [4].

2.1 Data Collection

The data collection consisted of complementary methods. Quantitatively, this study [19] used analyses of multi-temporal satellite imagery to map land use change in Routa All of the above studies have indicated the significant relief of access to forest resources with active and passive human activity. This assessment offered graphical and quantitative representations of the dynamics of landscape change across temporal scales, facilitating the discernment of trends and patterns in land use.

In the context of data collection, the research team conducted identification of existing conditions in Routa, which encompasses 5 environmental and land parameters: karst, river buffer zones, swamps, slopes, and cultivated land. The assessment of karst parameters, river buffer zones, and swamps is based on area size, coordinate points, and current land utilization conditions. The slope parameter is classified into 3 types of slopes: 0-20%, 20-40%, and above 40%. The cultivated land parameter is classified into 3 categories: productive land, low-productivity land, and critical land.

The criteria for productive land include land that is intensively cultivated by the community for pepper, oil palm, or other plantation crops, has high productivity, and serves as the main source of community income. The criteria for low-productivity land include land that is cultivated by the community for pepper, oil palm, or other plantation crops, but has low productivity and does not serve as the main source of community income. The criteria for critical land include land consisting of imperata grasslands or open ground that is no longer cultivated by the community.

To obtain representative primary data, the research team conducted structured surveys with 300 respondents, following the methodology outlined by [20]. First Phase: Data collection on perceptions, practices, and preferences related to land use and natural resource utilization from 300 respondents. Sample determination was conducted proportionally, consisting of 40 individuals per village from local communities, supplemented by 15 industry stakeholders in Routa, and 5 conservation officers in Routa. Second Phase: In-depth interviews with 75 key informants regarding perceptions, practices, and preferences of land use and natural resource utilization from 7 villages (10 people per village), plus 3 business stakeholders and 2 conservation officers. The qualitative aspect of data collection involved in-depth interviews with 75 key informants, adopting the approach recommended by [21]. Third Phase (FGD): Involving 75 key informants from various stakeholders (local communities, business actors, and conservation officers) to deepen understanding and facilitate dialogue among stakeholders. The Focus Group Discussions were conducted in 7 sequential sessions covering 7 villages. The substance of the FGD in each village involved participatory mapping of current land use conditions and spatial utilization zoning plans based on the analysis of 5 environmental and land parameters: karst areas, river buffer zones, swamps, slopes, and cultivated land, [22].

Complementing these methods, the research team also conducted participatory observation and participatory mapping with local communities, [23]. The primary methodology utilized in cartographic analysis is the overlay method, a sophisticated technique involving the superimposition of multiple spatial data layers to analyze the interrelationships among variables and delineate specific zones. This methodological approach is predominantly implemented in Geographic Information System (GIS) software platforms, such as ArcGIS, for the production of thematic maps. The conceptual framework of the overlay method encompasses two fundamental components: 1) the discrete mapping of each pertinent variable or criterion as an independent layer, and; 2) the systematic integration of these layers through mathematical or logical operations to generate a composite map that synthesizes all variables under consideration.

Field data collection procedures encompass: 1) topographic data acquisition utilizing equipment such as drones and geodetic GPS to obtain Digital Elevation Models (DEM); 2) peatland surveys conducted to map depth and distribution patterns, and; 3) cultural heritage site documentation performed using GPS to acquire precise coordinates. Secondary data collection comprises: 1) base maps including topography, land use, and spatial planning downloaded from official institutions such as the Geospatial Information Agency (BIG), and; 2) environmental data such as karst and critical land maps obtained from scientific reports or publications.

For initial data processing, all layer data are standardized to utilize the same projection and coordinate system (UTM WGS 84), and for data correction purposes, quality assurance procedures are implemented to identify and eliminate errors such as incorrect coordinates or incomplete attribute data, while field data are verified against observational results to ensure accuracy.

2.2 Data Analysis

The data analysis adopted a comprehensive multi-method approach, integrating quantitative and qualitative analysis techniques. In the quantitative aspect, spatial analysis using Geographic Information System (GIS) became a key component, [24]. Qualitative analysis involved several techniques. Data from in-depth interviews and FGDs were analyzed using the thematic analysis method, [25]. To enhance the validity of findings, the research team conducted data triangulation, [26]. Integration of quantitative and qualitative analysis results was carried out through several stages, adopting the approach outlined by [27]. First phase: Land Use Condition Analysis: This analysis aims to observe trends in land use changes according to 5 environmental and land parameters: assessment of karst parameters, river buffer zones, swamps, slopes, and cultivated land. The identification of area size, coordinate points, and utilization patterns is conducted based on field observations and interviews, which are subsequently mapped using GIS software, [28], [29], [30], [31].

Second phase: Spatial Utilization Zoning Analysis: This analysis aims to determine spatial planning strategies based on the results of 10 series of FGDs in 5 villages in Routa District. The Spatial Planning Criteria are divided into 3 categories: (1) Ecological Protection Zone: areas with high slopes (>40%), karst areas, river buffer zones, and swamps; (2) Community Management and Utilization Zone: areas with low slopes (0-20%) to moderate slopes (20-40%) and productive land cultivated by the community for plantation crops, food crops, and livestock; (3) Industrial/Business Management Zone: to accommodate intensive economic activities on land with moderate slopes (20-40%), low-productivity land, and critical land. Finally, the research team employed scenario planning techniques to develop an adaptive spatial planning model, [32].

2.3 Research Ethics and Validity

The study was conducted according to the ethical principles established by [33]. Several techniques were used to ensure the certainty and reliability of the research, such as triangulation of methods and data sources, [34].

2.4 Research Limitations

Despite this research being limited specifically to the context of Routa, Konawe, the findings can be a foundation for comparative studies on other karst regions with corresponding traits, [35].

3 Results and Discussion

3.1 Existing Spatial Conditions in Routa District

Researchers examined the current spatial conditions in Routa District by using a step-by-step mixed-method approach that combined explanation and analysis, [18]. They looked at five factors related to the environment and land: karst, river banks, swamps, slopes, and cultivation. What they found shows how complicated the relationships are between social, economic, and ecological aspects in Routa's local setting. This fits with the idea of complex social-ecological systems, [4], [6].

3.1.1 Karst

The karst area plays a key role in creating a spatial planning model to use natural resources in Routa Konawe. This study uses a step-by-step mixed-method approach [18] to grasp the complex nature of the karst ecosystem. It combines spatial analysis, field observations, and deep interviews.

Routa District has the biggest karst potential in Konawe Regency, which people call the Matarombeo Mountains, [36], [37]. Folks in the area split it into two parts: the Matarombeo Mountains in Lalomerui and the Pu'umbangi Mountains in Walandawe. This shows how the land's features and local stories are linked, [38], [39]. The alignment of the two karst mountains is illustrated in Figure 1.

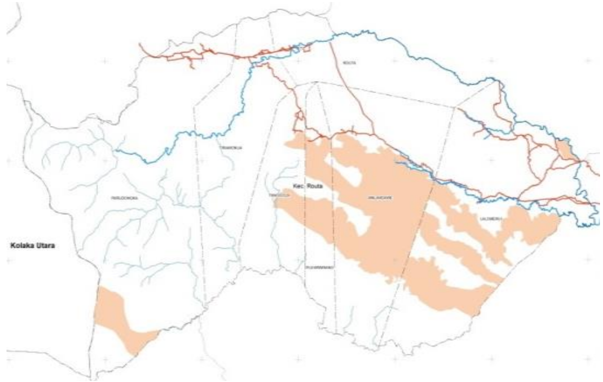


Fig. 1: Map of karst distribution in Routa District

Table 1. Villages, Area, and Indicative Coordinate Points of Karst Regions in Routa.

No.	Village	Area (Ha)	E	S
1.	Lalomerui	2,683.01	121° 45' 50.430"	3°10' 56.836"
2.	Walandawe	3,259.66	121° 43' 53.683"	3°10' 0.923"
3.	Pu'uwiwirano	494.56	121° 41' 26.326"	3° 8' 7.220"
4.	Tanggola	255.48	121° 39' 36.606"	3° 7' 5.350"
5.	Parudongka	114.99	121° 28' 44.432"	3° 15' 9.492"
TOTAL		6,807.77		

The karst area distribution within Routa District, encompassing five villages and covering a total area of 6,807.77 hectares, is presented in Table 1. Walandawe Village possesses the most extensive karst area at 3,259.66 hectares, while Lalomerui Village follows with an area of 2,683.01 hectares. Smaller karst areas can be found in several communities, including Parudongka Village (smallest at 114.99 hectares), Tanggola Village (255.48 hectares), and Pu'uwiwirano Village (494.56 hectares). Additionally, the table provides detailed geographical information for each karst area site by displaying suggestive coordinate points.

The region's high vegetation cover is one of its distinctive features, suggesting intricate relationships between the ecology of tropical forests and karst geology, [40]. For a variety of rare and endangered animals, the Routa karst ecosystem serves as an essential habitat, [41].

Apart from its ecological significance, the Routa karst region is home to a plethora of historical and archeological artifacts, such as paleoanthropological remains and cave paintings, [42], [43], [44]. However, land conversion is posing a growing threat to the ecosystem's integrity [45], which reflects the conflict between economic development and conservation, [46].

3.1.2 River Banks

In Routa, Konawe, river banks play a crucial role in the spatial analysis of natural resource use. This study combines field observations, in-depth interviews, and GIS spatial analysis using a sequential explanatory mixed-method approach, [18].

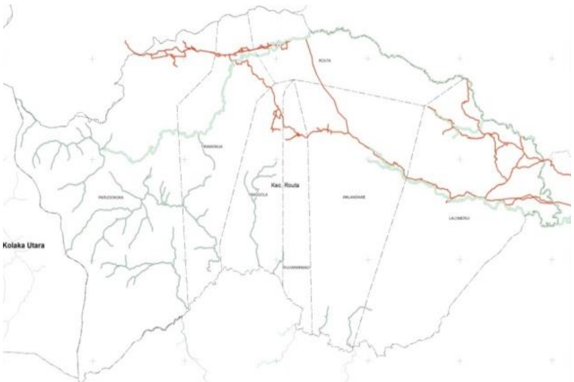


Fig. 2: Map of river flows in Routa District

Based on the above Figure 2, eleven rivers have been identified in the Routa District, with the primary river flow directed from the west (Towuti Lake) to the east. The tributaries located in the northern and southern regions all converge into the Wuaki River, which serves as the main river. The rivers in Routa have many uses, including providing clean water, irrigation for agriculture, transportation, mini-hydropower production, and animal protein. Rice fields, plantations, and other agricultural uses along riverbanks are examples of "riparian multifunctionality", [47] (Table 2).

As shown in Table 2, the Wuaki (Lalindu) River represents the longest watercourse, extending for 135.71 kilometers through Parudongka Village and 56.50 kilometers through Lalomerui. The riparian buffer zone encompasses a total area of 3,898.05 hectares, with its distribution varying across villages.

The river course is variable, reflecting the extent of karst hydrology. Some cities have full, continuous channels, while others have small, intermittent streams, [48], [49]. The persistence of river flows during the dry season indicates the large water storage capacity of karst aquifers [50], which are supported by well-maintained forest ecosystems, [51].

However, the Routa ecosystem faces various human pressures. Illegal logging, expansion of palm and pepper plantations, and mining threaten the integrity of the watershed and water quality, [52]. These activities also have the potential to significantly alter local hydrological regimes, [53].

Table 2. Flow Length and Area of River Banks in Routa District

No.	Village	Classification	Length (Km)	Area (Ha)
1.	Lalomerui	Small River	0.94	1.014.95
2.	Lalomerui	Large River	56.50	
3.	Parudongka	Small River	135.71	1.283.45
4.	Parudongka	Large River	15.78	
5.	Puwiwirano	Small River	1.08	10.10
6.	Routa	Large River	19.80	406.61
7.	Tanggola	Small River	24.02	212.44
8.	Tirawonua	Small River	28.20	698.09
9.	Tirawonua	Large River	22.13	
10.	Walandawe	Small River	10.81	272.41
11.	Walandawe	Large River	12.91	
TOTAL			327.90	3.898.05

This situation emphasizes the urgency of developing integrated watershed management strategies, balancing conservation needs with economic development aspirations, [54]. The main challenge lies in how to manage water resources sustainably while accommodating the economic needs of communities and industries, as well as maintaining the ecological functions of river banks in the context of a complex karst landscape.

3.1.3 Swamps

Swamp ecosystems play a crucial role in the spatial planning of natural resource utilization in Routa District, holding ecological, economic, and cultural value. This study employs a mixed-method approach [18] to analyze the spatial distribution, characteristics, and utilization of swamps, as well as the challenges in their management.

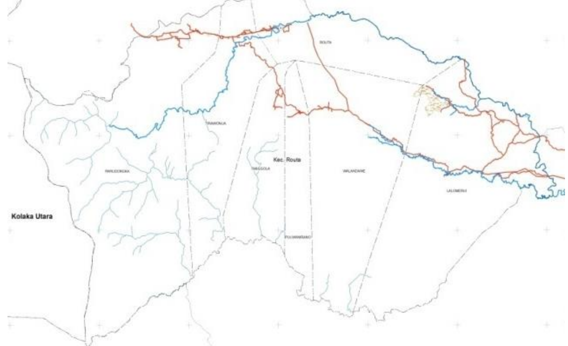


Fig. 3: Map of swamp distribution in Routa District

Spatial analysis, as illustrated in Figure 3, reveals that the total swamp area in Routa encompasses 503.22 hectares in Routa, concentrated in four administrative regions: Lalomerui Village (426.99 ha), Walandawe (63.95 ha), Parudongka (9.37 ha), and Routa Sub-district (2.91 ha). This variation in area reflects the heterogeneity of the karst landscape and local drainage patterns. For a more detailed explanation, please refer to the Table 3.

Table 3. Villages, Area, and Indicative Coordinate Points of Swamps in Routa

No.	Village	Area (Ha)	E	S
1.	Lalomerui	426.99	121° 49' 29.591"	2° 59' 53.707"
2.	Walandawe	63.95	121° 48' 56.979"	3° 0' 22.324"
3.	Routa	2.91	121° 38' 59.119"	2° 56' 0.093"
4.	Parudongka	9.37	121° 34' 31.350"	2° 56' 23.266"
TOTAL		503.22		

The swamp ecosystems in Routa exhibit unique hydrogeological characteristics, with abundant water content throughout the year, indicating high water storage capacity in karst aquifers, [50]. The resilience of swamps to seasonal variations is supported by the surrounding well-preserved forest conditions, [51].

The largest swamp, Hiuhiuka or Taparan Teo in Lalomerui Village, holds significant ecological importance and cultural value. Its existence reflects the concept of "cultural keystone places" [55], emphasizing the importance of integrating cultural values in natural resource management, [56].

The utilization of swamps by the Routa community illustrates the concept of "wetland multifunctionality" [57], encompassing sources of clean water, fish cultivation, rice farming, recreation, and ecotourism. This model reflects community adaptation to local resources, but also presents challenges in balancing economic needs with ecosystem protection.

Despite its great value, the wetland ecosystem in Routa faces significant threats. The conversion of wetlands into rice fields can threaten their ecological function as river basins, [58]. Expansion of oil palm plantations threatens the integrity of wetlands that support ecosystems, [59].

The most serious threat is the plan to convert Hiuhiuka into an industrial area within the mining concession, which indicates a conflict between economic development and ecosystem protection, [60]. This situation highlights the importance of designing integrated wetland management strategies, balancing conservation needs with economic development prospects.

The main challenge in managing the wetland ecosystem in the Routa is to balance conservation and economic use while preserving its cultural value. An integrated approach is needed that takes into account the complexity of interactions between ecological, social and economic systems in the context of this unique karst environment.

3.1.4 Slope Analysis

Landscape and slope analysis is fundamental to understanding the potential and challenges of landscape management in Routa District. The area exhibits complex geographical features that reflect the diversity of tropical karst landscapes typical of Sulawesi, [61].

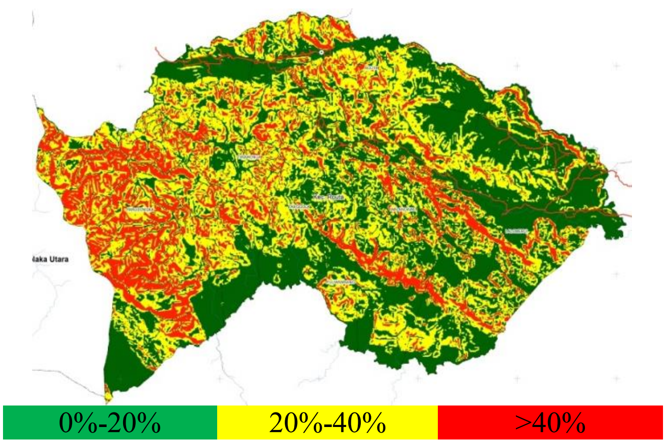


Fig. 4: Slope map of Routa District

The spatial analysis conducted through GIS, as illustrated in Figure 4, indicates the following distribution of slope classes: 0-20°: 93,142.08 hectares (54.45%), 20-40°: 51,284.01 hectares (29.98%), and >40°: 26,639.71 hectares (15.57%). The total area of Routa District reaches 171,065.81 hectares, with slope variations reflecting the complexity of karst geomorphology. The region consists of three main geomorphological units: karst mountains, forest mountains, and valleys. For a more detailed explanation, please refer to the Table 4.

Karst mountains dominate the southern sides of Lalomerui and Walandawe villages, indicating intensive karstification processes, [62]. Forest mountains, characteristic of tropical karst ecosystems [36], are widely distributed in the northern parts of several villages. Valleys, typically settlement locations, are found in smaller proportions. Routa's hydrological system is characterized by a complex river network, with the Wuaki (Lalindu) River as the main flow. The flow pattern reflects typical karst drainage characteristics, [63]. For a more detailed explanation, please refer to the Table 4.

Table 4. Villages, Land Area According to Slope Class in Routa District.

No.	Village	Slope Class (ha)			Total (ha)
		0-20	>20-40	>40	
1.	Lalomerui	28,054.90	6,468.68	3,650.76	38,174.34
2.	Parudongka	16,545.11	17,541.94	15,778.06	49,865.11
3.	Puuwiwirano	5,459.23	2,152.83	361.55	7,973.61
No.	Village	Slope Class (ha)			Total (ha)
		0-20	>20-40	>40	
4.	Tanggola	7,250.28	3,979.16	663.36	11,892.80
5.	Tirawonua	7,890.41	8,851.81	3,084.87	19,827.09
6.	Walandawe	21,704.81	6,509.87	1,228.83	29,443.51
7.	Routa	6,237.34	5,779.73	1,872.28	13,889.35
TOTAL		93,142.08	51,284.01	26,639.71	171,065.81

The morphology of Routa's mountains shows an east-west elongated layered structure, with vegetation dominated by mountain forests, savanna fields, and karst formations, [64]. Ecological boundaries are determined by significant geographical features, including Torukuno Lasampala in the north and Lake Towuti in the west. Torukuno Lasampala has ecological and administrative significance, serving as a natural boundary between regions and provincial borders. This strategic position reflects the important role of geological formations in determining administrative boundaries, [65].

Biodiversity in Torukuno Lasampala is exceptionally high, exhibiting characteristics of Sulawesi's typical tropical montane rainforests, [66]. This area hosts diverse species of timber, rattan, and other plants, indicating ecosystem complexity and ethnobotanical potential, [67].

Although the topographical configuration has important implications for spatial planning, field observations reveal land use patterns that contradict conservation principles. Cultivation and mining activities are found in areas with slopes >40°, as well as in sensitive areas such as swamps and river banks. These practices align with [68] findings on forest encroachment in topographically challenging areas.

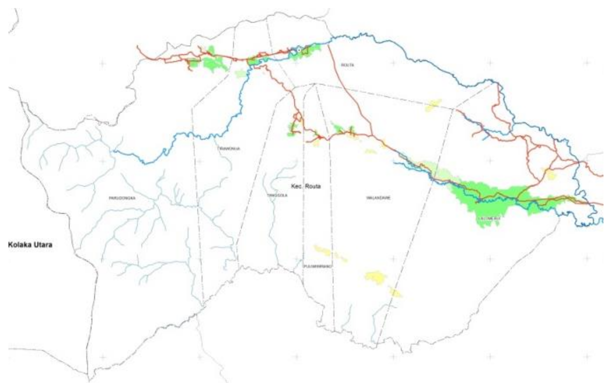
Surveys reveal rampant illegal logging and forest encroachment for agriculture, with intensity increasing since 2012. This phenomenon reflects the complex socio-economic dynamics behind deforestation [69] and indicates weaknesses in law enforcement and forest management, [70].

The main challenges of landscape management in Routa include: 1) Balancing conservation and economic use in areas with steep slopes; 2) Addressing unsustainable land use practices in sensitive areas ; 3) Controlling deforestation and illegal forest encroachment; 4) Integrating management of transboundary natural resources; and; 5) Maintaining biodiversity while meeting the economic needs of the community.

A thorough understanding of these topographical features and challenges provides an important basis for designing zoning and management strategies that take into account the uniqueness of the karst landscape and the socio-economic realities of the area.

3.1.5 Cultivated Land

The analysis of land productivity and agricultural problems in the Routa region highlights the challenges of land use in karst areas. The total cultivated area reaches 6,476.4 hectares, divided into production areas (72.54%), marginal areas (15.14%), and disadvantaged areas (12.32%). This grouping follows [71] approach to assessing soil quality and productivity in Indonesia.



Economically viable land	Critically degraded land	Economically marginal land

Fig. 5: Map of cultivated land distribution in Routa District

The spatial distribution of cultivated land, as illustrated in Figure 5, demonstrates intricate relationships between biophysical and socio-economic factors, [72]. Agricultural activities are concentrated along two main corridors: Lalomerui-Walandawe Village and Routa-Parudongka Village, indicating a tendency to utilize areas with more favorable soil conditions in the karst region, [62]. For a more detailed explanation, please refer to the Table 5.

Table 5. Villages, Cultivated Land Area According to Productivity Level in Routa District (Ha)

No.	Village	Productive	Low Productivity	Critical	Total
1.	Lalomerui	3,547.88	401.73	145.39	3,568.6
2.	Parudongka	447.87	22.88	0	447.9
3.	Puuwiwirano	30.69	15.96	113.70	31.3
4.	Tanggola	102.20	0	29.27	102.2
5.	Tirawonua	148.44	90.33	0	238.8
6.	Walandawe	120	449.69	454.68	1,024.3
7.	Routa	300.85	0	54.86	355.7
TOTAL		4,697.9	980.59	797.90	6,476.4

Variations in agricultural productivity are identified across different locations. In Lalomerui Village, pepper and oil palm crops show suboptimal growth, possibly due to land unsuitability or improper management, [73]. Walandawe is dominated by grasslands for grazing, reflecting adaptation to less productive land, [72]. Meanwhile, in Routa, Tirawonua, and Parudongka Sub-districts, pepper plantations demonstrate high success rates, perhaps due to a combination of land suitability, good management, and supportive microclimate, [74].

The main challenges in managing cultivated land include: 1) Soil erosion: Sloping land increases the risk of erosion and loss of humus layer, [35]. Local farmers have adopted soil conservation practices as recommended by [71]; 2) Pest and disease attacks: Particularly root and fruit rot in pepper plants [75]; 3) Land use conflicts: Occurring between agricultural, mining, and large-scale plantation sectors [1], and; 4) Land abandonment: When diseases are difficult to overcome, land becomes unproductive and critical, aligning with [76] land degradation model.

These conditions reflect the complexity of managing multifunctional landscapes in karst regions. The main challenge lies in balancing agricultural productivity with environmental conservation while addressing land use conflicts and degradation due to unsustainable practices.

Understanding the variations in land productivity and agricultural challenges becomes crucial in designing zoning and management strategies that consider the unique characteristics of the karst landscape and local socio-economic realities. An integrated approach is needed to reconcile the needs of agriculture, environmental protection, and economic development in the Routa region.

3.2 Spatial Planning Strategy

The spatial planning strategy of the Routa Region was developed by combining geographic information system (GIS)-based spatial analysis with harmony and cooperation. The principle of this concept combines the ecological planning principles of [77], which emphasizes the importance of understanding and respecting natural processes in planning, and also the mosaic landscape concept of [78], which sees landscapes as interconnected basic mosaics, with [79]. The mediation plan recognizes the complexity and dynamic nature of these systems.

The basic zoning in this strategy maintains three broad categories but uses a more flexible structure to suit the complexity of the Routa karst landscape. Ecological reserves cover the high-altitude area, karst area, riparian area and marshland, and follow the karst ecosystem protection principles of [35]. Community management uses areas focused on low to medium areas, excluding ecologically sensitive areas, according to the sustainable land use concept proposed by [4]. Commercial/business management zones are designed to accommodate intensive work in low-lying areas, including non-productive land, and to use sustainable development models defined by [80].

Elements of flexibility and adaptability are integrated into the strategy to enhance responsiveness to social-ecological dynamics. The implementation of buffer zones and the mosaic landscape approach, as recommended by [81] aims to facilitate gradual transitions between zones and maintain ecological connectivity. Concepts of conditional use and multi-criteria zoning are introduced to accommodate the complexity of land use in karst areas, adopting the approach proposed by [82] in multi-criteria land suitability analysis.

The planning and implementation process emphasizes active stakeholder participation and integration of local knowledge, in line with the principles of co-management advocated by [83]. Adaptive and scenario-based planning approaches, following the methodology developed by [9], are used to anticipate and respond to changes in ecological and socio-economic conditions. The ecosystem approach reflects the current paradigm in natural resource management, as noted by [84].

The implementation and management of this strategy is supported by the development of an integrated information system, an incentive system and a capacity building program. Multi-sectoral collaboration and participatory monitoring are emphasized to ensure effective coordination and community participation in landscape management, adopting the principles of adaptive management outlined by [9].

The aim of this integrated strategy is to achieve a balance between ecological protection, community resource use and economic development in Routa District. This approach allows for flexibility in implementation while maintaining the fundamental principles of conservation and sustainable development, reflecting current concepts in landscape planning that recognize the complexity and dynamics of social and ecological systems [85].

The spatial division of Routa district, based on an integrated strategy and available data, demonstrates the complexity of the karst landscape and the need to reconcile conservation and economic development. This analysis creates three main zones that have adaptive and adaptable characteristics: 1) Ecological protection space; 2) space for community use; and 3) Business management position, as illustrated in the Figure 6.

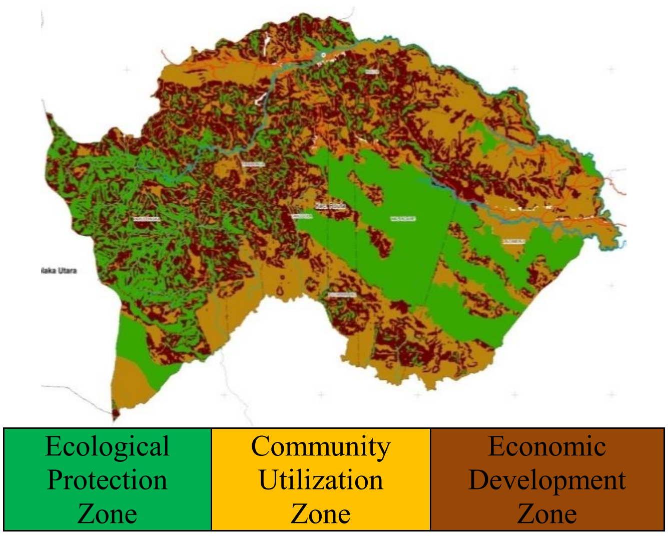


Fig. 6: Natural Resource Utilization Spatial Pattern of Routa District

3.2.1 Ecological Protection Zone

The Routa Ecological Reserve covers 31,040.97 hectares (18.15% of the total area) and consists of large slopes, landscaped areas, riverbanks and wetlands. Areas with slopes >40% (26,639.71 hectares) require special protection to prevent erosion and landslides, as well as to maintain hydrological integrity, [86], [87]. Visually, this can be observed in the Figure 7.

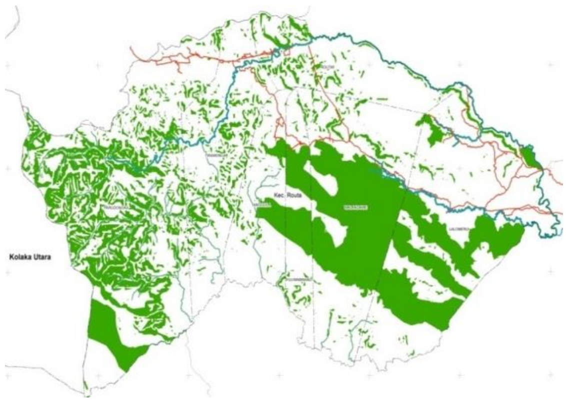


Fig. 7: Map of ecological protection areas in Routa District

Routa's karst region (6,807.77 hectares) represents a unique ecosystem with high endemism and significant conservation and archaeological value [40], [42], [88]. River banks (3,898.05 hectares) serve as ecological buffers and biodiversity corridors [17], while swamp areas (503.22 hectares) hold substantial ecological and cultural significance [89], [90]. For a more detailed explanation, please refer to the Table 6.

Table 6. Villages, Land Area of Ecological Protection Zone in Routa District

No.	Village	>40%	Swamp	River Bank	Karst	Total
1.	Lalomerui	3,650.76	426.99	1,014.94	2,683.01	5,092.69
2.	Parudongka	15,778.06	9.37	1,283.45	114.99	17,070.88
3.	Puuwiwirano	361.55	0	10.10	494.56	371.65
4.	Tanggola	663.36	0	212.44	255.48	875.8
5.	Tirawonua	3,084.87	0	698.09	0	3,782.96
6.	Walandawe	1,228.83	63.95	272.41	3,259.66	1,565.19
7.	Routa	1,872.28	2.91	406.61	0	2,281.80
TOTAL		26,639.72	503.22	3,898.05	6,807.77	31,040.97

The designation of the Ecological Protection Zone reflects an understanding of the interconnectedness of karst ecosystems and the importance of a landscape approach in conservation,

[62]. Effective implementation of zoning becomes urgent in the face of increasing development pressures, aligning with the principles of adaptive management, [79]. In conclusion, this zone represents a comprehensive effort to maintain ecosystem integrity, requiring an integrated approach that combines scientific knowledge with local wisdom, [85].

3.2.2 Community Utilization Zone

The Community Management and Utilization Zone in Routa District encompasses 86,962.33 hectares (50.84% of the total area), integrating the socio-economic needs of the community with sustainable land management. This zone is dominated by low to moderate slope areas, suitable for agriculture and settlements, in accordance with the FAO's land suitability assessment principles, [91].

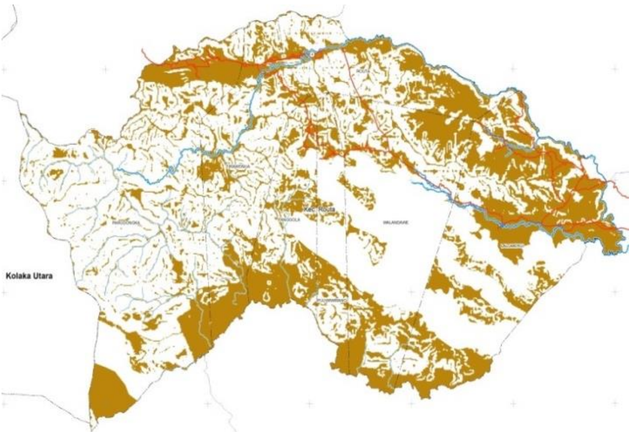


Fig. 8: Map of community utilization areas in Routa District

The concentration observed in the Lalomerui-Walandawe Village corridor and the Routa-Parudongka Village corridor, as illustrated in Figure 8, indicates both historical and current land use patterns. These areas have become centers of productive agriculture, particularly pepper plantations, demonstrating significant economic potential, [92]. The designation of this zone aligns with the concept of multifunctional landscapes [7], maximizing ecological and socio-economic benefits. For a more detailed explanation, please refer to the Table 7.

Key factors in zone designation include land suitability [93], existing land use patterns [94], agricultural productivity, accessibility [95], minimization of conflicts with protection zones [96], and agroforestry potential [97]. This approach also considers socio-cultural aspects, integrating local knowledge [84].

Table 7. Villages, Land Area of Community Utilization Zone in Routa District (Ha).

No.	Village	0-20%	Swamp	RB	PL	LPL	CL	Total
1.	Lalomerui	28,054.90	426.99	1,014.94	3547.88	401.73	145.39	26,065.85
2.	Parudongka	16,545.11	9.37	1,283.45	447.87	22.88	0	15,229.41
3.	Puuwiwirano	5,459.23	0	10.1	30.69	15.96	113.70	5,319.47
4.	Tanggola	7,250.28	0	212.44	102.20	0	29.27	7,008.57
5.	Tirawonua	7,890.41	0	698.09	148.44	90.33	0	7,101.99
6.	Walandawe	21,704.81	63.95	272.41	119.95	449.69	454.68	20,464.08
7.	Routa	6,237.34	2.91	406.61	300.85	0	54.86	5,772.96
TOTAL		93,142.08	503.22	3,898.04	4697.89	980.59	797.90	86,962.33

Note: RB=River Bank, PL=Productive Land, LPL=Low Productivity Land, CL=Critical Land

The main challenge lies in balancing agricultural intensification with conservation. Zone implementation must be accompanied by the promotion of conservative agricultural practices and adaptive agroforestry systems, [98]. In conclusion, this zone represents an effort to create multifunctional landscapes that meet the socio-economic needs of the community while maintaining ecological functions, in line with the sustainable development paradigm, [85].

3.2.3 Business Management Zone

The Business Management Zone in Routa District encompasses 53,062.51 hectares (31.02% of the total area), accommodating economic development needs within the context of a karst landscape. This zone includes areas with moderate slopes (>20-40%), as well as unproductive and critical lands, based on considerations of topographic suitability, utilization of unproductive land, existing economic realities, economic potential, and role as a regional economic buffer, [99], [100], [101], [102], [103].

According to the aforementioned Figure 9, this area hosts extensive economic operations, including the PT. Mulya Tani oil palm plantation, which spans 9,934 hectares, and the PT. SCM mining concession, covering 21,100 hectares. However, the designation of this zone also presents challenges related to ecological impacts, requiring a careful and integrated management approach, [80]. For a more detailed explanation, please refer to the Table 8.

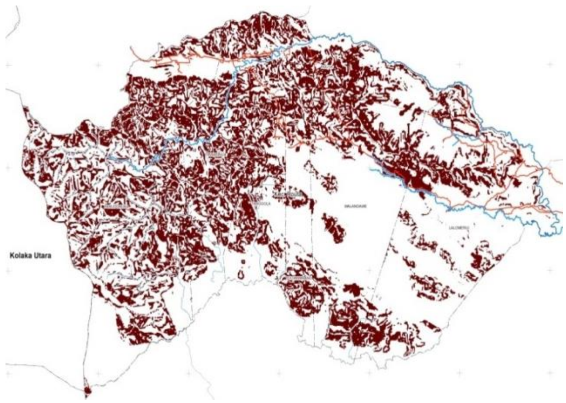


Fig. 9: Map of business utilization areas in Routa District

Table 8. Villages, Land Area of Business Management Zone in Routa District (Ha)

No.	Village	>20-40	LPL	CL	Total
1.	Lalomerui	6,468.68	401.73	145.39	7,015.8
2.	Parudongka	17,541.94	22.88	0	17,564.82
3.	Puuwiwirano	2,152.83	15.96	113.7	2,282.49
4.	Tanggola	3,979.16	0	29.27	4,008.43
5.	Tirawonua	8,851.81	90.33	0	8,942.14
6.	Walandawe	6,509.87	449.69	454.68	7,414.24
7.	Routa	5,779.73	0	54.86	5,834.59
Total		51,284.01	980.59	797.9	53,062.51

Note: LPL=Low Productivity Land, CL=Critical Land

Key strategies in zone management include implementing sustainable industry practices [104], internal zoning [105], ecological compensation [106], continuous monitoring and evaluation [107], and local community empowerment [108]. This approach aligns with the concept of "sustainable resource-based development" [109].

The implementation of spatial planning strategies in Routa combines elements of flexibility and adaptability, reflecting an understanding of the dynamics of social-ecological systems [9]. This approach includes the concepts of buffer zones and mosaic landscapes [78], the use of restrictions and multi-criteria zoning [82] and the identification of ecological pathways, [110].

This strategy requires an adaptive and participatory approach in terms of co-management [83] and periodic monitoring [111] that reflects adaptive management concepts. The aim is to balance conservation requirements with economic development and create a sustainable and multifunctional country, [112].

This approach recognizes the complexity of socio-ecological systems, combines local knowledge with scientific knowledge and can change different situations. The Routa territorial planning strategy reflects the current landscape planning paradigm in response to ecological and economic dynamics.

4 Conclusion

This study has developed a flexible and scalable framework for the Routa region, which integrates environmental protection, community use, and economic development. The regional strategy is expanded into three main areas: Environmental Protection, Community Use and Management, and Business/Business Management, which balances conservation needs with economic development. The adaptive and transformative elements in this strategy allow for an effective response to the socio-environmental context of the karst region.

Implementing this strategy requires coordination through partnerships and the integration of local knowledge. The success of regional planning depends on a balance between environmental protection, sustainable use of natural resources, and economic development. This research contributes to the development of the theory and practice in the planning of infrastructure in karst areas. However, further research is needed to evaluate the long-term impact and to explore its application in different regions and business markets.

Further long-term studies are needed in the future to assess the effects of land-use change on the karst ecosystems of the Route, including an assessment of the operational performance of the sub-sectors. In addition, more research is needed on the adaptive responses of local communities to changes in spatial planning and the economic and social impacts of zoning. This includes the need to develop methods for assessing site performance, advanced karst methods, clear indicators for environmental monitoring and evaluation, and the integration of land use and local knowledge. As such, these research directions reflect the broader goal of increasing understanding of karst system processes and contributing to better planning and management.

Implement and approve policies aimed at creating a management agency to manage high-density areas and improve the capacity of local governments in developing communities. Technical standards include the development of detailed spatial plans for each area and coordination and integrated spatial information systems within the framework of the law. Social and economic resources include the development of community empowerment programs, victim apology programs, and sustainable business strategies that are compatible with zoning requirements. In terms of policies, this suggests that regional karst management concepts should be developed and community policies should be integrated with karst management. These proposals constitute a major strategy that protects the environment and promotes human development, and enhances the karst landscape.

Declaration of Generative AI and AI-assisted Technologies in the Writing Process

During the preparation of this work the author(s) used [CLAUDE] in order to [improve the readability and language of my manuscript]. After using this tool/service, the author(s) reviewed and edited the content as needed and take(s) full responsibility for the content of the publication.

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Contribution of Individual Authors to the Creation of a Scientific Article (Ghostwriting Policy)

- Sarlan Adijaya conducted interviews and analysis of all sociocultural data and policy politics.
- Lukman Yunus performed analysis on all socioeconomic data and agricultural cultivation practices.
- Nasaruddin carried out analysis of ecosystem data.
- Jamal Mukaddas conducted spatial analysis utilizing a GIS approach.

Sources of Funding for Research Presented in a Scientific Article or Scientific Article Itself

No funding was received for conducting this study.

Conflict of Interest

The authors have no conflicts of interest to declare.