Integrating Spatial Planning and Agroecology to Enhance Agricultural Carrying Capacity in Rural Development Zones

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ABSTRACT

Spatial planning has been recognized as a critical tool for guiding regional development in alignment with environmental conservation and food security objectives. However, in practice, discrepancies often exist between formal spatial planning and adaptive, locally-based agricultural systems. This gap creates a knowledge divide in understanding how spatial and agroecological aspects can be synergistically integrated to support the sustainability of agricultural areas. This study aims to explore the integration of spatial planning and agroecology practices to enhance the carrying capacity of agricultural zones within rural development areas. The research employs a qualitative approach with a sequential explanatory design, beginning with in-depth interviews with local stakeholders in North Konawe Regency. The findings indicate that strengthening the carrying capacity of agricultural areas requires a more contextual integration between spatial planning policies and community agroecological practices, which, in turn, enhances the effectiveness of regionally-based development planning. These results have theoretical implications for expanding the understanding of the interrelationship between spatial planning and agroecology, as well as practical implications for formulating policies that leverage local potentials to achieve sustainable rural development.

Keywords: *Agroecology, Carrying Capacity, Rural Development, Spatial Planning.*

INTRODUCTION

Spatial planning is widely recognized as a strategic framework for managing land use efficiently and sustainably, reducing conflicts among agriculture, settlement, and conservation (Murmu & Neelam, 2022; Wang, 2022). It provides a basis for local governments to develop policies that integrate biophysical and socio-ecological land characteristics while supporting food security and environmental sustainability. Geospatial environmental carrying capacity models are key tools in land-use planning, incorporating land cover, ecoregions, and environmental indicators (Al-Mamun et al., 2021; Araújo et al., 2021; Abbasi et al., 2022). By combining GIS, field surveys, and index scoring, these models generate maps that guide regional planning (Badreldin et al., 2021). This approach helps keep resource use within environmental limits, reducing risks such as soil erosion, land degradation, and biodiversity loss (Abhilash, 2021).

Agricultural development is also significantly supported by spatial planning, as zoning enables the identification of areas most suitable for development or protection based on biophysical and social criteria, reducing the risk of inappropriate investments (Abdelkareem et al., 2021). Previous studies by Ali et al. (2021) and Araújo et al. (2021) emphasize that without effective spatial planning, agroecological potential may be overlooked or even damaged due to land conversion pressures or unsustainable input use. At regional and national scales, optimizing land carrying capacity through spatial planning becomes crucial, given pressures from urbanization and settlement expansion.

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Adaptive spatial planning must consider local characteristics such as climate, soil types, topography, and water resources (Murmu & Neelam, 2022). GIS-based zoning and ecoregion mapping are regarded as advanced methods that support more responsive spatial policy decisions (Badreldin et al., 2021; Bennett et al., 2023). In contrast, spatial planning can bridge the gap between agroecological theory and field practice in promoting sustainable agriculture (Beckman & Countryman, 2021).

Agroecology has been widely recognized as a transformative agricultural approach that focuses not only on productivity but also on ecosystem functions and social equity. Studies on productive agroecological system planning indicate that landscape connectivity between semi-natural habitats and productive lands supports ecological functions such as pollination and biological control, while also enhancing crop productivity (Banerjee et al., 2021; Bisht et al., 2022; Akanmu et al., 2023). Agroecology emphasizes structural landscape transformation and the spatial relationship between agricultural lands and natural elements rather than merely substituting inputs (Benos et al., 2021; Bernhardt et al., 2021). Recent systematic reviews by Eibl et al. (2021) and Deguine et al. (2023) highlight the importance of participatory methods and socio-economic assessments as essential components of agroecological transitions, positioning agroecology as a strategic element in sustainable agricultural development, particularly in rural areas facing land conversion pressures and environmental degradation.

Agricultural carrying capacity serves as a crucial parameter for assessing the extent to which a region can support agricultural activities without causing long-term environmental damage (Darmaun et al., 2023; Çakmakçı et al., 2023). A case study in Jombang Regency, Indonesia, demonstrated that land conversion, proximity to urban areas, and spatial planning policies were dominant factors influencing agricultural carrying capacity. Internationally, assessments that integrate biocapacity and ecological footprint have been proposed as a new standard for sustainable agricultural modeling (Humaira et al., 2025). Spatial modelling enables the prediction of future surpluses or deficits in carrying capacity and supports the design of agricultural zones that consider ecological and social boundaries (Gerber, 2022; Edan et al., 2023; Kumar et al., 2024).

Nevertheless, gaps often arise due to the mismatch between formal spatial planning policies and local agricultural practices, particularly in rural areas. Spatial planning documents often rely on macro-level data that do not reflect local land management, ecological values, or cultural significance (Bisht et al., 2022; Cordeau, 2022; Akanmu et al., 2023). Landscape agroecology studies show that traditional maps fail to capture agroforestry areas or local cropping systems, highlighting the need for more adaptive spatial policies responsive to local practices to prevent zoning conflicts or degradation of carrying capacity (Kumar et al., 2021; Fang et al., 2021; Kharel et al., 2022). This study aims to explore the integration of spatial planning and agroecology practices to enhance the carrying capacity of agricultural areas in rural development zones. This research aims to analyze the spatial and socio-agroecological conditions in agricultural development zones, explore local practices and policies related to spatial planning and agroecology, and develop an integrative conceptual model to strengthen the sustainable carrying capacity of agricultural areas.

LITERATURE REVIEW

Spatial Planning in Rural Development

Spatial planning is a crucial instrument in development planning, aiming to regulate land use efficiently and sustainably. In rural contexts, spatial planning not only focuses on infrastructure development but also on managing agricultural areas to maintain productivity and environmental sustainability (Boillat et al., 2022; Pan et al., 2022). Effective spatial planning allows for a clear separation of land functions between agriculture, settlements, and industry, minimizing land-use conflicts and preserving natural resources that are essential for rural livelihoods (Pan et al., 2021). Furthermore, spatial planning contributes to the management of irrigation systems, soil conservation, and disaster risk mitigation, all of which support local food security and long-term agricultural productivity.

Previous studies indicate that integrating spatial aspects into rural development enhances the community's ability to manage resources sustainably while strengthening resilience to environmental and economic changes (Cheng et al., 2022; Cardon & Marshall, 2024). Therefore, spatial planning serves not only as a formal guideline but also as a strategic tool to reinforce the carrying capacity of agricultural areas. Context-sensitive planning can optimize land use, support infrastructure development aligned with community needs, and promote sustainable land management practices. This underscores the importance of spatial planning as a foundation for productive, environmentally friendly, and sustainable rural development.

Agroecology in Sustainable Agriculture

Agroecology is an agricultural approach that integrates ecological principles, sustainability, and local knowledge in managing food production systems (Donovan et al., 2013; Cheng et al., 2023). This approach emphasizes crop diversification, the use of local resources, sustainable soil and water management, and balanced interactions among humans, crops, animals, and ecosystems. Agroecological practices enable farmers to adapt their production systems to local environmental conditions, thereby enhancing long-term productivity, food security, and ecosystem resilience (Gava et al., 2022). In rural Indonesia, the implementation of agroecology has been shown to improve resource-use efficiency, reduce dependency on chemical inputs, and strengthen community capacity to respond to climate change and market fluctuations (Dumont et al., 2021; Fiorino, 2023).

Beyond technical aspects, agroecology emphasizes the collaboration between scientific knowledge and local expertise, making farming practices more context-specific and sustainable (Hersperger et al., 2021). This approach not only improves productivity and food security but also reinforces the socio-ecological capacity of rural communities. Agroecology plays a dual role: as an efficient and adaptive agricultural production strategy and as a socio-ecological approach that strengthens the carrying capacity of rural agricultural areas. This approach is highly relevant for integration with spatial planning policies to ensure rural development proceeds synergistically, sustainably, and with a focus on local food security.

RESEARCH METHODS

This study employed a qualitative approach using a sequential explanatory design (Reiter, 2020; Carling, 2024). The design was selected to explore the integration of agroecological practices within spatial planning contexts in rural areas. Qualitative data were collected through in-depth interviews, focusing on agricultural development zones in North Konawe Regency, Southeast Sulawesi Province. This approach enables a comprehensive understanding of the dynamics of agroecological integration in enhancing agricultural carrying capacity (Eibl et al., 2021).

The qualitative method was used to examine local perceptions, practices, and values related to agroecology and its role in spatial planning. Semi-structured interviews were conducted with key informants who were purposively selected based on their direct involvement in agricultural practices and spatial management. Informants included local farmers, customary leaders, academics, and regional planners from relevant institutions. Data collection continued until thematic saturation was achieved. The primary research instruments consisted of interview guides, audio recordings, and field notes to capture participants' responses and contextual observations during the fieldwork.

Data collection was conducted in phases, beginning with preliminary field engagement to identify relevant participants, followed by in-depth, face-to-face interviews to gain detailed insights into agroecological practices and their interaction with spatial planning. Each interview lasted approximately 45–90 minutes and was conducted in the local language. Qualitative data were analyzed using thematic analysis, involving processes of data familiarization, initial coding, category development, and theme identification. Code mapping and data organization were supported by NVivo software to ensure systematic analysis. To enhance the validity and reliability of the findings, triangulation was carried out by comparing interview data with relevant policy documents and field observations. Member checking was also conducted with selected participants to confirm the accuracy of interpretations. The entire research process adhered to established ethical standards in social research, including informed consent, confidentiality, and voluntary participation, and received approval from the relevant institutional authorities (Arora & Sharma, 2023).

RESULTS

Spatial and Socio-Agroecological Conditions in Agricultural Development Zones

This study found that the integration between spatial planning and agroecology practices has not been optimally achieved in the rural development area of North Konawe. The inconsistency between the regional spatial plan and the reality of land use by the community became the dominant finding in in-depth interviews with key informants. For example, a number of farmlands that have historically been managed by farmers are included in residential zones, making them inaccessible to government agricultural subsidy and assistance programs. These findings show that there is an inequality between spatial regulatory frameworks and local agrarian practices that has the potential to weaken the region's food security capacity. In this context, the preparation of the Regional Spatial Plan (*Rencana Tata Ruang Wilayah*/RTRW) has not fully considered the social and economic dimensions inherent in land use by local communities (Kumar et al., 2024).

In addition, this study identifies weak harmonization between spatial data and social data in regional planning. Spatial data used by local governments tend to be descriptive of land cover without information about who manages the land, how it is managed, and its impact on the local ecosystem. Information gathered from academics and regional planners reveals that conventional map-based approaches are not able to capture the socio-ecological complexity of the region. This has implications for policy formulation that is less contextual, especially in encouraging agricultural sustainability through agroecological approaches (Hasan & Daryanto, 2024).

Table 1. Findings of Spatial Data Triangulation and Interviews

Aspects	Spatial Findings	Interview Findings	Triangulation Conclusion
Land Zoning	Agricultural areas are included in residential zones.	Farmers cannot access assistance programs.	There is a dissonance between spatial regulation and agrarian practices.
Land Cover	Seen as unproductive land.	Traditional leaders mentioned local agroforestry practices.	Spatial data do not capture the ecological and social functions of land.
Land Accessibility	The road network is not adequate.	Farmers have difficulty bringing their crops to the market.	Space infrastructure needs to be directed to agricultural production centers.
Pressure Transfer Function	Expansion of settlements on fertile land.	Farmers' complaints about the reduction in rice fields.	Need for sustainable food and agricultural land protection policies.

Table 1 presents the results of triangulation between spatial data and in-depth interviews, which reinforce the validity of qualitative findings. For example, zoning land classified as residential areas turns out to be active agricultural land according to farmers' acknowledgement, thus hindering their access to government assistance. In addition, the area that is seen as unproductive land on the map turns out to be a traditional agroforestry area according to indigenous leaders, which has an important ecological and social function for the community. This discrepancy underscores the importance of integration between geographic information systems and community-based participatory data. Thus, strengthening the carrying capacity of agricultural areas requires a more inclusive and adaptive spatial approach to the socio-ecological realities in the field.

Local Practices, Policy Gaps, and Integrative Conceptual Model

Another important aspect found in this study is the neglect of agroecological practices based on local wisdom in the spatial planning process. The informant who came from traditional leaders explained the existence of traditional planting systems that have been inherited across generations, such as crop rotation and the use of organic fertilizers from livestock waste. However, these practices are not reflected in the government's agricultural development planning documents or programs. The absence of recognition of this local production system indicates the weak inclusion of local knowledge in the formal process of spatial policymaking. As a result, sustainable agriculture strategies based on local potential do not receive adequate institutional support (Hasan et al., 2025).

Through the thematic mapping process in the NVivo software, several key themes were obtained that enriched the understanding of the issue of spatial integration and agroecology. These themes include zoning incompatibility, weak participation in planning, dependence on chemical fertilizers, and the existence of sustainable planting patterns that are not systematically accommodated. An analysis of these themes emphasizes that local agrarian practices contain sustainability principles that have been naturally implemented by communities but are not adopted in formal policies. This condition illustrates the epistemological disjuncture between local and institutional knowledge systems in the context of rural development (Hersperger et al., 2021).

This study reveals a mismatch between the regional spatial plan and the actual conditions of agricultural land, where a significant proportion of farmland is administratively classified as residential zones, thereby limiting farmers' access to agricultural assistance programs due to inappropriate legal land status. This condition reflects a dissonance between spatial policies and dynamic local agrarian needs rooted in traditional agricultural practices (Akanmu et al., 2023). Furthermore, spatial planning processes have not adequately incorporated agroecological practices grounded in local wisdom, such as crop rotation, the use of organic fertilizers derived from livestock waste, and agroforestry-based land management, which continue to be consistently practiced by local communities. The exclusion of these practices from formal planning documents, coupled with the limited involvement of local stakeholders in the planning process, indicates weak integration between modern spatial planning approaches and local knowledge systems, ultimately reinforcing the marginalization of agroecological practices in sustainable agricultural development.

In terms of spatial data, the study found that the land use maps used by planners only reflect physical cover without considering the social and ecological dimensions of land management. For example, areas that are indicated to be spatially unproductive turn out to be active agroforestry areas based on the results of interviews with community leaders. The lack of integration between spatial data and social data leads to information gaps in the policy formulation process (AbdelRahman, 2023). The data triangulation matrix shown in the visualization supports the need for a multi-data approach in spatial policy analysis.

Unexpected findings arise in the aspect of land conversion pressure, where settlement expansion occurs on fertile land that has high potential for agricultural production (Eibl et al., 2021; Kumar et al., 2024). Interviews with farmers revealed that the decline in rice field area has occurred significantly in the last five years due to the pressure of infrastructure and property development. The visualization of the triangulation results confirms that the aspect of conversion pressure is a serious threat to agricultural sustainability in the region. In this context, it is important to formulate agricultural land protection policies based on ecological zoning, not just administrative zoning. These findings suggest that the urgency of protecting agricultural carrying capacity should be a priority in rural spatial governance in the future.

DISCUSSION

The findings of this study indicate that the implementation of spatial planning in rural development areas remains normative and does not fully reflect local agrarian conditions. This is evident in the misalignment between the zoning in the RTRW and actual land use, leading to unequal access to agricultural support. This reinforces critiques of top-down planning models that tend to be technocratic and lack participatory geospatial data (Hersperger et al., 2021). By integrating participatory data through the triangulation of interviews and spatial information, the study highlights the critical role of agrarian social knowledge in enhancing the accuracy and legitimacy of spatial policies (AbdelRahman, 2023; Hersperger et al., 2024). Furthermore, local agroecological practices, such as crop rotation and the use of organic fertilizers, are absent from official planning documents, reflecting structural barriers to agroecological transition (Dumont et al., 2021). The study extends the discourse on integrating agroecology by emphasizing the recognition of local knowledge systems in spatial policy and recommending participatory approaches as a bridge between local practices and formal regulations.

This research also demonstrates that conventional methods for evaluating agricultural carrying capacity, which rely solely on land cover or physical productivity data, are insufficient for understanding local agrarian realities. Spatial maps indicating unproductive areas often obscure active agroforestry systems with high ecological and social value, challenging the standard bio-physical-spatial approach (Engerman et al., 2023). The findings underscore the importance of integrating socio-ecological indicators and involving local actors in practice-based mapping. Areas classified as unproductive based on satellite imagery often contribute to family food security through agroforestry and home garden systems. Therefore, developing more contextual carrying capacity evaluation models should involve farmers as primary contributors for data provision and land condition validation, ensuring that assessment methods reflect the complexity of land use and productivity in rural areas.

The study reveals a significant gap between formal zoning and local agrarian practices in North Konawe Regency, particularly in subsistence and agroforestry farming areas. RTRW zoning does not fully reflect local land management patterns, causing unclear land tenure and limiting farmers' access to subsidies, agricultural assistance, and land certification. This aligns with critiques that technocratic zoning often excludes local agrarian groups (Fiorino, 2023; Pan et al., 2024). To address this, the study applies a spatial-social triangulation approach integrating spatial data, agroecology practices, and social dynamics. This method enables the reconstruction of more adaptive zoning that reflects local farming practices and spatial conflicts. The approach emphasizes that spatial reform requires recognition of enduring agrarian values and systems rather than mere map revisions. Moreover, the study reinforces the urgency of developing spatial policies that map, protect, and support community-based agroecological practices. By operationalizing an integrative framework combining technical and social dimensions, the research provides empirical contributions to ensure that spatial planning is more inclusive, ecologically responsive, and supportive of sustainable local agricultural systems (Pan et al., 2022).

A critical finding of this study is that agroecology practices have yet to be integrated into spatial planning documents, despite long-standing community practices. Local farmers employ diverse cropping patterns, organic fertilizers, and biological pest control, yet the ecological value of these practices is not officially recognized. This indicates that current planning frameworks are still grounded in conventional production paradigms, which are misaligned with ecological agricultural approaches. Agroecological transition requires cross-sectoral policy support, including from spatial planning (Dumont et al., 2021). This study emphasizes the importance of integrating spatial planning, agrarian social practices, and agroecology practices as a holistic approach to building rural resilience. The integrative model combining spatial mapping, in-depth interviews, and field observations successfully reconstructs agrarian dynamics in the local context.

The theoretical contribution of this research lies in bridging ecological concerns, agricultural productivity, and social sustainability (Pan et al., 2022). Furthermore, the study emphasizes that spatial configurations supporting agroecology must be based on an understanding of historical and contextual human-land relationships. These findings provide guidance for spatial policies that are more responsive to local conditions while promoting the transformation of agrarian systems toward an inclusive, adaptive, and resilient model.

CONCLUSION

This study demonstrates that the implementation of spatial planning in rural development areas, particularly in North Konawe Regency, remains normative and does not accurately reflect local agrarian practices. The misalignment between the RTRW zoning and actual land use creates disparities in access to agricultural assistance programs, subsidies, and land certification, potentially reducing the carrying capacity of agricultural areas. Conventional methods for assessing carrying capacity, which rely solely on land cover or physical productivity data, are insufficient to capture active agroforestry systems and local agroecological practices that hold significant social and ecological value. Integrating spatial data with participatory information through interviews and field observations allows for the reconstruction of more adaptive zoning and highlights the importance of recognizing local agricultural practices and agroecological principles in enhancing both agricultural productivity and ecological sustainability.

The findings of this research have significant theoretical and practical implications. The study presents an integrative model bridging local knowledge, ecological principles, and spatial planning to support the transformation of agrarian systems toward inclusivity, adaptability, and resilience. In practice, it emphasizes the need for spatial policies that are responsive to local conditions, protect community-based agroecological practices, and promote active farmer participation in planning. Limitations include the restricted geographic and temporal scope and the constraints of quantitative data in fully mapping social dynamics. Future research is recommended to expand the study scale, utilize longitudinal data, and explore institutional mechanisms to achieve more holistic and sustainable integration of agroecology into spatial planning.

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