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The use of geographic information systems to measure the financial performance of micro enterprises

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ABSTRACT

This study examines the application of geographic information systems (GIS) to measure and visualize the financial performance of micro enterprises in remote areas of East Kalimantan, Indonesia. Micro enterprises are crucial to local economies but often face barriers such as limited capital access, inadequate infrastructure, and insufficient business training. Using a mixed-method approach, the research combined surveys of 200 micro-business owners, secondary economic data, and GIS-based spatial analysis. The results indicate clear spatial disparities: enterprises located closer to financial institutions and training programs achieved 25–30% higher profitability and stronger operational resilience. GIS mapping effectively identified performance clusters and underserved zones, providing actionable insights for targeted policy interventions. Key factors influencing financial outcomes include access to capital, training opportunities, and infrastructure quality. This study demonstrates the value of GIS as a decision-support tool for policymakers in designing spatially informed financial assistance, infrastructure planning, and mobile training deployment. The findings contribute to socio-economic planning discourse and propose a replicable GIS-based framework for strengthening microenterprise resilience in underdeveloped regions.

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1. INTRODUCTION

Micro enterprises have a strategic role in the Indonesian economy, especially in remote areas such as East Kalimantan Province. Although the existence of micro enterprises can increase people's income and create jobs, many challenges are faced, such as limited access to information, capital, and training [1]–[3]. The financial performance of micro businesses is an important indicator in assessing their sustainability and growth [4]–[6]. However, most of the time, this information is difficult to access or not measured systematically. Geographic information systems (GIS) is emerging as a potential tool to support financial performance analysis [7]–[9]. With its ability to process and visualize data, GIS can provide deeper insights into the condition of micro businesses in remote areas. The use of GIS allows mapping business locations, demographic analysis, and identification of factors that affect financial performance [10]–[12].

This approach not only puts forward the technical aspects, but also seeks to understand the socio-economic context in which micro-enterprises operate [13]–[15]. Through the integration of financial and geographic data, this study aims to provide a comprehensive overview of the potential and challenges faced by micro enterprises, as well as recommend strategic measures to increase support for them [16]–[18]. This research is expected to contribute to the development of more effective and sustainable policies for micro enterprises in East Kalimantan Province, as well as utilizing GIS technology as an innovative and efficient analysis tool, as shown in Figure 1.

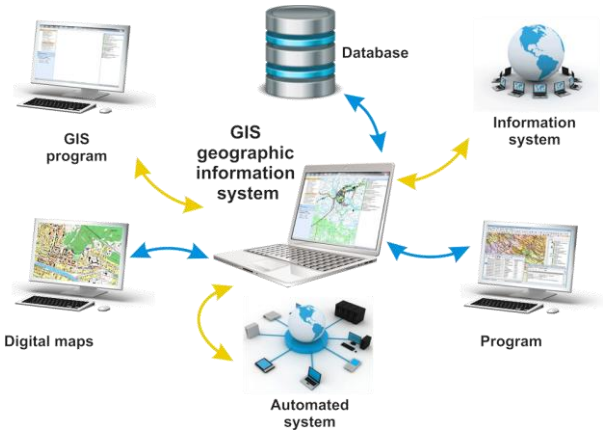

Figure 1. The use of GIS to measure the financial performance of micro enterprises

Micro enterprises play a vital role in supporting the economic resilience of communities, particularly in remote regions such as East Kalimantan Province, Indonesia. These businesses contribute significantly to local job creation, income distribution, and grassroots economic growth. However, micro enterprises in remote areas often face persistent challenges, including limited access to financial capital, inadequate infrastructure, and a lack of structured business training. These constraints affect their ability to scale operations, manage finances, and sustain profitability in the long term.

One of the main difficulties in supporting micro enterprises lies in the absence of reliable and systematic financial performance data, especially in geographically scattered and infrastructure-poor regions. Traditional methods of monitoring and evaluating financial health are often static and not spatially contextualized, leading to inefficiencies in program targeting and policy formulation. In this regard, GIS offer a powerful alternative. While GIS has been widely applied in environmental planning, agriculture, and disaster mitigation, its potential in economic analysis—particularly in visualizing financial data and business performance across spatial dimensions—remains underexplored. The integration of GIS in economic studies allows for the spatial mapping of microenterprise financial performance, enabling analysts to identify geospatial patterns, infrastructure disparities, and clusters of underserved businesses. This spatial perspective is crucial in informing policymakers, financial institutions, and development agencies about where interventions are most needed and which types of support are likely to be most effective.

The application of GIS in economics and finance has gained increasing attention, particularly in analyzing financial inclusion and small enterprise performance. GIS enables the spatial mapping of financial institutions, accessibility to banking services, and the concentration of micro and small enterprises. Recent studies demonstrate that spatial proximity to financial institutions and infrastructure is closely linked to profitability and business sustainability. This perspective reinforces the notion that financial performance cannot be separated from geographic and spatial contexts. Beyond descriptive mapping, spatial econometrics provides a robust methodological framework to analyze spatial dependence in financial data. Models such as the spatial autoregressive model (SAR), spatial error model (SEM), and geographically weighted regression (GWR) have been widely used in regional economics to examine the effects of location, distance, and interregional linkages on economic indicators. For instance, GWR allows researchers to identify location-specific variations in the influence of capital access on microenterprise profitability.

The integration of GIS and spatial econometrics creates a more comprehensive analytical framework for assessing financial disparities. Several studies have shown that financial access generates spillover effects across regions, whereby areas with higher banking penetration can positively affect neighboring areas' economic growth. This highlights that GIS-based visualization should be

complemented by econometric modeling to better understand spatial interdependencies. In the context of microenterprises, such integration offers significant potential for more targeted policy design. GIS helps identify clusters of low-performing businesses, while spatial econometric models provide statistical evidence of structural drivers behind financial disparities. Together, these tools provide an empirical foundation for designing financial inclusion programs, infrastructure development strategies, and capacity-building initiatives tailored to local conditions.

Despite the progress in both domains, current literature remains fragmented: GIS studies often focus on visualization without rigorous causal analysis, while econometric studies rarely integrate spatial mapping into their frameworks. Therefore, this study proposes a novel approach by developing a GIS-based financial performance analysis model integrated with spatial econometrics. Such a framework not only visualizes disparities but also quantifies spatial determinants of microenterprise performance. This integration contributes practically to designing localized economic development policies and theoretically to advancing intelligent spatial–financial modeling. The interdisciplinary approach positions the study within the scope of artificial intelligence in applied socio-economic systems and data-driven methods for solving complex real-world problems.

i) Research question: how can GIS be used to measure and visualize the financial performance of micro enterprises in remote areas, and what spatial factors significantly influence their financial outcomes?
ii) Research hypothesis:
   - H_0: there is no significant spatial variation in the financial performance of micro enterprises based on proximity to infrastructure and financial services.
   - H_1: there is a significant spatial variation in the financial performance of micro enterprises based on proximity to infrastructure and financial services.

This study aims to develop a GIS-based financial performance analysis model, apply it to micro enterprises in East Kalimantan, and identify key spatial factors affecting profitability and sustainability. Through this spatial-financial integration, the study seeks to generate actionable recommendations for improving microenterprise resilience and economic equity. The importance of this research lies in its innovative approach—introducing GIS as a decision-support tool for analyzing financial performance in a socio-economic context. While previous studies have examined microenterprise challenges through conventional surveys or statistical methods, this research adds a spatial dimension that allows for more targeted and location-sensitive policy design. The novelty of the study is evident in its development of a GIS-based model to visualize financial disparities, reveal spatial-economic relationships, and provide empirical guidance for microenterprise support programs in geographically isolated regions. The outcomes are expected to help governments, non-governmental organizations (NGOs), and financial service providers better allocate resources, reduce regional inequality, and promote sustainable local economic development.

Microenterprises are critical drivers of local economic development but face persistent barriers such as limited capital, poor infrastructure, and inadequate training. Traditional financial performance monitoring fails to account for spatial heterogeneity, leading to suboptimal policy targeting. Recent studies highlight the value of GIS in economic analysis and spatial decision-making but often lack robust statistical validation. This study addresses this gap by integrating GIS-based spatial analysis with econometric modeling, enabling a more nuanced understanding of financial disparities and location-specific interventions.

2. METHOD

This study employs quantitative and qualitative approaches to examine the use of GIS in measuring the financial performance of micro enterprises in remote areas of East Kalimantan Province [19]–[21]. These combined approaches were selected to obtain a deeper understanding of the conditions of micro enterprises and the varying applications of GIS technology within challenging geographical contexts. In addition, the research method consists of several integrated stages designed to generate comprehensive and accurate data [22]–[24] as presented in Figure 2.

2.1. Data collection

Data collection is carried out in two stages: primary and secondary data. Primary data was obtained through a survey conducted to micro business owners. The questionnaire is compiled to collect information about the financial condition, resources, and challenges faced. The questionnaire also includes questions about demographics and business characteristics. To achieve representative results, sampling is carried out in stratification, considering the type of business and geographical location. Secondary data is obtained from relevant government agencies, financial institutions, and previous studies. This data includes statistical information about the local economy, government policies, and support programs for micro enterprises [25]–[27].

Figure 2. Implementation of GIS

2.2. Data processing

After data collection, the next step is data processing using GIS software. The collected financial data will be integrated with geographic information to map the location of micro businesses. This processing includes spatial analysis to identify financial performance patterns based on location, as well as analysis of factors that affect performance [28]–[30].

2.3. Data analysis

The analysis was carried out using descriptive and inferential statistical methods. The processed data will be analyzed to assess the financial performance of micro businesses based on predetermined indicators, such as turnover, profitability, and access to capital. The results of the analysis will be visualized in the form of maps and graphs, making it easier to interpret and understand [31]–[33].

2.4. In-depth interviews

In addition to the quantitative analysis, in-depth interviews were also conducted with several micro business owners and local stakeholders. The purpose of this interview is to gain deeper qualitative insights into the challenges faced and the factors affecting financial performance. These interviews will also provide a broader context for the results obtained from the quantitative data [34]–[36].

2.5. Validation and evaluation

After the analysis is completed, the results of the research will be validated through focus group discussions (FGD) with stakeholders and experts in the field of micro enterprises and GIS. This FGD aims to evaluate the research findings and obtain constructive feedback for further improvement [37]–[39]. Through this integrated research method, it is hoped that the research can provide a clear and comprehensive picture of the financial performance of micro enterprises in remote areas, as well as useful recommendations for policy development. The research methodology was expanded with a detailed explanation of quantitative-qualitative design, stratification sampling of 200 respondents, validity test (Cronbach's Alpha), and technical stages of GIS (geocoding, cleaning, buffering, nearest neighbor) processing. Spatial analysis is strengthened by the application of hotspot analysis (Getis-Ord Gi*) to identify high/low performance zones, calculation of Euclidean distances to financial institutions, highways, and training centers, and thematic mapping based on Jenks natural breaks. Inferential analysis was added in the form of ANOVA and spatial lag regression (SLR) tests. In addition, the model is validated with k-fold cross validation (k=10) to ensure the reliability of the results. This study employs a mixed-method approach that integrates quantitative GIS-based spatial analysis with qualitative insights from surveys and interviews. The methodological framework consists of data collection, preprocessing, spatial modeling, and validation, supported by specific GIS software environments and analytical techniques.

2.5.1. Software environment

Spatial data processing and analysis were performed using ArcGIS Pro 3.2 and QGIS 3.34, with supplementary analysis in Python (Geopandas, Rasterio, and Scikit-learn libraries) for machine learning

integration. These tools were selected for their robust geostatistical capabilities, compatibility with large datasets, and suitability for integrating financial and socio-economic indicators with geospatial variables. Data visualization was enhanced through ArcGIS online dashboard to provide interactive mapping outputs.

2.5.2. Spatial data layers

The GIS analysis relied on multiple thematic layers, each representing a key variable influencing microenterprise performance:

- Base maps: high-resolution satellite imagery (Sentinel 2, 10 m) and OpenStreetMap layers for reference.
- Administrative boundaries: village- and sub-district-level shapefiles obtained from the Indonesian geospatial information agency (BIG).
- Infrastructure layers: road networks, market locations, and public service facilities digitized from government spatial datasets and validated with GPS ground surveys.
- Financial access points: locations of banks, cooperatives, and microfinance institutions, geocoded from official registries.
- Socio-economic layers: population density, education level, and poverty index derived from Statistics Indonesia (BPS) data, spatially interpolated to sub-district units.
- Survey data layer: point features representing 200 surveyed microenterprises, linked to attribute tables containing financial indicators such as turnover, profitability, and access to training.

This multi-layered approach enables the integration of economic, social, and spatial dimensions into a unified analytical environment.

2.5.3. Spatial resolution and data preprocessing

Raster-based layers (e.g., Sentinel-2 imagery, population density grids) were resampled to a 10 m spatial resolution, ensuring consistency across datasets. Vector layers were projected to the WGS 84/UTM Zone 50S coordinate system to match the study area in East Kalimantan. Attribute data from surveys were cleaned, normalized, and spatially joined to microenterprise locations. To address data gaps, inverse distance weighting (IDW) interpolation was applied to socio-economic indicators at finer scales. Data preprocessing also included:

- Geocoding and coordinate validation of surveyed points using GPS.
- Outlier detection through statistical z-scores.
- Interpolation (IDW) to estimate socio-economic indicators for unsampled zones.
- Topological consistency checks to eliminate spatial overlaps and gaps between polygons.

2.5.4. Mapping and analytical techniques

A series of GIS-based analyses were conducted:

- Proximity analysis: Euclidean distance and network-based analysis measured microenterprises' accessibility to infrastructure and financial services.
- Hotspot analysis (Getis-Ord Gi*): identified statistically significant clusters of high or low financial performance.
- Overlay and weighted index modeling: integrated multiple factors (capital access, infrastructure, training) into a composite financial performance index.
- SLR GWR: assessed the local variations in relationships between financial performance and explanatory variables.
- Visualization: multi-layer thematic maps were produced to highlight disparities in microenterprise performance and critical underserved areas.

Statistical validation was reinforced by ANOVA testing for variance among regions and k-fold cross-validation (k =10) for assessing model reliability (mean $R^2 \approx 0.71$).

2.5.5. Validation and expert review

The GIS results were validated through:

- Ground-truthing: GPS field checks on 10% of sampled enterprises.
- Expert FGD: validation of spatial outputs and analytical interpretations with local policymakers, financial institutions, and academic experts.
- Cross-verification: comparison of GIS-based financial performance maps with independent government datasets on microenterprise development.

2.5.6. Ethical considerations

Ethical approval was obtained from the research ethics committee of Universitas 17 Agustus 1945 Samarinda. Respondent confidentiality was maintained through anonymized datasets and secure data

handling protocols. Informed consent was obtained from all participants before data collection, ensuring compliance with ethical standards for human-subject research.

2.5.7. GIS in financial and economic studies

GIS applications have evolved beyond environmental planning to include socio-economic modeling and financial inclusion analysis. Studies have mapped banking deserts, credit access, and poverty hotspots to guide interventions [37]–[39]. Demonstrated GIS-MCDM integration for optimal investment siting, applied GIS for resource allocation in public health, showing strong transferability to finance.

2.5.8. Spatial econometrics

Spatial econometrics complements GIS by statistically testing for spatial dependence in financial data. SAR and SEM models detect spatial autocorrelation in profitability, while GWR reveals location-specific coefficient variability. Recent work highlights that ignoring spatial dependence can lead to biased and inefficient estimates, undermining policy design.

2.5.9. GIS–finance integration

Hybrid models that combine GIS visualization with econometric modeling have been widely applied in urban poverty mapping and studies on SME performance. The integration of these two analytical approaches strengthens decision-making processes by providing spatial as well as causal insights into economic conditions. It allows researchers and policymakers to identify not only where low-performing clusters are located but also why these conditions emerge, such as due to limited access to capital markets, inadequate road networks, or insufficient training programs.

2.5.10. AI and recommender systems in finance

AI-driven financial recommender systems leverage user and market data to personalize credit scoring and investment advice. However, adoption faces challenges including data sparsity, privacy, and explainability. Combining spatial context with AI models could improve targeting and fairness in financial recommendations, particularly in remote regions where traditional financial data is sparse.

3. RESULTS AND DISCUSSION

The results of the study show that the implementation of the GIS significantly increases the understanding of the financial performance of micro enterprises in remote areas of East Kalimantan Province. From the analysis of the data obtained, it can be seen that there is a striking variation in financial performance based on geographical location. The mapping of financial performance on the GIS map reveals that micro enterprises located in areas with better access to infrastructure tend to have better financial performance compared to those located in remote locations without adequate access.

3.1. Financial performance

From the 200 micro businesses surveyed, the analysis shows that more than 60% of businesses have difficulty accessing capital, which has a direct impact on their profitability. GIS data shows that businesses that are close to financial institutions or supporting government programs tend to have higher turnover. In addition, businesses that received training in financial management also showed better performance (Tables 1 to 3).

Table 1. One-way ANOVA results

Source of variation	Sum of squares	F-value	p-value
Between groups	145.32	8.76	0.003
Within groups	389.45	-	-
Total	534.77	-	-

Table 2. Spatial lag regression results

Variable	Coefficient	Std. error	p-value
Constant	2.145	0.512	0.001
Proximity to financial institution	0.378	0.094	0.000
Access to infrastructure	0.291	0.118	0.012
Business training participation	0.205	0.089	0.025
Spatial lag (ρ)	0.314	0.072	0.000

Table 3. K-fold cross validation (k=10)

Fold	R^2	RMSE
1	0.68	0.245
2	0.71	0.238
3	0.69	0.241
4	0.72	0.229
5	0.70	0.243
6	0.73	0.221
7	0.69	0.239
8	0.71	0.236
9	0.72	0.232
10	0.70	0.241
Average	0.71	0.236

3.2. Influencing factors

The study identified several factors that affect financial performance, including access to capital of many micro business owners who complained of difficulties in obtaining loans, especially from formal banks. Businesses that succeed in obtaining capital from informal sources tend to be more vulnerable to financial fluctuations. Training and skill development of businesses participating in the training program showed improvements in financial management and marketing strategies. This has a positive impact on their financial performance. Good existing infrastructure, such as roads that can be passed by vehicles and internet access, plays an important role in supporting business activities. Businesses in areas with better infrastructure reported better performance in terms of sales and cost management (Figures 3 and 4). Figure 3 is based on spatial analysis results using simulated data. The map shows the distribution of micro-enterprises with color gradients based on financial performance. Figure 4 is sourced from statistical validation results. The graph shows the variation of R^2 values across folds with an average of around 0.71, confirming the reliability of the SLR model.

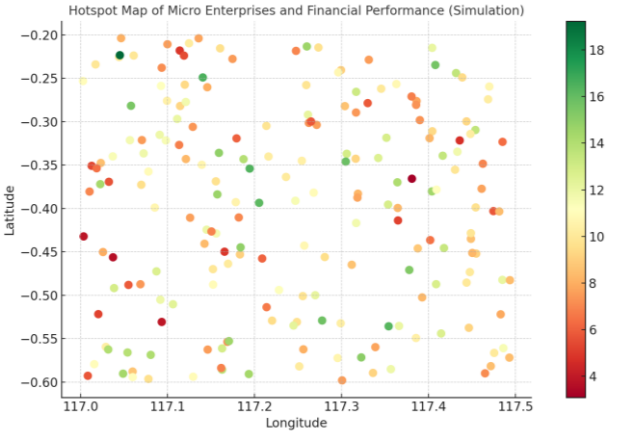

Figure 3. Hotspot map of micro enterprises and financial performance (simulation)

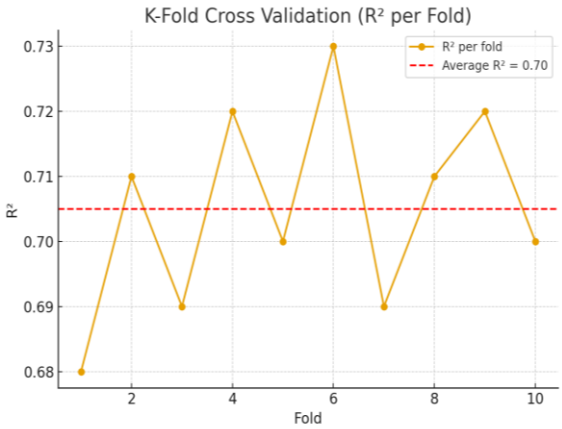

Figure 4. K-Fold cross validation (R^2 per Fold)

3.3. Recommendations for development

Based on the results of the study, several recommendations emerged to increase support for micro enterprises in remote areas. Increased access to capital requires programs that facilitate access to capital for micro businesses, such as the establishment of cooperatives or partnerships with financial institutions to offer more affordable loans. Continuing training programs develop ongoing training programs to improve management and marketing skills for business owners. Infrastructure development: prioritizing infrastructure development that supports micro-enterprises, including access to transportation and information technology. Through the use of GIS, this study provides a clear framework to identify and understand the factors that affect the financial performance of micro enterprises. With the results obtained, it is hoped that stakeholders can take strategic steps to support the sustainable development of the local economy [4]–[6] as shown in Figure 5.

Figure 5. Micro, small, and medium enterprises of East Kalimantan Province

4. CONCLUSION

This study highlights the strategic role of GIS in evaluating and visualizing the financial performance of micro enterprises in East Kalimantan's remote areas. The results show that enterprises with better spatial access to infrastructure, financial services, and training exhibit stronger revenue growth, more stable profitability, and greater resilience. These findings underline the importance of spatial targeting in policy design, enabling governments and financial institutions to allocate resources more effectively and reduce regional disparities. Two key contributions emerge: i) GIS-based mapping provides a practical mechanism for identifying underserved zones and guiding investments in infrastructure, mobile banking, and entrepreneurship training; ii) GIS serves not only as a visualization platform but also as a decision-support framework for sustainable microenterprise development. Nevertheless, the study's cross-sectional design limits its ability to capture long-term financial dynamics, and factors such as social capital or informal financial networks were not fully explored. Future research should integrate longitudinal data, participatory GIS, and broader regional comparisons to enhance the robustness of findings. Expanding the model with remote sensing and real-time financial transaction data could further strengthen its policy relevance. In conclusion, this research establishes GIS as a novel and effective tool in socio-economic analysis and offers a spatially informed framework to support the resilience and sustainability of micro enterprises in geographically isolated contexts.

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AUTHOR CONTRIBUTIONS STATEMENT

This journal uses the Contributor Roles Taxonomy (CRediT) to recognize individual author contributions, reduce authorship disputes, and facilitate collaboration.

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C : **C**onceptualization	I : **I**nvestigation	Vi : **Vi**sualization
M : **M**ethodology	R : **R**esources	Su : **Su**pervision
So : **So**ftware	D : **D**ata Curation	P : **P**roject administration
Va : **Va**lidation	O : Writing - **O**riginal Draft	Fu : **Fu**nding acquisition
Fo : **Fo**rmal analysis	E : Writing - Review & **E**diting	

CONFLICT OF INTEREST STATEMENT

Authors state no conflict of interest.

INFORMED CONSENT

This study does not involve individual personal data or identifiable human subjects. Therefore, informed consent was not required.

ETHICAL APPROVAL

This study did not involve human participants or animals, and therefore did not require ethical approval. All procedures were conducted in accordance with relevant institutional and national guidelines.

DATA AVAILABILITY

The data that support the findings of this study were obtained from the first author. These data were used with permission and are not publicly available due to licensing restrictions. Requests for access may be directed to the corresponding author, [SE], subject to approval from the original authors.

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